

The left side of the slide features a decorative design consisting of several vertical lines of varying heights and widths, and a series of orange circles of different sizes arranged in a descending pattern from top to bottom.

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BIOGAS WORKSHOP

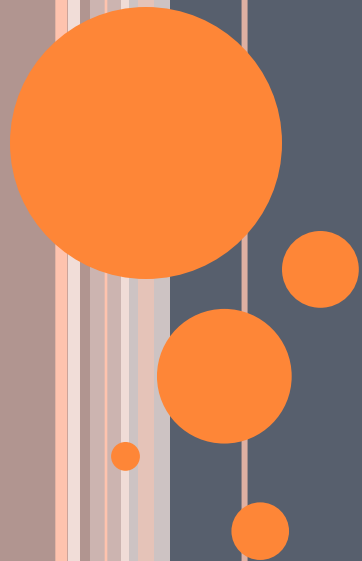
Presented by Tom Ferencevic

Technical Director,

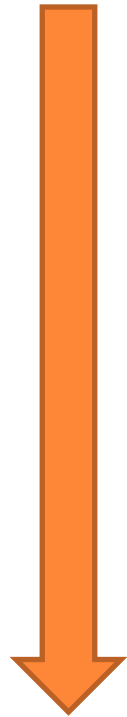
Yield Energy Inc.

OBJECTIVE

Provide quality information allowing potential AD clients to ask the right questions



BIOGAS LEVELS OF COMPLEXITY



Biological System

Digester System

CHP System

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INTRO TO BIOGAS TECHNOLOGIES

- 2 Main Types of Digester Systems
 - WET Fermentation
 - Completely Mixed
 - Plug Flow Types
 - DRY Fermentation
 - Garage type batch digesters
 - Plug Flow Types
- WWTP types are not dealt with here



TYPES OF DIGESTERS

- There are hundreds of ‘types’ of digesters
- Focus is on agricultural digesters and modified agricultural digesters treating SSO organic waste streams
- Main technological difference is how to deal with high solids content materials
- Competitive analysis is difficult as manufacturers deploy different technologies to deal with differences in feedstock



CONCRETE DIGESTERS WITH CONCRETE ROOF

Advantages

- Low heat loss
- Easy to modify
- Withstand pressures to 20 bar
- Little odour loss
- Wind protection
- Easy to access

Disadvantages

- No integrated gas storage
- Gas permeability, repair and leak identification are same for concrete as for steel or membrane roof digesters



CONCRETE DIGESTER WITH SINGLE (EPDM) MEMBRANE COVER

Advantages

- Lower capital cost vs. concrete or double membrane roof
- Integrated gas storage

Disadvantages

- Wind and Weather Sensitive
- Not 100% gas tight
- Difficult to monitor gas fill level



CONCRETE DIGESTER WITH AIR SUPPORTED DOUBLE MEMBRANE COVER (PVC/EPDM)

Advantages

- Integrated Gas Storage
- Weather Resistant
- Easy to monitor gas fill levels

Disadvantages

- Energy consumption to maintain air barrier
- Approximately same capital costs per sq. meter as concrete
- Not 100% gas tight



STEEL DIGESTERS

- Stainless Steel, Steel with + Stainless liner & Glass Enamelled Steel
- Different manufacturing technologies bending, winding and riveting, bolting
- All have concrete base
- Material costs are similar to concrete except when making very large tanks $>2500 \text{ m}^3$
- Cost differences come down to construction time labour i.e. forming and erecting



HORIZONTAL DIGESTERS WITH PADDLE MIXERS (MIX OF CONCRETE & STEEL)

Advantages

- High loading rates
- Digestion of high solids content feedstock
- Complete mixing
- Can be used for dry digestion

Disadvantages

- High capital costs
- Post digestion is needed
- Size limitations
- High parasitic energy use
- If thermophilic process then higher system instability



GARAGE TYPE DIGESTERS

Advantages

- High solids and substrate loading rates
- Modular with some redundancy
- Simple feeding (using a loader)
- Post Digestion Composting
- Less liquid to deal with

