



SMALL SCALE UPGRADING AND BUSINESS MODELS

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Bioscience and Materials
Agrifood



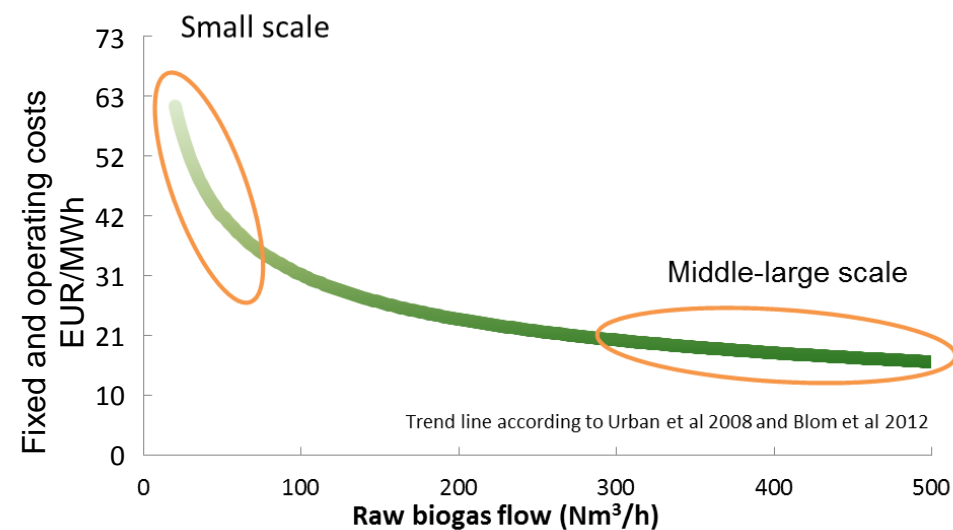
Why biogas upgrading at small scale biogas plants?

- Often hard to valorize all the heat that is produced at a small scale biogas plant
- Low electricity price – hard to achieve profitability
- Farmers are interested in energy autonomy to be in full control of in-put costs
- Significant need to reduce emissions in the transportation sector (GHG, particles, NOx)



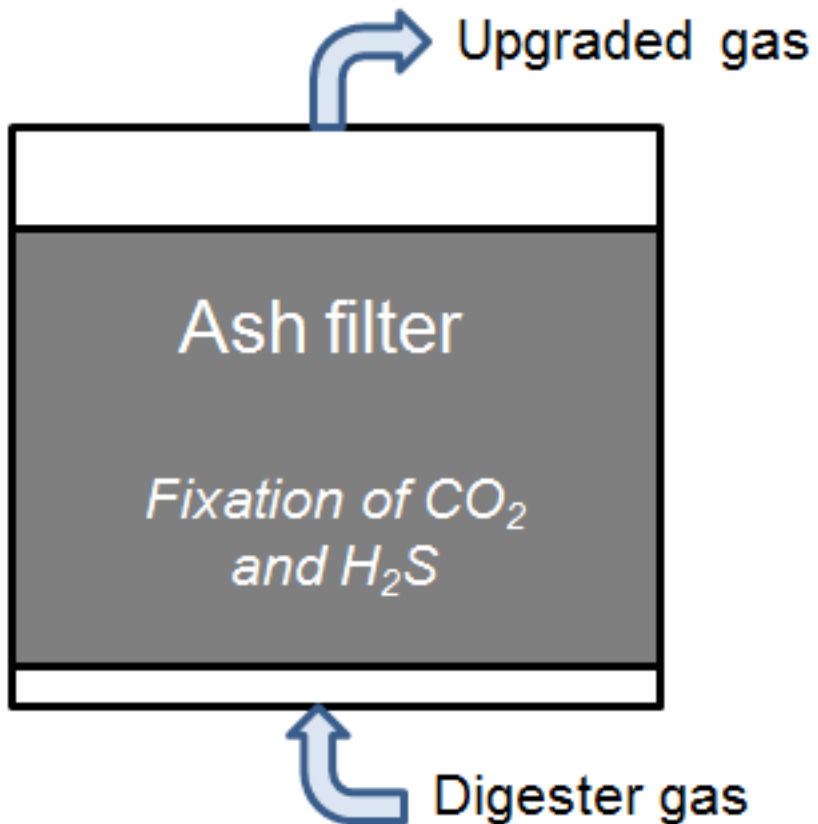
When we did a scan in early 2016 we found these eight technology suppliers/developers in this space + ourselves

