Introduction to Anaerobic Digestion Engineering Part 2

Michael Chesshire

University of Southampton
&
Evergreen Gas Ltd

UNIVERSITY OF Southampton

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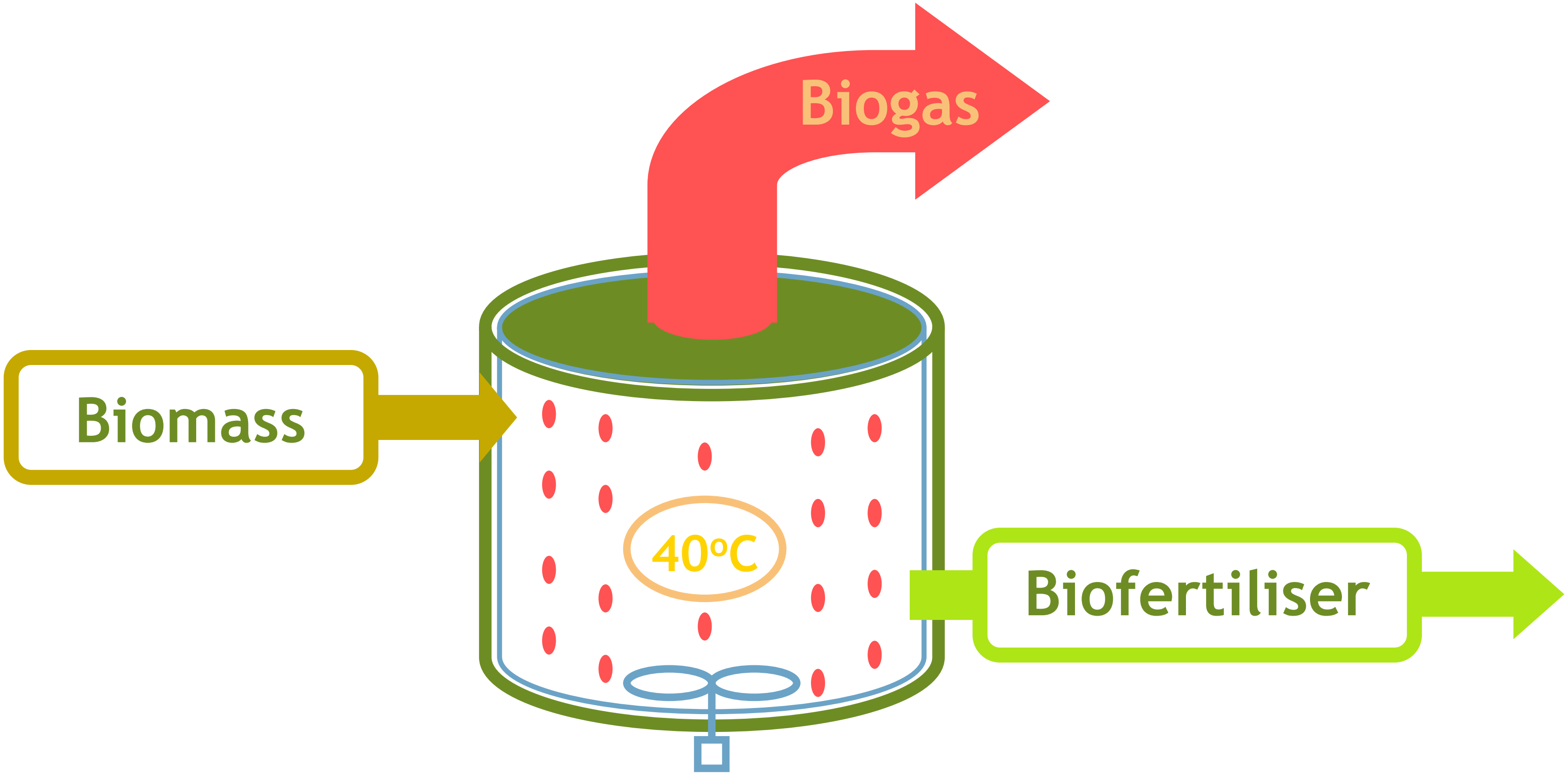
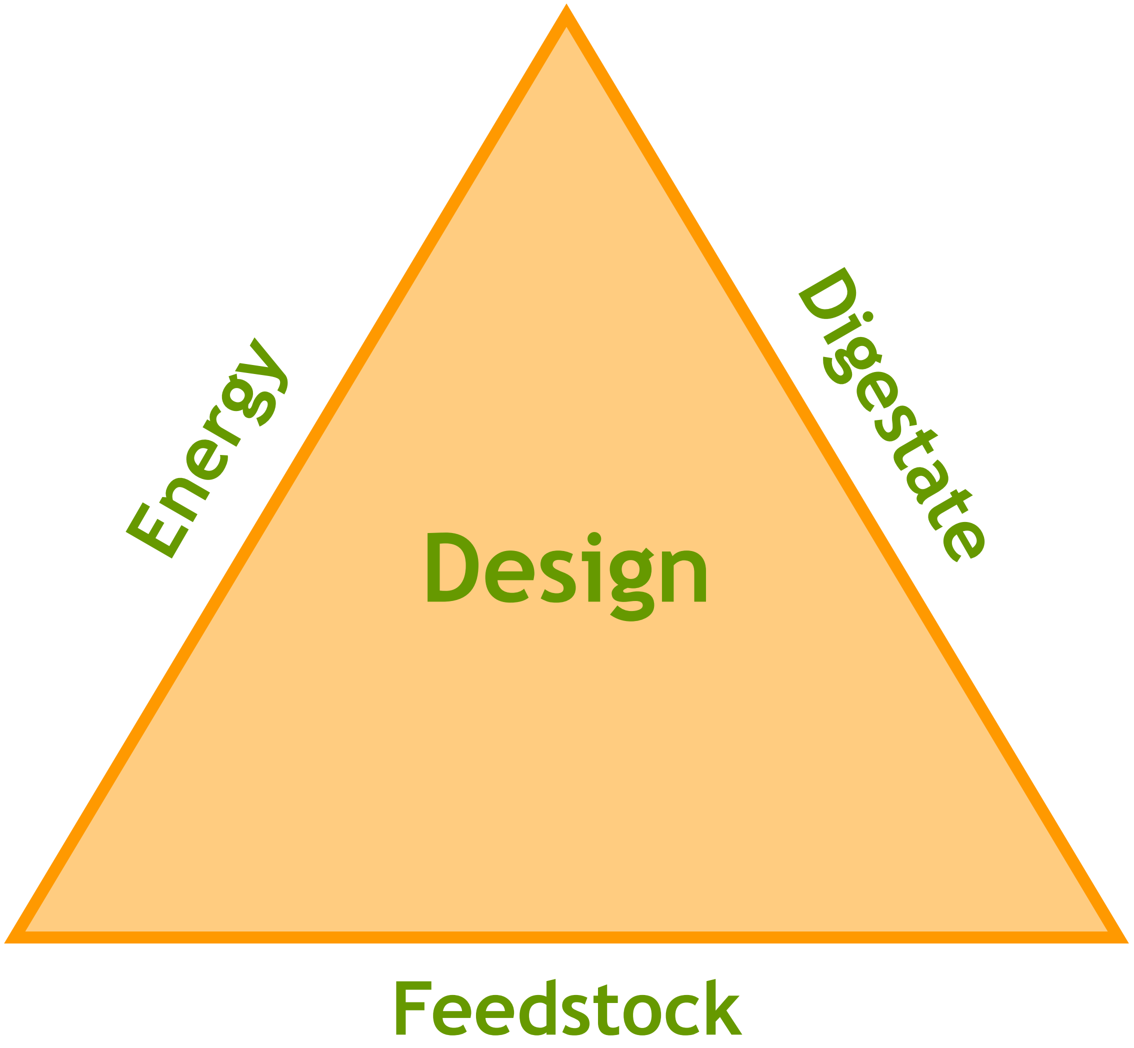
EvergreenGas

