# THE DEVELOPMENT OF BIOMETHANE: A SUSTAINABLE CHOICE FOR THE ECONOMY AND THE ENVIRONMENT

*Notes for the elaboration of a road map for the development of biogas done right and biogas refinery technologies in Italy*

FEBRUARY 2017


*Edited by:*

Dr. Agr. Stefano Bozzetto - Biogas Refinery Development srl

Eng. Christian Curlisi - CIB Italian Biogas Consortium

Dr. Claudio Fabbri - Centro Ricerche Produzioni Animali C.R.P.A. spa

Eng. Marco Pezzaglia - Gruppo Professione Energia srl

Dr. Agr. Lorella Rossi - CIB Italian Biogas Consortium

Dr. Fabrizio Sibilla - Technical-Scientific Committee CIB Italian Biogas Consortium

## Summary

## INTRODUCTION

The present study aims at highlighting the biogas refinery and the renewable gas potential in the energy transition towards a net carbon zero scenario to be achieved by 2050.

In particular, the study focuses on 2030 and 2050 targets analyzing the technical and economic potential and the actions that should be undertaken in the agricultural, industrial and support policies.

The ideas expressed by the authors of this paper represent nothing more than their original thinking and are aimed to stir a debate within the Italian Biogas Consortium for the preparation of a road map for the development of the technologies of biogas refinery in Italy according to principles of "biogas done right".

In the paper preparation, we considered the following scenarios:

a) The Italian context
b) The boundaries for the agriculture and energy sector that derived by the COP21 Paris agreement signature

In particular, we consider that bioenergy is not a discretionary option for achieving what is stated in Article 4 of the Paris Treaty, since bioenergy is the only renewable source able to act on the carbon cycle at a significant scale.

"In order to achieve the long term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, **so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century**, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty" [1][2] .

Among the different bioenergies we believe that the biogas refinery is one of the technologies that can provide in the long run positive returns in terms of decarbonization of energy and agriculture sectors. At the same time, the biogas refinery yields an economic development because it can act on a number of strategic and concurrent axes:

- Emission mitigation in the energy system,
- Carbon storage via creation of carbon negative systems starting from $CO_2$ capture via photosynthesis,
- Bringing back agriculture to a central role as engine for bioeconomy and circular economy.

[1] https://unfccc.int/files/meetings/paris_nov_2015/application/pdf/paris_agreement_english_.pdf
[2] http://theplate.nationalgeographic.com/2015/10/23/italians-show-energy-and-food-can-grow-in-harmony

In Italy, this process can play an impact due to the consolidated technologies developed in the renewable energy sector, gas and biogas, green chemistry and, not least, the importance of agriculture, food production and processing in the country image and economy.

Definitively we believe that  it is no coincidence that biogasdoneright movement emerged in Italy. In this country, there is a unique blend of environmental sensitivity and manufacturing industry where to test support schemes, business models, technologies useful to the development of a real "biogas refinery".

What will be possible for Italy, a country with climatic peaks typical of the Mediterranean environment, with a ratio of 0.1 ha SAU/inhabitant (ten times less than in the United States), with a difficult topography and a landscape carved by its long history as few others places in the world important constraints even from a point of view of the landscape modification, then it will be then relatively easy to deploy the biogasdoneright model elsewhere where population density is lower and natural resources are less limiting.

## FOOD AND FUEL

The European Commission issued a renewable energies directive proposal which foresees the reduction of the biofuels produced from starchy biomass, sugar and oil -the so-called first-generation biofuels-, lowering the obligation from the current 7% to 3.8% by 2030[3].

At the same time the Commission encourages the development of advanced biofuels, biogas, electrification and natural gas in transport as complementary elements toward the reduction of transport sector emissions: advanced biofuels obligation should raise from the current 0.5% to 3.6% by 2030.

This proposal was anticipated by a Communication of the EU Commission on sustainable mobility[4] and it is the result of a debate spanning over the last 10 years and related to:

- the biofuels real impact in $CO_2$ emission reduction;
- the effective possibility to allocate land currently used for food and feed production to the production of biomass for energy, therefore to quantify the role that biofuels can play in replacing fossil fuels;
- the possibility to achieve this transition at a cost comparable to current fuel costs.

Agriculture and livestock are responsible for 12% of global GHGs emissions while transport accounts for 14%. In order to reduce GHGs emissions in transport sector in a sustainable way, we need therefore first of all to produce biofuels with different, less emitting agricultural practices.

Moreover bioenergy is the only carbon based renewable energy:

- able to play an impact on the carbon cycle at the magnitude requested and even developing carbon negative systems, often required in many 1,5°C scenarios;
- it hold all the characteristics of hydrocarbons: it is a source of storable and dispatchable energy , storable at almost negligible costs, with different applications especially for markets that cannot be electrified.

But is it possible to reap bioenergies in the needed amounts, in a way to reduce at least 70% of GHGs emissions compared to fossil fuels up to achieve a carbon negative bioenergy system? Is it possible to achieve such target without lowering the production for the food markets, improving the farms economics and lowering bioenergy production costs?

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[3] Proposal for a directive of the European Parliament and of the council on the promotion of the use of energy from renewable sources (recast) COM (2016) 767 final 2016/0382 (COD)

[4] Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions "A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility" COM(2016) 766 final

These questions are summarizing the main characteristics that we are searching for via the biogasdoneright (BDR)[5] concept :

- a bioenergy that can be produced at TWh[6] scale while keeping farms food output and improving their overall economics;
- a bioenergy that contributes to a deep change in crop rotation and farming practices, soil usage and care. The BDR ranges from conventional farming practices GHGs emission mitigation to develop progressively more carbon efficient farming practices (organic fertilization , all year around soil covering, precision farming, water saving irrigation systems, etc.) toward carbon negative agricultural systems;
- a bioenergy able to reduce stepwise both food/feed and energy production costs.

In the following paragraphs, we will deepen two main aspects of the biogasdoneright:

- its overall production potential;
- its ability in lowering production costs for both food/feed and energy.

Regarding the effectiveness in GHGs emissions reduction, please refer to *Biogas Italy 2017* conference proceedings and the publications presented on that occasion and reported in the literature; its main message can be summarized in the graph below:

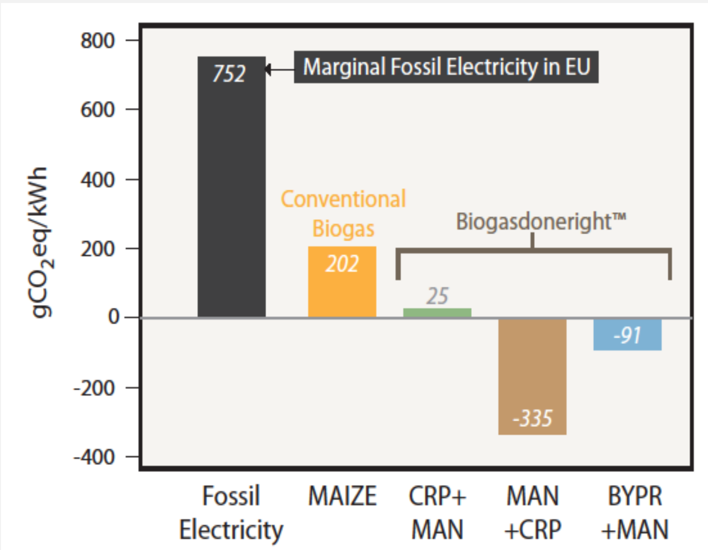


Figure 7. Greenhouse gas emissions of biomethane produced from four different biogas systems versus different fossil energy sources

Adapted from Valli L. and others, 2017, in course of publication.

[5] Bruce D. "Biogas Done Right: What does It Mean?" European Biogas Association Meeting Ghent, Belgium, September 27, 2016,
[6] The Italian hydrocarbons consumption for industrial and energy purposes amount to circa 1.800 TWh per year.

Although much work still lays ahead before reaching the maturity of the BDR technologies platform, the experience of a handful of Italian farmers attests that production of biogas can be coupled with the production of food and feed. Moreover, biogas is a cheap, programmable and dispatchable renewable energy that contributes making farms more competitive, less polluting and more resilient to climate change effect.

All of the above claims are true anyhow if the biogas is “done right”[7].

[7] Dale B. et al. (2010). “Biofuel done right: land efficient animal feed enable large environmental and energy benefits.” Environ. Technol. 44. 8385-8389,

# THE ITALIAN BDR PRODUCTION POTENTIAL

## Land efficiency

The overall Italian hydrocarbon current demand amounts to 1.800 TWh, of which 700-800 TWh are covered by natural gas consumption.

Bioenergy is in a certain how the perfect drop-in solution for the substitution of fossil hydrocarbons, since both are programmable energy sources and carbon based. But unlike hydrocarbons, bioenergy is characterized by being a diluted and not dense source of energy. For this reason, the modern bioenergy systems emerged from the use of densified biomasses with established logistics and commerce, such as grains of cereals, oils and sugars.

But the global availability of arable is limited, in the range of 1,5 billion hectares. In the USA, for example, the production of grain corn for bioethanol production amounts to 40% of the current corn grain production. Monocrop land use is poorly efficient and even in the case of the most efficient crop, maize, the surface dedicated for energy purposes corresponds to only 6% of US gasoline consumption.

Therefore, in view of the scarcity of "arable land" as for any other scarce resource what is important is to compare the land efficiency[8], i.e. the amount of energy that can be obtained from a unit of soil removed from the food and feed production.

In fact, as recently stated by the FAO director Da Silva[9], the use of agricultural land for bioenergy purposes -possibly in different than monocropping systems-, is beneficial if achieved in limited and reversible ways, leaving open the possibility to shift back to food and feed production when commodities price spikes signal the decrease of offer on the market, as it happened in 2009.

Therefore, bioenergy value chains with the best efficiency land use have an undisputable competitive advantage and their potential is measurable.

Here below is a comparison of the first crop land requirement, that is land removed from food and feed production, to produce about 580,000 MWh th of energy per year with a first or second generation bioethanol or biodiesel plant, and 27 biomethane plants connected to the gas grid and producing 500 $Nm^3/h$ of raw biogas each, equaling the production capacity of one centralized ethanol plant[10].

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[8] For a land efficiency definition see “Considerations on the Italian agricultural Biogasdoneright potential. Estimation methodology and data analysis regarding the Italian Biogas Consortium Position Paper” July 2016.

[9] Forum for Food and Agriculture, 2015 FAO Working Meeting “Addressing Food Security Challenges under Increasing Demand for Land, Soil and Energy” Opening speech of FAO director Josè Graziano D Silva, 16 January 2015, Berlin.

[10] The figures are only rough estimation only useful to show the difference magnitudes.

| | Ethanol from corn grains | Biodiesel from rapeseed | Ethanol from Arundo donax | Biogas from monocrop | Biogas doneright |
|---|---|---|---|---|---|
| n° of plants | 1 | 1 | 1 | 27 | 27 |
| Ethanol output (tons/year) | 80.000 | | 80.000 | 59.200.000 | 59.200.000 |
| MWh th/year | 586.667 | 586.667 | 586.667 | 586.667 | 586.667 |
| | | | | | |
| Biomass tons | 239.232 | 133.333 | 380.952 | 538.182 | 720.000 |
| FCLR ** ha | 22.688 | 35.088 | 15.238 | 10.764 | 2.960 |
| **Land efficiency (ha first crop land/10GWh th)** | **383** | **593** | **257** | **182** | **50** |
| **Land needed compared to Biogasdoneright option** | **8** | **12** | **5** | **4** | **1** |
| | | | | | |
| Land needed (ha) interested considering rotations and % row crop | 54.019 | 292.398 | 25.397 | 59.798 | 7.048 |
| | | | | | |
| ** ha area removed to food/feed production | ** In the FCLR should be removed the credits of panels | | | Nm3 of biomethane equivalent | * plants of 1MW el equivalent |
| | | | | | **(50 ha/1Mn NM3) |

The highest soil usage efficiency, and consequently the lowest amount of arable land needed, is achieved by the BDR compared to the other situations. Such target is achieved because the BDR uses large shares of **integration biomasses** over a small amount of monocrop biomass for feeding the AD plants.