Disadvantages

- Dry systems need high C:N ratio feedstock which means they may need to purchase carbon + \$30/tonne
- Incomplete digestion process resulting in post process composting requirements- this leads to increased land requirements
- Low biological stability
- Lower biogas yields and methane content
- If thermophilic process higher maintenance costs and lower stability
- Inconsistent sanitation/pasteurization
- More difficult material transport
- Emissions management-added costs

OTHERS

- Biogas Gas Induced Mixing Reactors
- Digestate/ hydrolytic Induced Mixing Reactors
- Upflow-Downflow-Reflow fixed film reactors
- Fixed Film Systems
- Lagoon Digesters
 - Capital costs is pretty close to concrete and steel
 - Beneficial when land costs are cheap and climate is suitable
 - Low parasitic energy demand



COMMON CONSIDERATIONS

- Every digester needs:
 - heat exchanger
 - insulation
 - mixing technology
 - feeding system (dry and/or wet)
 - moisture removal from biogas (active or passive)
 - monitoring for leakage



KEY CONSIDERATIONS

- Always think in practical vs. theoretical terms
- How easy does the system look to operate?
- How much water am I going to need to use?
- What and/or where am I going to discharge my waste water/digestate?
- What material and equipment are available locally versus imported?
- How easy is it to access internal equipment for repair and maintenance?





THE BIOCHEMICAL PROCESS

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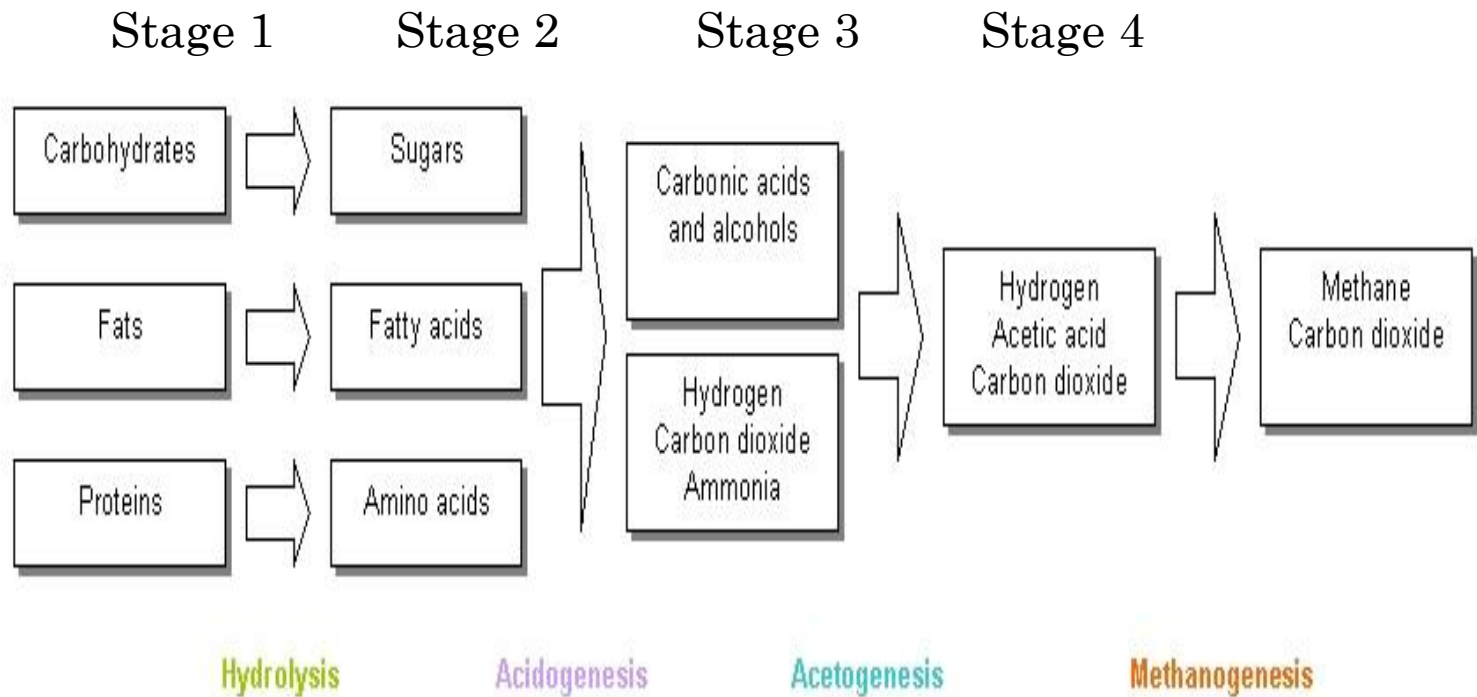
CONVERSION OF ENERGY

