Potential for Gasification and Electric Energy Production from Biosolids

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Presentation Structure

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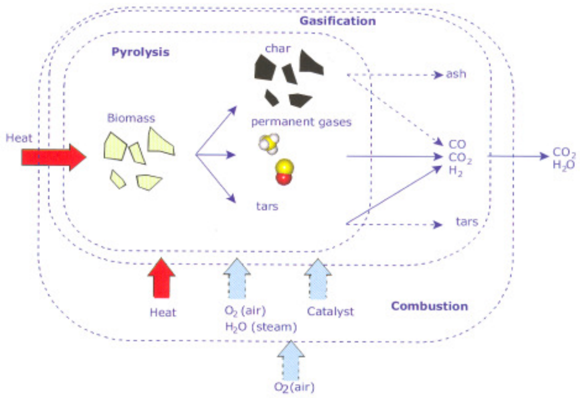
Main biosolids management options

What is gasification?

- Gasification is the thermal reforming of organic material, with main products: hydrogen, carbon monoxide (and to lesser extent: carbon dioxide and methane)
- It takes place under **reduction** conditions, between 700-1200˚C (arc plasma may reach 5000˚C)
- The ideal carbon÷oxygen ratio is 1÷1



Main chemical reactions in combustion and gasification processes

Combustion (Oxidation) Reactions

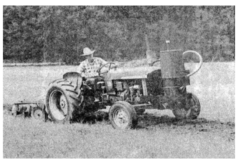
$C + O_2 \longleftrightarrow CO_2$	Oxidation of carbon
$½ O2 + H_2 \longleftrightarrow H_2O$	Oxidation of hydrogen
$N + O_2 \longleftrightarrow NO_2$ (NOx)	Oxidation of Nitrogen
$S + O_2 \longleftrightarrow SO_2$ (SOx)	Oxidation of Sulfur

Gasification Reactions

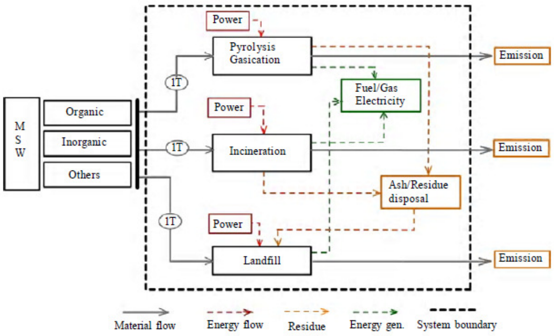
$C + ½ O_2 \longleftrightarrow CO$	(Gasification with Oxygen)
$C + CO_2 \longleftrightarrow 2CO$	(Gasification with Carbon Dioxide)
$C + H_2O \longleftrightarrow CO + H_2$	(Gasification with Steam)
$C + 2H_2 \longleftrightarrow CH_4$	(Gasification with Hydrogen)
$CO + H_2O \longleftrightarrow H_2 + CO_2$	(Water-Gas Shift Reaction)
$S + H_2 \longleftrightarrow H_2 S$	(Sulfur forms H_2S - not SOx)

Historical development of gasification

1850-1940	• Production of "town gas" for light and heat, from coal
1940-1945	• Used as power source to vehicles, due to lack of fossil fuels
1945-1975	• Production of fuels and chemicals
1975-1990	• First Integrated Gasification Combined Cycle (IGCC) electric power plant
1990-2000	• Focus on biomass gasification processes for the production of electricity
2000-Present	• Turnkey thermal & power gasifiers from biomass • Focus on MSW and biosolids gasification • Focus on reducing greenhouse gas emissions

