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Overview of Anaerobic Digestion for Municipal Solid Waste

***Updated*: October 2016**

About This Presentation

- Introduces the process of anaerobic digestion (AD) for municipal solid waste (MSW)
- Provides an overview of anaerobic digestion microbiology
- Helps you understand how you might benefit from AD
- Guides you through the key areas to consider when developing an AD project
- Reviews the status of AD globally and provides selected case studies

Using Bookmarks to Navigate

This presentation contains bookmarks to help you navigate. Using the panel on the left, click the bookmark to jump to the slide.

For Chrome users, the bookmarks can be viewed by clicking on the bookmark icon ( ) at the top right of the screen.

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GMI is a voluntary, multilateral partnership that aims to reduce global methane emissions and to advance the abatement, recovery and use of methane as a valuable clean energy source.

OBJECTIVES

- Reduce anthropogenic methane emissions and advance the recovery and use of methane while:
  - Enhancing economic growth
  - Promoting energy security
  - Improving local air quality and public health.

BENEFITS

- Decline in methane concentrations and methane utilization will result in:
  - Sustainability
  - Energy security
  - Health and safety
  - Profitability

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GMI Partners

- Grew from 14 to 42 Partner governments, plus the European Commission
- Accounts for nearly 70% of global anthropogenic methane emissions

Main Menu

1. Introduction – what is AD and why should it interest me?

Click here for an introduction to AD

2. Is AD suitable for me?

Click here for more info about the potential for AD

3. Step-by-step guide

Click here for detailed information about the key issues to consider when developing an AD project

4. Project implementation

Click here for guidance on the next steps and links to other information sources

Additional Information

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Overview: Anaerobic Digestion

What is anaerobic digestion?

How can anaerobic digestion benefit me?

Why should I consider anaerobic digestion?

How do I find out more?

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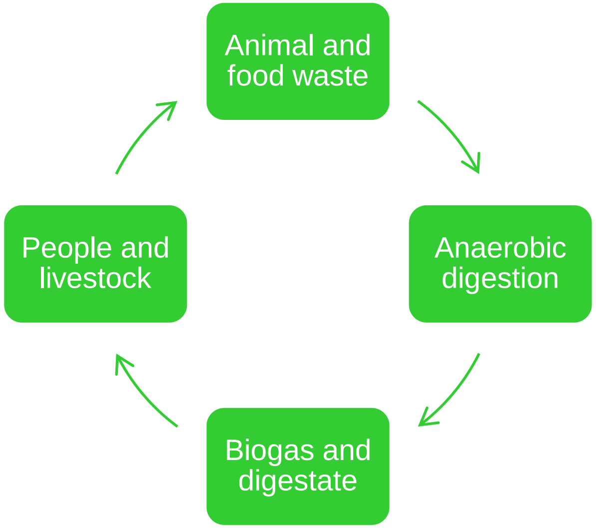
1.0 – Basics: What is Anaerobic Digestion?

Anaerobic digestion (AD) is the natural process that breaks down organic matter in the absence of oxygen to release a gas known as biogas, leaving an organic residue called digestate.



Biogas is a mixture of methane, carbon dioxide and water and can be used to produce electricity and heat or used as a natural gas substitute.

Digestate is a nutrient rich by-product of AD and can be used as a fertilizer and soil improver.

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1.1 – Why should AD interest me?

Treats food waste sustainably

Can reduce my reliance on landfill

Produces a renewable source of energy

Can help me to reduce greenhouse gas emissions

Can help save money on my energy bills

2.0 – Is AD suitable for me?

- Do you have a suitable feedstock for AD?
- Do you have a use for renewable energy or fuel?
- Do you want to improve the management of your waste?
- Do you want to reduce greenhouse gas emissions?

The following information will help you answer these questions…

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2.1 – Do you have a suitable feedstock for AD?

A digester needs feedstock to produce biogas. It is important to consider the feedstock available if you are starting an AD project. A wide range of biodegradable materials may be suitable feedstock, including:

- Manure or animal slurry
- Food wastes from domestic, commercial and industrial sources
- Green waste from parks and gardens
- Sewage sludge
- Energy crops (e.g., grass silage, whole crop wheat, and whole grain maize)

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2.2 – Do you have a use for renewable energy or fuel?

AD produces biogas, a renewable energy source.

- Biogas contains methane (CH_4), carbon dioxide (CO_2) and trace gases
- Biogas can be used to fuel internal combustion engines to produce electricity and heat (combined heat and power)
- Biogas can be compressed and used as a natural gas substitute and vehicle fuel

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2.3 – Do you want to improve the management of waste?

In many countries waste is badly managed and in some cases, not at all. Poorly or un-managed waste…

- is unsightly
- damages the environment
- impacts human health
- attracts flies and vermin

Improper landfill disposal is the favourable and unsustainable waste management method.

AD offers a more sustainable waste management option, recovering resources and diverting them from landfill disposal, and uses less space than landfills.

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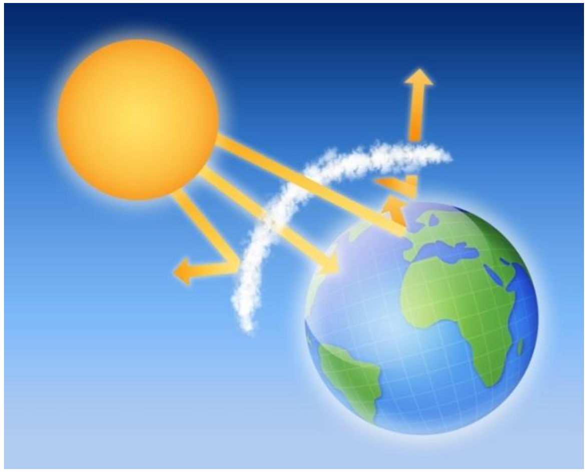
2.4 – Do you want to reduce greenhouse gas emissions?

Uncontrolled AD in landfills and waste dumps releases greenhouse gas emissions including methane and carbon dioxide.

Controlled AD systems can capture methane for use as a valuable renewable fuel.

Capturing the biogas reduces GHG in two ways:

- through preventing uncontrolled methane emissions
- by generating energy that displaces the use of fossil fuels



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2.5 – Is AD suitable for you?

- Do you want to improve the management of your waste?
- Do you have a suitable feedstock for AD?
- Do you have a use for renewable energy or fuel?
- Do you want to reduce greenhouse gas emissions?

If you answered yes to one or more of the above questions...

AD MAY BE FOR YOU!

The following sections provide more details about AD for MSW…

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2.6 – Overview of International AD Projects

- Europe:
  - Over the past 25 years, hundreds of AD applications for MSW have been constructed due to waste disposal policies and high landfill tipping fees.
- Canada and United States:
  - Several plants developed or in development ranging from 25,000 tonnes per annum (TPA) to 130,000 TPA.
- Household AD plants are common in rural areas of India and China.
- Projects have also been built in Japan and Australia.

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3.0 – Step-by-Step Guide

Scale and logistics	• How large does the plant need to be and how will feedstock be transported and delivered?
Feedstocks	• Where will the feedstock come from and what is its composition?
Process technologies	• What equipment and process technologies do I need?
Outputs	• What will the digestate and biogas be used for?
Operational requirements	• What expertise and staffing are needed to build and run an AD plant?
Affordability	• What are key costs and potential revenue streams?
Environmental issues	• What environmental issues do I need to consider?
Partnership and stakeholders	• What partnerships might be beneficial for the project?