- Energy Content of the Substrate
 - Yield= $\text{m}^3 \text{CH}_4$ /tonne of oDM (theoretical)
- Energy Delivered by the Digester
 - Yield= $\text{m}^3 \text{CH}_4$ /($\text{m}^3 \text{RV d}$) (theoretical)
- Electrical Efficiency of the CHP (%)
- Thermal Efficiency of the CHP (%)



BIOGAS FORMATION

Biomass



BACTERIA GENERATION TIME

Aerobic Bacteria
20 min-10 hrs

Acetogenic Bacteria

- Methanol, Acetic Acid, Lactic Acid **9-18 hrs**
- Butyric Acid **3-5 days**
- Propionic & other VFA's **2-10 days**

Acidogenic Bacteria

- carbs, fats, proteins **1-48 hrs**

Methanogenic Bacteria

- Degrade H₂ **48-72hrs**
- Degrade Acetic Acid **3-5 days**
- Degrade Propionic Acid **10-15 days**

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BACTERIAL STRAIN DEVELOPMENT

- Start of Experiment September 2006
 - Volumetric Load 2.5 kg oDM/m³/d
 - **Verified methane producing bacterial strains >20 types**
- End of Experiment April 2007
 - Volumetric Load >4 kg oDM/m³/d
 - **Verified methane producing bacterial strains 5 types**

*By Arne Dahlhoff, Biogas-Workshop Proceedings May 30 2007
Department of Agriculture Nordrhein-Westfalen*



BIOGAS PRODUCTION FROM SUBSTRATES

	CH ₄	CO ₂	NH ₃	H ₂ S
Carbohydrates	50%	50%	-	-
Fats	70%	30%	-	-
Proteins	68%	18%	8%	6%



BIOGAS PRODUCTION OCCURS SIMULTANEOUSLY IN TIME AND SPACE

- All stages are strongly dependent on each other
- Metabolites are needed for each following process
- Metabolites may accumulate and cause product inhibition
- As the stages progress (1-4) they take place from fastest to slowest



SUBSTRATE SOLUBILITY

- The solubility of various compounds depends on temperature (NH₃, H₂, CH₄, H₂S, VFA's)
- This is decisive for the AD process and can be determinate when choosing feedstock
- Significant in determining which substrate could have an inhibiting effect on the biochemical process
- NH₃ toxicity increases with temperature



OPERATIONAL PARAMETERS FOR ANAEROBIC DIGESTION

- Temperature
- pH
- Micronutrient Feeding



Psychrophilic (<25 C)

- Low growth rates
- Long retention times
- Uneconomical and rarely used

Mesophilic (32 – 45 C)

- Stable biochemical process
- Good gas yields after retention times of 30-50 days
- Most common operating parameters

Thermophilic (50-60 C)

- High gas yields after short retention times
- Good and hygenization of substrates
- Biochemical process is sensitive- rapid metabolites resulting from hyrolysis phase can upset the stability

TEMPERATURE & PH

- During the start up phase both pH and temperature increase relative to each other
- A loss of just 1 or 2 degrees can reduce biogas output by hundreds of m³/day
- Metabolites would reduce the pH if not for the buffer capacity (carbonates & ammonium)

	Hydrolysis	Methanogenesis
Temperature	25-35	Mesophilic 32-42
pH	5.2-6.3	Thermophilic 50-58



TEMPERATURE & PH

- pH values affect the growth rates of methanogens
- Affects the dissociation of NH_3 , sulfides, VFA
- High ammonia is inhibitory incr. temp causes an incr. free NH_3
- As pH increases VFA accumulation decreases thus starving the system