| Supplier | Technology | Approximate plant size [MWh/year] | Raw biogas flow [Nm ³ /h] | Specific cost [EUR/MWh] |
|--------------------------------|---|-----------------------------------|--------------------------------------|-------------------------|
| Biorega¹ | Water scrubber | 1000 | 19 | 65 |
| Biosling² | Water scrubber | 4500 | 86 | |
| Metener³ | Water scrubber | 600 | 11 | |
| Neo-Zeo⁴ | PSA | 3100 | 59 | |
| Blue BONSAI | Membrane separation | 100 | 2 | |
| | | 400 | 8 | 60 |
| MemfoACT AS⁵ | Membrane separation | 600 | 11 | 46 |
| Biofrigas | Kryogenic separation | 2200 | 42 | |
| Xebec | PSA/membrane | 1000 | 19 | |
| JTI | In-situ methane enrichment (up to 80 % methane) | 2600 | 49 | 15 |
| JTI⁹ | Ash filter | 500 | 10 | 36 |
| | | 1000 | 19 | 23 |



¹ Biorega AB. ² Biosling, 2014. ³ Persson, 2013. ⁴ Persson, 2013. ⁵ Liljemark m.fl., 2013. ⁶ Persson, 2013. ⁷ Nordberg, 2005. ⁸ Andersson, 2014. ⁹ Andersson, 2013.

Wood ash filter



- Wood ash rich of CaO for chemical fixation of CO_2 and H_2S from the biogas
- CO_2 fixation is based on the principle of carbonation



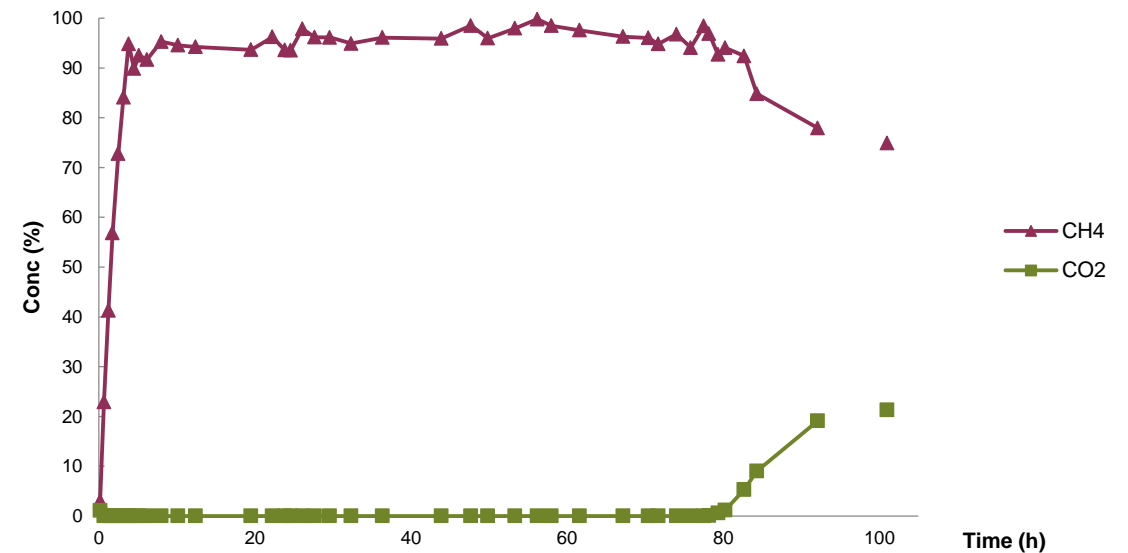
Initially studied by Mostbauer, P., Lombardi, L., Olivieri, T., Lenz, S., (2013). Pilot scale evaluation of the BABIU process – Upgrading of landfill gas or biogas with the use of MSWI bottom ash. Waste management 34 (2014) 125-133.

