Anaerobic Digestion Industry Overview and Opportunities for Process Intensification

Luca Zullo
VerdeNero LLC
Plymouth, Minnesota
luca.zullo@verdenero.com
651-270-6478

Arpa-E Rewiring Anaerobic Digestion Workshop, October 27-28, 2016
Hilton Arlington, Arlington, VA

VerdeNero

Anaerobic digestion: a long history

- Archeological records shows that biogas was used to warm water in Assyria in the X century BC
- In the XVI century, Jean Baptiste Helmond reports the first modern observations that flammable gas was released by disturbing the sediments of swamps, lakes and streams
- 1776: Alessandro Volta determines the existence of a direct correlation between amount of organic matter degraded and amount of gas produced.
- 1808: Humphrey Davy determines that methane is produced by cattle manure
- 1859: First application of an *engineered anaerobic digester* to capture gas methane in India
- 1895: The city of Exeter, UK uses gas from sewage to power street lamps
- 1907: The German patent office issues the first patent in the world for an anaerobic digester.
- 1950: First commercial scale agricultural digester in Germany

With brewing, wine and cheese making, one of the oldest bio-processes exploited by humankind. Probably the first used for industrial and energy rather than food applications

Sources:
Bond and Templeton, "History and future of domestic biogas plants in the developing world". Energy for Sustainable Development, 15 (2011) 347-354
"A short history of biogas" Penn State Extension

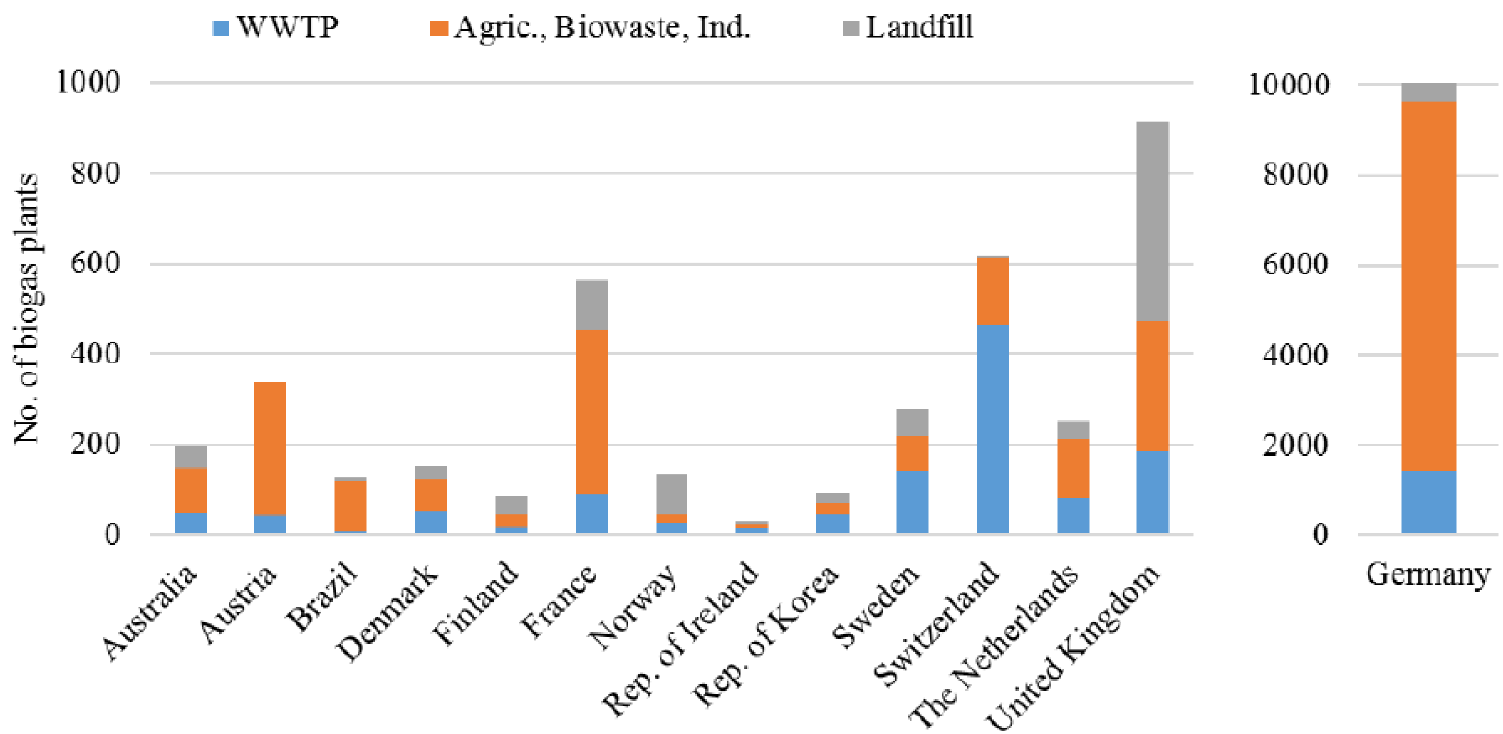
Anaerobic digestion in the world

- Very well developed European AD market, array of different incentives and policies have led to different implementation models
  - Many technology providers
  - Fragmented market
- Large Asian, African and South American market, however largely concentrated in small scale digesters at the household or family farm level
  - ~ 50M household scale digester to provide cooking gas in China
  - > 4 M in India
  - Considerable expansion of the sector following the implementation of the ”Clean Development Mechanism” of the Kyoto Protocol in the mid 2000’s
- 100’s of companies operating in the sector of virtually any size
- The US AD market remains underdeveloped and economically challenged.
- Overall, the potential for AD conversion of available biogenic material remains underutilized