MICRO-NUTRIENTS

- A wide range of macro and micro nutrients are needed to ensure proper growth and reproduction of your bacterial populations
- The amounts needed vary depending on your feedstock
- German biogas plant survey data provided by Birgit Pfeifer (Novatech) showed that manure and energy crop based plants benefited from improved systems stability and biogas production with the addition of trace elements



ENGINEERING PARAMETERS

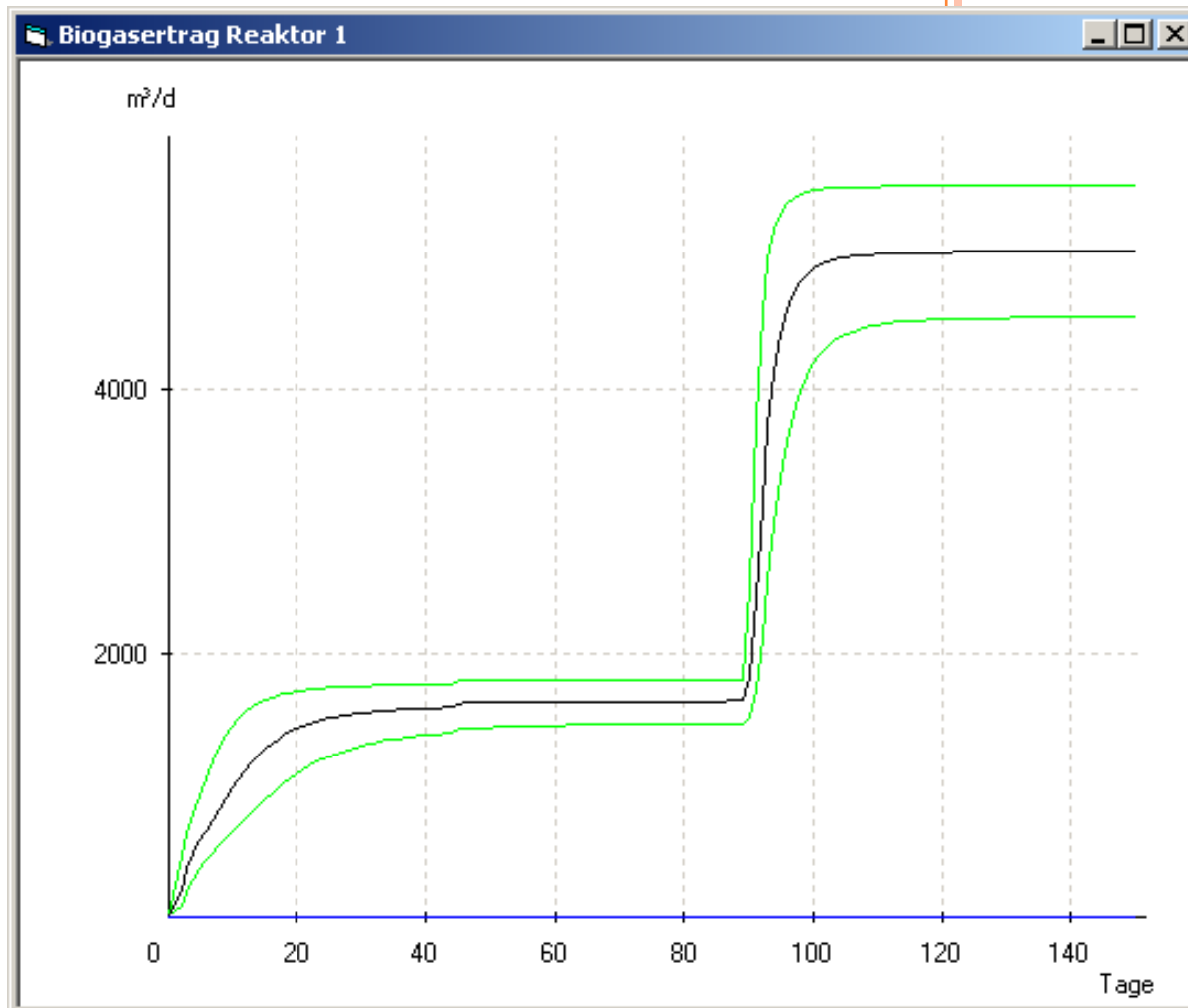
- Hydraulic Retention Time
- Organic Matter in Total Solids
- Organic Loading Rates
- Biogas & Methane Yields
- Volatile Fatty Acid Production



