# Small Scale Energy

**Woody Biomass Utilization Workshop**

May 25 & 26, 2010

UC Cooperative Extension

Quincy, California

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- Definition & Basic Technology
- Biomass Heat Systems
  - Components
  - Some Costs
  - Emissions
- Thermal Gasification
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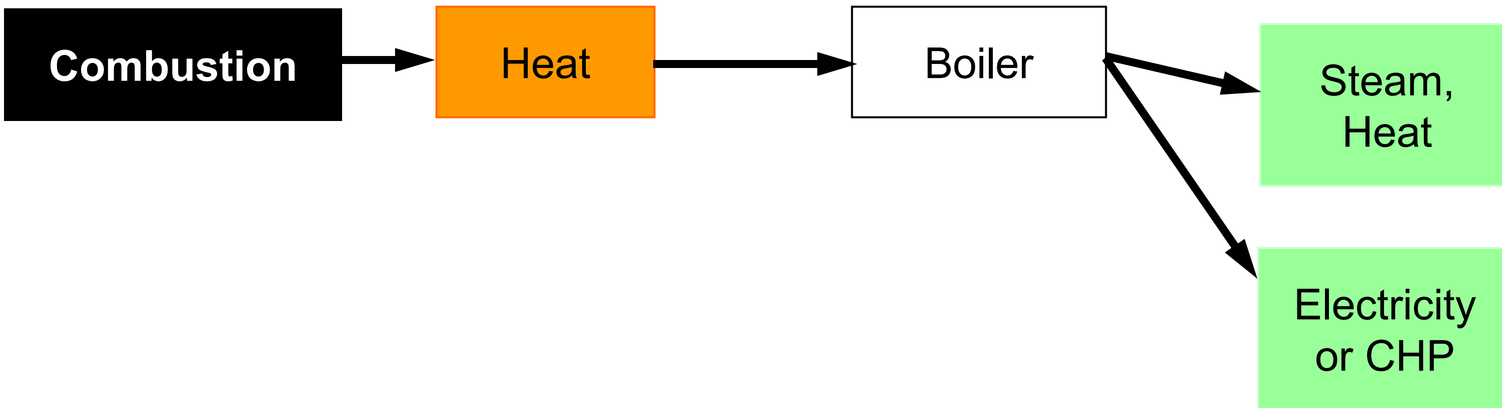
  - Cost of electricity
  - Emissions
- Conclusions

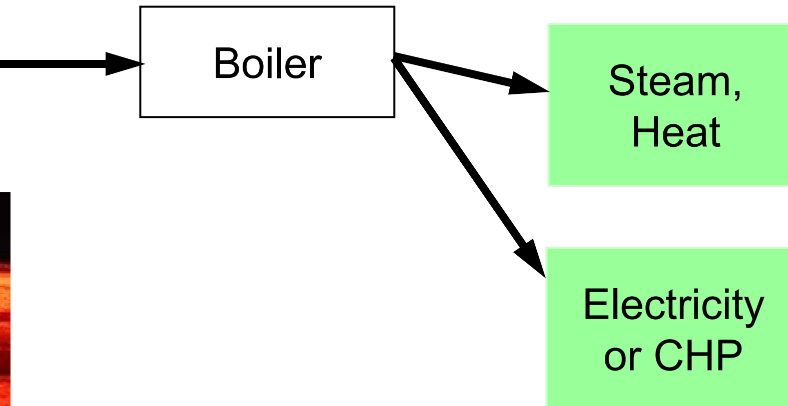
# Small Scale Energy

- Heat Systems (usually steam or hot water for building heat)
  - **0.3 to 10 MMBtu/h** peak output of boiler (e.g., schools and small rural hospitals)
  - **13 to 30 MMBtu/h** output for some larger institutions (college campus, Nevada prison)
- Electricity Production Systems
  - Less than ~ **1 MW (1000 kW)** capacity

# Basic Technologies



# Basic Technologies

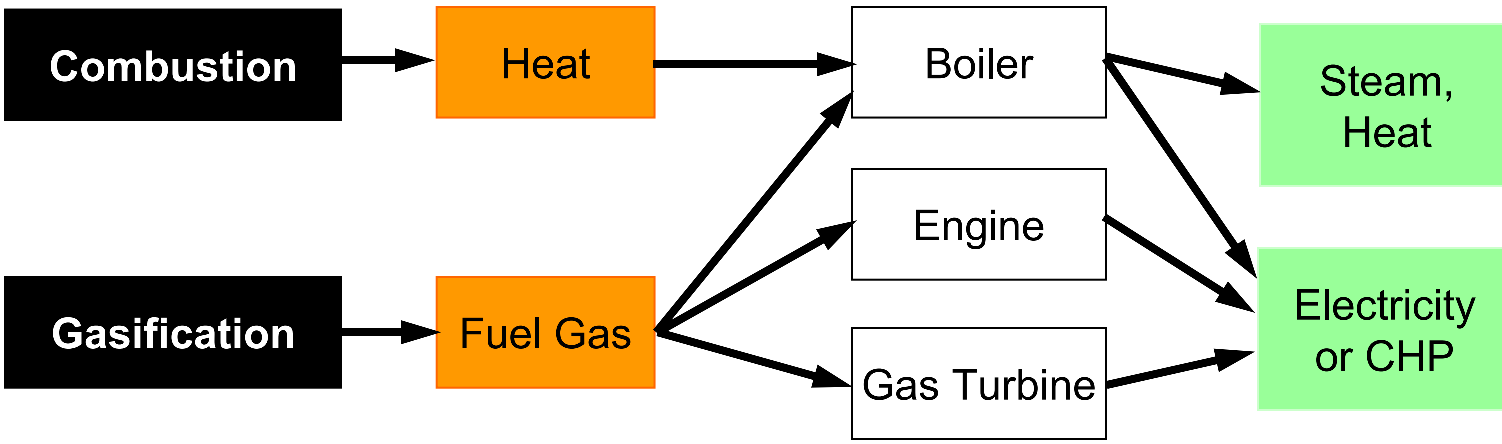



## Combustion:

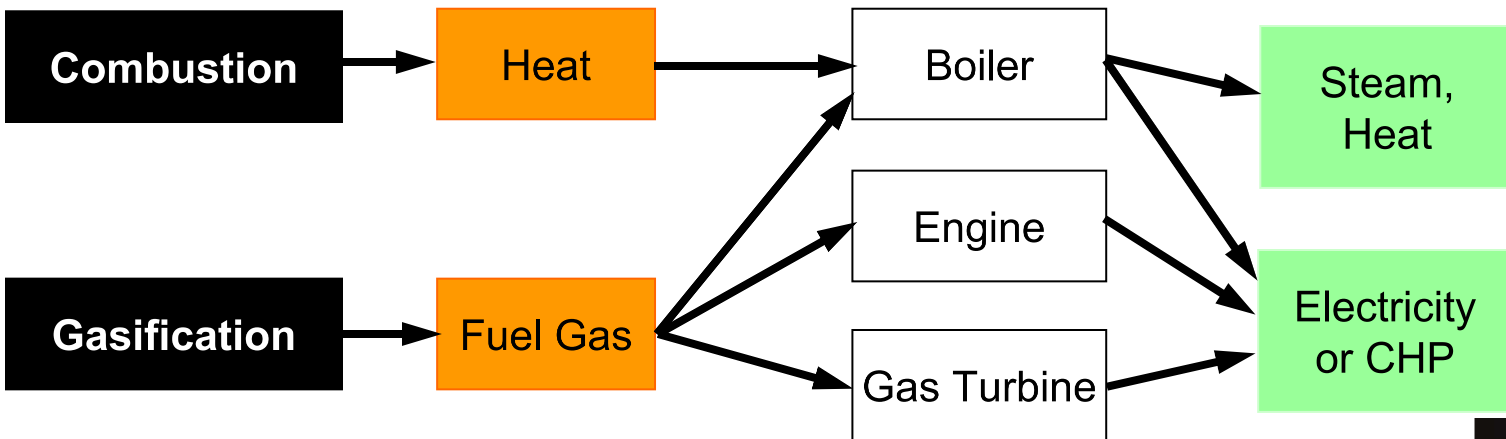
Fuel + Excess Air → **Heat**
+ Combustion Products ($CO_2$ + $H_2O$)
+ Pollutants (PM, CO, $NO_x$, $SO_x$, others)
+ Ash

