Influence of Feedstock Variables on Selection of Biomass Based CHP Systems

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Presentation Outline

- ❖ Overview of CHP System
- ❖ Biomass feedstocks for CHP system
- ❖ Key Issues for Biomass Utilization in CHP System
- ❖ Suitable biomass conversion technologies for CHP system
- ❖ Conclusion

CHP System Overview

- ☐ In CHP system ***thermal energy recovery*** is the primary goal to
  - ➢ Improve system’s efficiency (60 to 80%)
  - ➢ reduce the fuel consumption & improve energy security
- ☐ Biomass is one of the sources of thermal energy which can be achieved through:
  - ➢ Direct combustion/Incineration
  - ➢ Syngas combustion through gasification
  - ➢ Pyrolysis (bio-oil, bio-char and bio-gas)
  - ➢ Biogas combustion through biological conversion
  - ➢ Co-firing with solid fossil fuels
- ☐ **Densification**, **Pyrolysis** & **torrefaction** are the techniques to improve the characteristics of the biomass fuels.
- ☐ The recovered thermal energy can be used for: **Heating, Cooling, and Power production**

CHP Applications

Feature	CHP – industrial	CHP – commercial / Institutional	District heating and cooling
Typical Customer	Chemical, pulp & paper, food, textile, timber, minerals, oil refining sectors etc.	Hotels, hospitals, large urban offices, agricultural operations etc.	Office buildings, individual houses, campuses, airports, industry etc. within reach of heat network
Ease of integration with renewables & waste energy	Moderate – high	Low - Moderate	
Size	1 - 500 MW_e	1 kW_e - 10 MW_e	Any
Typical prime mover	Steam turbine, gas turbine, reciprocating engine (CI), combined cycle (larger systems)	Reciprocating engine (SI), Stirling engines, fuel cells, micro turbines	Steam turbine, gas turbine, waste incineration, CCGT

Source: ttps://www.iea.org/chp/chpanddhcapplications/

Biomass Feedstock for CHP System

- **The availability of a suitable biomass feedstock is the key for the success of biomass-fueled CHP project.**

Biomass Resources:

1. Wood & Woody biomass
2. Agricultural biomass (field & processed residues)
3. Animal & human wastes
4. MSW & industrial wastes
5. Residue derived fuel (RDF)

kitchen Waste

MSW/Sludge waste

Energy Crops

Straw Biomass

Manure/excreta

Empty fruit bunch

Sawdust

Compositional Characteristics of Biomass

Fuel type	MC	VM	FC	Ash
Wood and woody biomass	**5 – 63**	**30 - 80**	**7 – 24**	0.1 - 8.4
Herbaceous and agricultural biomass	**4.4 – 47**	**42 – 77**	**9 – 35**	**0.8 - 18.6**
Grasses biomass	**4.5 – 42**	**47 – 74**	**10 – 17**	0.8 - 9.4
Straw biomass	7 – 17	**58 – 74**	**13 – 18**	**4.3 - 18.6**
Hulls, shells & other biomass	**4 – 48**	**42 – 77**	**9 – 35**	0.9 - 16.1
Animal biomass	5.9	**52.5**	**12.8**	28.8
Mixed biomass (wood, agriculture, almond & straw residues)	**7.3 - 30.3**	**55 – 70**	**12.3 - 16.5**	2.3 - 11.4
RDF	4.2	**70**	**0.5**	25
Plastic waste	2.5	**61**	**5.5**	31
Mixed paper waste	8.8	**77**	**6.8**	7.6
Sewage sludge	6.4	**45**	**5.3**	43.3
Wood yard waste	38.1	**41**	**8.4**	12.6
Coal	0.4 - 20.2	**12 - 45**	**18 - 70.4**	5 - 49
Bituminous coal	3.1	**29.1**	**52.6**	15.2
Peat	14.6	**57.8**	**24.3**	3.3
Lignite	10.5	**32.8**	**25.7**	31
Sub-bituminous	8.2	**33.4**	**34.1**	24.3