Energy-wise comparison of gasification, incineration and landfilling



Key differences between incineration and gasification

Incineration	Gasification
Combustion vs. Gasification	
Designed to maximize the conversion of waste to CO_2 and H_2O	Designed to maximize the conversion of waste to CO and H_2
Employs large quantities of excess air	Operates under controlled amount of air
Highly oxidizing environment	Reducing environment
Gas Cleanup	
Treated flue gas discharged to atmosphere. Flue gas may contain dioxins and furans	Cleaned syngas used for chemical production and/or power production (with minimal dioxins and furan content)
Fuel sulfur converted to SOx and discharged with flue gas	Recovery of reduced sulfur species in the form of a high purity elemental sulfur or sulfuric acid byproduct is feasible
Residue and Ash Slag Handling	
Collected and disposed as waste (may qualify to be used as fertilizer)	Collected and disposed as waste (may qualify to be used as fertilizer)

Barriers to biosolids gasification

- Low cost of landfilling
- Technology, for biosolids gasification, is not fully developed, yet
  - A number of gasification technologies are in pilot stage
  - Full competition is practically non-exist, due to technology diversity
- Residue management (ash, tar)
- Syngas clean-up
- Regulatory complications
  - Gasification is often lambed with incineration
- Public perception
  - Public usually considers gasification to be a form of combustion
  - Public sees gasification as a dirty, contaminating process

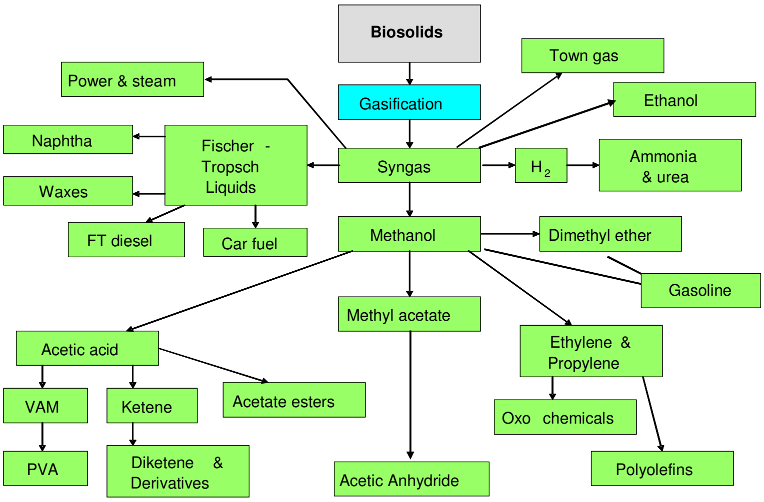
So why do it?

Why biosolids gasification?

- Biosolids is of itself an energy source
  - It is partially dried, collected and transported by default
- Increased landfilling regulations and costs
  - Directives for the reduction of landfilled biodegradable fraction
  - Sitting/permitting new landfills is increasingly difficult
- Reduction of carbon footprint
  - Gasses emitted from landfills contain methane, a greenhouse gas
  - Municipalities will be able to benefit from carbon credits
- Benefits from the production of renewable energy
  - Municipalities can claim subsidies for electrical energy produced from renewable sources
- Clean process with minimal residue
- Homogeneity of feedstock
- Production of high added value products from syngas (to the contrary of combustion)
  - Potential for production of hydrogen, ethanol, diesel fuel, chemicals etc.
- Viable projects are affordable in today's economy
  - The project pays off in relatively short time, due to revenue from electricity and tipping fees

Reduced overall cost of biosolids management!