Anaerobic digestion - a natural biological process



AD Engineering

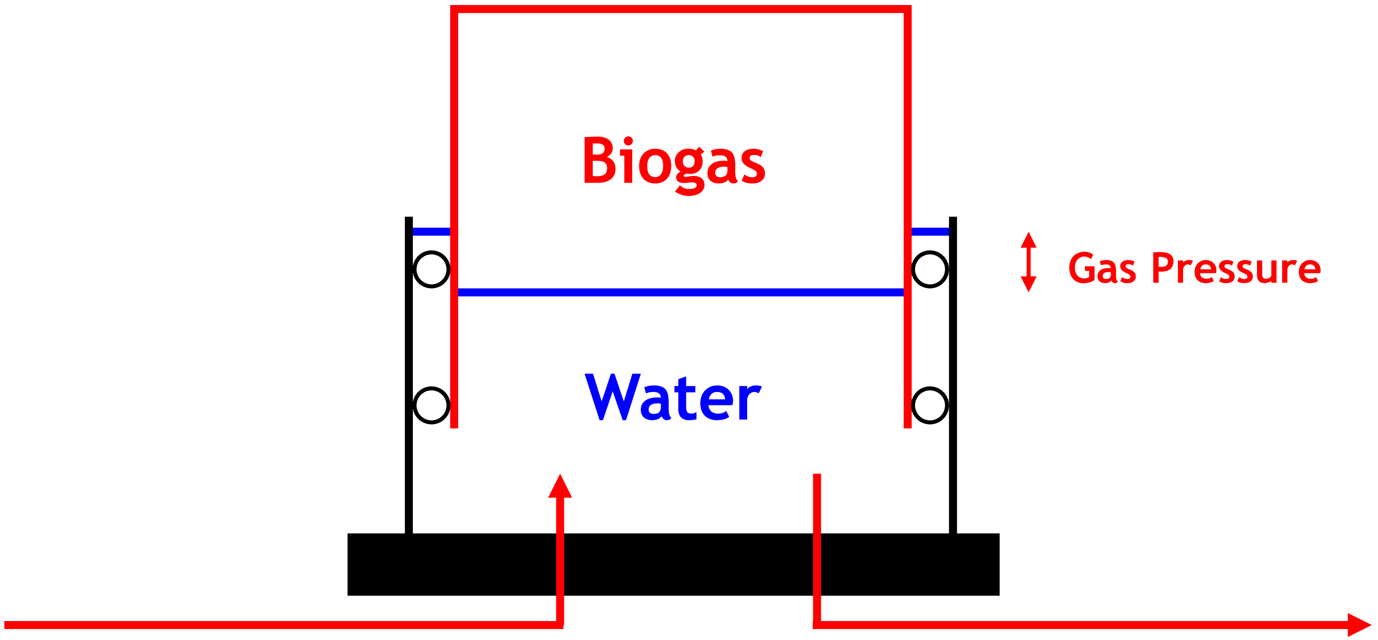
- Part 1a
- Reactor types and sizing.
- Part 1b
- Plant components – mixing, heating, feeding, etc..
- Part 2
- Gas storage & energy conversion
- Mass balance
- Energy balance