Source: Vassilev et al. (2010)

Key Issues for Biomass Utilization in CHP System

- ***Low bulk density, high porosity***
  - Road transport accounts ~ 70% of the total delivered biomass-fuel cost
- ***Non-homogeneous, larger particle sizes & Fibrous nature***
  - Imposes difficulties in maintaining constant feed rates & proper mixing between combustion or gasification agent with fuel.
  - Causes difficulty in size reduction
- ***High initial moisture content***
  - Increases flue gas volume in combustion & causes low thermal efficiency
  - Increases the volume of syngas need to be treated in gasification
  - Reduces heating value of product gas & causes problem during combustion in an engine for power production.
- ***Tar production in gasification*** limits the utilization of syngas in gas turbines or engines. **Extensive tar cleaning is required**.

Key Issues for Biomass Utilization in CHP System

- ☐ ***Less carbon & high Oxygen content*** is responsible for having low heating value compared to solid fossil fuels.

- ☐ **Bio-oil** has ***high viscosity*** & ***water content*** (~ 25%)

  - ➢ Reduces heating value
  - ➢ Exhibits excessive ignition delay i.e., high ignition temp.
  - ➢ Have to upgrade bio-oil or modify the existing engines & turbines.

- ☐ ***High ash content &*** the presence of ***Cl, K, N, Na, Si*** & ***S***, P & ***Al*** content in ash are responsible for:

Slagging/Fouling **Sintering** **Corrosion** **Erosion**

- ➢ Reduces ash deformation temperature (~<700^{o}C)
- ➢ Produces corrosive volatiles KCl, HCl & alkali-sulfates.

Ash: The Crux for Biomass Utilization in CHP System

- Low silica (**SiO_2**), Low **K** & High **Ca** → **High fusion temp.**

  Example: Woody biomass

- High silica (**SiO_2**), High **K** & Low **Ca** → Low fusion temp.

  Example: agricultural residues

- High **Ca**, High **P** & **Low fusion temp**.

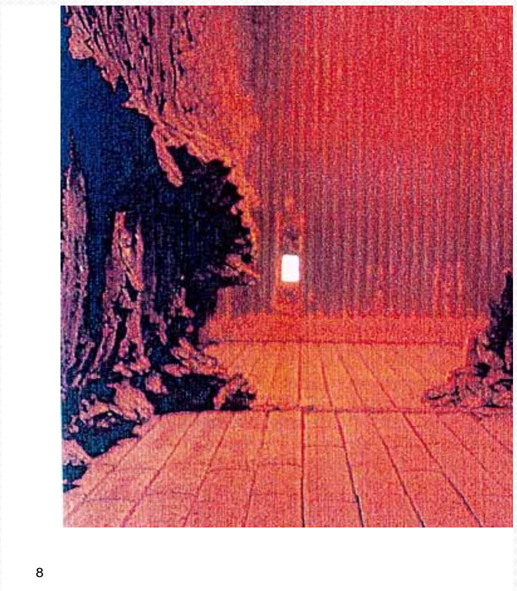
  Example: Manures, poultry litters and animal wastes.

Mineral	Melting temp. (^{o}C)
NaCl	801
KCl	770
K_2S	470
Na_2CO_3	851
K_2CO_3	891
$CaCl_2$	782
Metallic Al	660

Biomass	% Selected minerals in biomass ash			
	SiO_2	CaO	K_2O	P_2O_5
Sawdust	26.17	**44.11**	10.83	2.27
Pine sawdust	9.71	**48.88**	14.38	6.08
Forest residue	20.65	**47.55**	10.23	5.05
Wood pellets (pine)	4.3	**55.9**	16.8	3.9
Rice straw	**77.2**	2.46	**12.59**	0.98
Wheat straw	**50.35**	8.21	**24.89**	3.54
Refuse-derived fuel	**38.67**	26.81	0.23	0.77
Sewage sludge	**33.28**	13.04	1.6	**15.88**
Coconut shells	**66.75**	2.41	8.48	1.54
Sugar cane bagasse	**46.79**	4.91	6.95	3.87

