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WASTE TO ENERGY CONVERSION

ENERGY PRODUCTION FROM WASTES THROUGH PYROLYSIS-2

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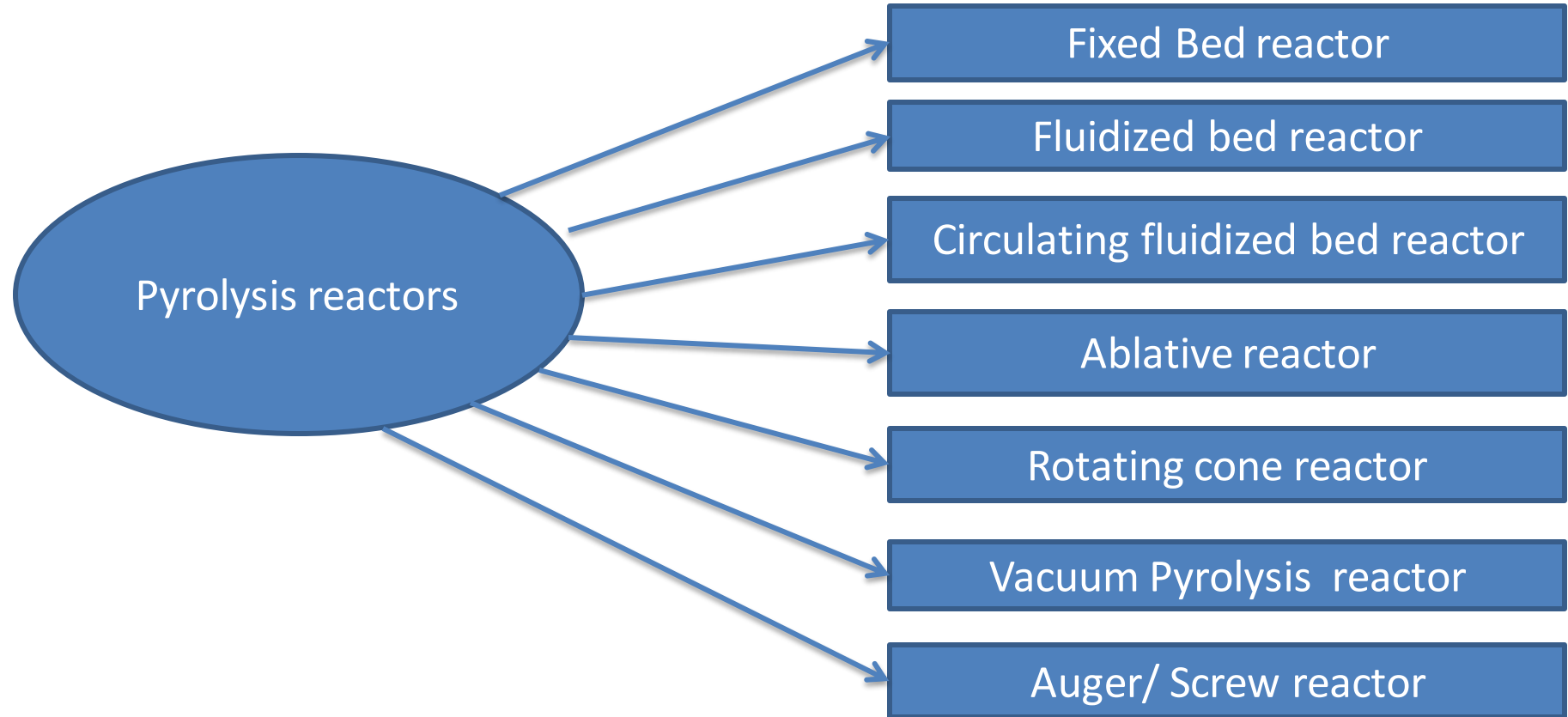