US and Europe are the most interesting market to look at future new applications for AD since in other parts of the world we can still look at AD as a way to address effectively basic human necessity

VerdeNero

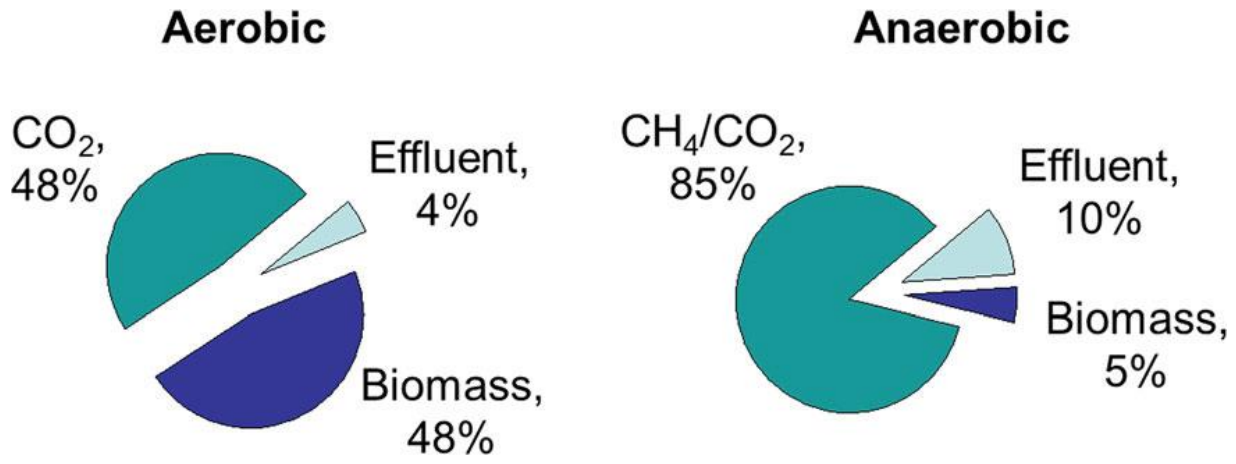
Adoption of anaerobic digestion in Europe



The relative number of installation in various sectors viz. the relative size of these sectors (e.g. the France ag sector is not 10x the German one) clearly indicate the impact of policy, legislation and incentives

Source: IEA, 2015

Anaerobic digestion and waste water treatment plant.



Aerobic	Anaerobic
- 1.1 MJ kg-COD^{-1}	+ 4.3 MJ kg-COD^{-1}
+ 31 gNH_4-N kg-COD^{-1}	+ 3.2 g-NH_4-N kg-COD^{-1}

Treatment needs drive the use of AD in wastewater plants, regardless of gas economics.

Source: van Lier JB, et al. (2008) Anaerobic wastewater treatment.
In: Henze M, et al. (eds) “Biological watewater treatment principles, modelling and design”
IWA Publishing, London, pp 401–442

Germany – Historical incentives

Substrate Category	Feed-in tariffs € cent/kWh	Electric power Up to
Biomass Ordinance [1)]	13.66 11.78 10.55 5.85	150 kW 500 kW 5 MW 20 MW
Biowaste [2)]	15.26 13.38	500 kW 20 MW
Animal manure [3)]	23.73	75 kW

[1)] dated 21 June, 2001, amendment article 12, dated 21 July, 2014
[2)] 90% by weight biodegradable waste (waste entry 20 02 01), mixed municipal waste (waste entry 20 03 01) or market waste (waste entry 20 03 02)
[3)] at least 80% by weight, poultry manure excluded

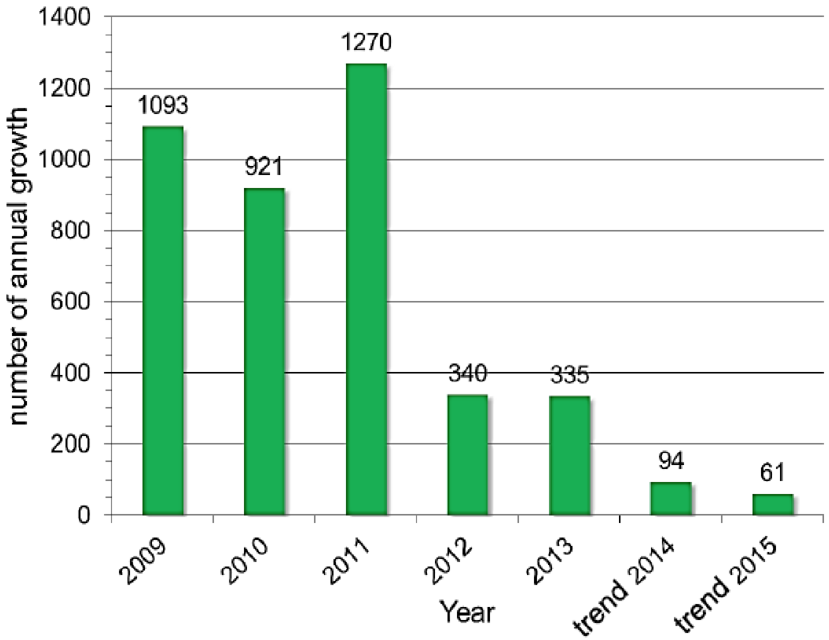
Source: Leibniz-Institut fuer Agrartechnik, Potsdam-Bornim and IEA

Impact of policies and incentives

“Financial support systems are very different from country to country. Various systems with feed-in tariffs, investment grants and tax exemptions exist. A clear correlation between the financial support system and the way biogas is utilized is evident in the Task 37 member countries. In the UK and Germany with feed-in tariffs for electricity, this has led to most of the biogas being used to produce electricity, while the system with tax exemption in Sweden favors utilization of the biogas as an automotive fuel. With benefits offered, gas grid injection, is also growing, such as in France, Denmark and the UK.”

