Torrefaction, Pyrolysis, and Gasification-Thermal Processes for Resource Recovery and Biosolids Management

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Presentation

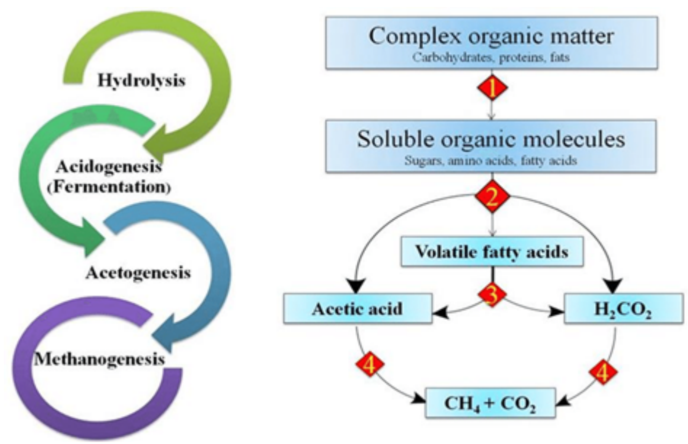
- Setting the stage
- Thermal Process
  - Description
  - Applications to biosolids resource recovery
- Comparison to Anaerobic Digestion
- Current status

Biomass

- UN defines it as non-fossilized and biodegradable matter derived from plants, animals, and microorganisms
  - Can include gases and liquids recovered from decomposition of non-fossilized and biodegradable organic materials
- IFP Energies Nouvelles
  - About 5% of global biomass available to produce energy
    - About 13.5 billion metric tons (14.9 tons (US)
    - Equivalent to 6 billion metric tons of oil or 45 billion barrels
- Products derived from biomass
  - Liquid fuels- ethanol, methanol, biodiesel, vegetable oil, pyrolysis oil
  - Gaseous fuels-biogas, producer gas
  - Solid fuels-charcoal, biochar coke

Setting the Stage

- New paradigm-Water Resource Recovery Facilities (WRRFs)
- Current biosolids management options
  - Stabilization methods
  - Current popularity of Anaerobic Digestion
- Drivers for alternative technologies
  - Issues with anaerobic Digestion
    - Size
    - Cost
    - Mass of solids for disposal



Anaerobic Digestion

Advantages

- Produces biogas
  - BTU value-600 BTUs/ft^3
    - Natural gas 1000
- Reduces pathogens and vector attraction (VS)
  - 38% minimum
- Produces a fertilizer if Class A or B technology used

Disadvantages

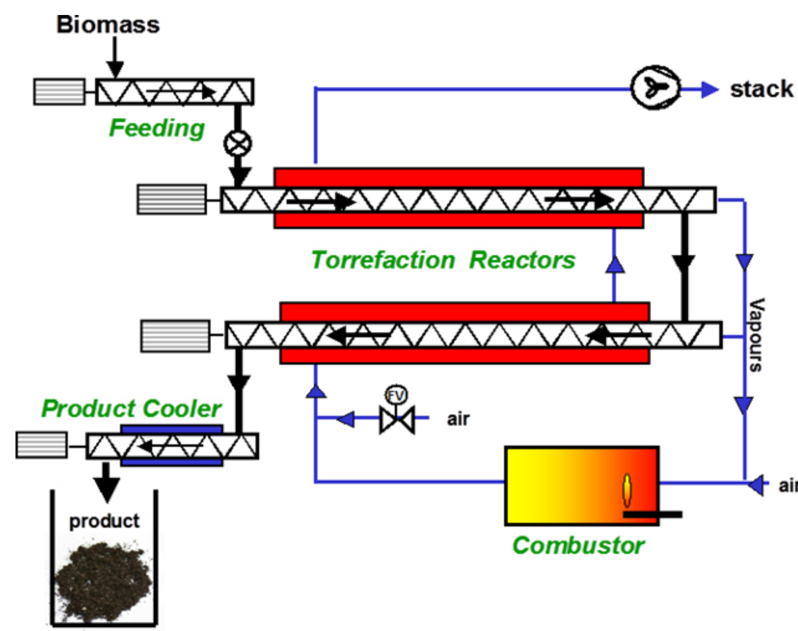
- Anaerobic digestion is a biological process
  - Subject to toxic discharges
  - Subject to biological imbalances
- At least 50% if input solids remaining for disposal
- High concentration of ammonia and some phosphorus recycled to treatment plant

