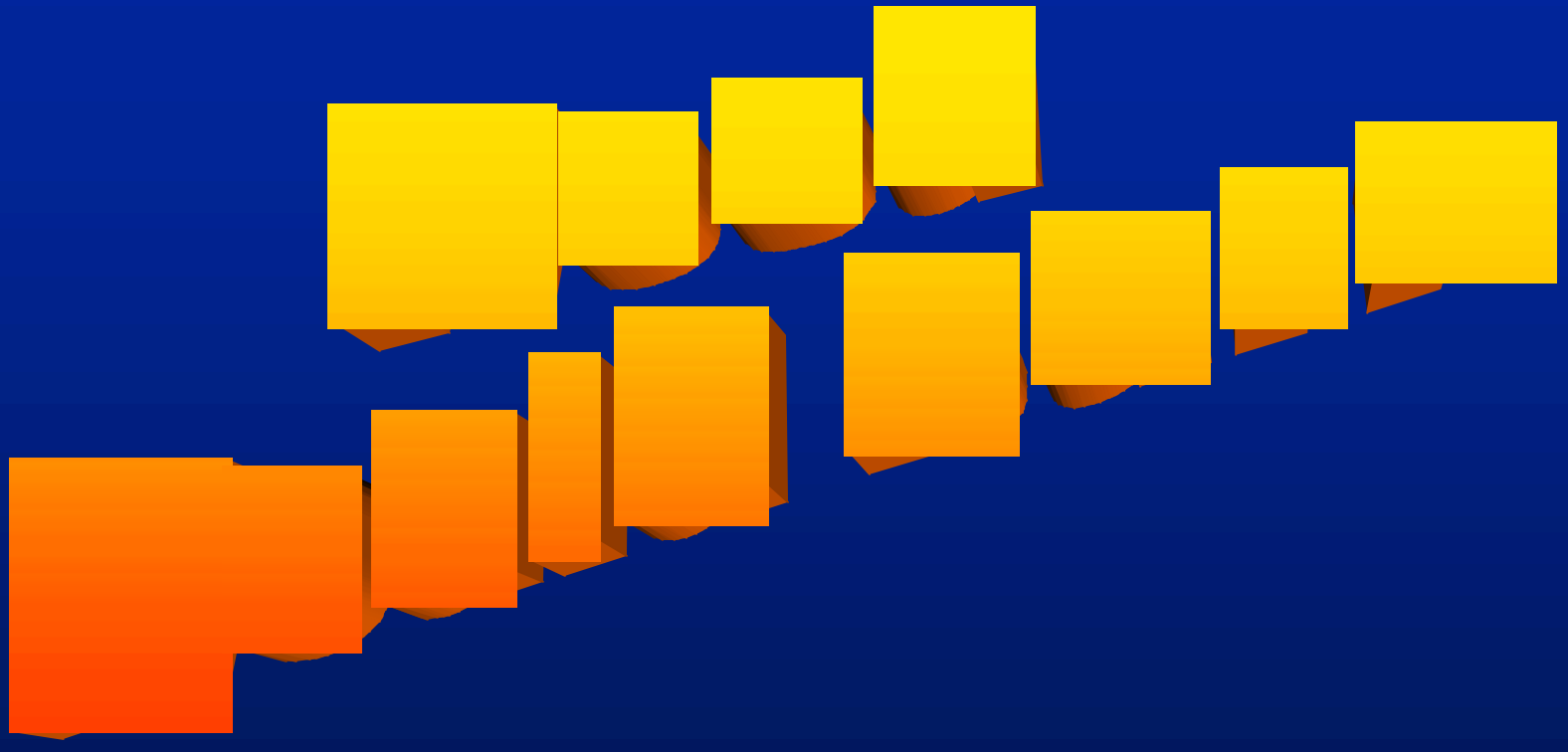
British French - French Flame Joint Meeting
Lille 9/10 March 2009