The ash filter works well as a simple on/off upgrader capable of delivering vehicle grade CBM



Wood ash filter

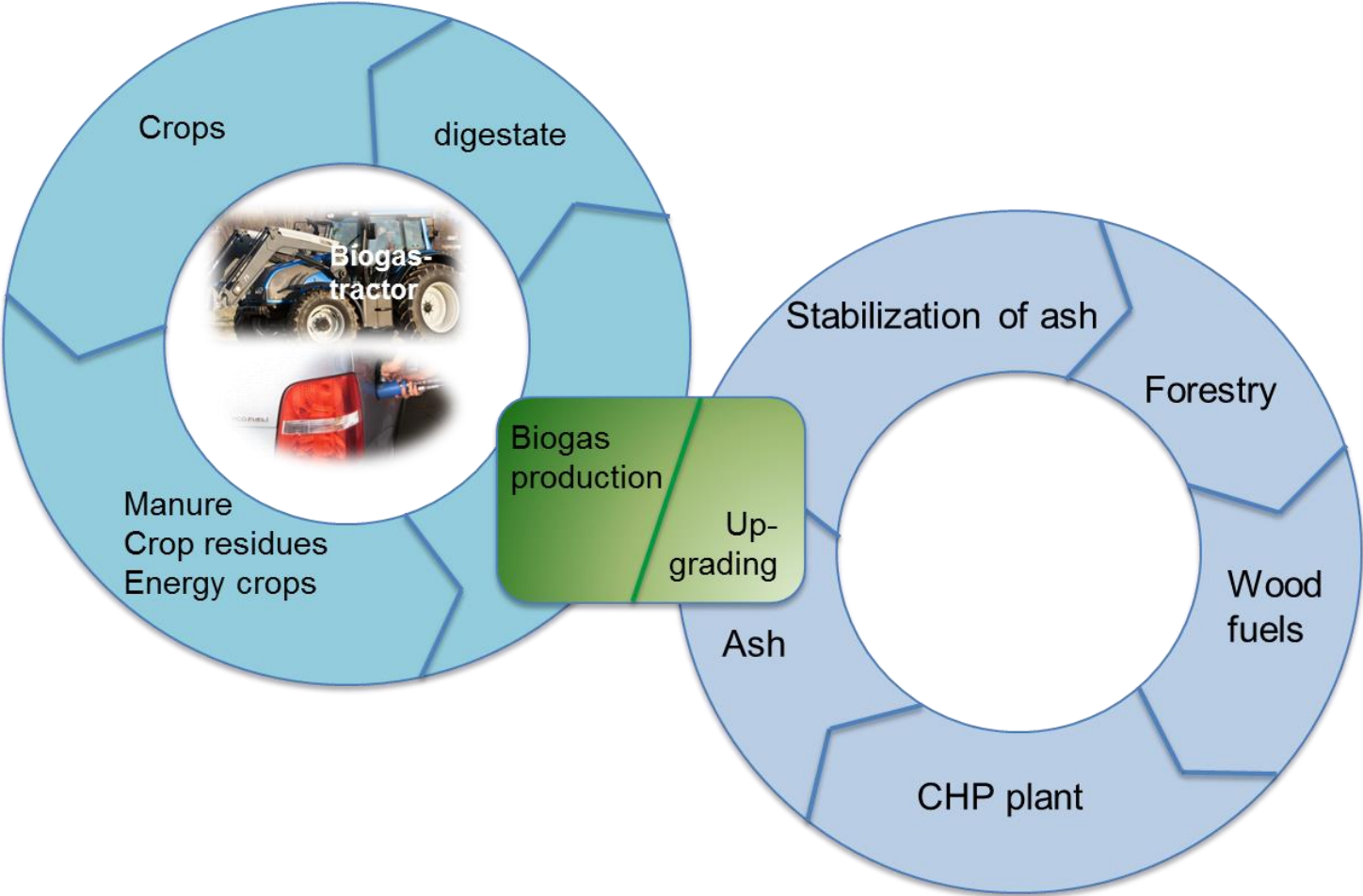
- Almost 0 % CO₂ in outlet gas
- CO₂ uptake: 0,1-0,2 g/g dry ash
- 0 % H₂S in outlet gas (up to 3000 ppm H₂S have been tested)
- pH in the ash is decreased by 2-3 units = stabilization
- Used ash is stable and works well to pelletize for forestry fertilization