Integration biomasses are:

a) sequential crops harvested as silages before or after main crops;
b) livestock effluents;
c) agriculture residues and agro-industrial by-products.

Biogas plants are much smaller than others centralized bioenergy plants, thus requiring less feed and allowing the use of water rich biomasses that otherwise would not be produced in sequential cropping[11] due to lack of local demand and often excessive logistic costs, or which constitute a residue or by-product to be disposed at a certain cost (e.g. livestock effluents, agroresidues…).

The biogas plant in fact can operate efficiently at the scale of a few MW thermal output thanks to a patent free and available biotechnology, able to convert the diverse organic matrices of different nature and quality in a renewable gas, with a transformation efficiency of organic carbon in biogas equal to 60-80% and 50-60% on an energy basis depending on the digestibility of the biomass used.

[11] See Ecofys study "Assessing the case for sequential cropping to produce low ILUC risk biomethane. Final report. November 4, 2016. Project number: SISNL17042.

In the above mentioned case, 27 biogas plants of 2.5 MWh thermal output are sufficient to produce the same amount of energy as a large centralized plant of 80,000 ton/year of ethanol from lignocellulosic feedstocks.

The small scale efficient production allows:

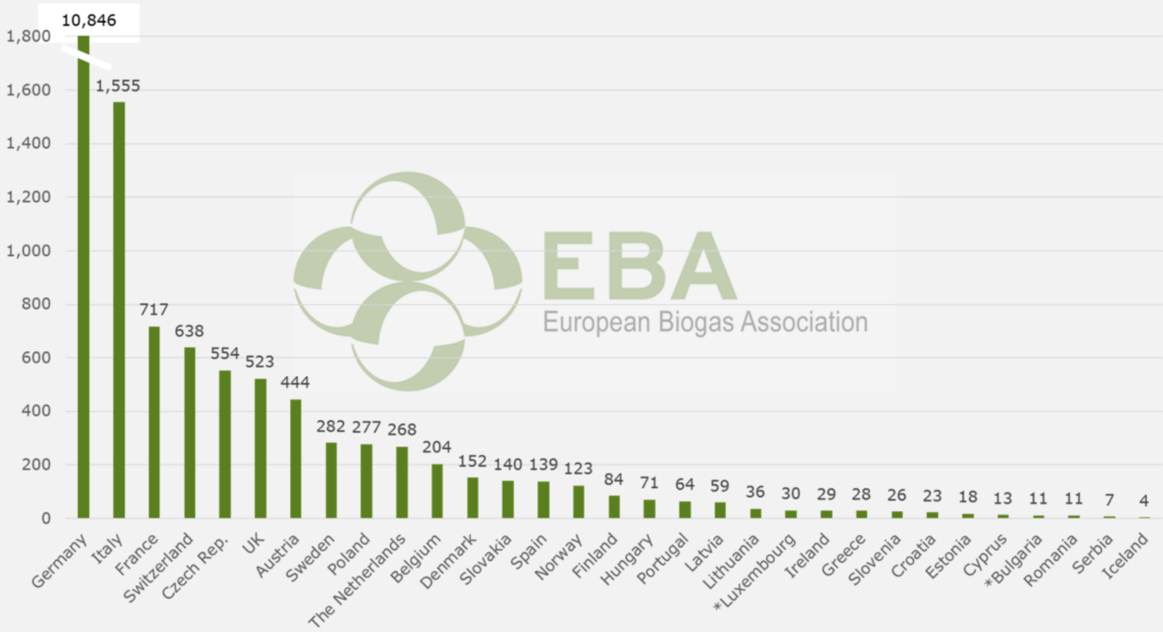
- to lower biomass transport costs;
- low cost local recycling of an organic fertilizer (the digestate) containing all the fertilizing elements and the carbon undigested after the anaerobic digestion process;
- securing a biomass procurement plan decoupled by the agricultural commodities price cycles. This is achieved because many farming production costs are now under direct control of the biogas farm (fertilizers, energy, etc.) and the produced biomass, in form of silage, is not a commodity for the market, usually traded only in the range of few km

Due to the decentralized production, the efficiency of conversion into gas, and a large variety of integration biomasses consisting of sequential crops[12], livestock effluents, agricultural residues and agro-industrial by-products, **the land requirements of first crop removed from food and feed production on a temporary and reversible basis it is markedly lower than that of other bioenergies supply chains, for example up to 10 times lower than that for biodiesel obtained by a monocrop rape seed[13]**

[12] Regarding the sequential cropping potential see the Ecofys study reported in literature.
[13] Notice that sequential cropping should be applied at biodiesel and ethanol industry as well , but the silage use make the yields penalties in the double cropping sequel less impacting.

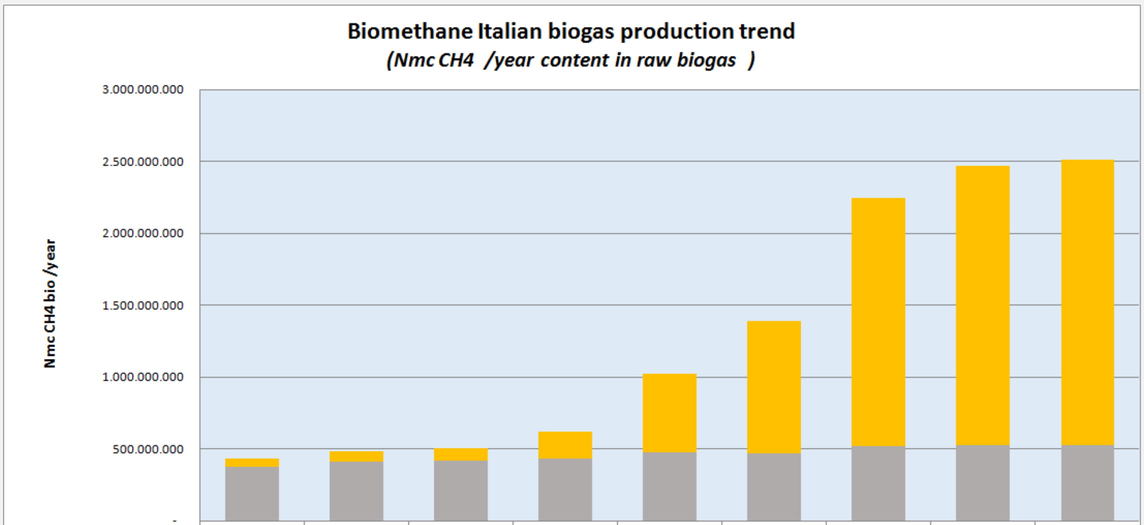
## The Italian biogasdoneright potential by 2030

The Italian biogas in the last 5 years, thanks to a simple supporting scheme, attracted large investments and became the second largest agriculture biogas sector worldwide after Germany.




The growth achieved in the last years reached at the end of 2015 an installed capacity of 1,450 MW electricity output realized in 1,900 Organic Municipal Waste[14] (OMW) and agriculture biogas plants, corresponding to 25 TWh thermal biogas output.

[14] Organic Municipal Waste




| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|---|---|---|---|
| agricultural biogasdoneright | 57.575.210 | 69.210.828 | 82.022.065 | 184.240.670 | 546.874.058 | 920.118.165 | 1.723.186.833 | 1.941.188.883 | 1.979.170.435 |
| OMW | 378.700.187 | 412.943.872 | 419.907.156 | 434.979.201 | 479.471.876 | 472.508.591 | 521.854.464 | 530.204.377 | 530.204.377 |

The investments realized in the last years amount to 4 billion euro and created 12.000 direct, stable and qualified jobs[15].

A large part of this growth has been achieved via sequential cropping and livestock effluents. We estimate that these matrices correspond to approx. 30-35% of today produced energy and are expected to double by 2030 since their lower costs compared to monocrops for biogas.

Years ago, the Italian Biogas Consortium elaborated a roadmap[16] for the production of about 8 billion $Nm^3$ biomethane equivalent from agriculture matrices, utilizing aprox. 6% of the Italian row crop UAA, a surface amount in the same range of what was previously used in set-aside[17].

[15] Irex Annual Report – Althesys 2015
[16] Considerations of the Biogasdoneright potential obtained from different matrices. Estimation method and data analysis of the Italian Biogas Consortium position paper.
[17] EU mandatory area where it is not allowed a cultivation and the land must remain fallow.

| | | | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| (A) | Total Biomethane | ($Gm^3$/year) | 0.70 | 2.20 | 4.20 | 5.50 | 8.00 |
| (FCLR) | - UAA Monocrop | (ha) | 85,000 | 200,000 | 250,000 | 300,000 | 400,000 |
| | | (% UAA) | 1% | 3% | 4% | 4% | 6% |
| | | (ha/$Mm^3$ $CH_4$) | 121 | 91 | 60 | 55 | 50 |
| (C x P) | - Monocrop BioCH4 yield | ($m^3$/ha $CH_4$) | 6,720 | 6,720 | 6,720 | 6,720 | 6,720 |
| (A/FCLR) | LAND EFFICIENCY | (m3/ha CH4) | 8,235 | 11,000 | 16,800 | 18,333 | 20,000 |
| (A - I) | - BioCH4 from monocrop | ($Gm^3$/year) | 0.6 | 1.3 | 1.7 | 2.0 | 2.7 |
| (I) | - BioCH4 from integration biomasses | ($Gm^3$/year) | 0.1 | 0.9 | 2.5 | 3.5 | 5.3 |
| (I) | - BioCH4 from integration biomasses | (%) | ***18%*** | ***39%*** | ***60%*** | ***63%*** | ***66%*** |

Considering therefore a potential of 8 billion $Nm^3$ biomethane equivalent from agricultural matrices, 0.8 billion from OMW and 1.2 billion from other sources[18], **the overall Italian biogas potential amount to aprox. 10 billion $Nm^3$ per year in 2030**. This amount corresponds to 100 TWh per year and it will require an increase in land efficiency up to 50 ha First Crop Land Requirement (FCLR).

## Long term perspectives

### Biomethane production until 2050

100 TWh represents indeed an important amount of energy, but is this the maximum amount that can be envisaged for Italy if biogas plants were even more integrated in farms?

While biogas from OMW is limited, agricultural biogas allows different considerations about its scalability.

The large-scale application of biogasdoneright is an Italian peculiarity that did not emerge by chance: the Italian quality food production has been a constraint that rapidly prompted the Italian biogas producers to ask themselves how to feed their biogas plants while continuing to produce feed for the cows whose milk, for instance is used to make Parmigiano Reggiano and Grana Padano cheeses. Indeed, it was unthinkable for them to conceive the idea to close the stables to allocate their farmland to monocrops intended only for feeding the biogas plants. Italian farmers therefore have been able to step into a new path and demonstrate that it is possible, even in their agro-ecological conditions, to

[18] Biomethane from wood gasification and renewable gas from hydrogen methanation.

produce in a decentralized way large quantities of renewable methane. In the main time, they discovered that the biogas plant is an essential infrastructure for:

a) starkly change the soil usage at the farm;
b) lower the fossil input in the farm activities (fertilizers and energy are self produced and bio-based);
c) recycle all farm residues and by-products for producing energy and fertilizers.

The anaerobic digestion integrated at the farm level and tuned according to the principles of biogasdoneright is now an indispensable tool for the farmers to make European agriculture more competitive both from the economic and the environmental point of view[19].

Italian agriculture is currently facing an economic crisis, especially regarding cereal production and animal husbandry. In this context the introduction of sequential cropping, more pulses in the rotations, livestock manure recycling, stark reduction on fossil fertilizers uses, improved agronomic techniques (strip tillage, sod seeding, precision farming…) are all chances to lower production costs at the farm level, diversify markets and rethink farm activities. Big changes are under way also on the demand side of food market, since younger generations prefer a lower animal protein consumption, high quality cereals, meat and dairy products obtained via sustainable farming, either organic or with lower input than products from conventional farming.

Cost competition and new consumer attitudes are structural phenomena that call into question the very existence of many farms that are traditionally dedicated to the production of cereals, milk or meat with conventional techniques.

The demand for quality products at competitive prices that are also locally sourced and create benefits for the local communities in terms of sustainability are phenomena that require stark changes in production systems and in the organization of supply and value chains.