"Complete Oxidation"

# Basic Technologies



# Basic Technologies



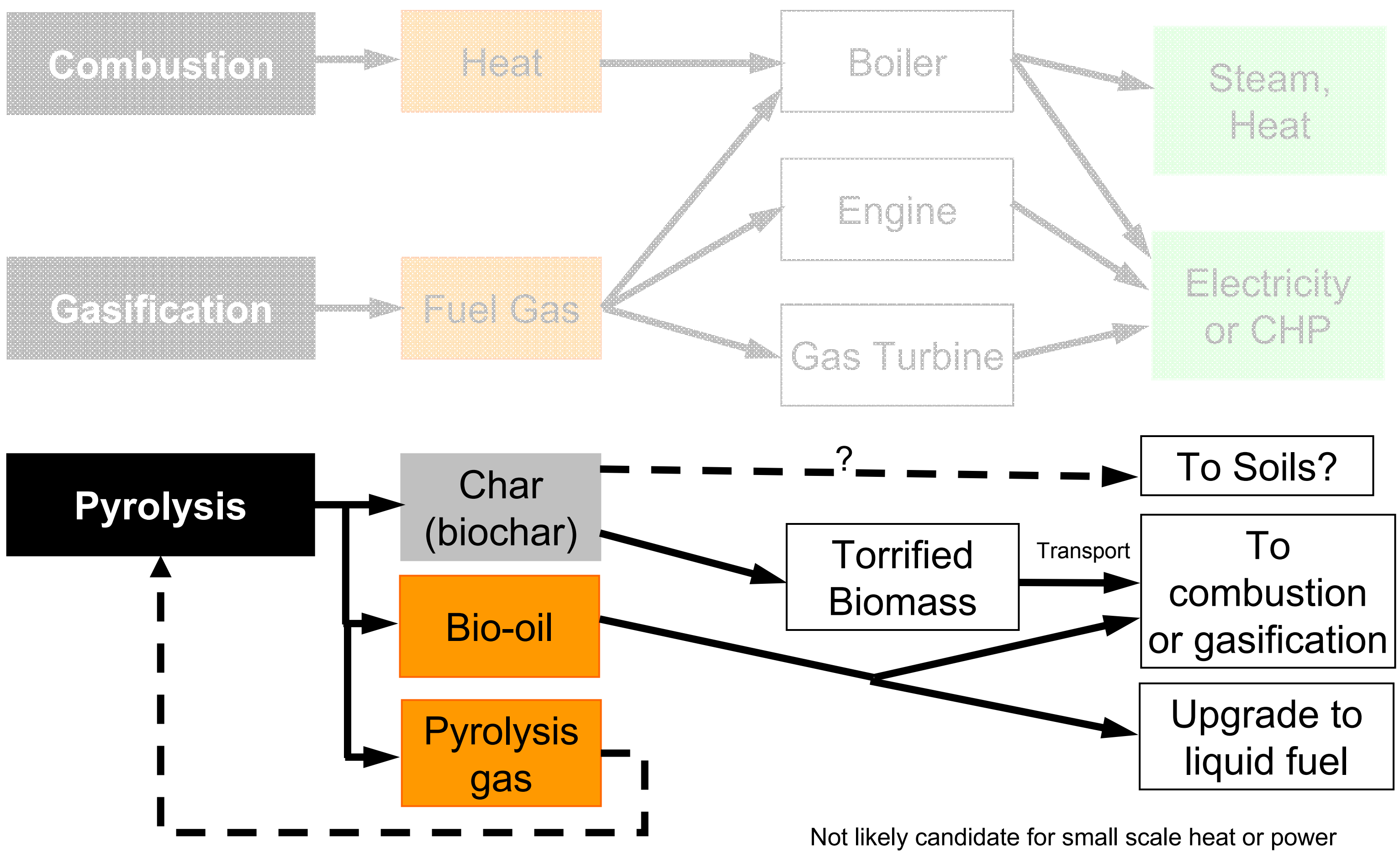

"Partial Oxidation" - insufficient air to burn all solid fuel or indirect heat

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

## Gasification:

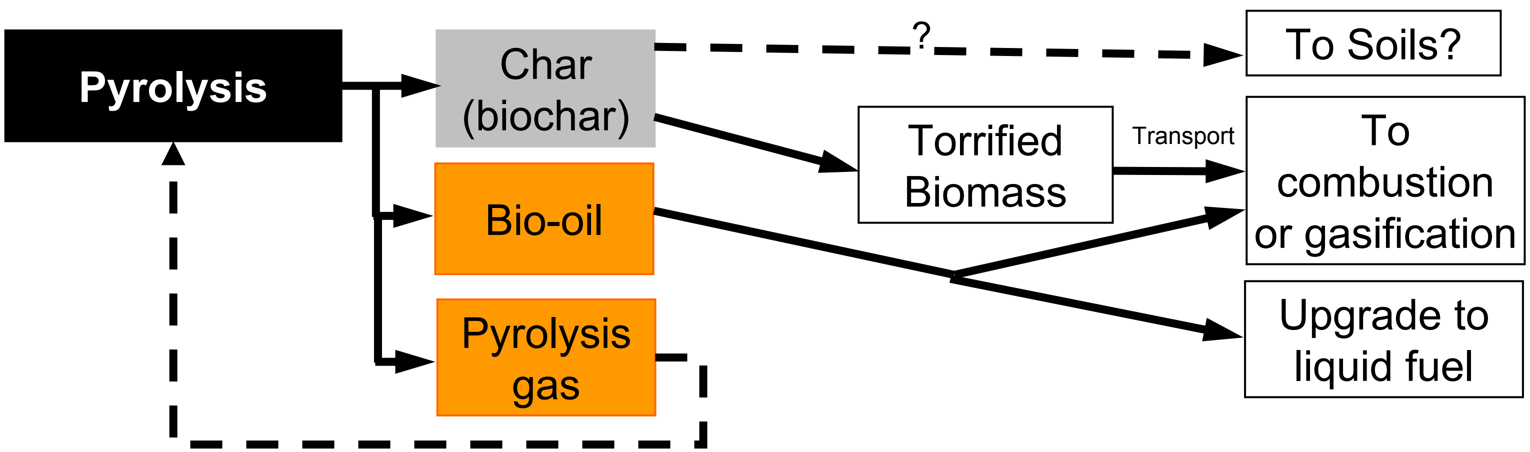
Fuel + Oxidant/Heat → $CO + H_2 + HC + CO_2 + N_2 + H_2O$ + Char/Ash + Tar + PM + H2S + $NH_3$ + Other + Heat

