Gasification

Woody Biomass Utilization Workshop

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UC Cooperative Extension

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Contents

- Definition & Basic Technology
- Gas use and characteristics
- History and Status
- Tar and its' issues
- Economics
- Conclusions

Principal Biomass Conversion Pathways

Conversion

- Thermochemical Conversion
  - Combustion
  - Gasification
  - Pyrolysis
- Bioconversion
  - Anaerobic/Fermentation
  - Aerobic Processing
  - Biophotolysis
- Physicochemical
  - Heat/Pressure/Catalysts
  - Refining
  - Makes e.g. Esters (Biodiesel), Alkanes

Products

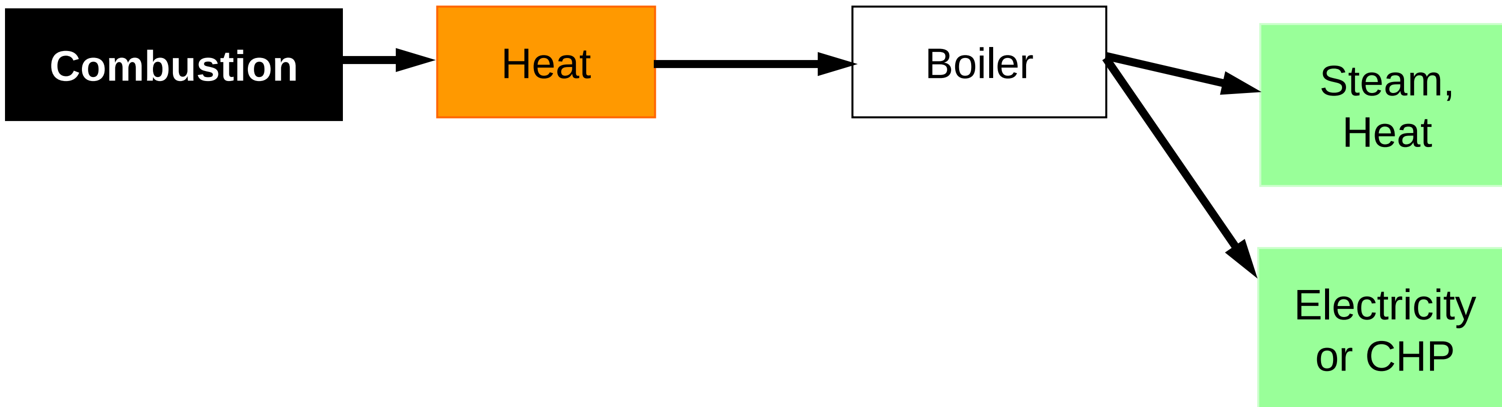
- Energy
  - Heat
  - Electricity
- Fuels
  - Solids
  - Liquids
  - Gases
- Products
  - Chemicals
  - Materials

Thermal Gasification*

- Gasification - high temperature conversion of (usually solid) carbonaceous feedstocks into a gaseous fuel
  - 1300 – 2200 °F (700-1200 °C)
  - Overall process is endothermic
    - Requires burning some of the fuel to provide heat for the process (i.e., partial oxidation)
    - Or heat is supplied to reaction from some external source / (indirect gasification)

* “Bio-gasification is a term that usually means ‘making biogas from anaerobic digestion’