Contents

- Definition of pyrolysis, mechanism
- Types of pyrolysis
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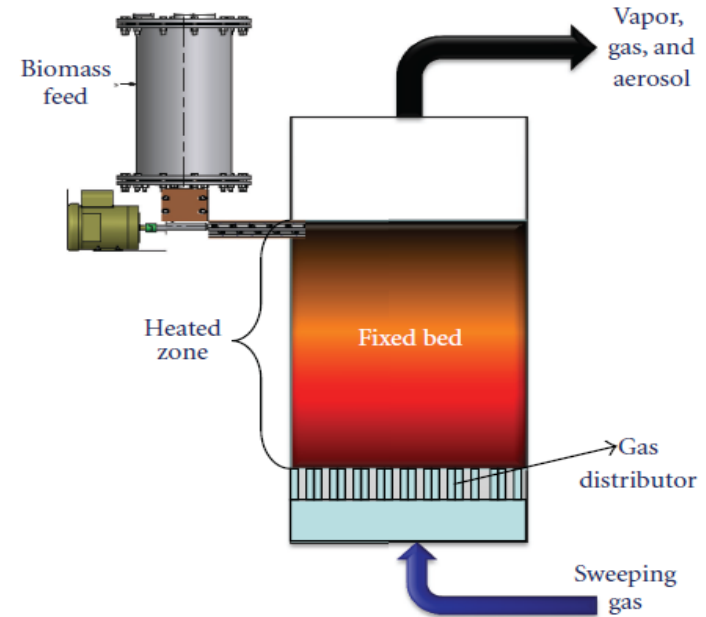


Important pyrolysis reactors



Fixed bed reactor

Main features	Description
Advantages	➤ Simple design ➤ Reliable ➤ Biomass size independent
Disadvantages	➤ High carbon conservation ➤ Long solid residence time ➤ Low ash carry over ➤ Difficult to remove char
Bio-oil Yield	35%–50%



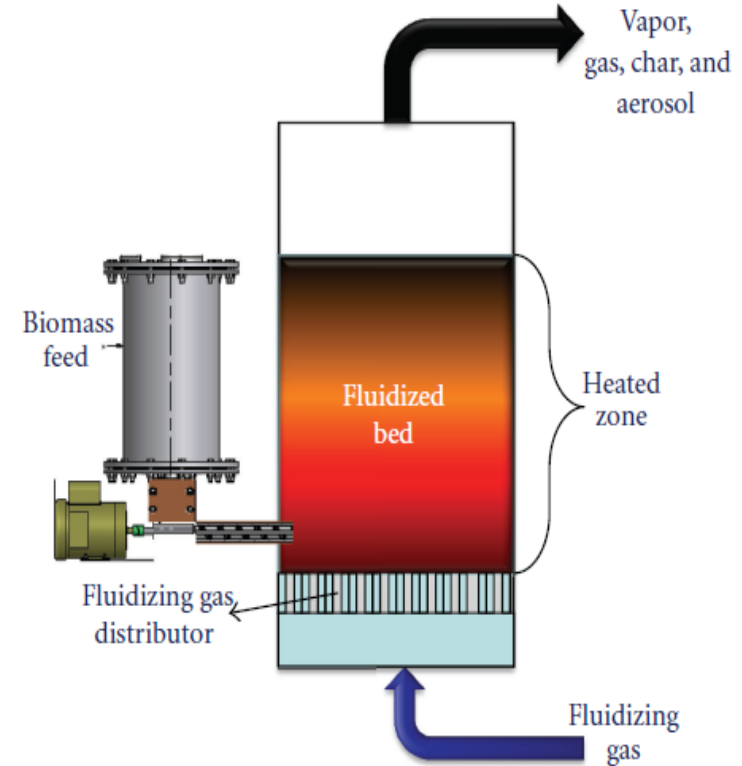
Verma et al. 2012, International Journal of Chemical Engineering, 2012;
<http://dx.doi.org/10.1155/2012/542426>



Fluidized bed reactor

Main features

- High heat transfer rates
- Heat supply to fluidizing gas or to bed directly
- Limited char abrasion
- Very good solids mixing
- Particle size limit $< 2\text{mm}$ in smallest dimension
- Simple reactor configuration
- Residence time of solids and vapors controlled by the fluidizing gas flow rate