Task 37 Biogas Country Report Summary. IEA, 2015

However some German incentives are sun setting



New plants are required to:

- Use no more than 60% silage
- Sell energy under a “market premium model” which takes in to account demand rather than just a guaranteed feed in tariff
- Major drop of new ag and small to medium installation

Source: German Biogas Association

The extensive use of silage and other energy crop in digesters remains highly controversial

sign in | become a supporter | subscribe | search | jobs | US edition

theguardian

election 2016 | US | world | opinion | sports | soccer | tech | arts | lifestyle | fashion | business | travel | environment | all sections

home › environment › energy | pollution | climate change | wildlife

Biomass and bioenergy
George Monbiot's blog

How a false solution to climate change is damaging the natural world

In growing maize for biogas, the crop that does most damage to the soil is being specifically exempted from the rules

George Monbiot
@GeorgeMonbiot
Friday 14 March 2014 06.01 EDT

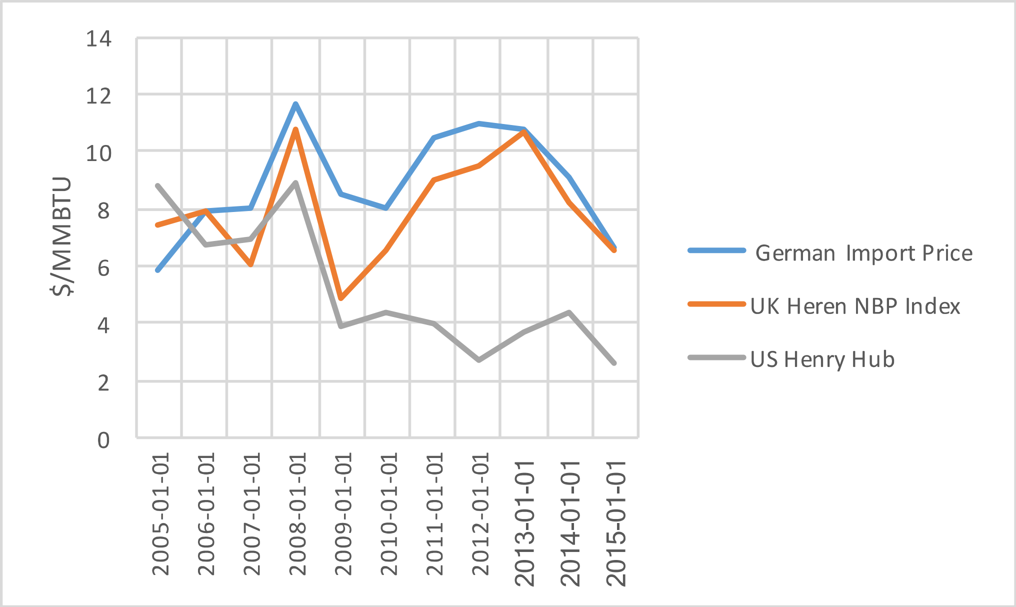
Shares 805 | Comments 116

Save for later

A harvester collects maize in a field. Maize being grown for biogas in the UK has trebled to 15,000 hectares in the past two years. Photograph: David Levenson/Getty Images

In principle it's a brilliant solution. Instead of leaving food waste and sewage and animal manure to decay in the open air, releasing methane which contributes to global warming, you can contain it, use micro-organisms to digest it, and capture the gas.