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3.1 – Stages of the AD Process

Hydrolysis

- Breakdown of complex insoluble organic matter into simple sugars, fatty acids and amino acids

Acidogenesis

- Further breakdown of simple sugars, fatty acids and amino acids into alcohols & volatile fatty acids (VFAs)

Acetogenesis

- Conversion of VFAs and alcohols into acetic acid, CO_2 and hydrogen

Methano-genesis

- Finally, the acetic acid and hydrogen is converted into methane and carbon dioxide by methanogenic bacteria

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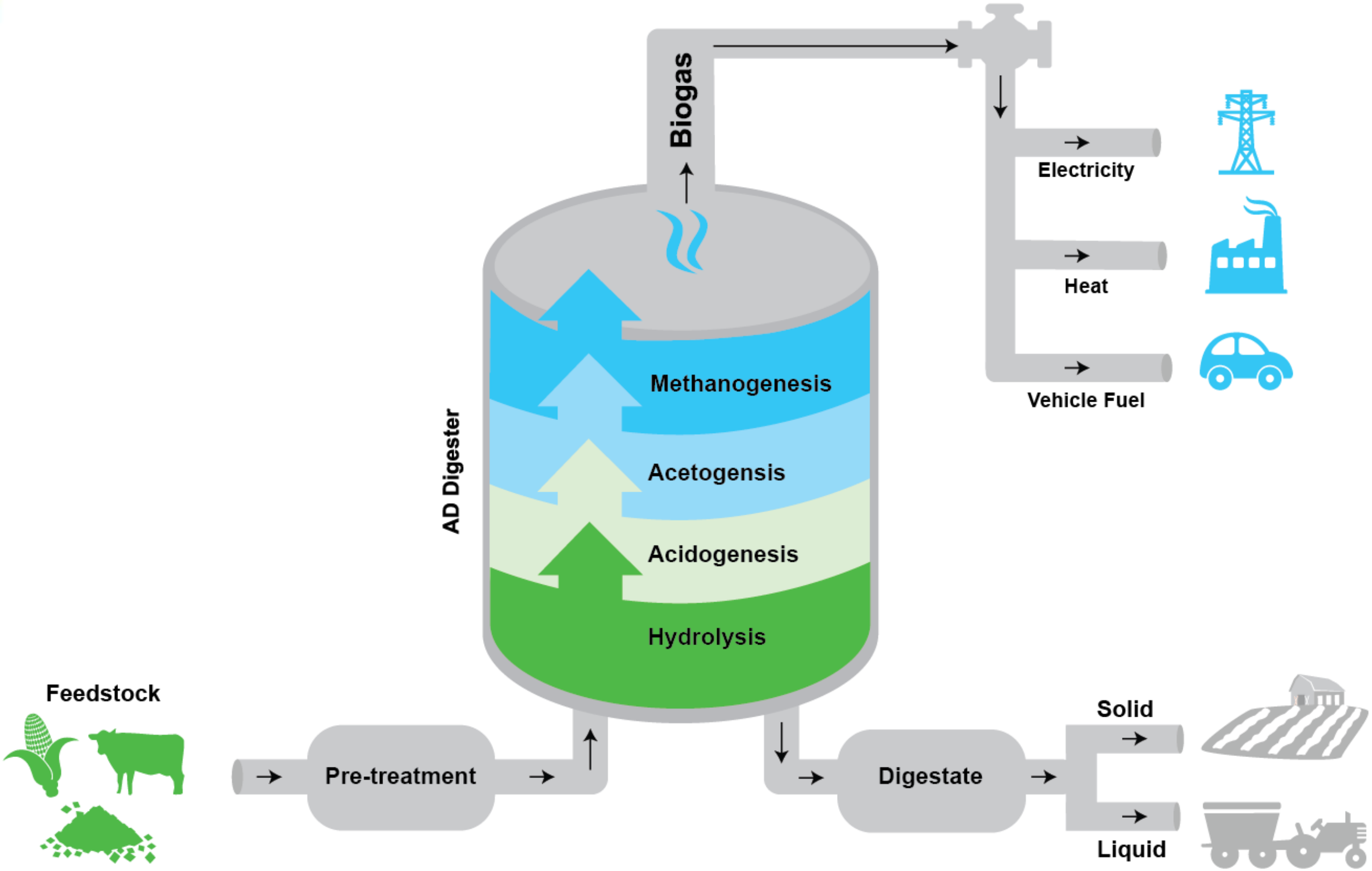
3.1.1 – AD Process



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3.1.2 – Scale and Logistics

The following slides provides an overview of plant scale and logistical issues, including:

- Small-scale versus large-scale or centralised, AD
- Finding an appropriate location
- Logistical issues to consider for inputs and outputs

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3.1.3 – Scale of AD

Size	Approximate tonnage	Approximate energy production	Typical Applications
Small	up to 7,500	25 – 250 kW(e)	Household or farm
Medium	7,500 – 30,000	250kW – 1MW(e)	Farm or manufacturing facilities producing digestible waste
Large	30,000 or more	>1 MW(e)	Centralized, mixed feedstock sources (municipal, commercial & industrial)

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3.1.4 – Differences Between AD Sizes

Small-Scale AD	Large-Scale AD
On-site waste management	Multiple sources of feedstock
Low to no transport cost	Feedstock delivered to site as a source of income
Rural locations	Centralised facilities
Can attract higher subsidies	Subsidies may be available
Can offer simple design and maintenance	More complex design and maintenance

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3.1.5 – Household Digesters

The use of household digesters is not widespread; however, in rural parts of developing countries, anaerobic digesters provide a valuable source of cooking gas.

- In India and China, household scale digesters are common
- Feedstocks include animal, human and food waste

3.1.6 – Finding a Suitable Site

The location of an AD plant will be determined predominantly by feedstock availability, capacity and intended output use.

- Small-scale AD facilities are generally suitable for rural development areas (e.g., farms)
- Large-scale, centralised AD facilities are more suited to commercial/industrial urban areas
- Sites should be away from sensitive receptors (e.g., people and ecosystems)
- Facilities could be co-located with existing infrastructure (e.g., heat users, other waste treatment facilities)

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3.1.7 – Logistics of Input and Output Materials

You need to ensure you can transport and use your input and output materials:

- Is there a good existing transport network(s)? Are there low bridges that could impede trucks/lorries?
- Is there an existing grid connection for electricity and gas?
- Where are the feedstocks located?
- How will the digestate be managed?
- How will feedstocks and digestate be transported and unloaded?

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3.2 – Feedstocks

AD can treat a wide range of organic materials but it is important to understand the feedstock available for your digester.

Key issues to consider:

- Source – where is it coming from?
- Composition – what is it made of?
- Variability – how variable is it?
- Contaminants and rejects – will it contain contaminants that will harm the AD process?
- Storage – how will it be stored?
- Seasonal fluctuation - will the feedstock vary through the year?

Remember: the feedstock creates the biogas, not the digester!

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3.2.1 – Feedstock Source

Feedstocks are normally biodegradable wastes, but energy crops can also be used. Common sources include:

- Municipal, commercial and industrial food wastes
- Agricultural wastes (e.g., slurries, poultry litter and manure)
- Wastewater and sludges from industrial waste treatment
- Food/beverage processing waste
- Energy crops (e.g., maize, grass and silage)

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3.2.2 – Feedstock Composition

Feedstocks vary in composition and should be carefully selected:

- Variable composition
- Bacteria require nutrients

Composition includes:

- Dry solids (DS)
- Volatile solids (VS)
- C:N (carbon to nitrogen ratio)

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3.2.3 – Feedstock Contaminants

Contaminants can cause damage to AD equipment. Components not suitable for AD treatment plant include:

- Inorganic materials (e.g., glass, plastics, metals and sand)
- Wood wastes
- Bone from food wastes
- Soil
- Disinfectant, pesticides and antibiotics in feedstocks

3.2.4 – Storage of Feedstock

It is important to consider how and where you will store feedstock. Factors that determine storage include:

- Feedstock type
- Duration
- Quantity

3.3 – Process Technologies

The following slides provide an overview of the technology required for the process of AD:

- Pre-treatment
- Digestion processes
- Digestate storage
- Biogas storage
- Biogas clean-up / up-grading

Source: ZWEDC

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3.3.1 – Pre-treatment of Feedstock

Pre-treatment is necessary to ensure process efficiency, maximise product yield and reduce operation costs. It is used to remove non-biodegradable materials and homogenize the feedstock.

There are several different types of pre-treatment method:

- Physical: mechanical, thermal, ultrasound, electrochemical
- Chemical: alkali, acid, oxidative
- Biological: microbiological, enzymatic
- Combined process: extrusion, thermochemical

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3.3.2 – Pre-treatment of Feedstock

Pre-treatment can be a vital step in an AD process.