Energy
Digestate
Design
Feedstock

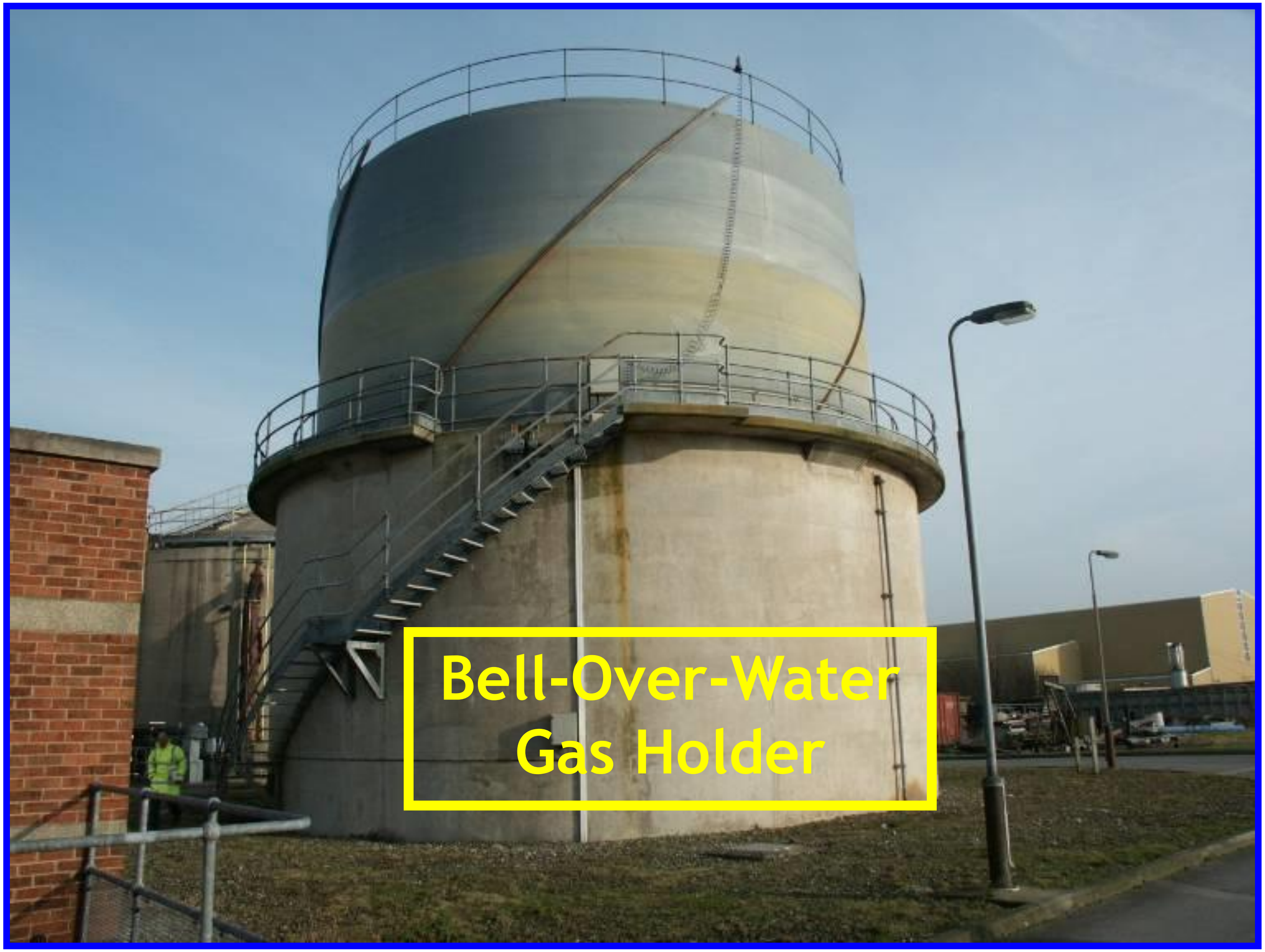
Biogas Storage

- Biogas is produced continuously and is either collected in a flexible membrane which is integral to the digester or is piped to a separate biogas holder, which can be of the double-membrane type or a bell-over water type.
- At atmospheric pressure 1 m3 of biogas is equivalent to about 0.6 litres of fuel oil; long term storage is therefore not practical.
- A commercial plant will have only a few hours of storage.

