Valorization of a Food Residue Biomass product in a two-stage anaerobic digestion system for the production of hythane

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Introduction

- ✓ Global urbanization trends are expected to lead to a dramatic increase in the Municipal Solid Waste generation
- ✓ The biodegradable MSW is the most promising, in terms of valorization opportunities, and at the same time the less exploited fraction of MSW.
- ✓ The biodegradable MSW corresponds to 30-50% of the total generated, and dramatically up to 95% is ultimately landfilled.
- ✓ In Europe, 88 million tons of food are wasted annually, with an overall cost estimated at 143 billion euros
- ✓ Household Food Waste (HFW) is comprised of materials rich in sugars, minerals, and proteins that could be used for other processes as substrates or raw materials.

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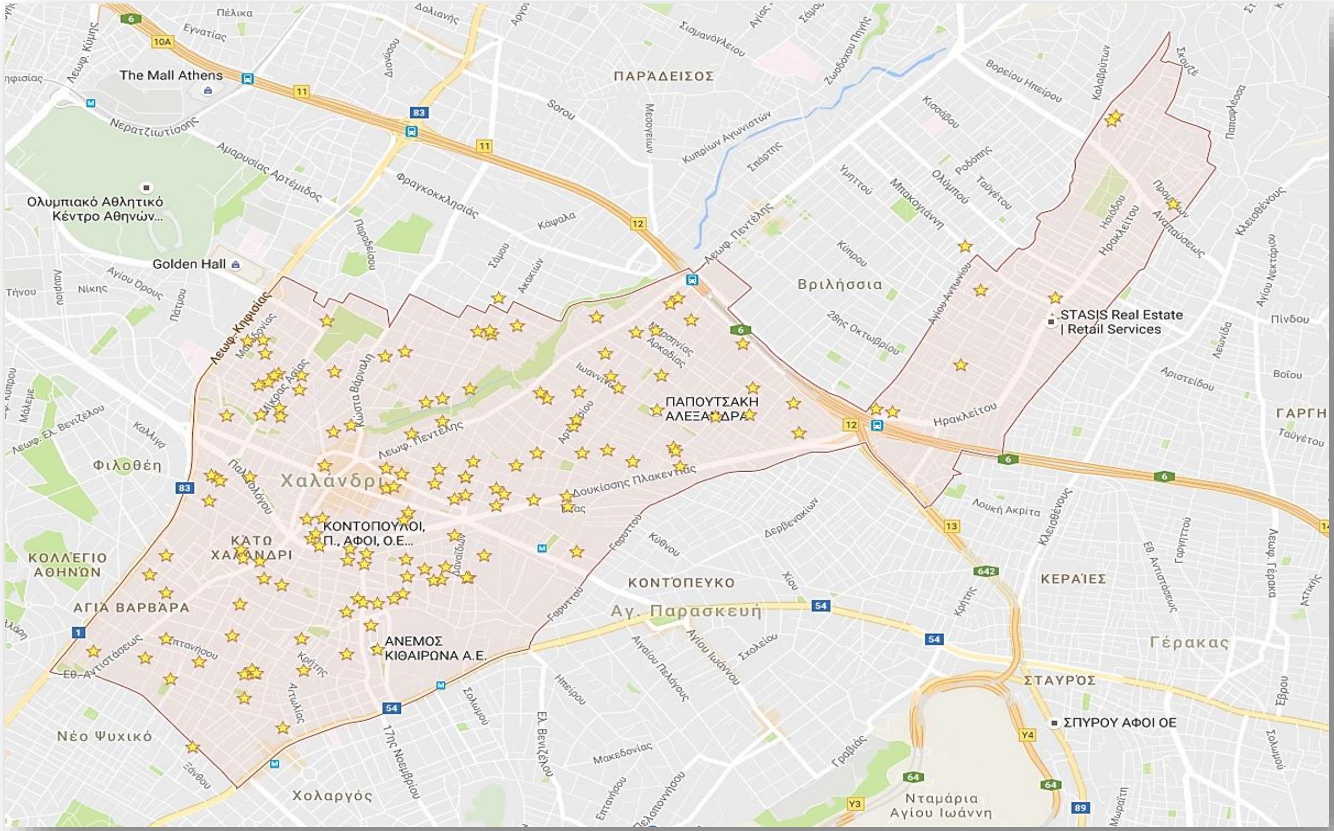
- ✓ The present work is in the framework of Waste4Think, a Horizon 2020 project, which proposes source separation and separate collection of the Household Food Waste (HFW) in the Municipality of Halandri, followed by drying and shredding at the Municipality level.

HALANDRI

236 households
732 citizens



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citizens

Biodegradable Bags

30L bins

120L bins

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Halandri's pilot location ($24m^2$)

Dryer (92-98^{0}C)/shredder for the production of **FORBI** (Food Residue Biomass product).

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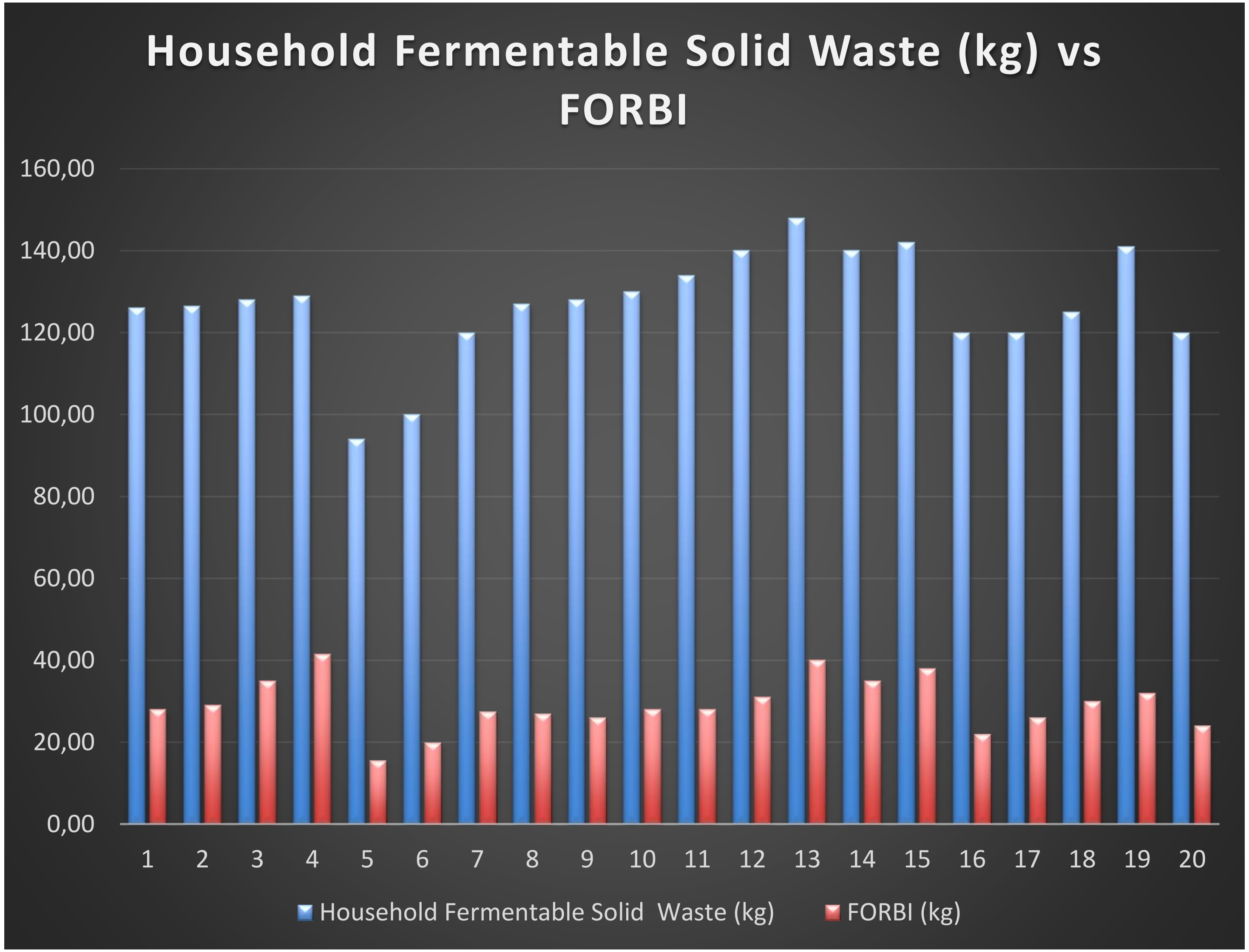