Syngas to Biofuels / Biochemicals



Gasifier designs

According to gasification agents

- Air-blown gasifiers
- Oxygen gasifiers
- Steam gasifiers

According to heat for gasification

- Autothermal or direct gasifiers
- Allotermal or indirect gasifiers

According to pressure

- Atmospheric
- Pressurized

According to the design

- Fluidized bed
- Fixed bed
- Entrained flow
- Rotary drums
- Plasma

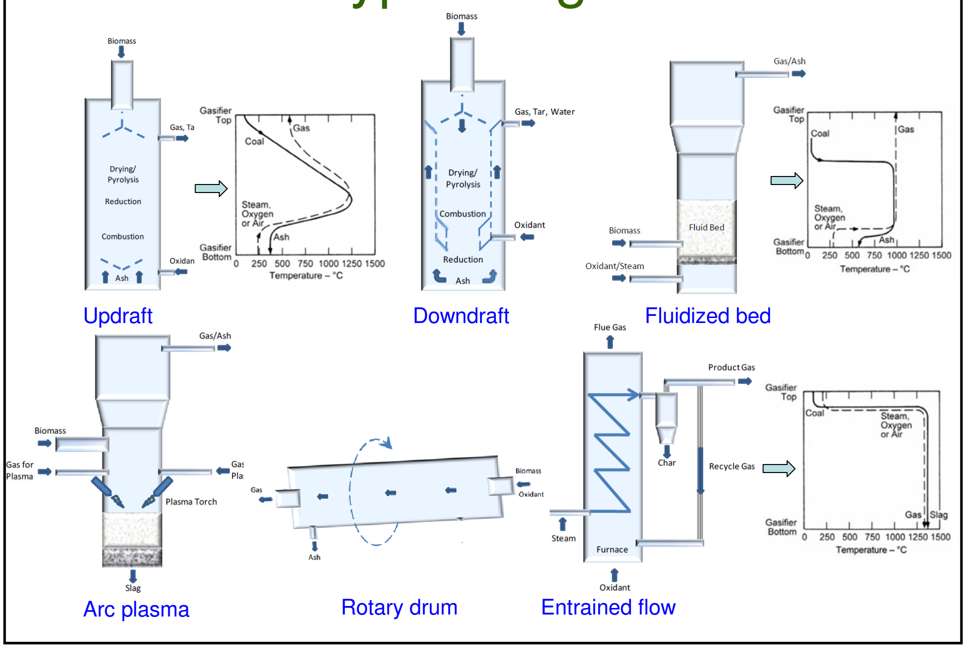
Syngas composition

Component (%)	Gasification medium		
	Air	Oxygen	Steam
H_2	15	40	40
CO	20	40	25
CH_4	2	-	8
CO_2	15	20	25
N_2	48	-	2

Heating value of syngas: 6-12 MJ/Nm^3

(depends on composition)