Although the biogasdoneright does not provide the answer to all the different challenges faced by agriculture, it is anyway a good tool to improve the economics of the farms and food sector, it improves the cash flow of farms and allows them to invest in their activities producing higher added value products with a faster return on their investments, **making thus the primary sector overall more attractive for investments**.

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[19] As example to understand the role of Biogasdoneright on the economics of farms and pollution mitigations see this movie from the FCA homepage https://youtu.be/sx9-zXONob8 that describes the experience of a farm producing bovine meat and also this other http://www.fattoriadellapiana.it/index.php?option=com_content&view=article&id=117&Itemid=122&lang=it that describes a dairy farm experience in Calabria.

The change that is needed in the agricultural sector is neatly demonstrated by the FAO[20] food price index here below: the current prices adjusted for inflation are in the range or even below of the prices in the `60s.


In the next years for the Italian row crops and livestock sector (2/3 about of the Italian agriculture) a revolution is needed, similar to the one that the Italian wine sector experienced in the aftermath of the methanol scandal in the `80s, a revolution that can be summarized as:

- stark reduction of the vineyards surface,
- strong increase of the economic turnover, especially with strong export, due to higher quality and link to local land of origins.

Row crops and livestock are value chains different from wine industry although some lessons can be drawn from the wine evolutions. The consumer demands are similar and producers will find their own ways to adapt the wine revolution in different markets.

Therefore in the next years we foresee the following trends:

a) a stark reduction in dairy cattle in areas where no PDOs cheeses are produced;
b) a reduction in beef cattle raising, due to the current drop in red meat consumption;
c) an increase in land cultivated for pulses for both human and animal consumption. It must be noticed that in Italy pulses production for human consumption[21] decreased 80%[22] in the last 50 years.

[20] FAO Food price index , accessed in January 2017 http://www.fao.org/worldfoodsituation/foodpricesindex/en/
[21] http://www.corriereortofrutticolo.it/2016/05/11/ismea-crescono-consumi-legumi-litalia-dipende-dallimport/
[22] It is worth to notice that until 50 years ago the surface dedicted to nitrogen fixing crops in rotation was 80% of the current UAA.

These aspects will play a role in:

a) the possibility to achieve sequential cropping for nitrogen fixing crops in the rotation either for animal feed or for human consumption[23],
b) reduction in feed production for animal husbandry, especially for beef cattle.

In the light of experience gained in these years and in relation to the above mentioned evolution of the agricultural sector, we have elaborated these assumptions to quantify the potential of the Italian biogasdoneright at 2050:

a) an increase in the areas intended to produce ensiled biomasses for the biogas plant in mono or in sequential cropping, replacement of forage productions up to 10% of the current Italian UAA for the decrease in animal husbandry described above;
b) monocrop (30 ton DM/ha) and sequential crop (20 ton DM/ha) yield increase;
c) an increase of the surface dedicated to pulses in rotation from the current approximately 310,000 to 1,000,000 ha, a portion of which can be a winter crop silage for the digester before the legumes for the market;
d) a steady amount of energy recovered by livestock effluents. This can be achieved although the livestock size will decrease, since more efficient livestock effluents recovery systems will be in place.
e) an increase in the energy that can be recovered by straws, corn cobs and other by-products.

Taking into accounts all these considerations, here below an estimation of the long term (2050) agriculture biomethane potential will amount to 18.5 billion Nm$^3$, **75% of it at least will be covered by integration biomasses.**

| | | | AGRICULTURE BIOMETHANE ROAD MAP | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | 2010 | 2015 | 2020 | 2025 | 2030 | 2040 | 2050 |
| (A) | Total Biomethane | (Gm$^3$/year) | 0.70 | 2.20 | 4.20 | 5.50 | 8.00 | 13.00 | 18.50 |
| (FCLR) | - UAA Monocrop | (ha) | 85,000 | 200,000 | 250,000 | 300,000 | 400,000 | 525,000 | 650,000 |
| | | (% UAA) | 1% | 3% | 4% | 4% | 6% | 8% | 10% |
| | | (ha/Mm$^3$ $CH_4$) | 121 | 91 | 60 | 55 | 50 | 43 | 35 |
| (C x P) | - Monocrop BioCH4 yield | (m$^3$/ha $CH_4$) | 6,720 | 6,720 | 6,720 | 6,720 | 6,720 | 8,400 | 10,080 |
| (A/FCLR) | LAND EFFICIENCY | (m3/ha CH4) | 8,235 | 11,000 | 16,800 | 18,333 | 20,000 | 24,762 | 28,462 |
| (A - I) | - BioCH4 from monocrop | (Gm$^3$/year) | 0.6 | 1.3 | 1.7 | 2.0 | 2.7 | 4.4 | 4.4 |
| (I) | - BioCH4 from integration biomasses | (Gm$^3$/year) | 0.1 | 0.9 | 2.5 | 3.5 | 5.3 | 8.6 | 14.1 |
| (I) | - BioCH4 from integration biomasses | (%) | ***18%*** | ***39%*** | ***60%*** | ***63%*** | ***66%*** | ***66%*** | ***76%*** |

http://www.ansa.it/canale_terraegusto/notizie/mondo_agricolo/2016/10/07/legumi-toccasana-ma-produzione-italia-calata-80-in-50-anni_ab378584-20cc-4175-af78-6d9300943a19.html

[23] For its short maturation term and adaption to crop rotation, the silage production is ideal before a legume production.

## The production of renewable gas in 2050

Biomethane from agriculture and OMW are not the only ones that can be produced in Italy, since there are also:

a) biomethane from gasification of solid biomasses, and
b) biomethane from not biogenic sources.

Biomethane obtainable from the gasification of solid biomass is considered in some Countries as the most promising source of biomethane in the medium term[24]. This is due to the high-energy conversion theoretically achievable. Even Italy has certainly forest resources useful for this purpose, and their use in direct combustion will also be increasingly limited for reasons of air pollution. At the current moment, however the production of methane from gasification is negligible compair to the production of methane from anaerobic digestion in Europe. It is not therefore possible in this context to make a reliable prediction about the impact of this technology since the problems related to biomass procurement, to the gasification plant scale, and the production costs are still being examined, as are the actual performance in GHGs of emissions.

We intend for methane produced from not biogenic sources, the methane produced by reacting Carbon Dioxide with renewable hydrogen obtained through electrolysis or photocatalysis and then converted into methane by either thermochemical processes (Sabatier) or by biotechnological route (with biocatalysts such Archea for example). The European Commission, in its recent proposal has included them in the advanced biofuels list[25] and Italy is allowing their use in the updated biomethane supporting legislation[26] as advanced biofuels.

Taking into account the existing infrastructure and the availability of C-$CO_2$ in the ratio of approximately 0.8: 1.0 compared with the C-$CH_4$, we see a real "biogas refinery" combining the different available technologies with a proper business case as the emerging biogas application of the future.

Methanation reaction with renewable hydrogen can be performed also with $CO_2$ from fossil flue gases and with $CO_2$ captured from the atmosphere. In any case, in the biogas refinery the $CO_2$ is available locally and in the business case it represents an avoided cost (the biogas to biomethane upgrade cost), whereas in the other cases the $CO_2$ needs to be captured and transported to the methanation unit.

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24 Oliver Guerrini "Gassification technologies and their contribution to Biomethane development industry perspective" February 2017 EBA Workshop – General Assembly.
25 Proposal for a directive of the European Parliament and of the council on the promotion of the use of energy from renewable sources (recast) COM(2016) 767 final 2016/0382 (COD)
26 Ministry Decree for Biomethane, version for public consultation December 2016-January 2017.

Therefore, we focused our reasoning only to the potential of methanation considering the C-$CO_2$ of the biogas refineries[27].

Here below a summary of the renewable gas potential for Italy in 2050, with a rough estimation of direct production costs targets[28] (before injection into the grid) related for the various kinds of renewable methane (OMW, agriculture and renewable from gasification or biogenic).

| | 2015 | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| | | | | | | |
| BIOMETHANE FROM OMW | 500,000,000 | 650,000,000 | 750,000,000 | 900,000,000 | 1,200,000,000 | 1,500,000,000 |
| | | | | | | |
| AGRICULTURAL BIOMETHANE | 2,000,000,000 | 3,550,000,000 | 5,500,000,000 | 8,000,000,000 | 13,000,000,000 | 18,500,000,000 |
| | | | | | | |
| RENEWABLE GAS FROM NO BIOGENIC SOURCES AND BIOMETHANE FROM GASIFICATION | | | 50,000,000 | 1,100,000,000 | 5,800,000,000 | 15,000,000,000 |
| | | | | | | |
| **TOTAL Nm$^3$ CH4 bio** | **2,500,000,000** | **4,200,000,000** | **6,300,000,000** | **10,000,000,000** | **20,000,000,000** | **35,000,000,000** |
| **TWh th** | **25** | **42** | **63** | **100** | **200** | **350** |
| | | | | | | |
| | **2015** | **2020** | **2025** | **2030** | **2040** | **2050** |
| **BEST PRODUCTION COSTS** PROJECTION FOB ANTE GRID INJECTION | | | | | | |
| AGRICULTURAL BIOGAS ( MWh th ) | € 60 | € 50 | € 45 | € 40 | € 35 | € 30 |
| AGRICULTURAL BIOMETHANE ANTE INJECTION ( €/MWh th ) | € 75 | € 62 | € 56 | € 50 | € 43 | € 37 |
| RENEWABLE GAS ( €/MWh th ) | | | € 100 | € 70 | € 60 | € 50 |

The biomethane potential from agriculture can therefore amount to **185 TWh,** a quantity corresponding to 1,5X the current national fossil production[29]. It must be noticed that this potential is for Italy, a Country with high fossil resources consume and with a UAA/inhabitant ratio among the lowest in the world (US has for example 10 more than Italy UAA/inhabitant) and a Country with very high pro-capita fossil consumption.

Then the total renewable gas potential (agriculture, OMW, biomass gasification and not biogenic sources) can be estimated to **300-350 TWh.**

These evaluations are under scrutiny and will be addressed in great detail in a peer-reviewed study that is currently in preparation and that will outline and quantitatively analyze the assumptions behind this technical and economic potential of biogasdoneright also in other contexts. The team of scientists includes Jeremy Wood (Imperial College London, UK), Tom Richard (Penn State University, USA), Kurt Thelen (Michigan State University, USA), Jorge Hilbert (INTA, Argentina), Claudio Fabbri (CRPA), Lorella Rossi and Fabrizio Sibilla (CIB) under the coordination of prof. Bruce Dale of Michigan University. The whole team was presented during Biogas Italy in 2017 and the results will be presented in next year Biogas Italy event.