Ash: The Crux for Biomass Utilization in CHP System

- At low melting temperature components present in the flue gases impact & deposit on heat transfer surfaces.
- Typical sticky alkali compounds are NaCl, KCl, Na_2CO_3, K_2CO_3
- Al is also highly problematic – melting temperature of metallic aluminum is 660^{o}C



Slagging in Furnace

Fouling in Furnace

Fouling in Convective Surfaces

Ash: The Crux for Biomass Utilization in CHP System

Fouling in Superheaters

Bed Agglomeration

Bed Sintering In FB Systems

Biomass to Energy Conversion Technologies for CHP System

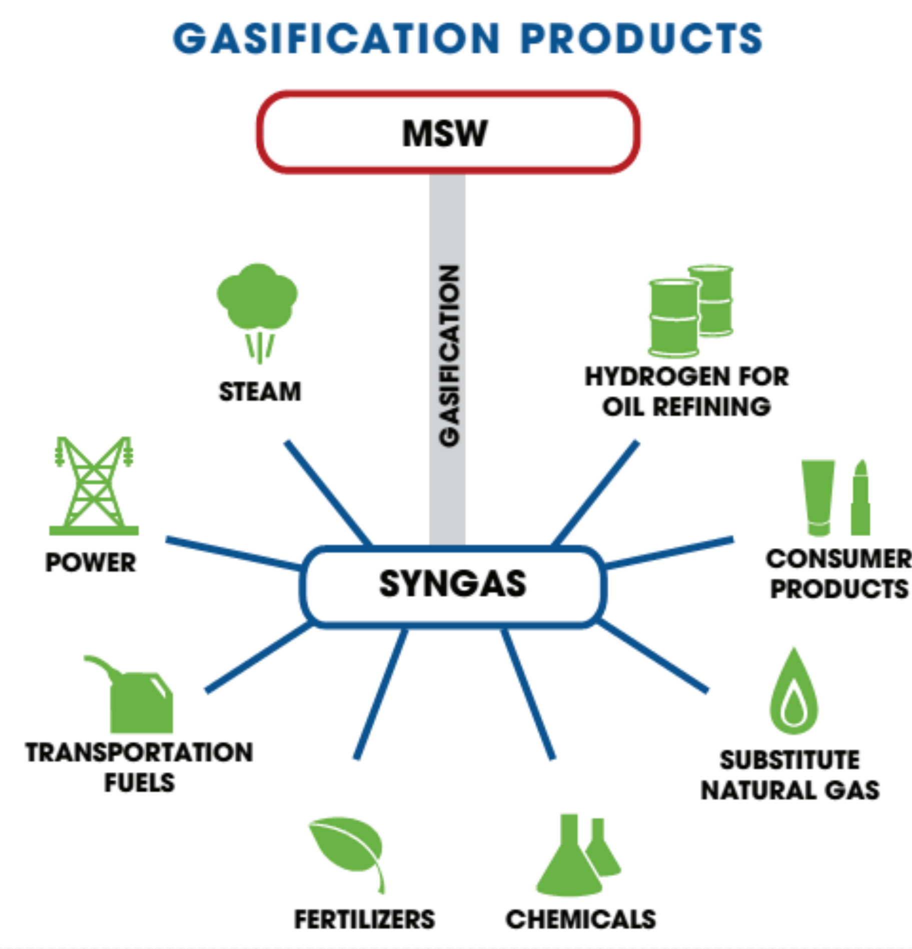
- ❖ **Direct fuel combustion technologies**
  - ▪ Fixed bed combustion
  - ✓ **Fluidized bed combustion (FBC)**
    - o Bubbling fluidized bed combustion (BFBC)
    - o Circulating fluidized bed combustion (CFBC)
  - ▪ Pulverized fuel combustion system
  - ✓ **Co-firing with coal**
  - ▪ Auger-fed automatic combustion systems
  - ▪ Batch firing system
  - ▪ Cigar burning system
  - ✓ **Whole tree energy (WTE) system**
- ❖ **Indirect fuel combustion technologies**
  - ✓ **Gasification, pyrolysis & AD technologies** ⇨ Syngas/ producer gas or biogas or bio-oil

