GASIFICATION TO PRODUCE ELECTRICAL ENERGY FROM BIOSOLIDS

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Presentation Content

- Energy consumption concerns
- Biosolids as an energy source
- History of gasification
- Gasification technology
- Wastewater Residuals
- Full Scale Test Results
- Conceptual Design

Energy Consumption

- The energy required for treatment and delivery of drinking water accounts for as much as 80% of its cost, and an insufficient supply of affordable energy will have a negative effect on the price and availability of water.

Energy Consumption

- Wastewater treatment plants use 3% of all the energy generated in the US
  - Energy costs represent over 20% of a treatment plants operating budget
- Wastewater facilities estimated in the top 10 industries for emissions of GHGs.

Energy Consumption

- The energy usages commonly reported and observed in the field are as follows:
  - Aeration 35 to 75% (typically at 50%);
  - Wastewater pumping (influent) 10 to 25% (typically at 15%); and
  - Facilities (lighting and heating, ventilation, and air conditioning) 5 to 15% (typically at 10%).

Energy Consumption

- The typical unit electricity requirements given for publicly owned treatment works are:
  - 908 kJ/m3 (955 kWh/mil. gal) for trickling filter plants,
  - 1257 kJ/m3 (1322 kWh/mil. gal) for activated sludge plants,
  - 1466 kJ/m3 (1541 kWh/ mil. gal) for advanced wastewater treatment (with filtration), and
  - 1817 kJ/m3 (1911 kWh/mil. gal) for advanced treatment (with filtration and nitrification).

Renewable Energy

- Energy production from biosolids is truly is a sustainable energy source.
  - Anaerobic Digestion
  - Gasification
- CHP to augment energy production
  - Thermal and Electrical

Anaerobic Digester Gas

- Heating digesters
- Heating buildings
- As a renewable energy source for generating electricity
  - About 550 to 800 kWh per dry ton of biosolids

Disadvantages

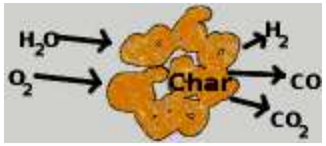
- Anaerobic digestion is a biological process
  - Subject to toxic discharges
  - Subject to biological imbalances
- Although about 45% of the biological solids are converted to biogas, there is still remaining a considerable amount for disposal.
- High concentration of ammonia back to treatment plant.

Gasification

- A process which converts carbon-containing fuels into gas.
  - The gas produced can be referred to as producer gas, synthesis gas or syngas.
  - Gasification has now been brought up to modern standards for reliability, emissions, automation and safety using today's technology

Basics of Gasification

- Gasification is a thermo-chemical reaction with the following distinct stages:
  - Drying
  - Pyrolysis (thermal decomposition)
  - Char combustion
  - Ash removal (15-20% depending on volatile solids content.



Basics of Gasification

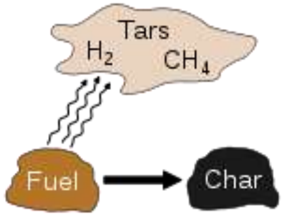
- Different gasification technologies result in different levels of particulate matter and tar in the syngas stream
  - This will affect the final application and emissions treatment

Gasification

- Performed at sub-stoichiometric oxygen concentrations and pressure (low or high)
  - Produces CO and H_2 with some methane which is a synthetic gas known as Syngas
- Snygas can be used as a gaseous fuel or for other purposes, e.g., Fischer-Tropsch liquids; methanol, etc.

What happens in a gasifier?

- Carbonaceous materials under different processes
  - Pyrolysis(or devolatilization) process occurs as the carbonaceous particle heats up.
  - Volatiles are released and char is produced
- Process is dependent on
  - properties of the carbonaceous material which
  - determines the structure and composition of the char



What happens in a gasifier?

- The next step is combustion
  - occurs as the volatile products and some of the char reacts with oxygen
  - form carbon dioxide and carbon monoxide
  - which provides heat for the subsequent gasification reactions

$$C + \tfrac{1}{2}O_2 \longrightarrow CO$$

What happens in a gasifier?