# Basic Technologies



# Pyrolysis

- Thermal decomposition without 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.
- Not likely a candidate for small scale heat or power – but char and bio-oil product could be used for energy, e.g., centralized facility



# Biomass Heat (and cooling)- Potential users

- Schools
- Hospitals
- Prisons
- College Campuses
- Aquatic Centers
- Shopping complexes and large warehouses
- Greenhouse operations
- Industrial process heat

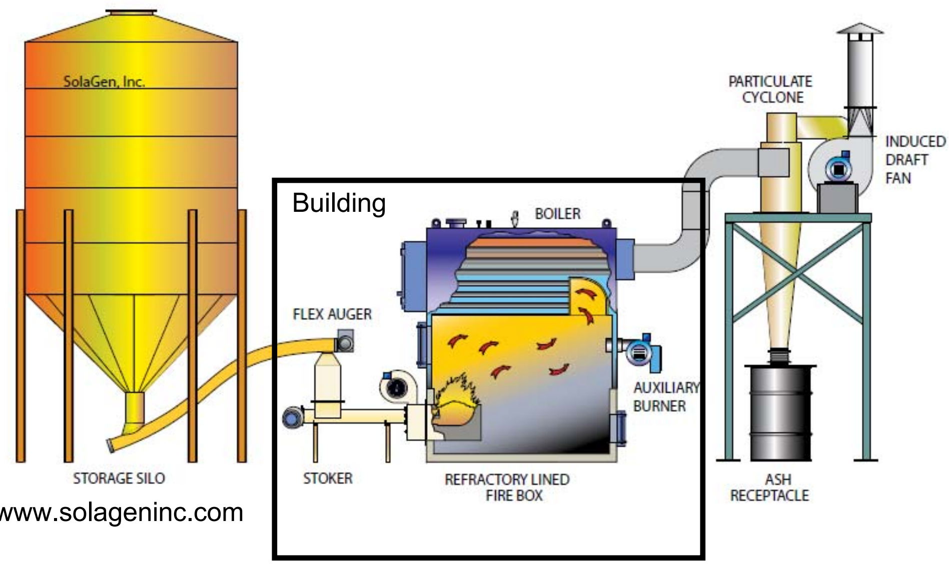
Courtesy: Gareth Mayhead

# Why utilize small scale biomass heat?

- It can be cheaper than current practice or alternatives
- Opportunity to keep energy $$ local if biomass is local (pellets may come from a distance)
- Support local jobs and, perhaps, thinning and fuels removal projects (biomass supply)
- Reduce or displace open or prescribed burns
- Low to neutral life-cycle-carbon energy source
- Off the Shelf Technologies
- History of Performance (Vermont, Montana schools, 25+ years at Chadron Community College, Nebraska)

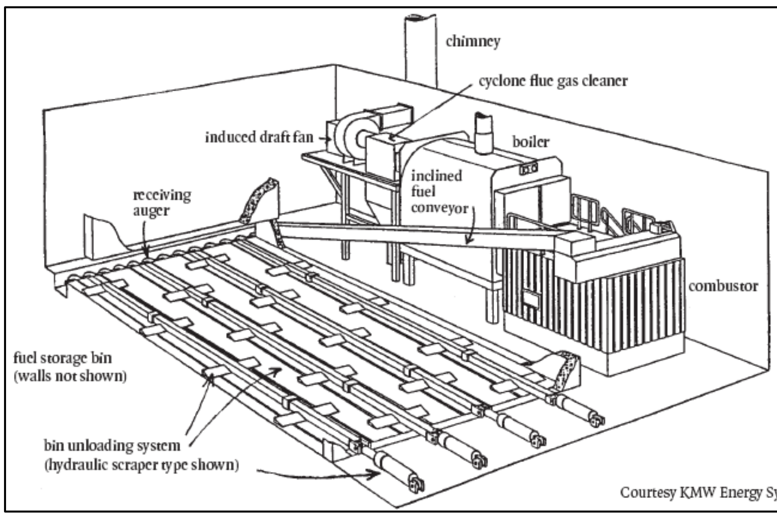
Courtesy: Gareth Mayhead

# System Components




http://www.solageninc.com

- Fuel receiving and storage
- Fuel handling and conveyance (maybe processing)
- Conversion device (furnace)
- Boiler (steam or hot water, high or low pressure)
- Building to house boiler
- Control system
- Ash conveyance, storage, disposal
- Fans, pumps, maybe baghouse for particulate material removal, exhaust stack