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Presentation Outline

- **Energy, Environment and Sustainability**
  - Wood Fuel: (experiments show less particulate emissions than coal)
  - High moisture Þ Condensing boiler (CHP)
- **Power generation Þ High Pressure Combustion**
  - 80bars – condense moisture > 200°C hence recover energy for power
  - 80bars – 'condense' CO_2 > 30°C, Þ sequestration of 'liquid' CO_2
  - 80bars – low superheater stress Þ Higher temperature and efficiency
  - Liquid oxygen – pump to high pressure
- **Fluidized bed**
  - Wood chip slurry fuel - pump to high pressure
  - Water moderates oxy-fuel flame temperature
  - Hydrogen from water-gas reaction Þ Ultra-superheated steam
  - Steam turbine entry temperature 1000°C to 1400°C
  - Overall electrical power generation efficiency > 60% possible
- **Conclusion: System removes CO2 from the atmosphere!!**

Properties of coal, wood and RDF samples

		Coal	White Oak	Pine bark	RDF
Proximate analysis (%)	Fixed Carbon	55.8	17.2	33.9	9.8
	Volatiles	33.9	81.3	54.7	67.6
	Ash	10.3	1.5	0.4	18.9
Ultimate analysis (%daf)	C	84.2	50.2	56.5	61.2
	H	5.6	5.5	5.6	8.2
	O	5.5	43.8	37.9	26.6
	N	1.3	0.4	0.0	1.3
	S	3.5	0.0	0.0	0.2
HHV (MJ/kg) DRY!		31.75	19.42	21.78	22.3

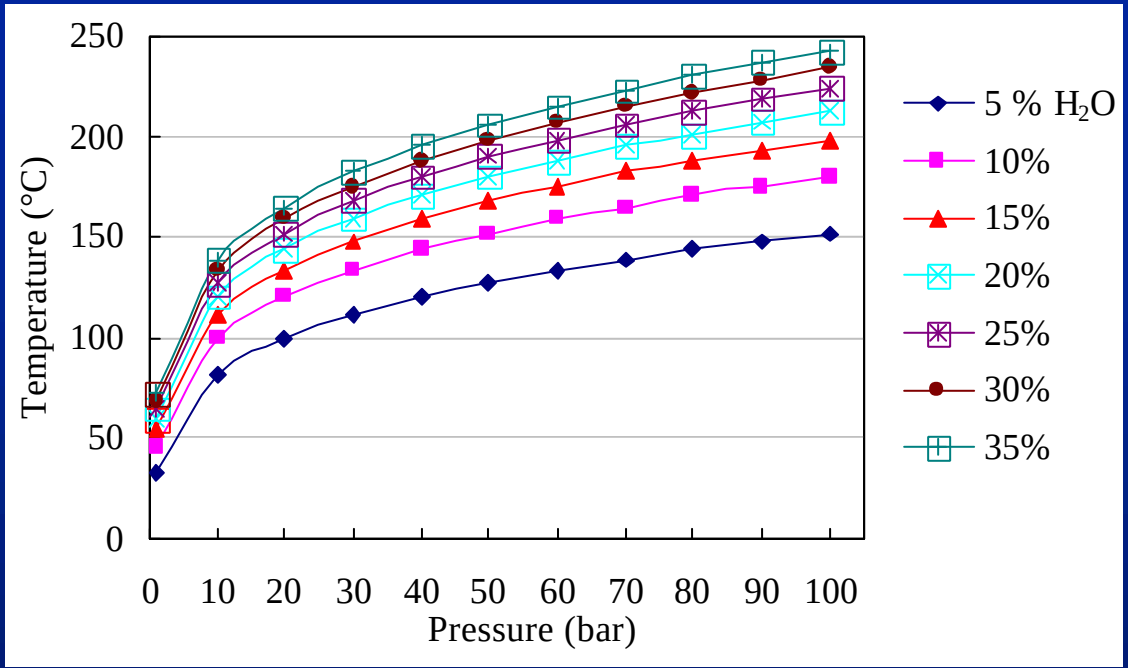
But: Raw wood contains 60% moisture and combustion products include water.
Each 10% moisture reduces heating value by 2MJ/kg
Thus raw wood heating value is typically ~8MJ/kg.
Therefore:
Use low grade waste industrial heat to "add value" to wood by drying