Feedstock Requirements for Combustion & Gasification

Method	Common fuel types	size (mm)	MC (%)
Stoker grate, under fire stoker boiler	Sawdust, bark, chips, hog, fuel, shavings, end cuts, Bagasse, rice husk & others	6 -50	10- 50
Fluidized bed boiler (BFB or CFB)	Bagasse, Wood residue, low alkali content Fuels	< 50	< 60
Co-firing: pulverized coal boilers	Sawdust, bark, shavings, sander dust	< 6	< 25
Co-firing: stoker, FB boilers	Sawdust, non-stringy bark, shavings, flour, sander dust	< 72	10- 50
Updraft FBG	Chipped wood, rice hulls, shells, sewage sludge	6–100	< 20
Downdraft, moving bed gasifier	Wood chips, pellets, wood scrapes, nut shells	< 50	< 15
CFB, dual vessel Gasifier	Wood & chipped agr. residues no flour or stringy material	6-50	15-50

Example: Gasification of MSW for CHP System

- Gasification is a better choice than incineration, reasons are:
  - Final product: Syngas, even composition & homogeneous
  - Post-combustion emission control system
  - Syngas is suitable to burn in turbines or reciprocating engines.
  - Provides infertile atmosphere to form or reform of the most **toxic chemicals dioxins & furans**.



Source: http://www.gasification-syngas.org/uploads/downloads/GTC_Waste_to_Energy.pdf

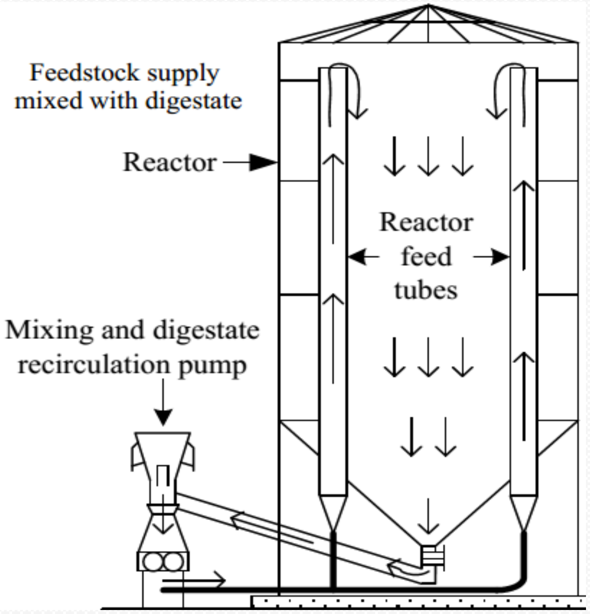
Feedstock Selection for AD ⇨ Biogas for CHP system

- Co-digestion of feedstocks is the adjustment of the carbon-to-nitrogen (C:N) ratio & digester stability (PH value).
- Co-digestion of sewage sludge with agricultural wastes or MSW can improve the methane production.
- Grasses, straws from wheat, rice, & sorghum are promising feedstock for biogas production.
- Manure contains recalcitrant organic fiber which reduces biodegradability. The addition of Food waste is able to solve the issue.
- Thermophilic (55°C) AD of organic fraction of MSW shows ***higher micro-organisms*** growth rate & has the potential to **reduce operating time** & ***increase biogas yield*** compared to mesophilic (35°C) AD.

Source: Ward et al. (2008); Fernández-Rodríguez et al. (2013); Sebola et al. (2014);

Example: Biogas Production from MSW

- **Dranco Process,** Partial stream single-stage Dry anaerobic fermentation system.
- **Soridsep** (Sorting–Digestion-Separation) integrated waste treatment system for the maximum recovery of recyclables & landfill diversion.
- **Substrate (< 40mm)**: Restaurant & food waste, dewatered sludges, Energy crops, source separated organics with or without the addition of non-recyclable paper/cardboard.