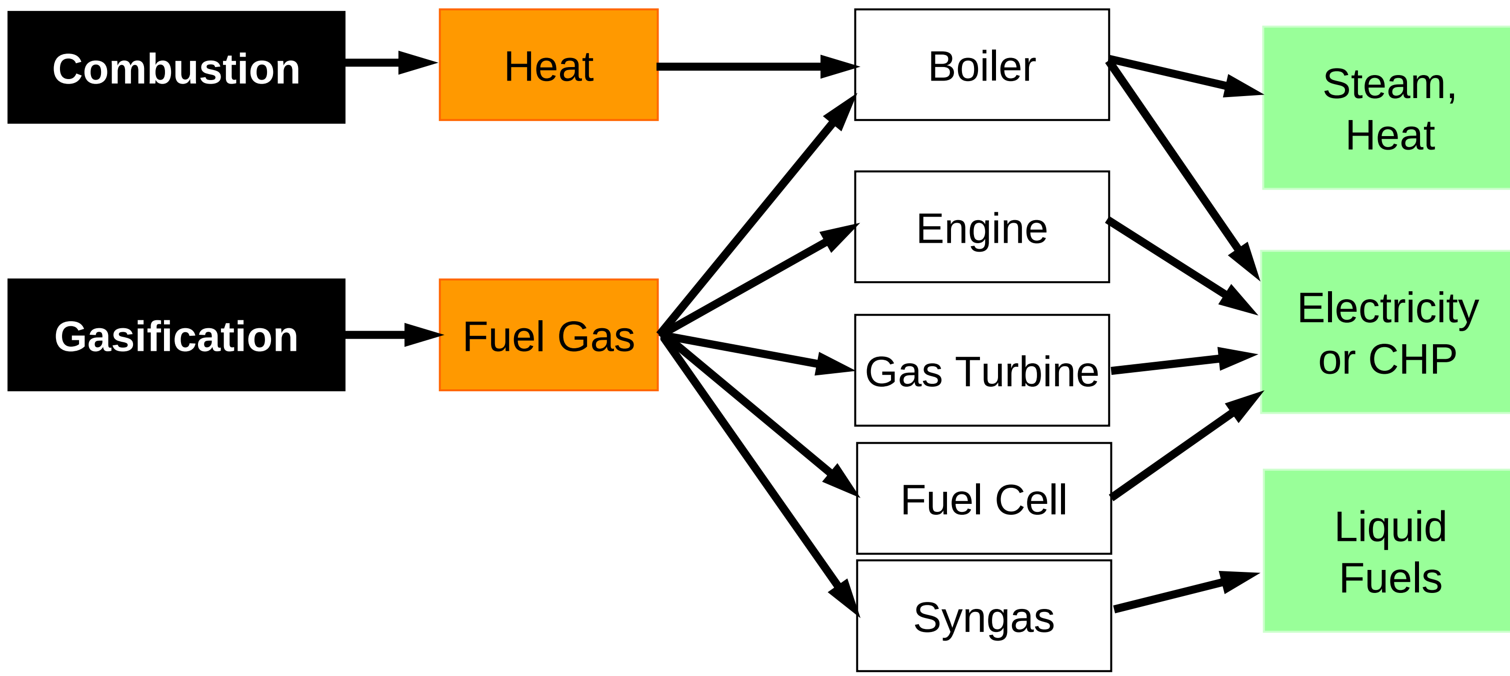
Basic Thermal Technologies



Combustion: Goal is "Complete Oxidation"

Fuel + Excess Air → **Heat**
+ Combustion Products (CO_2 + H_2O)
+ Pollutants (PM, CO, NO_x, SO_x, others)
+ Ash

Basic Thermal Technologies



Gasification:

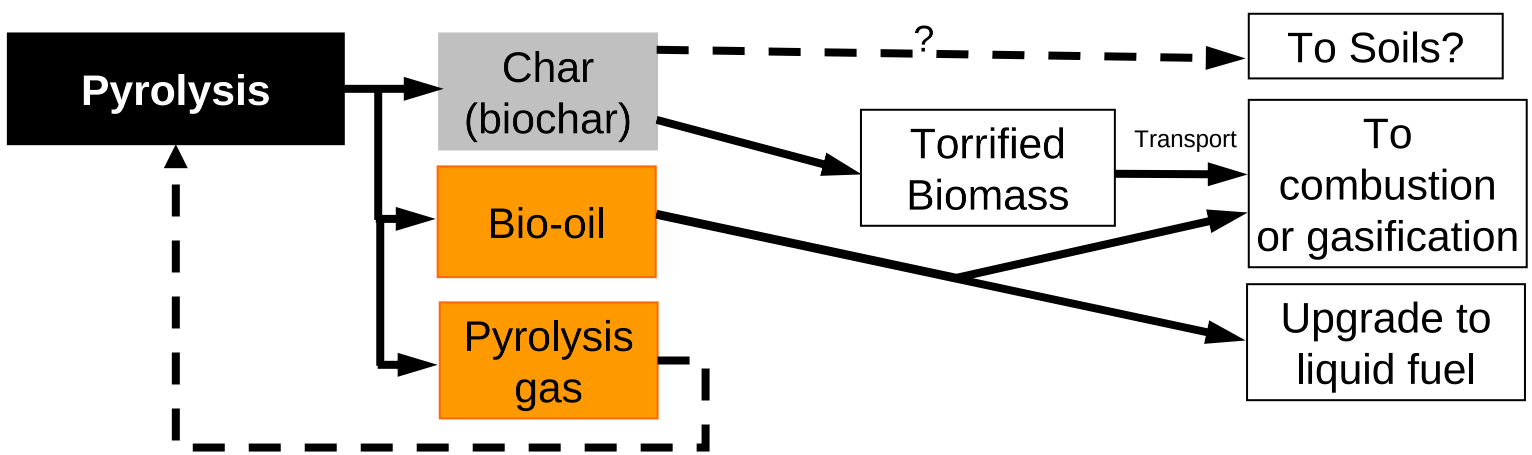
Fuel + Oxidant/Heat → Fuel Gas (CO + H_2 + some hydrocarbon gas)
+ Some combustion products (CO_2+H_2O+N_2)
+ Tar, PM, H2S, NH_3 + Other
+ Char/Ash & Heat

By "Partial Oxidation" (insufficient air) or indirect heat

Produces a combustible gas or Fuel Gas (a.k.a. producer gas, syngas)

Pyrolysis

- Thermal decomposition without the presence of oxygen -> External heating
- Classified by time and temperature treatment
  - **Fast Pyrolysis:** Rapid conversion of small particles (< 2 sec.) at higher temperature (900 °F). Optimized for bio-oil production, minimal char and gas produced
  - **Slow Pyrolysis** [carbonization]: low temperature (400 - 750 °F) – long time (30 mins. to days). Biochar, Activated Carbon, Charcoal, Torrified Biomass.