Main types of gasifiers



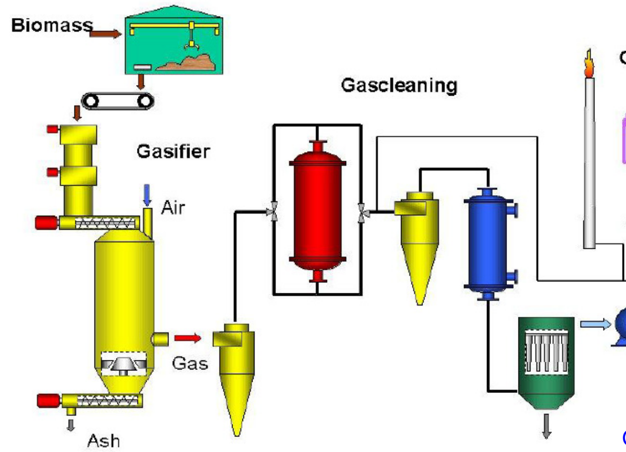
Characteristics of gasifiers

Gasifier Type	Scale	Fuel Requirements		Efficiency	Gas Characteristics	Other Notes
		Moisture	Flexibility			
Downdraft Fixed Bed	5 kW_{th} to 2 MW_{th}	<20%	· Less tolerant of fuel switching · Requires uniform particle size · large particles	Very Good	· Very low tar · Moderate Particulates	· Small scale · Easy to control · Produces biochar at low temperatures · Low throughput · Higher maintenance costs
Updraft Fixed Bed	<10 MW_{th}	up to 50% - 55%	· More tolerant of fuel switching than downdraft	Excellent	·Very high tar (10% to 20%) ·Low particulates ·High methane	· Small and medium scale · Easy to control · Can handle high moisture content · Low throughput
Bubbling Fluidized Bed	<25 MW_{th}	<15%	· Very fuel flexible · Can tolerate high ash feedstocks · Requires small particle size	Good	·Moderate tar ·Very high in particulates	· Medium scale · Higher throughput · Reduced char · Ash does not melt · Simpler than circulating bed
Circulating Fluidized Bed	A few MW_{th} up to 100 MW_{th}	<15%	· Very fuel flexible · Can tolerate high ash feedstocks · Requires small particle size	Very Good	·Low tar ·Very high in particulates	· Medium to large scale · Higher throughput · Reduced char · Ash does not melt · Excellent fuel flexibility · Smaller size than bubbling fluidized bed
Plasma	<30MW	any	· Greater feed flexibility without the need for extensive pretreatment · solid waste capability	Very Good	· Lowest in trace contaminants; no tar, char, residual carbon, only producing a glassy slag	· Large scale · Easy to control · Process is costly · High temperature (5000°-7000°F)
Liquid Metal	<7MW	<5%	· Generally requires low moisture due to the possibility of steam explosion	Very Good	.Low trace contaminants; virtually no tar, char, residual carbon	· High syngas quality
Supercritical Water	UNK	70 - 95%	· Suitable for the conversion of wet organic materials	Good	· Suppressed formation of tar and char	· Short reaction time · High energy conversion efficiency by avoiding the process of drying step · Selectivity of syngas with temperature control and catalysts

The “ideal” gasifier

- Low capital cost
- Low operational and maintainace cost
- Low operational risk
- High syngas yield
- Appropriate syngas composition and temperature
- Low emissions
- Minimal requirements for feedstock pretreatment
- Feedstock diversity
- Non-complicated start up / shut down processes
- Proven technology

Gasification power generation system



Gasification solid residue

1 ton biosolids (at 17-30% moisture) → **0.29-0.37 MWh net electric output** (depends on technology)

Heating value of syngas: 6-12 MJ/Nm^3 (depends on composition)

Examples of operating biosolids gasification facilities

157 ton/d Sanford, Florida

9 ton/d Emmerich, Germany

872 ton/d Kiyose, Japan

147 ton/d Kamloops, British Columbia

25 ton/d Munich, Germany

41 ton/d Balingen, Germany

Biosolids gasification as renewable energy source

- Energy production depends on wind/sunshine
- Relatively large footprint
- Limited integration to grid, especially in non-interconnected islands
- Relatively trouble free processes

- Stable energy production 24h/d
- Relatively small footprint
- Full integration to grid → suitable for non-interconnected islands
- Biosolids management along with energy production
- Relatively complicated process

Biosolids gasification potential in Greece, and especially in non-interconnected islands

- No permanent solutions for biosolids management are in place, yet
- It is now clear, that the biosolids management cost is paid by the water consumer
- The electrical energy production cost varies significantly from site to site
- The electrical energy production cost escalates in non-interconnected islands

↓

- Biosolids gasification can be a cost effective alternative solution for biosolids management and power generation
- Based on existing data, emission criteria can be met
- Gasification of biosolids along with locally produced woody biomass and/or MSW can provide a sustainable power solution for non-interconnected islands

Regulations and legislation should be further clarified

Biosolids:
Gasification versus anaerobic digestion*

Net power capacity per 1000 m^3/d of raw wastewater

18.8 kW

9.9 kW

Biosolds are a homogeneous product, and thus more suitable than MSW to be used as gasification feedstock

* P. Gikas, 2014, Environmental Technology, 35(17), 2140-2146

MSW gasification: Yield and cost data

Yield, capital and operational cost depends on the selected technology and feedstock characteristics

For a reliable **1MW** gasification process it is estimated:

- Yield ~ **1.2-1.6 MWh/ton**
- Capital cost (only engineering and equipment) ~ **3 – 4 M€**
- Capital cost (turn key) ~ **4.5 – 5.5 M€**
- Operational cost ~ **0.05 – 0.06 €/kWh**
- Return on investment ~ **10 – 25 %** (depends on tipping fee and market price of kWh)

