Thermochemical and Hydrothermal Conversion Processes

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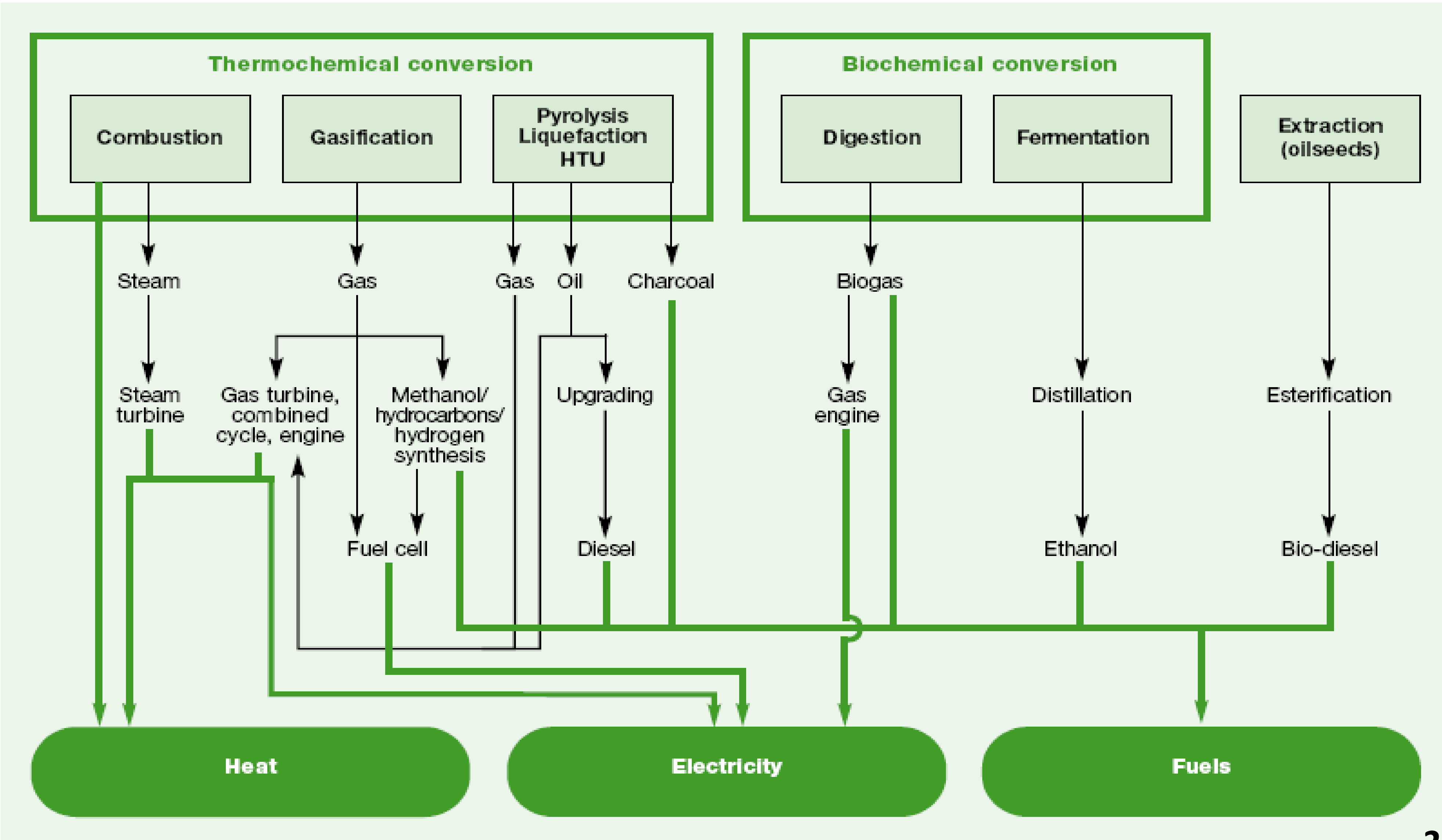
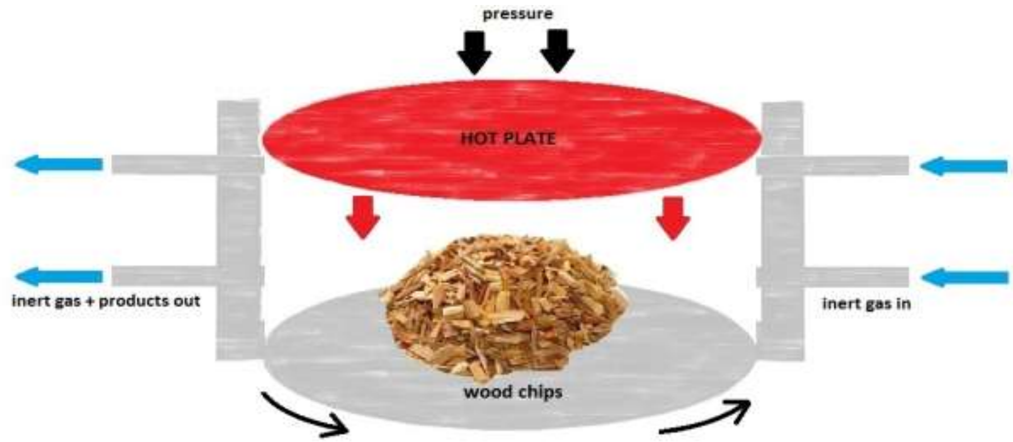
Biomass to Fuels/Energy

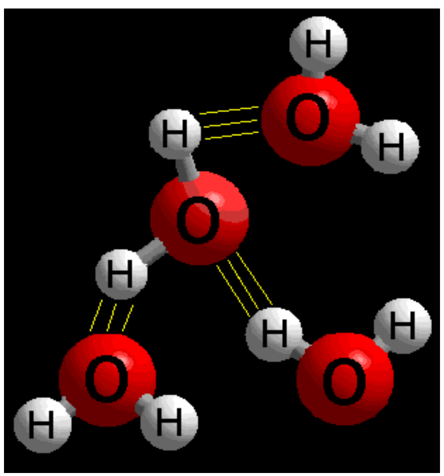


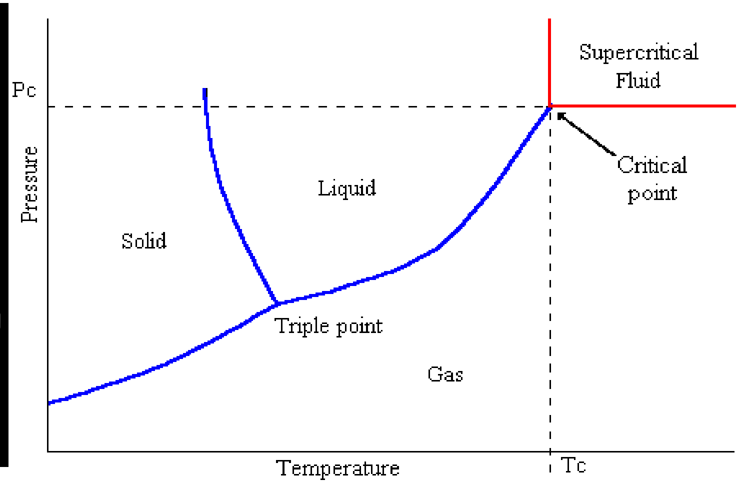
Thermochemical/Hydrothermal Conversion of Biomass