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Fluidized bed reactor

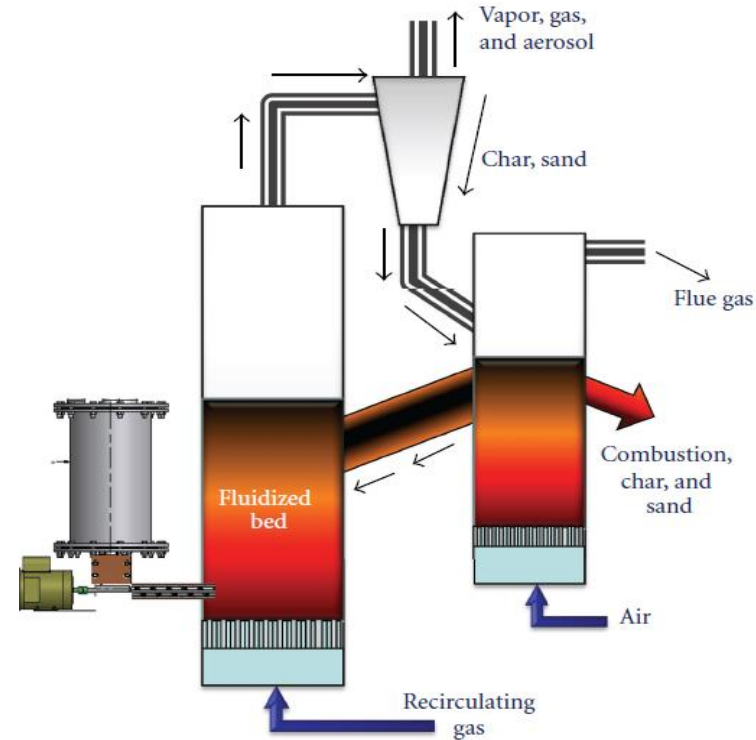
Features	Description
Modes of heat transfer	90% conduction, 9% convection, 1% radiation
Primary heat transfer method	Solid-solid; Gas-solid
Heating method	Heated recycle gas; Hot inert gas; Partial gasification
Advantages	Simple design Easy operation Good temperature control Suitable for large scale
Disadvantages	Small particle sizes are needed
Bio-oil Yield	70%-75%



Circulating fluid bed (CFB)

Main features

- High heat transfer rate
- High char abrasion from biomass and char erosion leading to high char in product.
- Char/solid heat carrier separation required
- Solid recycle required
- Increase complexity of system
- Maximum particle size up to 6 mm
- Possible liquid cracking by hot solids
- Possible catalytic activity from hot char
- Greater reactor wear possible



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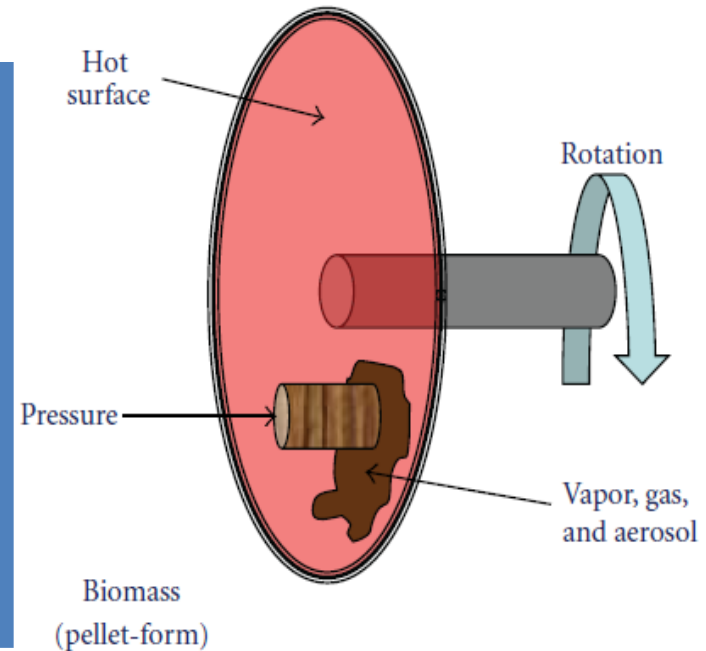
Circulating fluid bed (CFB)

Main features	Description
Modes of heat transfer	80% conduction, 19% convection, 1% radiation
Primary heat transfer Method	Solid–solid Gas–solid
Heating method	In-bed gasification of char to heat sand
Advantages	Well-understood technology Good thermal control Large particle sizes can be used
Disadvantages	Unlikely to be suitable for large scale Complex hydrodynamics; Char is finer
Bio-oil Yield	70%–75%

Ablative reactor

Main features

- Accepts large size feedstock
- Very high mechanical char
- Abrasion from biomass
- Compact design
- Heat supply problem
- Particulate transport gas not always required