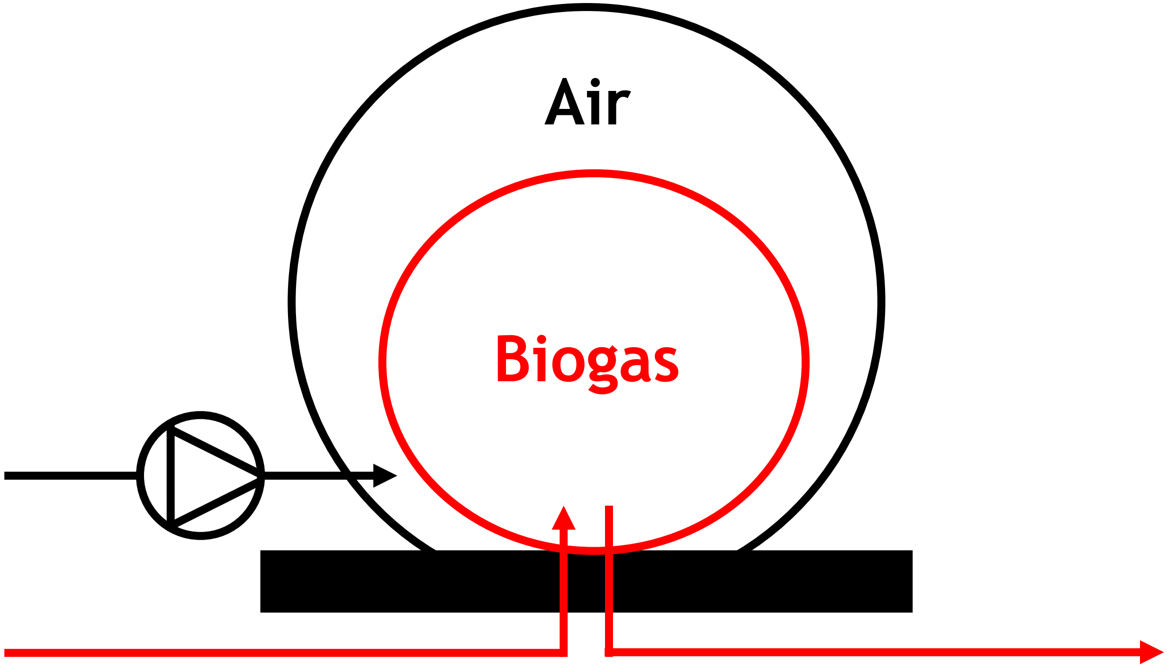
Bell-Over-Water Gas Holder



The gas bell floats on a tank of water guided by rollers. The gas pressure is determined by the weight of the bell and the internal area. The difference between the water level inside & outside is equal to the gas pressure.


Bell-Over-Water
Gas Holder

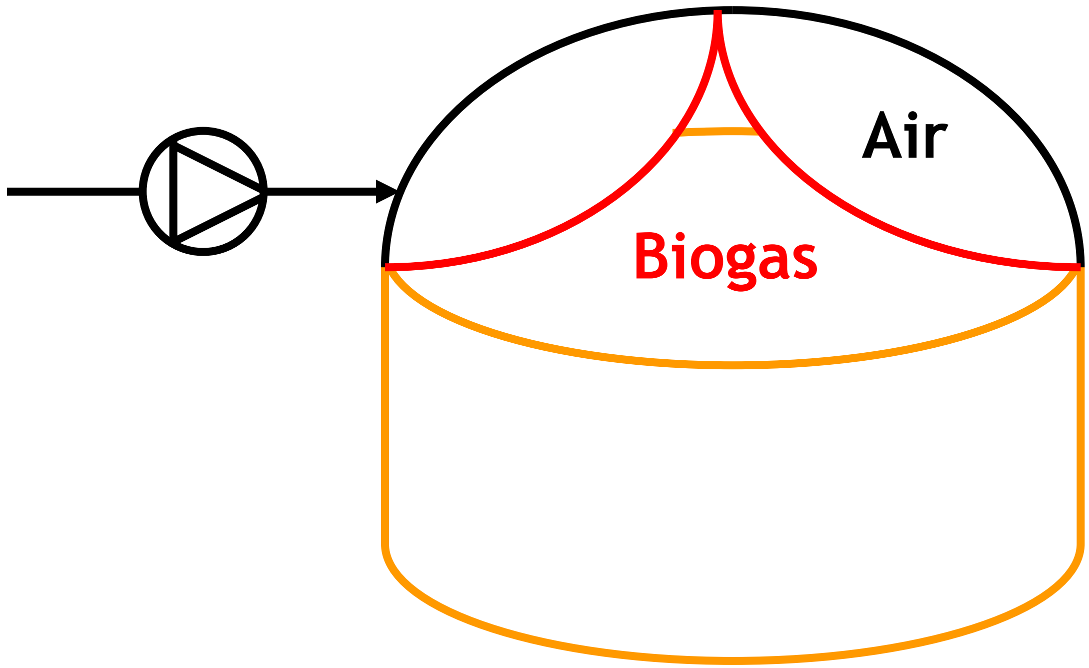
Double-Membrane Gas Holder



The air space between the two membranes is kept under a pressure of 100 to 200 mm water gauge by an air blower. The inner membrane expands and contracts under constant pressure to allow for variations in gas production and gas utilisation.


Double-Membrane
Gas Holder

Double-Membrane Digester Roof



A very common digester design is to combine a double-membrane gas holder with the digester roof.


Double-Membrane
Digester Roof

Biogas Utilisation

Biogas comprises about 60% CH_4, 40% CO_2 with some H_2S, normally 100 to 1000 ppm.

The stoichiometric combustion of 1 m3 of biogas @ 60% CH_4, 40% CO_2 & 1000 ppm H_2S is:-

600 litre CH_4 + 400 litre CO_2 +1 litre H_2S + 1201.5 litre O_2

→

1000 litre CO_2 +1201 litre H_2O* + 1 litre SO_2 + <u>21.4MJ</u>.