Low Moisture Biomass (~10 wt %):

✓ Ablative Pyrolysis of Beetle-killed Trees





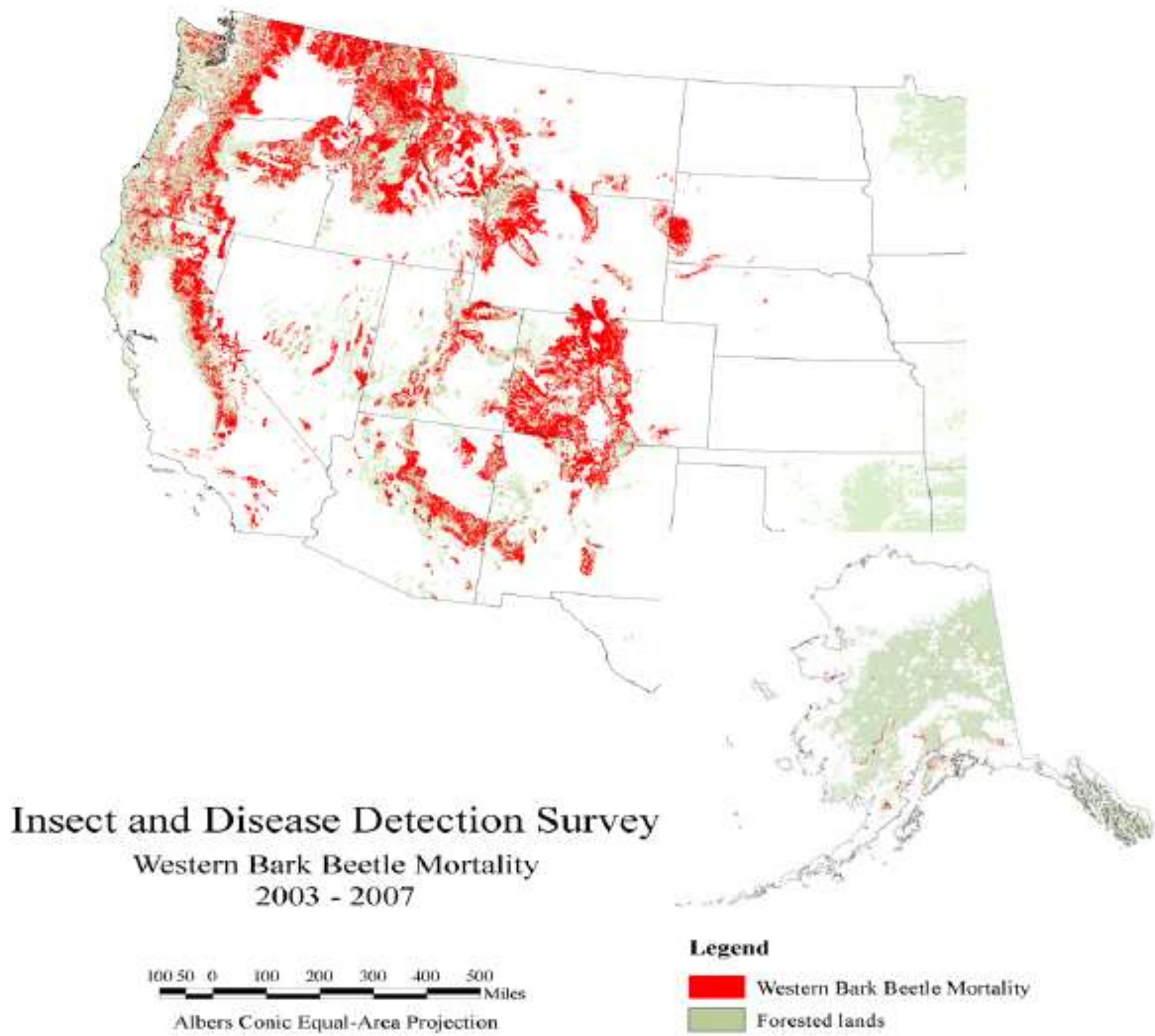


High moisture biomass (> 40 wt %):

✓ Hydrothermal Gasification/Liquefaction of Biomass

The beetle-killed trees problem

- MPB attacking Lodgepole pine: droght, warmer winters, aging forest
- More than 10 million acres of west forest affected
- Trees mortality causes a fire hazard
- Disposal methods include piling and burning (wastes energy, carbon and nutrients)



Western Forest Leadership Coallition, “Western Bark Beetle Assessment: A Framework for Cooperative Forest Stewardship”, 2009 Update.