The requirements vary depending on the feedstock:

- Contaminants must be separated; for example, through screening, trommels and magnets
- The feedstock is usually macerated to create the right consistency
- A pasteurization stage may be required for certain feedstocks. Animal by-products legislation can vary for different countries

Pre-treatment can help prevent damage downstream

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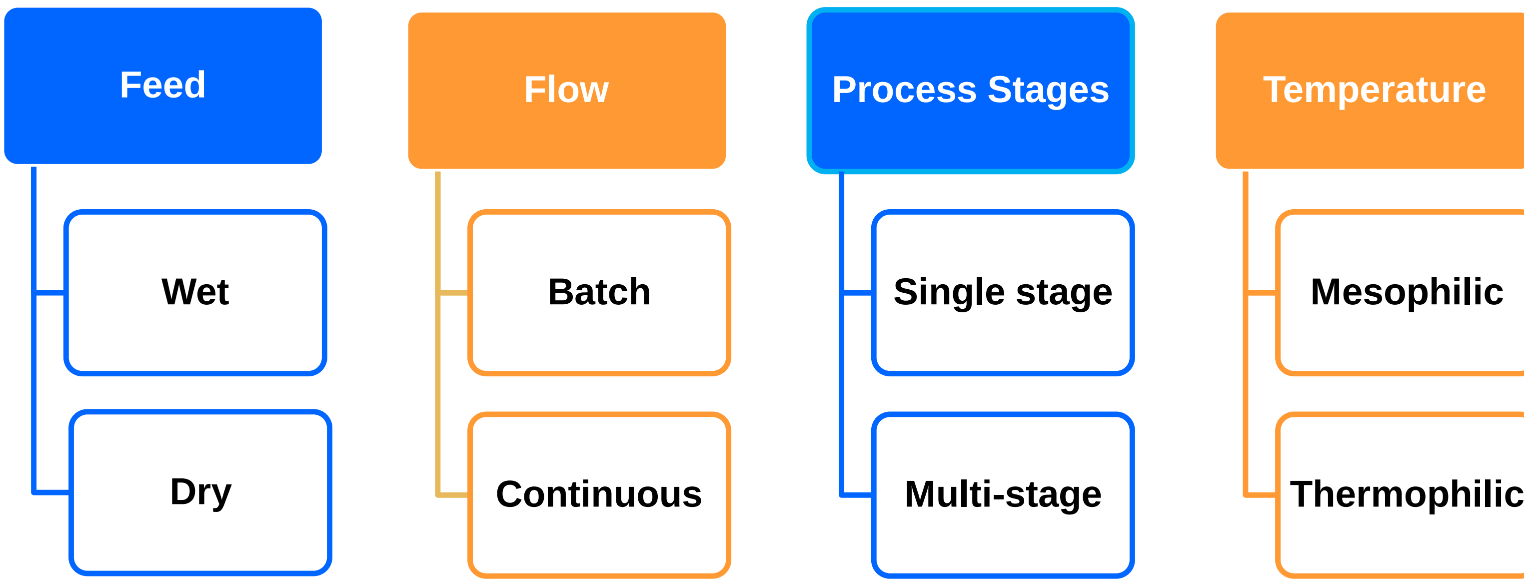
3.3.3 – Pre-treatment Requirements

Feedstock	Pre-treatments
Separated food waste	De-packaging may be required depending on contamination levels.
Manures / slurries	Minimal pre-treatment required, usually used with other feedstocks.
Commercial & industrial wastes	De-packaging is required to remove plastics and metals. Often highly contaminated so screening is also required. Effluents require minimal pre-treatment.
Energy crops	Screening to remove stones, cutting or shredded. Silage is usually pre-shredded.

3.3.4 – AD Process Characteristics

AD processes are characterized by the following:



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3.3.5 – Digestion Process: Feed

Wet

- <15% dry solids
- Waste is macerated prior to processing
- Examples include food waste, manure, slurry

Dry

- Higher dry solid content 15-40%
- No water addition
- Less mechanical treatment
- Examples include green wastes and energy crops

3.3.6 – Digestion Process: Flow

Batch

- The digestion process, or a stage of the digestion process, is allowed to start and finish in a single vessel.
- Once complete the vessel is emptied and the process is restarted with new feedstock.
- A series of vessels may be used to overcome peaks and troughs in flows of feedstock and gas production.

Continuous

- Feedstock flows through the plant continuously.
- Avoids the need to empty digesters and restart the process – a labour-intensive and time-consuming process.
- Biogas generation tends to be more consistent, although biogas generation rates may be lower than for batch processes.

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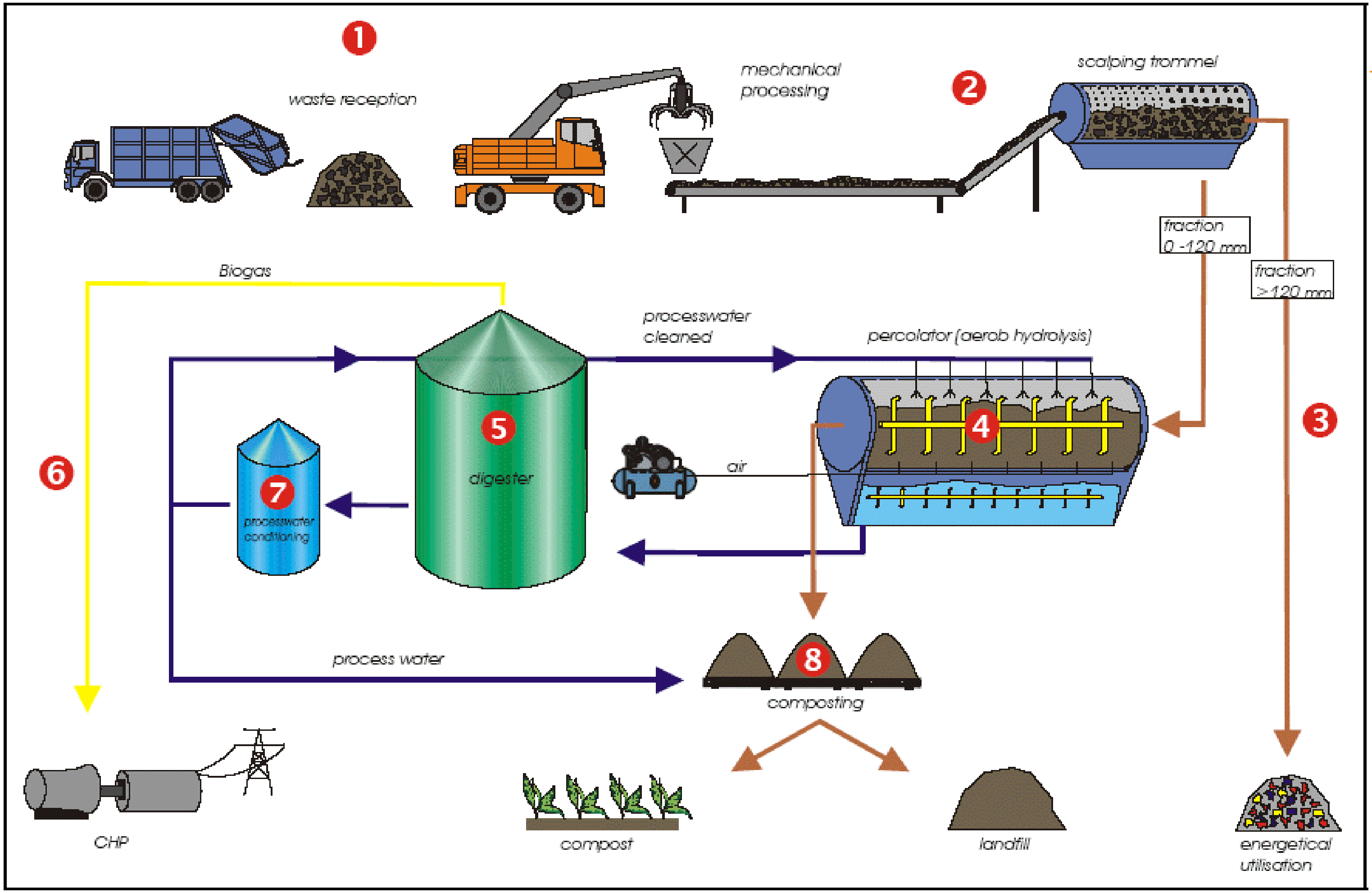
3.3.7 – AD Process Flow Example



3.3.8 – Digestion Process: Temperature

Mesophilic

- Operates at 30-40°C
- Stable process
- Suitable for slurries and industrial and commercial food wastes
- Most popular option in developed countries
- Retention time 15-30 days

Thermophilic

- Operates at 50-60°C
- More complex & less stable
- Suitable for a wider range of feedstocks
- More expensive due to higher energy input requirement
- Retention time of 12-14 days

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3.3.9 – Digestion Process: Process Stages

Single-stage process

- Digestion occurs in a single reactor
- The plant design is simpler and more economical
- Produces less biogas
- Feedstock takes longer to digest

Multi-stage process

- Two or more reactors to optimize process
- Helps to further degrade feedstock
- Extracts more biogas

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3.3.10 – Categories of AD Systems Used for Treating MSW

Low-solids (Wet, < 15% solids) OR High-solids (Dry, > 20% solids) ?