Feedstock

a. Primary fine sieved solids partially dried

b. Primary fine sieved solids after size reduction

Overall Inlet and Outlet from the Gasifier

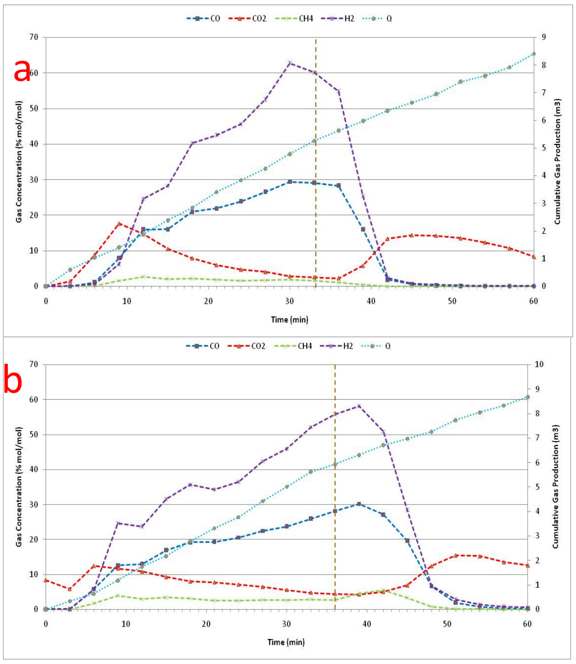
Run No	P F-S solids (kg)	Moisture (%)	Temp. (°C)	CO (%)	CO_2 (%)	CH_4 (%)	H_2 (%)	Other gases (%)	Ash (kg)
Run1	8.15[a]	17	1050	29.87	2.63	1.79	62.96	2.75	0.52[b]
Run2	8.15[a]	17	950	29.86	4.14	2.92	62.18	0.90	0.52[b]

a: Combined weight of infeed charge for Run1 and Run2
b: Total measured weight of ash from both Run1 and Run2 combined

Syngas production → 1.56 m^3 / kg (17% wet basis)

Energy production → 12.63 kJ / kg (17% wet basis)

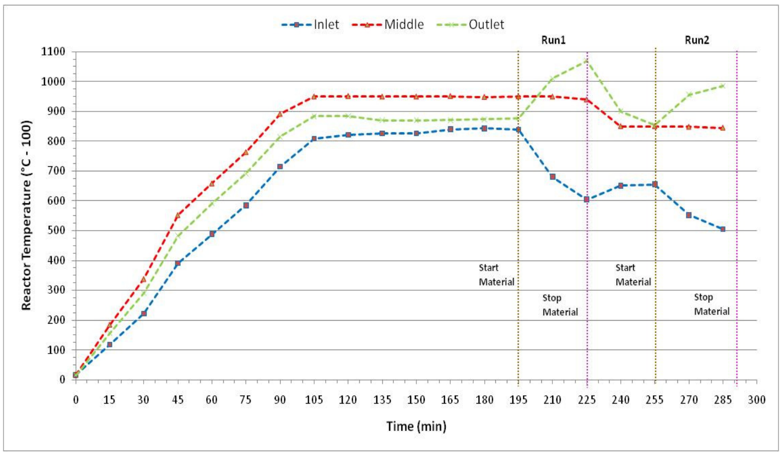
Syngas composition and production rate



a. Run 1: Maximum temperature = 1050 ℃

b. Run 1: Maximum temperature = 950 ℃

Reactor Temperature versus Time



Mass and Energy Balance (Combined Runs)

29.8% CO
3.8% CO_2
2.3% CH_4
62.7% H_2
1.4% other

Heating value of "other gases" is not included

Energy produced: 18.15kg PFS(17% H_2O) → 12.75m³ syngas = 160.9MJ

Energy consumed (electrical): 12 kW for 90min = 66.2MJ

Energy yield: 160.9 MJ / 66.2 MJ ~ 2.4

Concluding remarks

- Biosolids is a renewable energy source
- Gasification is a clean and reliable process. It has been employed successfully for biomass to energy processes
- Gasification can be used for biosolids to energy processes
- Gasification produces a stable electrical output, appropriate for non-interconnected islands
- A proven gasification technology should be selected for biosolids to energy processes
- A 10-25% return on investment may be expected

Thank you for your attention