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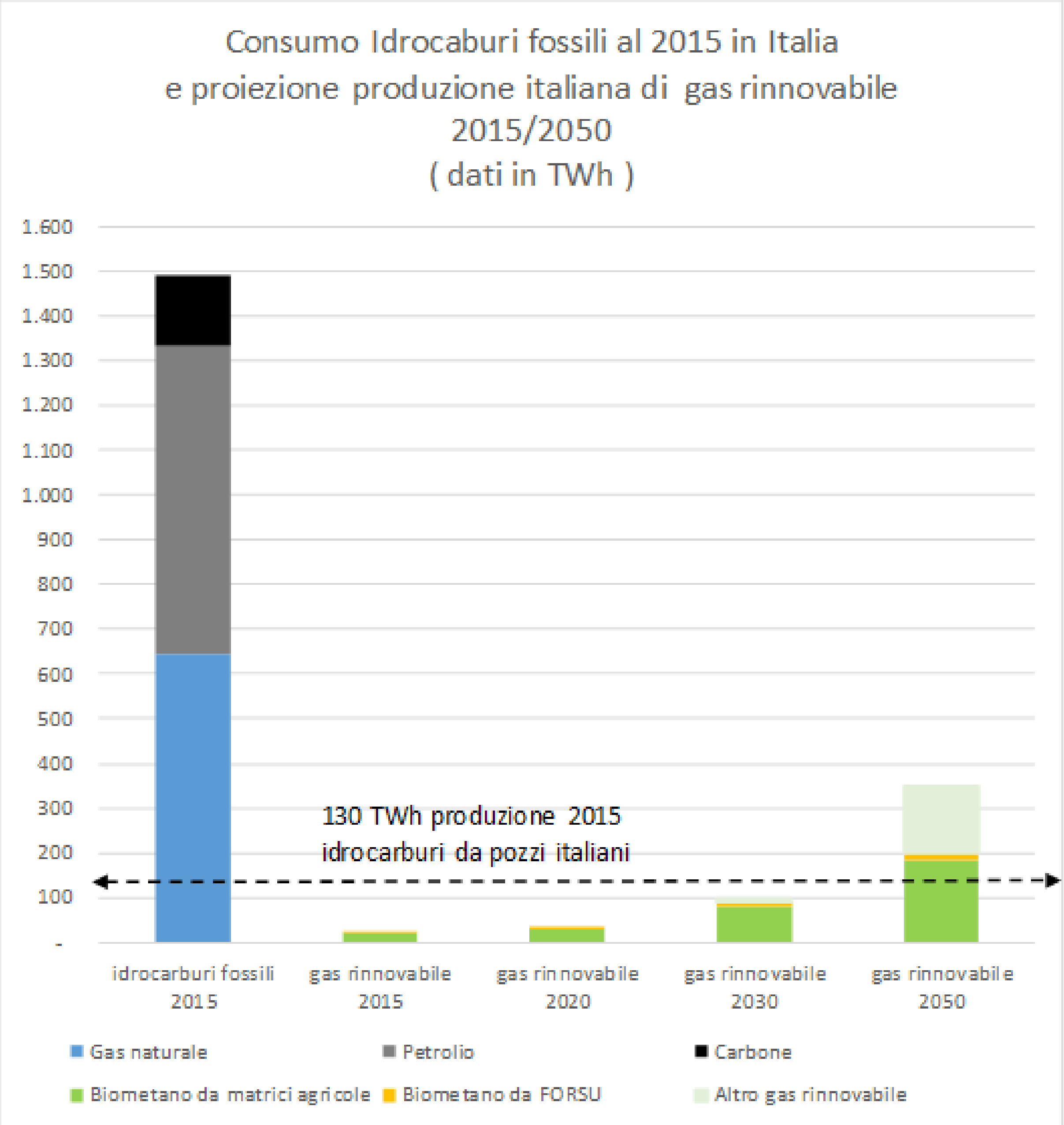
[27] Regarding the renewable gas please refer to "Renewable Gas. The Transition to Low Carbon Energy Fuels" Jo Abbess Associate Research Fellow, Birkbeck College, University of London, UK 2016

[28] See later for more detailed explanations

[29] Circa 68 TWh from natural gas and 62 TWh from oil.




Such a national renewable gas production represents a significant potential but cannot replace the current consumption of fossil resources. It can be envisaged anyway that, through natural gas imports from abroad, also biomethane will be imported.

In any case, it represents a valuable contribution for the reduction of foreign fossil resources imports. Moreover it could contribute significantly to reduce the fossil carbon fraction of the gas grid toward a progressive replacement of oil and coal with methane.

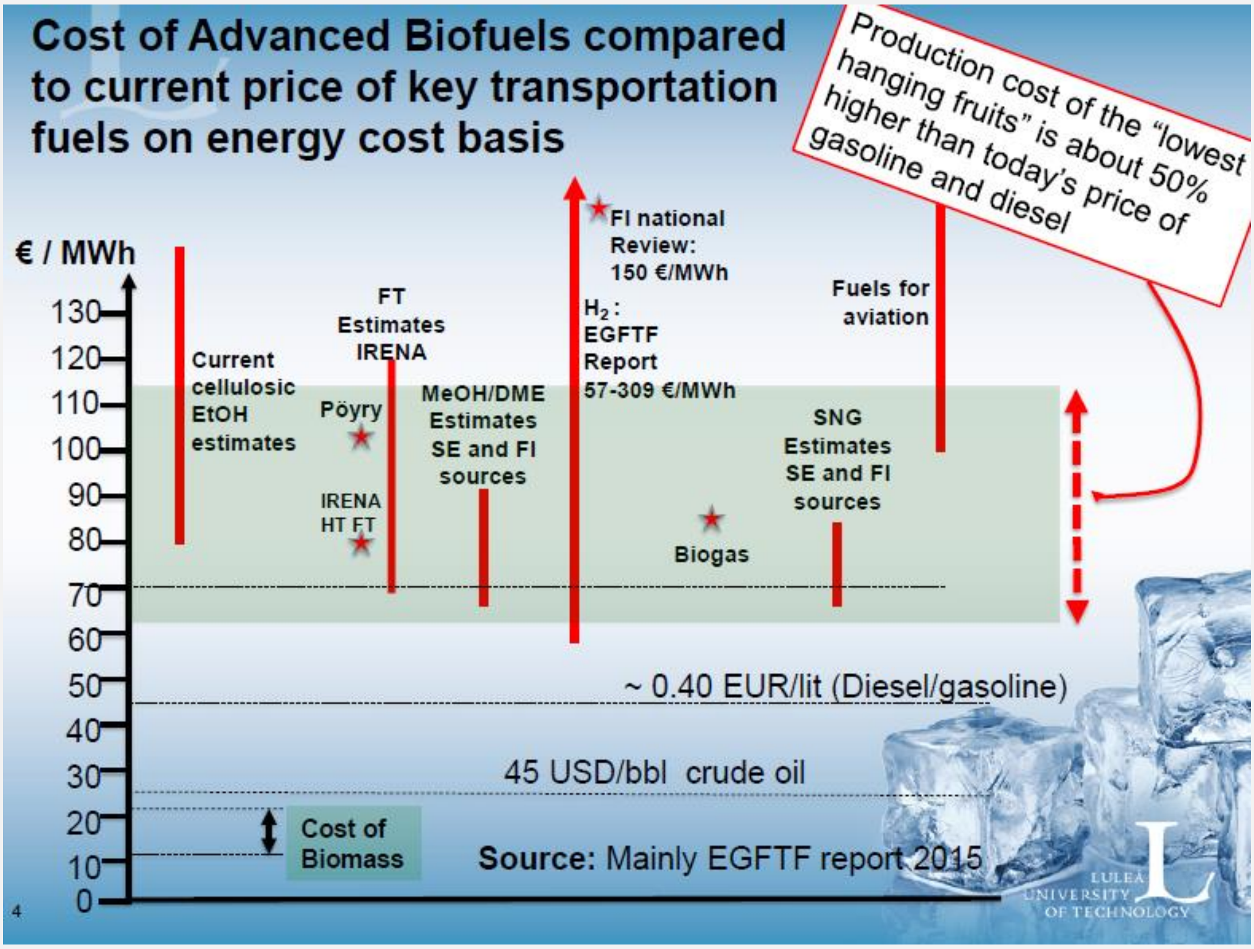
But more realistically the renewable gas can be considered a strategic renewable hydrocarbon in a energy mix required for the national energy transition, it can be transported through the gas network, stored and immediately available through the current gas grid infrastructure for both energy and industrial sectors; it can be mixed with fossil gas in any ratio and it does not require any special modification to the gas grid. It represents therefore a real drop-in multi market solution.

## BIOGASDONERIGHT ENERGY COST REDUCTION TRAJECTORY

### Foreword

One of the arguments against bioenergy says that it is limited[30] in amount if obtained sustainably and it cannot show a cost reduction trend similar to those of PV and wind energy.

A recent study promoted by the EU Commission[31] outlined the following results for bioenergy economics for advanced biofuels, a category where biogas fits.




It is therefore evident from the graph that with a diesel cost of 45-60 €/MWh th, corresponding to a crude oil price of 45-100 \$ per barrel, a biofuel with a cost of 100-120 €/MWh th is too high and it would mean to have a cost of avoided $CO_2$ of 300 €/ton $CO_2$. There are very likely cheaper technologies to decarbonize transport costs.

[30] Pete Smith and others "Biophysical and economic limits to negative CO2 emissions" "http://www.globalcarbonproject.org/global/pdf/Smith_2015_Biophysical%20and%20economic%20limits%20to%20negative%20CO2%20emissions.NatureCC.pdf

[31] Sub-group on advanced biofuels - Bruxelles 31 may 2016.

The cost issue is therefore unavoidable for biofuels in general and advanced biofuels especially: biofuels will not be able to play the expected impact in the energy transition if their **production cost cannot stay well below 60 €/MWh th.**

As shown, today many of these advanced biofuels have higher costs. At the current state this is also true for biomethane produced from monocrops, with its current cost of 80-100 €/MWh th.

But biomethane is still in its infancy, very few $Nm^3$ are used in the transport sector and very low are the current investments in R&D for the biogasdoneright.

**What is important therefore is to understand the cost reduction potential and in particular the trajectory and the actions needed to reduce stepwise the feedstock costs for the production of renewable gas**. As a matter of comparison, in fact in a mature technology as diesel production from crude oil the feedstock cost represent 70-80% of the total costs.

Therefore it is essential in order to understand the potential of a technology to estimate the feedstock cost reduction potential and also how to secure a feedstock supply chain with deflated costs in the short-medium term. In fact, a future scenario with the prevalence of no carbon-based energy sources like solar, wind and (maybe) uranium represents a new paradigm in the energy markets. The challenge that no carbon based energy sources pose is not only placed in terms of cost, but it regards also how we can provide a relatively constant price of energy in the medium term, since their cost structure is almost indifferent to inflation and, if plants are built during a cycle of low interest rates as now, they can provide energy for a long time in conditions substantially indifferent to the economic cycle since their operating costs represent normally less than 10% of the total costs[32].

This fact is different from what happens to programmable energy sources, where there is the need to buy the feedstock on the global market.

## Biogasdoneright biomasses

To produce large biomethane quantities with low production costs we cannot look at monocrops as feedstocks. We need conversely to undertake a shift to the biomasses of the biogasdoneright, that means biomasses that do not lower the farm food and feed output and allow the biomethane to qualify as advanced biofuel[33]:

- sequential crops before or after a crop as food or feed;
- crop rotations with annual crops, instead of the set aside, such as the case for Italian Sainfoin in rotation to durum wheat in Sicily;

32 The fact that LCOE doesn't reflect the solar and wind is under discussion anyway… for more informations on the subject let see http://neon-energie.de/en/ .

33 With the EU directive 2015/1513 that modifies the directive 98/70/CE related to gasoline and diesel quality and the directive 2009/28/CE for the promotion of Renewable Energy sources it has been modified the ILUC approach, since sequential crops are before or after food crops are now allowed for the production of advanced biofuels and biomethane is an advanced biofuel.

- perennial crops where C3 and C4 plants are not profitable (such as alfalfa on the Monferrato hills in Piedmont);
- livestock effluents;
- agricultural residues and agro-industrial by-products.

The use of monocultures in the coming years will therefore diminish, being likely authorized in limited quantities, because it is useful to create extra demand in particularly unfavorable economic circumstances where commodities prices are extremely low such as the current moment. But in any case, their amounts will lower: monocultures are simply too expensive for bioenergy purposes.

Here below a table that compares the feedstock cost for a plant that uses maize monocrop and another one that uses a maize variety suitable for late seeding in sequential crop after wheat grain for the market.

| | **MONOCROP** | **SEQUENTIAL CROPPING** | | **MONOCROP** |
|---|---|---|---|---|
| | **Food** | **Food** | **Fuel (digester)** | **Fuel (digester)** |
| | **WHEAT** | **WHEAT** | **Corn silage** | **Corn silage** |
| Land opportunity cost | € 500 | € 500 | | € 500 |
| Technical inputs | € 250 | € 250 | € 300 | € 300 |
| Digestate application | € 180 | € 70 | € 100 | € 100 |
| Irrigation - pivot | - | - | € 100 | € 100 |
| Labour, tillage | € 200 | € 200 | € 160 | € 370 |
| Insurance | € 30 | € 30 | € 40 | € 40 |
| Third parties harvesting transport and silaging | € 100 | € 100 | € 288 | € 360 |
| **TOTAL COST (€/ha)** | **€ 1.260** | **€ 1.150** | **€ 988** | **€ 1.770** |
| Yelds - Fresh matter (t/ha) | 7 | 7,0 | 48 | **60** |
| Biogas (Nm3/t FM) | | | 220 | **230** |
| Biogas (Nm3/ha) | | | 10.560 | 13.800 |
| BioCH4 (Nm3/ha) | | | 5.491 | 7.176 |
| **Selling price (€/t)** | **€ 200,00** | **€ 200,00** | | |
| **PLV (€/ha)** | **€ 1.400** | **€ 1.400** | | |
| **Return (€/ha)** | **€ 140** | **€ 250** | | |
| (€/t) | | | € 21 | € 30 |
| Biogas (€/Nm3) | | | € 0,09 | € 0,13 |
| Energy (€/MWth th) | | | € 18 | € 25 |
| BioCH4 (€/Nm3) | | | € 0,18 | € 0,25 |
| | -79% | | | 37% |

From the table analysis two elements are to be noticed:

a) the sequential crop maize production costs are 37% lower than in the maize monocrop case in term of energy. This happens because the fixed costs are better amortized using the land twice per year.

b) At the same time the organic fertilization of wheat in sequential cropping yields an almost double income compared to the monocrop with chemical fertilization and the same yield per hectare.