Results from wood ash filter i lab. scale:

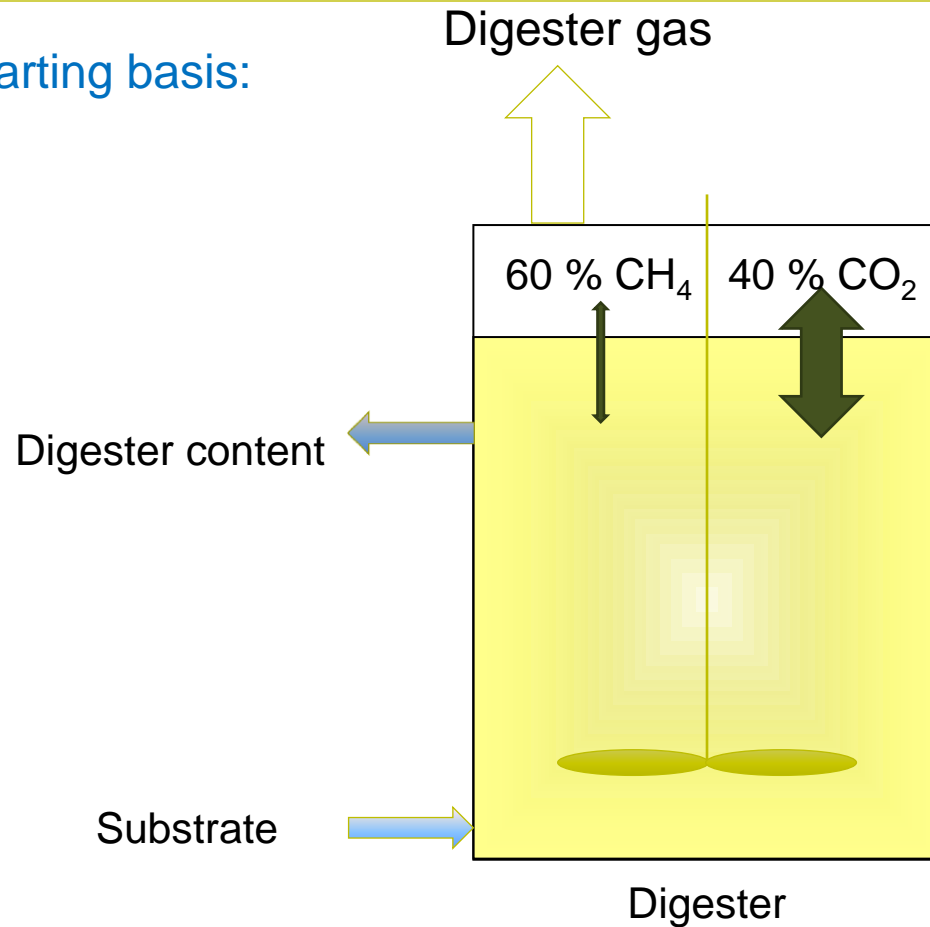
- Andersson, J. (2013). Uppgradering av biogas med aska från trädbrenslen. ISSN 1654-9392. SLU, Uppsala 2013.
http://stud.epsilon.slu.se/5224/1/andersson_j_130124.pdf

