Gasification

Woody Biomass to Energy Workshop

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UC Cooperative Extension

Eureka, California

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Contents

- Definition
- Some History
- Gasifier Types
- Status
- Economics
- Conclusions

Thermal Gasification

- Gasification - high temperature conversion of (usually solid) carbonaceous fuels 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)

Pyrolysis

Usually means "thermal decomposition of solid/liquid fuel without air or oxidant"

Can be optimized for liquid production (bio oil), or char (biochar). Also produces combustible gases.

Thermal Gasification

Fuel + Oxidant/Heat

Partial Oxidation:
Air or Oxygen
Steam/Indirect Heating

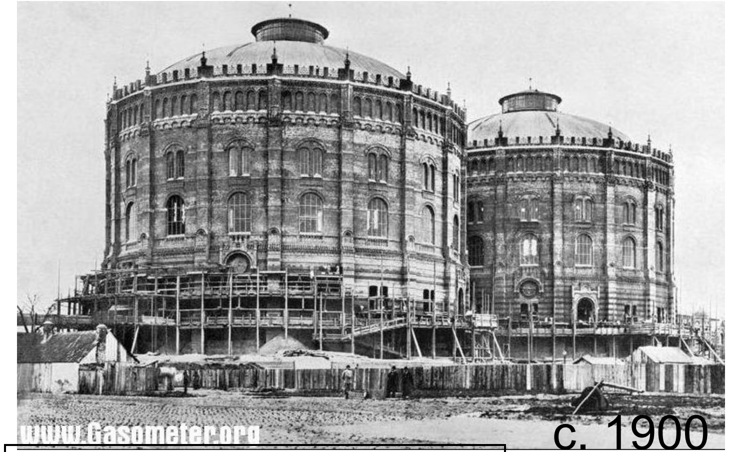
$CO + H_2 + HC + CO_2 + N_2 + H_2O +$ Char/Ash + Tar + PM + $H_2S + NH_3 +$ Other + Heat

Uses of product gas

- Heat/direct use
  - Stoves or burners for space heat, boilers for steam, gas lamps
- Electricity
  - Boiler fuel for steam Rankine cycle
  - Fuel for reciprocating engines (internal combustion or Stirling)
  - Fuel for gas turbine
- Other Fuels
  - Liquids (Biomass to liquids, e.g. via Fischer-Tropsch)
  - Gases (e.g., synthetic natural gas)
- Chemicals

History

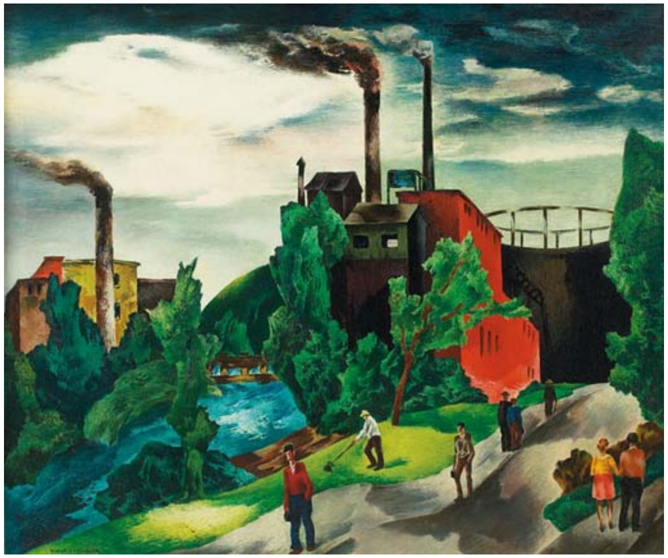
- 1790s- Coal gas used for lighting factories in England and Philadelphia
  - Actually external heating vessel of coal w/o air (pyrolysis gas was combustible for heat and lighting purposes
  - Street lighting and 24/7 Factory Ops.
  - Significant environmental impacts – Tar/water disposal and air emissions
- 1860 Town gas is prevalent.
  - Lenoir develops reliable 'explosion engine' fueled by town gas to power machinery (3% thermal efficiency)
  - 1876 Otto develops the 4-stroke gaseous fuel engine (1883 Daimler and Benz develop carburetor to enable liquid fuel induction to 4-stroke engine)
- ~1919- Town gas use reaches maximum
- 1920s- Welding techniques allow piping natural gas under pressure--Town gas declines gone by 1960s
- WW II –Special case re: gasification



c. 1900

'Town gas' storage in Vienna, Austria.