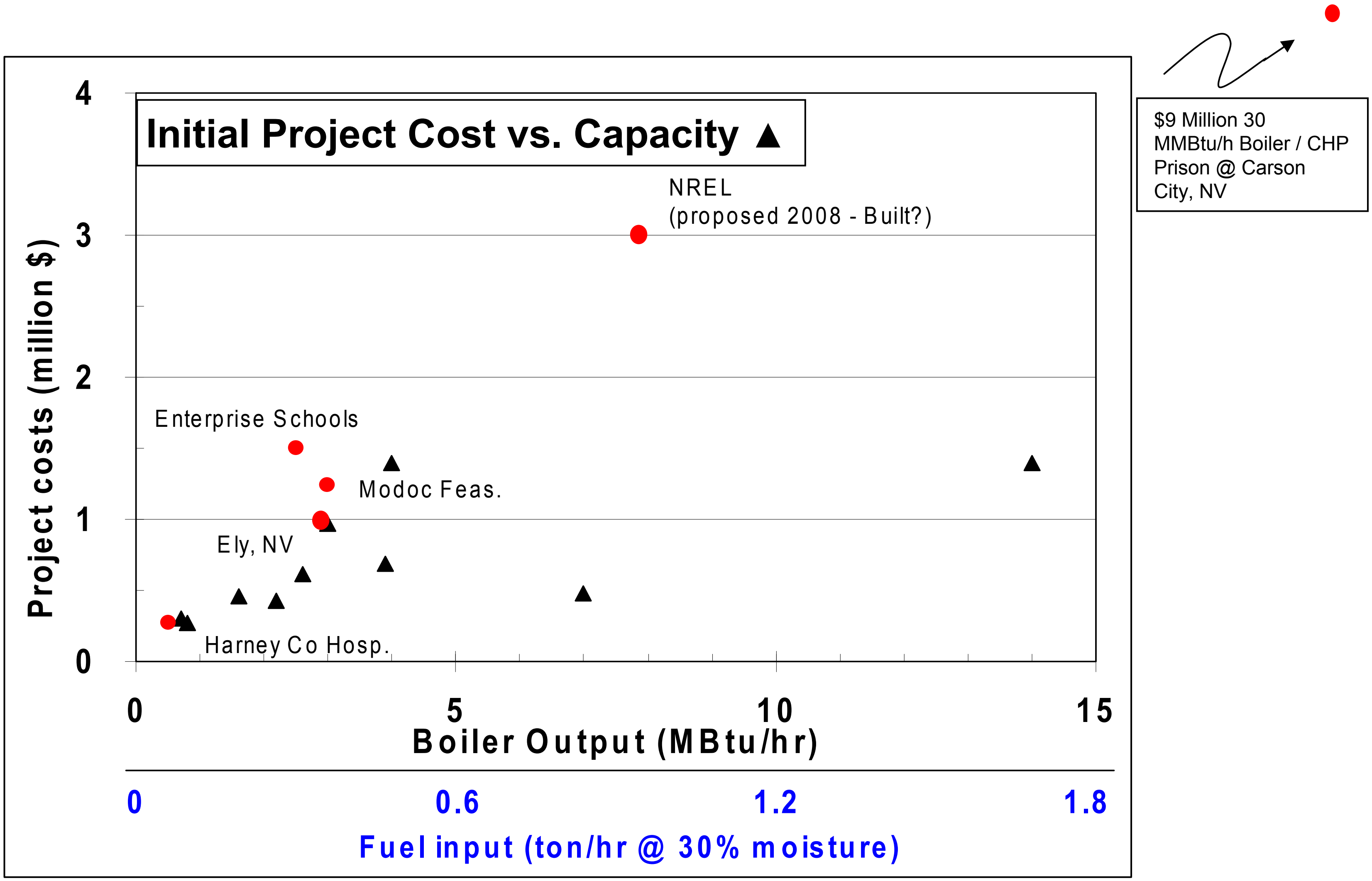


Wood Chip Heating Guide. Tim Maker. BERC VT. Photos: Tim Maker, Gareth Mayhead

# A basic feasibility study includes

- Fuel supply: price, availability, and predictability
- Recommended suitable system and capacity
- Estimated Project Economics and sensitivity analysis
  - It helps economics if:
    - High demand for heating (climate) and costly existing fossil fuel price
    - Space at site allows for system, fuel storage and delivery access
    - You can build into new construction rather than retrofit to existing facility
- Initial, but thorough, determination of air quality issues, potential impacts or mitigation measures and possible required permits
- Comment on owner commitment and ability to finance, operate, and maintain the facility [consider an energy savings performance contract (ESPC) if eligible]

# Biomass Heat Systems Economics

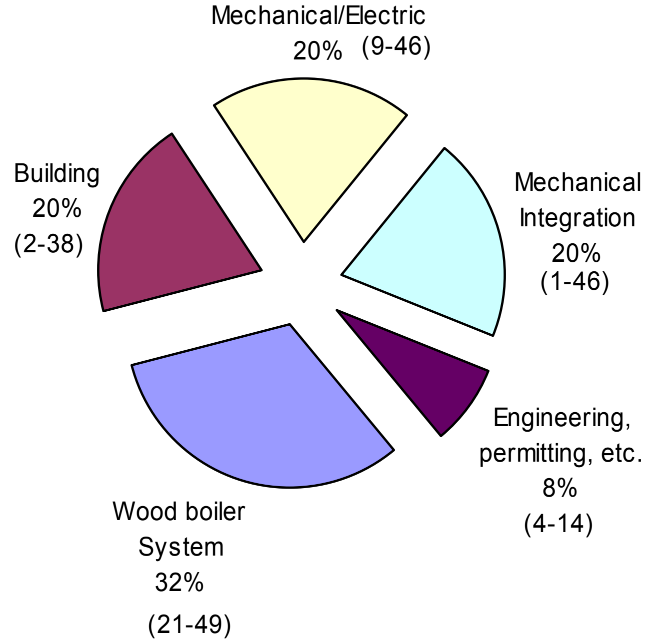



▲ From Table 1 in Biomass Boiler Market Assessment –Montana. CTA Group (2006)

● From various sources

# Biomass Heat Systems Economics

## Relative Project Component Costs*



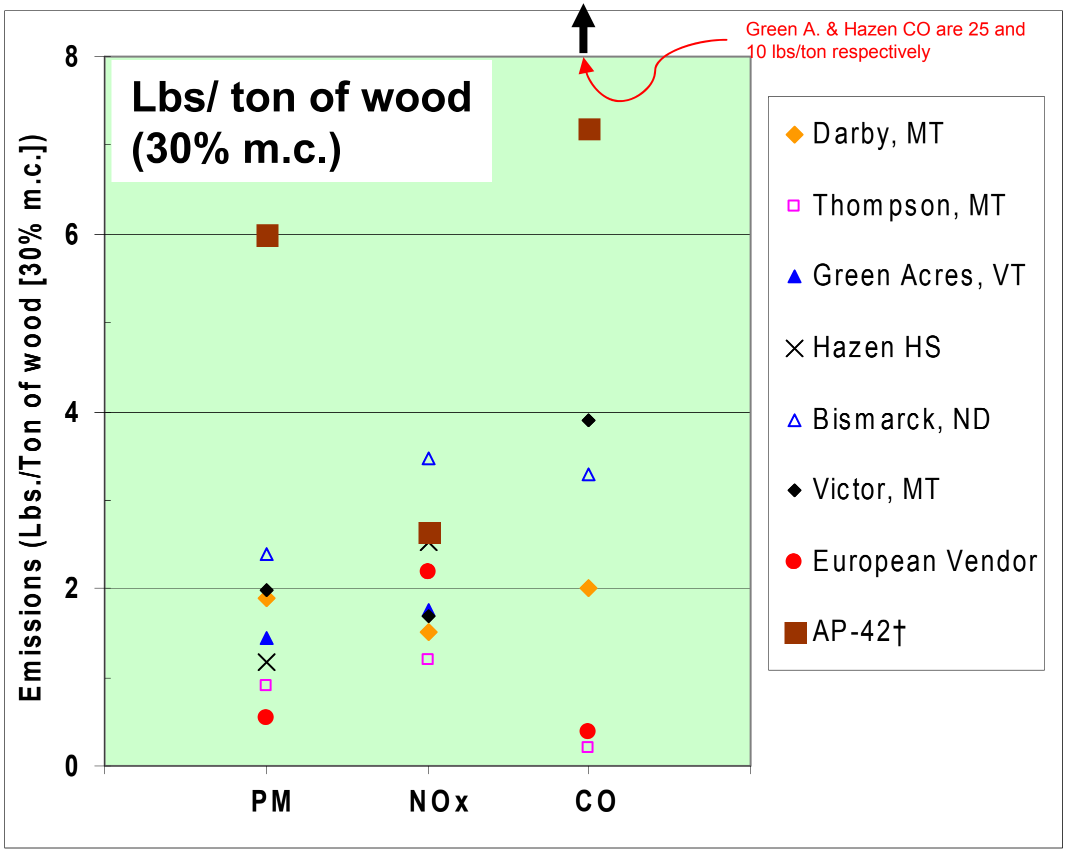

On average, the boiler and heat system accounts for only 1/3 of upfront costs

- 'Simple payback'** estimates generally ranged from 10 years for 10MBtu/hr systems to >30 yrs (or never) for small < 1MBtu/hr systems (CTA study)**
- Shorter 'simple payback' periods for small systems are possible
- Site specific-every project is different
- Highly sensitive to fuel costs (both wood and displaced fuel)