Dranco Process

Steam → Anaerobic Digestion

MSW —100%→ Dry sorting —66%→ Anaerobic Digestion —56%→ Wet separation —20%→ Aerobic stabilization

Dry sorting →
- RDF (28%)
- Ferrous metals (5%)
- Non-ferrous metals (1%)

Anaerobic Digestion →
Biogas (12%)

Wet separation →
- Sand (8%)
- Fibers (10%)
- Inerts (8%)
- Fine rest (10%)

Aerobic stabilization →
- Evaporation (5%)
- Dry matter loss (1%)
- Stabilized sludge cake (14%)

Source: http://www.ows.be/household_waste/dranco/ & https://www.youtube.com/watch?v=lbM6R_uvfPc&feature=youtu.be

Example: MSW Based CHP System, Dranco Plants

BRECHT, Belgium

Capacity: 50,000 tpy

Digester volume: 3,150 m^3

Biogas (125 Nm^3/t) is used in **gas engines (3×700 kW_{el})** & **Heat is used to produce steam.**

HENGELO, Netherlands

Capacity: 50,000 tpy

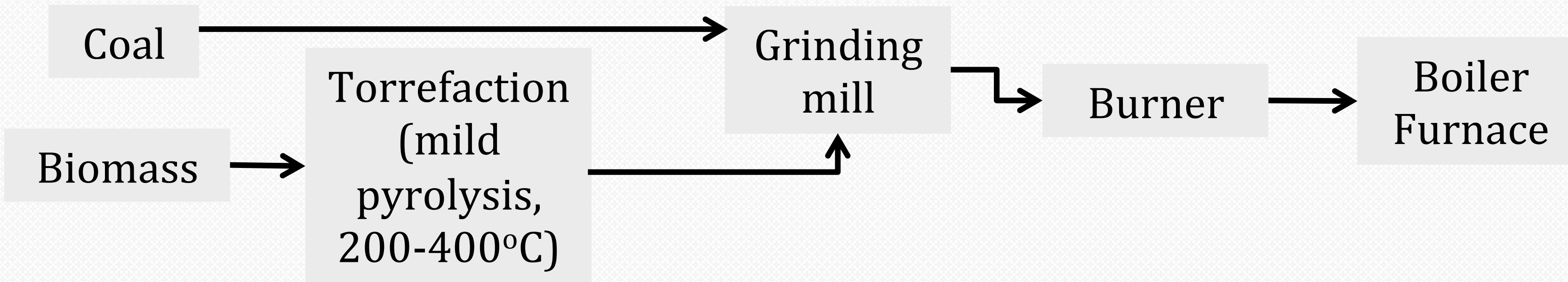
Digester volume: 3,450 m^3

Biogas is used in **gas engines (2×1.2 MW)** & **Heat is used in district heating network**.

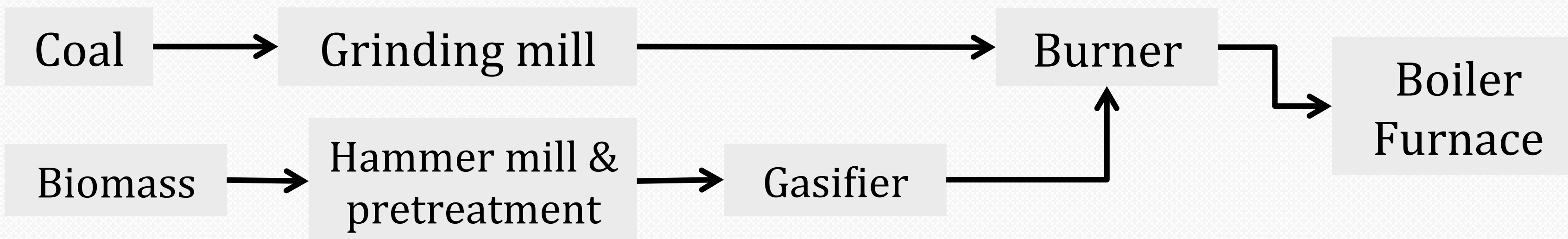
Source: Murcia (2015)