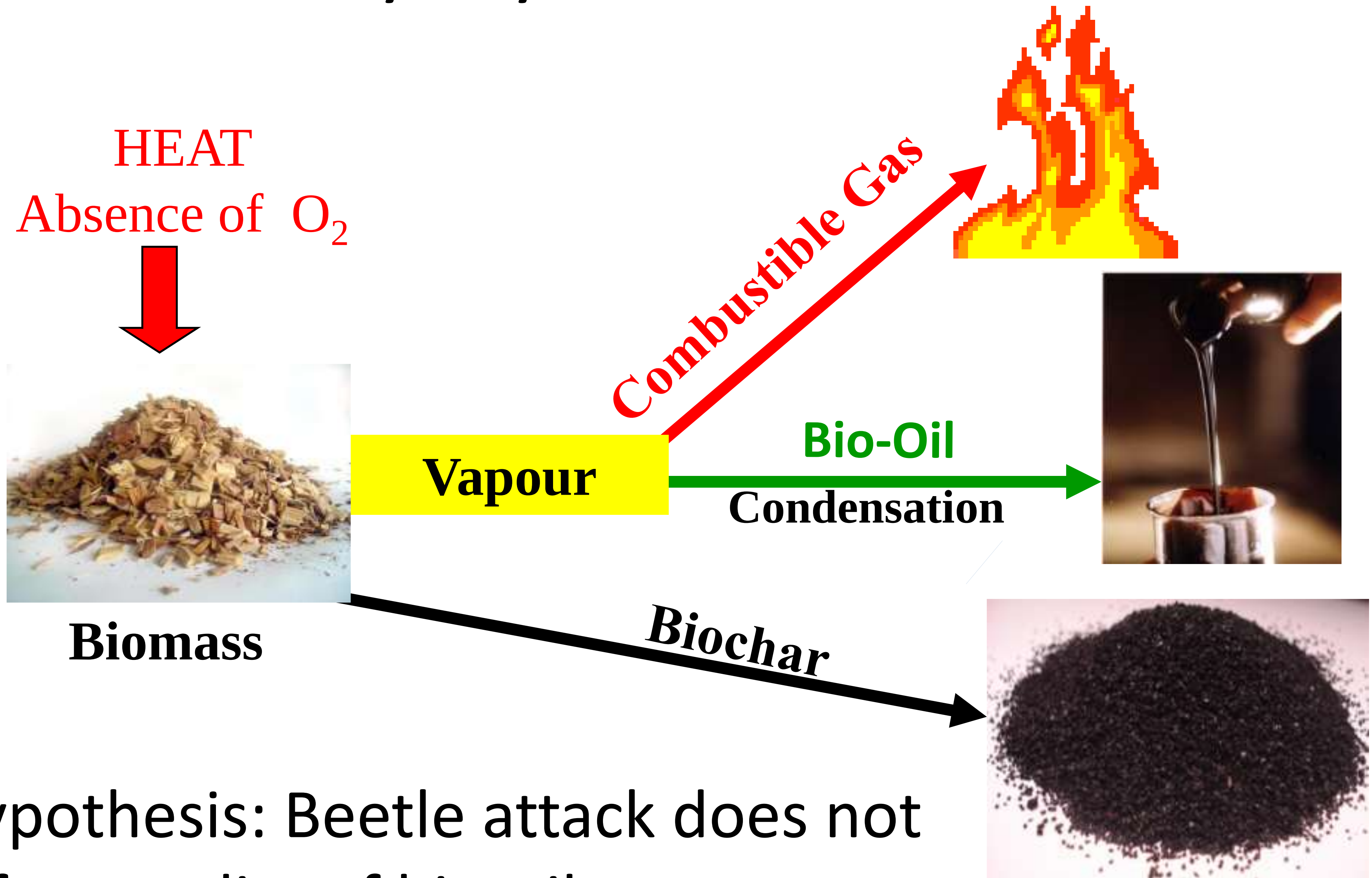
Applications for beetle-killed trees

Low moisture content of the dead trees → Checking of wood → Improper for solid-wood industry sector

Checking of wood → Fast Pyrolysis → Bio-oil

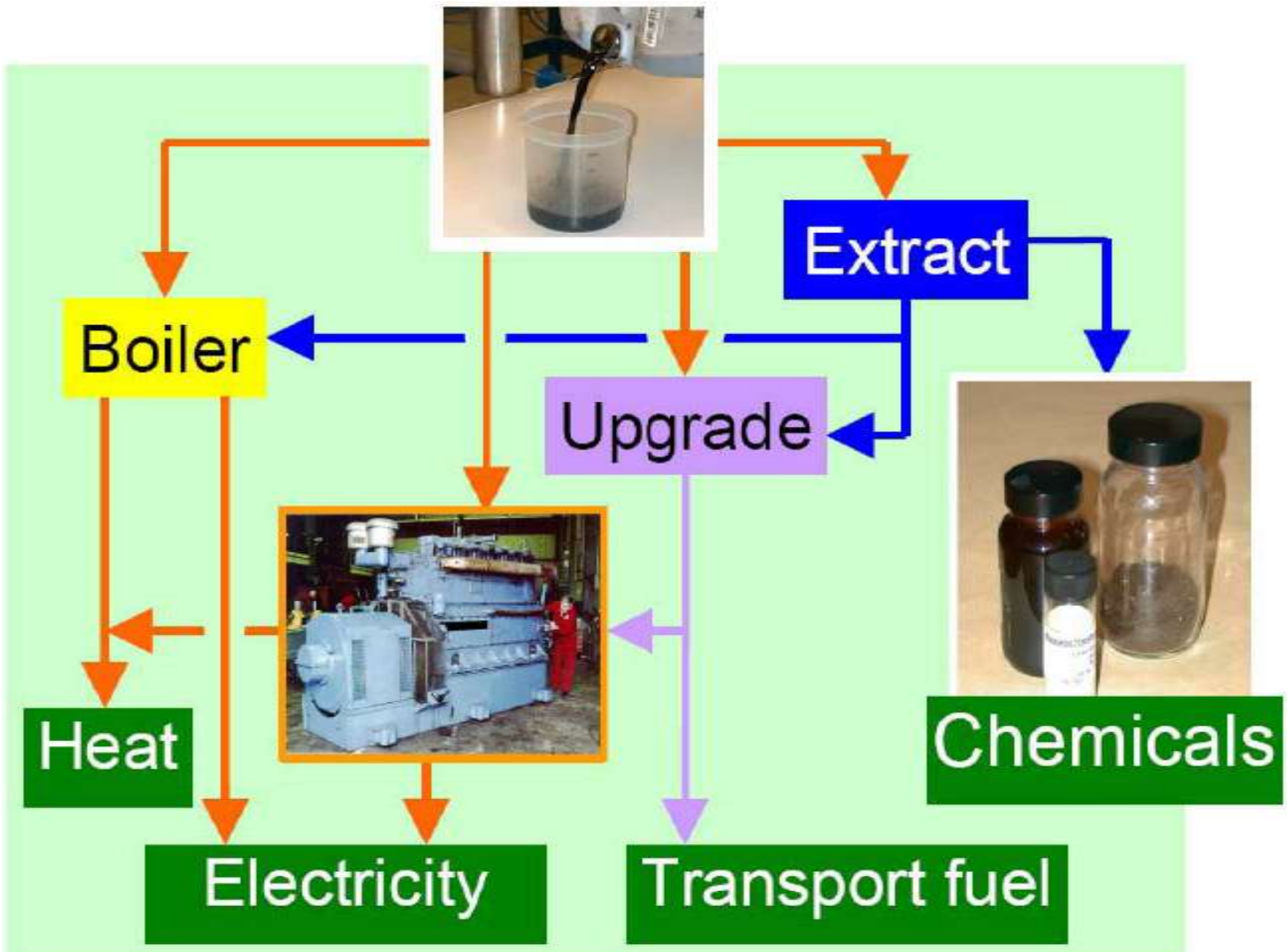
Opportunity to reduce the volume of dead trees and produce a high-value product

Pyrolysis of biomass

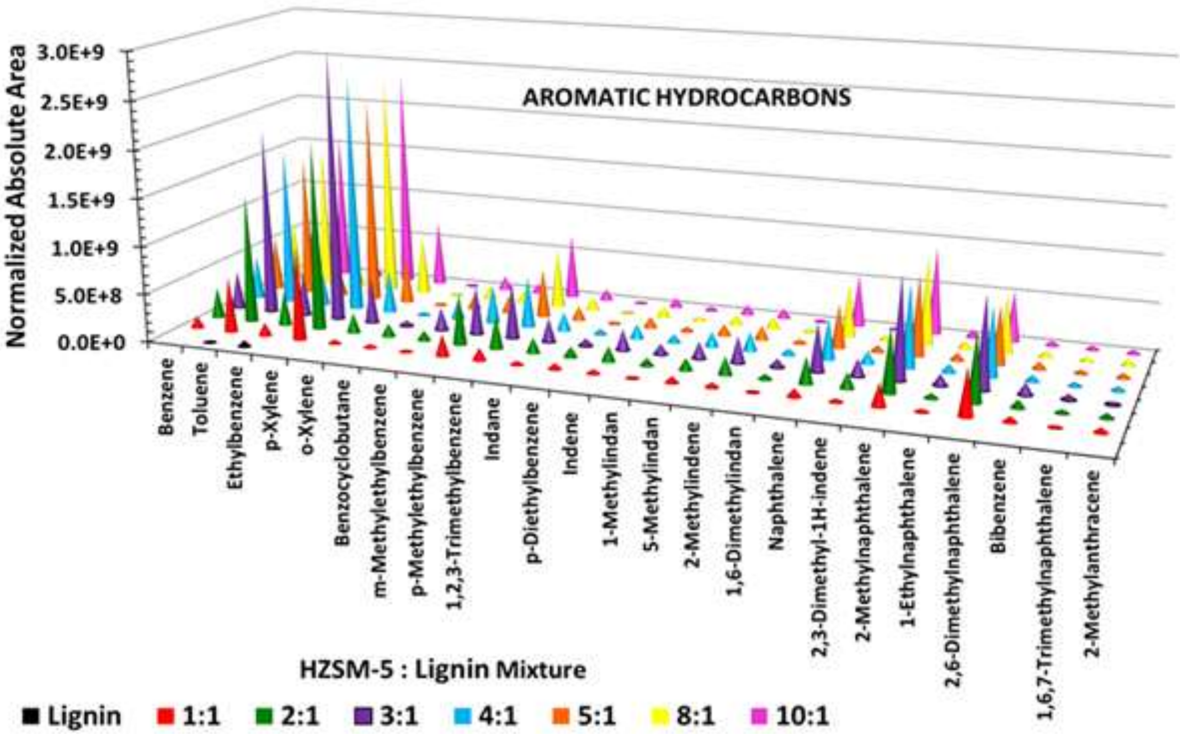


Hypothesis: Beetle attack does not affect quality of bio-oil

Bio-oil as a liquid fuel for transportation?