- Gasification occurs as the char reacts with carbon dioxide and steam to produce carbon monoxide and hydrogen $C + H_2O \rightarrow H_2 + CO$
- Finally, reversible gas phase water gas shift reaction reaches equilibrium balancing the concentration of carbon monoxide, steam, carbon dioxide and hydrogen.

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

What happens in a gasifier? Summary

- limited amount of oxygen or air is introduced into the reactor to allow some of the organic material to be "burned" to produce carbon monoxide and energy
- which drives a second reaction that converts further organic material to hydrogen and additional carbon monoxide.
- Then carbon monoxide and residual water from the organic material form methane and excess carbon dioxide.

Composition of Syngas

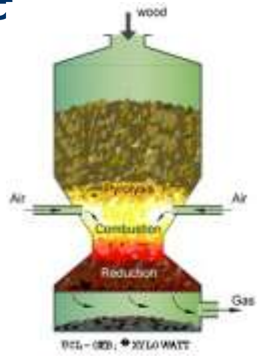
- Typical constituents of Syngas produced from biomass gasification
  - Water vapor (from moisture content of the fuel)
  - Hydrogen
  - Carbon Monoxide
  - Methane
  - Nitrogen

Composition of Syngas

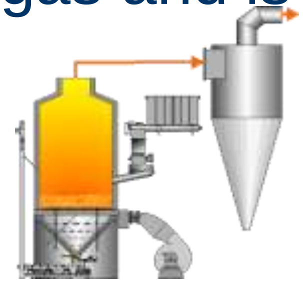
- Syngas is a low energy gas
  - Natural gas has a lower heating value of ~1000 Btu/scf
  - Syngas typically has a lower heating value of 100-300 Btu/scf

Types of gasifiers

- Downdraft (small systems such as home use)
  - Fuel and air flow co-currently down through the gasification vessel
  - Ash discharges from the bottom of the vessel



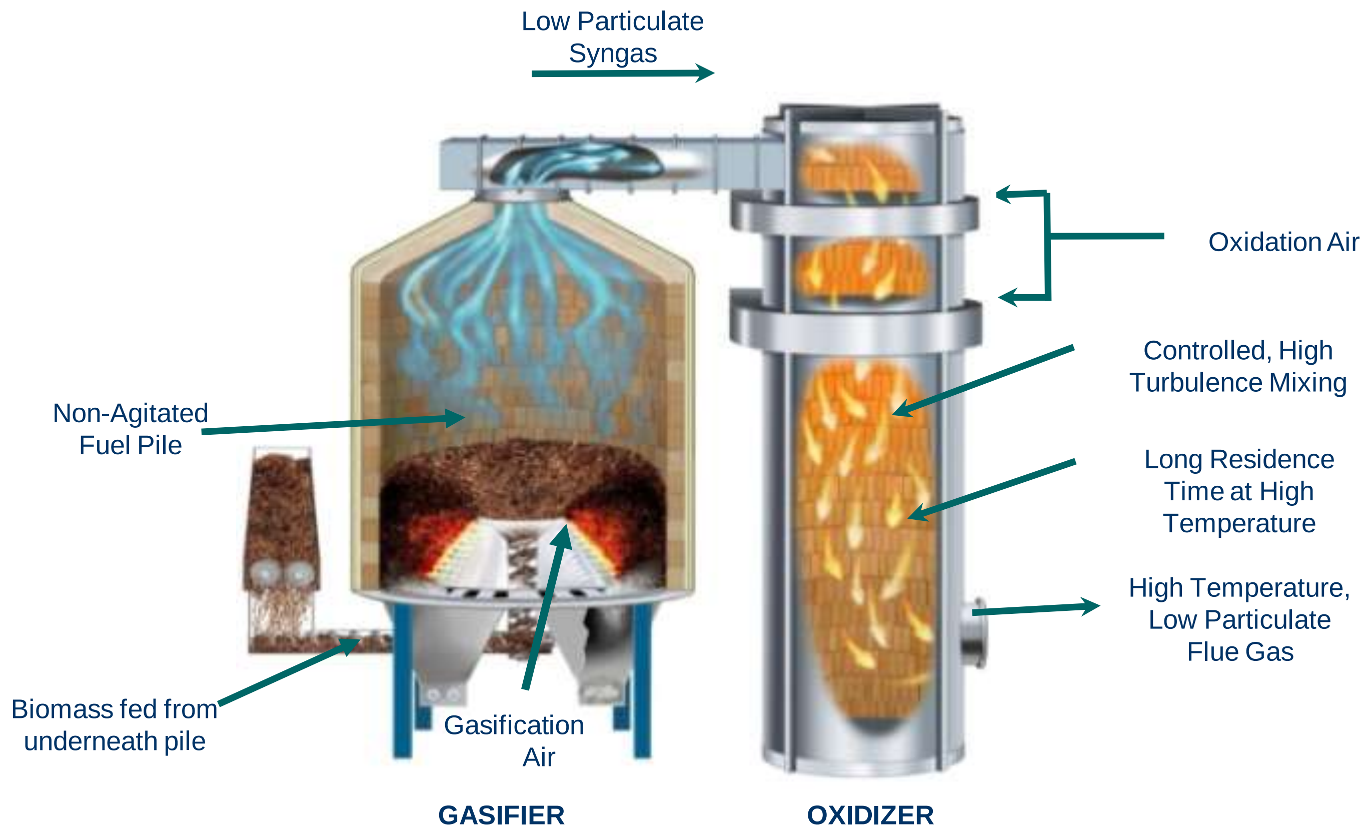
- Fluidized Bed (large scale systems)
  - Air fluidizes fuel bed
  - Ash is entrained in the syngas and is separated from the syngas in a cyclone