Condensing Boilers

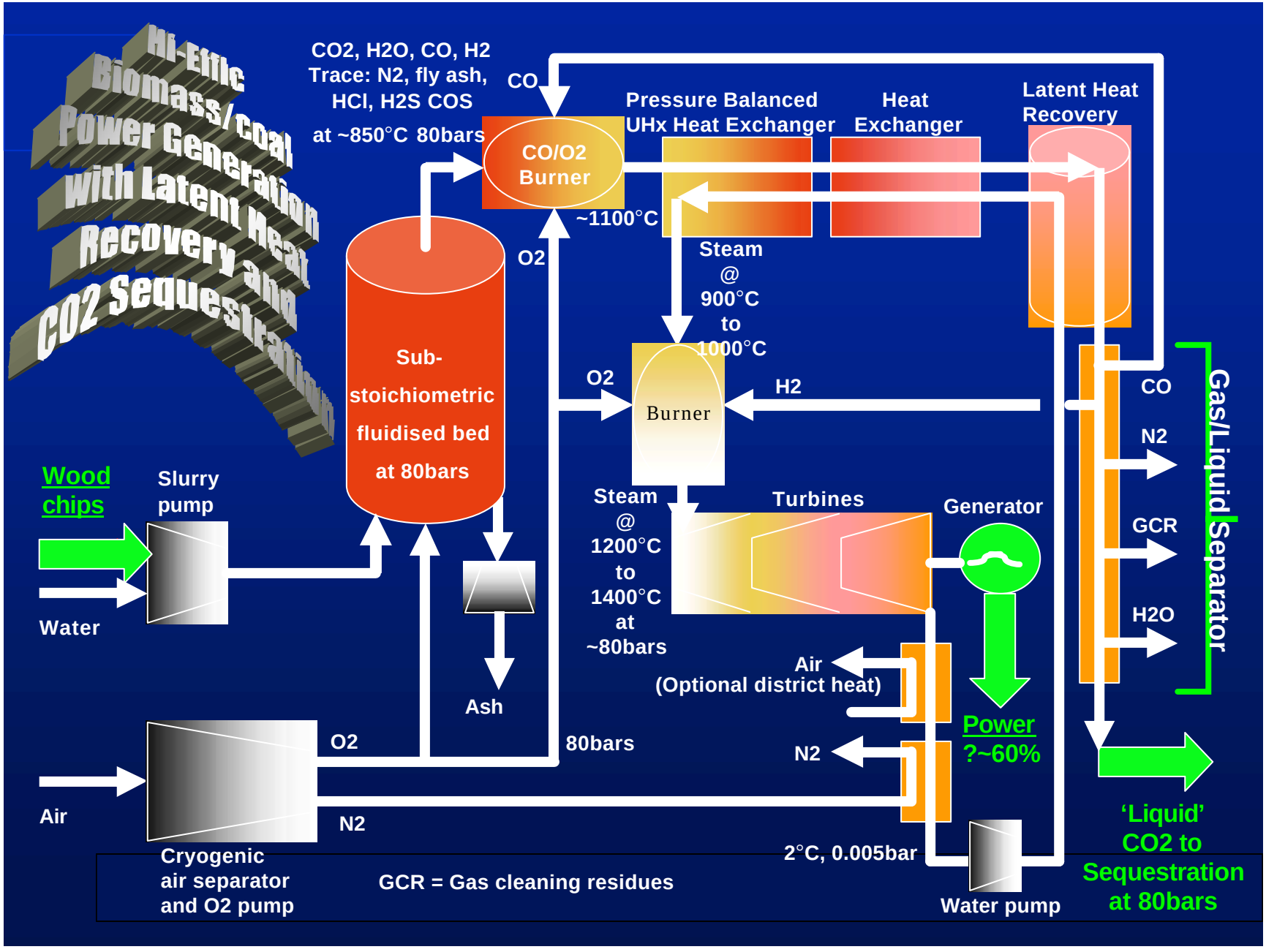
- **CHP – Sheffield is lead city in the UK. Current district heating return water temperature is ~70°C**

- **Condensing boilers recover latent heat of water in the flue gas**
  - **Atmospheric pressure condensation temperature is ~55°C**
  - **Hence require return building heating water at 30°C using large radiators or under-floor heating in order to recover the latent heat energy**

- **Alternatively; Dew point increases with pressure**
  - **Use high pressure combustion to raise dew point to more than 200°C**
  - **Large amount of heat recovered at this high temperature can be recycled into power generation by:**
    - **Heating boiler feed water,**
    - **Heating combustion air or oxygen**
    - **etc**