↓

Batch OR Continuous?

↓

Single-stage OR Multi-stage?

- All systems can be mesophilic (operated at 35°C) or thermophilic (operated at 55°C).
- Optimum technology depends on waste composition (e.g., solids content), co-product markets, and other case-specific variables.

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3.3.11 – Common Digester Types for Treating MSW

Digester type	Typical Scale	Typical Feedstock
Continuous, flow solids, single-stage	Large and small	Slurries, effluents (e.g., from the dairy processing)
Continuous, high solids, single-stage	Large	Green waste, food waste
Continuous, low solids, multi-stage	Large	Food waste
Batch, low solids, single-stage	Small	Slurries, effluents, food wastes

3.3.12 – Digester Types: Continuous, low-solids, single-stage

- **Advantages**
  - Simple to design and operate as compared to multi-stage processes
  - Less expensive than multi-stage technologies
- **Disadvantages**
  - Requires low organic loading rate (OLR) because methanogens can easily be disrupted
  - Longer contact times required
  - MSW slurries can separate and a scum layer can form that disrupts microbial degradation and clog pipes and pumps
  - Pretreatment to remove inert solids and homogenize waste is required
  - Waste dilution with process water can lead to buildup of inhibitors
  - If toxic compounds are present in MSW, they can readily diffuse throughout the reactor and shock microorganisms, including sensitive methanogens

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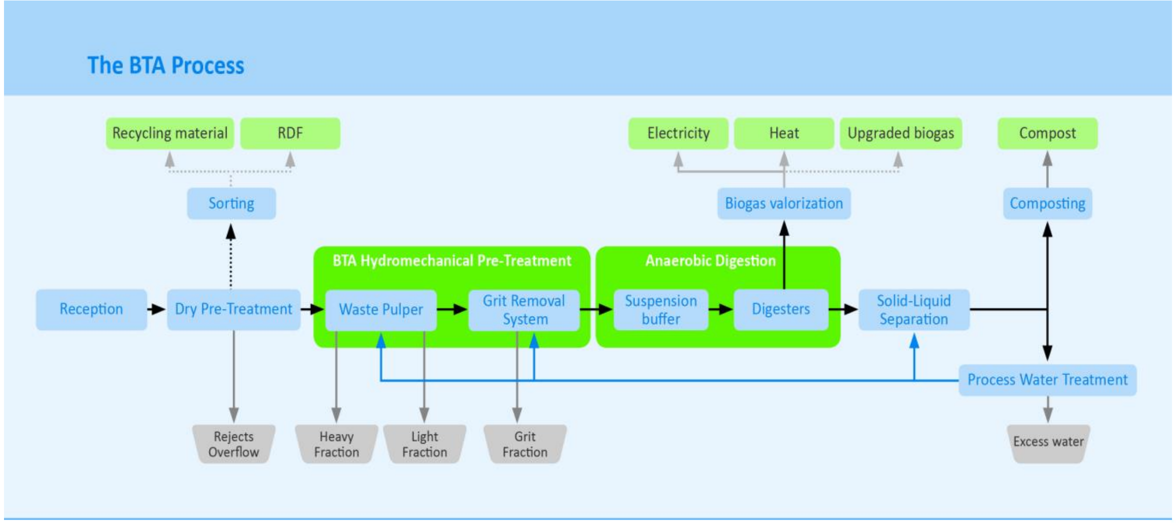
3.3.13 – Example: BTA Process (Continuous, low-solids, single-stage)

- Project: Toronto Disco Road (Ref: 2)
- Country: Canada
- Type of Waste: Source Segregated Organics (SSO)
- Capacity: 75,000 tons/year



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3.3.14 – Digester Types: Continuous, low-solids, multi-stage

- **Advantages**
  - Each type of microorganism has different optimal conditions, can optimize processes separately
  - Fermenters prefer lower pH
  - Methanogens prefer 7-8.5
  - Dilute to raise pH prior to methanogenesis
  - Can incorporate high-rate methanogenesis technologies
  - Up-flow anaerobic sludge blankets
  - Fixed-film reactors
  - Higher OLR
  - Higher methane production rates
- **Disadvantages**
  - Higher capital costs

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3.3.15 – Example: Schwarting (Continuous, low-solids, multi-stage)

- Location: Ulsan, South Korea (Ref: 3)
- Feedstock: 70 m³/day liquid food waste & 30 m³/day pig manure
- Digester volume: 2 units x 330 m³ each
- Biogas: 300 m³/hour

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3.3.16 – Digester Types: Continuous, high-solids, single-stage

- **Advantages**
  - Biogas generation rates comparable to or greater than wet systems
  - Dilution water often not required
  - High OLR: ~10 grams/liter/day (Dranco), depends on VS content
  - Lower diffusion rate prevents toxic compounds from impacting microbes throughout reactor systems are more robust
  - Minimal pretreatment requirements – removal of large materials (> 5 cm)
  - Systems more tolerant of contaminants (rocks, glass, plastics, metals, wood, etc.) and contaminants can be removed after digestion
- **Disadvantages**
  - Handling, mixing and pumping of waste are challenging
  - Heavy duty pumps, augers and conveyors are required to handle waste, which can be expensive
  - Higher capital costs
  - Impacted by general disadvantages of single-stage systems

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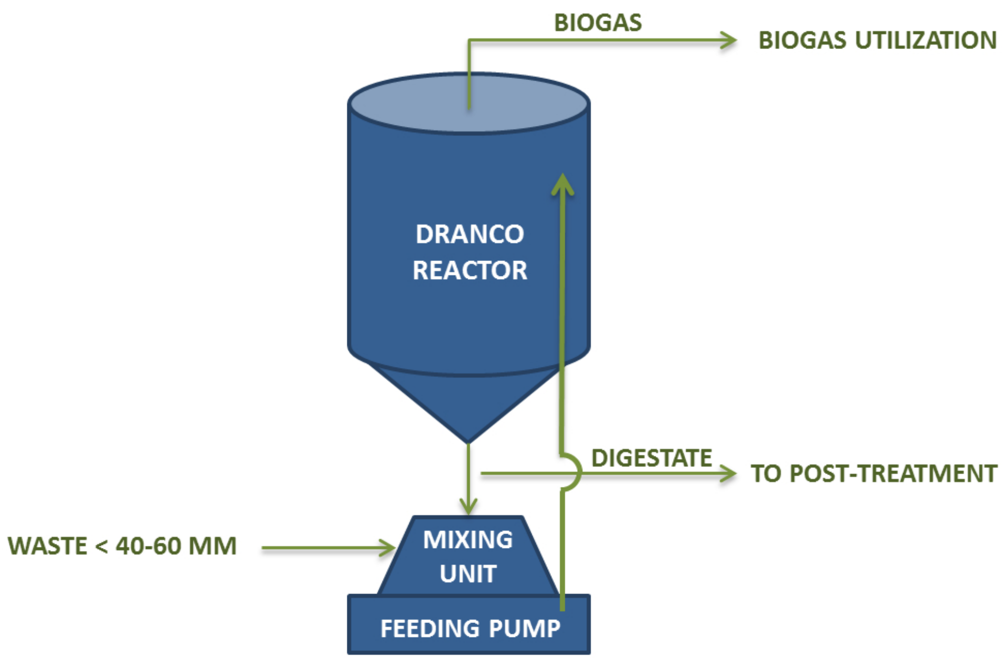
3.3.17 – Example: Dranco System (Continuous, high-solids, single-stage)

- Location: Mirandela, Portugal (Ref: 4)
- Plant capacity: 55,000 tons per year
- Digestion capacity:10,000 tons per year
- Waste type: mixed waste
- Reactor volume: 750 m^3