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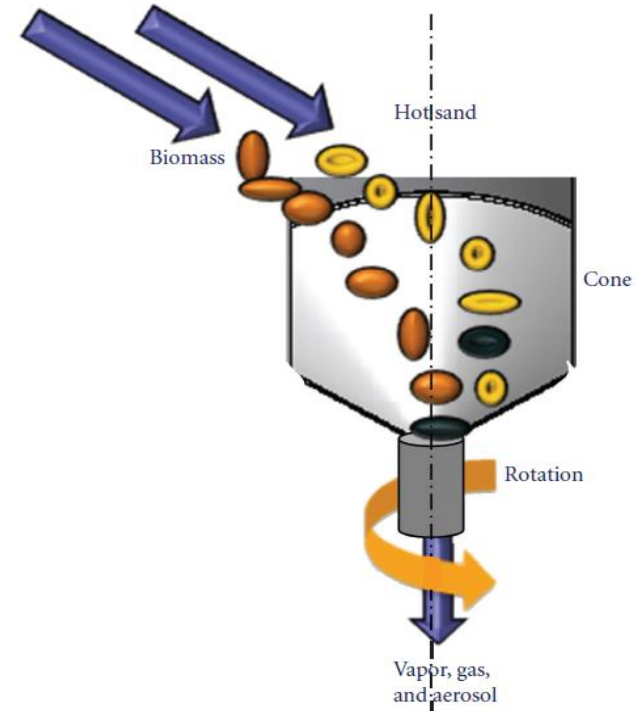
Ablative reactor

Features	Description
Modes of heat transfer	95% conduction,4% convection,1% radiation
Primary heat transfer method	Solid–solid
Heating method	Reactor wall/disc
Advantages	Inert gas is not required Large particle sizes can be processed System is more intensive Moderate temperature required
Disadvantages	Reactor is costly Low reaction rate
Bio-oil Yield	70%



Rotating cone reactor

Main features	Description
Advantages	Centrifugal force moves heated sand and biomass No carrier gas required Less wear
Disadvantages	Complex process Small particle sizes needed Not proven yet for large scale
Bio-oil Yield	65 %



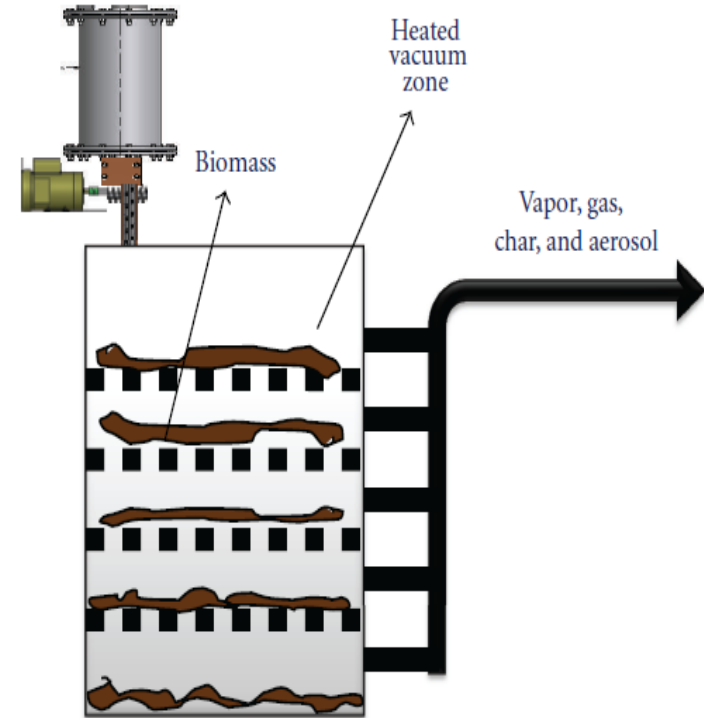
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Vacuum pyrolysis reactor

Main features	Description
Advantages	- Produces clean oil - Can process larger particles of 3–5 cm - No carrier gas required - Lower temperature required - Easier liquid product condensation
Disadvantages	- Slow process - Solid residence time is too high - Require large scale equipment - Poor heat and mass transfer rate - Generates more water
Bio-oil Yield	35-50 %