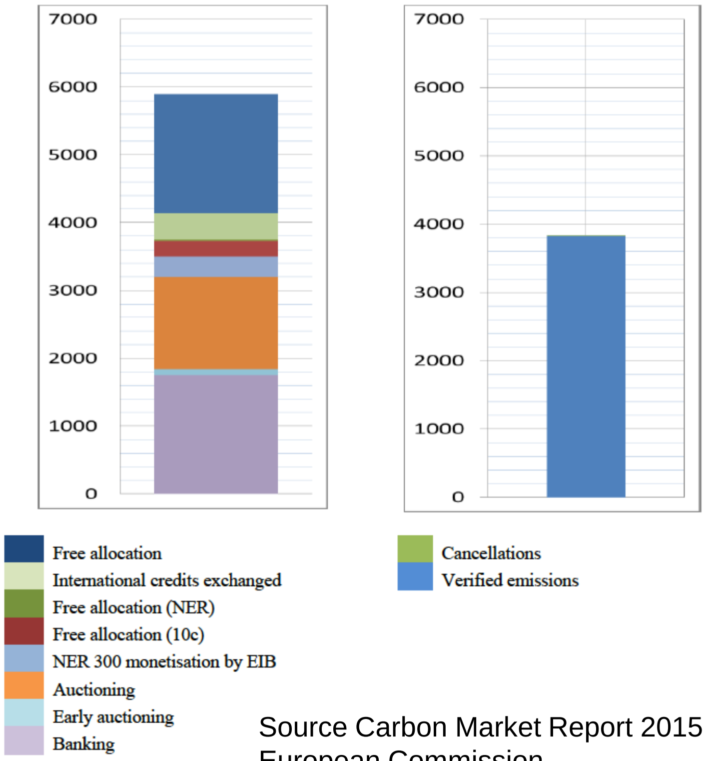
Market drivers in Europe



Source: BP Statistical Review of World Energy 2015

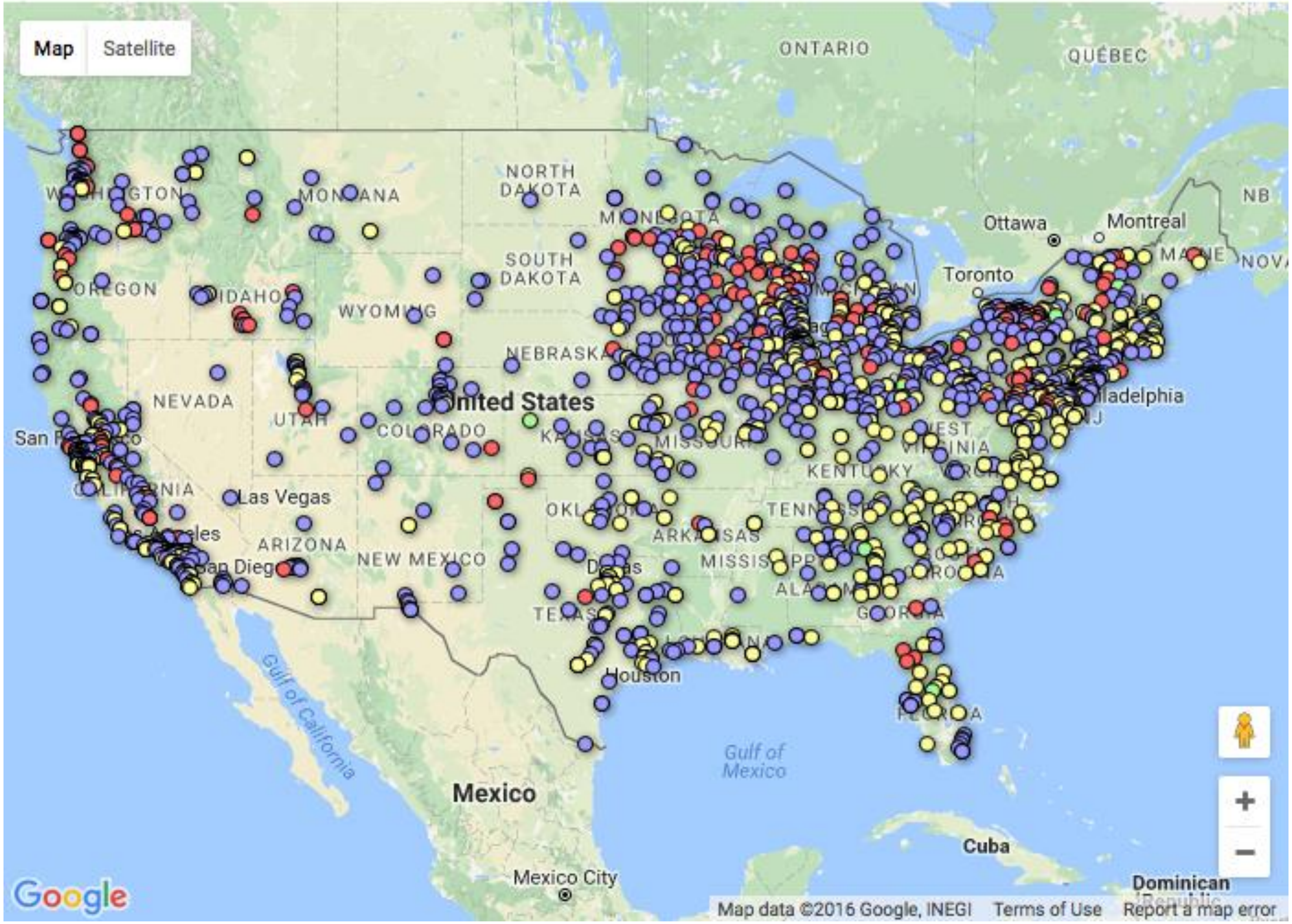
Pipeline injection may remain viable but under pressure without a support mechanism because of lowering gas costs

Carbon credits in the ETS market are currently not a reliable support mechanism because of oversupply



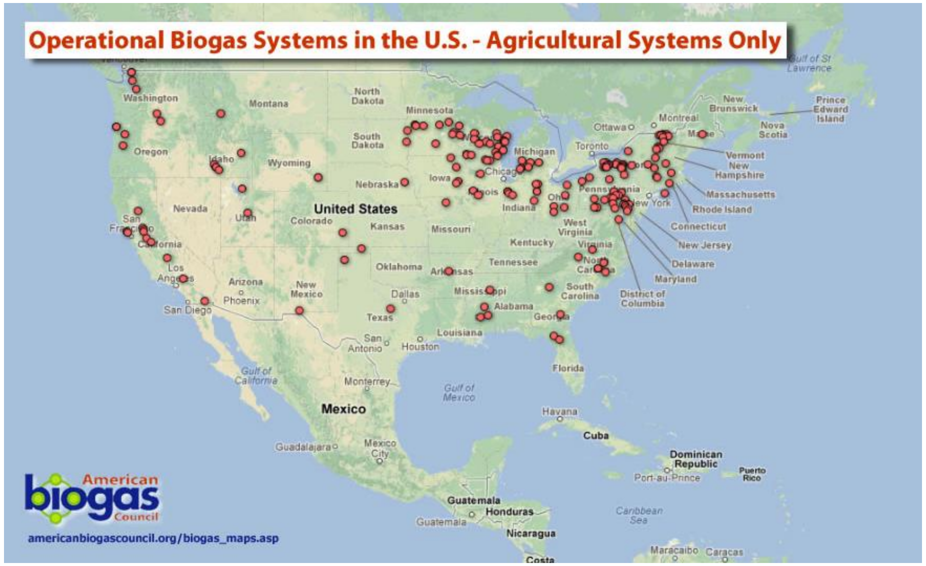
Source Carbon Market Report 2015 European Commission

