BANZ Webinar, 8 February, 2022

The Potential for Gasification and Pyrolysis of Biomass

Shusheng Pang

Department of Chemical and Process Engineering,
Wood Technology Research Centre,
University of Canterbury, New Zealand

Outline

- Biomass resources and characteristics
- Biomass gasification:
  - Process and equipment;
  - Technical challenges;
  - Commercial/demonstration plants.
- Biomass pyrolysis:
  - Process and equipment;
  - Technical challenges;
  - Commercial/demonstration plants.
- Recent advances
- Concluding Remarks and Future Perspective

Biomass Resources and Characteristics

- Forest residues
  - Harvesting;
  - Young stems from thinning;
  - Damaged trees.
- Wood processing residues
  - Chips;
  - Barks;
  - Sawdust.
- Damaged stems
- Demolition wood

Forest Residues

Most is not used, but costly to use

- Branches, cutovers, stump/roots, leaves

It is not used, but costly to use & may damage surrounding trees

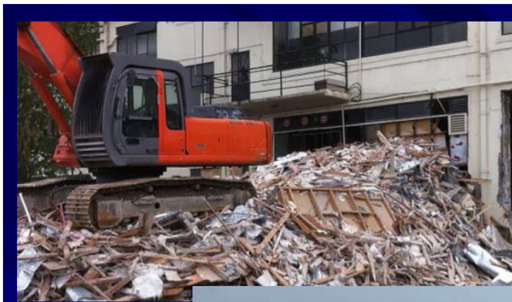
Wood Processing Residues:
Barks, sawdust and off-cuts

largely used for energy and MDF, pulp

Damaged stems and harvesting left overs
(washed to beaches and river sides)

https://www.stuff.co.nz/business/farming/117141715/tolaga-bay-a-beach-covered-in-forestry-waste

not used – an issue for environment



Demolition wood

https://www.stuff.co.nz/the-press/news/118153213/christchurchs-rubble-mountain-the-end-of-an-earthquakedemolition-dump

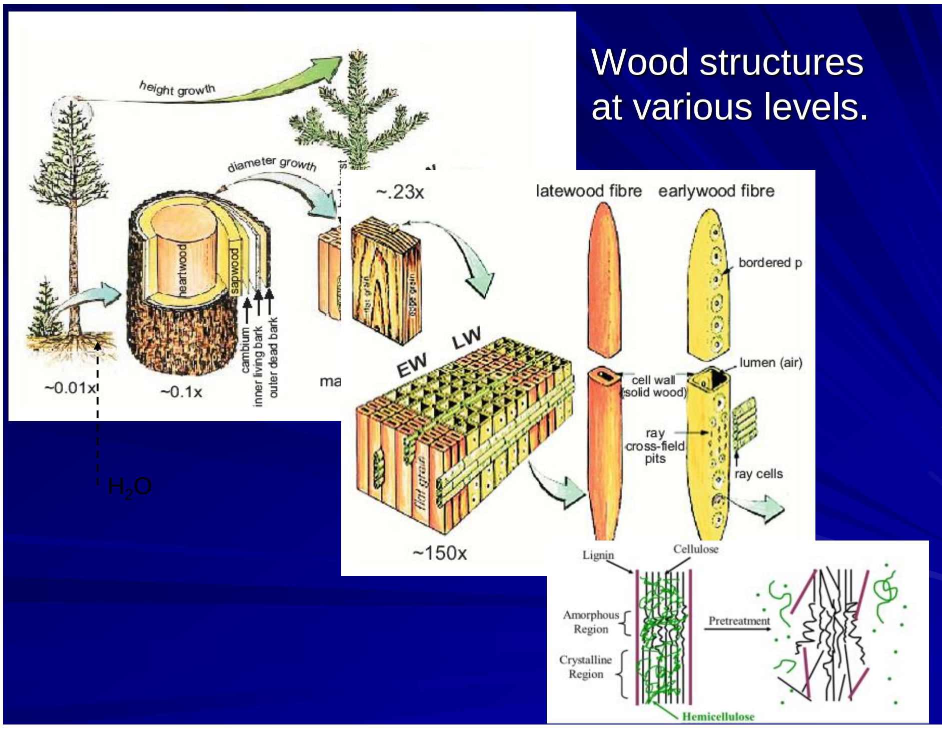
Most is not used – complicated composition

A significant quantity of woody biomass is a potential resource for energy, but is still not used. Why?

- Costs
- Maturity of effective technologies
- Market and uses of the biomass derived energy products
- Environmental issues
- Other factors?

Most of these factors are related to inherent characteristics of the material – complex chemical composition and physical structure!

Wood structures at various levels.