BIO TIP SIMULATION TOOLKIT

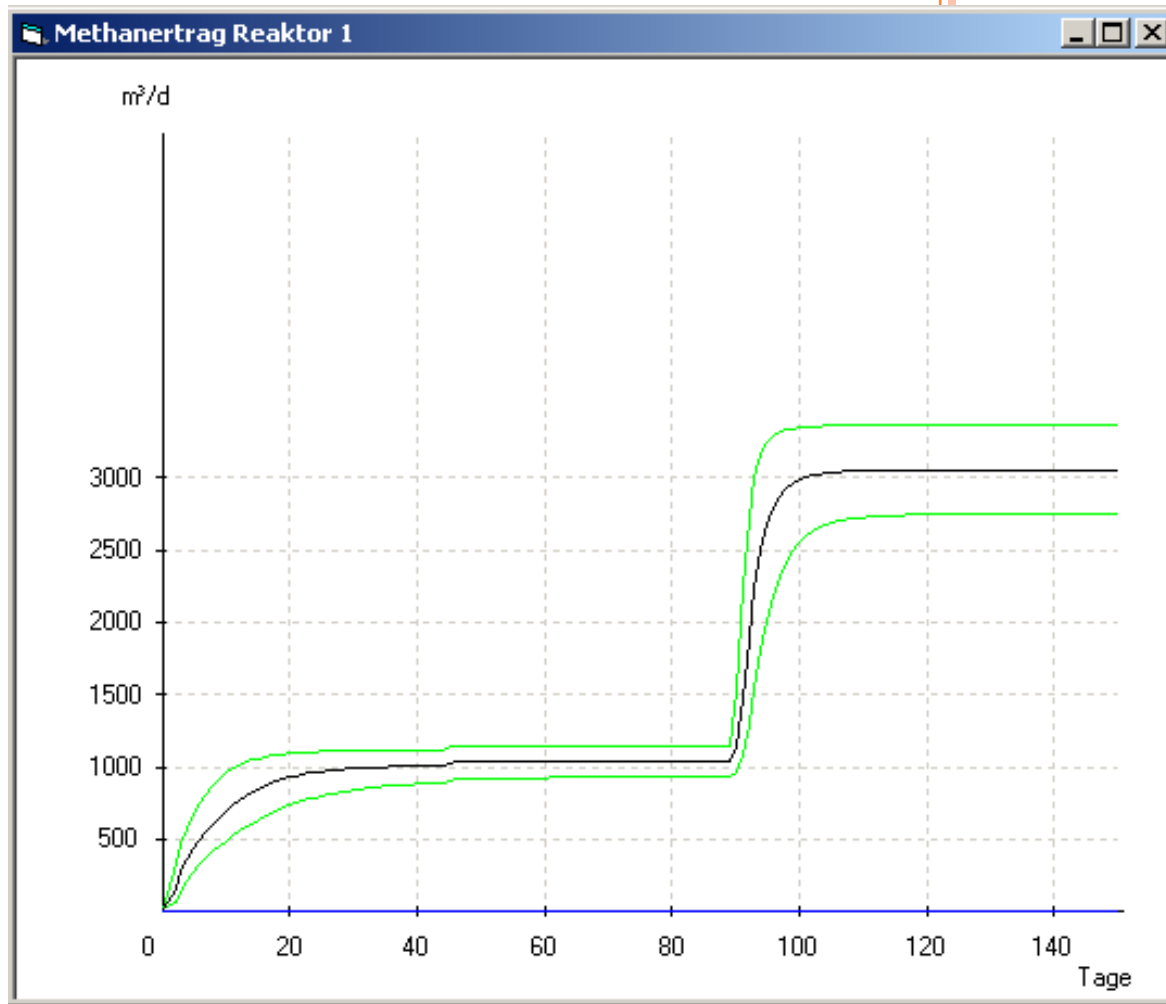
- Calculates the biogas yield, methane yield, concentration of organic acids, pH, the buffer capacity, anaerobic bacterial concentration and growth rate.
- The simulation concurrently models hydrolysis acidogenesis, acetogenesis and methanogenesis until the system achieves steady state or fails.
- Converts batch testing of substrates into a continuous biogas process