Updraft Gasifier

- Updraft
  - Air flows upwards through the fuel pile, counter-current to the fuel flow
  - Ash discharges from the bottom of the vessel
  - Updraft best suits medium scale systems 1 to 10 megawatts

Updraft Gasifier



Wastewater Residuals

- Wastewater residuals (sludge, biosolids) are a renewable energy source with a relatively high BTU value.
- Characterization
  - Proximate Analysis
  - Ultimate Analysis

Biosolids Characterization

- Proximate Analysis
  - moisture content,
  - volatile content (when heated to 950 C),
  - free carbon remaining at that point,
  - ash (mineral) in the sample and
  - high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water.

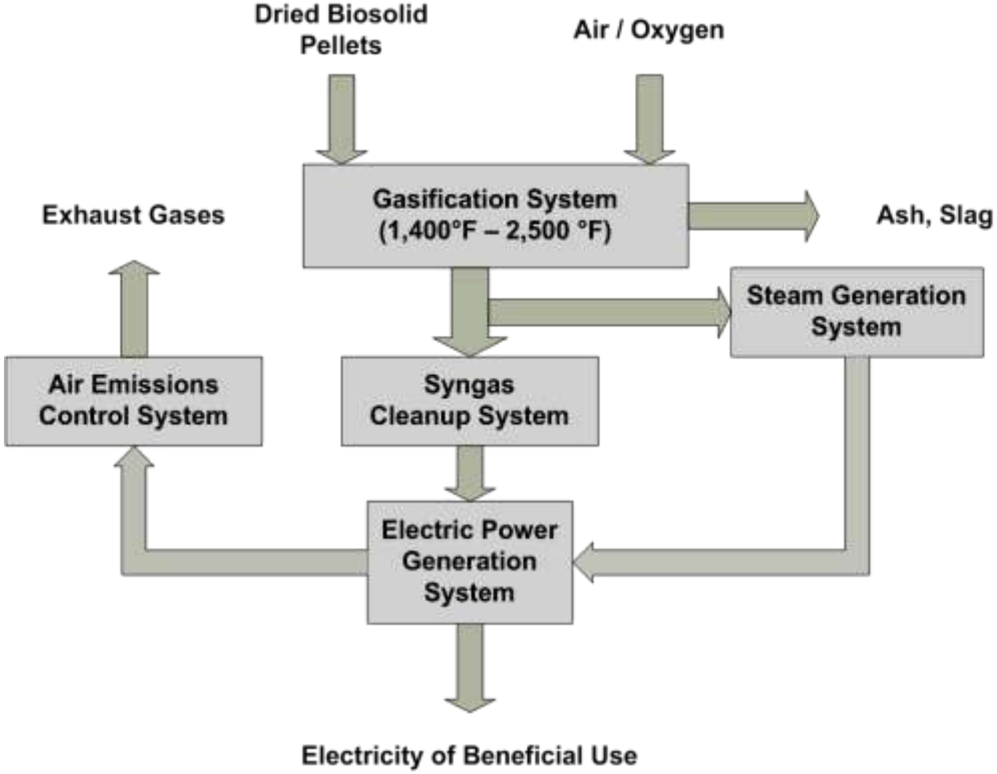
Biosolids Characterization

- Ultimate Analysis
  - composition of the biomass in wt% of carbon,
  - hydrogen and
  - oxygen (the major components)
  - as well as sulfur and nitrogen (if any).
- Fusion Point
  - Temperature at which material will vitrify or fuse

Biosolids Characteristics-primary/WAS