Energy in Product Gas & Relative Characteristics of Gasifier Types

Energy Content (Btu/ft^3)

- Air gasification* (partial oxidation in air) — ~ 100-200
  - Generates Producer Gas with high N_2 dilution low heating value.
- Oxygen gasification (partial oxidation using pure O_2) — ~ 300-400
  - Generates synthesis gas (Syngas) with low N_2 in gas and medium heating value
- Indirect heat w/ Steam gasification — ~300-450
  - Generates high H_2 concentration, low N_2 in gas and medium heating value. Can also use catalytic steam gasification with alkali carbonate or hydroxide

* Small systems are generally "Air-blown" downdraft or updraft gasifiers

Natural Gas → ~ 1000 (Btu/ft^3)

		Downdraft	Updraft	Bubbling FB	Circulating FB	Entrained Flow
Fuel Particle Size (in.)		0.5 - 4	0.25 - 4	0.5 - 3	0.5 - 3	Small < 0.1
Moisture Content (%)		<30 (prefer<15)	< 60	< 40	< 40	< 15
Relative Tar Production		low	high	moderate	moderate	very low
Scale (Fuel input)	(MM Btu/hr)	< 34	< 70	34 - 340	34 - ??	> 340
	(Dry tons wood/hr)	< 2	< 4	2 - 20	2 - ??	> 20

Knoef, H.A.M., ed. (2005). Handbook of Biomass Gasification. BTG biomass technology group: Enschede, The Netherlands.

History

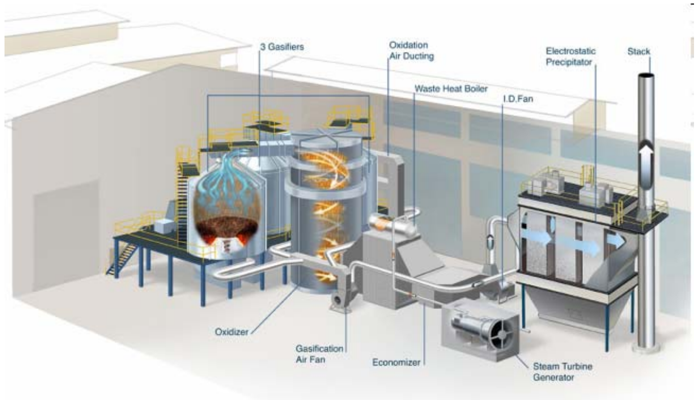
- 1790s- Coal gas used for lighting factories in England and Philadelphia
  - Street lighting and 24/7 Factory Ops.
  - Significant environmental impacts –Tar/water disposal and air emissions
- 1860 Town gas is prevalent.
  - Lenoir develops reliable 'explosion engine' for town gas. Otto develops the 4-stroke gaseous fuel engine
- 1920s- Welding techniques allow piping natural gas under pressure--Town gas declines gone by 1960s
- WW II – Acute shortage of liquid fuels for civilian use
  - Cars, trucks, fishing boats fueled by gasifiers Europe, Japan, China, Brazil, Australia
  - Volvo, Saab, Daimler-Benz, Peugeot, Renault, Fiat, Isuzu
  - More than 1 million wood gas vehicles during the war
- Increased interest during 1970's oil embargo – Advanced biopower demonstrations Europe and US in mid 1990's
- Many applications in rural village electrification - 'off grid'

"Wood Gas" Vehicles

http://www.gengas.nu/kuriosa/biljournalen/01.shtml
http://www.greencarcongress.com/2006/09/everything_old_.html
http://ww2.whidbey.net/jameslux/woodgas.htm

Status of Gasification

- Gasifiers for Heat, Power, and CHP are not new and are considered commercial in many places
  - India, China, some developing nations
    - Low labor rates allow simple manual operation
    - Emissions (air and liquid) regulations may not be as strict as here
  - Examples in Europe due to
    - Use of district heat, especially northern Europe
    - High energy prices & GHG policies allow (high feed-in tariffs, $ for RECs or carbon credits)
  - Examples in US and Canada where economic (direct heat applications, some steam power systems, or grant funded demonstrations)



Nexterra Biomass Gasification System at Johnson Controls' University of South Carolina Cogeneration Project.

UCDAVIS CALIFORNIA biomass

Status of Gasification

- In California and much of US, economics are marginal
  - Air Emissions (especially NOx) are difficult to meet in large areas of California (San Joaquin Valley, LA basin)- NOx control adds expense, and may not even be achievable
  - Labor costs (and emissions/discharge requirements) lead to more automation and sophistication increasing capital costs