DEVELOPMENT OF BIOGAS YIELD



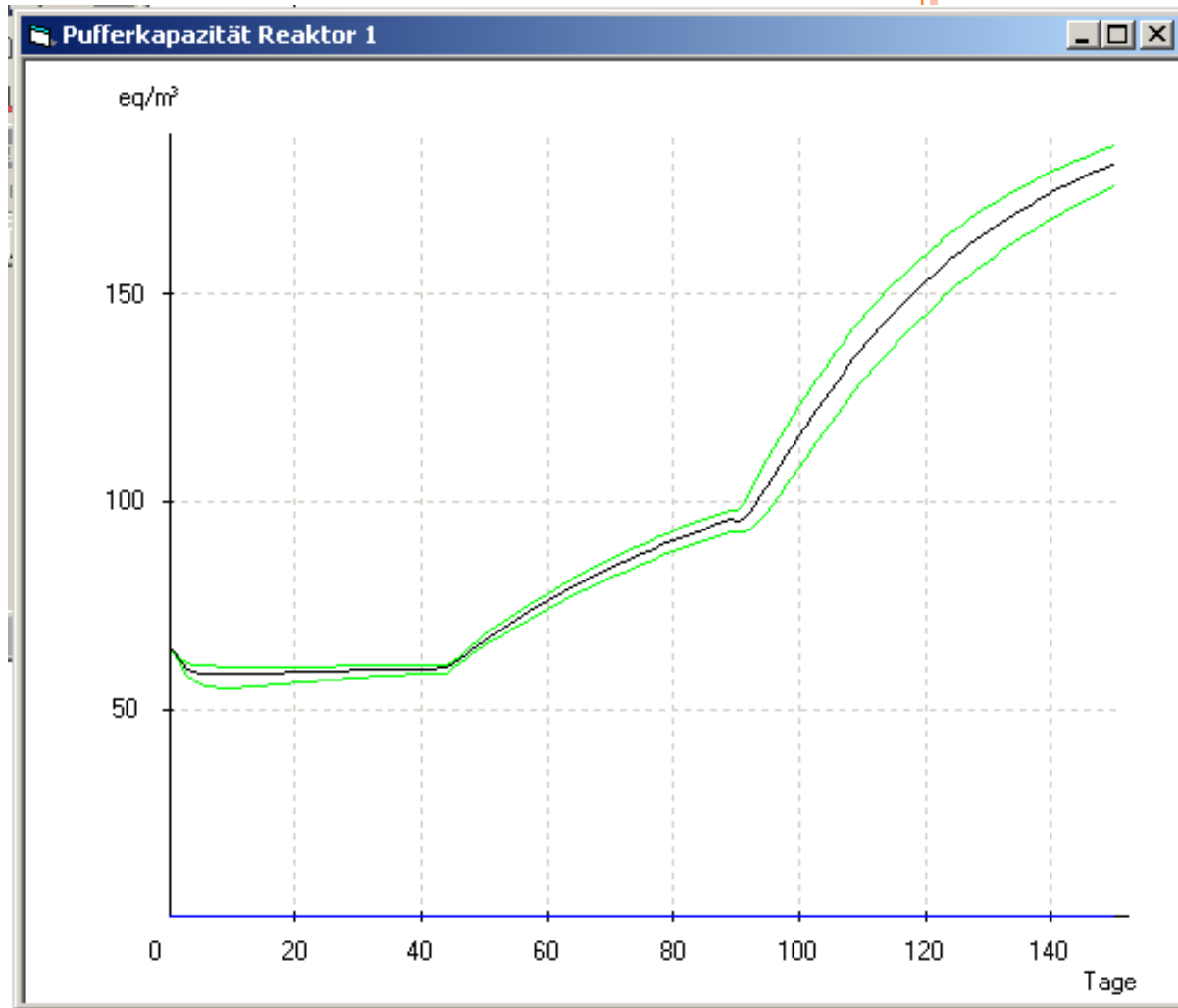


DEVELOPMENT OF METHANE YIELD

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BUFFER CAPACITY DEVELOPMENT

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BIO TIP SIMULATION

Answers some of the most critical questions in biogas plant design prior to any work being done