Proximate Analysis	
Moisture, %	6.7
Ash, %	16
Volatile, %	73.9
Fixed C, %	10.1
BTU/lb (HHV)	8,529
MMF BTU/lb	10,322
Ultimate Analysis	
Carbon, %	47.1
Hydrogen, %	6.1
Nitrogen, %	6.6
Oxygen, %	23.4
Sulfur, %	0.7
Fusion Temperature	
Reducing Atmosphere, C	1093
Oxidizing Atmosphere, C	1142

Gasification Waste to Energy



Full Scale Test Results

- Downdraft Gasifier
- Fluidized Bed Gasifier
- Updraft Gasifier

Downdraft Gasifier

- Throughput-@300 kg/hr
  - Originally designed for waste wood
- Design Output
  - 50 kw to grid
- Feed
  - heat dried undigested primary/WAS

Operation

- Operating temperature-900 to 950 C
  - Some clinker production
  - Did not have good method of measuring bed temperature
- Small amount of tar formation
- Small amount of ammonia and organosilicates (siloxanes)

Syngas Characteristics-Downdraft System

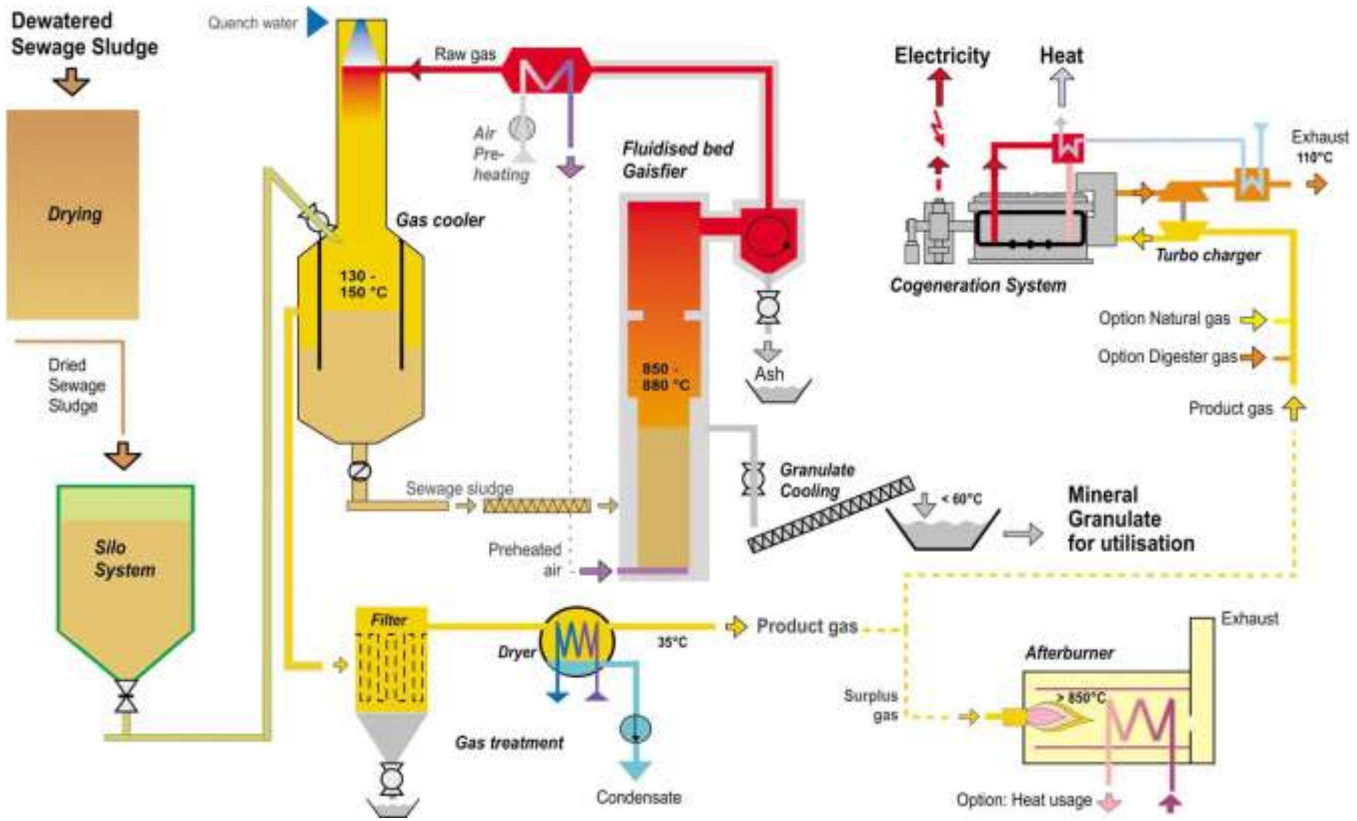
Constituent	
Hydrogen (vol %)	13.9
Carbon Monoxide (vol %)	14.4
Methane (vol %)	2.9
Carbon Dioxide (vol %)	15.4
Nitrogen (vol %)	51.9
C_xH_y (vol %)	1.4
Other (vol %)	0.1