- **Collection and treatment of HFW**
- **In 1 month collected 4021 kg HFW from 732 citizens.**
- **Produced 1006 kg of FORBI**
- **HFW weight reduced by 77%**

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Results for 1 month

Houses	Persons	Persons /house	Collection kg	Collection route km	Fuels consumed L/week	Cost of Fuels consumed €/L	Production of HFW/person (kg)
236	732	3.1	4021	40	18	1.45	**0.20**

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FORBI CHARACTERISTICS

Component	%, w/w, dry basis
Protein	13.70 ± 0.44
Lipids	12.26 ± 0.11
Extractives (mainly sugars)	27.29 ± 1.71
Starch	10.68 ± 0.07
Pectins	3.27 ± 0.82
Cellulose	10.31 ± 0.07
Hemicellulose	11.32 ± 0.17
Total lignin	6.75 ± 0.15
Ash	7.16 ± 0.27

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FORBI advantages

- Has 1/4 to 1/5 the weight of biowaste, implying reduced transportation costs
- Has low-moisture and may be stored for prolonged periods of time without deterioration
- Is homogeneous
- Does not emit odors
- May be used for producing fuels, energy and other products

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FORBI valorization

1. Gaseous Biofuels (Methane, Hydrogen, HYTHANE)
2. Liquid Biofuels (Bioethanol)
3. Solid biofuels (pellets, AF for the cement industry)
4. Direct production of Electricity (microbial fuel cell technology)
5. Compost
6. Adsorbent
7. Animal Feed

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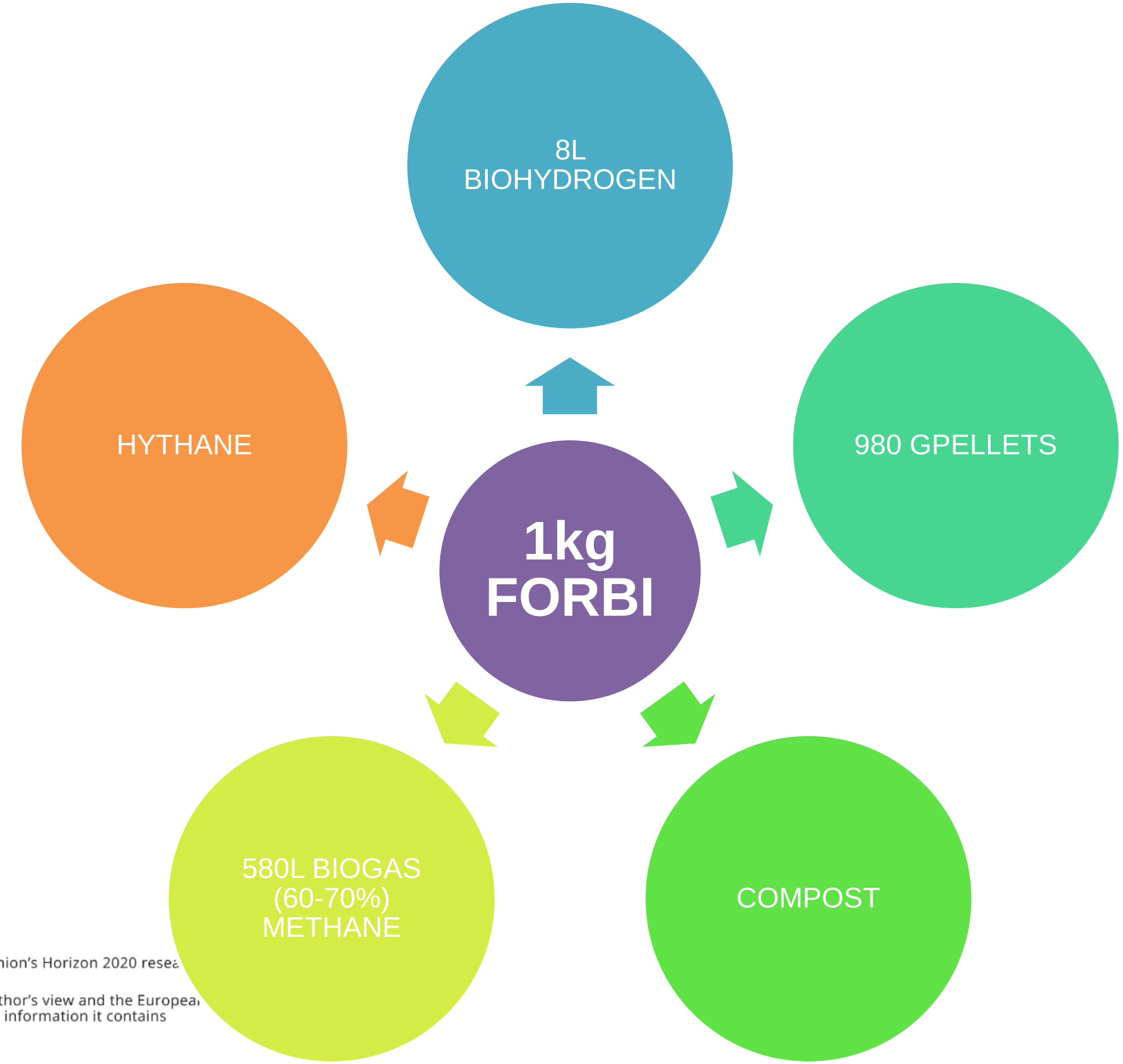
AFTER 20 MONTHS
FOCUS ONLY ON HIGH TRL ECO-SOLUTIONS

- 580 L BIOGAS (60-70% methane)
- 8 L BIOHYDROGEN
- 15 L/kg FORBI HYTHANE + 430 L/kg FORBI METHANE
- 980 g PELLETS
- COMPOST



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Scope of the study

- ✓ An alternative HFW management scheme has been introduced, including the drying and shredding of the raw food waste. The end-product of this process is named FORBI (Food Residue Biomass)
- ✓ FORBI is a high quality homogenized and dry biomass product with a weight approximately 25% of the original food waste, which may be stored for prolonged periods of time without deterioration.
- ✓ In the present study the potential valorization of FORBI for the production of Hythane through a two-stage anaerobic digestion process, is explored.