Catalytic Fast Pyrolysis with a zeolite catalyst



Products:

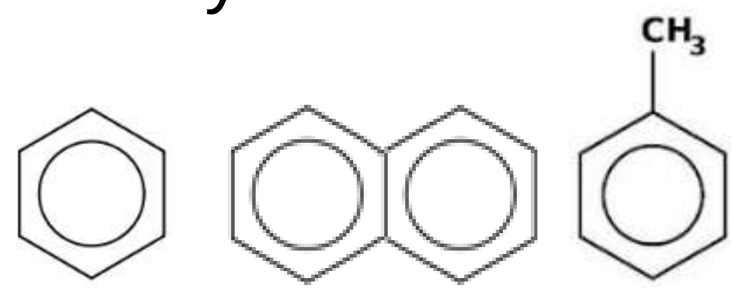
CO

CO_2

Char

water

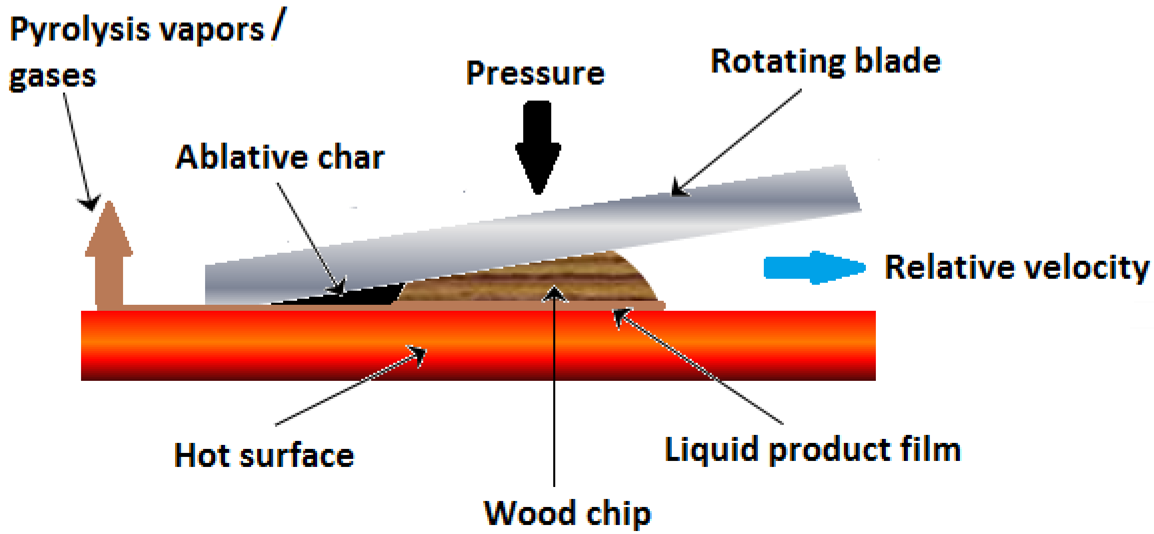
Aromatic Hydrocarbons



Mobile Pyrolysis Units

- Mobile units: reduce transportation costs for low-density biomass (50 dry tons/day)
- Bio-char can be used on-site as soil-amendment
- Process economics depends on bio-oil yield: 70 gal/ton is needed for feasibility (73 wt % conversion)
- Grinding estimated to be 7 % of costs

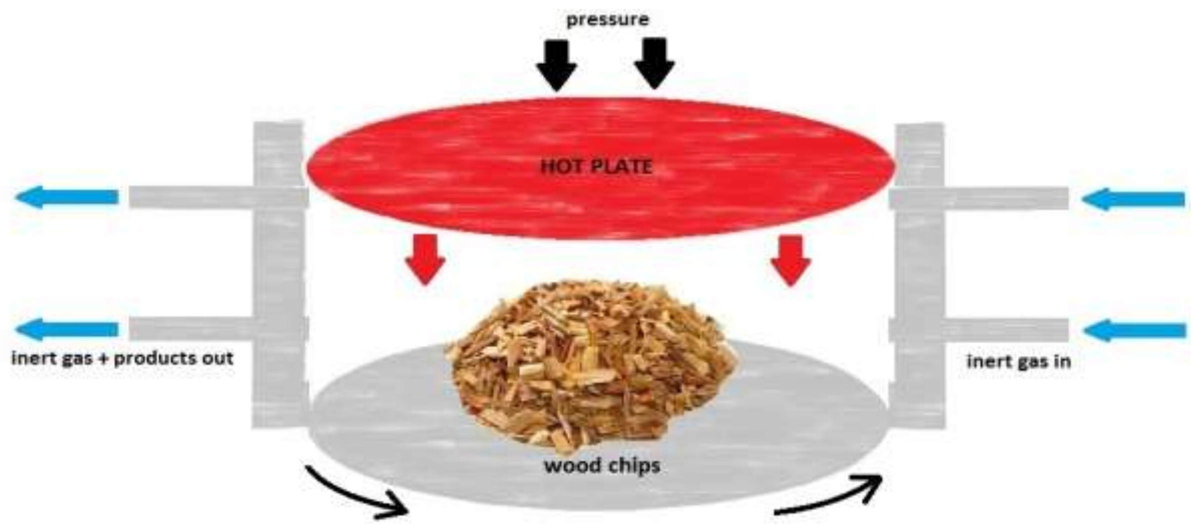
Ablative Pyrolysis: "Melting butter in a frying pan"



Reaction rate not limited by heat transfer through particle → no upper limit to particle size → Reduced grinding costs

- Up to 81 wt % conversion has been observed
- Low reactor volume (only appropriate for small scales)
- Low capital and operational costs