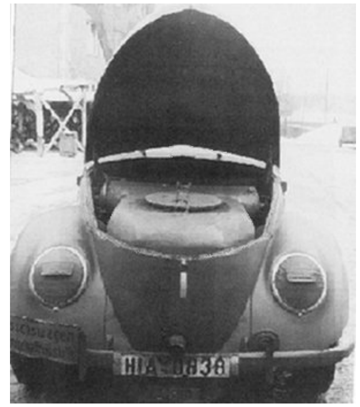
Converted to apartments ~ 2001



William S. Schwartz "Gas Factory" c. 1948 (US)

“Wood Gas” Vehicles

- Acute shortage of liquid fuels for civilian use during WW II
- Cars, trucks, fishing boats fueled by gasifiers Europe, Japan, China, Brazil, Australia
- Gas producers built by Volvo, Saab, Daimler-Benz, Peugeot, Renault, Fiat, Isuzu
- More than 1 million vehicles operated on producer gas during the war (350,000 in Germany)



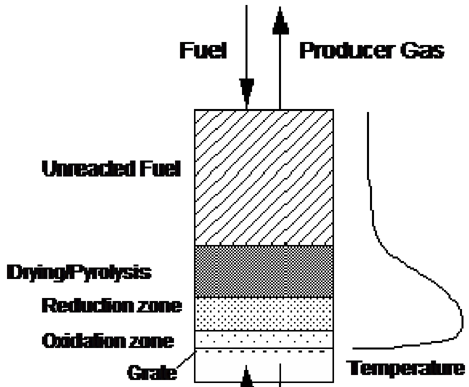
http://www.gengas.nu/kuriosa/biljournalen/01.shtml
http://www.greencarcongress.com/2006/09/everything_old_.html
http://ww2.whidbey.net/jameslux/woodgas.htm

History

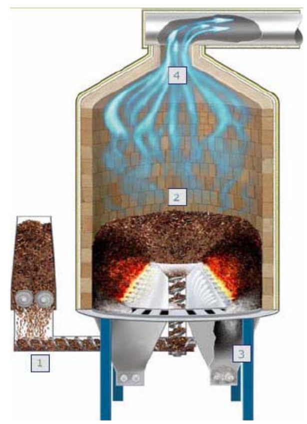
- Resurgence of interest and research due to Arab oil embargo (1973)
- Led to fuels and power research at UCD and elsewhere
- Mid 1990s saw numerous advanced biopower gasification demo projects in Europe and US
- Energy prices, GHG policies, use of district heat, all contribute to many biomass gasification for combined heat and power (CHP) installations in Europe

UC Davis (late 1970s)

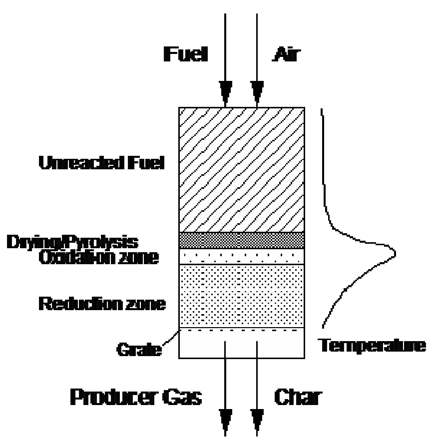
Classification by Reactor Type: Fixed/Moving Beds



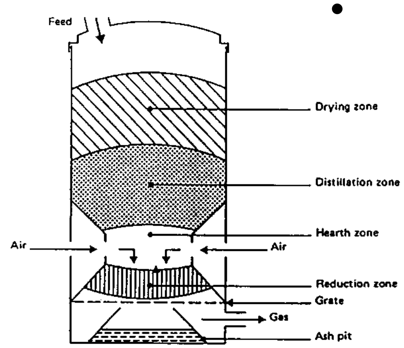
Updraft gasifier



- Updraft
  - Countercurrent
  - Simplest
  - High moisture fuel (<60% wet basis)
  - High tar production except with post-reactor tar cracking/removal or dual stage air injection
  - Low carbon ash
  - Good for direct heat applications
  - Small to Medium Scale
  - Cigarettes are updraft gasifiers



Downdraft gasifier



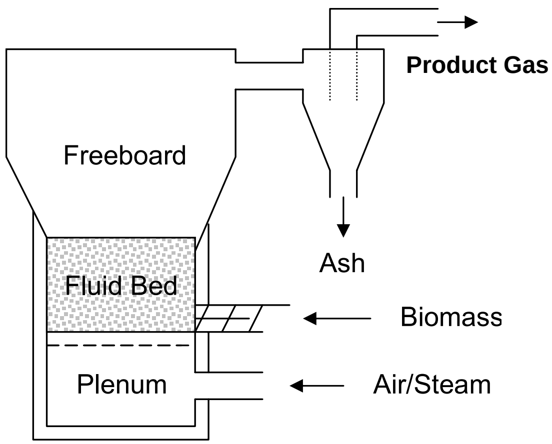
- Downdraft
  - Cocurrent
  - Moisture < 30% (preferred <15)
  - Lower tar than uncontrolled updraft
  - Carbonaceous char
  - 'Wood gas' Vehicles
  - ~ 200 – 500 kW (electric) maximum