3.3.18 – Digester types: Batch system, low-solids, single-stage

- **Advantages**
  - Simple to build, low capital investment
  - Low water input
  - Could be used to separate other useful products (organic acids)
  - Can also be used for hydrolysis stage in multi-stage processes
- **Disadvantages** (when used for single-stage processes)
  - Uneven biogas production
    - Lag phase
  - Lack of stability
  - Typically larger footprint than continuous, dry digestion systems
    - Footprint is a function of reactor height and retention time selected

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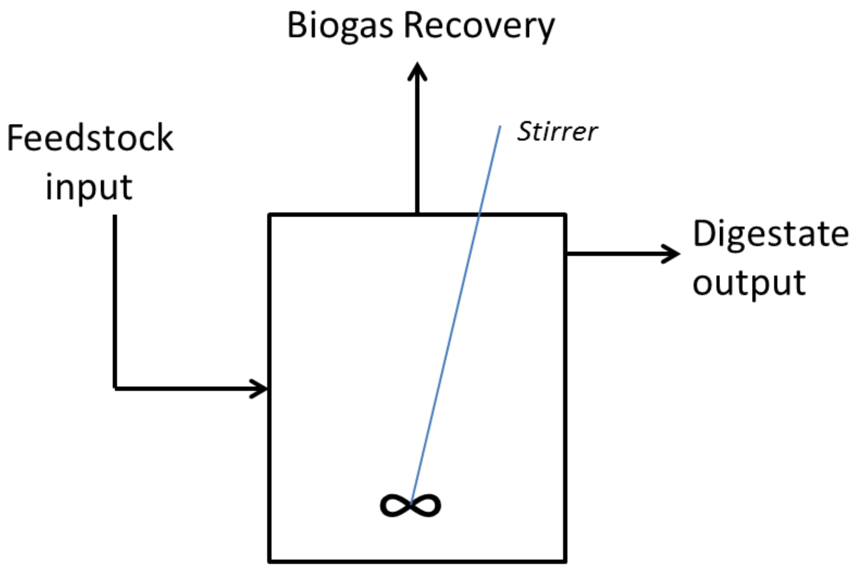
3.3.19 - Example:
(Batch, low solids, single stage)

- Example to be inserted

3.3.20 – Common digestion process technologies for MSW

Continuously Stirred Tank Reactor (CSTR)

- Common, proven
- Large reactor with mechanical stirrer
- Ideal waste solid content between 5-10%



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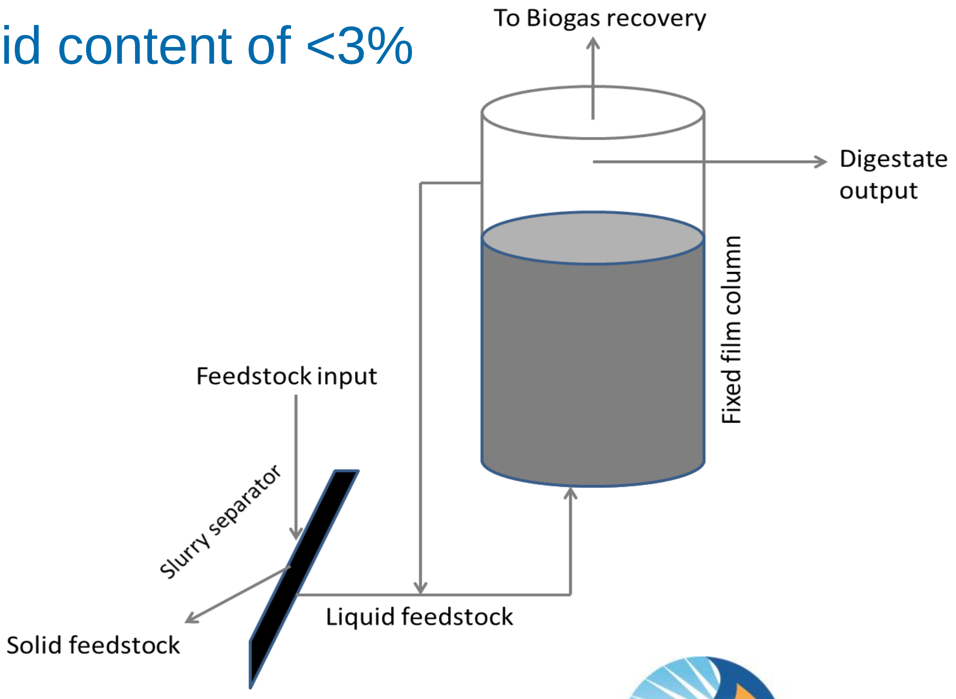
3.3.21 – Common digestion process technologies for MSW (continued)

Fixed film digester

- Bacteria are colonised on a fixed column packed with media (e.g., PVC rings, wood chips)
- Typical waste solid content of <3%



3.3.22 – Co-digesting MSW with Other Wastes

- Simultaneous anaerobic digestion of multiple organic wastes in one digester
- Can increase methane production
- Common to co-digest agricultural waste with food waste and energy crops
- Possible to co-digest wastes in water treatment plants
- Feedstocks must be compatible

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3.3.23 – Example: East Bay Wastewater Treatment Plant (Co-digestion)

- East Bay Municipal Utility District (EBMUD) wastewater treatment plant in Oakland, California (USA) treats wastewater from 7 cities
- Food waste, fats, oils and grease are co-digested with primary and secondary wastewater solids
- 120 tonnes/day food waste, 910,000 liters/day food processing waste, and 2.6 million liters/day municipal sludge
- Total capacity: 11 MW
- In 2010 the facility produced 90% of electricity needs from biogas
- Approximately $3 million saved in energy costs (Ref: 5)

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3.3.24 – Process Monitoring

What should you monitor?

- pH
- Carbon : Nitrogen
- Methane (CH_4)
- Volatile Fatty Acids
- Alkalinity
- Ammonia concentration
- Trace elements
- Retention time

Monitoring is vital!

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3.4 – Outputs: Biogas and Digestate

The process of AD breaks down organic matter to release a methane rich gas known as biogas. The remaining organic matter is a valuable biofertilizer known as digestate.

3.4.1 – Biogas

Biogas is the term used for the methane-rich gas produced from AD:

- Typically 50-75% CH_4, 25-50% CO_2 and trace gases
- Can be used as a fuel, similar to natural gas
- Energy comes from the methane content
- Has a calorific value (CV) of 21 MJ/m^3
- Methane has a CV of 38 MJ/m^3
- Biogas yield and composition is dependent on feedstock used

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3.4.2 – Biogas Composition

Compound	Range
Methane	50 – 75%
Carbon dioxide	25 – 50%
Nitrogen	0 – 10%
Hydrogen	1 – 5 %
Oxygen	0.1 – 2%
Water vapour	0 – 10 %
Hydrogen sulphide	10 – 30,000 ppm
Ammonia	0.01 – 2.5 mg/m^3

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3.4.3 – Typical Biogas Yields

Feedstock	Biogas Yield (m^3/tonne)
Mixed food waste	75 - 200
Cattle slurry	15 - 25
Pig slurry	15 - 25
Poultry litter	30 - 100
Grass silage	160 - 200
Maize silage	200 - 220
Maize grain	560
Crude glycerine	580 - 1000
Fats	up to 1200

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3.4.4 – Biogas Storage

- Biogas produced from the AD process is collected and stored to manage fluctuations in the production and consumption rates.
- Biogas can be stored in the digestion tanks in headspace or in a separate storage vessel at low pressure.
- Once upgraded to biomethane, the gas is pressurized for use.