Flue gas dew point temperature as a function of pressure and moisture content


Hi-Effic Biomass/Coal Power Generation with Latent Heat Recovery and CO2 Sequestration
CO2, H2O, CO, H2
Trace: N2, fly ash, HCl, H2S COS
at ~850°C 80bars
CO
CO/O2 Burner
Pressure Balanced UHx Heat Exchanger
Heat Exchanger
Latent Heat Recovery
~1100°C
O2
Steam @ 900°C to 1000°C
Sub-stoichiometric fluidised bed at 80bars
O2
Burner
H2
CO
N2
GCR
H2O
Gas/Liquid Separator
Wood chips
Slurry pump
Water
Steam @ 1200°C to 1400°C at ~80bars
Turbines
Generator
Ash
Air
(Optional district heat)
Power ?~60%
O2
80bars
N2
Air
N2
'Liquid' CO2 to Sequestration at 80bars
2°C, 0.005bar
Cryogenic air separator and O2 pump
GCR = Gas cleaning residues
Water pump

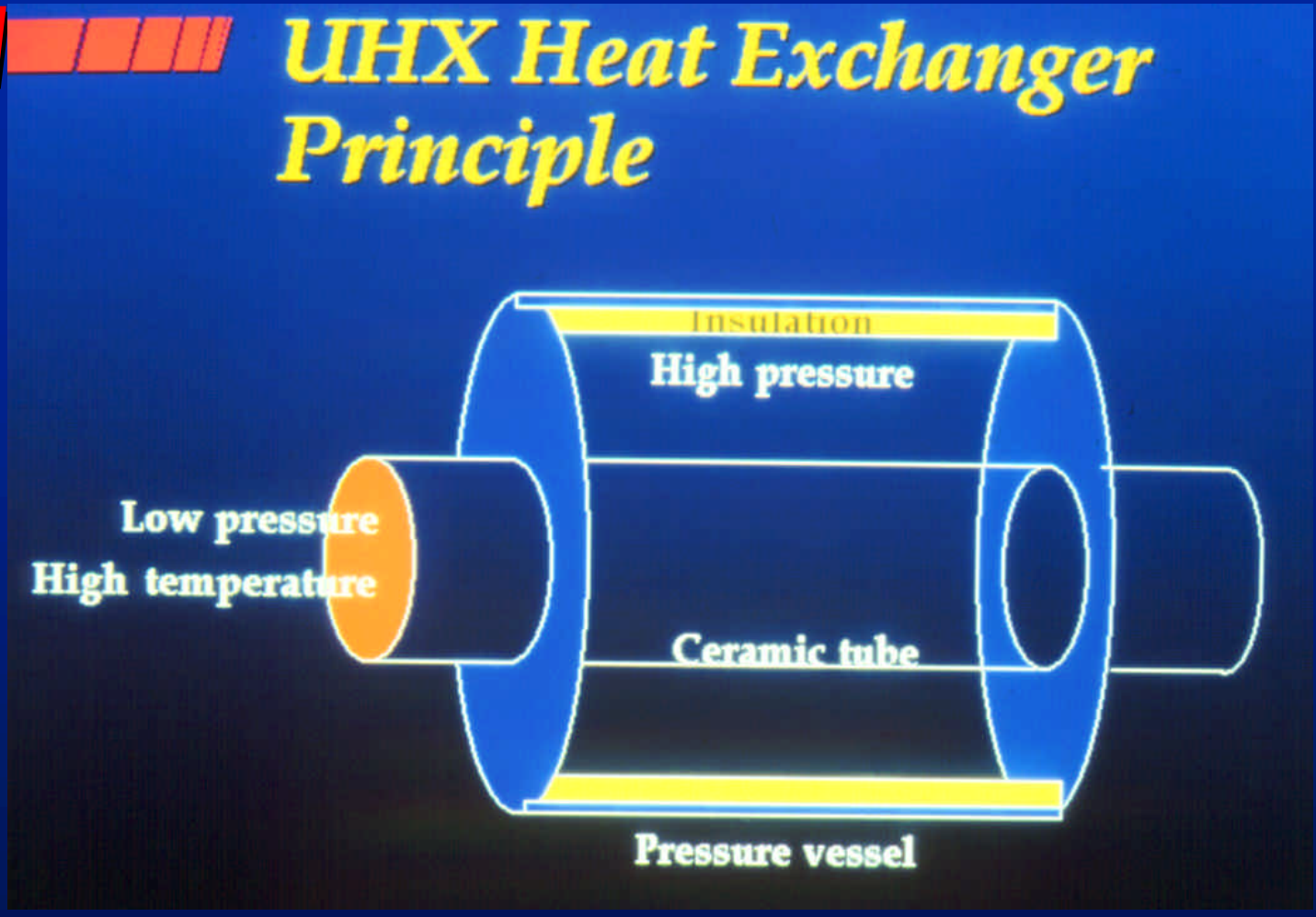
High Pressure (>80bars) Combustion of Wood