If we consider also that the Anaerobic Digestion can use diverse varieties of feedstocks, it results that:

- the biogasdoneright biomasses are the key elements to lower feedstock costs;
- the biogas plant makes the farm more and more independent from fossil energy and fertilizer input.

In this way, the farmer can lower stepwise its feedstock costs for both food and feed market and for the energy market. The farm can decouple itself from the commodities cycles[34] of fossil fuel and fertilizer inputs and produce on defined production costs.

## Biomasses and digestate cost reduction path.

As a starting point, we take the feedstock cost of a current best case: maize from monoculture covering about 60% of energy needs, the rest being fulfilled by manure, with a daily cost of supply of about € 1,550/day (for a 500 Nm$^3$/h biogas around 1 MW el equivalent). In this case, we envisioned to act on three factors to reduce the biogas cost centers, by reducing the presence of monocultures in the diet mix:


1. valorization of the digestate, in particular of the solid phase, to be applied as a soil conditioner and fertilizer on specialized market crops such as orchards or vegetables. Anyway even other digestate valorization market can be pursued;
2. the reduction of the silage costs, using sequential cropping, not burdened by fixed costs already allocated in food production;
3. increase in crop yields: as an example, see the case study of the Palazzetto farm (of Folli Ernesto CR, Italy) recently investigated by Ecofys with the support of the University of Wageningen and the CRPA Reggio Emilia[35]. It has been verified in several plots that the production of dry matter silage per hectare rose from 20 ton DM/ha to more than 30 ton DM/ha, due to the increasing of sequential cropping and to a more

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[34] In a farm run with the Biogasdoneright principles only the personnel and seed costs are linked to economic cycles, whereas all the other costs are self determined.
[35] Ecofys "Assessing the case for sequential cropping to produce low ILUC risk biomethane. Final report. November, 4th 2016. Project number: SISNL17042.

efficient use of the digestate. Although the incidence of farming variable costs accounts for more than 80% of the total, in a conservative approach it was decided to consider only a reduction in the cost equal to 10% of the silage.

Therefore, it is assumed to rise from the current € 25/MWh in the best-case scenario to:

- 17-20 €/MWh th in the medium term (2030),
- with the long-term target (after 2030) to 15 €/MWh th, with a cost reduction of 40% compared to the best current costs, that means a supply cost of about 800-900 €/day for a plant of 500 $Nm^3$ / h of raw biogas.

As reminder: 15 €/MWh th corresponds to a cost of crude oil amounted to $ 25 per barrel, and to a methane gas equal to approximately 0.15 € / $Nm^3$: the overall competitiveness of biomethane therefore depends on the improvement of the processing costs for the transformation into biogas and its upgrading costs.

## Biogas production cost reduction

In its transition from biomass to biogas, the organic matter passes through a series of biochemical transformations performed in controlled conditions using a patent free biotechnology freely available in nature, especially in the manure. The variable composition of different biomasses that can be used in Anaerobic Digestion and the need to intercept the organic matter variable flows is largely compensated by the complex microbiology of the process and its simple adoption. On the contrary, in the case of ethanol production, the use of biomass almost standardized and simplified setting (monoculture) of the industrial process determines the need to resort to the use of enzymes, one of the major operating costs.

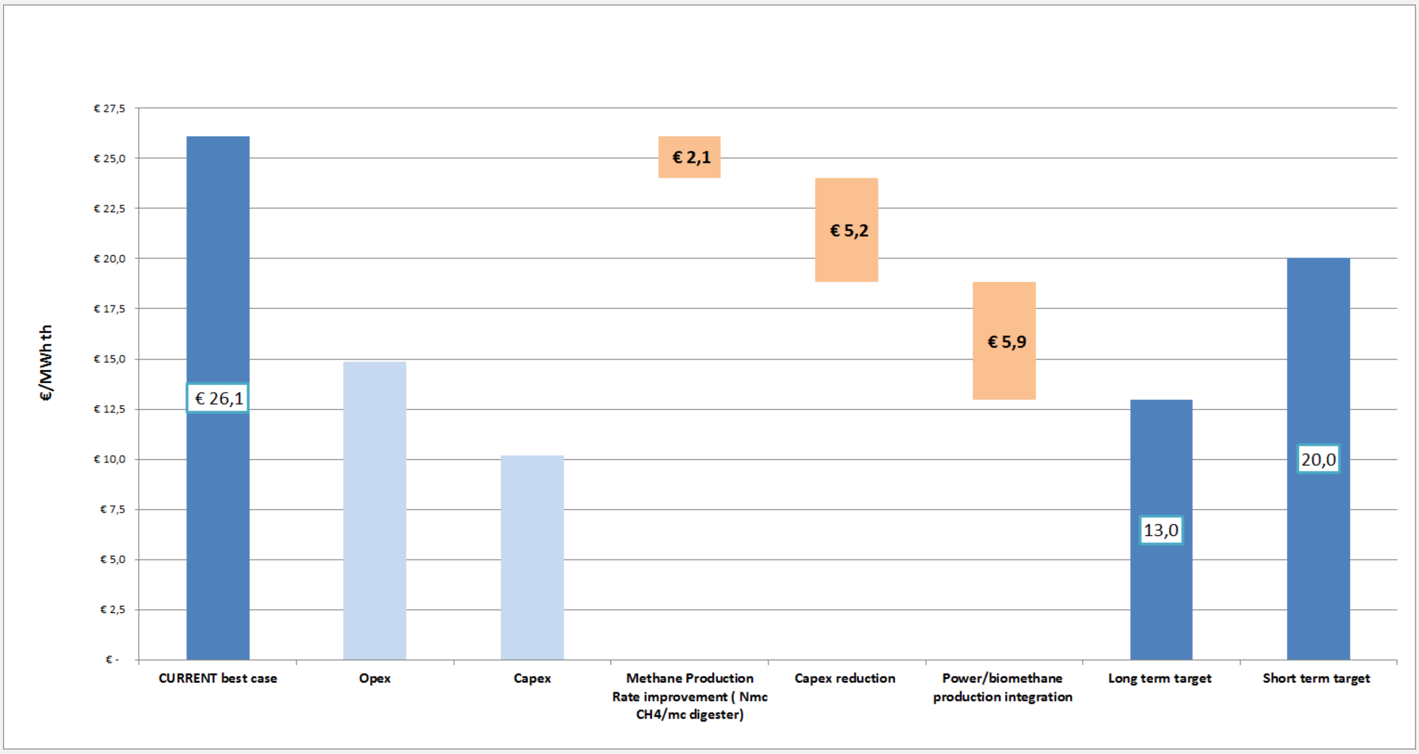
In view of the aimed cost objectives, we consider not necessary at this point in time the use of inoculum of specific microbial cultures or proprietary enzymes in order to increase the yields of biological transformation of organic matter in gas. Anaerobic digestion naturally fulfill three of the goals that i.e. the cellulosic ethanol industry would like to achieve:

a) simultaneous hydrolysis and methanation processes in a single reactor;
b) gas separation from the slurry, thanks to the natural phenomena of gaseous phase separation from liquid phase;
c) self-production and propagation of the microbiome necessary for the degradation of organic matter.

The decrease of biomass-to-biogas transformation costs should therefore be directed towards other factors such as:

a) improvement of Methane Production Rate[36], that is the quantity of biogas obtainable per unit of reactor volume per unit of time;
b) an increase of the biogas plant unit size from the current 300-500 Nm³/h to 700-1,000 Nm³/h achieving an economy of scale of industrial fixed costs[37]. This growth in size can be realized also by connecting several plants through the same biogas pipeline towards a joint upgrading unit of biomethane into the grid. The biomethane can be upgraded in a joint facility shared by more farmers. There are already some virtuous cases in Denmark, and a few similar plants are being projected in Italy;
c) a reduction in investment costs and longer depreciation period of plants, since they are no longer limited to the duration of the incentive fee (15 years), but to the service life and obsolescence of goods (about 25 years).

Here the breakdown of the planned cost reductions.




## Industrial cost reduction of biogas into energy

In this section we refer only to the cost of upgrading biogas to biomethane; we consider the pure cost, without compression expenses, metering and transport, since those are not standardized and are dependent from local conditions.

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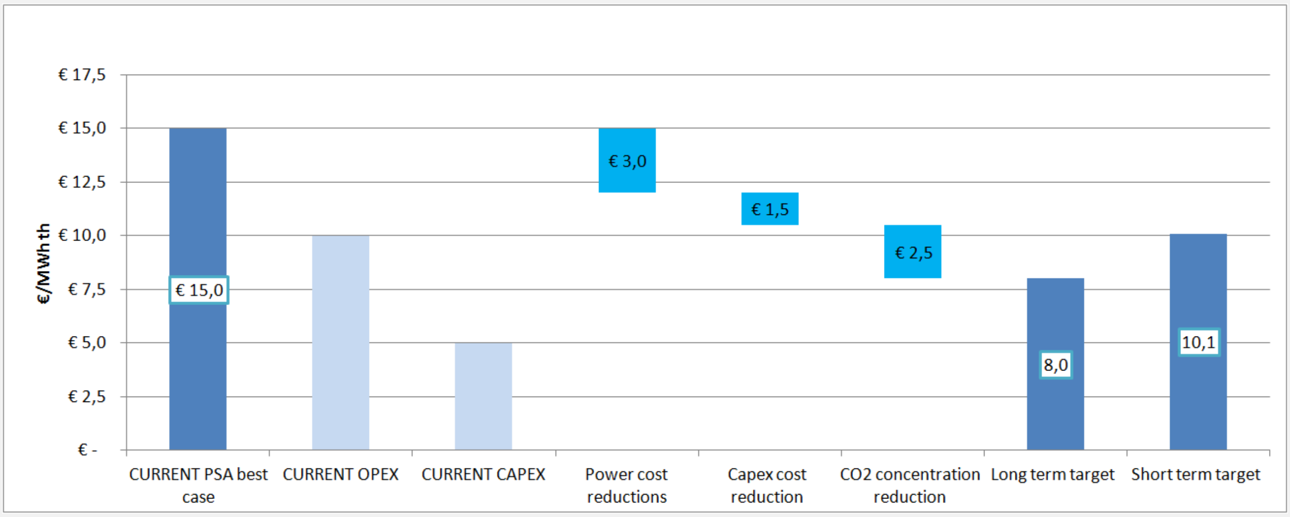
[36] A greater MPR can be achieved via improvement of the AD plant management and process parameters, the use of thermophilic bacteria and therefore a faster biogas production rate.
[37] A shift to biogas plants with 1,000 Nm³ output and connected among them via biogas pipeline will allow a further saving of personnel and maintenance costs.

Here below the foreseen cost reduction breakdown:

1. reduction of the electricity costs via self-produced electricity in cogeneration and integrated with intermittent renewable energy sources, when needed and economically profitable[38];
2. 30% reduction of the investment cost unit: those are mature technologies, yet there is room for improvement while increasing the installed quantity;
3. reduction of the $CO_2$ concentration in the biogas, through $CO_2$ hydrogenation using hydrogen coming from intermittent renewable sources. It is quite evident that with regard to the OPEX, the cost of upgrading is inversely proportional to the amount of $CO_2$ in the biogas.