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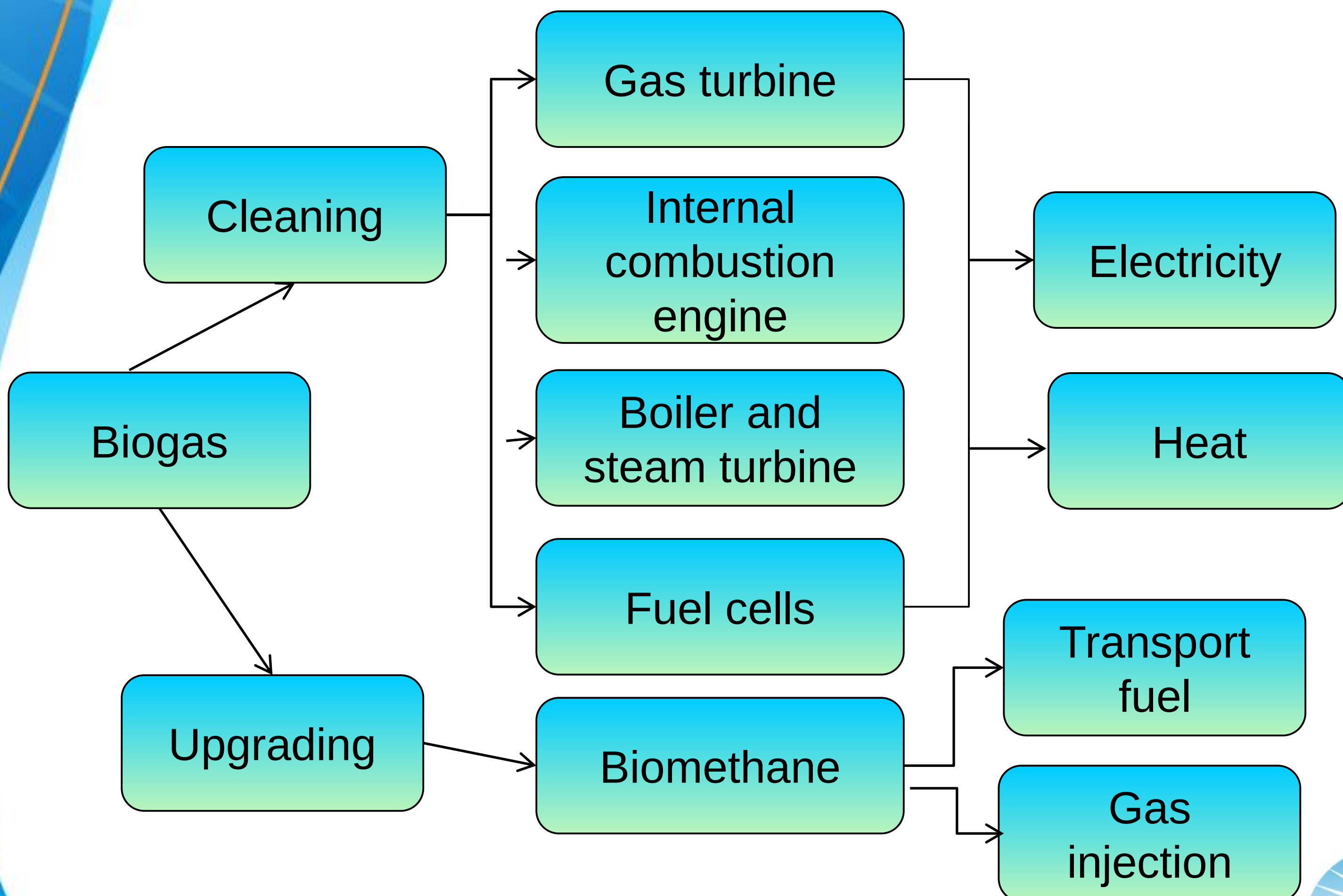
3.4.5 – Biogas Utilization



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3.4.6 – Biogas Utilization

Biogas can be used to produce **electricity, heat and cooling:**

- Biogas can be burned directly; however, impurities can cause maintenance issues
- Without removal, H_2S and water can cause maintenance issues such as corrosion and effect efficiency

Direct use in boilers in place of fossil fuels (end user located no more than 5-10 km)

Upgraded to biomethane:

- for use as a natural gas substitute
- injected into a gas network for heating and cooking
- for use as a transport fuel

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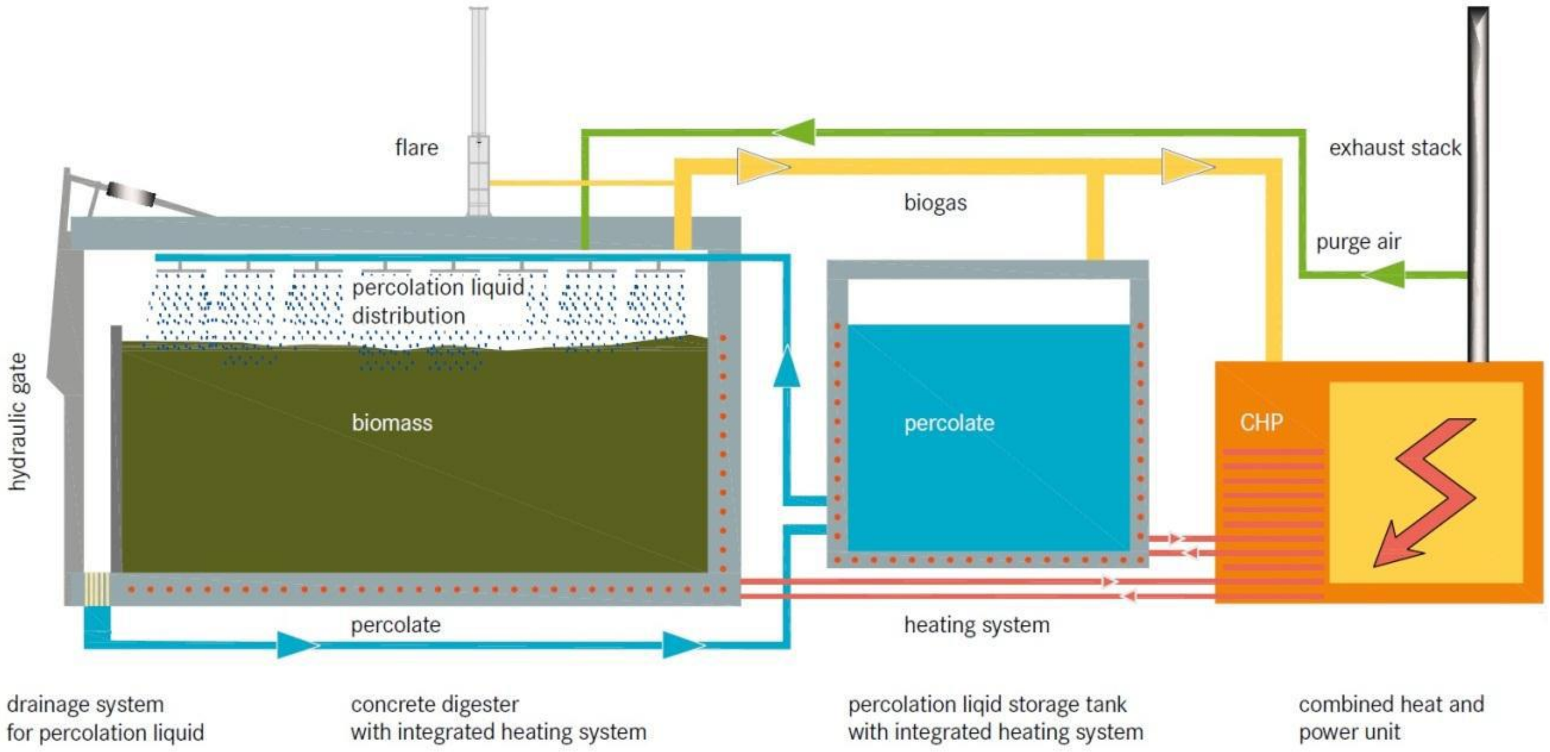
3.4.7 – Biogas CHP Application



3.4.8 – Electricity Generation

Qingdao Jiaonan Green Investment Environmental Protection Co. in Qingdao City, China:

- Processes 216,000 tonnes of MSW per year (600 tonnes per day), generating 6.2 MW of electricity
- Expected to avoid over 90,000 tonnes CO_2e emissions per year
- Project cost = 162 million RMB ($26.5 million)
- Estimated 10% IRR including CDM revenues (5% IRR without CDM revenues)


· Bird's-eye view of the plant ·

Source: Beijing Fairyland Environmental Technology Co.