Gasifiers – An incomplete List

Name	Location	Type	Application	References
Bioneer	Finland	Updraft	Heat or Steam	About a dozen - mid 1980s- 1990s
PRM Energy Systems	Hot Springs, AR	Updraft	Heat or Steam	~a dozen rice hull , straw for heat / steam (overseas, some Gulf States, US) ~ 4 steam CHP (2 in the US?)
Nexterra	Vancouver, BC	Updraft	Heat, Steam	Recent installations and claimed sales
Energy Products of Idaho	Idaho	Bubbling Fluidized Bed	Heat or Steam	Several in North America (since mid 1980s)
Energy Products of Idaho	Idaho	Bubbling Fluidized Bed	Electricity (Steam Turbine)	~ 6 MW (one or two in US)
PRM Energy Systems	Hot Springs, AR	Updraft	Electricity (Engine)	~ 3 projects producing electricity (engines)
Nexterra	Vancouver, BC	Updraft	Electricity (Engine/steam)	CHP- Building @ University of British Columbia, 2MWe – Jenbacher engine(s)
Biomass Engineering, Ltd	UK	Downdraft	Electricity (Engine)	A dozen or so units reported in Europe (~ 100 - 400 kW)
Aruna	India	Downdraft	Electricity (Engine)	Many small scale - rural electrification India (10-1-- kw)
Ankur Scientific	India	Downdraft	Electricity (Engine)	Many in India (25 - 400 kW)
Ankur Scientific	US	Downdraft	Electricity (Engine)	Demos/Research at Humboldt State and EERC, North Dakota. Phoenix Energy using Ankur design
Community Power Corp.	Colorado	Downdraft	Electricity (Engine)	Perhaps a dozen demonstration units (25 -75 kW) throughout US (no known commercial units). Grant and Investor supported

Gasifiers – Some Projects in California

Name	**Location**	Type	Application	Comments
Phoenix Energy	Merced	Downdraft	Electricity (Engine)	Currently Commissioning: Wood pallets & orchard prunings; ~ 500 kW, Ankur gasifier derivative. (3300 $/kW estimated capital cost) Loan from CA Waste Board
Community Power Corp.	Winters	Downdraft	Electricity (Engine)	50 kW Demo at Dixon Ridge Farms (walnut shell fuel) Several thousand hours of operation
Pro-Grow Nursery, Tom Jopson Owner	Etna	Downdraft	Burner fuel (+ engine generator)	Built - beginning final testing stages. Replace propane for greenhouse heating. Fluidyne gasifier (Doug Williams, New Zealand) ~ 100 kWe, TR Miles Consulting, UC Davis Bio.&Agr. Engr.
West Biofuels	Woodland	Dual Fluidized Bed (indirect gasifier)	Syngas to liquid + engine generator	5 ton/day, R&D (UC San Diego, Davis, Berkeley). Several Grants supporting work - commissioning
Sierra Energy	Sac.	Slagging Updraft	Syngas	Modified blast furnace – early development- lab/pilot scale
G4 Insights Inc	?	?	Reform to SNG	Recent $1.2 million grant from CEC. “Forest biomass to compressed biomethane”
Harvest Power/ Agnion	San Jose	Indirect- dual bed	Reform to SNG	Recent $1.9 million grant from CEC. “Urban wood waste to biomethane”
Humboldt State, UC Davis, Riverside, Berkeley, San Diego, Merced	Through-out CA	various	Fundamental & applied- heat, power, liquids	Various research efforts underway

Gasifiers produce tar which must be dealt with if gas

- runs an engine or gas turbine
- is to be used for synthesis gas (syngas) for liquids and chemical production

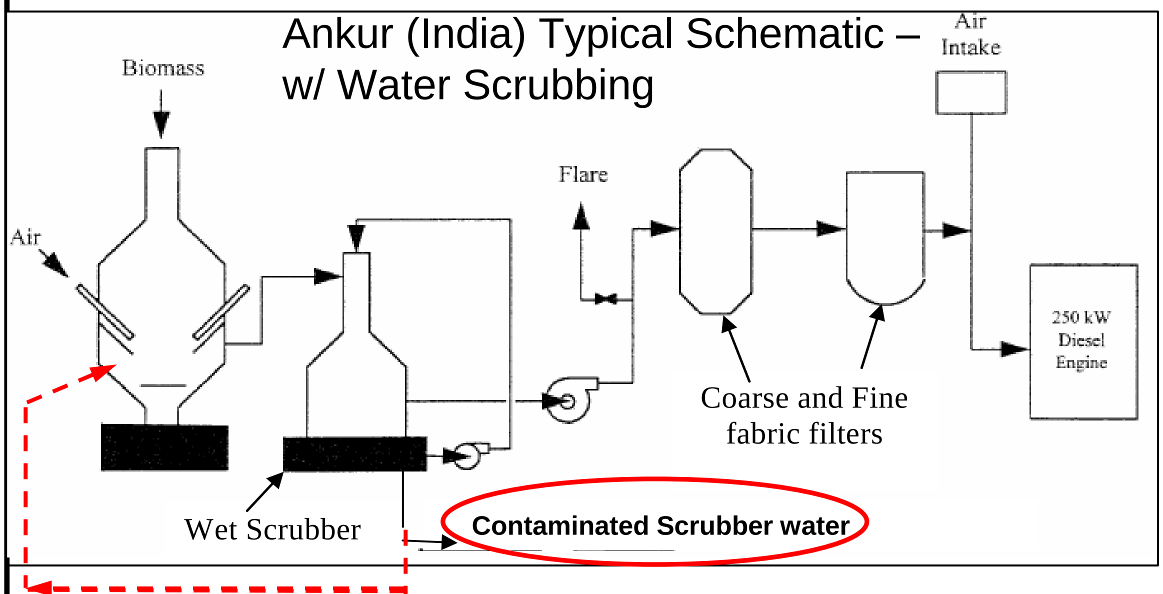
Tar is less of a problem if gas is burned directly in a boiler (close-coupled combustion)