US AD market



WWT, Landfill, dedicated food waste processing and agricultural
(Source: American Biogas Council)

Only agricultural and dedicated organic waste



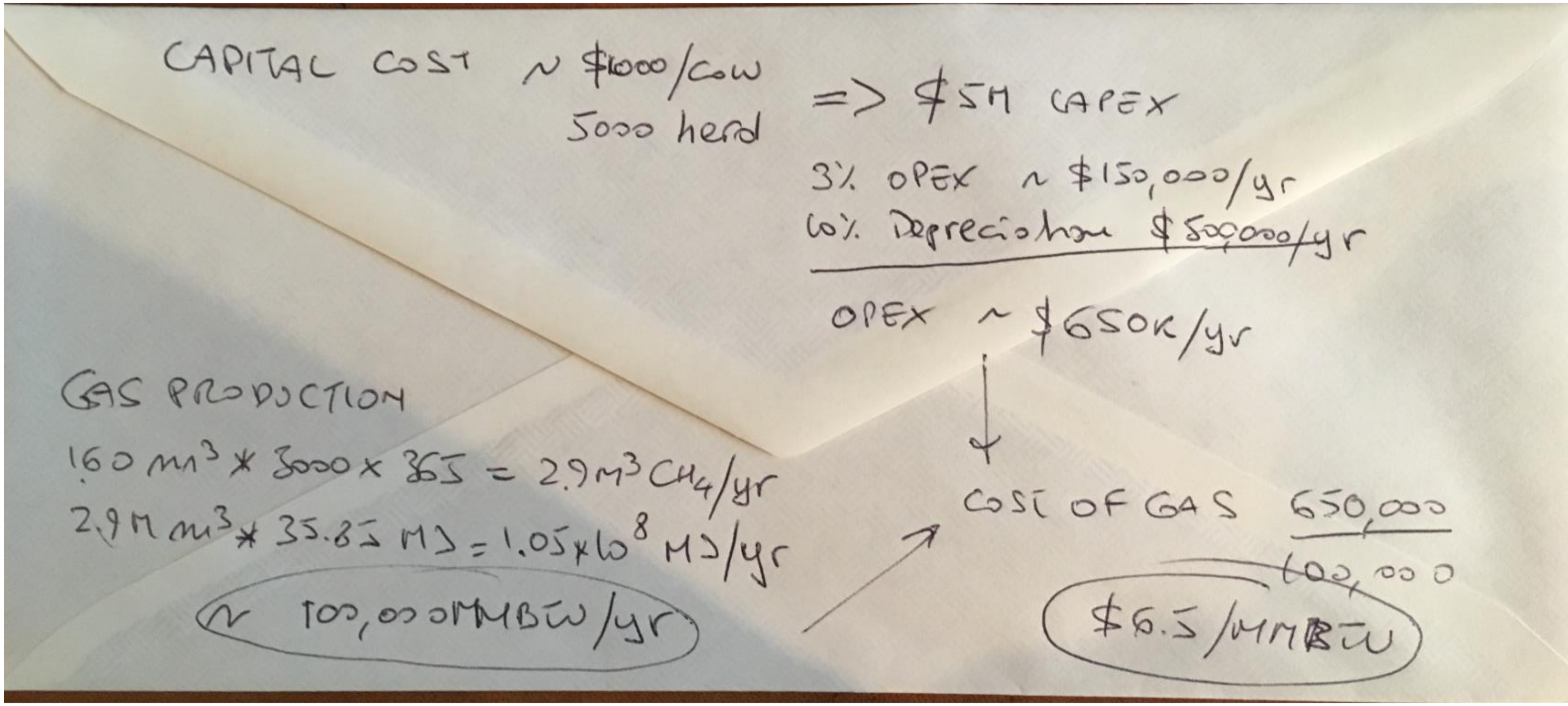
When WWT plants are excluded, the AD sector in the US is quite underdeveloped with only 260 operational digesters as and 61 known plant closure as end of 2015 (source EPA) in the AG sector

AD Economics

- TSS: 7.0 ± 0.5 kg/cow/day
- VSS: 5.6 ± 0.2 kg/cow/day
- VSS destruction rate: 38 ± 3 %
- CH_4 yield: 0.76 ± 0.1 m3 CH_4/kg TSS destroyed
- Gas per cow
  - 5.6 x 0.38 x 0.75 = 1.60 m3 CH_4/cow/day
- Energy content of methane: 35.85 MJ/m3
- Electrical efficiency 35%
- Energy per cow
  - Fuel 35.85 x 1.60 = 57.36 MJ/day/cow
  - Electric 57.36 x 0.2278 x 0.35 = 5.57 kWh/day/cow
- Power per cow
  - 5.57/24 = 0.23 kW/cow
- Methane in biogas 60%

Let us use standard average design specs for dairy manure AD to look at some economics