An ablative pyrolysis reactor for beetle-killed trees

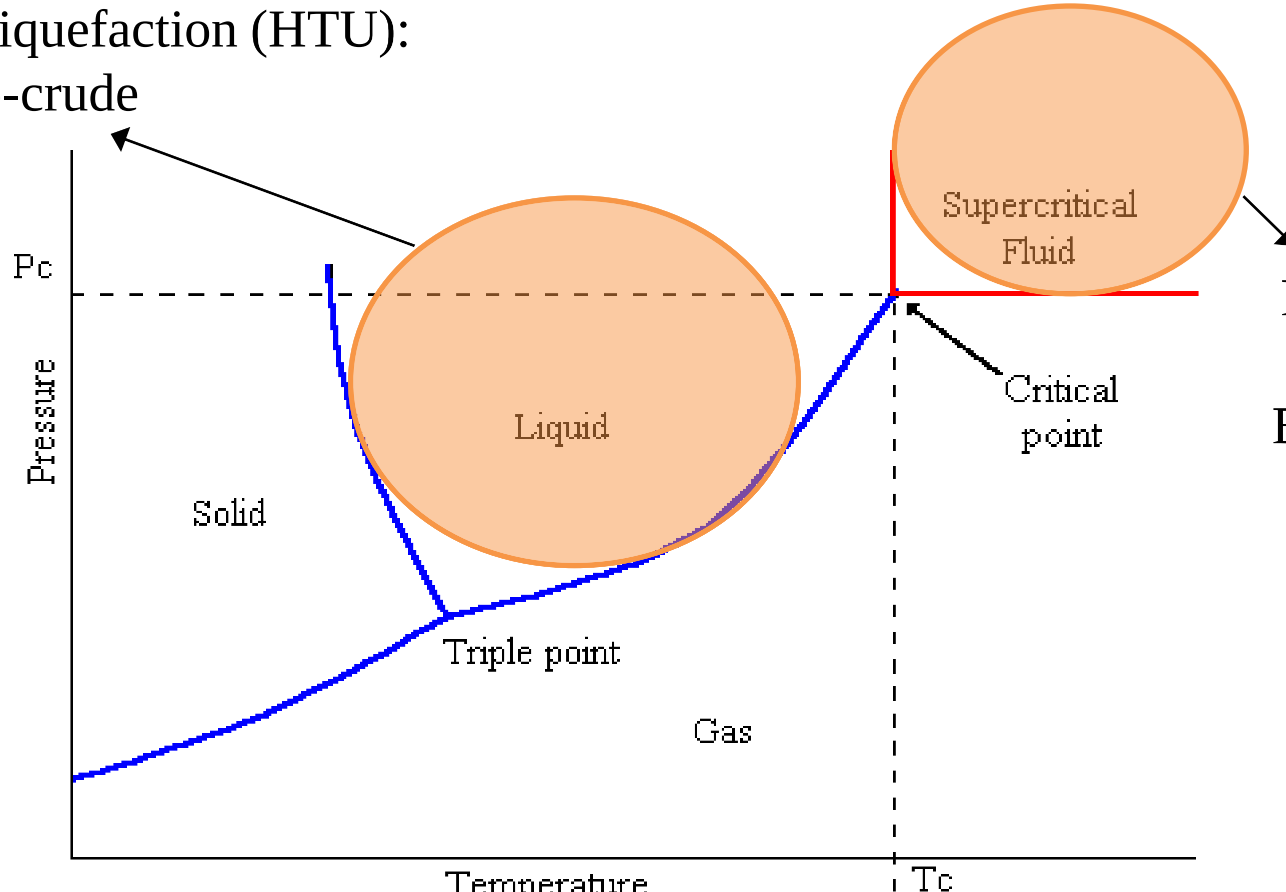


- Influence of decay stage on the quality of the bio-oil?
- What are the variables that control process yields?
- How to keep the bio-oil over 73 wt %?
- What is the maximum size of wood chips allowable?
- Does the low-density of the wood affect the ablative process?
- What is an optimum reactor design for the conversion?

Applications for High Moisture Biomass

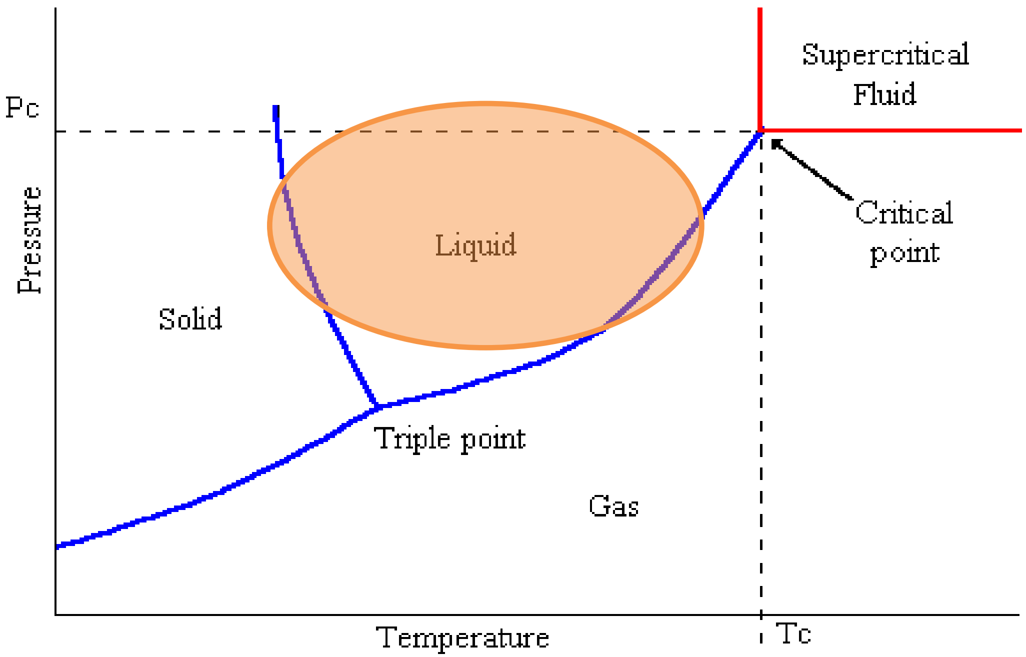
Water as a solvent:
Avoids the drying step

Hydrothermal Liquefaction (HTU):
Bio-crude

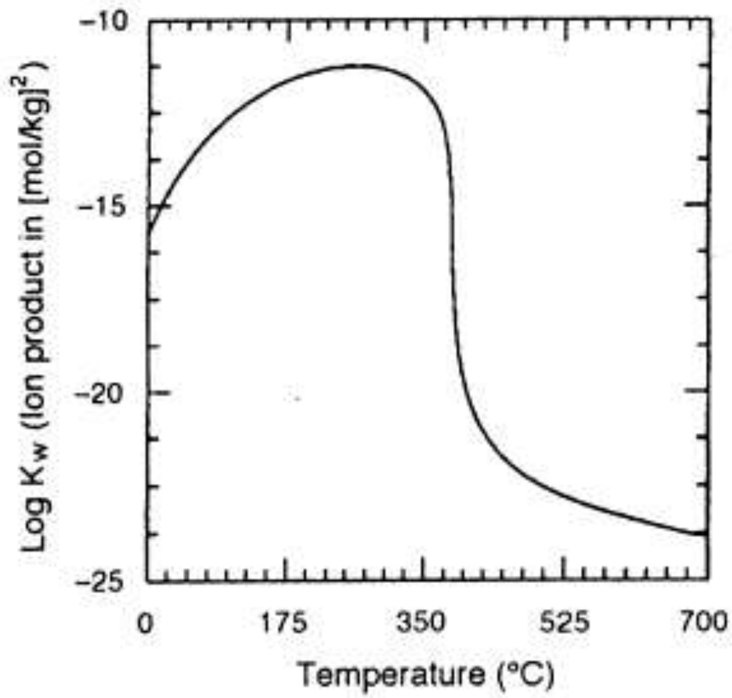


Hydrothermal
Gasification:
Bio-gas for FT
H_2
CH_4
CO

Hydrothermal Liquefaction
(Hydrothermal Upgrade, HTU)