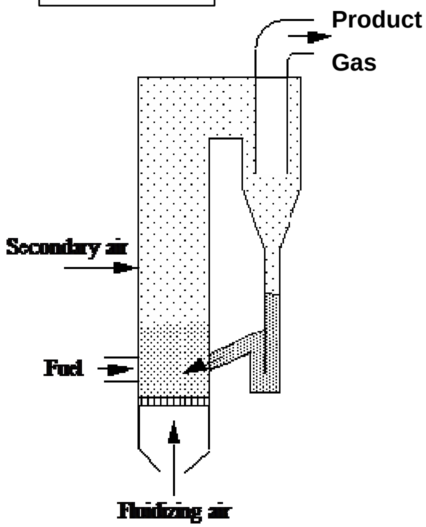
UCDAVIS

CALIFORNIA biomass

Classification by Reactor Type: Fluidized Beds

–"Fluidize" bed of hot sand – inject fuel – well mixed – speedy reactions



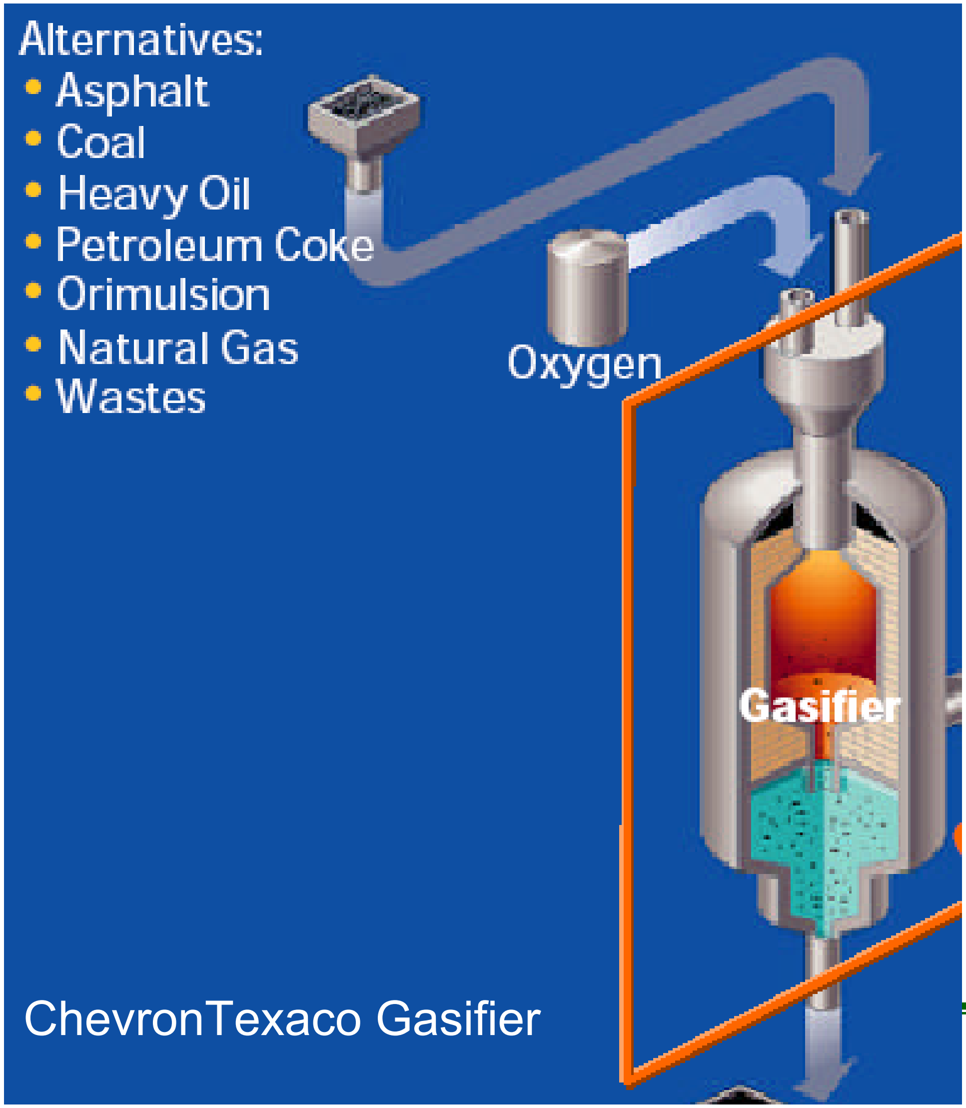


Circulating Fluidized Bed

- Bubbling beds
  - Lower velocity
  - Low entrainment/elutriation
  - Simple design
  - Moderate tar production
  - Medium to high capacity

- Circulating beds
  - Higher velocity
  - Solids are recirculated
  - More complex design
  - Moderate tar production
  - Higher conversion rates and efficiencies
  - Medium to high capacity