Thermal Process

- Oxidative processes
  - Combustion
- Starved or no oxygen processes
  - Torrefaction and carbonization
  - Pyrolysis
  - Gasification
- Can be used to produce liquid, gaseous, and solid fuels from wastewater residuals

Torrefaction

- Thermochemical process
  - Inert or limited oxygen
  - Biomass slowly heated
    - Within specific temperature range
    - For a specified time
- Objective
  - Increase energy density of biomass by increasing carbon content while decreasing hydrogen and oxygen content



Torrefaction

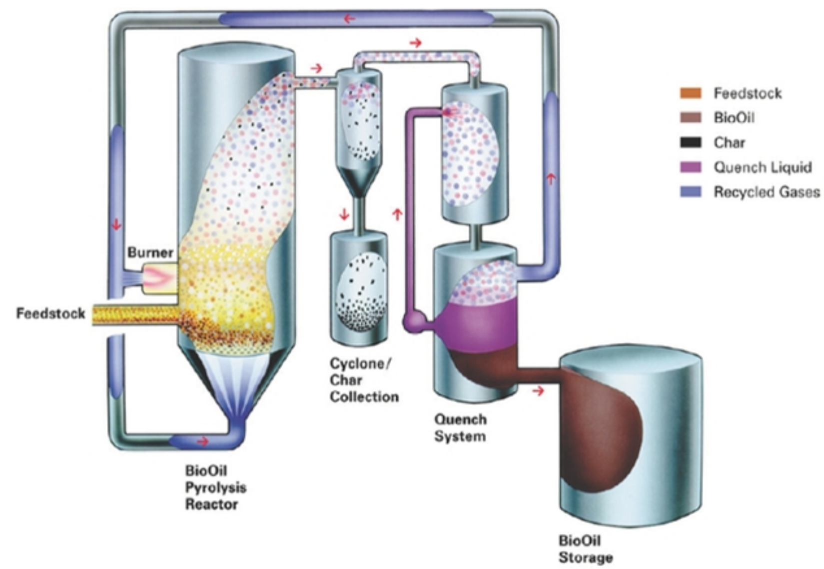
- Typical temperature range-200 to 300° C
- Optimum is oxygen free environment
  - Can tolerate small amounts of O_2
- Similar to carbonization
  - Produces charcoal
  - Drives off most of the volatiles whereas torrefaction retains them
  - Operates at higher temperatures
- Main goal is maximize biochar production
  - Gas production minimized but can be used