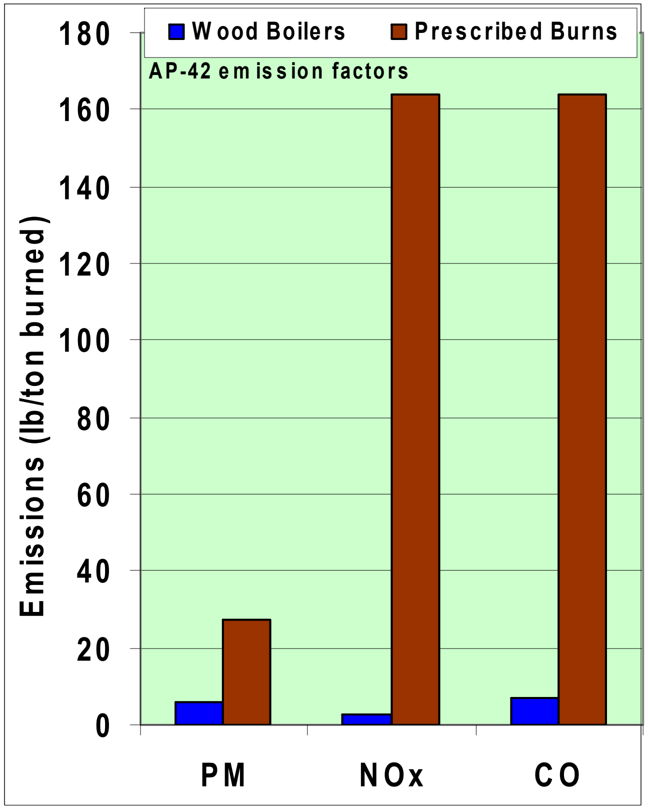
**Assumes no grant for capital buy-down, site specific-every project is different- highly sensitive to fuel costs (both wood and displaced fuel)

* Based on eight case studies where biomass boilers were added to existing steam or water building heating systems --CTA Group (2006)

# Wood Boiler Combustion Air Emissions




**Wood Boiler vs. Prescribed Burns (Lbs/ ton wood)**




- Many existing smaller facilities (i.e., schools) have not needed air permits or source testing.
- Regions with winter temperature inversions may require cyclone separators for PM reduction.
- Some $PM_{2.5}$ emissions data is available, most particulate data is $PM_{10}$
- Toxic emissions and health impact/risk assessments should be considered for school sites

Sources: Aspen Consulting (2004&2006), ERL (1996) for N.E. Govs. Coaliton, Resource Systems Group, EPA AP-42

# 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

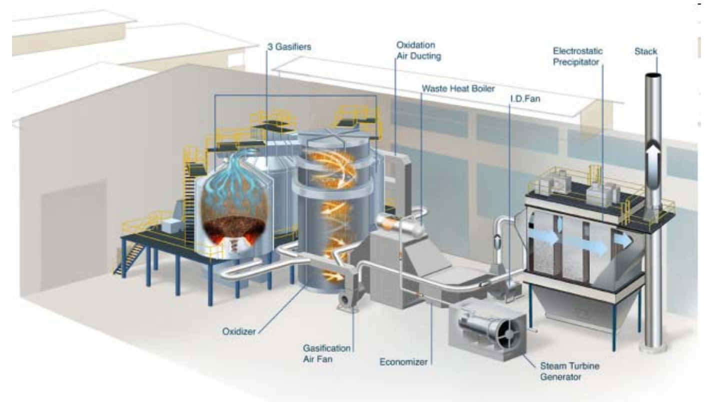
- Produces a gaseous fuel
- Overall process is endothermic
  - Requires burning some of the fuel to provide heat for the process (i.e., partial oxidation)
- Or heat is supplied to reaction from some external source / (indirect gasification)

# Uses of product gas

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

# 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 – 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) | 50 kW 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 |

# Relative characteristics, scale, tar production, energy in gas

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

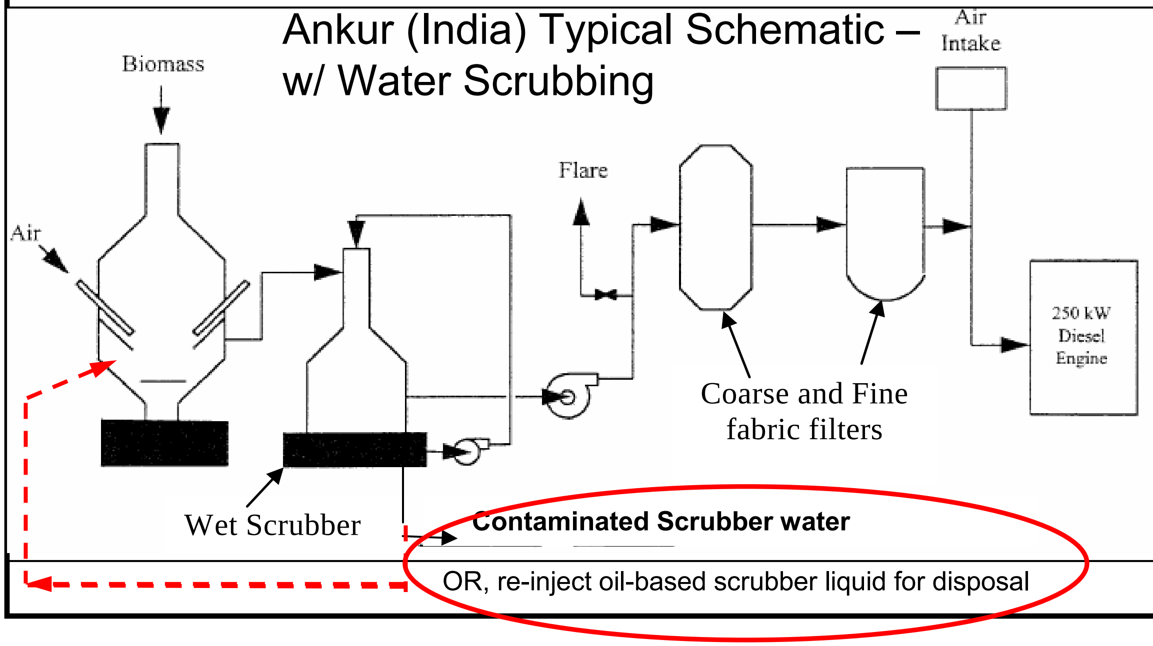
* Small systems are generally "Air-blown" downdraft or updraft gasifiers

**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.

Gasifiers produce tar which must be dealt with if gas runs an engine – less of a problem if gas burned in a boiler



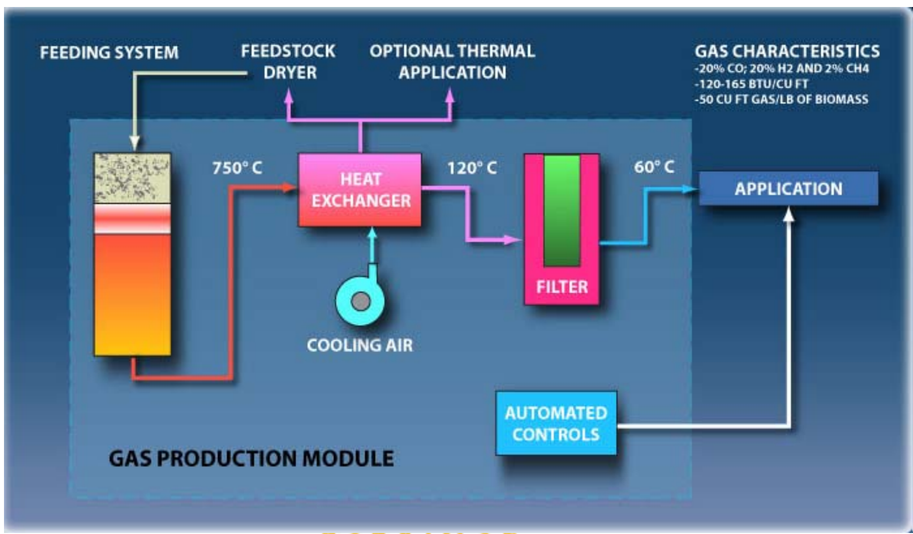

Scrubber water and condensate contain:

- 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

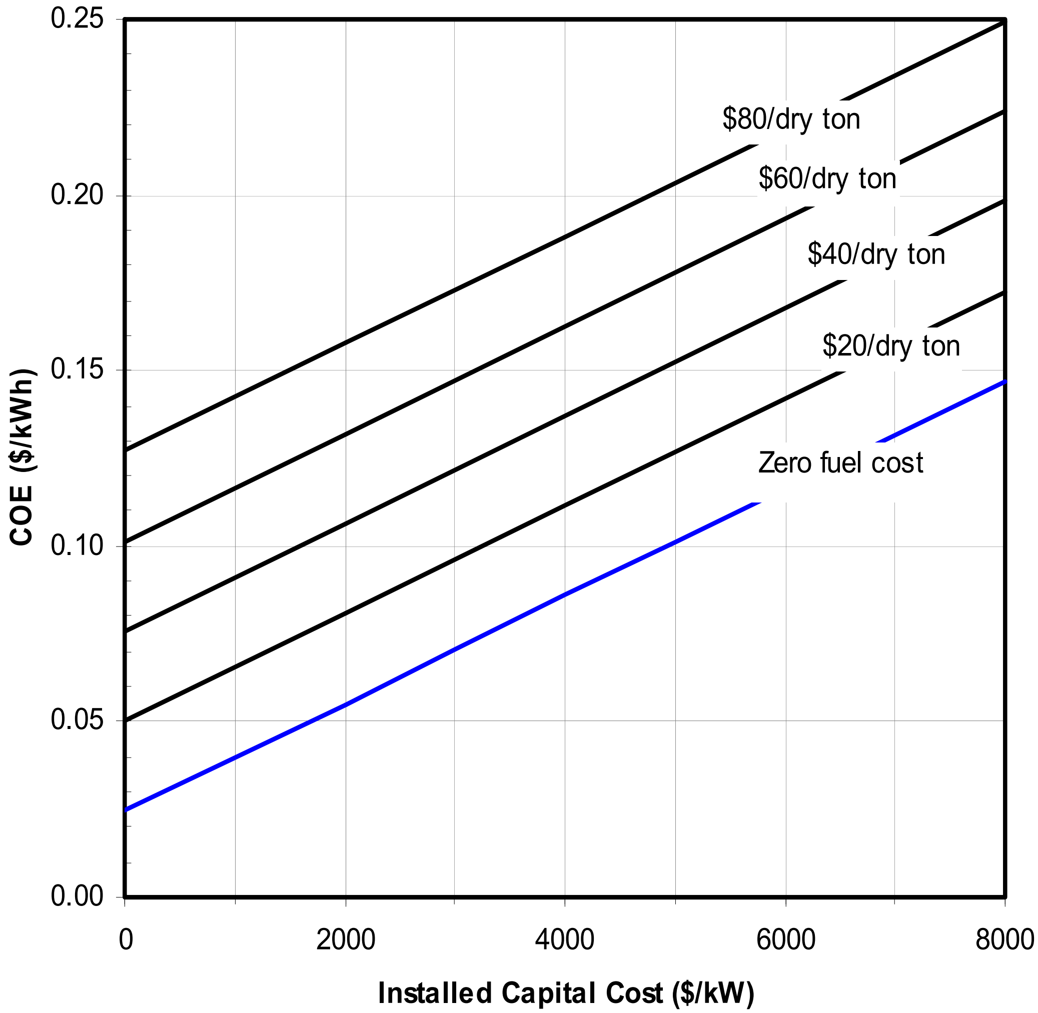
## Community Power Corporation ‘Biomax’ – no liquid scrubbing of gas