3.4.9 – Biogas Cleaning and Upgrading

Depending on the intended use of the biogas it may be cleaned or upgraded: organics (siloxane), water and CO_2 removed; H_2S reduced to ~5 ppm. Techniques include:

- Biological desulphurization
- Oxidation (dry and liquid phase)
- Physical absorption
- Water scrubbing
- Chemical absorption
- Pressure swing adsorption
- Membrane separation

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3.4.10 – Biogas to Vehicle Fuel

St. Landry Parish Landfill in Louisiana (USA):

- Converts 85 m^3/hr LFG into 950 liters of gasoline equivalent/day of CNG
- CNG fuels government vehicles including local sheriff department cars, light duty trucks, and solid waste district utility trucks
- Self-developed with help from several contractors

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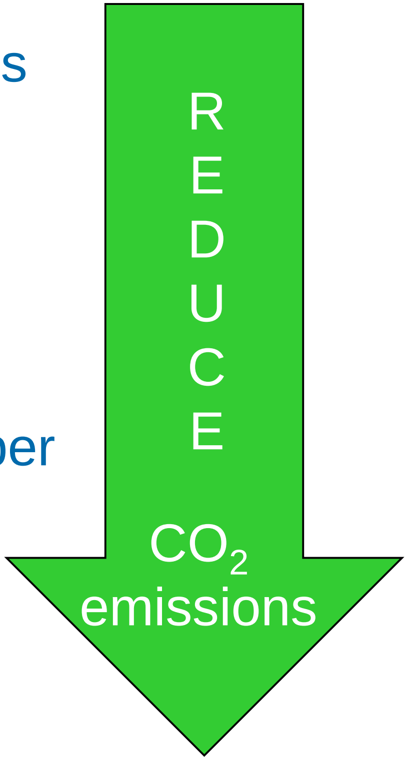
3.4.11 – Biogas Carbon Savings

The following carbon savings can be achieved when substituting biogas for fossil fuels (savings per tonne of bio-waste processed, Ref. 6):

- Using biogas as a vehicle fuel saves **97 kgCO_2 equivalent** per tonne
- Using biogas for on-site combined heat and power (CHP) saves **86 kgCO2 equivalent** per tonne
- Pumping biogas straight to the gas grid saves of **85 kgCO_2 equivalent** per tonne
- Using biogas to produce electricity saves **62 kgCO_2 equivalent** per tonne



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3.4.12 – Digestate

Digestate is a valuable biofertilizer and has many benefits including:

- Source of nitrogen, phosphorous and potassium (NPK)
- Greater availability of nutrients for crop uptake
- Improves soil quality and structure
- Increases crop yields
- Can reduce odors
- Reduces reliance on chemicals = financial saving
- Reduced pathogens
- Potential income from sales

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3.4.13 – Digestate Storage

- Wet AD produces a liquid form of digestate while a dry AD produces a fibre-based digestate
- Storage of digestate depends on:
  - Market
  - Location
  - Soil type
  - National regulation on digestate application

- Solid digestate - easier to store and transport
- Storage can either be on an AD site or at the point of land application
- Storage facilities must comply with regulations

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3.4.14 – Digestate: Key Considerations

- Commonly used in agriculture
- Securing an outlet for digestate is important to avoid disposal
- How will digestate be transported (e.g., by tankers or pumped)?
- Restrictions on where and when digestate can be spread
- Sufficient storage is key!

Don't spread in wet conditions!

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3.4.15 – Digestate Fractions

Whole digestate:

- Typically 2 – 6 % dry solid content (wet system), 18 – 24 % (dry system)
- Nutrient content is dependent on the feedstocks used

Liquid fraction:

- Can be used as a liquid fertiliser and for irrigation
- Nutrients can be concentrated into the liquid fraction
- Can be pumped easily
- Used in irrigation systems

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3.4.16 – Digestate Fractions

Solid fraction:

- Improves soil structure
- Can be easier to transport in vehicles
- Stacked for storage, can be stored in fields

Implement a digestate management plan to maximize the benefits and improve your business case!

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3.4.17 – Digestate Fractions

Separation techniques include:

- Centrifuge
- Screw press
- Belt press
- Evaporation
- Bio-drying
- Membrane filtration

3.5 – Operational Requirements

The following slides provide an overview of operational considerations, including:

- Staffing levels and employment opportunities
- Maintenance requirements

3.5.1 – Staffing Levels

- Staff levels will depend on the scale and type of operation
- A small-scale batch flow plant may be operated by a single individual
- Large-scale plants typically have a site manager, operators to load waste, and maintenance staff

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3.5.2 – Employment Opportunities

A range of employment and training opportunities may be available throughout the development of an AD facility:

A variety of skill levels are required, including:

- construction (short term)
- labouring
- technical
- scientific
- maintenance engineers
- administrative staff

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3.5.3 – Maintenance Requirements

Some of the maintenance requirements of an AD facility include:

- General engine maintenance
- Grit removal
- Electrical, fuel, and air system inspection
- Inlet and outlet pump cleaning
- Valve and pipe leakage checks
- Mixing equipment servicing

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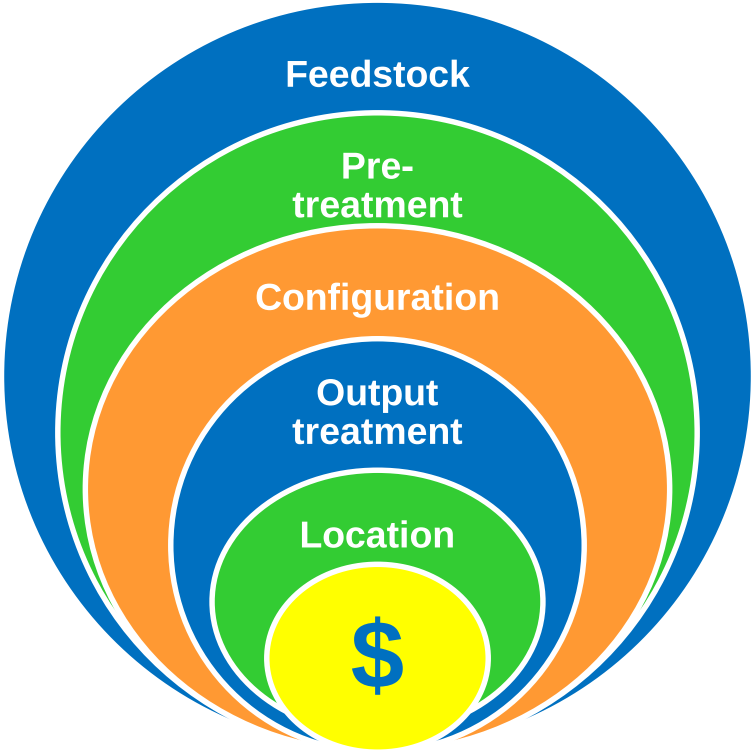
3.6 – Affordability

Costs are variable and specific to the project. As with many waste technologies, there are economies of scale. Costs are dependent on:



3.6.1 – Economic Considerations for AD Projects

- Accurately predicting costs and revenues remains challenging due to few projects operating in developing countries
  - Local factors vary (e.g., tipping fees, labor costs, site conditions)
- Costs to consider:
  - *Predevelopment:* siting, permitting, planning and design, and environmental impact assessment
  - *Construction:* infrastructure, buildings/reactors, equipment, and labor
  - *Operations:* maintenance, manager training, labor, materials, water and energy, wastewater disposal, solids disposal, and other fees
- Costs savings possible if incorporated with existing waste management facilities (e.g., co-located at a landfill)
- Economies of scale apply
- Maximizing all revenues is critical (energy, tipping fees, secondary products, and incentives)

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3.6.2 – Capital Costs (CAPEX)

A range of capital costs (CAPEX) are reported for different facility types and scales.

“Rules of thumb”:

- UK: an average cost of £4 million per MW
- USA: $600 per (short) ton of annual waste throughput capacity (Ref: 7)

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3.6.3 – Typical Technology Costs

	Capital	Operational
Thermophilic	$$$	$$$
Mesophilic	$	$
Wet	$	$$$
Dry	$$$	$
Continuous	$$$	$
Batch	$$$	$
Singe stage	$	$
Multi stage	$$$	$$$

$$$ = higher
$ = lower

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3.6.4 – Operational Expenses (OPEX)

As with capital costs, operational expenses (OPEX) are varied and depend on the scale, location, system configuration and product utilization. Typical costs include:

- Utilities
- Staff costs
- Effluent disposal
- Mobile plant hire / running costs (e.g., front loaders)
- Permit / licence fees
- Insurance
- Consumables
- Disposal of rejects
- Health & safety (e.g., signage)
- Facilities (office, telephone)
- Digestate transport costs
- Gas cleaning / upgrading
- Lifecycle – maintenance

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3.6.5 – Revenues

The revenue generated depends on the choice of feedstock and product utilization.