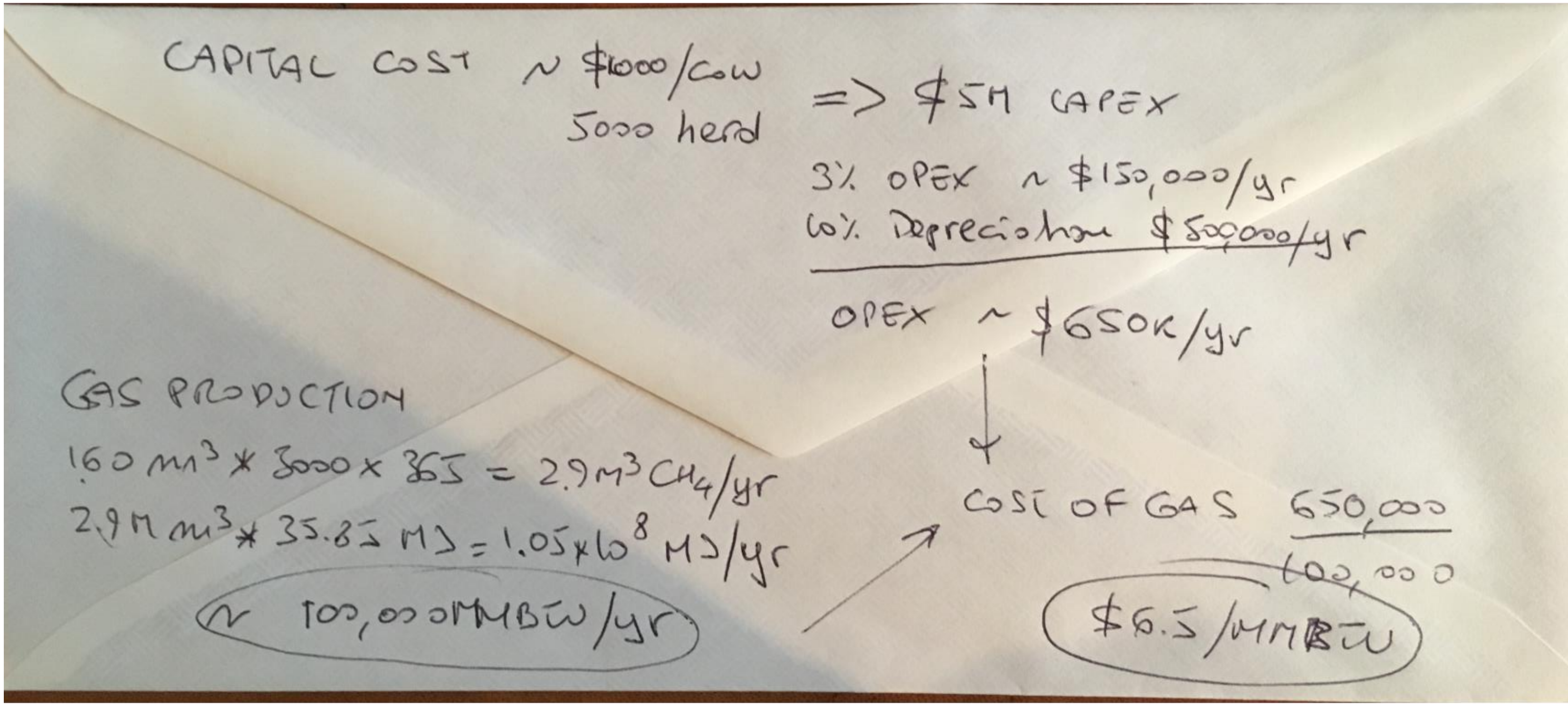
Cost of production of gas using the most powerful engineering calculation tool



In reality one will find that **$6-7/MMBTU** is a common cost of production cost estimate for most US AD projects. Gas values **>$8/MMBT**U are necessary to obtain a reasonable return on investment.

At today's and foreseeable natural gas prices, US AD project **are not sustainable on energy value alone without support mechanism**

Cost of production of gas using the most powerful engineering calculation tool



2x process intensification ($6/MMBTU -> $3MMBTU)
would already bring the process
in striking distance of economic feasibility under market conditions in today environment

VerdeNero

What next

- AD remains technically attractive for its ability to process a wide variety of biogenic materials. Billions of tons of readily available feedstock are potentially suitable.

- The current economics should not belittle the potential of AD to provide energy and beneficial environmental mitigation of human activities including GHG release and other environmental impact of large scale agriculture and urbanization