Classification by Reactor Type: Entrained Beds

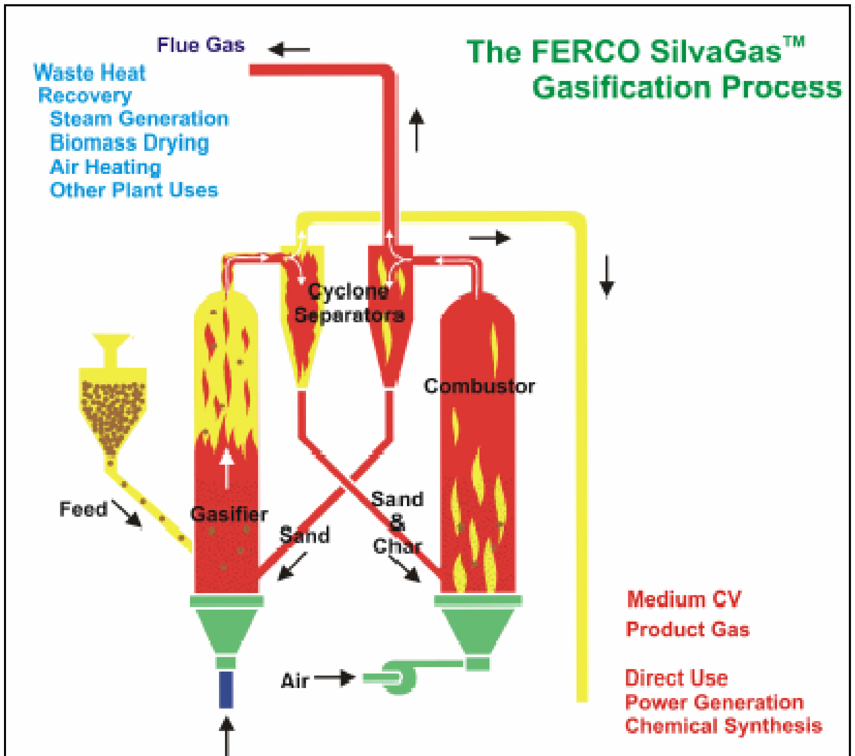


ChevronTexaco Gasifier

- Solids or slurry entrained on gas flow
  - Small particle size
  - Very low tar production
  - Often pure oxygen rather than air (yields higher temperature)
  - Economics favor very large capacity (>100 MW thermal input)
  - Likely biomass application is for syngas-to-liquids
  - "Slagging gasifier" design
    - Melt the ash for easy removal as liquid

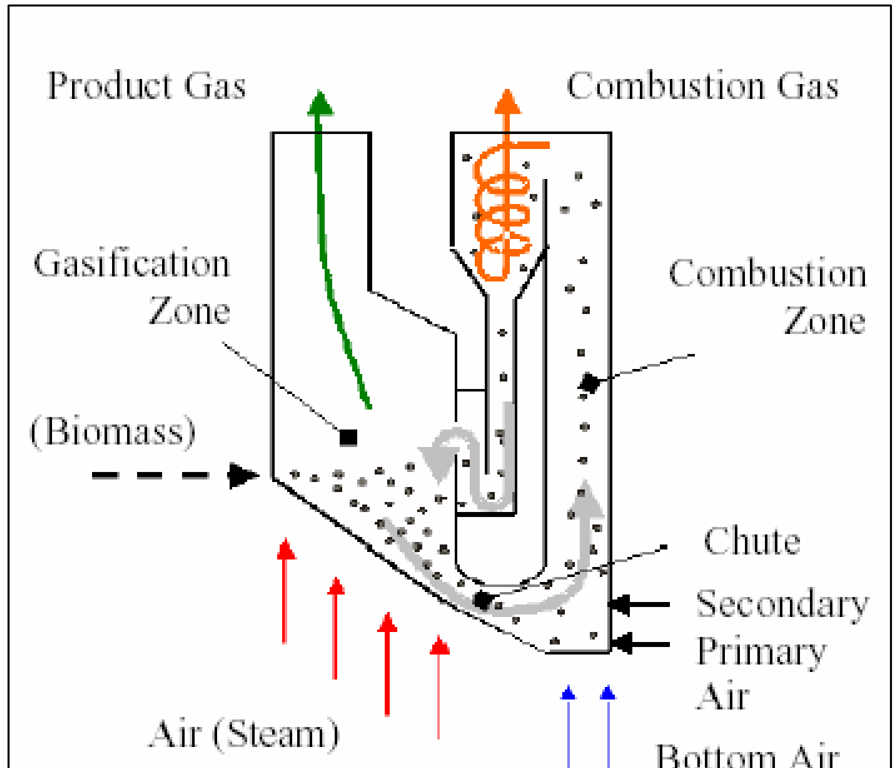
Classification by Reactor Type: Indirect Heat

Battelle/ FERCO gasifier*



*(Mark Paisley, FERCO)

Fast Internal Circulating Fluidized Bed (FICFB) gasifier, Güssing, Austria



Bolhar-Nordenkampf, et al. (2002)

Relative characteristics, scale, tar production, energy in gas

		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

- Air gasification (partial oxidation in air)
  - Generates Producer Gas with high N_2 dilution low heating value.
- Oxygen gasification (partial oxidation using pure O_2)
  - Generates synthesis gas (Syngas) with low N_2 in gas and medium heating value
- Indirect heat w/ Steam gasification
  - 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