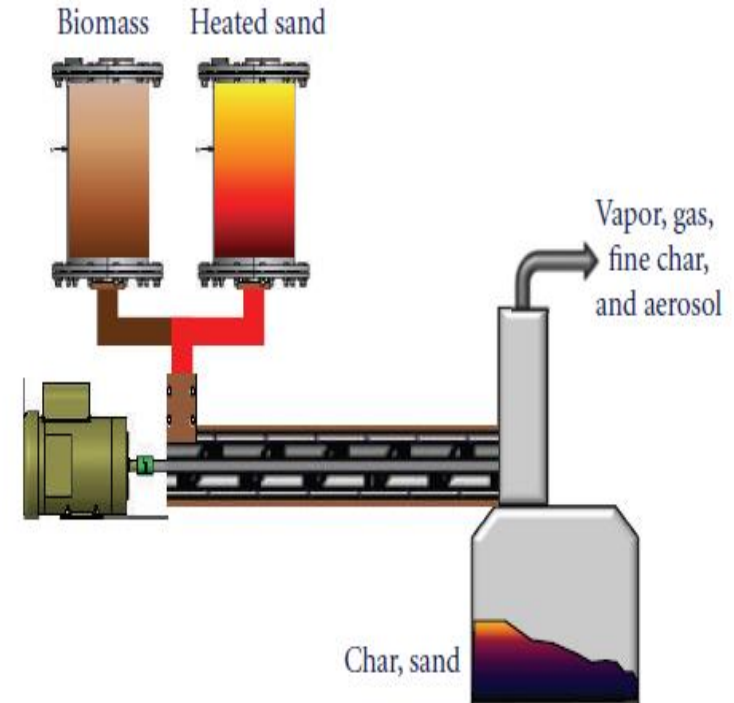
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Auger/screw reactor

Main features	Description
Advantages	Compact No carrier gas required Lower process temperature
Disadvantages	Moving parts in hot zone Heat transfer in large scale is not suitable
Bio-oil Yield	30%–60%



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Plasma reactors

Reactor	Advantage	Disadvantage	Bio-oil yield
Plasma	High energy density High heat transfer High temperature Very good control	High electrical power consumption High operating costs Small particle sizes required	30%–40%



Comparison of various types of pyrolysis reactors

Properties Reactor → ↓	Status	Bio-oil yield (wt%)	Complexity	Feed size specification	Inert gas requirements	Specific reactor size	Scale up
Fluid bed	Commercial	75	Medium	High	High	Medium	Easy
CFB	Commercial	75	High	High	High	Medium	Easy
Rotating cone	Demonstration	70	High	High	Low	Low	Medium
Ablative	Laboratory	75	High	Low	Low	Low	Difficult
Auger	Pilot	60	Medium	Medium	Low	Low	Medium
Vacuum	None	60	High	Low	Low	high	Medium

Pyrolysis bio-oils production processes in 2012 (above 10 kg/h)

Host/ organization	Country	Technology	Capacity kg feed/h	Capacity kg bio- oil/h	Applications	Status
ABRITech/ Advanced Biorefinery Inc., Forespect	Canada	Auger	70–700		Fuel	Operational Commissioning
Agri-Therm/ University of Western Ontario	Canada	Fluid bed	420		Fuel	Upgrade
Biomass Engineering Ltd.	UK	Fluid bed	250		Fuel and products	Construction
BTG	Netherlands	Rotating cone	250	200	Fuel and chemicals	Operational
BTG Bio Liquids EMPYRO	Netherlands	Rotating cone	6500	5000	Fuel	In design phase

Pyrolysis bio-oils production processes in 2012 (above 10 kg/h)