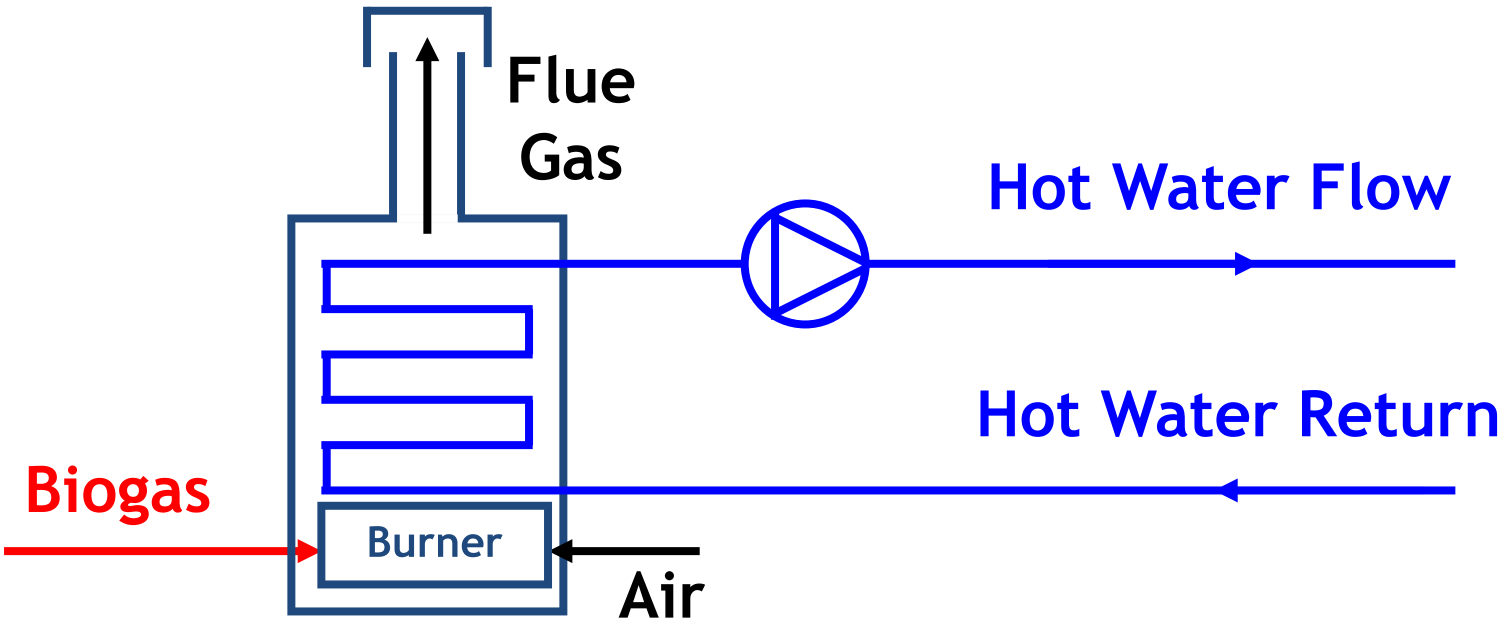
(* H_2O as steam)

Biogas can be used as the fuel for:-

- Cooking;
- Gas boiler for hot water or steam;
- Gas engine to drive a generator;
- Injection into the gas grid; or
- Vehicle fuel.