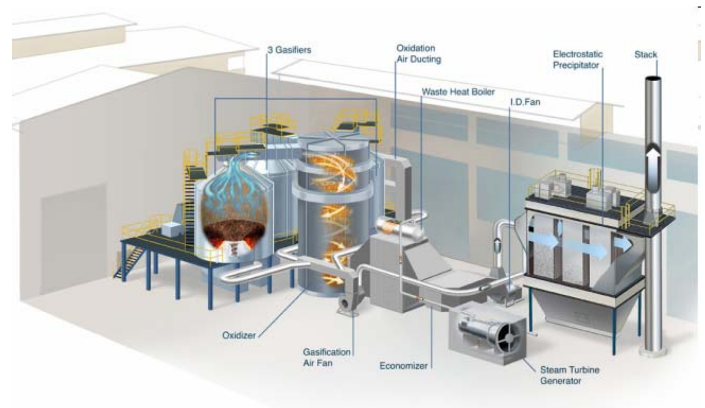
Energy Content (Btu/ft^3)
~ 100-200
~ 300-400
~300-450

Natural Gas → ~ 1000 (Btu/ft^3)

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

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 where economics allow (high feed-in tariffs, $ for RECs or carbon credits)
  - Examples in US where economic (direct heat applications, some steam power systems)
- 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



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

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 or Steam	Recent installations
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)	Marketing
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	Proposed Modesto area	Downdraft	Electricity (Engine)	Ankur design gasifier. ~ 500 kW (3300 $/kW estimated capital cost) Loan from CA Waste Board
Community Power Corp.	Winters, CA	Downdraft	Electricity (Engine)	Demo at Dixon Ridge Farms (walnut shell fuel) Several thousand hours of operation
Pro-Grow Nursery, Tom Jopson Owner	Etna, CA	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, CA	Dual Fluidized Bed (indirect gasifier)	Syngas to liquid + engine generator	5 ton/day, Research and Demo (UC San Diego, Davis, Berkeley). Several Grants supporting work
Humboldt State, UC Davis, Riverside, Berkeley, San Diego, Merced	Throughout CA	various	Fundamental & applied science, heat, power, liquids	Various research efforts underway

Air permit examples

Phoenix Energy Authority to Construct (SJVAPCD)