- **Pressurised Combustor Technologies**
  - Moving Grate
  - Entrained pulverised fuel jet
  - Shaft combustor
  - Rotary kiln
  - Circulating fluid bed
  - Bubbling fluid bed *** (preferred technology)
- **Fuel feeding**
  - Wood slurry pump (liquid, therefore high efficiency)
  - Drain surplus water, but wet wood is OK
- **Bed temperature control**
  - Heat load, fuel-oxygen ratio, flue gas CO_2 recycle, or water
  - Large heat recovery at high temperature is recycled into power generation
- **Hydrogen generation**
  - Water increases hydrogen production by water-gas reaction

High Pressure Combustion of Wood

- **Pressurised System Heat Transfer**
  - Radiation increases with pressure
  - Convection increases faster with pressure
  - Heat transfer areas are much smaller
  - 500MW power plant CO_2 exhaust pipe is ~30cm diameter
- **Pressurised Bubbling Fluidised Bed**
  - Contained in pressure vessel insulated on inside
- **Gas Cleaning**
  - Particles removed in high temperature heat recovery condenser
  - Scrubbers small as gas density is very high
  - Carbon dioxide recovery directly as supercritical 'liquid' at this pressure
- **High temperature technology**
  - Heat transfer tubes are in **compression**
  - Ceramic heat exchangers >1000°C

UHX Heat Exchanger Principle



A Plate Heat Exchanger could be used with balanced pressures!

UHX Heat Exchanger (70kW)