Potential revenue streams include:

- Gate fees
- Digestate sales
- Electricity and heat sales
- Further sources of income may be available through incentive schemes set up to support renewable energy

3.6.6 – Revenues

Gate fees

In some countries, waste producers such as municipalities and commercial and industrial producers may pay a gate fee to the AD facility for accepting and treating their waste.

Typical gate fees are:

- £40 - £60/ tonne in UK
- $50 - $60 / tonnes USA (Ref: 8)

Will you be able to charge a gate fee?
For how long?

Digestate

Digestate may be sold as a fertiliser and soil improver, generating a further source of income.

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3.6.7 – Revenues

Electricity and Heat

- Electricity can be sold to existing network operators or used via a local distribution system (private wire)
- Electricity is easy to transport through existing networks; no ‘user’ has to be identified; constant market if exported to a network; no marketing is required
- Heat can be used on site and can be sold to adjacent properties for space and water heating, cooling and manufacturing processes
- Heat is not transported as efficiently as electricity; district heating networks can be hard and expensive to retrofit

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3.6.8 – Revenues

Biomethane

- Biomethane can be used as a natural gas alternative for gas injection and as a transport fuel
- A study found that, compared to diesel vehicles, fuel costs (direct substitute) were 12.8% less; however, vehicles had higher capital costs (Ref: 9)
- Biomethane as a transport fuel can be an attractive option for fleet vehicles
- Similar to electricity and heat Feed-in-Tariffs (FiTs), other financial incentives may be available for biomethane such as the Renewable Transport Fuel Obligation Order and biomethane injection FiT in the UK

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3.6.9 – Financial Support

To support the growth of the AD industry and renewable energy, financial support may be available:

- Grants
- Loans
- Funding
- Incentive schemes (e.g., FiT)

Incentives are often critical for the economic feasibility of AD projects

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3.7 – Environmental Issues

- To operate an AD facility, environmental legislation must be considered
- An environmental permit(s) may be required from the relevant regulatory body
- An Environmental Permit sets out rules you must follow to prevent damage to the environment and human health

Contact the relevant regulatory body early to discuss your plans

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3.7.1 – Environmental Issues

Potential environmental impacts

- **Odor** – feedstocks can cause odorous emissions; these can be managed through an odor management plan and suitable control and abatement techniques (e.g., inside storage)
- **Water emissions** – run off from wastes stored outside, site must be bunded to prevent leaks in the event of tank failures
- **Bioaerosols** – can be emitted from storage areas
- **Air emissions** from burning biogas (compared to fossil fuels)
- **Proximity** to sensitive receptors
- Potential **litter** if waste is contaminated

3.7.2 – Environmental Issues

Potential environmental benefits

- Reduces reliance on fossil fuels
- Diverts waste from landfill
- Reduces GHG emissions
- Provides a valuable fertilizer / soil improver
- Reduces reliance on chemical fertilizers and associated production emissions
- Can reduce odor intensity of waste
- Reduces pathogens
- Reduces weed seeds

AD can provide many benefits if correctly designed and managed

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4.0 – Project Implementation: Partnerships and Stakeholders

Developing an AD project in partnership with relevant stakeholders can help ensure the success of the project:

- Feedstock producers – farmers, food manufacturers, local authorities/municipalities
- Landowners
- Local communities
- Energy companies
- Heat users – leisure centers, hospitals
- Investors – banks, private investors

Engage with stakeholders early and often!

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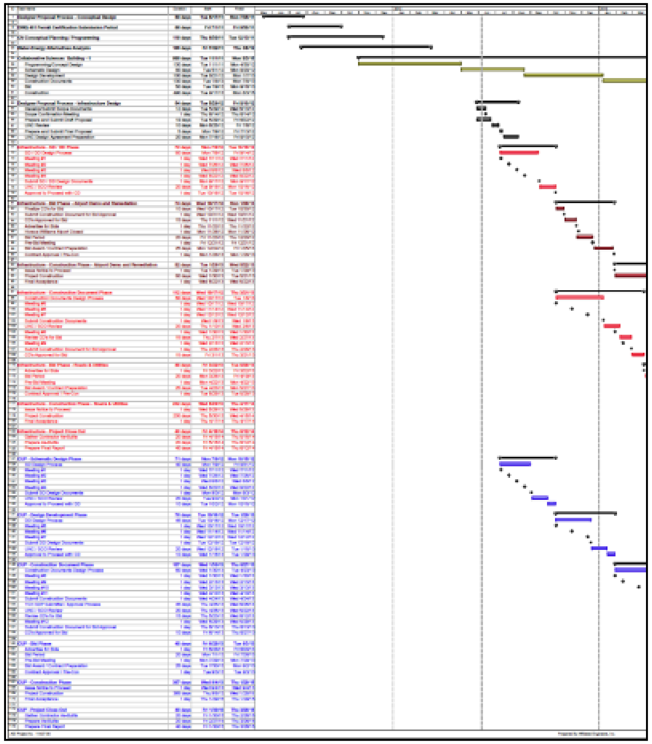
4.1 – Project Implementation

Typical timeframe for a large-scale AD plant:

- Scoping: ~2 months
- Project development: up to 12 months
  - full feasibility – 4 months
  - detailed design – 3 months
  - Planning and permitting – 3-6 months
- Construction: up to 12 months from mobilization
- Commissioning (hot / cold): up to 4 months



4.1.1 – Project Implementation

If you think AD is for you, complete a feasibility study to help you decide whether you should proceed. Here are just a few of the questions answered by a feasibility study:

- Do you have the right feedstock?
- How much will the project cost?
- How much biogas could the feedstock produce?
- How will you use the biogas?
- Do you have an outlet for the digestate?
- What is the potential revenue from biogas and digestate?

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4.1.2 – Project Implementation

Once you have completed a feasibility study, developing a business case will help secure investment. A business plan looks at:

Make sure it adds up!

- **Technical description**: feedstock, outline design, technology options, mass & energy balance, output markets
- **Technology option**: proven? reference plants?
- **Financial**: CAPEX, OPEX, cash flow, revenues
- **Project management**
- **Contract lengths, letters of support from locals / companies, feedstock providers**

A + B = ???

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5.0 – Things to Remember

- The feedstock creates the biogas, not the digester
- Secure your feedstock
- Feedstocks must be digestible
- Pre-treatment can help prevent damage downstream
- Monitoring is vital
- Digesters never stop operating – maintain!
- Digester performance is best compared on a volume of methane produced per gram of Biological Oxygen Demand (BOD)
- Biogas generation rates are more useful for evaluating financial viability

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5.1 – More Things to Remember!

- Maximize digestate storage (especially in wetter climates)
- Don’t spread digestate in wet conditions
- Implement a digestate management plan
- Life cycle analysis (LCA) has shown that AD is the most environmentally beneficial waste management option (Ref. 10)
- Consider whether you will be able to charge a gate fee
- Can you access financial support?
- Contact the relevant regulatory body early
- Engage with stakeholders early
- Make sure it all adds up!

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6.0 – Sources of Support for AD

Examples of potential sources of support for international AD projects:

- Global Environment Facility (GEF) http://www.thegef.org/gef/gef_projects_funding
- Green Climate fund http://www.gcfund.org/about-the-fund/mandate-and-governance.html
- UNFCCC http://unfccc.int/cooperation_and_support/financial_mechanism/adaptation_fund/items/3659.php
- Green Investment Bank http://www.greeninvestmentbank.com/investment-sectors/waste-and-bioenergy/

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8.0 – Abbreviations/Acronyms

- AD – Anaerobic Digestion
- BOD – Biological Oxygen Demand
- CAPEX – Capital Costs
- C:N – Carbon to Nitrogen Ratio
- CH_4 – Methane
- CNG – Compressed Natural Gas
- CV – Calorific Value
- CO_2 – Carbon Dioxide
- DS – Dry Solids
- EPA – U.S. Environmental Protection Agency
- FiTs – Feed-in-Tariffs
- GHG – Greenhouse Gas
- H_2S – Hydrogen Sulphide
- LCA – Life Cycle Analysis
- MJ/m^3 – Mega joule per cubic meter
- MSW – Municipal Solid Waste
- NPK – Nitrogen, Phosphorous and Potassium
- OFMSW – Organic Fraction of Municipal Solid Waste
- OLR – Organic loading rate
- OPEX – Operating Expenses
- SSO – Source Separated Organics
- TPA – Tonnes per annum
- VFA – Volatile fatty acids
- VS – Volatile solids

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