Tar is a mixture of small & large hydrocarbon molecules that

- **condense as a sticky substance in piping and appliances,**
- **foul catalysts and**
- **force frequent shutdowns and costly maintenance if not properly dealt with.**

Gas cleaning and tar issues are the primary technical hurdles for implementing gasification in gas-turbine and fuels and chemicals production applications

A typical system for tar removal from producer gas is a wet scrubber technique



Scrubber water and condensate contain:

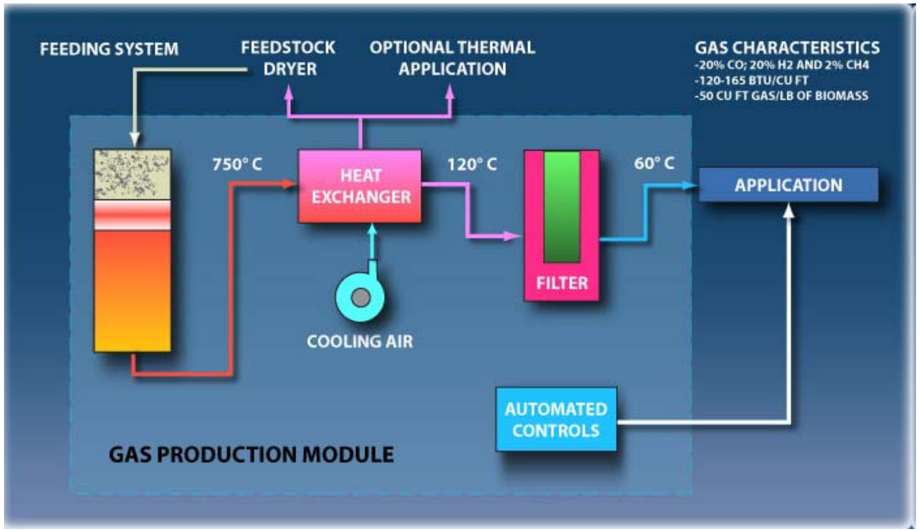
- PAHs
- Naphthalene
- Benzene, Toluene, Xylene

Contaminated waste water must be treated before discharge.

Some use organic liquid (e..g, biodiesel) as scrubber liquid and re-inject to gasifier for disposal

OR, re-inject oil-based scrubber liquid to gasifier for disposal

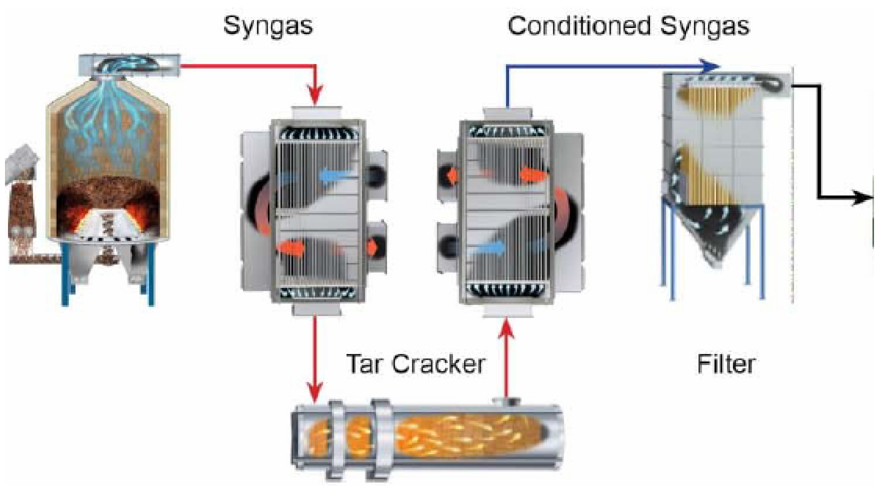
Community Power Corporation ‘Biomax’ – no liquid scrubbing of gas



- Fixed bed downdraft gasifier
- 12,15 & 50 (75?) kWe systems demonstrated
- Gas cooled to ~ 120 F & filtered to reduce tar and particulate matter for engine **(no liquid scrubber- this is positive feature)**