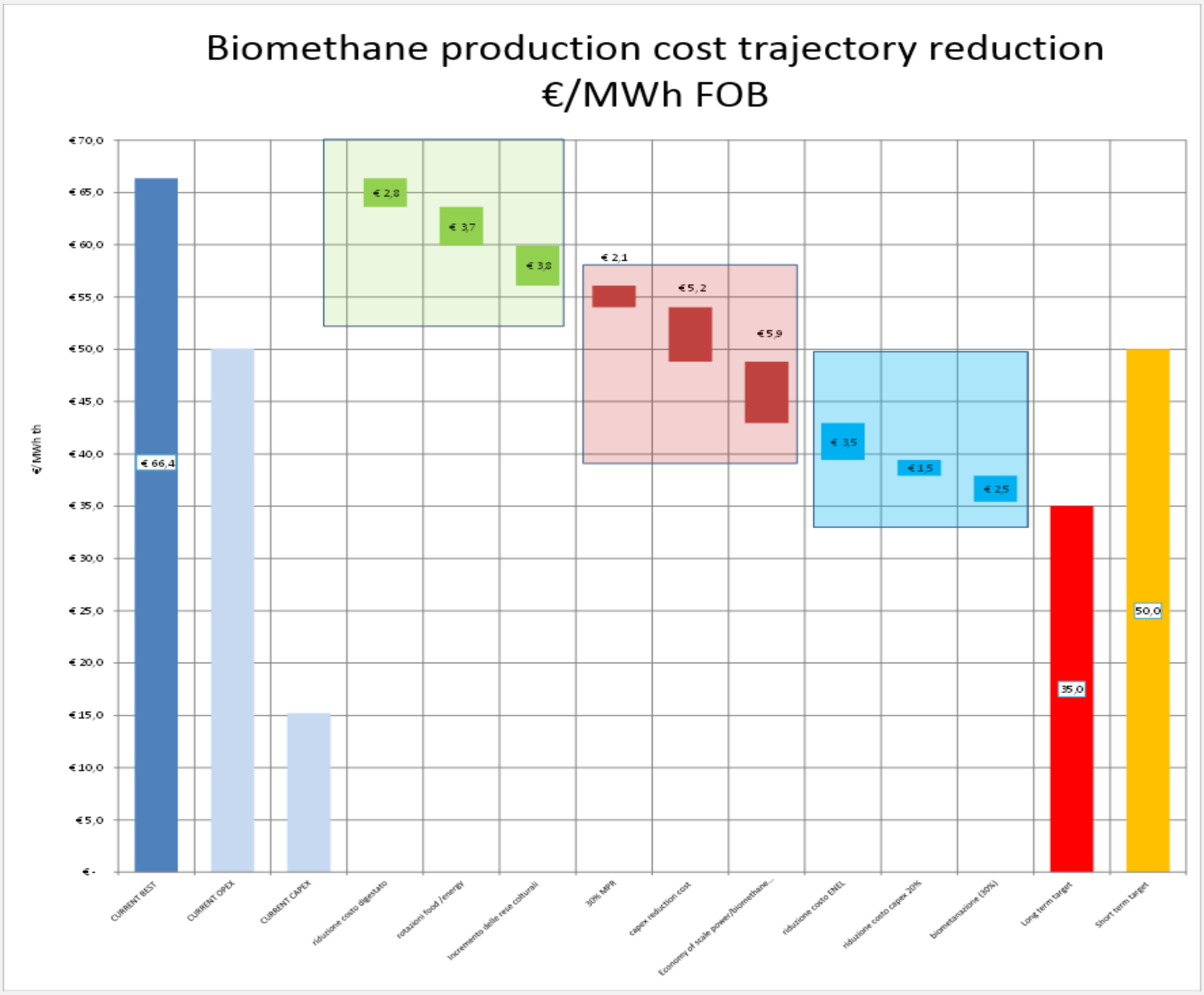



[38] It is possible to think for southern Italy plants to use PV electricity for the auxiliaries, utilizing CHP for the residual energy demand and producing process heat at the same time.

## Summary of the cost reduction trajectory

Here below a summary of cost reduction assumptions.

**It is necessary to remember that -from a methodological point of view- there is no reference in this study to the methodology of the LCOE[39]: only production costs are indicated, without considering: the entrepreneur profit, the cost of capital and compression metering and transport**

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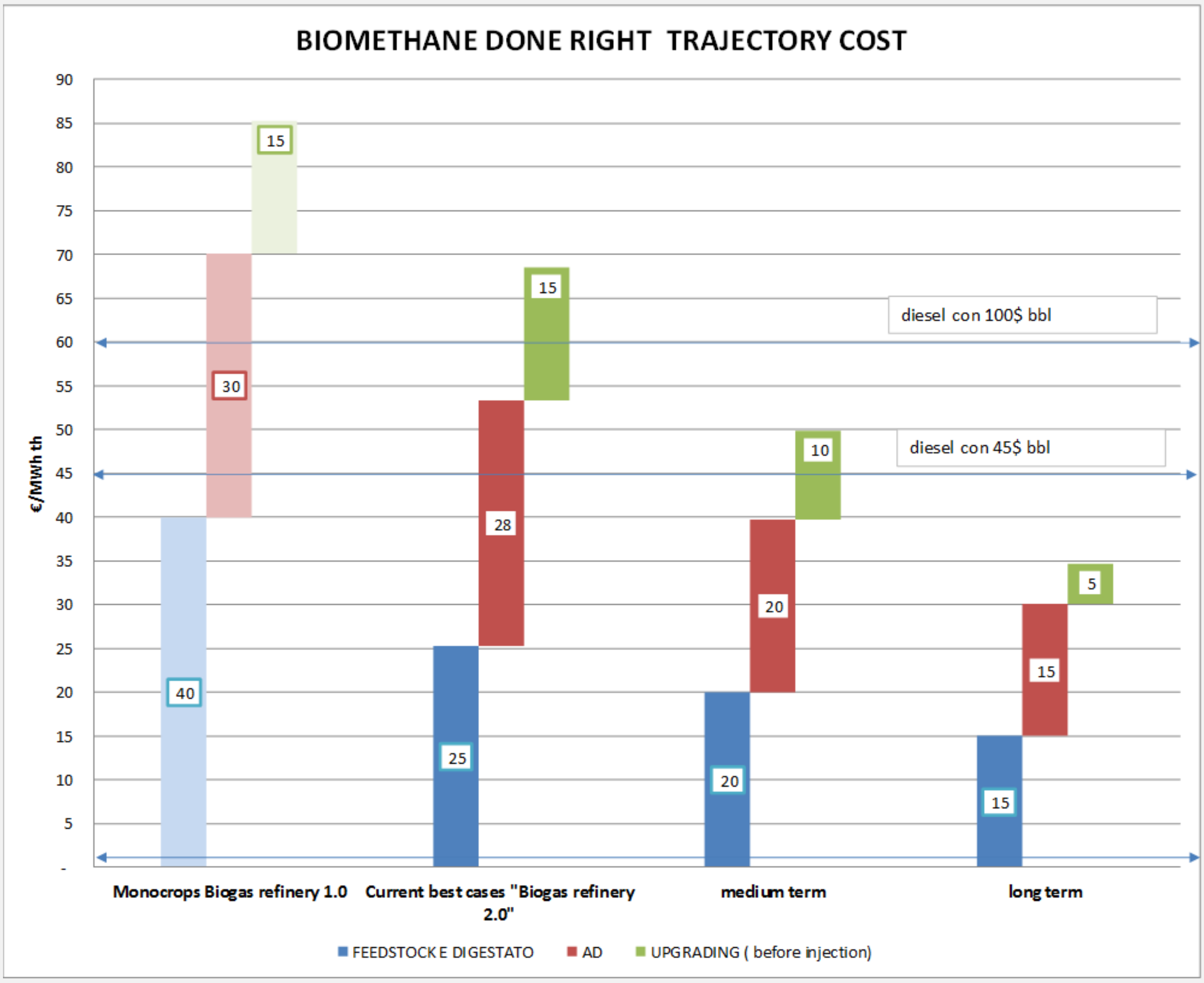
[39] LCOE Levelized COst of Energy. The levelized cost of energy** (or **levelized electricity cost**, LEC) is the most common basis used for comparing the cost of power from competing technologies. The **levelized cost of energy is found from the present value of the total cost of building and operating a generating plant over its expected economic life. Costs are levelized in real dollars, i.e., adjusted to remove the impact of inflation**. http://www1.eere.energy.gov/geothermal/pdfs/egs_appendix.pdf

Currently the best cases of Italian biogas from agriculture have a production cost[40] of around 65 €/MWh th (60-80 €/MWh).

Compared to the above-mentioned cost, measures to reduce the cost of production of biogas and biomethane are described and expected to lead the costs to 50 € and 37 €/MWh in the medium and long term.

Here below a breakdown of four situations considered:

a) a biogas plant fed only by monocrops;
b) a biogas plant fed with 30% monocultures and sequential crops, animal manure, agricultural and agro-industrial by-products, connected to both the electricity and the gas grid (biogas refinery 2.0);
c) the 2030 target;
d) the long-term target.




[40] In this study the LCOE methods are not used. Injection and metering costs are not considered as well as the profits and capital costs.

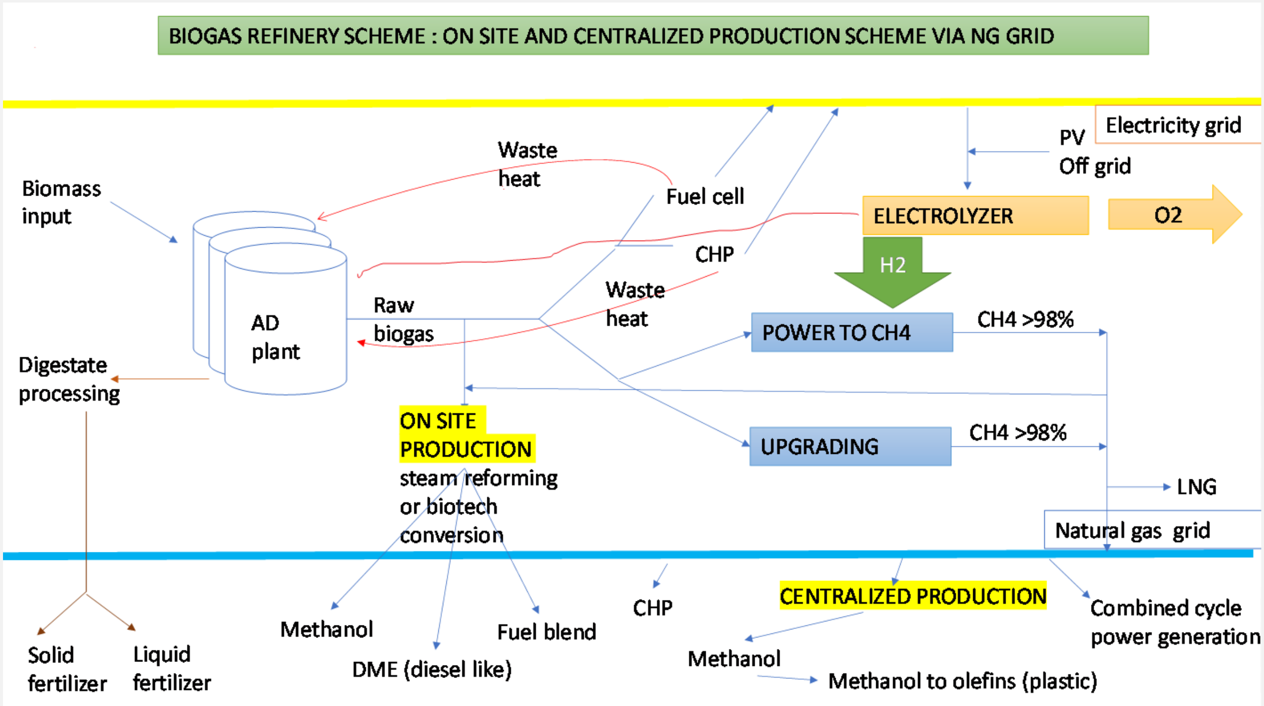
# THE ROLE OF THE BIOGAS REFINERY IN THE ITALIAN ENERGY TRANSITION

## The biogas refinery

For multiple reasons the biogas refinery might play an important role in the energy transition toward a net zero carbon energy system.