Biomass Co-firing Options for CHP System

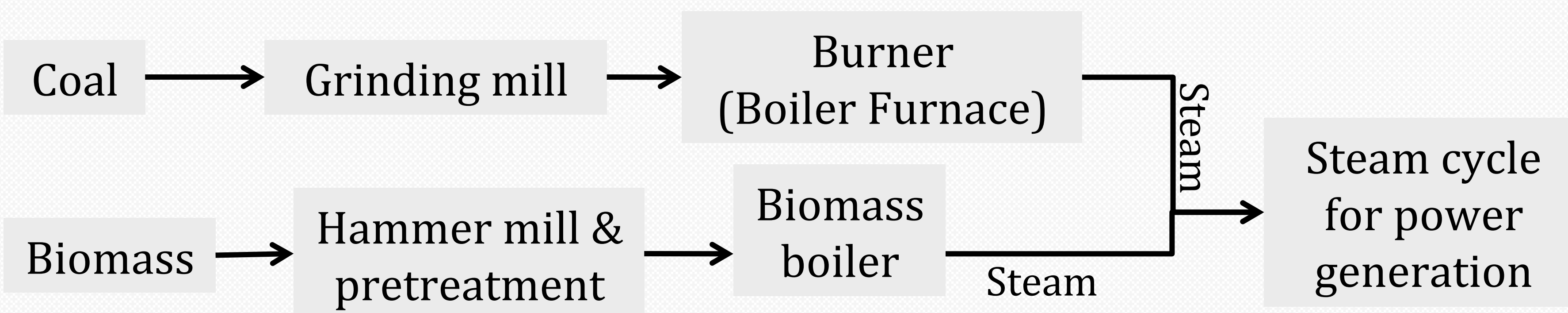
❖ **Direct co-firing (direct combustion)**



❖ **Indirect or external co-firing (through gasification)**



❖ **Indirect or external co-firing (parallel co-firing)**



Comparison of Biomass Co-firing Technologies

Technology variant	Co-firing Technology		
	Direct Co-firing	Indirect Co-firing	Parallel co-firing
Energy efficiency with CHP system	33-42% for traditional system & **44-85% with CHP system**		
Capacity factor, %	20-100%, but **typically between 60-80%**		
Typical plant size, MW	10 to 1,000		Up to 1,000
GHG Emissions (emitted/ avoided) by using local biomass resources	Lignite co-fi ring: 950-1,100 gCO_{2av}/kWh_e		
	Coal co-fi ring: 900-1,000 gCO_{2av}/kWh_{el}		
Other pollutants	On average, 15% NOx emissions reductions with 7% co-fi ring		
Cost scenario (2010 USD)			
Investment cost, USD/kW	430-550	3,000-4,000	1,600 - 2,500
O&M cost, % of investment per year	2.5-3.5% of capital costs	5% of capital costs	For steam cycle, ~ 4% of capital costs
Levelised cost of electricity, USD cents/kWh	**2.2 - 6.7**	**5.0 - 13.0**	**7.0 - 15.0**

Source: IRENA (2013)