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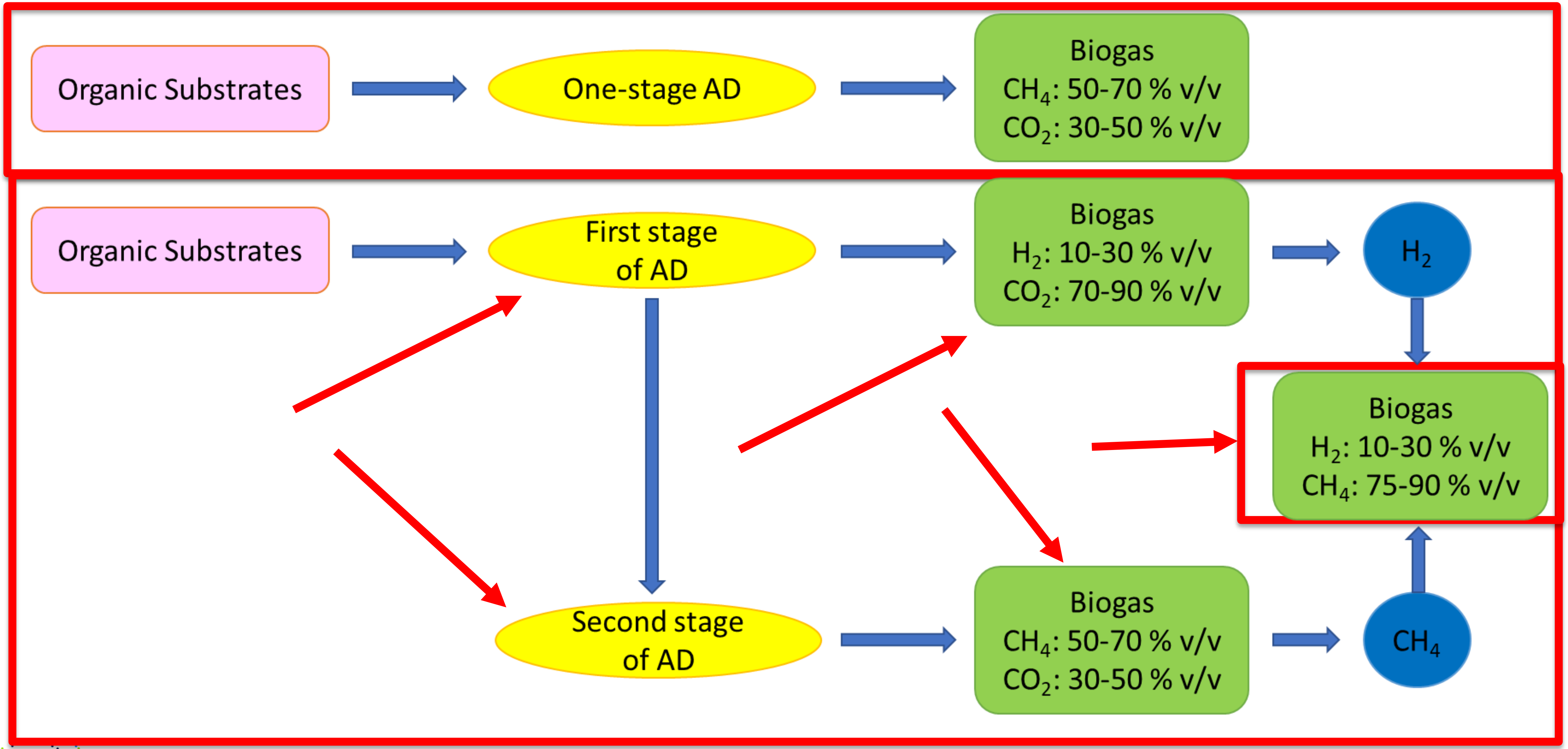
TWO SCENARIOS



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Hythane as a gaseous biofuel

- ✓ The term hythane was proposed in the 90s by Hydrogen Component Inc.
- ✓ They showed that a mixture of hydrogen (7% in energy content or 20% by volume) and CNG reduces pollutant emissions by a CNG engine (mainly NOx), while maintaining its performance (Mishra et al., 2017).
- ✓ No special storage and equipment modification are necessary for the use of the mixture.
- ✓ Hythane offers proven benefits over CNG:
  1. Improved ignitability, since hydrogen burns 8 times faster than methane
  2. Hydrogen helps methane burning with improved catalytic performance at lower temperatures
  3. It implies lower carbon emissions

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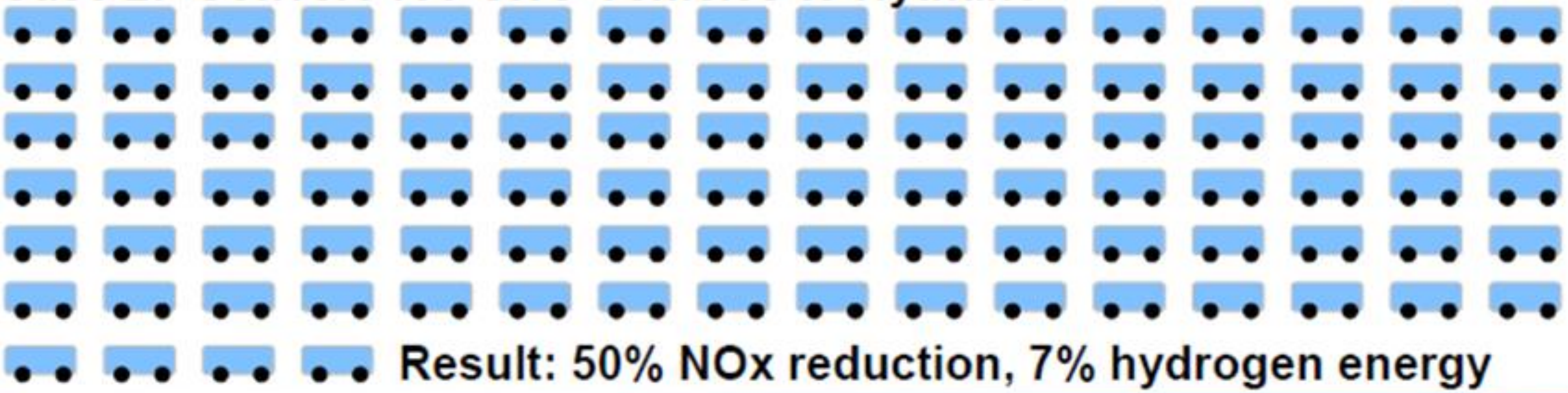
What is the best use of 7% Hydrogen Energy?