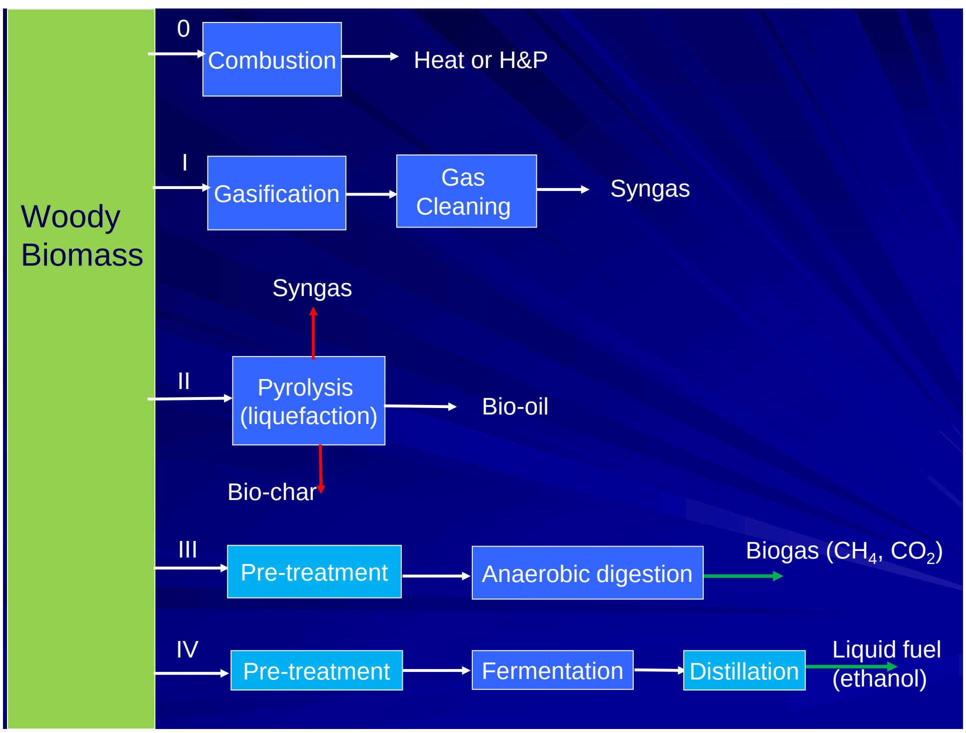
Chemical Composition of Wood (% of Oven-dry Weight)			
	Cellulose	Hemicellulose	Lignin
Softwoods	40 - 44 (40*)	15 - 35 (31*)	18 - 25 (27*)
Hardwoods	40 - 44	20 - 32	25 - 35

*: values in brackets are for radiata pine.

Elemental Composition of Wood	
Element	% of Dry mass
Carbon (C)	44 - 49
Hydrogen (H)	6 - 6.3
Oxygen (O)	41.3 – 44
Nitrogen (N)	slight amount
Ash	0.2 - 1.0

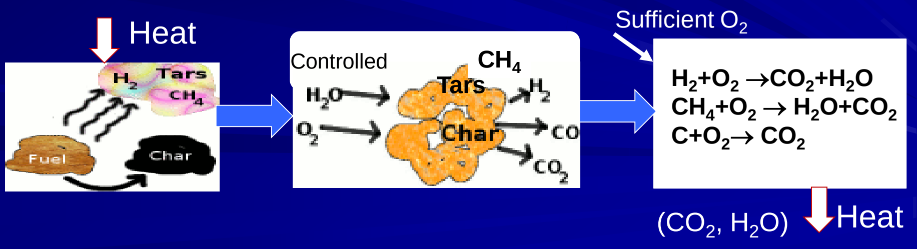
Heating Values of Woody Biomass

- Lower heating values: 19 MJ/kg dry for pine wood
- High heating value: 20 MJ/kg dry for pine wood
- Comparison to fossil fuels (HHV, MJ/kg):
  - Diesel: 44.8
  - Petrol: 47.3
  - Crude oil (heavy): 43
  - Natural gas: 47
  - Methane (CH_4): 50
  - Coal: 20-30



Combustion, Gasification and Pyrolysis

- Biomass combustion includes 3 stages:
  - Devolatilization (release volatiles)
  - Partial oxidation of volatiles
  - Complete oxidation of volatile and char



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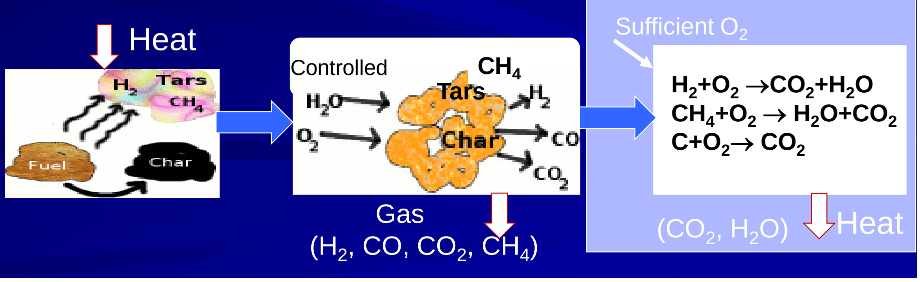
- Gasification includes 2 stages:
  - Devolatilization (release volatiles)
  - Partial oxidation or reactions of volatiles, injected reactant gas and char.