We define the biogas refinery as a decentralized biogas plant built on a scale corresponding the size of some MW(thermal) and connected to both the electricity and gas grids.

The biogas refinery is able to produce increasing amounts of biogas to be used locally or be injected into the natural gas grid to be transported where and when its use is necessary.




Hereby is a brief description of the concepts depicted in the above diagram above:

a) The biogas refinery is able to produce TWh of energy through anaerobic digestion plants realized either as single stand alone or as consortium plants operating in a decentralized environment. In the Italian agro-ecological conditions, we estimate that plants on the scale of 250-1,000 $Nm^3$ have the best size to optimize costs and allow a correct integration into local agricultural context. Considering an average of 750 $Nm^3/h$ of biogas, the national target production corresponds to approximately 10,000 plants by 2050, a number similar to the actual German biogas plants, eight times higher than the currently operating AD plants in Italy. The new plants must be located close to the gas grid, that will have to adjust to collect as much energy as possible from the surrounding area too.

b) Bioenergy production will take place in the base load regime (closest at 8,760 hours full load yearly, except for scheduled maintenance).

c) The plant will produce organic fertilizer on a daily basis, through which will be able to recycle all of the nutrients (recalcitrant undigested carbon, NPK, microelements, etc.) entered into the system and not converted into biogas. The digestate will be stored and intended for on-site use with agronomic technologies such as precision farming and minimum tillage, which are aimed at pursuing the maximum efficiency (Nitrogen Use Efficiency) according to nutrients balance and to prevent the phenomena of soil compaction due to excessive use of machinery on the fields, or soil carbon oxidation

d) Since the AD plant will be connected to both the electric and gas grid, the biogas will be destined to the most profitable market according to the moment of the day, the week or the season. Anyway will be necessary to produce process heat by cogeneration; for example in an AD plant operating even under thermophilic conditions (52° C) and with 1,000 $Nm^3/h$ of raw biogas output the heat demand can be over 12 MWh th per day. Since the heat can be stored at low cost, the cogeneration using internal combustion engines or Fuel Cell (or an hybridization between the two[41]) will follow the electricity demand, producing electricity in the hours of peak demand (and value) and storing heat for the moments of actual need.

e) The Biogas that is not used in cogeneration will be either upgraded to methane at the purity specifications needed for the natural gas grid injection or processed into liquid fuel (LNG or methanol) when feasible in a decentralized site, or even at large facilities fed via the gas grid at the scale required

[41] https://www.ge.com/sites/default/files/GE_FuelCells.pdf

f) The decentralized methane production can be increased via Power-to-Gas process using electricity from the grid during excess supply moment, something that will happen due to the growing supply of electrons from non-programmable renewable sources. The electrical energy will be then converted into hydrogen, ideally by means of reversible electrolytic systems (SOEC/SOFC) in order to obtain a greater use of the equipment (ideally 5,000 h/year between electrolysis and hydrogen production in cogeneration), and then reacted with the $CO_2$ of the biogas to yield renewable methane either via a thermochemical or biochemical route[42].

g) In these terms, the Power-to-Methane systems are a real upgrading tool of biogas to natural gas (methane). Once injected into the gas grid, the biological and the renewable methane can be used for transport, seasonal storage and as feedstock for industrial processes: combined cycles, cogeneration *in situ*, methane heat pumps and condensing boilers, industrial uses for the production liquid fuel (methanol among the others) and bioplastics, biochemicals, etc. Allowing the injection of biomethane and, in the future, of renewable gas into the gas grid paves the way to the availability of renewable methane in programmable fashion, adequate amounts and at transparent price, competitive with that of other organic carbon sources currently used in green chemistry. As a consequence, the industrial projects using renewable methane as a raw material become feasible and attractive.

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[42] It is evident that electrolysis and biomethanation have thermodynamic losses; 40% of the initial electricity is lost in the methane formation.
Keeping in mind anyway that:

- Intermittent renewable energy will become the cheapest commodity;
- Within the biogas refinery frame the $CO_2$ is available at negative costs since it is avoided upgrading cost;
- The possibility to use infrastructure whose costs are already allocated for the biomethane production (grid connections, infrastructures)
- The easiness of processes, especially for the biotech ones.

The transformation of electric energy in methane at a biogas refinery is therefore a wise option to produce, transport and utilize hydrogen via gas grid.

It is worth to mention that storage costs for electricity in form of renewable gas in the existing gas grid infrastructure is lower than 1 €/MWh th whereas the best future projections for electrochemical storage are in the range of 100 €/MWh el. If we consider also the oxygen value and that the biomethanation reaction is also endothermic thus it creates process heat for the biogas refinery, then a target of 50 €/MWh th production cost for the renewable gas can be envisaged and such target is in line with other options for seasonal storage of renewable energy.

## The biogas refinery as "biomass densification center" and its role in the natural gas grid

We identified four challenges for the biogas refinery:

a) maximum possible integration at the farm level in order to utilize the biogasdoneright biomasses and produce bio-methane in quantities corresponding to more than 100 TWh per year;
b) aiming at injecting the highest quantity possible of renewable methane in the gas grid, to optimize their final uses at reasonable costs;
c) stimulate the growth of a bioenergy and biomaterial industry, decoupling feedstock and raw material cost (the biomass produced in the agricultural sector has a control of the cost factors equal to approximately 80% of the variable costs and over 90% of total costs in the production of energy from renewable sources). This means the possibility to build business plans for the gas industry, plans not subjected any more to the volatility of agriculture and energy markets ,as it happens for biofuels or green chemistry from starches, sugars or oils where the raw material price is linked to the agricultural commodities prices;
d) to operate in a decentralized environment to a scale determined by watered biomasses with low energy density and by the digestate transport and distribution; to operate biological processes in base load feeding steadily the ADs; to use the biogas in a diversified and flexible manner achieving the highest value possible from the gas itself.

These are the elements of the biogas refinery which lead to peculiar characteristics of versatility thanks to the possibility to be connected simultaneously to both electricity networks and gas grid.

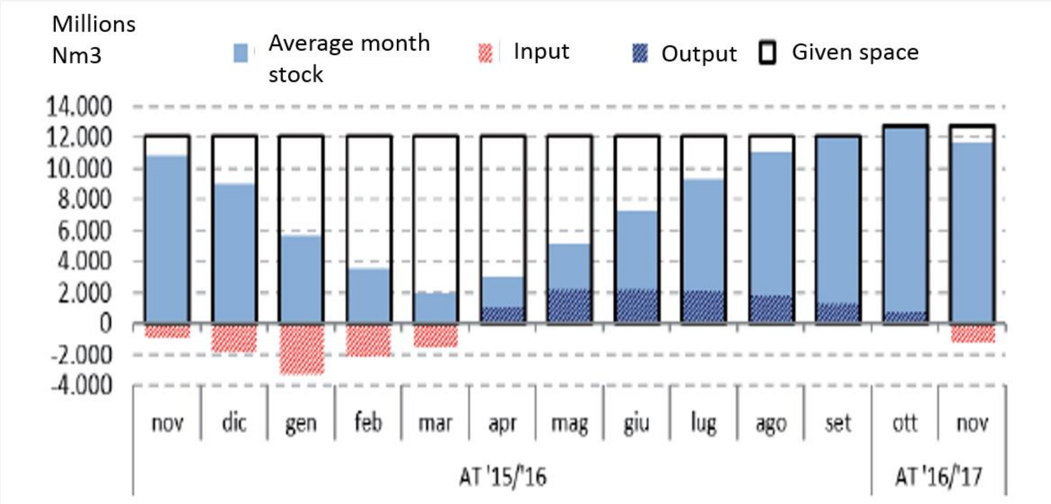
In this context, the advantage of biogas refinery becomes more evident with the increased availability of non-programmable renewable energy sources and the requirements of the electricity grid in terms of more flexibility and higher reserve capacity that until today was covered by fossil fuels. The biogas refinery can offer programmable energy with stepwise lowering costs, offering a grid stabilization service at competitive costs compared to alternative solutions; this because the biogas refinery acts at two levels: as energy supplier in the dispatching markets and a storage system via Power-to-Gas or upgrade of biogas to biomethane.

This biogas refinery traits comes from its possibility to be linked to two grids; moreover the peculiar trait of the gas grid is to be an infrastructure that has:

a) transports costs not comparable with the biomasses road transport[43];

b) a transport capacity of some GWh/day with an already existing and paid back infrastructure that connect the country from North to South, without the need of new infrastructure that can have a negative impact on the environment or on the landscape.

c) a storage capacity of 120 TWh, with the possibility of seasonal storage at low costs.




While some Countries[44] are considering the complete electrification of some energy markets -such as domestic heating- proposing to delete the connection to the gas grid of civilian homes, we see conversely this choice as rather illogical, considering the technical value of the infrastructure that should be dismissed, and furthermore it is a particularly uneconomical choice if we consider the cost required to have storage and transport capacities comparable to those of the gas system.

In fact, the gas grid and methane are two key elements particularly suitable to facilitate a larger share of intermittent sources in all segments of the energy markets and the methane industrial uses at a reasonable cost[45].

Therefore, in our view a deep decarbonisation of our economy at a reasonable cost cannot be separated from the integration of energy systems (heat, electricity, fuel) and an increasing amount of renewable gas in the grids.

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[43] As a matter of comparison we refer to the transport costs of straw pellets rather than natural gas transport costs from the same area.

[44] "Why Amsterdam Is Giving Up on Natural Gas. The city plans to wean its homes off domestic natural gas by 2050, starting now." http://www.citylab.com/cityfixer/2016/11/amsterdam-natural-gas-ban-2050-climate-change-regulations/508022/

[45] Lund H. Renewable Energy Systems: A Smart Energy Systems Approach to the Choice and Modeling of 100% Renewable Solutions. Academic Press, Elsevier, Massachusetts, USA, 2014 http://www.energyplan.eu/smartenergysystems/

**It is also necessary that the gas grid changes its rules and organizes its industrial and business plans to match the needs of a renewable gas production which will be diffused all over the country.**

The ability to adapt the injections to the local grid to the requirements of local biogas production and supporting schemes for socializing the connection costs in remote areas with long-term projects (30 years) are essential gas grid requirements to catch as much as possible renewable gas from South to North of Italy, bringing from the countryside to the cities a renewable source of methane. This, coupled with 6 billion $Nm^3$/year Italian domestic natural gas production, both substantially increases the level of energy security of the Country and reduces the fossil carbon content conveyed by the natural gas grid.

## Biogas refinery markets

In the future, the biogas energy will be utilized in an ever more smart way, with supporting schemes that will foster at the same time:

- a stepwise increase of decentralized biogas production that considers also local effects;
- diverse decentralized and centralized uses via gas grid.