- Hydrogen Vehicle
- CNG Vehicle
- Hythane Vehicle

Case 1: Convert 7 CNG Vehicles to Hydrogen

Result: 7% NOx reduction, 7% hydrogen energy

Case 2: Convert 100 CNG Vehicles to Hythane®

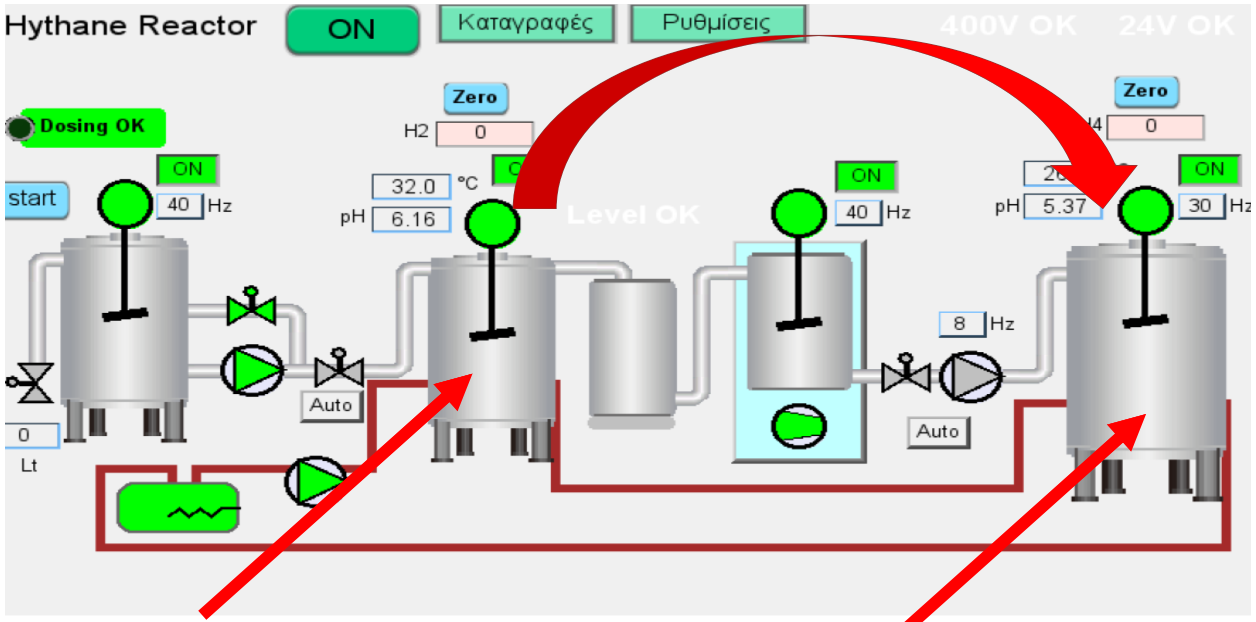


Result: 50% NOx reduction, 7% hydrogen energy

Test description	Hydrogen yield (L/kgVS)	Methane yield (L/kgVS)	Reference
HFW treated at thermophilic condition during dark fermentation with HRT of 1.5d. Mesophilic condition and short HRT (5d) for the methanogenic phase.	205	464	Chu et al. (2008)
HFW treated at thermophilic conditions for the both phases. OLR was changed during test.	270	[illegible]	Lee et al. (2010)
HFW treated at thermophilic condition with a HRT of 3 d for dark fermentation and 12.5d for the methanogenic phase.	52	410	Cavinato et al. (2011)
HFW treated at thermophilic condition with a HRT of 3 d for dark fermentation and 12.5d for the methanogenic phase with recirculation.	220	710	Micolucci et al. (2014)
HFW and sewage sludge co-digested at 5 different ratios at mesophilic condition.	174	264	Cheng et al. (2016)
Sewage sludge treated at thermophilic condition (60^{0}C) with HRT of 6 and 18 days for dark fermentation and methanogenic phase , respectively.	81.5	310	Khongkliang et al. (2015)
Sewage sludge treated at mesophilic condition	75	187	Liu et al. 2016

RAW HFW

Two-stage Anaerobic Digestion setup



4L CSTR, H_2 (dark fermentation)

40L CSTR CH_4

- A fully-automated and remotely controlled lab-scale anaerobic digestion system was designed and constructed.
- Operates under mesophilic conditions (35^{o}C)
- It consists of a 4L CSTR, as a hydrogen producing acidogenic step (dark fermentation) followed by a 40L CSTR for the methane production.
- Part of the effluent from the acidogenic reactor is fed to the methanogenic reactor
- The acidogenic bioreactor operated at Hydraulic Retention Times (HRTs) of 4 and 6 hours, while the methanogenic at HRTs of 20 and 15 days.
- During the whole process no pH adjustment was implemented.

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Operational parameters

	Phase #1		Phase #2		Phase #3	
Bioprocess stage	Acidogenic	Methanogenic	Acidogenic	Methanogenic	Acidogenic	Methanogenic
HRT	4 hours	20 days	4 hours	15 days	6 hours	15 days
Duration (days)	0-77		77-88 (11 days)		88-107 (19 days)	
Mean $tCOD_{inflow}$ (g/L)	21.2	18.6	20.5	18.1	25.4	21.5