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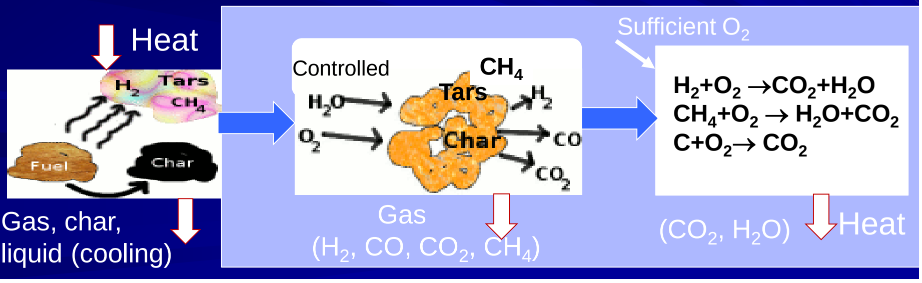
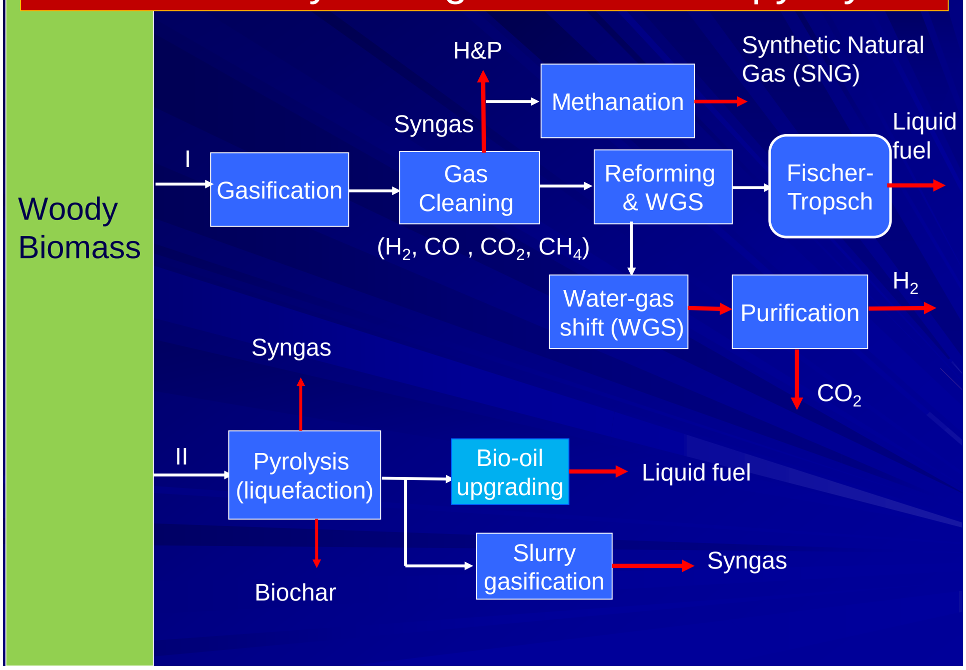
- Gasification includes 2 stages:
  - Devolatilization (release volatiles)
  - Partial oxidation or reactions of volatiles, injected reactant gas and char.
- Pyrolysis: Devolatilization (release volatiles) plus secondary cracking and repolymerisation of volatiles of volatiles if time allows.



Our focus today is on gasification and pyrolysis



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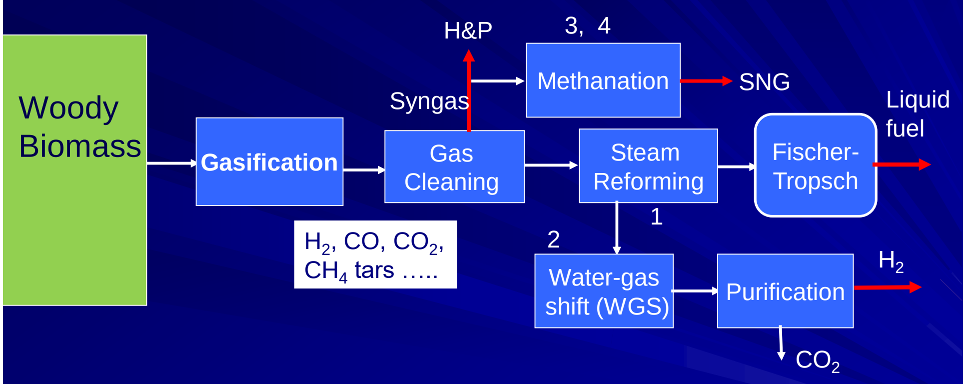
Gasification Process, Technology Challenges and Applications

Gasification, Gas Reforming/Methanation, Liquid Fuel Synthesis.



1. Steam-methane reforming: $CH_4 + H_2O \rightarrow CO + 3H_2$
2. Water-gas shift: $CO + H_2O \rightarrow CO_2 + H_2$
3. CO methanation: $CO + 3H_2 \rightarrow CH_4 + H_2O$
4. CO_2 methanation: $CO_2 + 3H_2 \rightarrow CH_4 + H_2O$

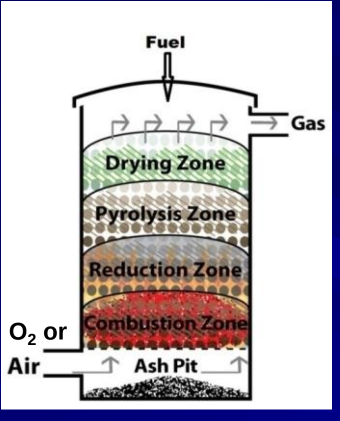
Biomass Gasification

- **A thermochemical process** to convert biomass into a gas product (product gas, producer gas or syngas) consisting of H_2, CO, CO_2, CH_4 and other species under a controlled amount of gasification agent (O_2, air, steam).
- Advantages of biomass gasification:
  – High efficiency for energy conversion;
  – Flexibility for the product gas use.
- Operation temperature is lower (700 - 900°C) compared to combustion, corrosive ash elements in the feedstock (such as bio-wastes) can remain in ash, allowing clean gas production.

Effects of gasification agent

- Air is cheap, but
  – The product gas contains N_2, thus has low heating value (4-7 MJ/nm^3).
  – Low energy efficiency.
- Oxygen removes N_2 related problem and product gas has high heating value (12 – 14 MJ/nm^3) but
  – High cost for O_2 production.
- Steam (H_2O) also removes N_2 related problem, can enhance gas yield, particularly for H_2, and has high heating value as well, but
  – Needs external heat input – reactions overall are endothermic.