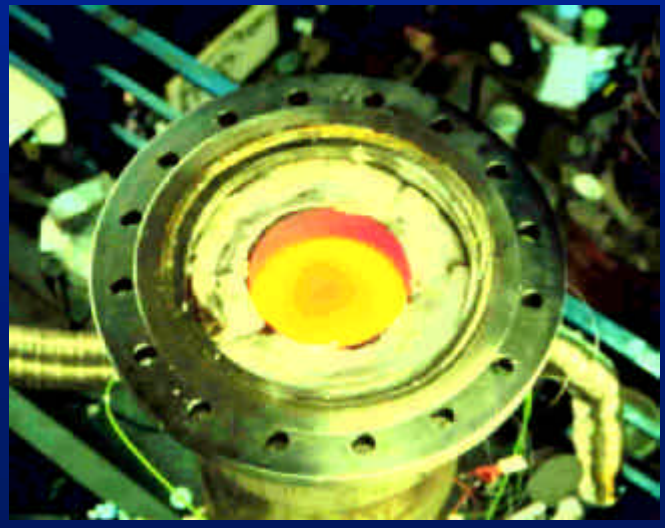


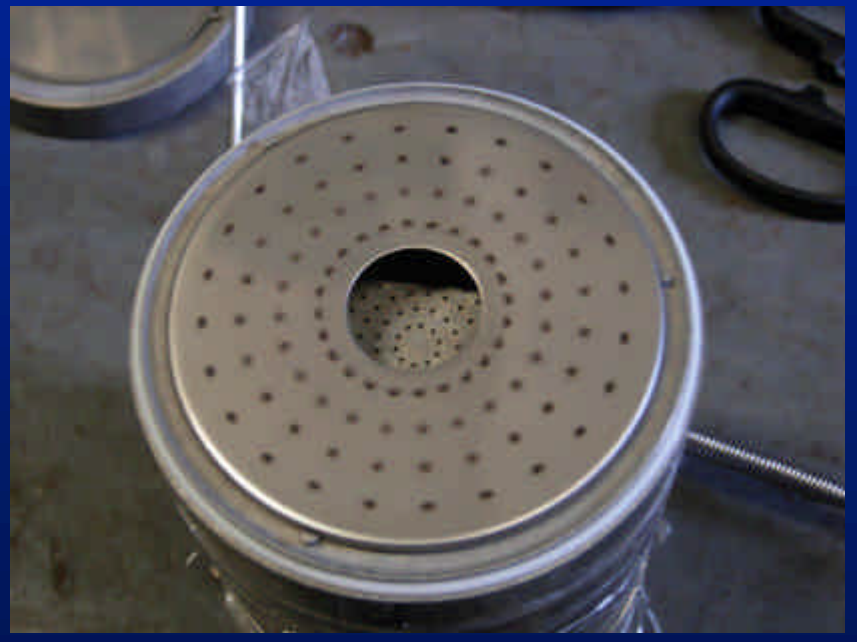
Fig.7

Gas Cleaning

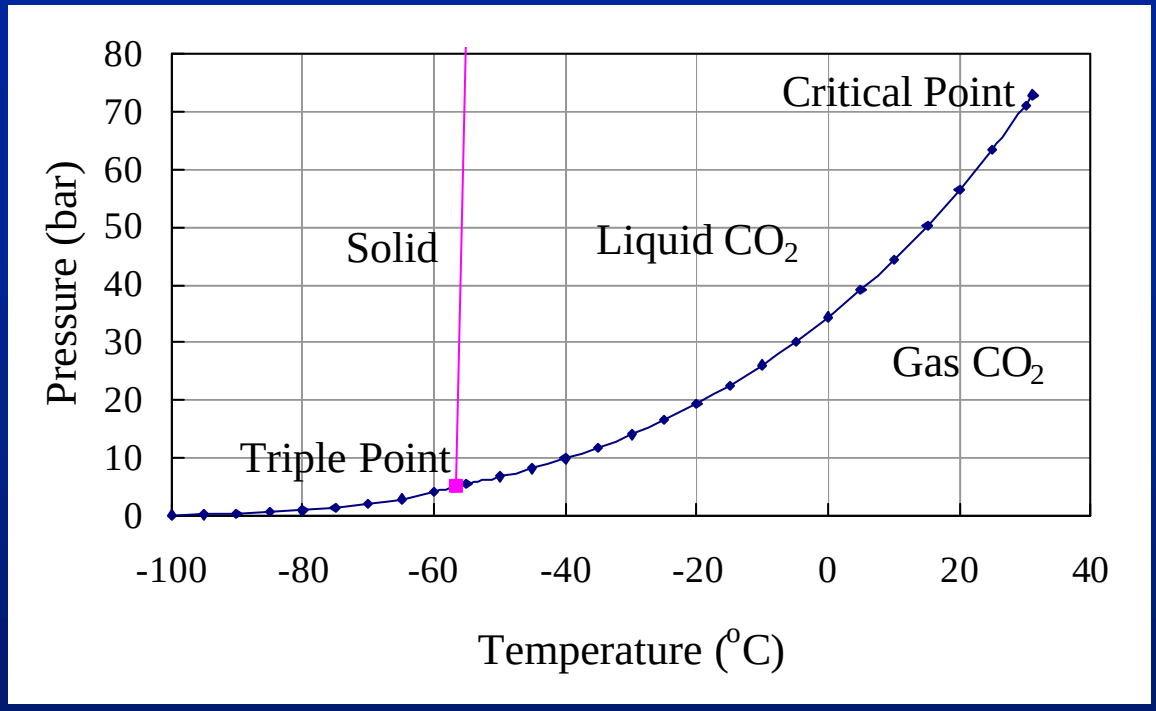
- **Contaminants change the dew point for water condensation**
- **‘Liquid’ carbon dioxide recovery by ‘condensation’ at atmospheric pressure!**
- **Contaminants also change the ‘dew point’ for CO_2 condensation**
- **Must carry out exact calculations for condensations**