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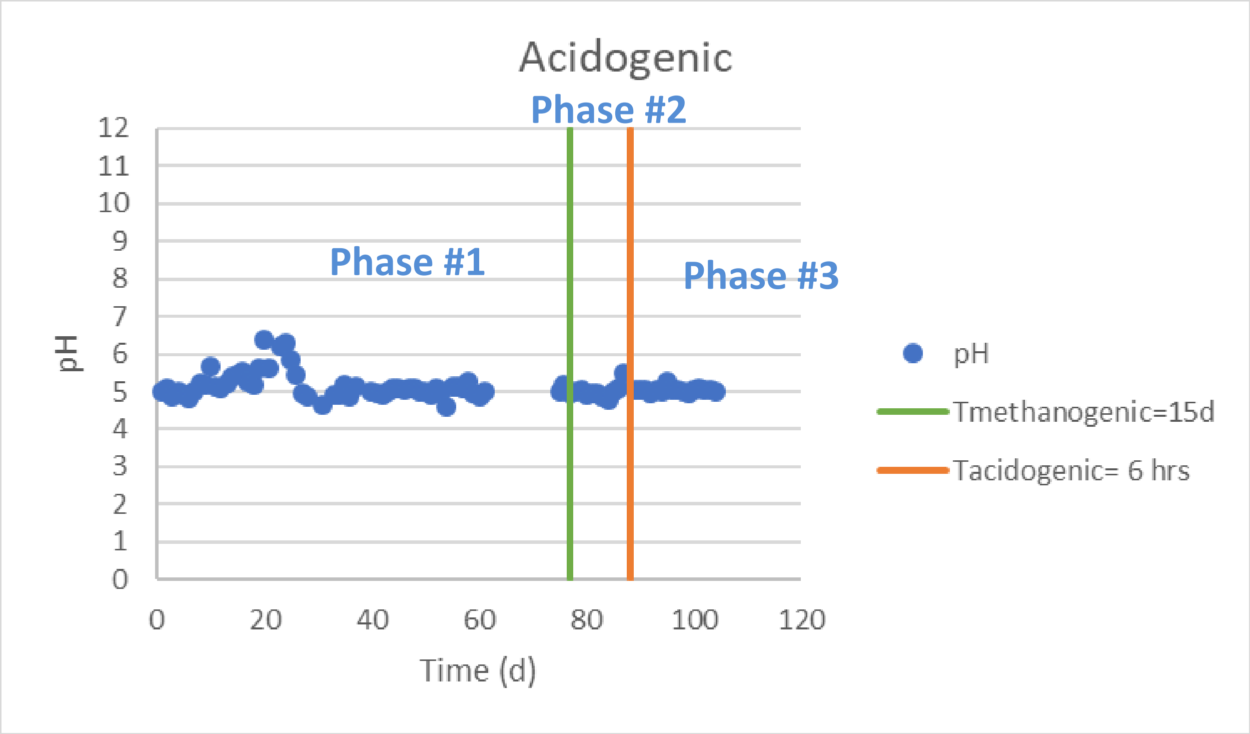
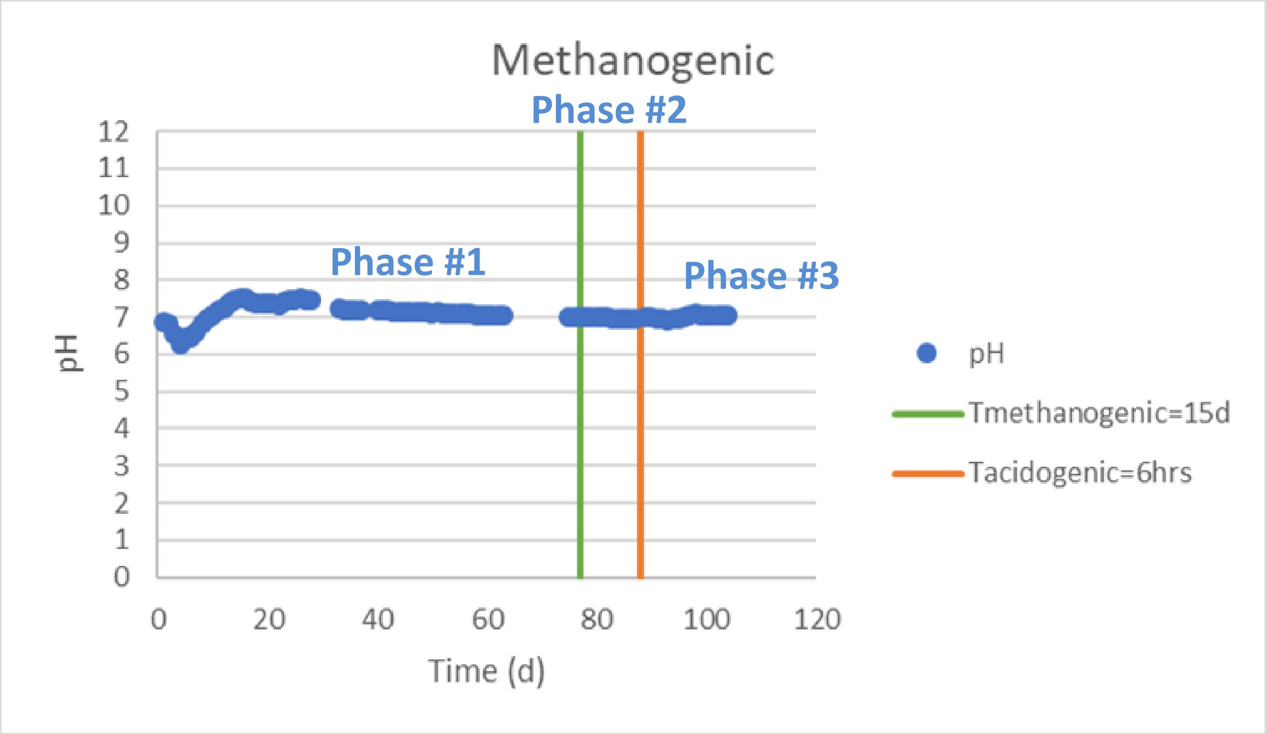
pH

Acidogenic bioreactor



Methanogenic bioreactor



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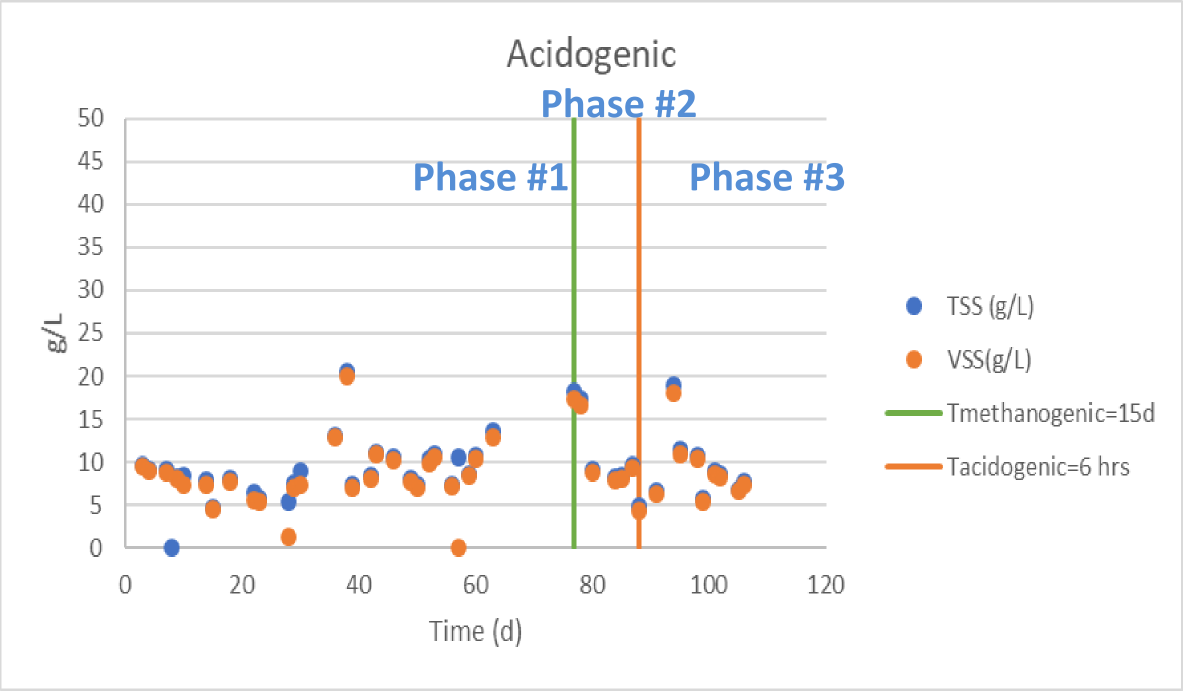
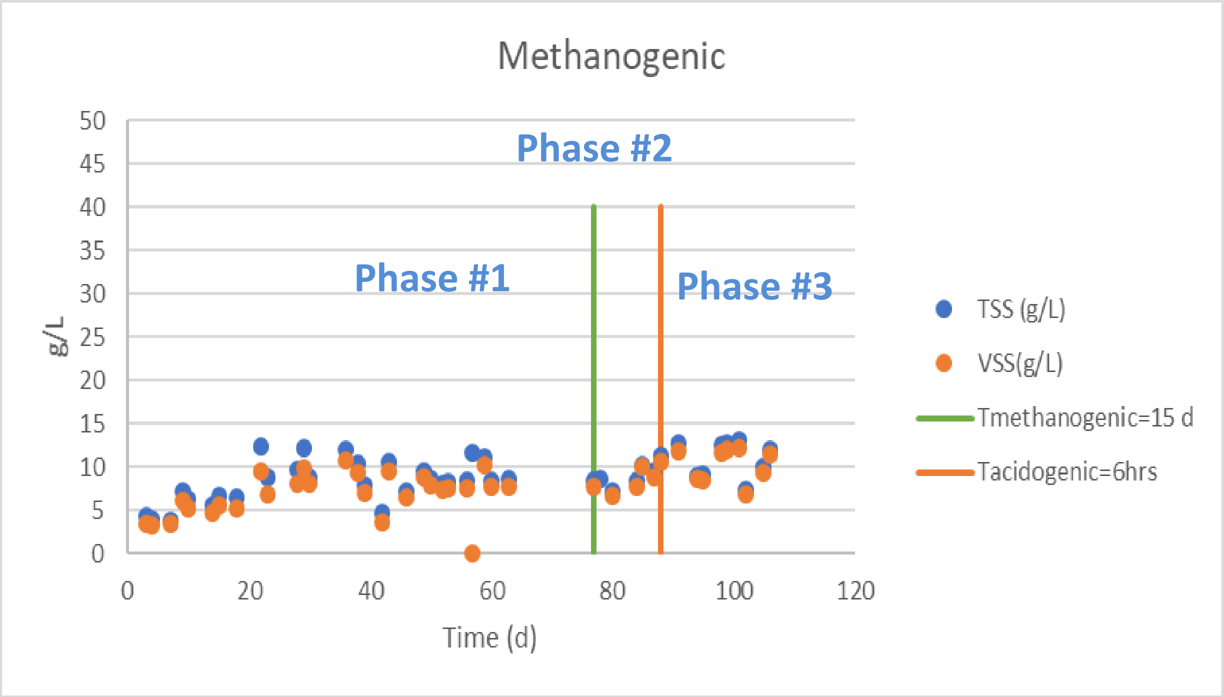
Total & Volatile Suspended Solids