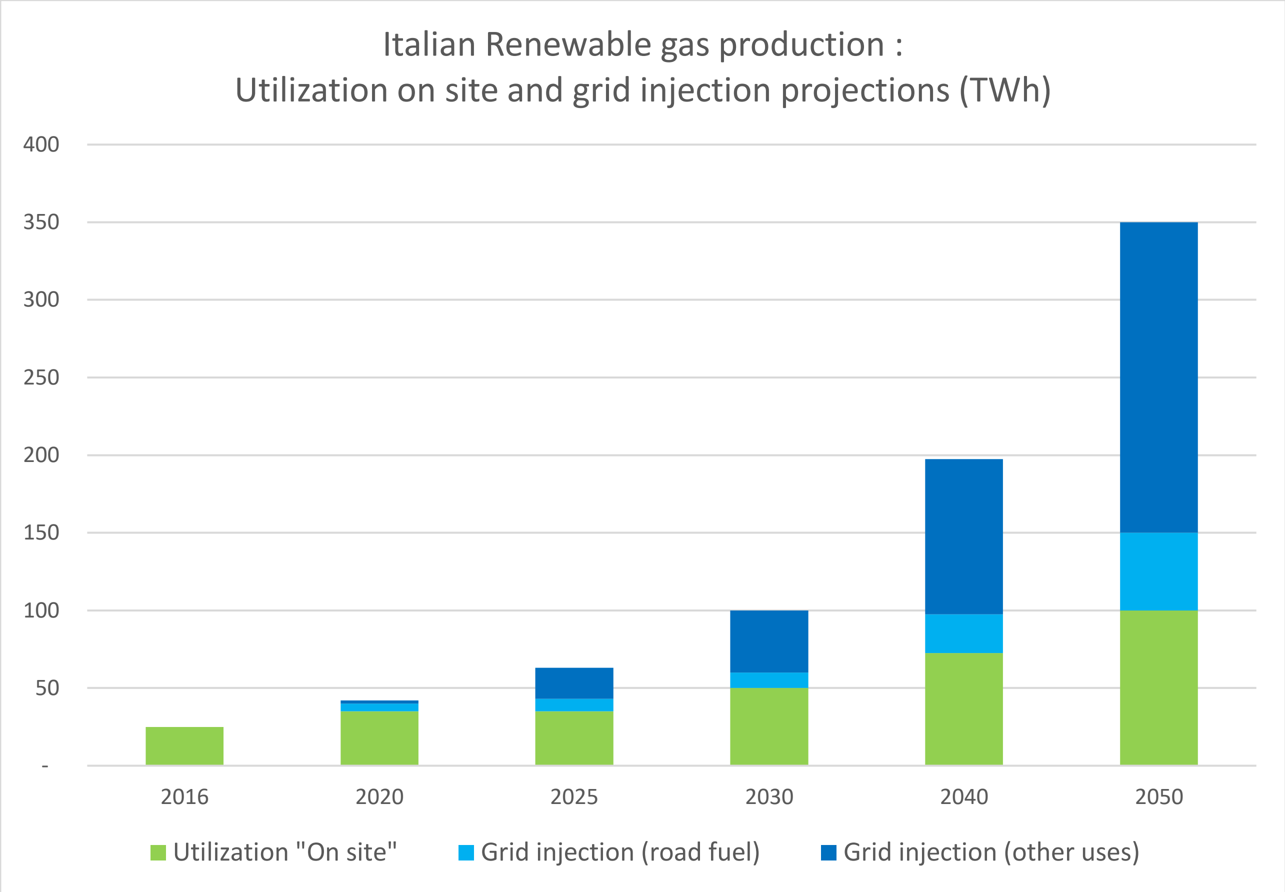
The medium term targets (2030) can be summarized as:

- expanding the biogas feedstocks (increasing quantities of biogasdoneright biomasses, Power-to-Gas, gasification of solid biomasses);
- developing biomethane as advanced biofuel for road transport;
- enabling the retrofit of first generation biogas plants from base load electricity production to a production based on the electrical network needs, also by changing the installed power output;
- seeking diversification of biogas uses in different industrial applications, for example via biogas to plastic biotechnological conversion or also and maybe more likely utilizing the existing infrastructure of the Italian chemical industry, thus valorizing the already existing infrastructure and achieving easily the needed economy of scale.

**But the pre-condition to capitalize the potential of the Italian renewable gas is to increase the amount of biomethane fed into the network compared to that utilized *in situ*.**

It is therefore necessary to put in place a simple and adequate supporting scheme, which allows the injection of biomethane in the gas grid and where the use of biomethane for road transportation is the ideal starting point.

Here below an ideal roadmap.


Italian Renewable gas production :
Utilization on site and grid injection projections (TWh)
400
350
300
250
200
150
100
50
-
2016
2020
2025
2030
2040
2050
Utilization "On site"
Grid injection (road fuel)
Grid injection (other uses)

## RELEVANT TECHNOLOGIES FOR THE BIOGAS REFINERY DEVELOPMENT: AN ITALIAN LEADERSHIP?

Meeting the ambitious target previously outlined can be achieved only with relevant RD&D investments[46].

Today this effort is very modest and insufficient to achieve these objectives. The idea of the biogas refinery emerged in the Italian farmers' community from the pioneering initiative of some players, then it found a fertile dialogue platform with domestic gas industry, biogas, cogeneration, agriculture machinery, in some academic and not academic research institutes with relevant international reputation.

But all the prerequisites to achieve an Italian leadership in this field are already present, and here below some of them are listed:

- *75% of the natural gas vehicles circulating (NGVs) in the EU are in Italy. Italy is therefore the key market to test the capacity of the biogas refinery to provide biomethane as road fuel.*
- *An agriculture focused on high quality food rather than mere commodities production is one of the key factors to innovate farming protocols toward the agronomy of the biogasdoneright.*
- *FCA and its satellite firms are among the largest producers of cars and components for NGVs.*
- *The gas grid infrastructure is comprehensive, efficient and interested in enhancing its assets, thus contributing to the energy transition.*
- *Italian gas and biogas industry are among the best in the world, with a strong focus on export.*
- *The Combined Heat and Power (CHP) industry is strong and with high reputation and presence on international markets.*
- *Italian tradition in industrial chemistry is well known, especially for the "green chemistry".*
- *Recycling and reuse industry are among the most efficient globally.*
- *High penetration of intermittent renewable energy sources with a high potential for cost reduction, especially in the South of Italy.*

There are therefore all the prerequisites to believe that the forthcoming legislation on biomethane will lead to the first industrial experience worldwide of biogas refinery: an AD plant producing electricity and heat together with biomethane to be injected into the gas grid and used as fuel for all transport sectors , in agricultural machinery as well

[46] Research Development and Demonstration.

Certainly, the use of biomethane as road fuel would be just the initial application, since this market is smaller than the potential of the biogas refinery. Then, the creation of additional markets is essential to develop technologies, as experienced with the first wave of incentives with the feed-in tariff for biogas to electricity.

Italy will be one of the first Countries in the world to develop a business case for biogas refineries that produce electricity and biomethane as road fuel on a large scale.

In this contest, the Italian biogas has to adapt to better fit with the new challenges. The development of new solutions with the help of supporting schemes will come from the combination of already available technologies such as:

a) biogasdoneright agronomy technologies;
b) biogas production technologies;
c) upgrading technologies;
d) higher added value uses of biogas options.

The following are examples of currently available technologies, at different degree of maturity, which are essential for achieving the production objectives and cost reduction outlined in this study:

- development of legume crops for feed and human consumption;
- biomethane as fuel for agricultural machines;
- precision farming e minimum/strip tillage;
- CHP at high efficiency and stationary fuel cells;
- reversibile fuel cell (soec/sofc);
- methane steam reforming;
- Power-to-Gas via biotech;
- bioplastics or biomethanol from biogas via biotech;
- direct solar energy into hydrogen;
- centralized catalytic conversion at large scale of biomethane into chemicals, fuels and plastics.

## CONCLUSIONS

This paper summarizes some issues currently under examination by a group of experts coordinated by the Italian Biogas Consortium. This investigation will be finalized at the end of 2017.

The peculiarity of this work is to be carried out jointly by academics of international relevance together with farmers. This is a rational choice, since often agronomists and farmers are not involved in the debate on bioenergy; yet they add value in this discussion, due to their direct experience in cultivation.

Finally, farmers have also thoroughly understood that even agriculture has to change, **from being a polluter to become part of the solution in the Climate Crisis.**

The work plan coordinated by prof. Bruce Dale of Michigan University includes a series of documents (the ones already published are reported in the bibliography, others are under preparation). These publications cover some of the following topics:

a) BDR scalability
   - sequential cropping to prevent ILUC risk[47].
   - utilization of biogasdoneright biomasses for producing large quantities of biogas[48] at cost-competitive level.

b) BDR carbon efficiency
   - biogasdoneright effectiveness in mitigating GHGs emissions[49];

c) BDR cost competitiveness and value creation in a smart energy system
   - The role of natural and renewable gas in the creation of a smart energy system. This study suggests in fact some options that need to be developed in the future.

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[47] Here we refer to "Assessing the case for sequential cropping to produce low ILUC risk biomethane. Final report. November, 4th 2016. Project number: SISNL17042. Today the Low ILUC risk is published on the EU commission website.
(https://ec.europa.eu/energy/sites/ener/files/documents/ecofys_methodologies_for_low_iluc_risk_biofuels_for_publication.pdf)

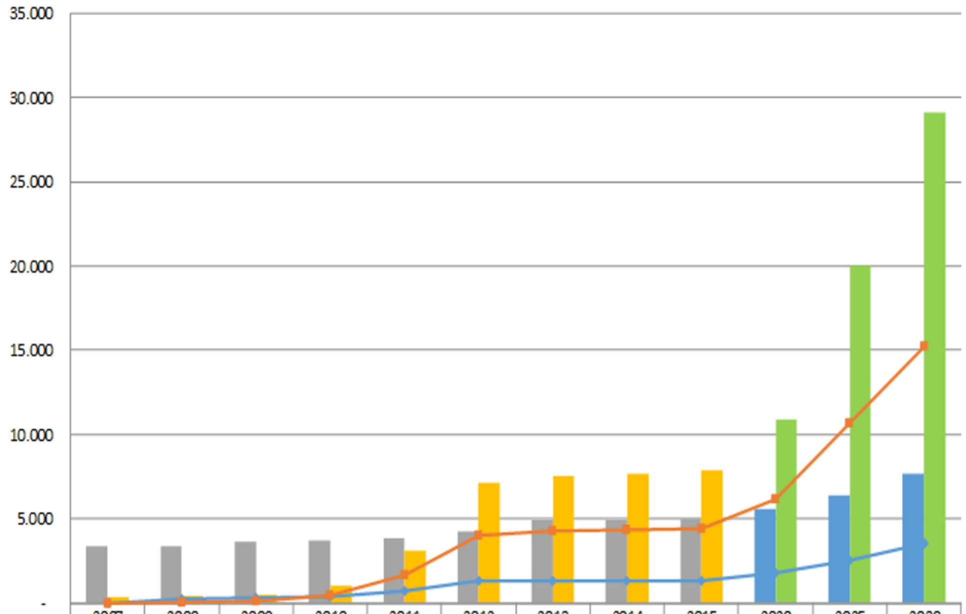
[48] At Biogas Italy it has been presented an international working group aimed at evaluating the potential of Biogasdoneright in a wider international perspective. The group is coordinated by Prof. Bruce Dale of Michigan State University and other team members are prof. Kurt Thelen, Michigan State University: agronomist, farmer, expert in double cropping, very knowledgeable about bioenergy, prof. Tom Richard, Pennsylvania State University, agricultural engineer, bioenergy expert, prof Jorge Hilbert, National Institute of Agricultural Technology of Argentina, agricultural engineer, expert in AD, and very, very knowledgeable about bioenergy and Argentine row crop agriculture, prof. Jeremy Woods, Imperial College, London, bioenergy expert, knowledgeable about Africa and African agriculture

[49] Valli L., and others "Greenhouse gas emissions of electricity and biomethane produced using the Biogasdoneright™ system: four case studies from Italy" in course of publication.

Italy has the honor and the responsibility of having highlighted for the first time the potential of biogas refinery if developed according to the principles of biogasdoneright[50]: yet, a lot of work has still to be done to understand the contribution of biogas done right to an energy transition towards a net zero carbon energy system, and to make agriculture more productive and resilient to the effects of climate change.

It is already clear that, when the biogas is done right, it is not only a renewable gas available in large quantities for the energy transition, but it is also a great opportunity for the Country growth, with significant investments (€ 12 billion) and the creation of 25,000 permanent jobs by 2030, it increases national energy security and strengthens the competitive position of the Italian primary sector.

**Investments and jobs creation potential Italian biogas sector**




| | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Direct jobs agricultural Biogas | 3.354 | 3.354 | 3.658 | 3.719 | 3.853 | 4.247 | 4.940 | 4.940 | 4.969 | 5.571 | 6.417 | 7.686 |
| Direct jobs agricultural Biogas | 326 | 392 | 465 | 1.044 | 3.099 | 7.149 | 7.566 | 7.686 | 7.854 | 10.909 | 20.000 | 29.091 |
| Investimenti progr. (.000.000€) biogas da Rifiuti | - | 248 | 299 | 408 | 730 | 1.297 | 1.297 | 1.321 | 1.321 | 1.813 | 2.506 | 3.544 |
| Investimenti progr. (.000.000€) biogas Agricolo | - | 45 | 95 | 457 | 1.690 | 4.019 | 4.253 | 4.321 | 4.416 | 6.134 | 10.679 | 15.225 |

**Lodi, February 2017**

[50] http://theplate.nationalgeographic.com/2015/10/23/italians-show-energy-and-food-can-grow-in-harmony/

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