http://www.gocpc.com/technology.html

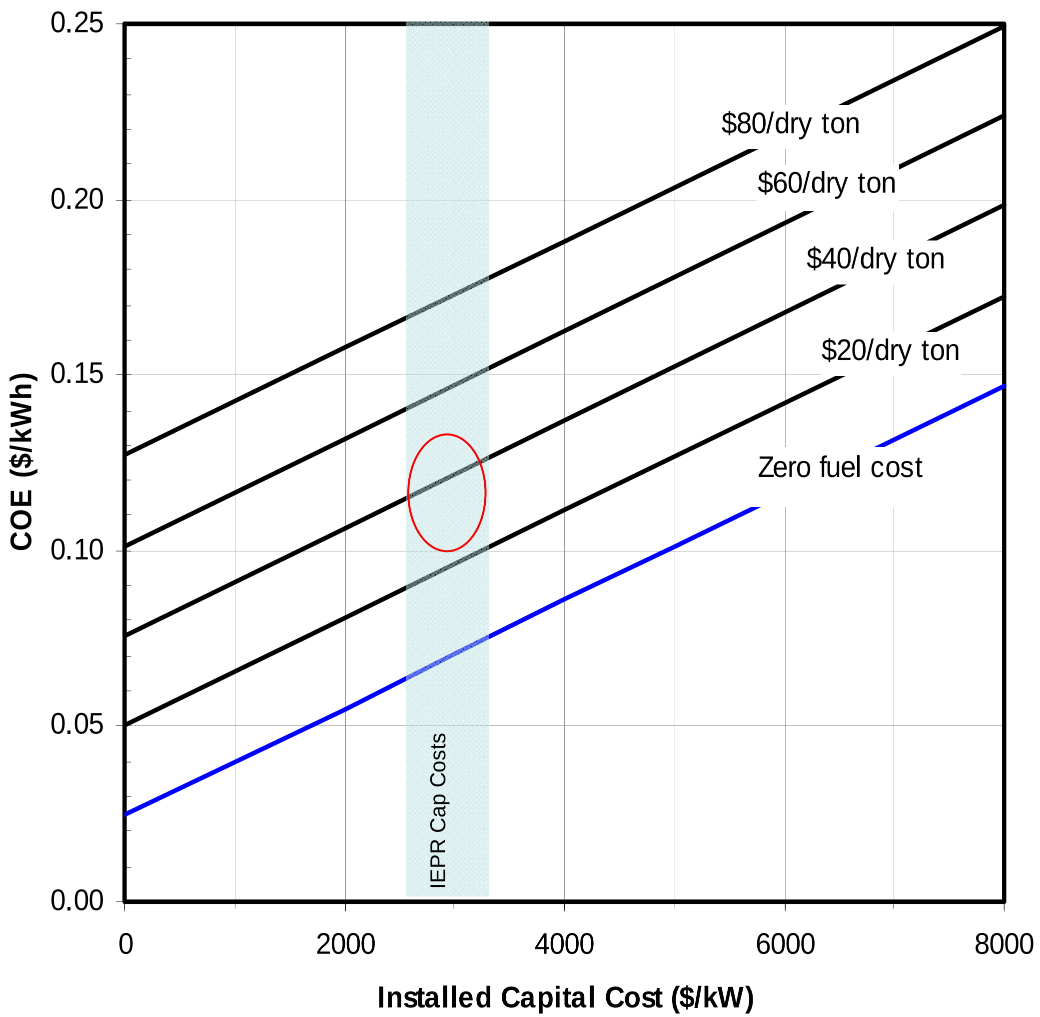
Nexterra – no liquid scrubbing of gas



Source: Nexterra

- Fixed bed updraft gasifier
- Building CHP system (2MWe + steam) at University of British Columbia
- Jenbacher engine(s)
- Will employ “Thermal Cracking” of tar
  - add small amount of air to gas
  - It burns, increasing gas temperature
  - Tar molecules break apart (crack) and some form CO & H2
  - Hopefully, no condensable tar remains **(no liquid scrubber)**

Levelized Cost of Electricity-
"Central Station Biomass Power"



Required Revenue ($/kWh) vs. Installed Cost, or "Cost of Electricity/' (COE)