Average Syngas Heating Value: 146 Btu/scf
Supplied 50 kw for 6.5 hrs to the electrical grid

Fluidized Bed Gasifier

- Throughput-@ 700 kgs/hr
  - Designed for biosolids
- Output-
  - 700 kw
- Feed
  - heat dried undigested primary/WAS

Fluidized Bed Gasifier Schematic



Results

- Hydrogen 16.9 %
- Carbon Monoxide 12.8 %
- Fixed carbon in ash <8 %
- Air testing results not available at this date
- Low tar concentration in gas

Updraft Gasifier to Steam

- Throughput-@ 2000 lbs/hr
  - Designed for all types of biomass
- Output-
  - 1 megawatt
- Feed
  - Heat dried, undigested primary/WAS

Results

- Hydrogen 15.5 %
- Carbon Monoxide 10.8 %
- Fixed carbon in ash 22 %
- Air testing excellent and within permit limits
- Tar not an issue with their technology

Updraft Gasifier to Electrical Energy

- Throughput @ 1000 lbs/hr
- Output-500 Kw
  - Designed for wood
- Feed
  - Heat dried primary/WAS

Syngas Quality Dry Biosolids

Syngas Composition-biosolids	
Moisture	7.0
CO (mole %)	14.1
H_2 (mole %)	12.0
CH_4 (mole %)	2.9
C_2H_6 (mole %)	0.7
CO_2 (mole %)	16.6
O_2 (mole %)	0.0
N_2 (mole %)	53.6
HHV of syngas (BTU/sft^3	134.2
LHV of syngas (BTU/sft^3	123.6

Ash Discharge

- Ash was free flowing
- Visual indications are that it is low in carbon
- Ash can be used beneficially
  - Soil conditioner
  - In conrete