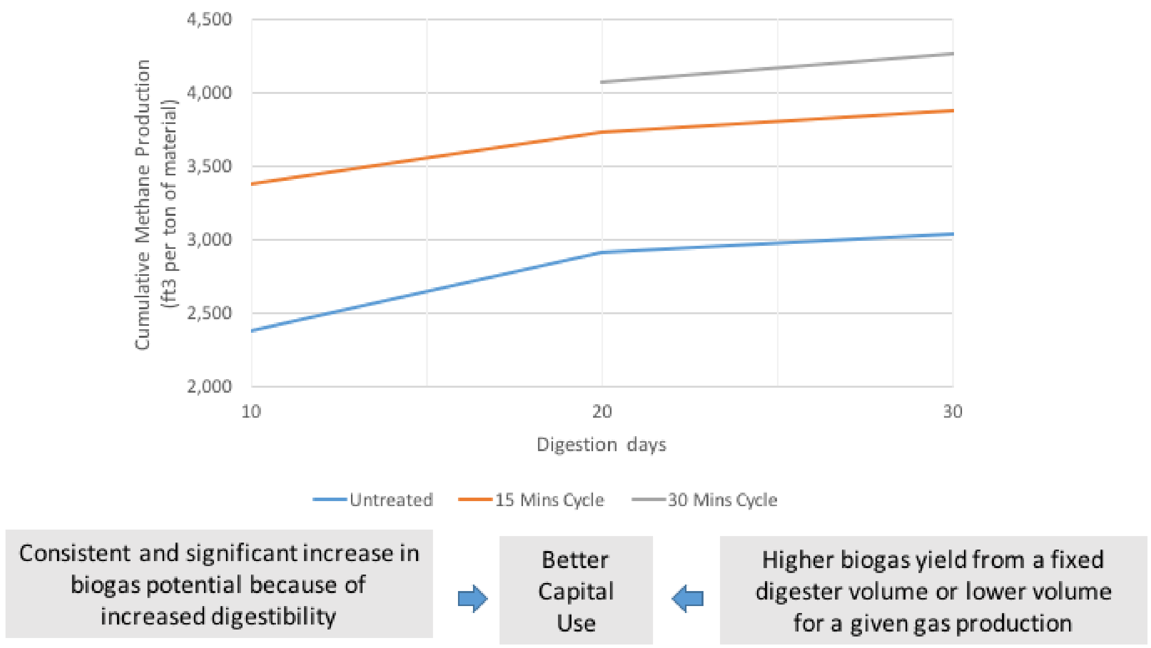
- We should recognize that we are not very sophisticated in exploiting AD
  - Large gaps in understanding of the biology
  - Very minimal attempts to optimize the bacterial consortia
  - Limited knowledge of interactions with specific substrates
  - Great opportunity for improvement of reactor and system design in particular for high solid content

- Goals:
  - Reduction in the cost gas of gas production
  - Expansions of the horizons for AD past energy and waste management
  - Provide research direction to help formulate meaningful policies.

A more sophisticated approach to feedstock management

- While generally understood as beneficial, feedstock pretreatment beside size reduction is still not very widespread
- Mechanical, chemical and physical pretreatment have all proven to be improve biogas production and in general biological availability of the feedstock

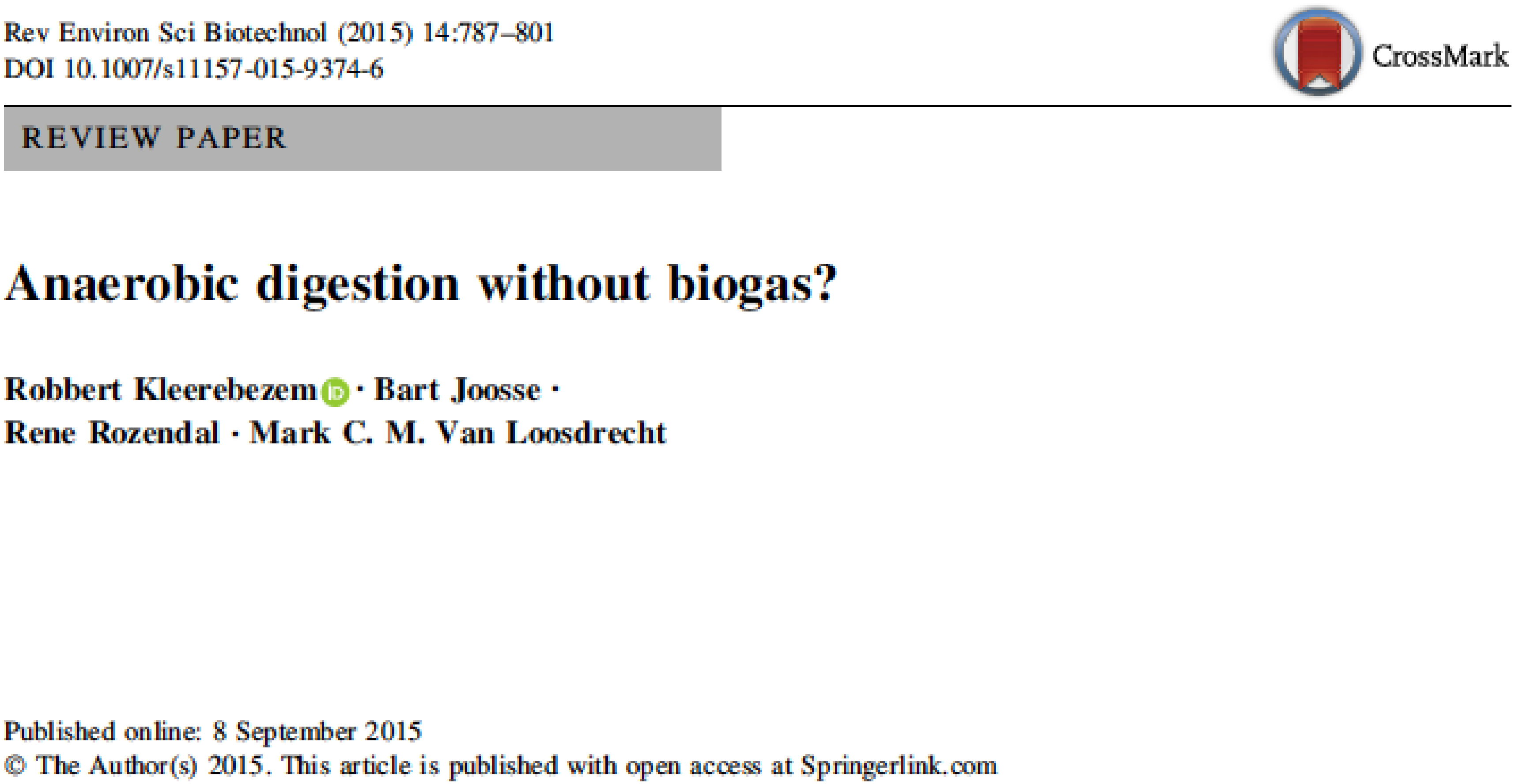
(Pretreatment of feedstock for enhanced biogas production, IEA Bioenergy, 2014)