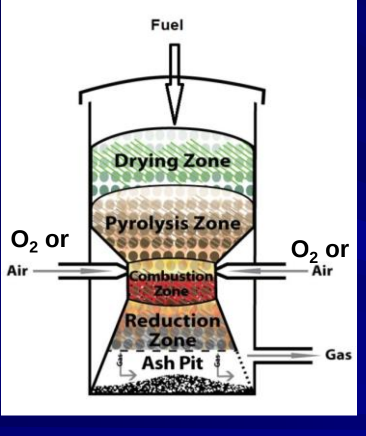
Fixed bed gasifier: updraft (counter-current)



- Simple and robust construction.
- High residence time of solids.
- High carbon conversion.
- Producer gas with high level of tars.
- Non-uniform temperature profile within the gasifier.
- Suitable for small to medium scale of 1-10 MWth

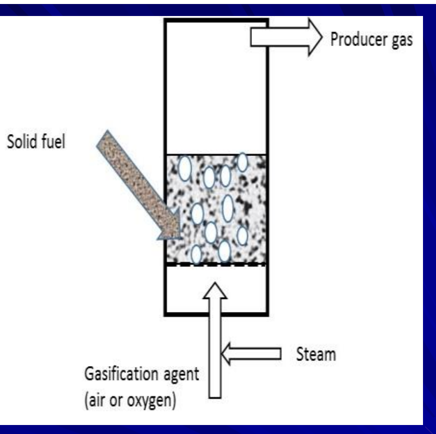
  (200 – 2000 kg/hr dry biomass feeding)

Fixed bed gasifier: downdraft (co-current)



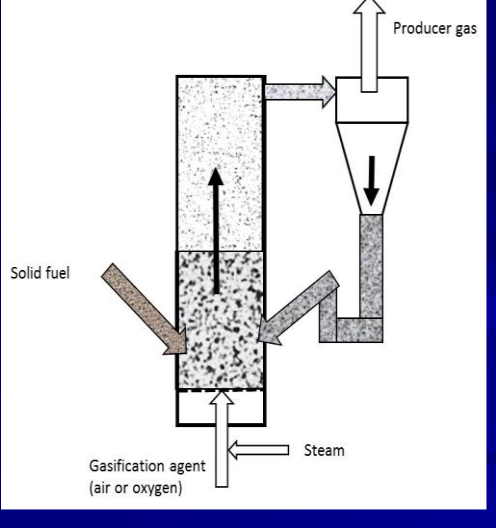
- Simple and reliable.
- High carbon conversion.
- Tar cracking occurs around the throat which is high temperature zone.
- Produces relatively clean gas.
- It requires low MC biomass.
- Long residence time for solids.
- Non-uniform temperature profile within the gasifier.
- Suitable for small scale of 100 kWth - 2 MWth.

Bubbling fluidised bed gasifier



- Good temperature control.
- High transfer/reaction rates.
- Moderate tar level in producer gas.
- Tolerable for variable biomass in certain ranges (sizes, MC).
- Higher ash carry-over.
- Suitable for medium scales < 25 MWth (<5 tonne biomass feed /hr).

Circulating fluidized bed gasifier



- Similar characteristics to the bubbling fluidized bed gasifier, but smaller size at the same capacity (high gas velocity).
- Easier to scale-up.
- Equipment and operation are more complicated.
- Suitable for large scale, 10-100 MWth.

Product Gas Quality from Different Types of Gasifiers

	Gas composition, %v/v dry					HHV, MJ/Nm^3	Gas quality	
	H_2	CO	CO_2	CH_4	N_2		Tars	Dust
Fluid bed air-blown	9	14	20	7	50	5.4	Fair	Poor
Updraft, air-blown	11	24	9	3	53	5.5	Poor	Good
Downdraft, air-blown	17	21	13	1	48	5.7	Good	Fair
Downdraft, oxygen-blown	32	48	15	2	3	10.4	Good	Good

Issues for Gasification: Product gas contains tars and contaminant gas species

- Tars in the product gas:
  - High molecular weight organic compounds which are undesirable in the downstream applications of the producer gas.
  - Condensable at reduced temperatures.
- Contaminant gas species:
  - Converted from N (NH_3) and S (H_2S) in the biomass;
  - Can be poisonous for downstream catalyst.
- Research has been focussed on the low cost solutions.
- Product gas quality vs complexity (costs).
- Handling of feedstock variability (density, size, MC).

Gas Composition and Application Requirement

Gas parameter	Gas from the DFB gasifier	Gas for gas engine	Gas for liquid fuel synthesis and syngas production
Calorific value MJ/Nm³	11-14	>4	NA
H_2/CO molar ratio	1-4	NA	2
Particles (soot, dust, ash)	Not measured after cyclone and filter	Free of >5µm	none
Tar, mg/Nm³	2000-9000	Below tar dew point	Below tar dew point
NH_3, ppmv	500-1000	≤20	<1
Sulphur (H_2S) ppmv	50-150	≤150	<1

Biomass Gasification Demonstration/Commercialisation Projects

– There are currently around a hundred of biomass energy and biofuel plants in the world (many are at demonstration scale):
- Most were successful, having achieved the targets.
- About a quarter were below targets.
- Some were stopped before commissioning.
- Some failed during operation.