Wood ash filter – system perspective



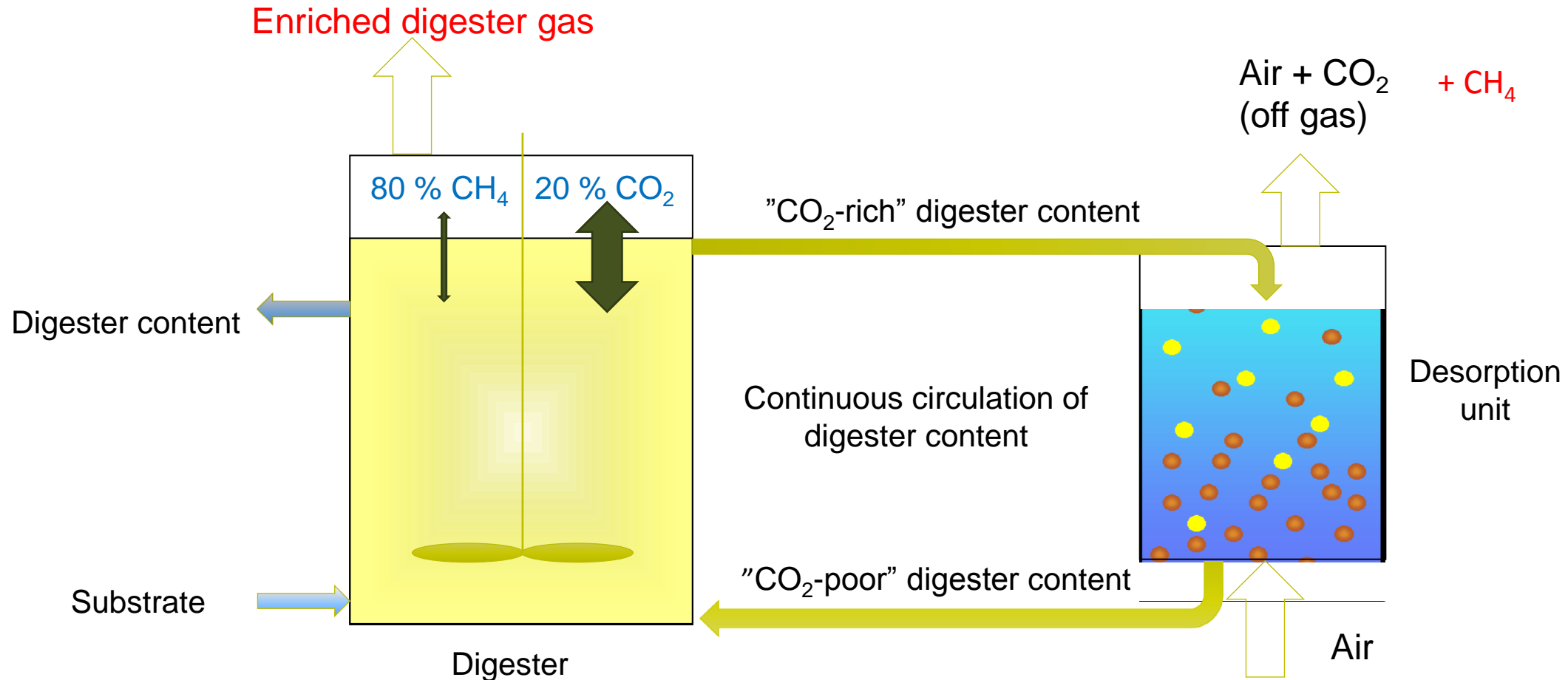
In-situ methane enrichment

Starting basis:



Initially studied by: Richards BK, Herndon FG, Jewell WJ, Cummings RJ, White TE. In situ methane enrichment in methanogenic energy crop digesters. *Biomass Bioenergy* 1994;6(4):275-282.