Acidogenic bioreactor



Methanogenic bioreactor



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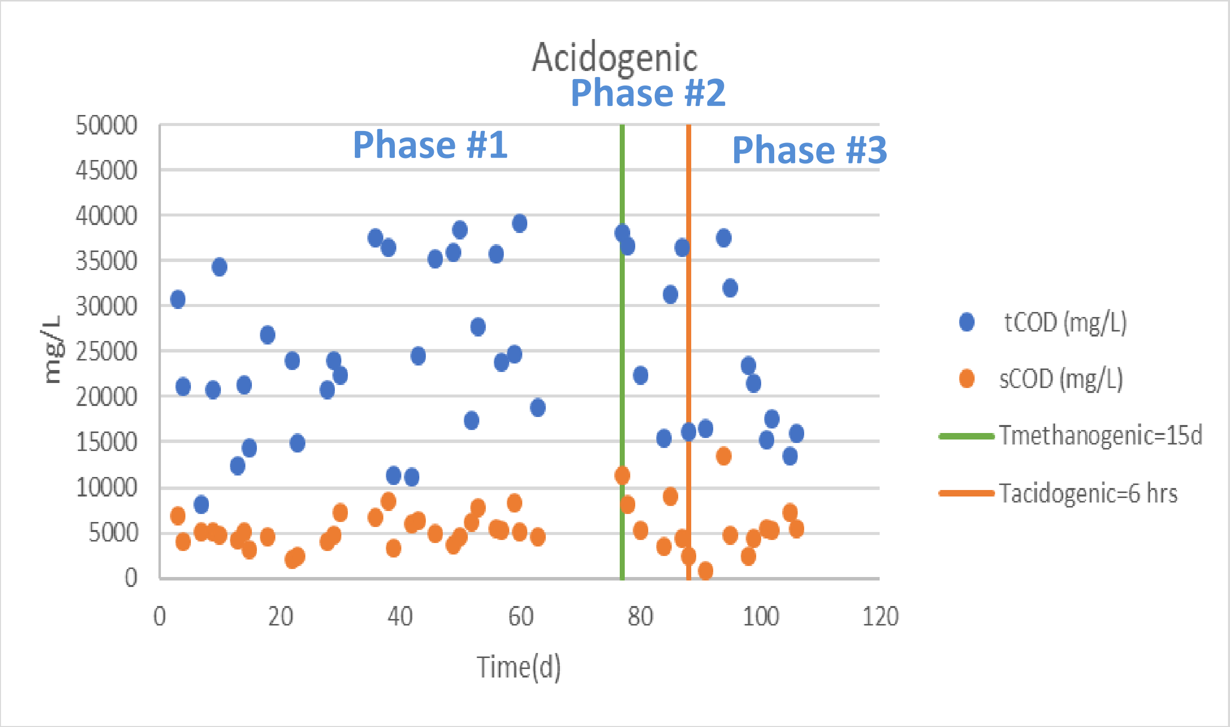
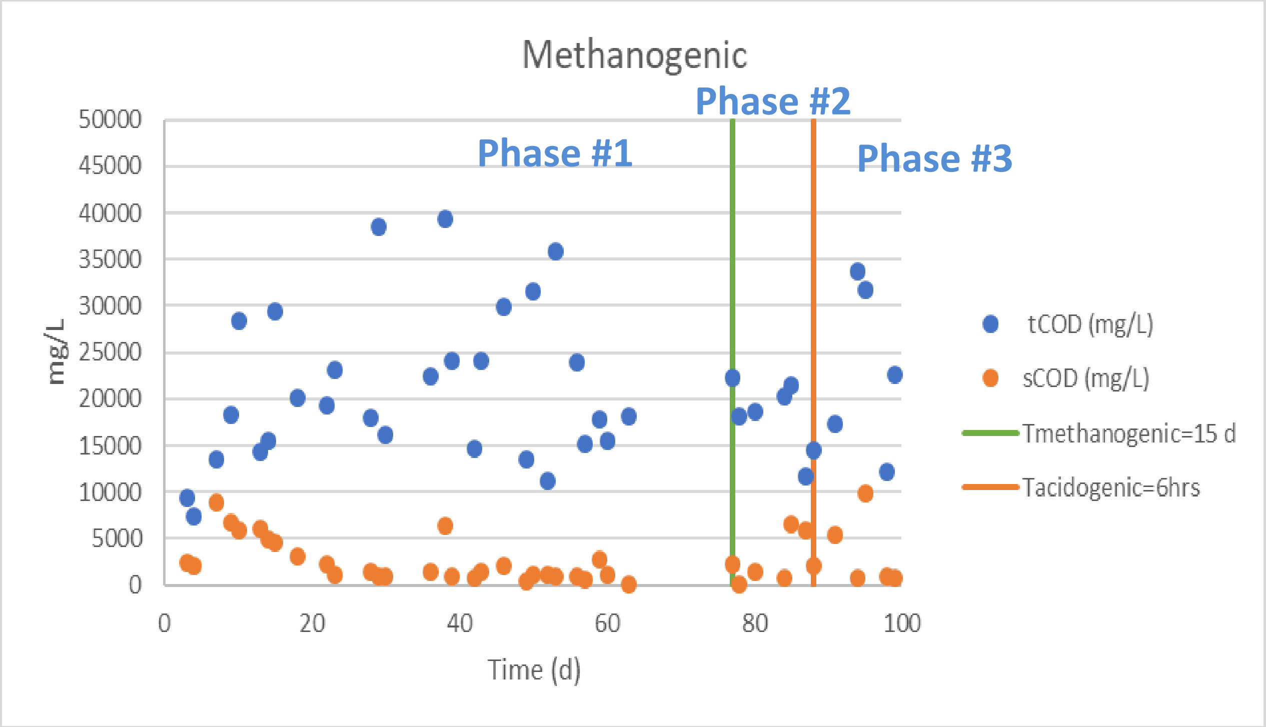
tCOD & sCOD