– Examples of gasification technology suppliers:
- Güssing Renewable Energy Ltd (https://www.gussingrenewable.com/)
- Ankur Scientific Energy Technologies Pvt. Ltd. (https://www.ankurscientific.com/)

GÜSSING RENEWABLE ENERGY

- Güssing Renewable Energy Ltd owns the Güssing biomass gasification technology (dual fluidised bed system).
- Focus on carbon cycling technologies.
- Has been marketing in EU and established a branch in Thailand, and built a 4 MWth plant in Nong Bua near Bangkok.
- A representative (Janjira Hongrapipat: janjira.hongrapipat@gmail.com) has been promoting the technology in Asia/New Zealand.

Steam Gasification – Güssing Demonstration Plant, Austria

Start of construction	September 2000
Start up	January 2002 (stopped for overhaul)
Feed fuel	2 t/hr, wood chips
Moisture content in fuel	15 to 35wt%
Feed capacity	8 MW
Electrical power	2 MW
Heat output	4.5 MW
Electrical efficiency	20 to 25%
Overall efficiency	85%

Dual Fluidised Bed Gasification Technology for H&P

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1st commercial plant Thailand, Nongbua

TU WIEN TECHNISCHE UNIVERSITÄT WIEN
LABORATORY

Güssing Renewable Energy
TECHNOLOGY

HOST

SCG
EPC

METRO CAT
GENSET

Commissioning
Q3 2017

Feedstock
Multi

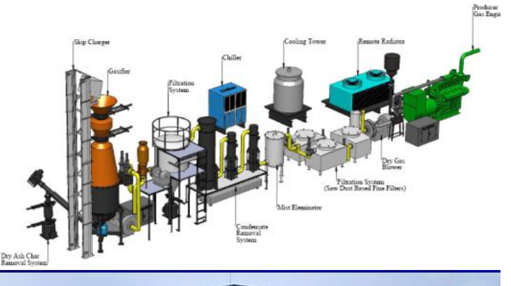
Fuel Power
4 MW

Electric Energy
1 MW

Thermal Energy
1 MW

- Ankur Scientific Ltd., India, was established in 1986, specialising in waste gasification technologies (mostly fixed bed) for energy.
- Including power and heating systems.
- Marked over 35 countries.
- Gavin Headley (gavinlhedley@gmail.com) has been trying to import the Ankur's technology to New Zealand.
- Ankur contact: ashok.chaudhuri@ankurscientific.com

STEC gasifier project, Samoa



- Capacity 750 kW power
- Feedstock: Forest Residue (woody biomass)
- Technology: Ankur
- Commissioned 2018-19, under operation since then.
- Engineer and Project Manager:

Fonoti Perelini Perelini: perelini48@gmail.com

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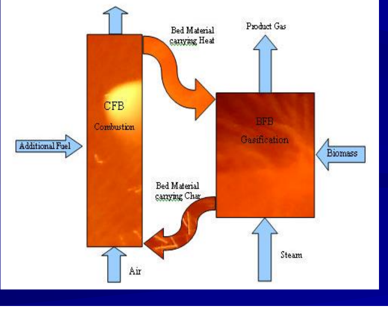
Gasification Activities in New Zealand

Advanced Biomass Gasification for H_2-rich Syngas Production

- We developed and constructed a 100kW$_{th}$ dual fluidised bed gasifier.
- Steam is used as gasification agent.



Advantages of the dual fluidised bed (DFB) steam gasification

- The producer gas has high calorific value (11-14 MJ/Nm^3) in comparison with producer gas from air gasification (4-7 MJ/Mm^3).
- By management of bed material and operation conditions, producer gas can have a wide range of H_2 to CO ratio from 0.9 to 4.1, which provides flexibility for gas applications.
- The dual fluidised bed structure is ideal for in-bed CO_2 capture and management.

Experiments performed

- Feedstock tested:
  - Wood pellets (radiata pine).
  - Blends of wood pellets and sewage sludge pellets (biosolid).
  - Pellets of biomass and coal blend.
  - Corn Stover, rich husk.
- Bed materials tried:
  - Silica sand.
  - Olivine sand.
  - Calcite.

Selected results from tests on the 100kw DFB steam gasifier

Run	Bed Material	BFB Temp, °C	H_2	CO	CH_4	CO_2	H_2/CO	LHV, MJ/Nm^3
1	100% Greywacke (control)	767	29%	32%	12%	23%	0.9	13.3
2	100% Olivine	700	35%	29%	12%	19%	1.2	12.9
3	50% Olivine 50% Calcite	694	40%	20%	12%	23%	2.0	12.8
4	50% Greywacke 50% Dolomite	699	40%	23%	12%	20%	1.7	13.8
5	50% Greywacke 50% Calcite	713	50%	18%	11%	18%	2.8	12.3
6	100% Calcite	716	62%	15%	11%	11%	4.1	12.5

Fluidyne Gasification Ltd

- Fluidyne sold overseas its downdraft gasifiers (100kW-2MW).
- Sadly, the founder (Mr Doug Williams) passed away in sudden in 2019.
- The family donated two pilot gasifiers to University of Canterbury.

Agder Biocom-Windsor Engineering Gasifier

- Agder Biocom (Norway) through Windsor Engineering built a 1.5MWth gasifier at Waiariki Institute of Technology in Rotorua in 2010-2011:
  - A training facility for wood processing students at the WIT.
  - Gas is used to replace natural gas for existing boiler to generate steam for two Windsor timber drying kilns.