Pyrolysis

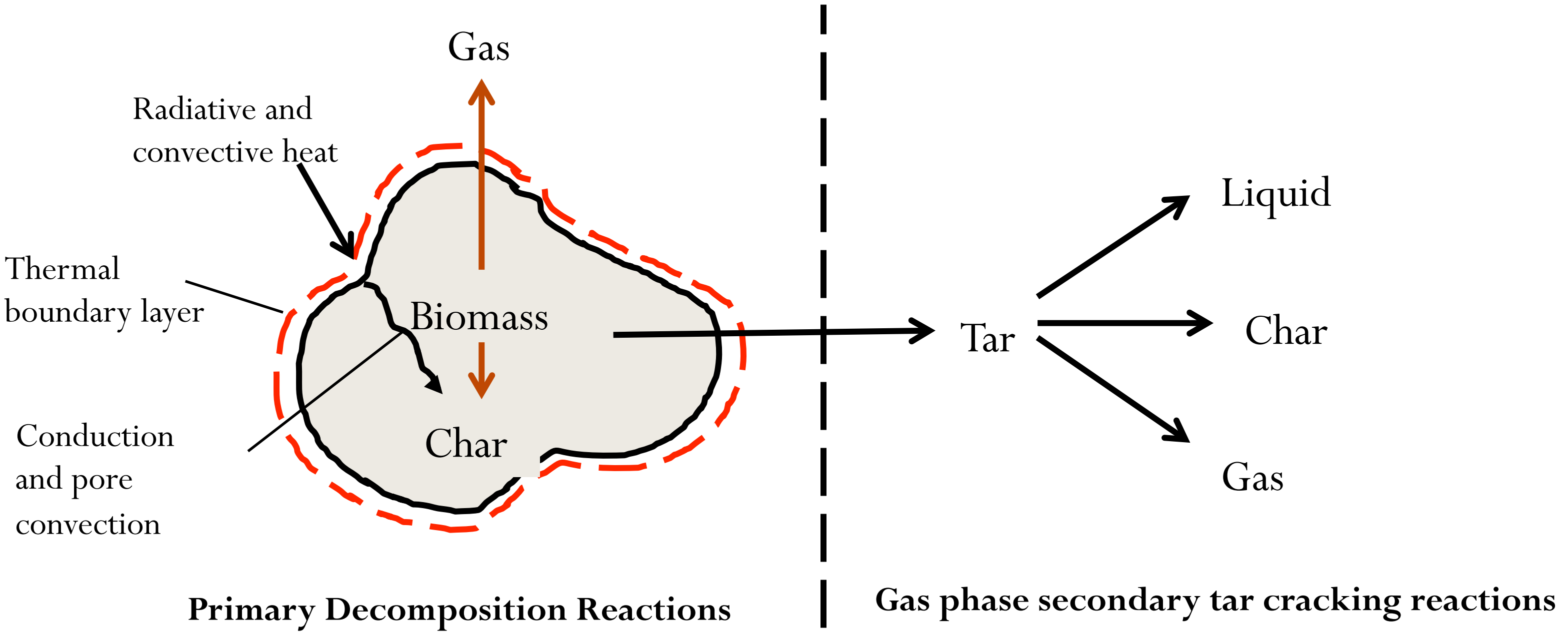
- Pyrolysis
  - Total absence of oxygen
  - Useful products
  - Precursor to gasification
- History
  - Used to produce charcoal from wood to extract iron from iron ore in ancient China and India~4000 BCE
  - Mid-1840's pyrolysis process invented to produce kerosene

Pyrolysis

- Process conditions
  - Rapid heating of biomass
  - No oxygen or air
  - Held for a specific period at high temperatures
- Produces
  - non-condensable gases
  - Solid char
  - Liquid products



Pyrolysis Process

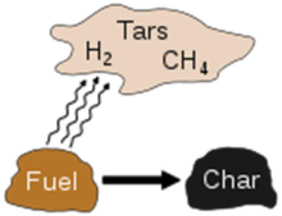


Pyrolysis-Operating Conditions

- Temperature-Depends on desired product
  - Maximize char production
    - Slow heating <0.01 to 2.0^{o} C/s
    - Final Temperature $\leq 300\uparrow o\ C$
    - Long residence time, 10-60 minutes
  - Maximize liquid products (bio-oil)
    - Rapid heating
    - Peak temperature $\sim 650^{o}$ C
  - Maximize gas production
    - Rapid heating
    - Temperatures $\sim 1000^{o}$ C

Gasification

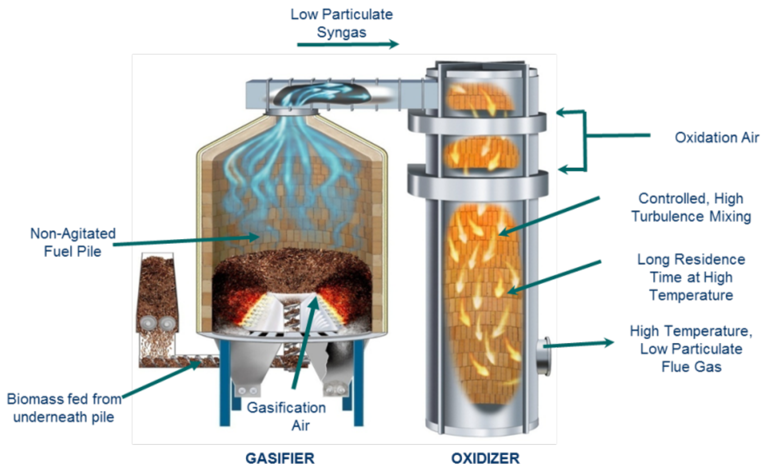
- Gasification is a thermo-chemical reaction with the following distinct stages:
  - Drying
  - Pyrolysis
  - Char combustion