"Central Station: Biomass Boilers"*

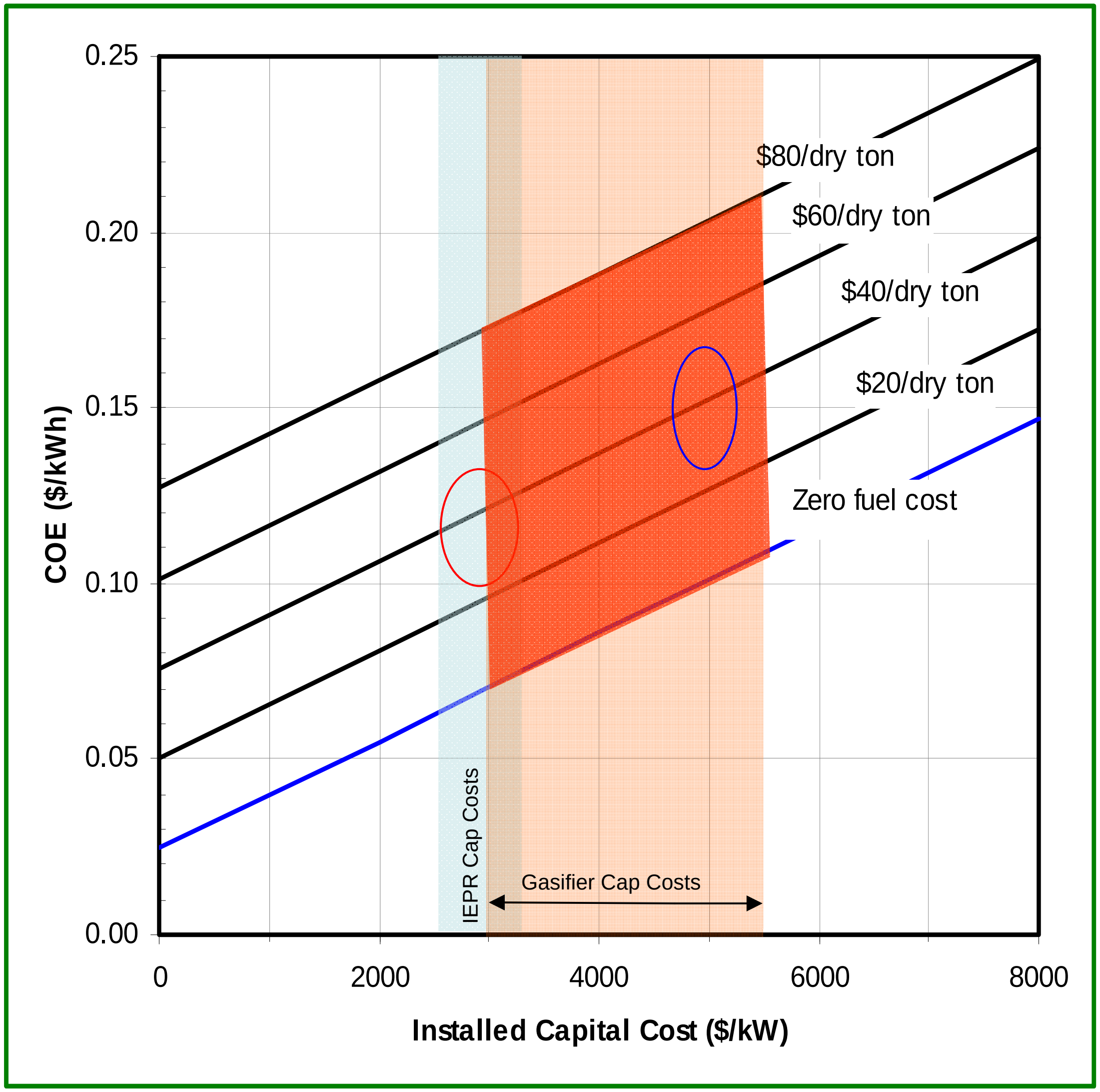
- 2,660 – 3,300 $/kW installed – capital
- 0.10 - 0.11 $/kWh Levelized COE (using 43 $/dry ton fuel cost) [CEC 2009]
- Other sources say capital costs for new facilities are higher ($3000-$4000/kW)

Assumptions

- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
- Debt and Equity recovered over 20 yrs.
- 2.1% general inflation and escalation
- 23% Net Efficiency of Power Generation
- 85% Capacity Factor
- $0.025 / kWh Non-Fuel Operating Expenses

* Klein, J. (2009) 2009 IEPR CEC-200-2009-017-SD

Levelized Cost of Electricity- Biomass Power



Capital Costs of Gasifiers*

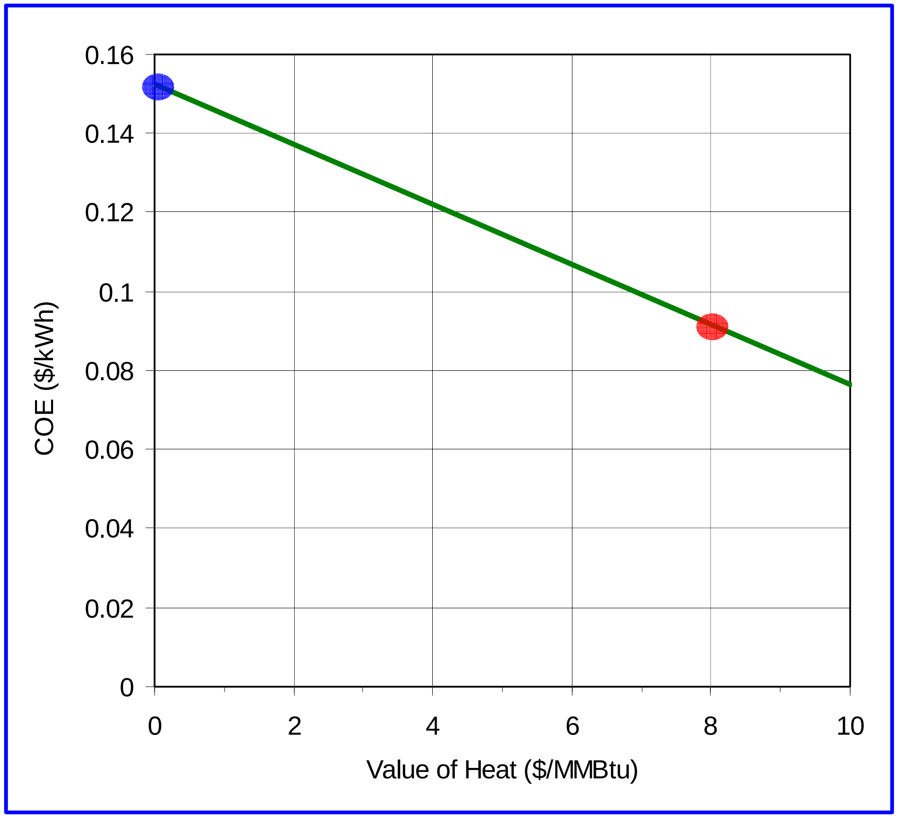
- Proposals ranging from 3300 -5500 $/kW installed (maybe as high as $10,000/kW - CPC??)
- Those that are built seem to come in at ~ 5000 $/kW
- Target is
  - 3000 $/kW for elect. only
  - 5000 – 6000 $/kW for CHP