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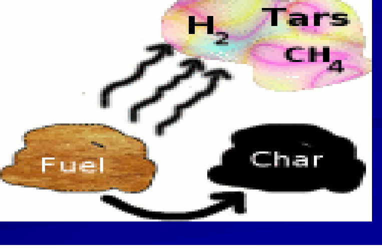
Pyrolysis Process, Technology Challenges and Commercialisation

Biomass Pyrolysis

- Direct thermal decomposition (devolatilization) of the biomass organic components in absence of oxygen to yield vapours (bio-oil when cooled down), non-condensable gases and solid char (bio-char).
- Pyrolysis operation can be classified by residence time, heating rate and pyrolysis temperature.
  - Carbonation, a traditional method for charcoal production.
  - Conventional pyrolysis or slow pyrolysis.
  - Fast pyrolysis, which produces high yield of liquid or gases.



Typical Product Yields (dry feed basis) under Different Conditions in Pyrolysis of Wood

	Charcoal	Liquid	Gas
Fast	12%	75%	13%
Conventional	35%	30%	35%

Pyrolysis Technologies and Characterisations

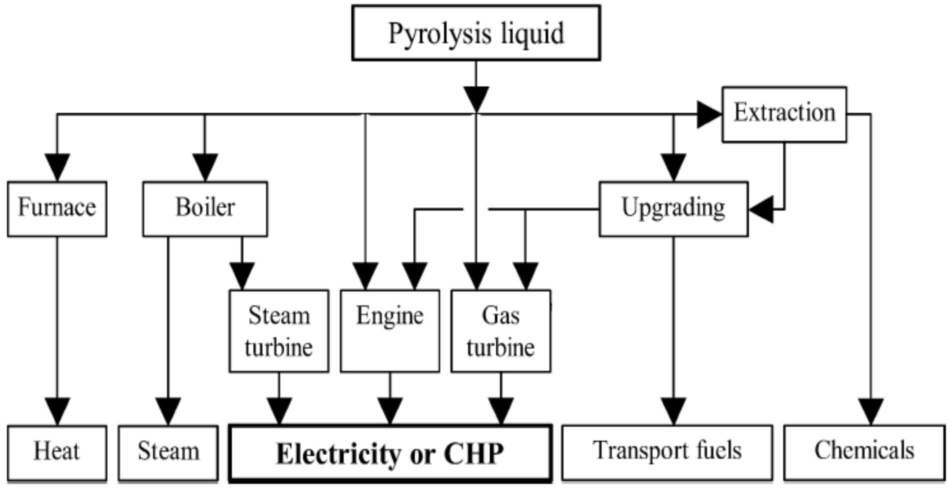
Technology	Residence time	Heating rate	Temperature °C	Target products
Carbonation (torrefaction)	Hours to days	Very low	<300	Charcoal
Conventional pyrolysis	5-30 min	Low	400-450	oil, gas, char
Fast pyrolysis*	0.5-5s	High	450-650	bio-oil
Flash-liquid pyrolysis*	< 1 s	High	< 650	bio-oil
Flash-gas pyrolysis#	~1 s	High	~650	chemicals, gas
Hydro-pyrolysis (liquefaction)	< 10s	High	< 500	bio-oil

*. With rapid cooling of pyrolysis vapours, more bio-oil is formed.
#. With slow cooling of pyrolysis vapours or applying catalysts, more gas is formed.

Characteristics of pyrolysis liquid compared with conventional liquid fuels

		Pyrolysis liquid	Diesel	Heavy fuel oil
Density	kg/m³ at 15°C	1220	854	963
Typical composition	%C	48.5	86.3	86.1
	%H	6.4	12.8	11.8
	%O	42.5	–	–
	%S	–	0.9	2.1
Viscosity	cSt at 50°C	13	2.5	351
Flash point	°C	66	70	100
Pour point	°C	−27	−20	21
Ash	%wt	0.13	<0.01	0.03
Sulphur	%wt	0	0.15	2.5
Water	%wt	20.5	0.1	0.1
LHV	MJ/kg	17.5	42.9	40.7
Acidity	pH	3	–	–

Application of the Pyrolysis Liquid



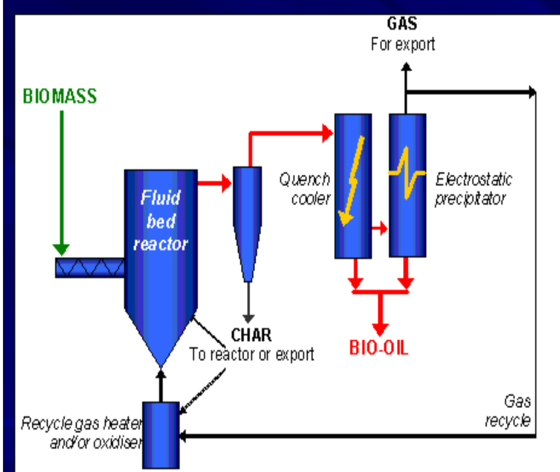
Chemical Upgrading of Pyrolysis Oil

- Bio-oil can be upgraded to chemicals, hydrocarbons or intermediates for further refining.
- Catalytic cracking and hydro-treatment are two main methods for converting bio-oil into transport fuel, such as diesel and gasoline.
- Generally bio-oil derived from biomass contains about 70% of the energy.
- While the energy content of upgraded bio-oil is 50-60% of the feedstock after upgrading.