- a) Retention Times
- b) Tank Sizes
- c) Biogas Quantity and Quality
- d) Biological System Integrity (120 days out)





PRE-TREATMENT & PRE-STORAGE

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PRE-TREATMENT TECHNOLOGIES

- Chopping/Milling
 - Increases the surface area to volume ratio for bacteria
 - Improves pumping ability
- Mixing of Substrates
 - Adjusts the dry matter
 - Part of the recipe process for multiple feedstocks
- De-Packaging
 - Technologies to deal with packaged food wastes and sso's
- Pasteurizing
 - BMP for pathogen destruction Min 70 Celcius for 1 hour/
m³
- Ensiling
 - Lactic acid fermentation destroys waxy layers and increases digestibility and methane content



FEEDSTOCK SORTING AND SEPARATION

- Depends on feedstock
- Agricultural feedstocks <2% contamination
- Sand and stone can be removed via agitation or sediment removal
- Household wastes, restaurants and food processing wastes are full of impurities
- Several technologies to separate non-digestible matter
 - **Either removal before AD process or during it**



MASS BALANCE

- Mass Balance - a calculation tool that always starts with the feedstock
- A Mass Balance is key in ultimately determining a projects potential for success or failure
- The Mass Balance is always combined with our BioTip Simulation





STEP 1: FEEDSTOCK CHEMICAL AUDIT

Taking representative samples and properly analyzing your organic wastes will give you the renewable energy potential of the fuel source

MASS BALANCE CHEMICAL DATA

- 1) Carbohydrates, fats, proteins, moisture
- 2) Total Solids, Total Organic Solids
- 3) Methane Content (BioTip Calculation & Reference Data)
- 4) Biogas Yield (BioTip Calculation & Reference Data)





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STEP 2: FEEDSTOCK PHYSICAL AUDIT

You must understand how much of your feedstock will generate you energy, how much will cost you a disposal fee and how well your pre-treatment technology works

MASS BALANCE-PHYSICAL DATA

- The more contaminated and complex the feedstock the more critical effective pre-treatment becomes.
 - 1) Contaminants as a % of total solids
 - 2) Total Contaminants (tonnes/yr)
 - 3) Digestible Organics in total solids





PRE-TREATMENT AUDIT

What goes in
must come
out...all inputs
and outputs
must add up
mathematically.



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CRITICAL FORMULA

The following output sum must equal the total inputs into the biogas plant:

$$\begin{aligned} & \text{Quantity of Substrate} \\ & + \text{Quantity of Contaminants} \\ & + \text{Quantity of Wastewater} \\ & + \text{Mass of Biogas} \\ & + \text{Quantity of Compost} \\ & - \text{Diluting Water} \\ & = 100\% \text{ of Inputs} \end{aligned}$$



COGENERATION

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QUESTION: DOES THE PROPOSED CHP UNIT FIT MY BIOGAS YIELDS?

- **Why is this important?**
 - **Efficiency of the generators vary depending on the load**
 - **Should ask what the efficiency will be at 100, 75 and 50% load**
 - **Therefore if you size your CHP unit incorrectly you will not achieve the optimal efficiency ratings for your units**
 - **Another reason this important to know is that it is better to run your CHP unit on full load rather than on partial loads**
 - **If you are not producing enough biogas it's better to shut it down completely and wait for full load again**



QUESTION: DOES THE PROPOSED CHP UNIT FIT MY BIOGAS YIELDS?

- If you drop your output to below a certain level, depending on the unit- usually 50% then the turbo charger no longer operates and your efficiency will drop dramatically.
- DDACE has a wide range of available CHP units from 50 kW to 4 MW
- For GE Jenbacher, the el. Efficiency is guaranteed at full load and backed by financial penalties



IMPORTANT MASS BALANCE CALCULATIONS

- **kwh of energy in a cubic meter of biogas = methane content x volume**
 - **60% CH₄ content x 1000 m³ biogas = 6000 kwh of energy**
 - **6000 kwh of energy x 38% el. efficiency = 2280 kwh**
 - **22280 kwh/24 hrs = 95 kw**

1L of diesel = 10 kwh

1 m³ of natural gas = 10 kwh



QUESTION: WHAT ARE MY TOLERANCES TO HYDROGEN SULFIDE?