Acidogenic bioreactor



Methanogenic bioreactor



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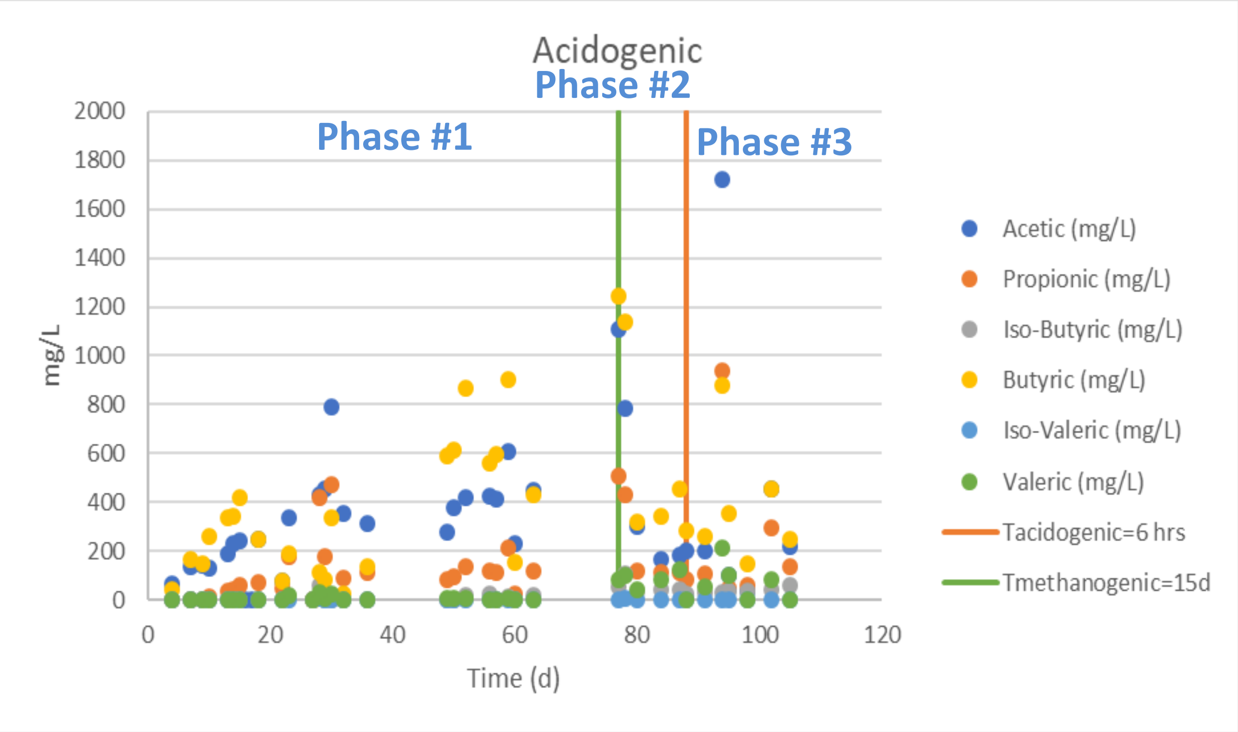
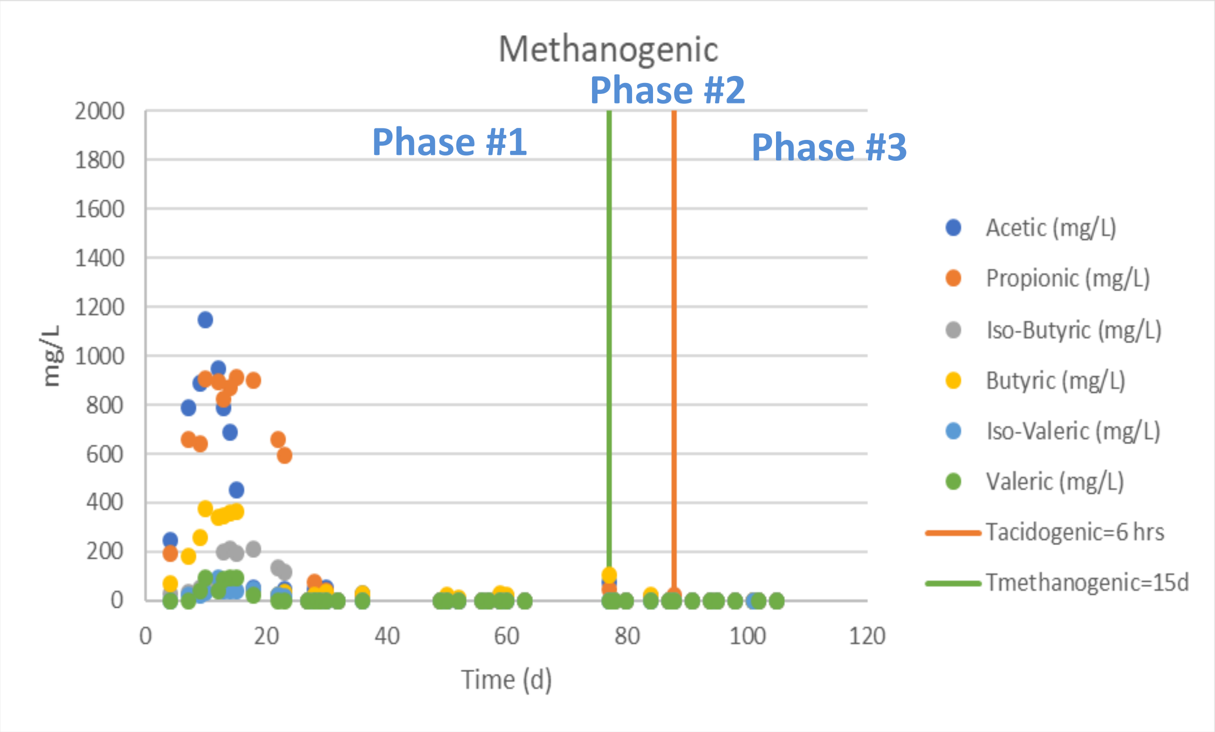
Volatile Fatty Acids