Fast Pyrolysis Reactor

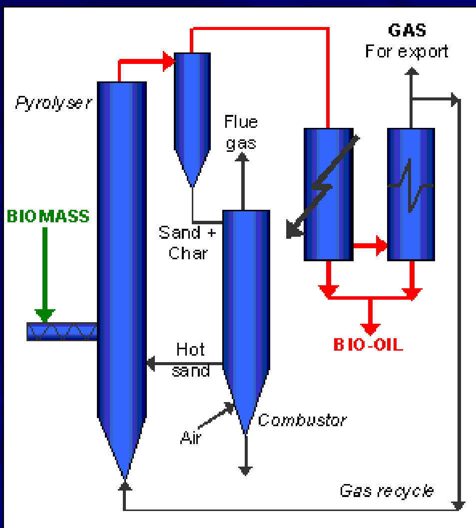
- The pyrolysis for bio-oil system needs to have:
  - Very high heating rate,
  - Well controlled reaction temperature, and
  - Rapid cooling or quenching rate of the vapours to liquid product.
- Types of reactors:
  - Bubbling fluidised bed;
  - Circulating fluidised bed;
  - Rotating cone.

Bubbling Fluidised Bed System



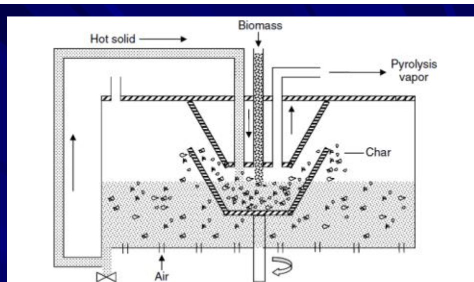
- Silica sand is used as bed material.
- Good temperature control.
- Easy scale-up.
- Good and consistent performance.
- High liquid yield 70-75% (mass) from wood.

Circulating Fluidised Bed System



- Commercial unit available.
- Silica sand is used as bed material.
- Integrated char combustion in a secondary reactor to provide heat.
- Good temperature control.
- Liquid yield 60-70% from woody biomass.

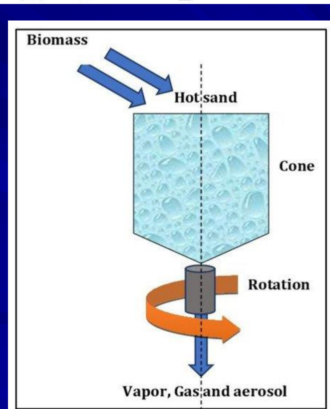
Rotating Cone System



- Enhance heating transfer between sand and biomass thus uses less inert gas and smaller reactor size.
- Internal separation of gas/vapour phase with solid phase (char and sand).

But:

- Consumes power.
- Equipment wear.



Challenges in Biomass Pyrolysis

- Bio-oil production for liquid fuel:
  - Upgrading is a complex and costly process at high pressure/temperatures.
  - Bio-crude at industrial capacity production still needs refining for drop-in liquid fuel.
- Bio-char production:
  - For solid fuel – comparing with torrefaction.
  - For soil amendment – benefits against costs.
  - For carbon sequestration and solid amendment – large scale verification.
- For chemical production:
  - Large number of species (>200) thus needs huge efforts for upgrading and purification.
  - Needs to demonstrate high value products.

Commercialisation of biomass pyrolysis: BTG/Empyro

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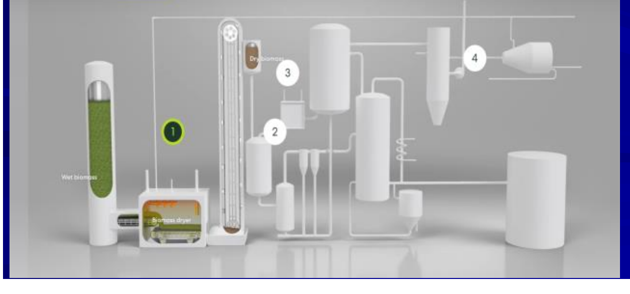
https://www.btg-bioliquids.com/plant/empyro-hengelo/

- Built in 2014 by BTG bioliquids and Empyro BV, in Hengelo, The Netherlands
- 5 tonnes feed/hr
- 24,000 tonnes bio-oil/year

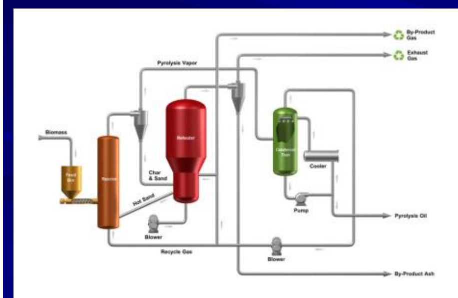


- Based on rotating cone reactor technology.

Commercialisation of biomass pyrolysis: ENSYN

https://www.ensyn.com/

- Ontario ENSYN plant, in Canada.
- Commissioned in 2006 and second phase in 2017
- 3 million gallon (11.4 million L) per year liquid bio-crude.
- Based on circulating fluidised bed technology.



Other Technologies for liquid bio-fuels based on solvent liquefaction

- Licella (https://www.licella.com/)
- Steeper Energy (https://steeperenergy.com/)
- Genifuel (http://www.genifuel.com/)

Biomass Pyrolysis Activities in New Zealand

Biomass Pyrolysis Research at University of Canterbury

- We have developed a process:

Biomass pre-treatment→ Pyrolysis→ Fractionation→upgrading.

- Different upgrading technologies are used for different fractions.