Example: impact of low temperature vacuum pretreatment on the biogas production of the organic fraction of MSW

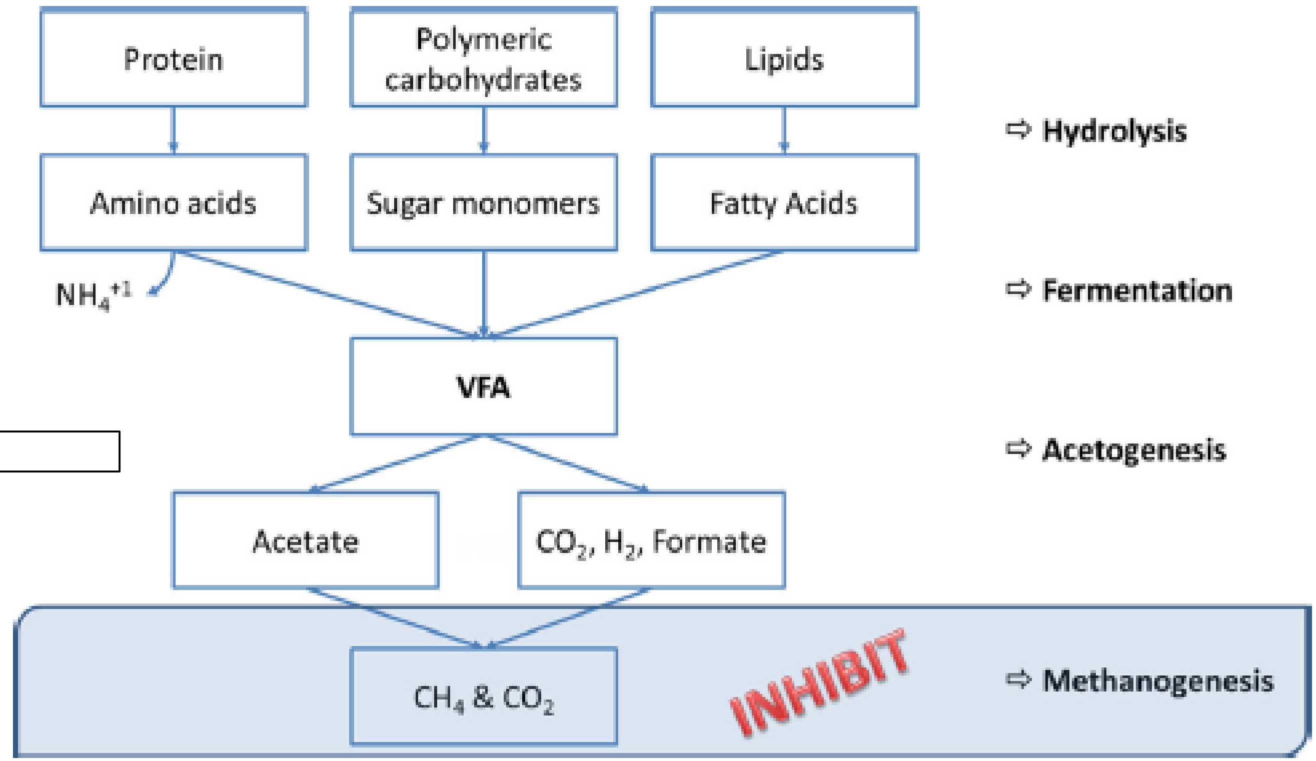
Source, Cornerstone LLC, Dover Equipment Co., UNC

A new frontier



Can we identify technology developments which improve AD without being immediately and solely dependent on biogas economics?

AD without methanogenesis



Higher Value Processes

Can we exploit what we typically we do not want to happen in a digester?

VerdeNero

Development opportunities for gasless AD

- Recovery of organic acids:
  - Relatively low value of organic acids
  - Recovery and separation in high solids diluted medium
- Feedstock for higher value products
  - PHA
  - Single Cell Proteins
- Use of H2 as reducing gas for integrated use of alternative carbon sources
  - CO2 as a feedstock
- Improved management of nutrients such as NPK.

What else?

Technical challenges and development opportunities

- Reactor design
  - Increase hydrolysis rate by optimizing pH, temperature, while inhibiting methanogenesis
  - Sequenced operations
  - High solids/slurry feedstock and high rates
  - Design for low cost (disposable) or high availability (low maintenance, self-sufficiency)
- Separation technologies
  - Remove target products selectively
  - High solids environment
  - Enabler for sequenced operations
- Feedstock technologies
  - Understanding in detail relationship of feedstock technologies which include thermal, chemical, mechanical and biological methods with feedstock types and characteristics, reactor design and biological consortia.
- Process Control/Monitoring
  - Today the only way AD is monitored is by biogas production rate. This is often inadequate.
- Rate enhancement
  - High hydrolysis rate, high acido-genesis rate, lower methano-genesis rate in high solid, poorly mixed environment.
- Electro-catalysis
  - Enhance digestion processes or digestion products
  - Integration with renewable energy production
- Optimization of microbiome and metabolic pathway
  - The Holy Grail
- Improved understanding of natural occurring digestion
  - What we can learn from bovine rumens and the bottom of the swamps