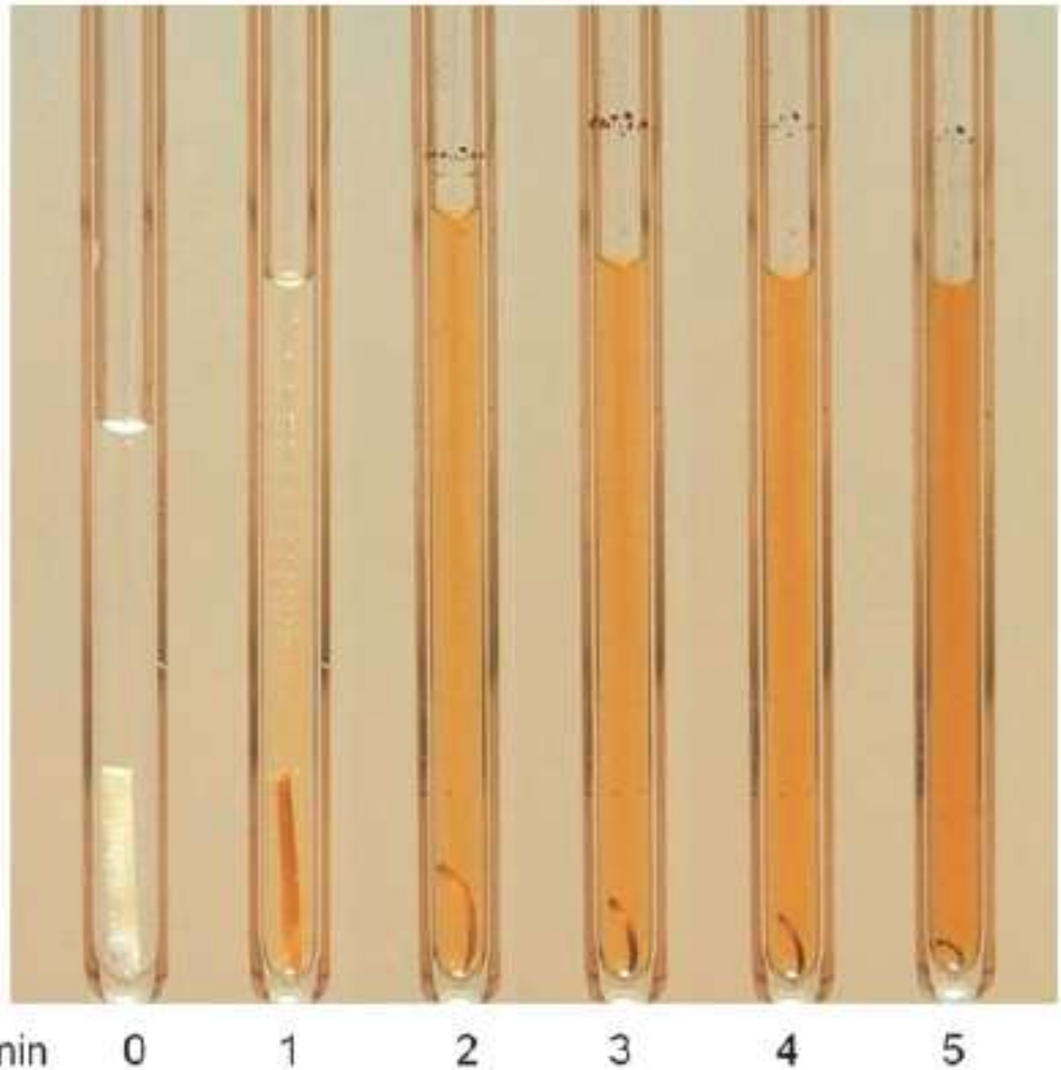
Kw increases 1,000 at 200-300°C



Temperature: 280-380°C
Pressure: 5-40 MPa

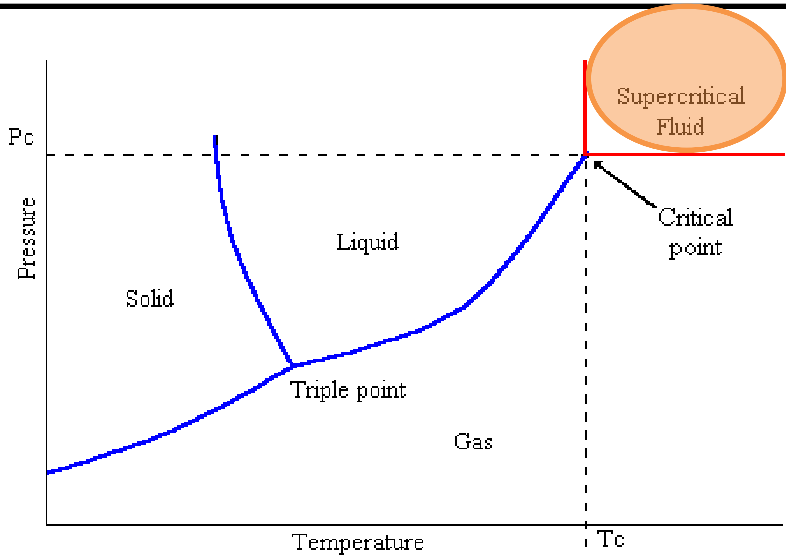
Water self-ionization:
$2\ H_2O \leftrightarrow H_3O^+ + OH^-$

Wood liquefied at 340°C

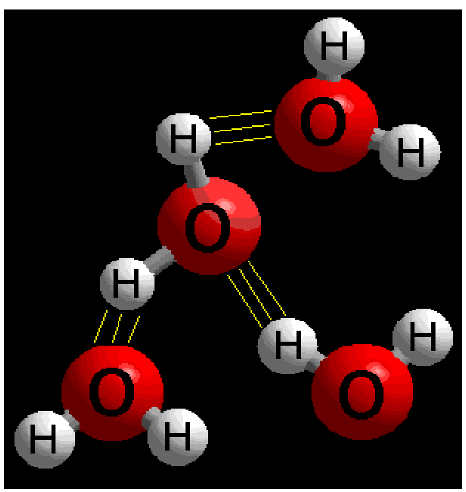


Peterson, A.A.; Vogel, F.; Lachange, R.P.; Froling, M.; Antal, M.J.Jr.; Tester, J.W.; "Thermochemical biofuel production in hydrothermal media: A review of sub- and supercritical water technologies", Energy & Environmental Science, 2008, 1, 32-65

Hydrothermal Gasification (SCWG)



Water above 374° C and 22 MPa



Properties of Supercritical Water:

High Temperature and Pressure

⇓

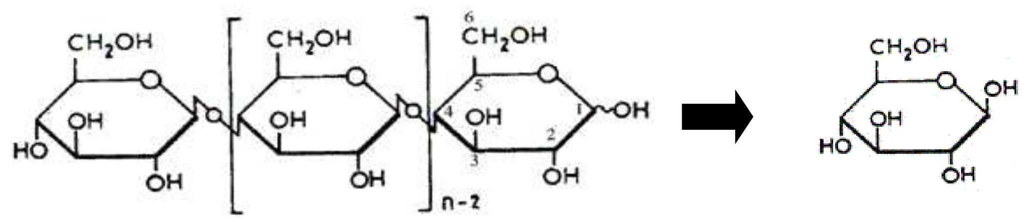
Weakens H bonds

⇓

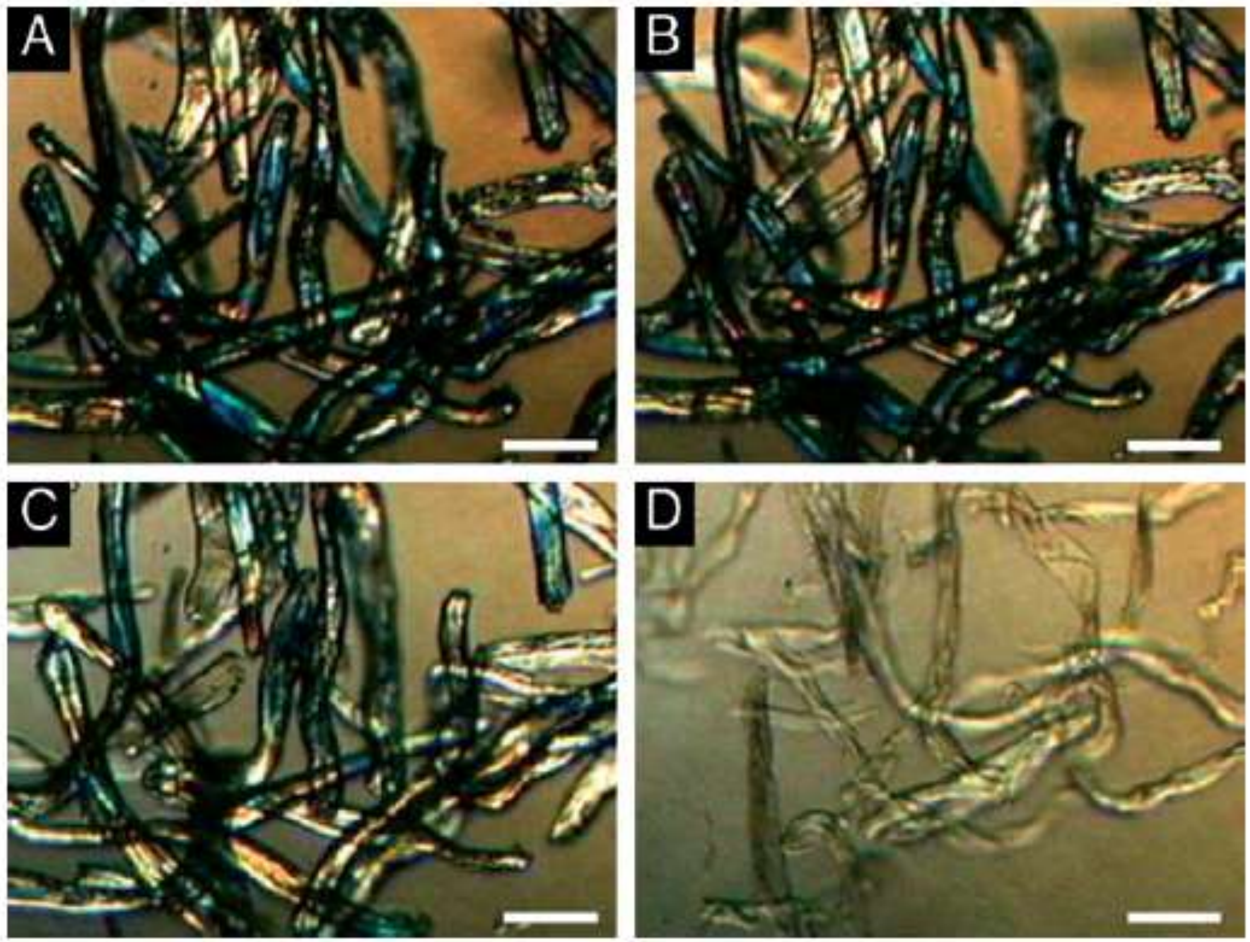
Decreases dielectric constant

⇓

Dissolves organic compounds:



Cellulose dissolving in hot compressed water



S. Deguchi, K. Tsujii and K. Horikoshi, Cooking cellulose in hot and compressed water, Chem. Commun., 2006, 3293–3295.

Supercritical Water Gasification (SCWG)

Water as solvent:

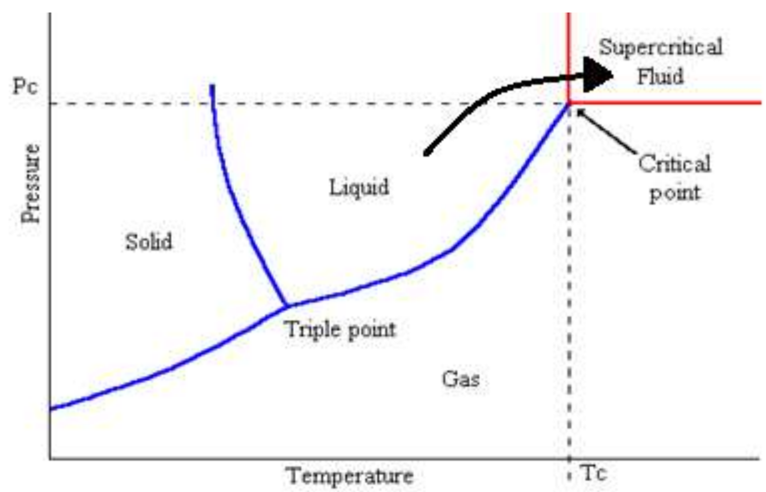
- Avoids the drying step

- H_2 rich gas can be produced via the water-gas shift reaction:

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

(water is also a reactant)

- Avoids phase change (no latent heat)