In-situ methane enrichment



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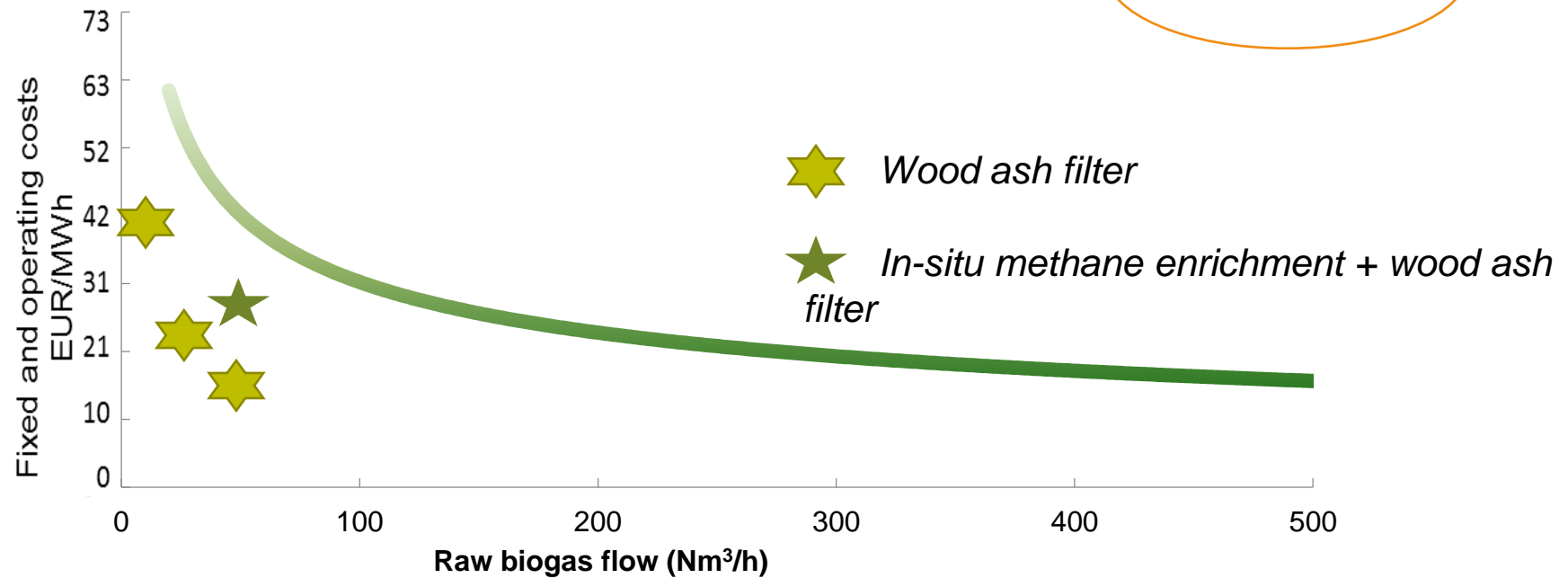
Calculations full scale

Wood ash filter (standalone)

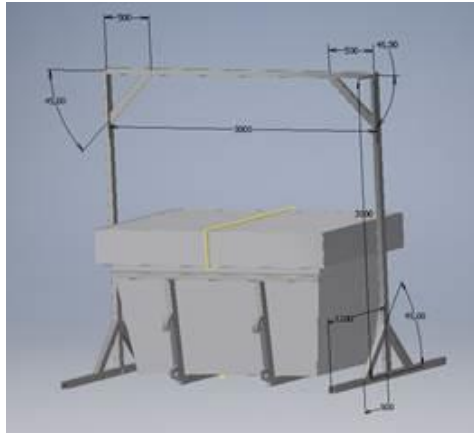
| | | | | |
|-------------------|--------|-----|------|------|
| Biogas production | MWh/yr | 500 | 1000 | 2000 |
| Dry ash | ton/yr | 325 | 650 | 1300 |