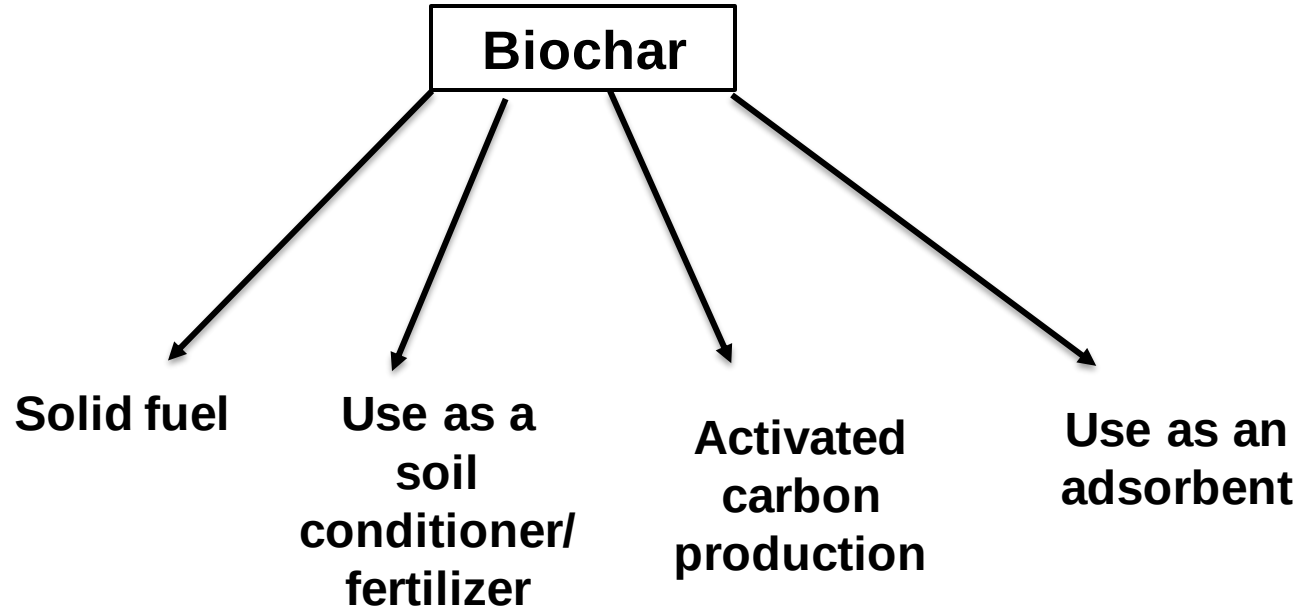
Host/ organization	Country	Technology	Capacity kg feed/h	Capacity kg bio- oil/h	Applications	Status
Fraunhofer UMSICHT	Germany	Ablative	250		Fuel	Commissioning
Fortum	Finland	Fluid bed	10 000		Fuel	Construction
Mississippi State University	USA	Auger	200	150	Fuel	Construction
National Renewable Energy Laboratory	USA	Fluid bed	12	10	Fuels and chemicals	Operational
Renewable Oil International LLC	USA	Auger/ moving bed	105		Fuel	Operational



Pyrolysis bio-oils production processes in 2012 (above 10 kg/h)

Host/ organization	Country	Technology	Capacity kg feed/h	Applications	Status
RTI International	USA	Catalytic fast pyrolysis	40	Transportation fuel	Construction
UOP	USA	Circulating fluidised bed	40	Transportation fuel	Construction
University of Science and Technology of China, Hefei	China	Fluid bed	120	Fuel	Operational
Virginia Tech	USA	Fluid bed	250	Fuel	Operational
VTT	Finland	Fluid bed	20	Fuel	Operational

Application of char

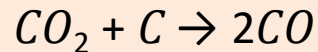
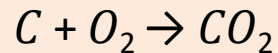
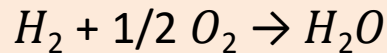
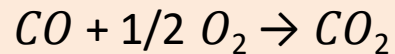
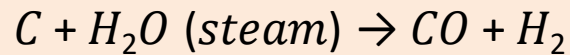


Activated carbon from pyro char

- Activated carbons ($500\text{-}2500\text{ m}^2/\text{g}$) can be produced via two types of industrial processes:
 - Reaction of the solid pyrolytic bio-char material using hot oxidizing agents, such as steam or CO_2 at around $800\text{-}1000^\circ\text{C}$.
 - Chemical activation through the use of an impregnating agent, such as a strong acid or base at temperature between $450\text{-}700^\circ\text{C}$. Phosphoric acid, zinc chloride and potassium hydroxide are commonly used for this purpose.
- Chemical method can produce higher surface areas, However this method presents three main drawbacks:
 - Use of chemicals that are potentially toxic, such as zinc chloride (Rambabu, 2014);
 - Intensive washing required after activation,
 - Risk of leaching chemicals that have not completely been washed.



- Physical activation burns off remaining tars and further oxidizes the carbon structure from the skeleton of pores that were formed during carbonization.
- CO_2 is normally preferred for this application, since it is clean, easy to handle and facilitates the control of the process.
- Important reactions during physical activation are:



Application of Gaseous Products

- It mainly contains CO_2 , CO , CH_4 , and H_2 with gross calorific value of 6.4-9.8 MJ/kg
- It can be used to provide the process heat for pyrolysis.
- Carbon monoxide and hydrogen can be utilized as syngas for liquid fuel production.
- Hydrogen can also be used for upgradation of bio-oil.



Thanks...