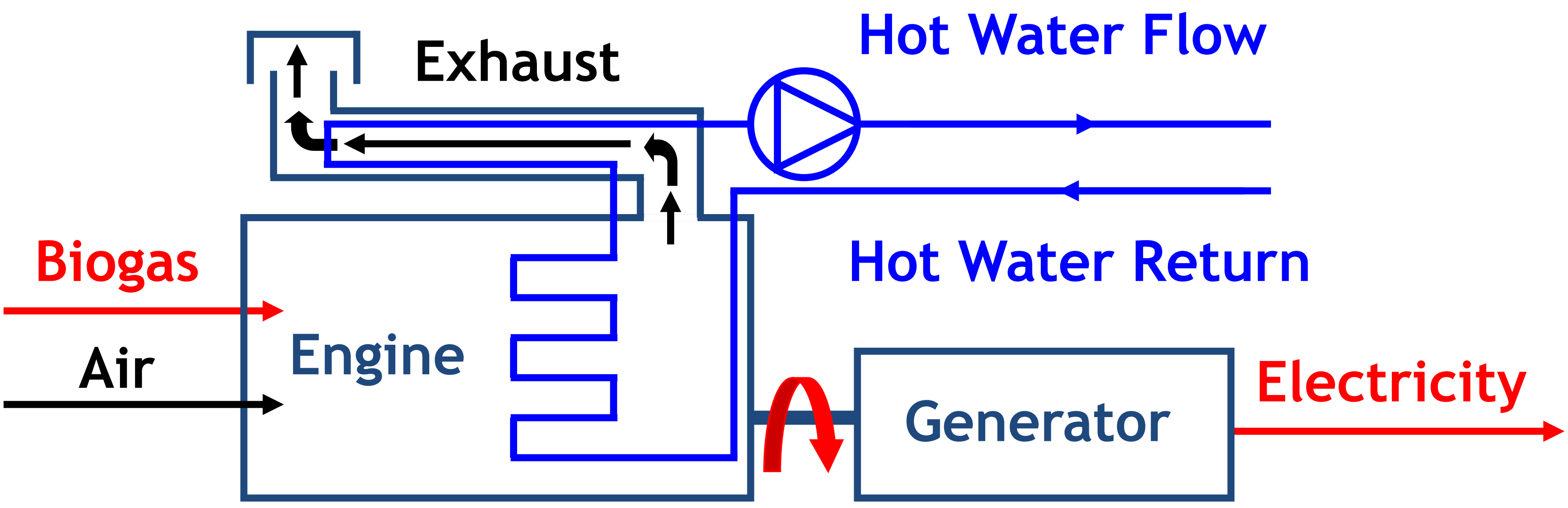

Biogas Stove

Biogas Boiler



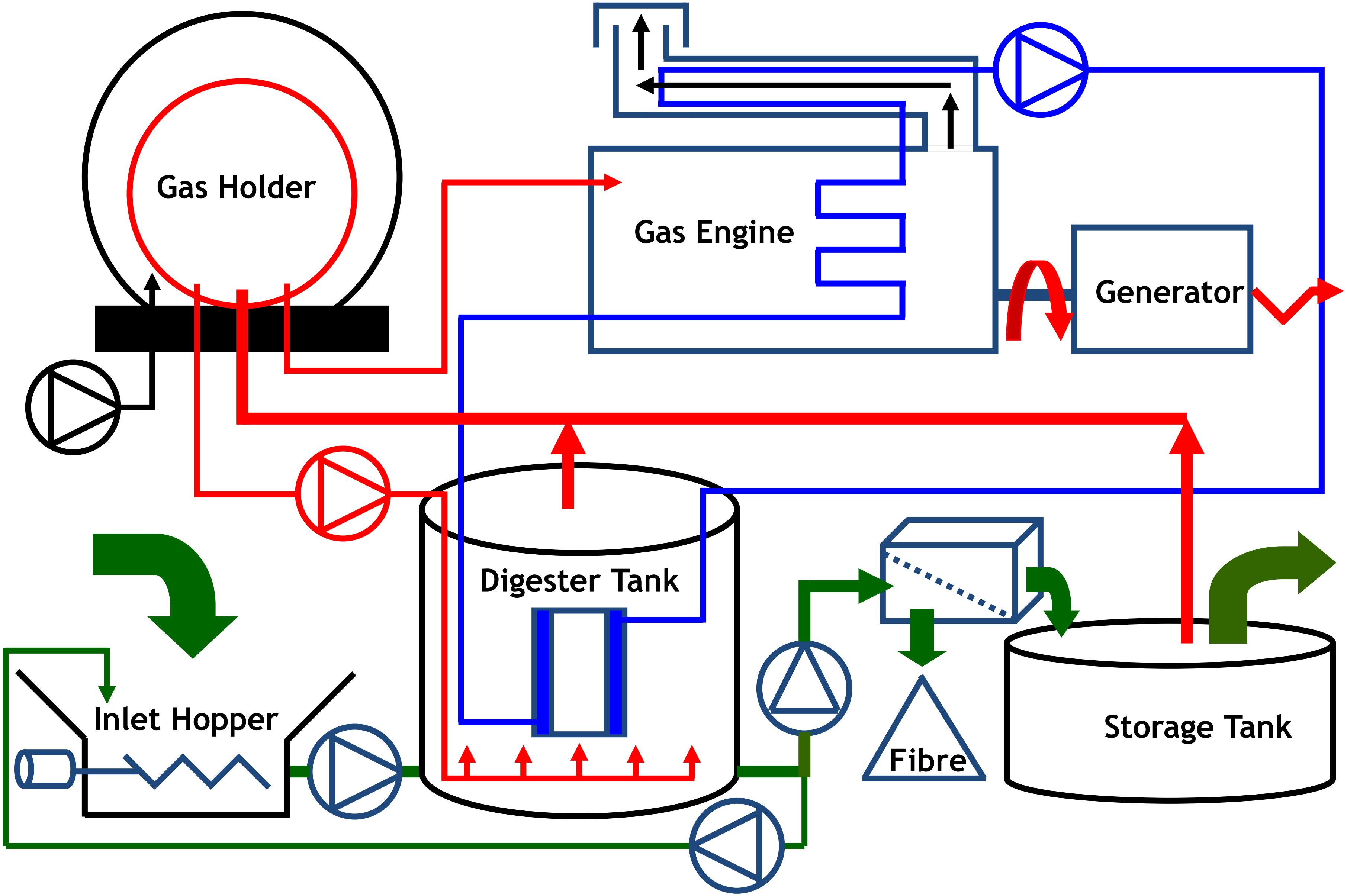
Gas boilers may be either atmospheric or pressurised burner type. Hot water is produced at an efficiency of about 85% with the rest of the energy as radiant heat and flue heat.

Combined Heat & Power Unit



Biogas is piped to an engine which is either spark-ignition or dual fuel (with a fuel oil pilot). Heat is recovered from the engine jacket, the oil cooler and from the exhaust gas. Electricity conversion efficiencies vary from 25% to 42%, and 43% to 60% of the energy value of the biogas is converted to heat.


CHP Unit


Gas Holder
Gas Engine
Generator
Digester Tank
Inlet Hopper
Fibre
Storage Tank

Process Calculations

- Feedstock Parameters
- Digester Sizing
- Energy Balance
- Mass Balance

Key Feedstock Parameters

- Mass – $tonne.d^{-1}$
- Dry Matter - %DM
- Organic Dry Matter - %ODM
- BMP – $m^3_{CH4}.tonne_{ODM}^{-1}$
- CH_4 - %

% Dry Matter

The figure for %DM is measured as follows:

A measured amount of biomass is weighed (x gms).

The biomass heated to a temperature of 105^{o}C until all the moisture is driven off.

The dry biomass is weighed (y gms).

%DM = y/x*100

% Organic Dry Matter

The figure for %ODM is measured as follows:

Dry biomass from the %DM test is weighed (y gms).

The dry biomass is heated in an oven to a temperature of 550^{o}C and maintained at this temperature for a period of two hours.

The oven drives off all the volatile material leaving the inert fraction, which is weighed (z gms).

%Inert = z/y*100 (expressed as % of dry matter).

%ODM = 100-%Inert =100-(z/y*100).