Exhaust Gases

- Operation with dry biosolids resulted in visually clean stack emissions

Conceptual System Design

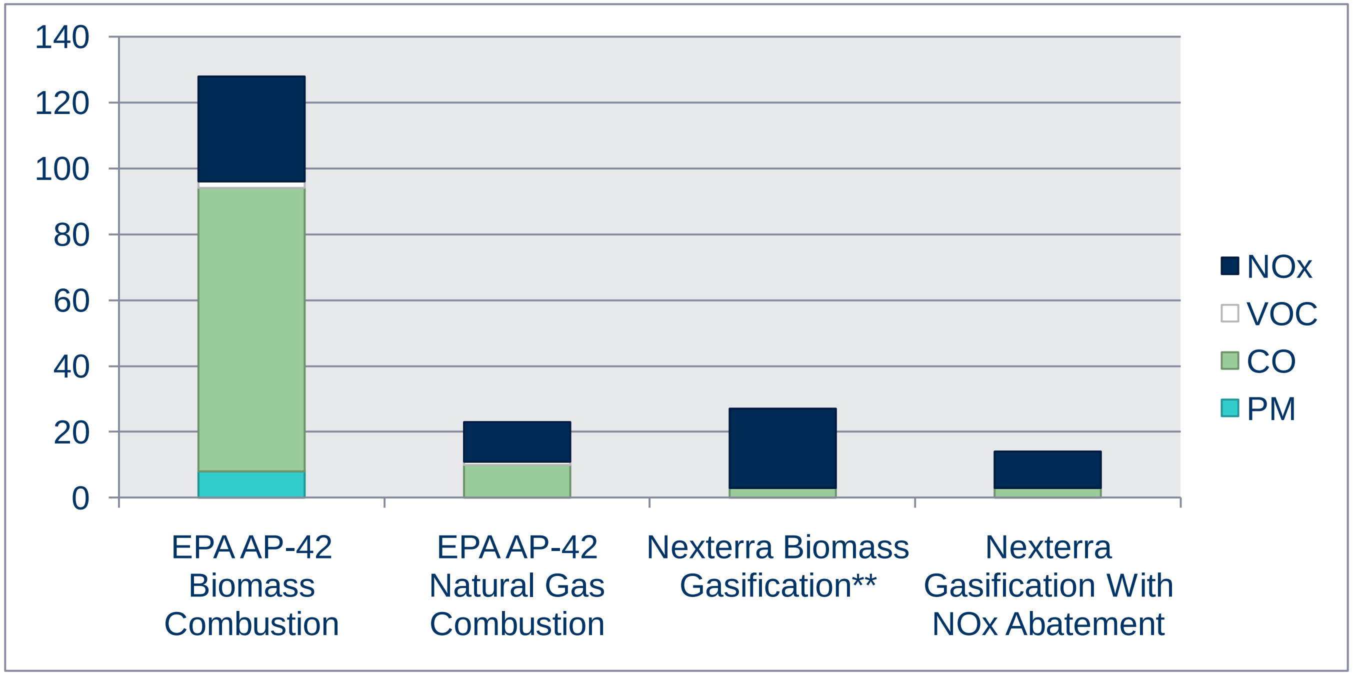
- Economic at small-scale 2 – 10 MWe
- Game changing, breakthrough technology for biomass to power
- Combines technologies with IC gas engines
- Significantly more efficient than conventional steam power generation
- Firm, base load green energy vs intermittent power such as wind or solar
- No steam engineers and natural gas comparable emissions for PM

System design using Nexterrra Gasifier and GE Jenbacher Engine

Internal Combustion Engine

Photo Credit GE Jenbacher Engine Division

Syngas Emissions



* Data is for on 24 MMBtu/hr system, 45% mc fuel
** Third party test results from plant at the University of South Carolina (USC)

Data Provide by Nexterra, Vancouver, BC

Tars

- Removed by Cracking
- Removed by water

Tar- (By-products of Gasification)

- Soluble tars
  - Phenols
  - Acetone
  - Napthalene
  - Pyrene
  - BTEX
- Insoluble tars
  - Acenaphthylene
  - Fluorene
  - Phenanthrene
  - Pyrene
  - Chrysens

Uses of Syngas

- Generate power
- Steam to heat buildings
- Liquid fuels
  - Methanol
  - Gasoline

Conclusions

- Gasification has tremendous potential
  - Need to demonstrate technology
  - Perfect tar removal system
- Biosolids are an ever renewable energy source
- Gasification will change the way we manage biosolids