Emission Limits

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

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

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

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

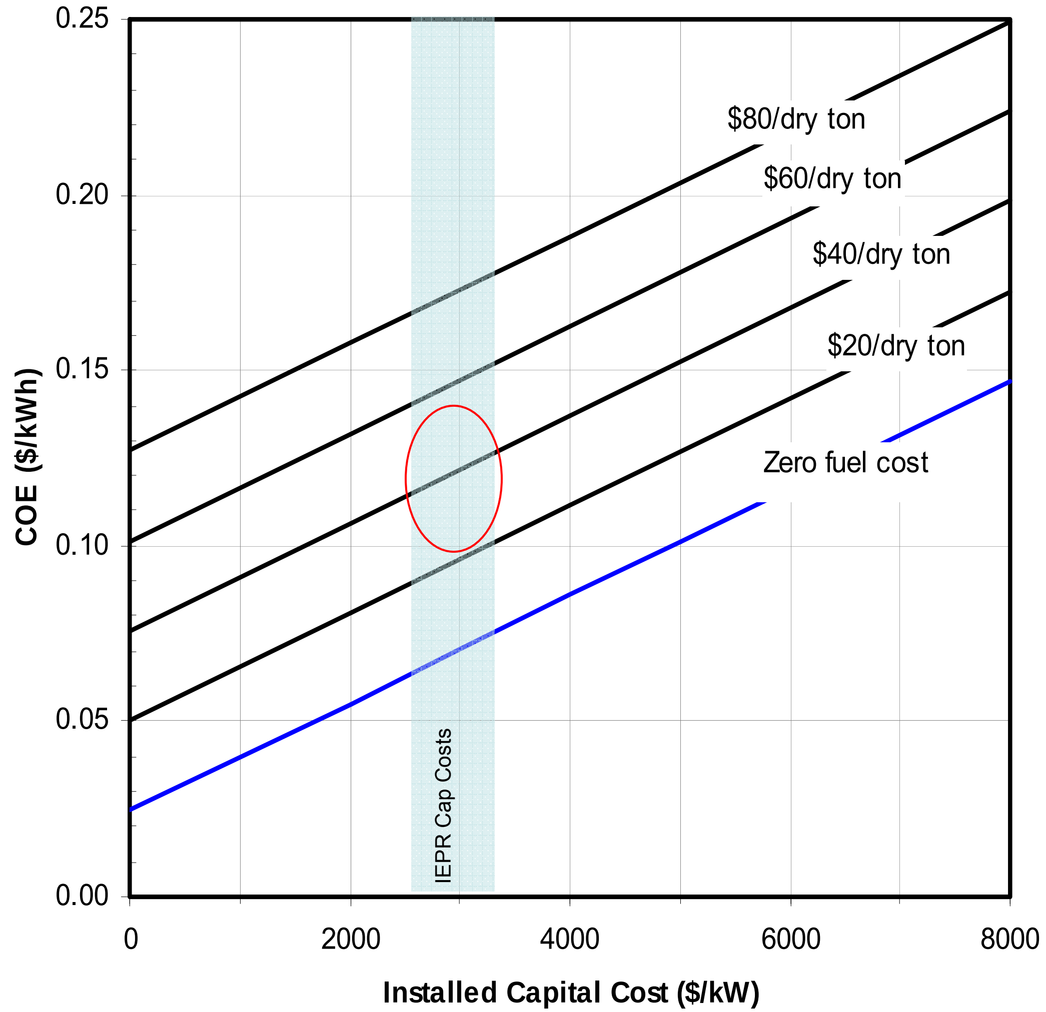
Emission Limits and Test Results

	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

UCDAVIS CALIFORNIA biomass

Levelized Cost of Electricity- Biomass Power



Assumptions

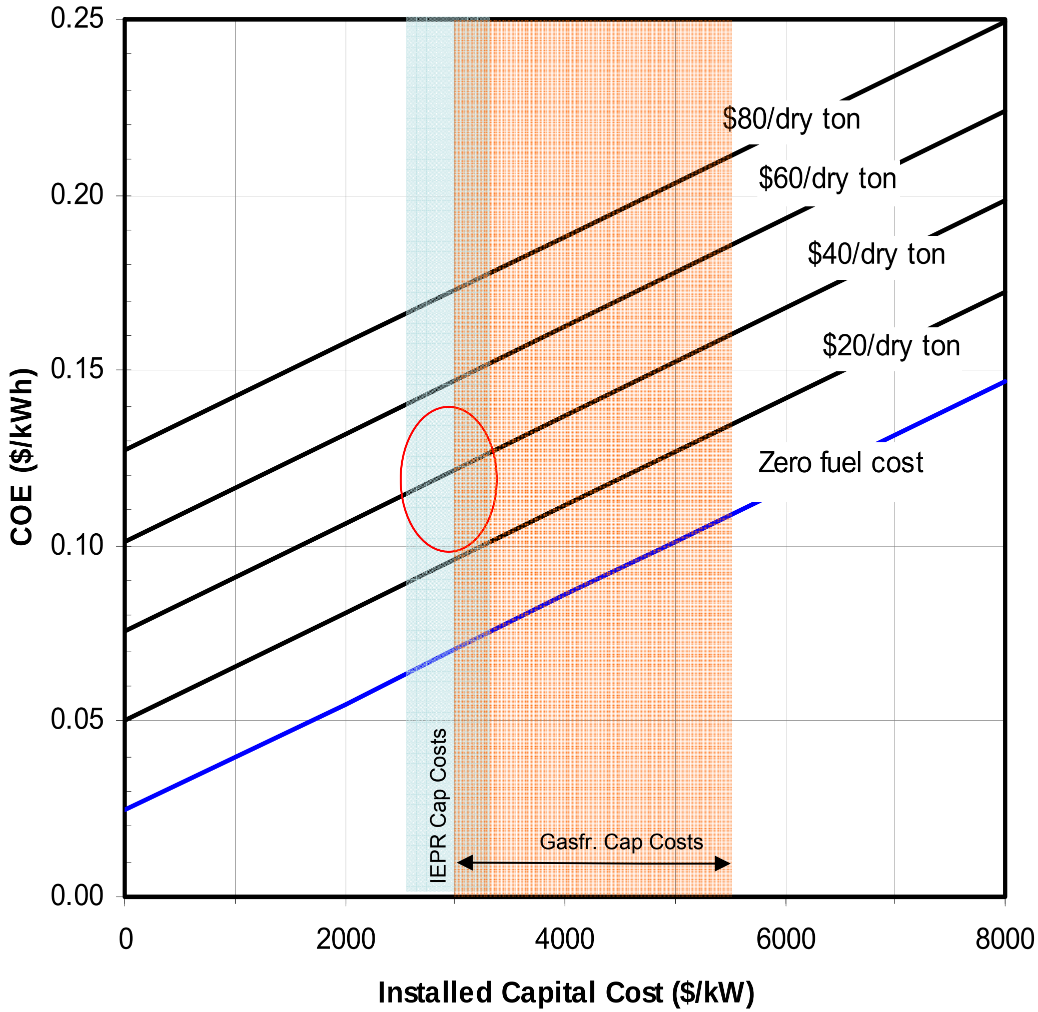
- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
- Debt and Equity recovered over 20 yrs.
- 2.1% general inflation and escalation
- 23% Net Efficiency of Power Generation
- 85% Capacity Factor
- $0.025 / kWh Non-Fuel Operating Expenses