Energy Efficiency

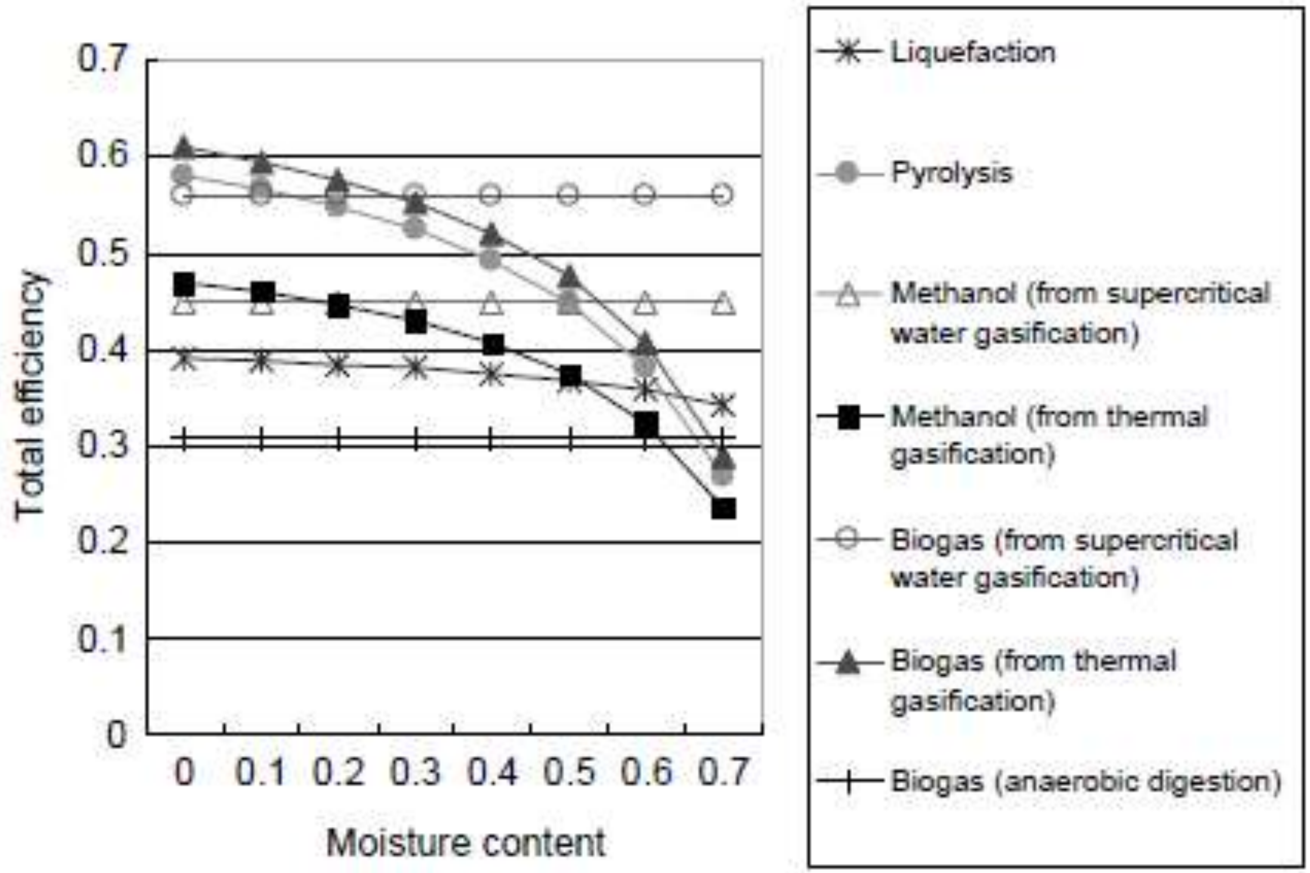
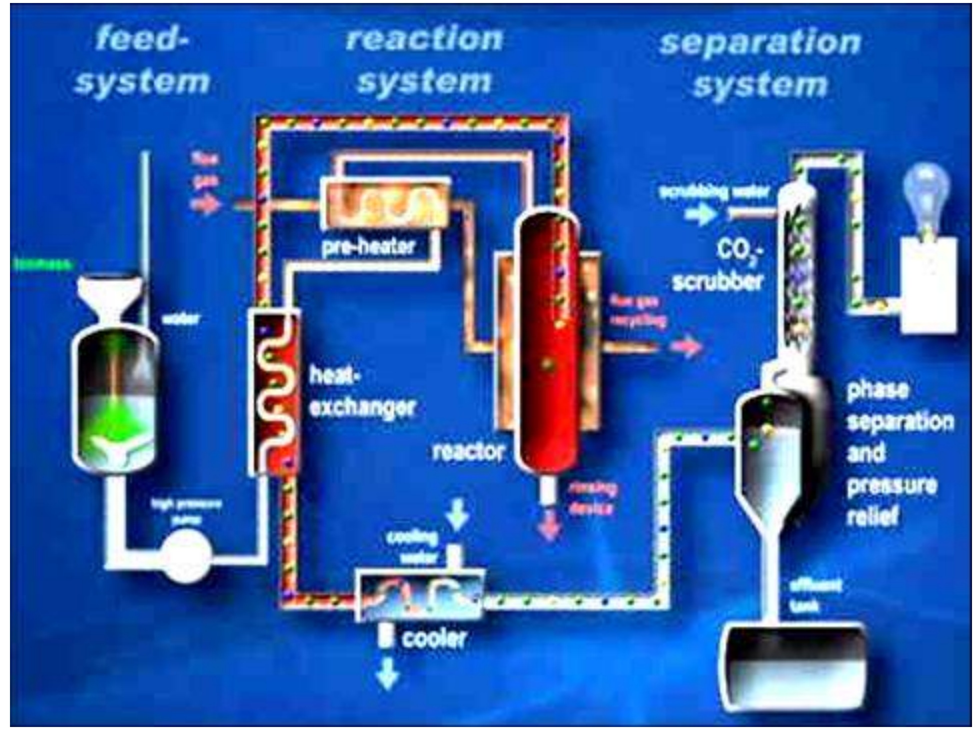


Fig. 4. Total efficiency of heat utilization processes versus biomass moisture content.

Yoshida, Y.; Dowaki, K.; Matsumura, Y.; Matsuhashi, R.; Li, D.; Ishitani, H.; Komiyama, H.; "Comprehensive Comparison of efficiency and CO2 emissions between biomass energy conversion technologies – position of supercritical water gasification in biomass technologies", Biomass and Bioenergy, 25, 2003, 257-272.

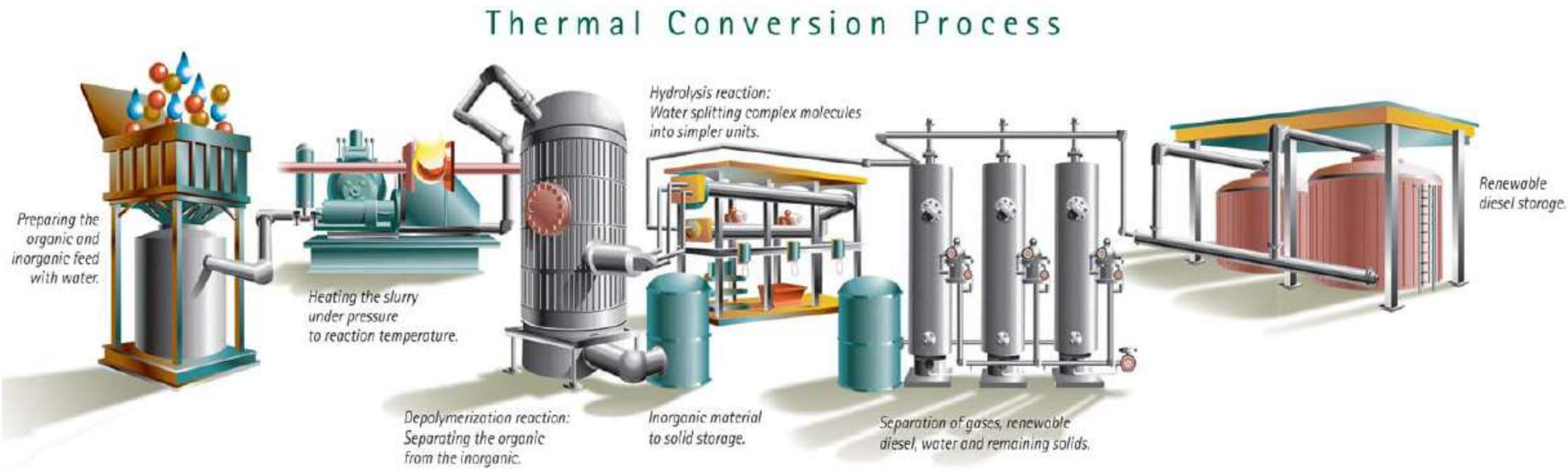
Questions?

VERENA Gasification Plant, Germany



- 100 kg/h
- 700°C, 350 bar
- Residual biomass from the food and beverage industry, sludge

Hydrothermal Liquefaction Plant
Changing World Technologies (CWT, Carthage, Missouri)



- ✓ Converts wastes from turkey production (fatty acids) into diesel and fertilizers
- ✓ Fatty acids have chain lengths similar to gasoline and diesel (15-20 carbons)
- ✓ Elimination of carboxyl group results in diesel