Acidogenic bioreactor



Methanogenic bioreactor



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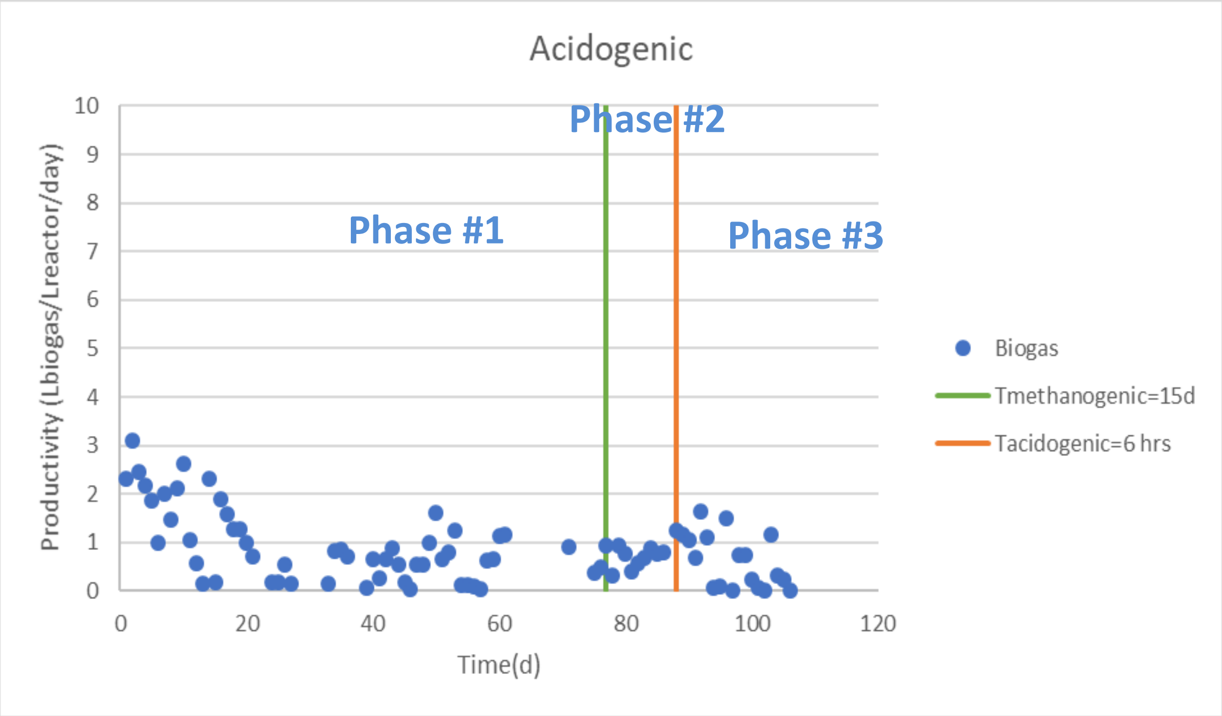
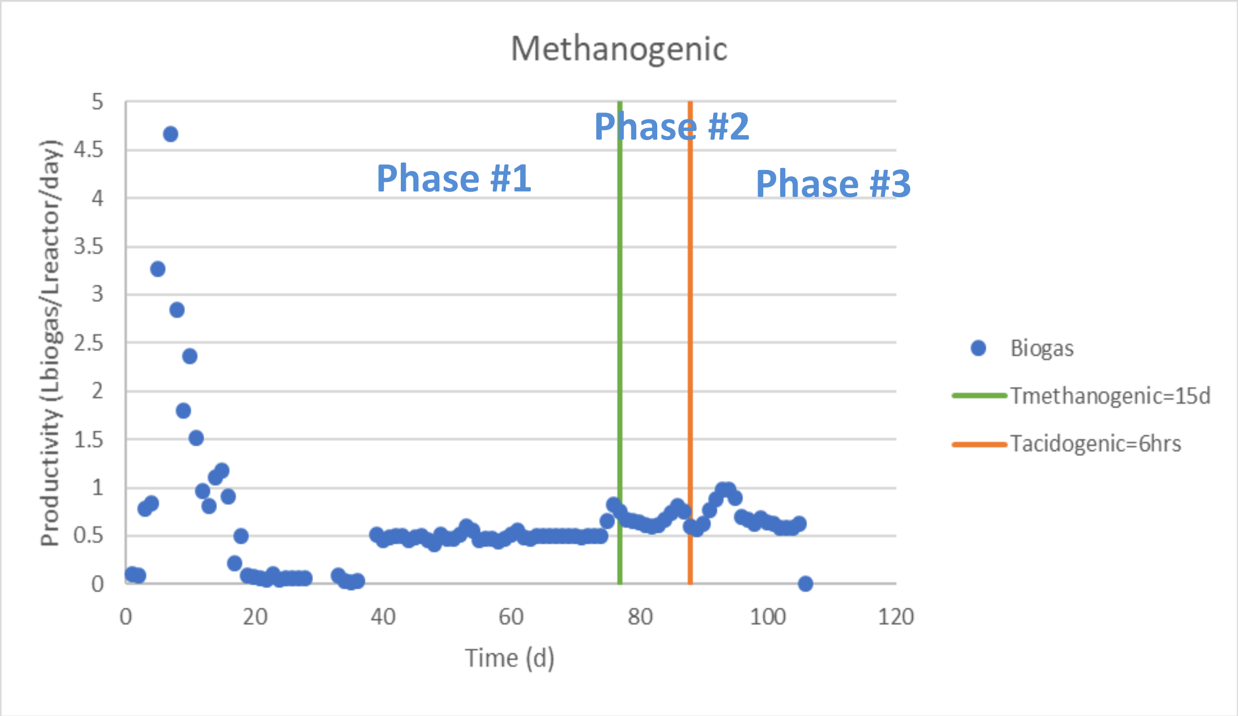
Biogas productivity





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Biogas productivity potential of FORBI

Hythane: 2.48L H_2 + 14L CH_4= 16.5L hythane (0.15*16.5=2.48 & 0.85*16.5=14)

	Phase #1	Phase #2	Phase #3
Hydrogen (L/kg$_{FORBI}$)	2.48	2.07	1.55
Methane (L/kg$_{FORBI}$)	475	436.5	470
Hythane (L/kg$_{FORBI}$)	16.5	13.8	10.3
Remaining Methane as extra stream (L/kgFORBI)	451	424.7	461.3

475 L CH_4 – 14L (used for hythane)= 451 L CH_4 remaining

- A H_2/CH_4 ratio of 18/85 was assumed for Hythane's composition.
- The remaining CH4 will be treated as a separate biogas stream.

Conclusions

- Fermentable Household Waste may be used for the production of hythane in a two-stage anaerobic process.
- FORBI, as a feedstock, offers the opportunity to produce two separate gaseous biofuels streams: a Hythane stream and a Methane stream.
- The **Phase #1** ($HRT_{acidogenic}$= 4hrs, $HRT_{methanogenic}$= 20d) was the most productive in terms of Hythane productivity.

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