- 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

Gasification

- Pyrolysis 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
- 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



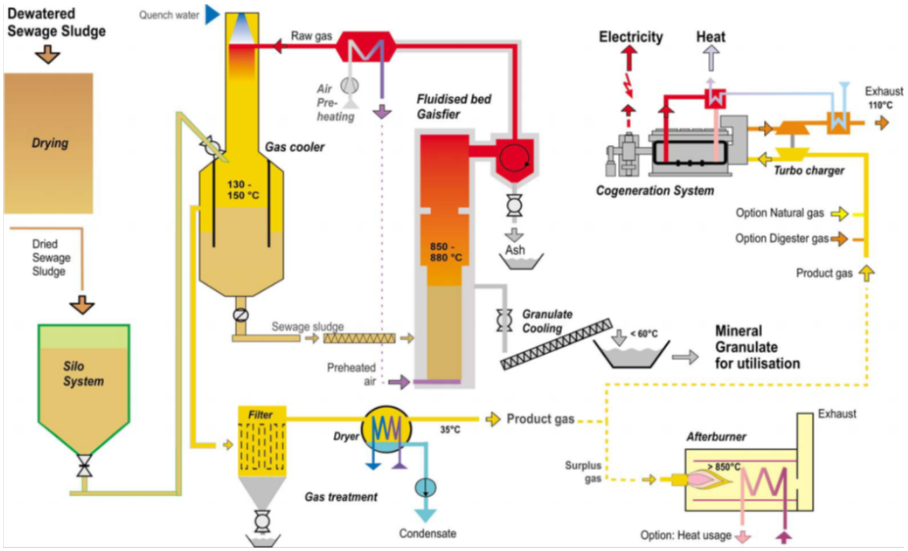
Gasification

- 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.

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



Comparison of Technologies

- Torrefaction
  - Lower heat
  - Biochar production
  - Limited gas production
    - Low value gas ~100 BTU's/ ft^3
- Pyrolysis
  - Bio-oil
  - Biochar
  - Syngas
    - Higher value gas~250 to 500 BTU's/ft^3
- Gasification
  - Mostly gas~125 to 300 BTU's/ft^3
  - Some Biochar
  - Lowest ash production

Biomass from WW Residuals

- Wastewater residuals (sludge, biosolids) are a renewable energy source with a relatively high energy value value.
- Characterization
  - Proximate Analysis
  - Ultimate Analysis
- Undigested primary/WAS
  - ~8500-12,000 BTU's/lb (16 to 22 MJ/kg)

Advantages-Disadvantages of Thermal Processes

Advantages

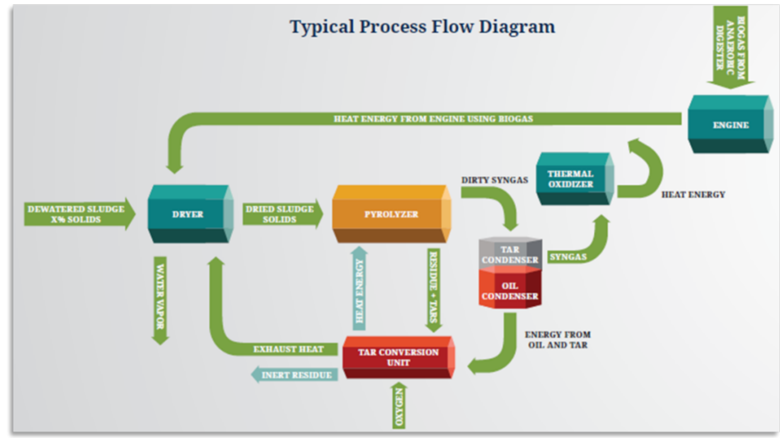
- Easy to operate
- Very high reduction of mass
- Production of useful products
- Low capital and operating costs