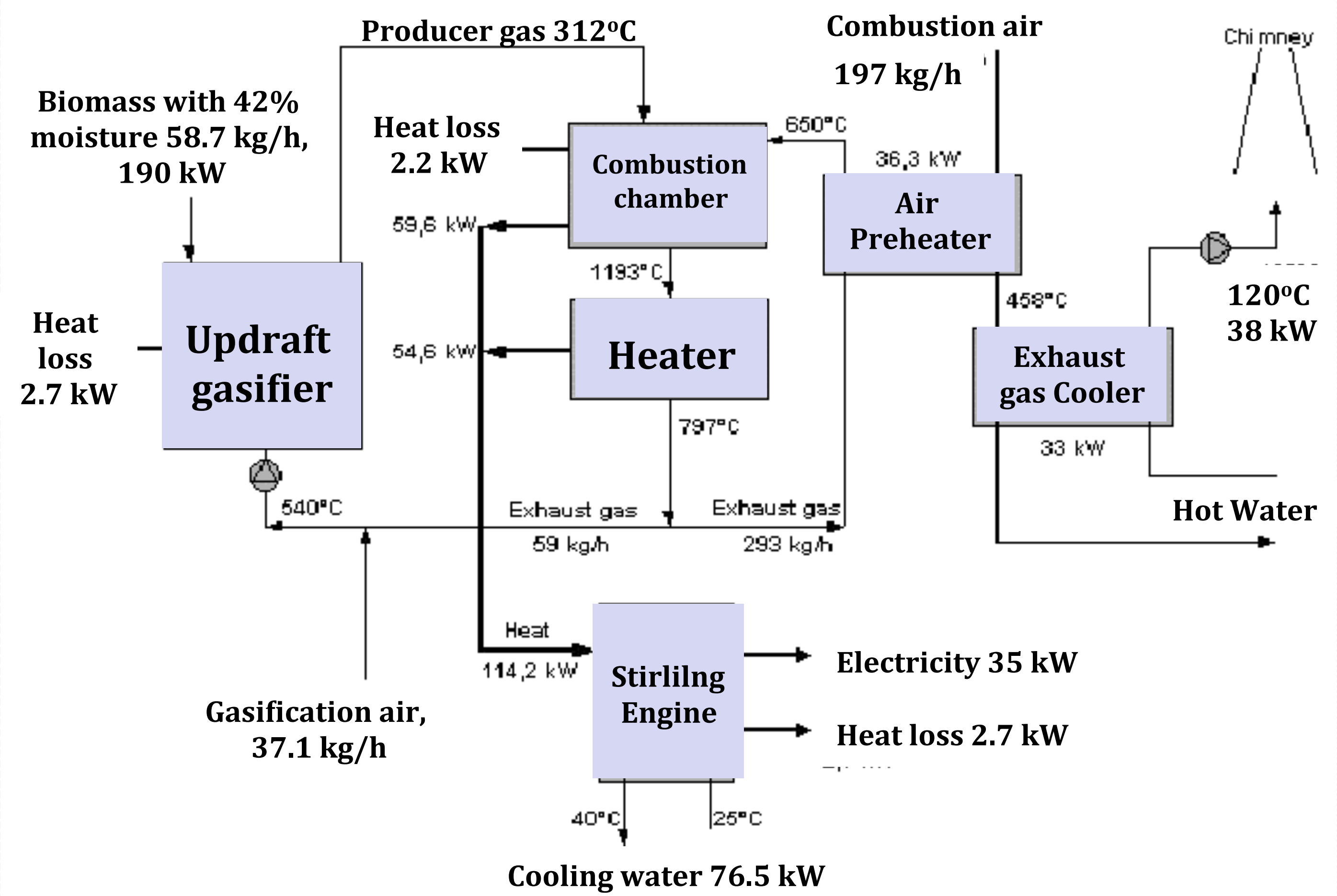
CHP Plant Based on Stirling Engine & Gasifier

- CHP system with ***updraft gasifier and stirling engine*** with a net electrical efficiency of 17.7% & total energy conversion efficiency of 75.3%.

Tar cleaning & cooling of syngas are not required

Exhaust heat can be used for Vapor Absorption Chiller System

Biogas from AD & low-grade biological fuels also can be used as feedstock



Biomass Pyrolysis for CHP Application

- **Hemicellulose, Cellulose & Lignin** are the major components of biomass materials.
- Cellulose is the main source of bio-oil, and Hemicellulose & Lignin are the major source of bio-char.