"Central Station: Biomass Boilers*

- 2660 – 3300 $/kW installed – Capital
- 0.10 - 0.11 $/kWh Levelized COE (using 43 $/dry ton fuel cost)

* 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

Assumptions

- 75% Debt (@ 5% annual interest), 25% Equity w/ 15% rate of return => overall cost of money = 7.5%
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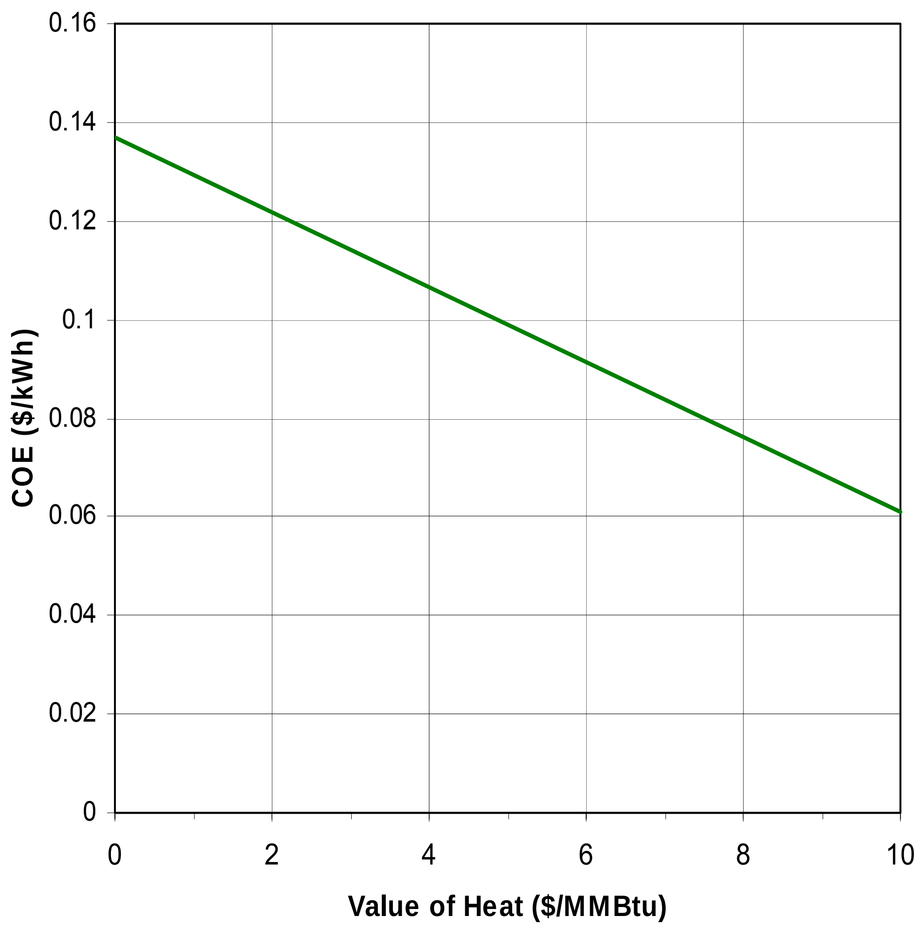
* Tom Miles, TR Miles Consulting

Levelized Cost of Electricity- Influence of Heat sales on COE



- Same Financial Assumptions as above
- $4000/kW cap. Fuel cost ~$40/dry ton
- 23% fuel-to-electricity efficiency
- 47% fuel-to-heat recovery efficiency
- Which gives 70% overall energy efficiency

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 expense.
- Potential for higher efficiency conversion using gas-turbine combined cycle at larger scale (compared to combustion-steam systems).
  - Biomass-Integrated-Gasifier-Gas-Turbine-Combined-Cycle (BIGGCC) is Emerging Technology ; Demonstrated but not commercial – no known currently operating

Gasification Challenges

- Fuel particle size and moisture are critical for downdraft gasifiers (which are most often used for small scale power using reciprocating engines)
- Gas cleaning required for use of fuel gas in engines, turbines, and fuel cells
  - For reciprocating engines, tar and particulate matter removal are primary concerns,
    - Tar removal difficult to achieve. Reactor designs influence tar production
    - Need for cool gas to maintain engine volumetric efficiency leads to tar condensation and waste water production (from wet scrubbing systems).
    - Engine derating for gas from air-blown reactors (low Btu gas).
  - 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
- Costs

Conclusions

- Gasifiers for heat, power, and CHP are employed in many parts of the world
- Some in the US, but fewer examples.
- For those contemplating biomass heat or power systems, need to understand the issues (real cost, risks, operational effort and potential problems).
- Accurate information about existing projects and demonstrations is needed
  - Need long-term operational data: [monitor mass and energy flows, emissions over time, document operating costs, etc.]