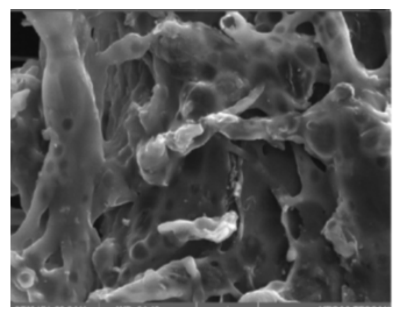
Disadvantages

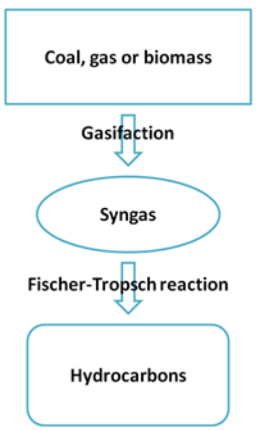
- Production of tars
  - Insoluble
  - Soluble
- Low energy value gas
  - Depending on process
- Fear of unknown

Product Characteristics and Uses

- Biochar
  - High carbon content
  - High water holding capacity in soil
- Gas
  - Generate electricity
  - Produce liquid fuels and chemicals
    - Methanol
    - Fischer-Tropsch Synthesis
      - Liquid Hydrocarbons

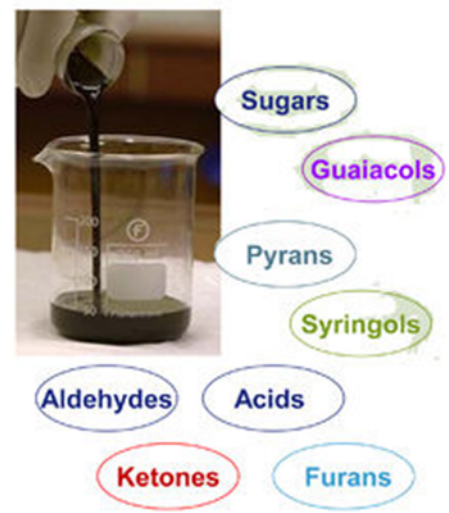






Product Characteristics and Uses

- Bio-oil
  - Renewable fuel
    - Used to fire boilers
    - Bio-diesel
  - Produce most of the same products from bio-oil as petroleum
    - Resins
    - Agro-chemicals
    - Preservatives



Comparison of AD and Thermal Processes

Anaerobic Digestion

- Biogas
  - 600 BTUs/ft^3
- Solids
  - About 50% for disposal
    - Can be used beneficially
    - Subject to continuous testing for land application
- Operation
  - High level of process control
- Capital costs
  - high

Thermal Processes

- Synthetic gas
  - Torrefaction
  - Pyrolysis
  - Gasification
- Solids
  - 10% residuals
    - Can be used beneficially
    - Only limited testing required
- Operation
  - Minimal process control
- Capital costs
  - Low

Current Status on WW Biomass

- Torrefaction
  - Currently being used in UK to produce soil conditioner
  - Unaware of any systems in US
- Pyrolysis
  - South Africa
  - UK
  - US
    - BPS (Biowaste Pyrolysis Systems
      - Evaluating demonstration locale in Northeastern US
    - Kore-California
  - Gasification
    - SÜLZLE KOPF-Germany
      - 3 full-scale installations
    - Being evaluated as a technology in two US states and Canada

Conclusions

- Thermal processes can be used effectively to produce energy and useful byproducts
- Need demonstration facilities to inform and educate end-users
  - Better understand operational requirements
  - Tar formation and destruction
  - Gas clean-up needs
- A good alternative to anaerobic digestion
  - Especially if land application is not available or is prohibited

Questions?