Biochemical Methane Potential

BMP is expressed as m^3 CH_4 per tonne ODM.

The figure for BMP is obtained empirically by experiment, either in laboratory digesters or in full-scale digesters.

The BMP varies from as low as $190m^3{}_{CH4}.tonne^{-1}{}_{ODM}$ for the anaerobic digestion of cattle manure (the cow is a very good digester) to as high as 450 for some food waste and energy crops.

(The use of %DM, %ODM and BMP is a convention for the AD of biomass; it is not scientifically exact.)

% Methane of Biogas

The % methane of the biogas is important for two reasons: first, the design of the gas utilisation system; and second, the mass balance.

It is assumed that the balance of the biogas is CO_2.

CH_4 has a density of 0.71kg.m^{-3}. (This is on the basis that 1 kmol of a perfect gas occupies 22.4m^3).

CO_2 has a density of 1.96kg.m^{-3}.

The density of biogas is approximately:-

$\%CH_4/100*0.71+(100-\%CH_4)/100*1.96$.

Biogas @60% CH_4 has a density of about 1.21kg.m^{-3}.

Anaerobic Digestion Parameters

For this lecture the only type of anaerobic digestion being considered is the Continuous Stirred Tank Reactor ("CSTR"). This is one which is fed semi-continuously (at least once per day) and is fully mixed.

The following are parameters measured in the anaerobic digestion stage:

- Hydraulic Retention Time (HRT)
- Organic Loading Rate (OLR)

Hydraulic Retention Time (HRT)

The Hydraulic Retention Time (days) is defined as the volume of the digester (m^3) divided by the daily feed rate ($m^3.d^{-1}$).

The retention time is not the same as the length of time the biomass is in the digester, unless there is a perfect plug flow.

The parameter is useful when considering feedstocks with %DM between about 4% and 12%, e.g. for animal slurry, in which case the optimum retention time will be between 20 and 40 days.

Organic Loading Rate (OLR)

The Organic Loading Rate ($kg_{ODM}.m_R^{-3}.d^{-1}$) is defined as the mass of organic matter (kg) fed to the digester in one day divided by the volume of the digester (m^3).

The OLR tends to be the rate-limiting parameter when the %DM of the feedstock is more than about 12%; below this the HRT is the rate-limiting parameter.

A well-designed anaerobic digester will maximise the organic loading rate, and this will vary according to the feedstock and according to the digester design.

A typical figure is between 2.5 & 5.0 kg $ODM.m_R^{-3}.d^{-1}$.

Energy production

- Methane production - CH_4 ($m^3.d^{-1}$)

  = Feedstock A ($t.d^{-1}$) x %DM x %ODM x BMP ($m^3_{CH4}.t^{-1}_{ODM}$)

  + Feedstock B ($t.d^{-1}$) x %DM x %ODM x BMP ($m^3_{CH4}.t^{-1}_{ODM}$)

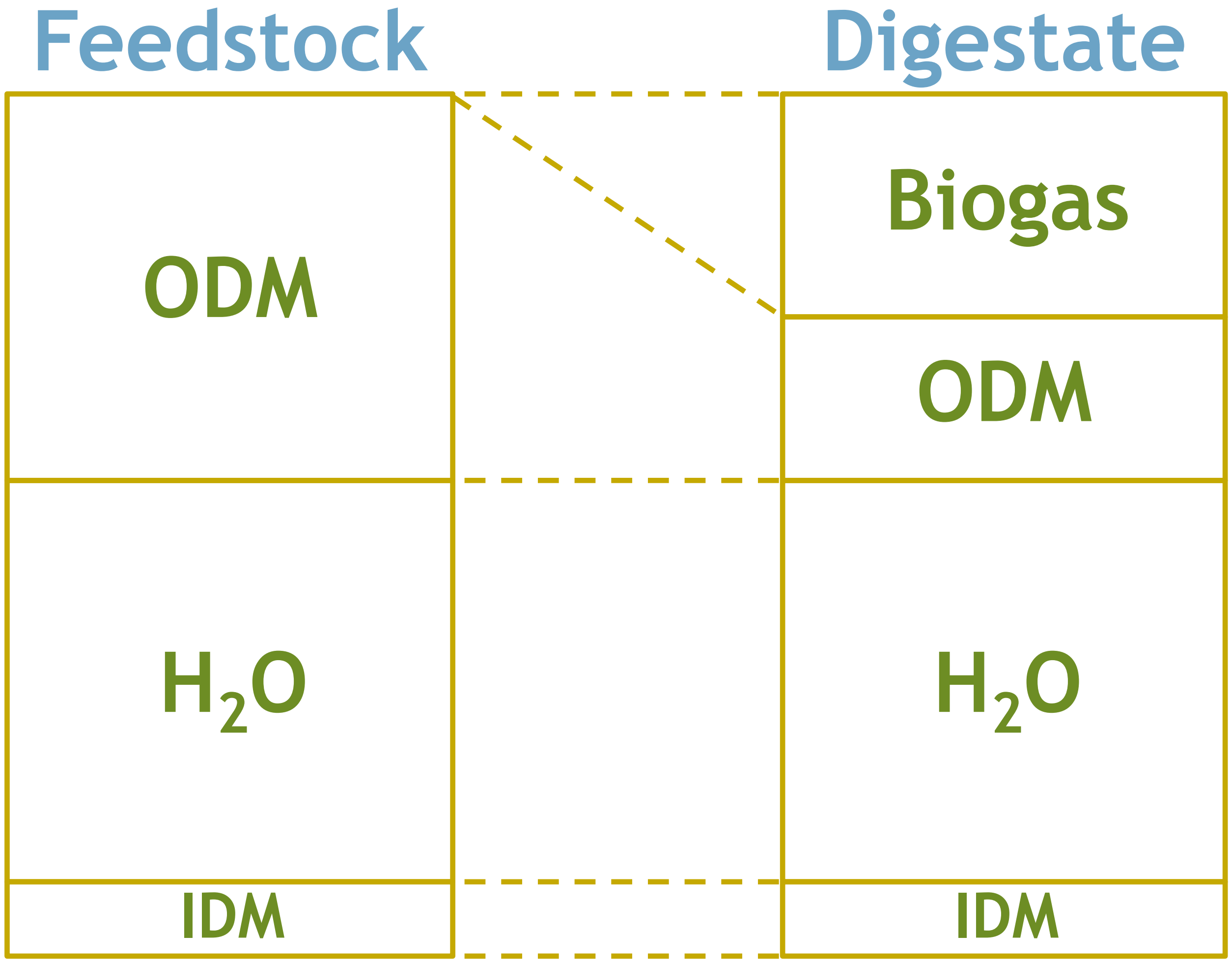
  + Feedstock C ($t.d^{-1}$) x %DM x %ODM x BMP ($m^3_{CH4}.t^{-1}_{ODM}$)