In-situ+wood ash filter

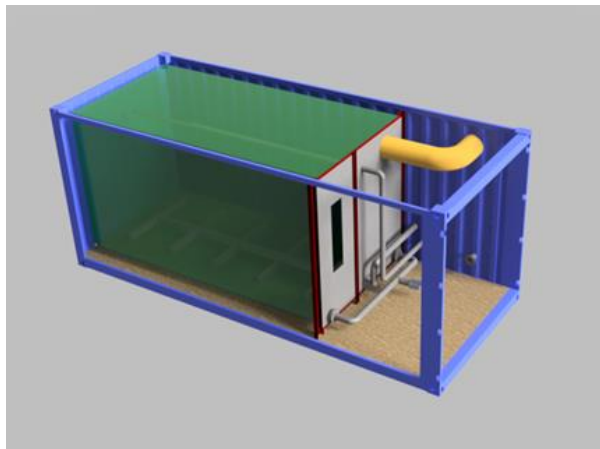
- 2000 MWh biogas prod
- 490 ton ash/yr



Projects: Biogas2020



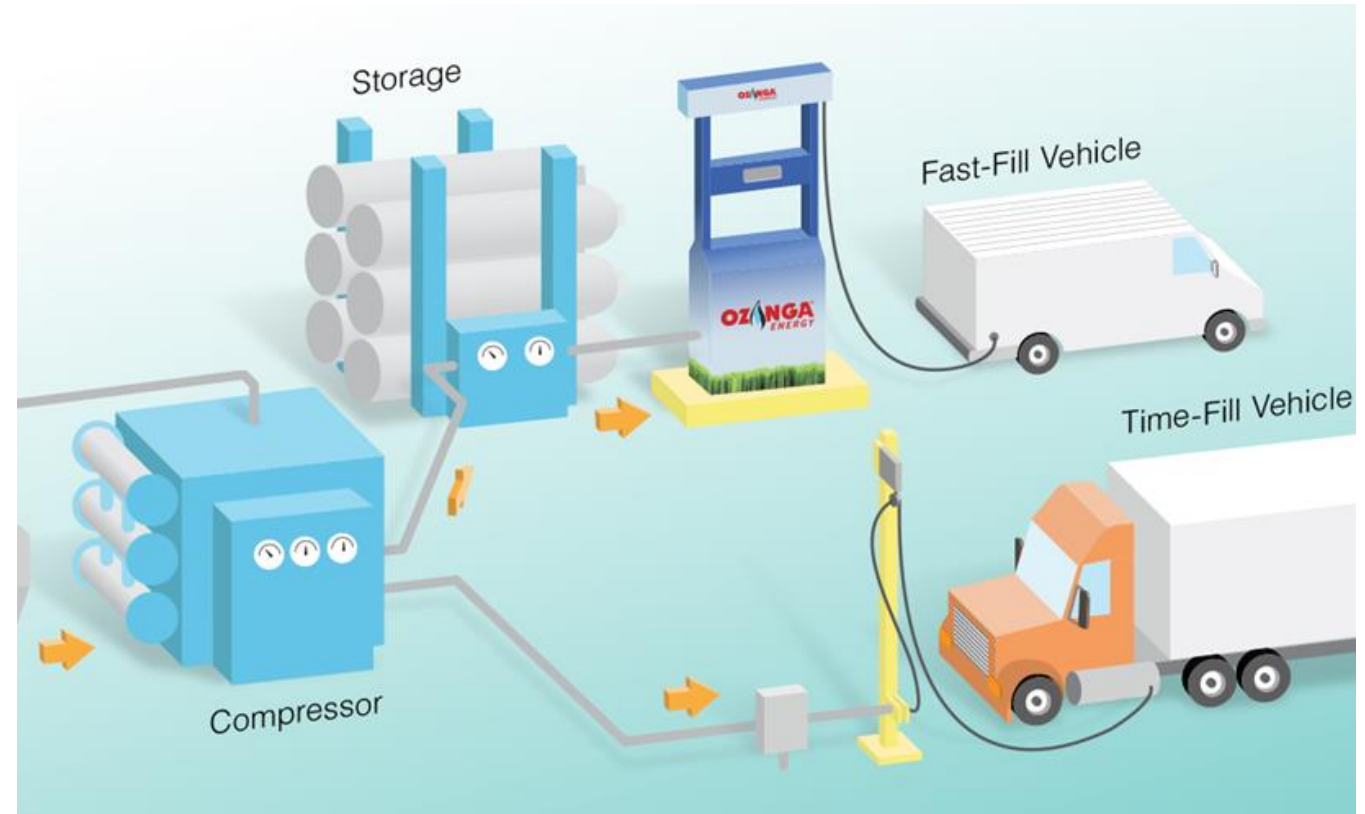
Demonstration of a combination of In-situ methane enrichment and ash filter at an industrial pilot scale – 10 Nm³/h