Assumptions

- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
- Debt and Equity recovered over 20 yrs.
- 2.1% general inflation and escalation
- 23% Net Efficiency of Power Generation
- 85% Capacity Factor
- $0.025 / kWh Non-Fuel Operating Expenses

* Tom Miles, TR Miles Consulting, TSS Parlin Fork Draft

Levelized Cost of Electricity- Influence of Heat sales on COE



- Same Financial Assumptions as above
- $5000/kW capital cost (a target CHP cost)
- Fuel cost ~$40/dry ton
- 23% fuel-to-electricity efficiency
- 47% fuel-to-heat recovery efficiency
- Which gives 70% overall energy efficiency

Industrial price of natural gas in California is ~ $7/MMBtu

Cost of heat from natural gas is ~ $8/MMBtu (fuel cost only)

http://tonto.eia.doe.gov/dnav/ng/hist/n3035ca3m.htm

Air permit examples

Phoenix Energy Authority to Construct (SJVAPCD)

Ankur derivative downdraft gasifier, gas scrubbing/filtering, recip. engine-generator (~500 kWe)

Emission Limits

NOx (ppm)	CO (ppm)	VOC (ppm)	PM10 (g/hp-hr)	SOx (g/hp-hr)
9	75	25	0.05	0.03

CPC 50 kW at Dixon Ridge Farms (Winters, CA) [Yolo-Solano AQMD]

Downdraft gasifier, gas filtering, automotive V-8 engine-generator (~50 kWe)

Emission Limits and Test Results

	NOx (ppm)	CO (ppm)	VOC (ppm)	PM10 (gr/dscf)	SO2 (ppm)
Permit	98.8	2823	14.1	0.012	28.2
Source Test	58	362	ND	0.0005	<0.4

New 3-way Catalytic converter just prior to source test

Advantages of Gasification

- Produces fuel gas for more versatile application in heat and power generation and chemical synthesis.
- Smaller scale power generation than direct combustion systems although gas cleaning is primary concern and large expense.
- Potential for higher efficiency conversion using gas-turbine combined cycle at larger scale (compared to combustion-steam systems).

Gasification Challenges

- Costs
- Gas cleaning and tar management required for use of fuel gas in engines, turbines, and fuel cells
  - For reciprocating engines, tar and particulate matter removal are primary concerns,
  - Gas needs to be cleaner for gas turbines, and cleaner still for fuel cells and chemical or fuels synthesis
- In some air districts in California, meeting air emissions requirements is challenging
- Fuel particle size and moisture are critical for downdraft gasifiers (which are most often used for small scale power using reciprocating engines)

Acknowledgments, References and Information Sources

- Gareth Mayhead
- Tom Miles -- TR Miles Consulting www.trmiles.com
- Gasifier page http://gasifiers.bioenergylists.org
- Gasification Discussion List Gasifiers.bioenergylists.org
- Biomass Energy Foundation www.woodgas.com
- Doug Williams FluidyneLtd. www.fluidynenz.250x.com
- IEA Task 33 Gasification of Biomass www.gastechnology.org/iea

Thank You

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Pyrolysis

Source: Gareth Mayhead

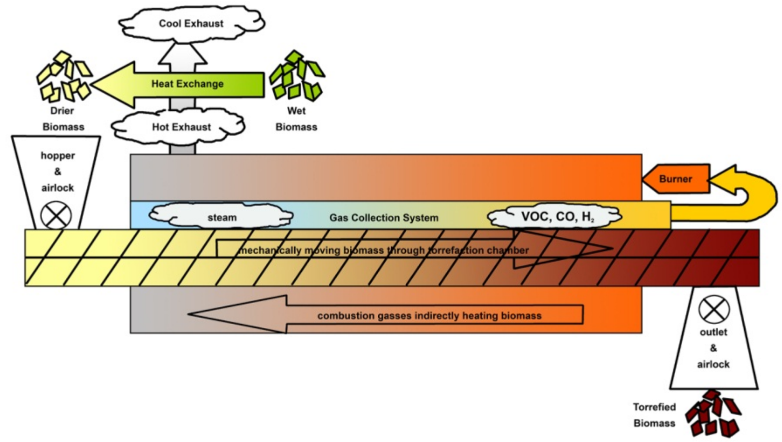
Charcoal Production in the woods

•This method used for > 1000 years

•Burns part of the batch for heat input

•Air Quality issues with this method

Schematic of Torrefaction Machine



Source: Agri-Tech Producers, LLC

Torrefaction or Torrefied Biomass

•Mild pyrolysis, pre-pyrolysis, airless drying, “wood browning”

•About 1 hour at 450 °F

•Removes moisture and light volatile material, leaves about 70% of original dry-weight of feedstock and about 90% of original energy

•Product is a solid with properties similar to coal (handling, grindibility, energy density)

•Easy and relatively inexpensive way to introduce biomass to coal-fired power plants

“Biocoal” Pellets