- Andersen probe and particle sample photos

Andersen Probe



Particle sample plate

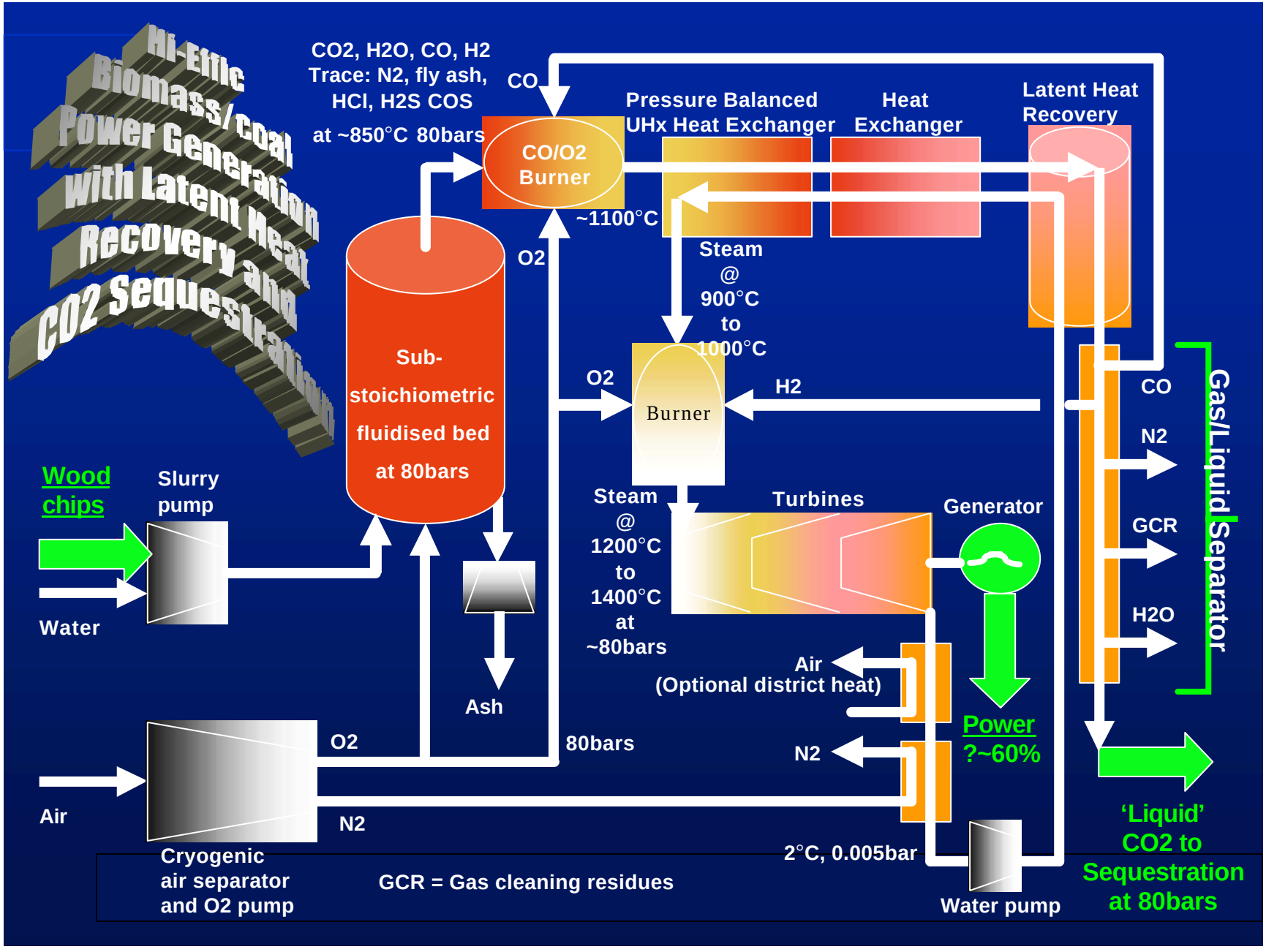


Phase diagram for pure carbon dioxide

- **High temperature technology**
  - Ceramic heat exchangers >1000°C
  - Burn hydrogen-oxygen in steam to raise its temperature to 1400°C
  - Efficient steam turbine engine cycle with cooled turbine blades

Ultra Superheated Steam

Steam at 1600°C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Conclusions

- **Decarbonise the atmosphere with advanced wood burning technology**
- **Particles emitted by wood combustion for CHP must be controlled**
- **Moisture in Wood: Dry wood using low grade heat, or condense after combustion to recover latent heat of water**
- **Burn and Condense at High Pressure: Recovers latent heat >200°C for energy generation and allows 'condensation' of CO_2 for sequestration; Pump liquid wood chip slurry efficiently to high pressure; Inverted heat transfer tube stress (compression) allows advanced materials.**
- **Oxy-fuel Combustion: Control flame temperature with water (forms H_2 by water-gas reaction) or recycled CO_2 . Pump oxygen as liquid to high pressure.**
- **Raise power generation efficiency for biomass and/or coal fuel > 60% by oxy-hydrogen superheating steam to ~1400°C**