Product		Pyrolysis type	Reactor	Heating Method	Temp. (°C)	Biomass
Bio-char		Slow	Fixed bed	Furnace or kilns	< 3000	Walnut shell, olive husk, hazelnut shell
Bio-oil	Large scale	Fast	BFB	Heated recycle gas	450 - 550	Agriculture residue, wood chip, fruit shell
	Medium scale	Fast	CFB	Wall & sand heating	450 - 550	Forest residue, municipal waste, dry wood, waste tyre
	Small scale	Flash	PyRos	PyRos heating	450 - 550	Grass, husk, wood dust
Bio-gas		Slow/ Fast	Microwave	Electromagnetic	> 800	Rice husk, Rice straw, wood dust

Whole Tree Energy (WTE) System for CHP System

- The waste heat generated in biomass combustion (power generation) is utilized to dry whole trees (short rotation woody crops).
- A 50 MW power plant requires 18,400 ha of tree (Hybrid Poplar & cotton wood) farms, which is 1% of the land within a radius of 80 km.

Example:

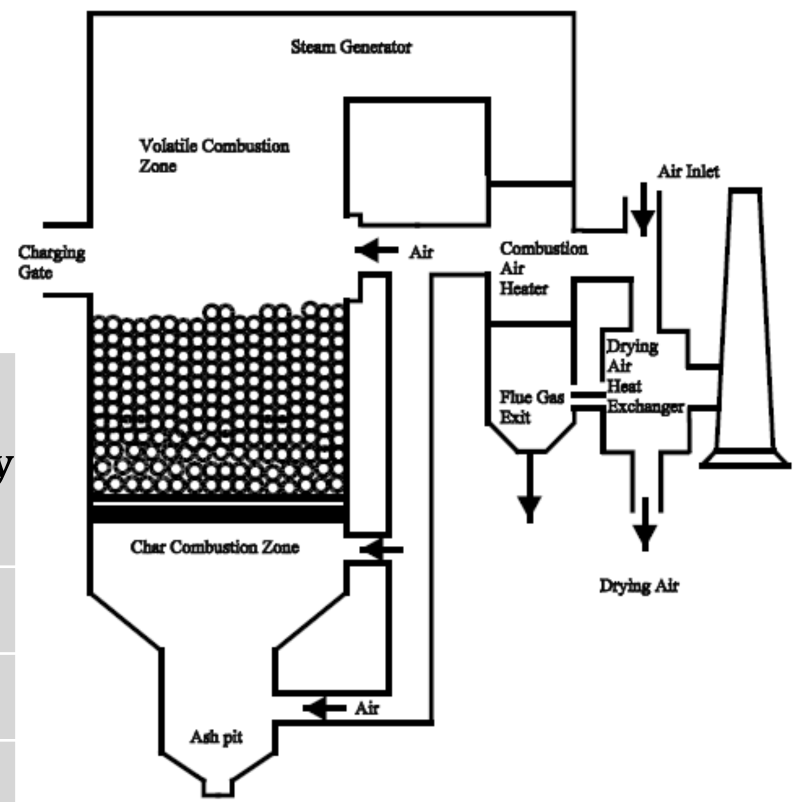
Plant capacity factor: 86.3%

Biomass yield: 11.3 dry ton/ha

HHV: 20.2 MJ/kg

Fuel supply period: 20 years

Power Plant Size (MW)	Total Capital Cost ($ million)	Power Plant Efficiency (%)	Total Land (ha)	Cost of Electricity ($/kWh)
25	85	28.4	10,520	0.064
50	138	32.5	18,400	0.049
150	321	34.1	52,610	0.036



Conclusions

- **Resource availability** (feedstock production, collection & supply) should be ensured.
- **Biomass characterization** is important to select the appropriate biomass energy conversion technology.
- **Biomass Ash** is the major issue in the case of using biomass in combustion based CHP systems.
- **Integrated approach (co-firing & Co-densification)** will maximize the biomass resource utilization.
- **Gasification, Pyrolysis & AD** are the potential energy conversion technologies to utilize biomass resources efficiently.

Energy Park at AIT

Thank You

For more information, please contact:
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