- 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

# Levelized Cost of Electricity- Biomass Power

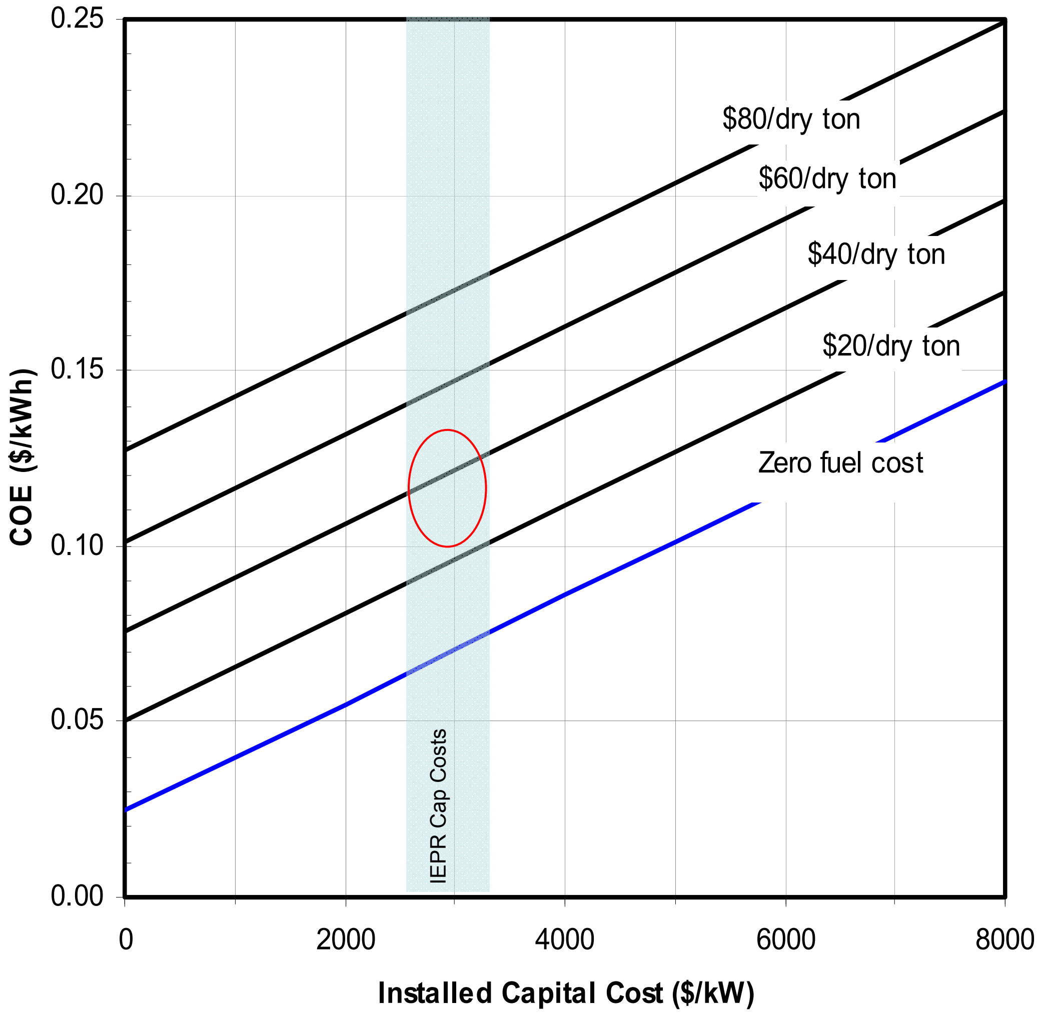



**Required Revenue ($/kWh) vs. Installed Cost**

**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

# Levelized Cost of Electricity-Biomass Power




**"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]

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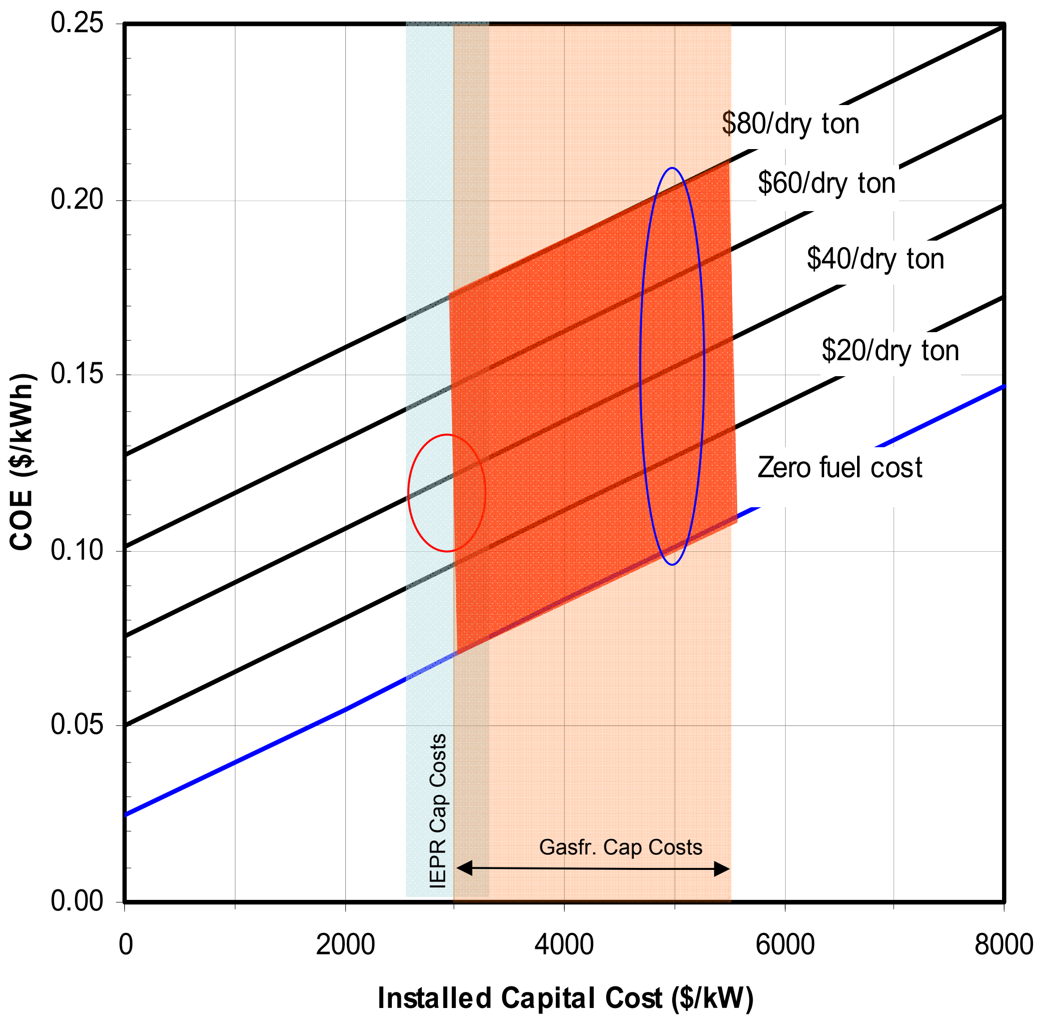
* Klein, J. (2009) 2009 IEPR CEC-200-2009-017-SD

# 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**

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- Debt and Equity recovered over 20 yrs.
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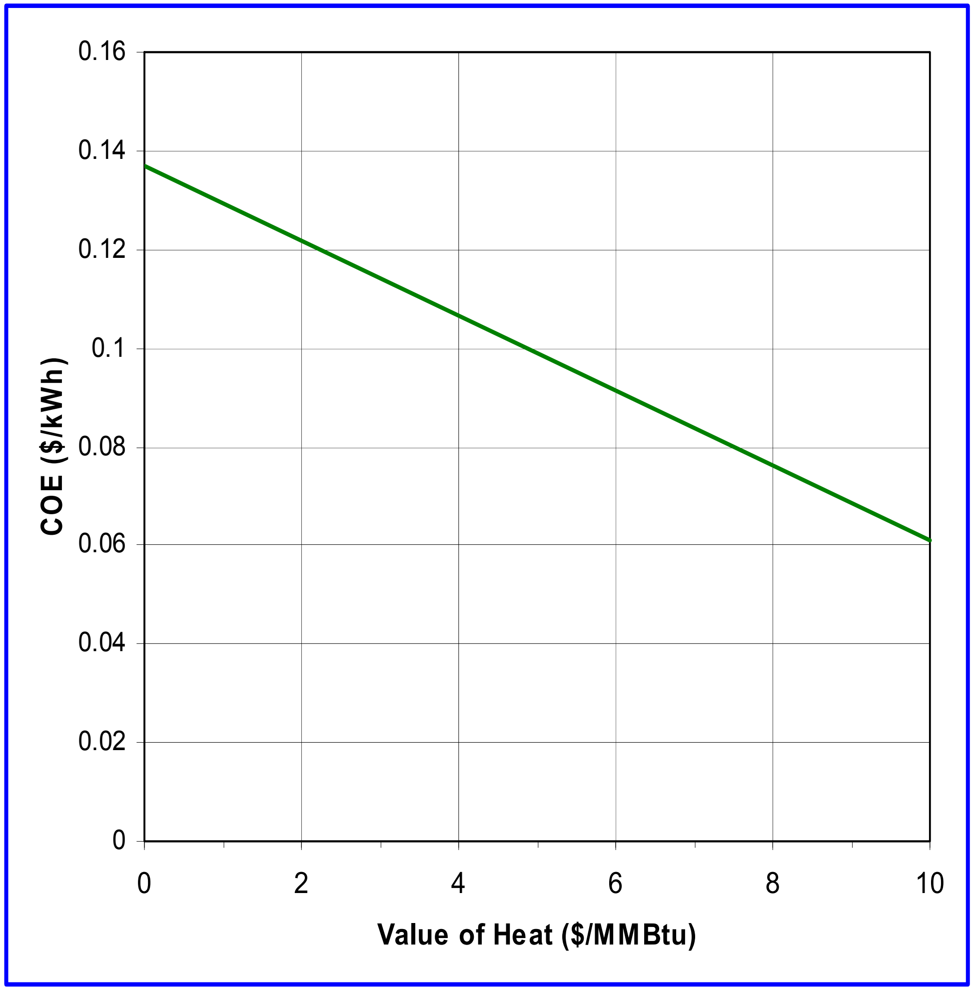
* Tom Miles, TR Miles Consulting, TSS Parlin Fork Draft

UCDAVIS

CALIFORNIA biomass

# 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

# 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

# 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

- Costs
- 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

# Conclusions

- Biomass for building and distributed heat systems is viable and appropriate in many instances (more than 100 such systems in public and institutional settings in the US).
- Combustion and staged combustion boilers for heat are commercial in the US and Europe.
- Gasifiers (biomass) for heat, power, and CHP are employed in India, China and Europe – Fewer examples in US
- For those contemplating switching to small biomass heat or power, need to understand the issues (real cost, risks, operational effort and potential problems).
- Accurate information about existing projects and demonstrations is always needed – the more the better.