Construction of a small scale fueling system for 8 vehicles and 1 tractor used on the farm.

Other components of the system is all existing off-the shelf technology

- Drying
 - Compression
 - Odorization
 - Storage
 - Dispensing
 - Distribution
- 1 – 2 c/kWh



For example plenty of suppliers sell time-fill solutions for fueling your car directly from your home natural gas connection

| Supplier | Model | Gas flow [m ³ /h] | Price (CAD) |
|-------------------------------|----------------------|------------------------------|--------------------------|
| Nardi compressor ¹ | CNG 1.0 | 3,6 | |
| | CNG 5.0 | 18 | |
| Gasfill ² | HOME | 2 | 6 000-9 500 ⁷ |
| | PHILL | 1,5 | |
| BRC fuelmaker ³ | FMQ 2.5 | 3 | 14 000 ⁵ |
| | FMQ 10 | 12 | 42 000 ⁵ |
| Motor Jikov CNG ⁴ | MJ compact 05 | 5 | 9 500 ⁸ |
| CNG Canada Inc. ⁶ | MCH5 CNG Compressor | 5 | |
| | MCH10 CNG Compressor | 10 | |

¹ Nardi compressor, 2016. ² Gasfill, 2016 ³. BRC fuelmaker, uå. ⁴ Motor Jikov, 2012. ⁶ Sällvik m.fl., 2011. ⁷ CNG Canada Inc., 2012. ⁸ Gasfill, 2016. ⁹ Kättström, 2016.



BRC fuelmaker, uå.

On the user side there is plenty of CNG/CBG cars and trucks. A new development is that we are also seeing biogas tractors coming to market.

- Valtra: dual fuel tractors
 - Diesel engine, catalytic methane converter
 - 3 models – same capacity as when run on diesel
 - Ready for market – awaits EU standard for biogas use in a diesel engine
- New Holland: T6.140 Methane Power
 - Otto-cycle engine
 - 135 hp och 620 Nm torque
 - Emission standard EURO 4
 - Not quite ready for market intro



Building on these developing and existing technologies and components we have worked on a couple of business models

| Components | Partial upgrading for internal use | Upgrading all for internal use | Upgrading all for internal and external use | Upgrading all for external use as industrial gas |
|------------------------------------|------------------------------------|--------------------------------|---|--|
| CHP | Yes | No | No | No |
| Upgrading | Yes | Yes | Yes | Yes |
| Drying, odourizing and compression | Yes | Yes | Yes | Yes |
| Time-fill dispenser | Yes | Yes | Yes | No |
| High pressure storage | No | Yes | Yes | Yes |
| Fast-fill dispenser | No | Yes | Yes | No |
| Distribution to external customers | No | No | No | Yes |



THANK YOU!

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