  etc.

- Energy value of biogas - kW (LCV)

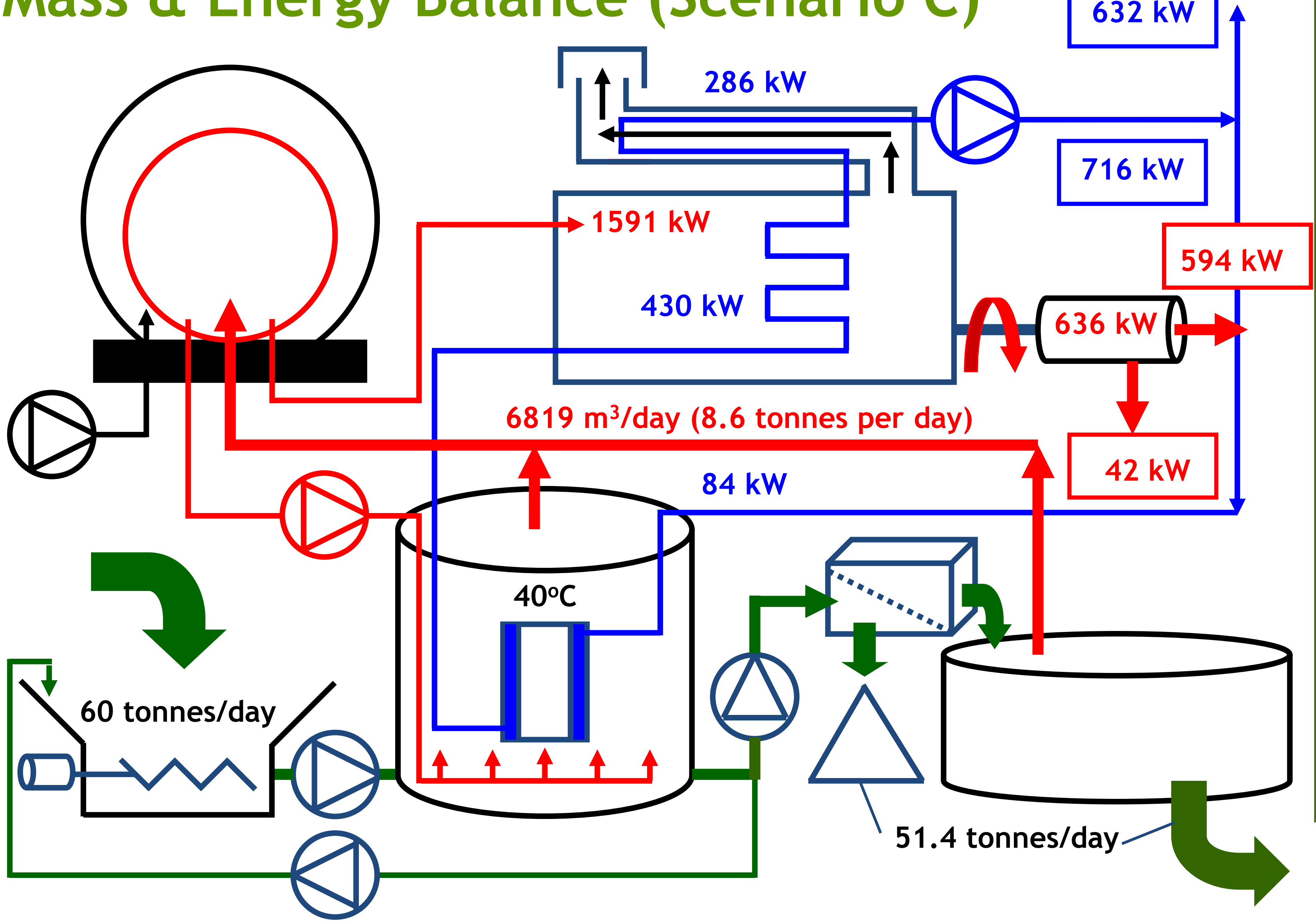
  = CH_4 ($m^3.d^{-1}$) x 9.9 ($kWh.m^{-3}$) ÷ 24

Mass balance



Process Calculations

Mass & Energy Balance (Scenario C)



Thank you