○ Why is this important?

- Your CHP tolerance to hydrogen sulfide will effect your maintenance intervals and your costs to clean up your biogas.
- The cleaner the biogas the longer the oil change intervals will be.
- You need to be ready to calculate how much you will save if you can extend your oil change intervals and compare that to desulphurization costs



QUESTION: WHAT ARE MY TOLERANCES TO HYDROGEN SULFIDE?

There are biological desulphurization technologies available that are very cost competitive to alternatives on the market.

- Note air injection alone will not be enough to bring down hydrogen sulfide levels to below 200ppm depending on the feedstock.
- Improved engine performance and extended oil change intervals



QUESTION: DOES ELECTRICAL EFFICIENCY MATTER?

- Yes and No unless it matches the actual gas yields from your facility
- What are the actual gas yields achieved?
- Maybe better to have 2 smaller units running at 100 load
- Figure out how long it will take you to get the extra investment costs back (2-3 years?)



QUESTION: HOW DO THE COSTS AND AVAILABILITY OF SPARE PARTS COMPARE?

- Can CHP parts can be available in 24 hrs
- is the warehouse managed to stock the most used and critical wear and tear parts
- Can your supplier have entirely new engine in place in less than 2 weeks



QUESTION: HOW DOES THE SERVICE SIDE OF THE COMPANY STACK UP?

- \$/kw-hr- must include the cost of ALL inputs
- Maintenance Intervals
- Unscheduled maintenance offerings
- Do they provide Liquidated Damages for excessive downtime
- Do they offer remote monitoring services



CHP VS. BIOMETHANE

- Capital Costs slightly favours biomethane
 - Need to remember there is still waste gas from this process and CHP will still be beneficial
- Feed In Tariff in Ontario is driving CHP
 - OPA claims carbon credits
- Heat use needs to be calculated into ROI
 - Greenhouse where heat offsets NG use
- Vehicle fuel likely provides the best rate of return
 - Ideal for Municipalities




2 KEY POINTS

In the end your biogas plant design and engineering parameters are a compromise between getting the highest possible biogas yields at a justifiable capital and operational cost.

Understanding your feedstock goes a long way to making or breaking a project.





GREEN ENERGY AND ECONOMY ACT

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RENEWABLE ENERGY APPROVALS

- Streamlined approvals for renewable energy
- Feed-in-tariff system to provide 20 yr fixed price contracts
- Develop a smart grid which is intended to support new energy supply



FIT RATE STRUCTURE

Local Restrictions	Size	Average Price (c/kWh) (including peak hrs bonus)
On-farm	< 100 kW	19.5
On-farm	>100 kW < 250 kW	18.5
n/a	< 500 kW	16
n/a	>500 kW < 10 MW	14.7
n/a	> 10 MW	10.4

Capacity Allocation Exemption if you are < 250 kW on single phase (5 kV)
Or < 500 kW on a 3 phase line (15 kV)

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4 CLASSES OF BIOGAS PLANTS

- Regulated Mixed AD Facility (MRDAF)
 - Exempt from REA, regulated under NMA
- Class 1 (on farm)- agricultural waste or energy crops + series of BMP's
- Class 2 (on farm)- All biomass & pre-consumer SSO + series of BMP's = REA Approval
- Class 3 (off farm)- All biomass & SSO's = REA Approval



DIGESTATE MANAGEMENT

- Related to Class of Biogas Plant
- If your AD facility did not receive biosolids or septage and at least 50% by volume of the substrate is on-farm then your digestate does not require a CoA for land application
- If you are a Class 3 off-farm you can get a CFIA Fertilizer Reg for sale and land application of your digestate



DIGESTATE COMPOSITION

- Variable based on feedstock-nothing is created or destroyed
- What improves is nutrient availability
- 6-10% total solids
- 3-5% N; 1-2% P; 3-5% K
- C:N ratio usually 10:1





THANK YOU

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