A joint PhD (X. Xing) project of Scion-UC on catalytic pyrolysis of pretreated wood: Experimental Setup at Scion, Rotorua (0.5-1 kg/hr)

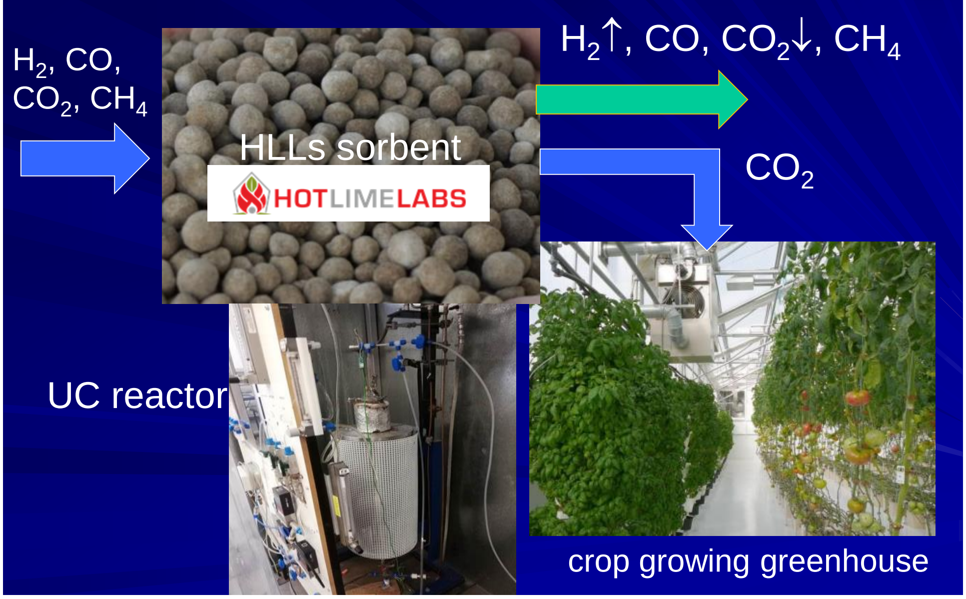
Effects of torrefaction, and combined torrefaction and acid leaching pretreatment

C/B ratio 2.5	Rwood 500 °C	Twood 500 °C	ALTwood 500 °C
Yields of products, wt.%			
Oil	8	12	10
Produced water	24	16	18
Solid	24	32	29
Gas	39	36	37
Key properties of oil product			
Oxygen content, wt.%	13.2	14.9	13.7
O/C (mol/mol)	0.12	0.14	0.13
Main compounds in oil product by GC/MS analysis (%)			
Aromatics	76	77	76
Aromatics, oxygenated	10	9	9
Phenols	14	13	14

Recent Advances

- Integration with CO_2 capture and CO_2 utilisation
- Bio-coke production from torrefaction.
- Biomass densification through pyrolysis for centralised gasification.
- Hydrogen production.

Post-gasification CO_2 capture (Hot Lime Labs and Canterbury University)



Torrefaction (batch pyrolysis) for Production of Solid Fuel (Bio-coke)

- Waste Transformation plant in Timeru.

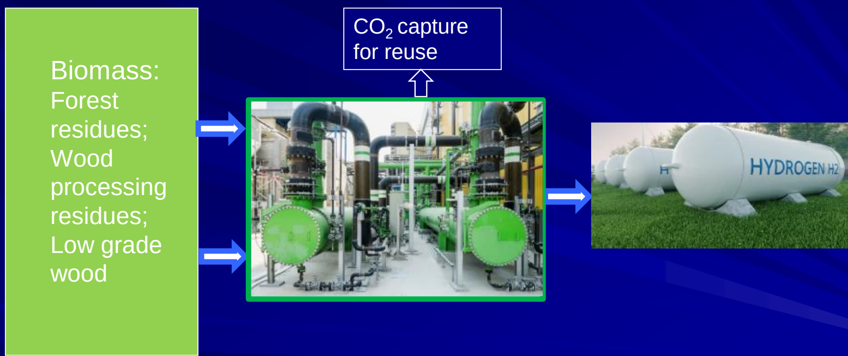


- Pyrolysis is used as a densification tool to increase the feedstock density. The bio-oil/char slurry is then gasified for production of clean producer gas.

↑ University of Canterbury' entrained flow gasifier (4 kg bio-oil feed/hr)

→ Karlsruhe Institute of Technology's BioLiq^R pilot plant (1 tonne biomass/hr).

Hydrogen production from biomass through advanced biomass gasification with CO_2 capture



Challenges in Converting Biomass to Energy and Fuels

- Challenges for commercialisation:
  - Reduction of production cost (better economic returns);
  - Increasing conversion efficiency;
  - Minimizing negative impacts on environments.
- From engineering points of view:
  - Large scale plants have high efficiency and low capital/operating costs for unit product output.
- However, biomass has low density and most available biomass is widely distributed, thus costs of biomass transportation and handling increase with biomass quantity needed for a large scale plant.

Future Perspectives

- At present:
  - Combustion of biomass for heat or H&P.
  - Needs to handle variable feedstock, reduce emissions and increase efficiency.
- Short – Medium:
  - Clean fuels (solid, gaseous and liquids) based on gasification, pyrolysis, torrefatcion and liquefaction.
  - Needs to consider new technology demonstration /verification, process integration, multi- (poly-) generation.
- Longer term:
  - Resource development;
  - Technology options available (both thermochemical and bio-processing).

Future Perspectives (cont.)

- Economics hold the key, and
- Government financial support for R&D and demonstration plant is critical!

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