Acknowledgments, References and Information Sources

- 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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Thermochemical Conversion

(combustion, gasification, pyrolysis / indirect gasification)

- Combustion

Fuel + Excess Air → Heat + Hot Exhaust Gas + Ash

- Direct Gasification

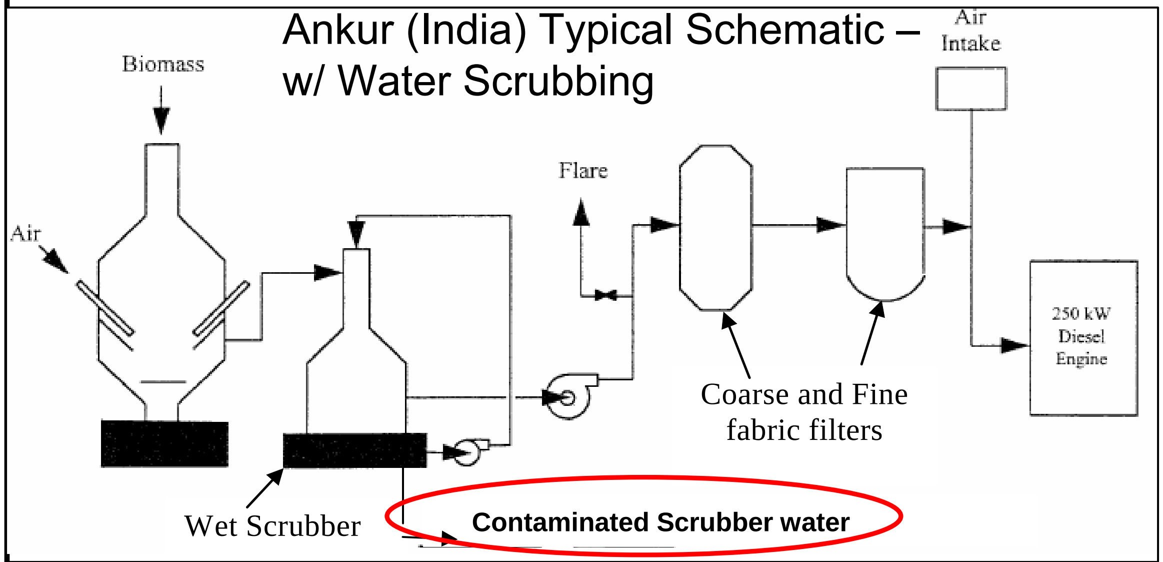
Fuel + Limited Air (N_2 & O_2) → "Producer Gas" + Heat + Char/Ash + Tar ("Air Blown")

Fuel + Limited Oxygen → "Syngas" + Heat + Char/Ash + Tar ("Oxygen Blown")

- Indirect Gasification and Pyrolysis

Fuel + Heat → "Syngas" or "Pyrolysis Gas" + Heat + Char/Ash + Tar (+ pyrolysis liquids)

Adapted from Paskach. (2010). Frontline Bioenergy

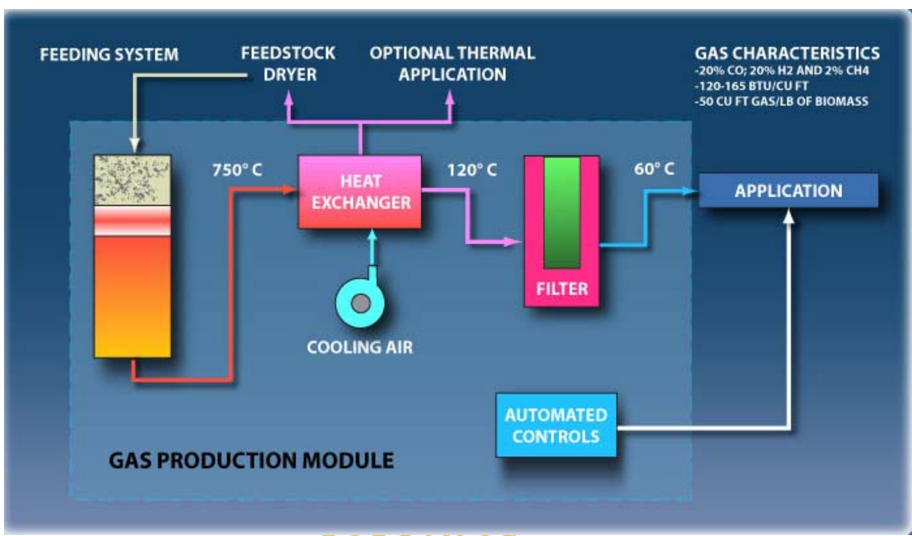


Scrubber water and condensate contain:

- •PAHs
- •Naphthalene
- •Benzene, Toluene, Xylene

Contaminated waste water must be treated before discharge

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



- Fixed bed downdraft gasifier
- 12,15 & 50 (75?) kWe systems demonstrated
- Automotive spark ignition engine –generator
- Gas cooled to ~ 120 F & filtered to reduce tar and particulate matter for engine **(no liquid scrubber- this is positive feature)**
- 3-way automotive catalytic converter for emissions control

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