# Potential Useful Information

- Links to some manufacturers and consultants
  http://www.fuelsforschools.info/
- Biomass Boiler Market Assessment for Montana, CTA Group (2006)
  http://www.fuelsforschools.info/pdf/Final_Report_Biomass_Boiler_Market_Assessment.pdf
- Biomass Energy Resource Center (BERC)
  http://www.biomasscenter.org/resources/publications.html
- Economic Feasibility Calculators
  http://www.mwcc.edu/renewable/documents/boilermanual.pdf
  http://www.fwe.wisc.edu/extension/BoilerProgram.xls
  http://www.michiganwoodenergy.org/
- Fuels for Schools Case Study, Darby MT (2007)
  - USDAFS FPL-GTR-173

  http://treesearch.fs.fed.us/pubs/28239
- Air Emissions Test Reports
  http://www.fuelsforschools.info/air_emission_test_reports.html

# 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

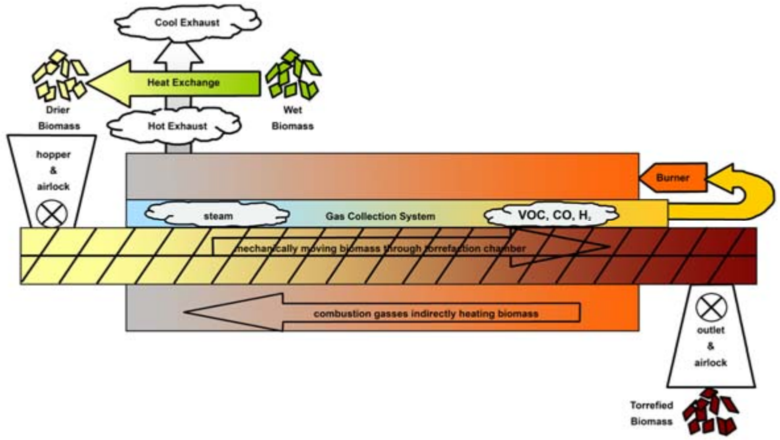
Charcoal Production in the woods

•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

# Update on "Lessons Learned"

## (Tahoe Workshop, 1 June 2007)

**White Pine School District, Ely NV (Paul Johnson)**

- $1M project-- 3 MBtu/hr capacity hot water system
- Two seasons operation
- $35/ton wood, several years supply stored near by in field (desire covered storage)
- Power surge knocked out computer control system, black plume from stack,
- Manual control difficult & poor support from boiler manufacture led to use of stand-by oil system
- Air permit not needed.

Boiler house and School, Ely NV

**Correctional Facility, Carson City, NV (Lori Bagwell)**

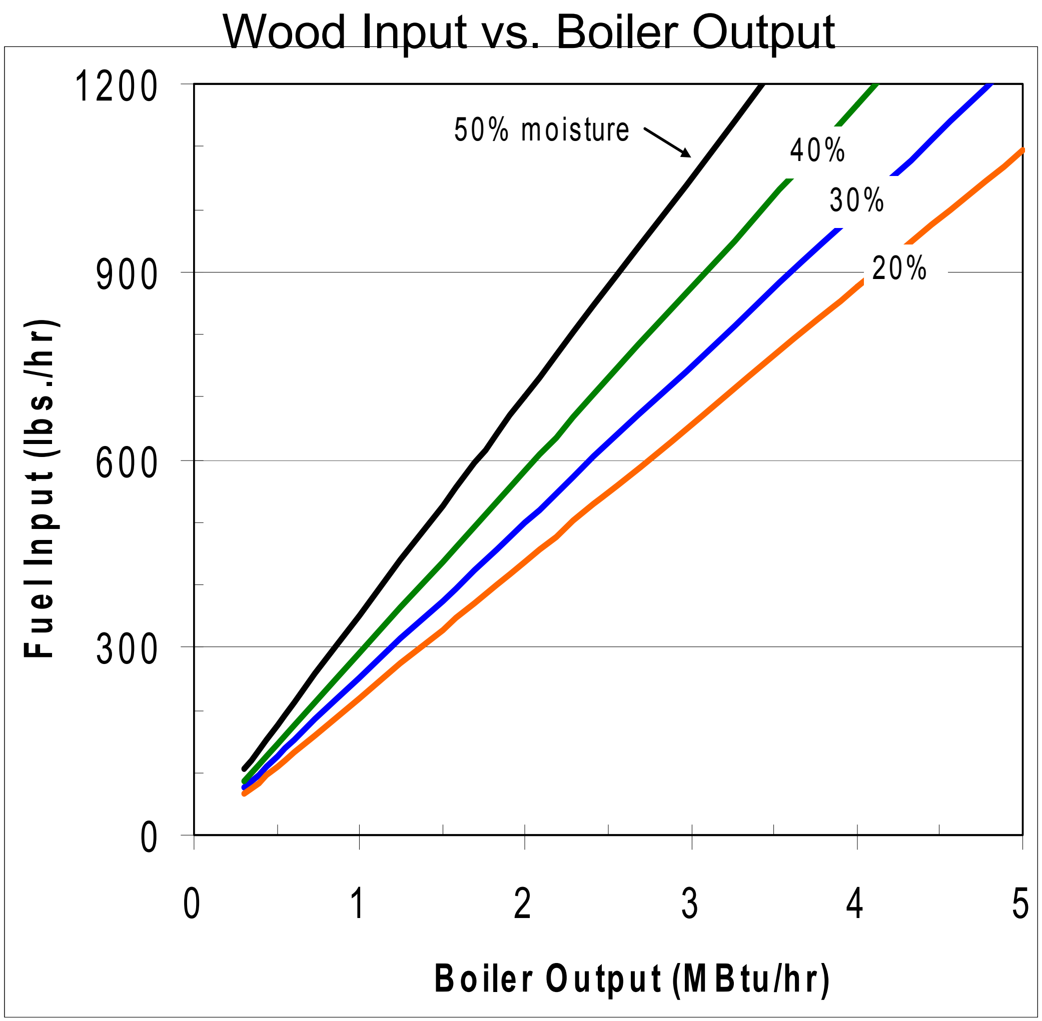
- $9M project– 30 MBtu/h Boiler with 1 MWe (steam turbine) CHP
- Intent is to supply most heat and power for facility
- Could have used full time person to coordinate project from inception to day-to-day operation"
- Performance guarantees for equipment but not on project overall financial performance
- Fuel price now uncertain, expected to rise: project assessed on $29/ton chipped wood supply contract but fuel source (thinning projects) did not develop as expected
- Overall economics are quite sensitive to fuel price
- Continuous emissions monitoring (CEM)


Boiler Installation, Correctional Facility, Carson City, NV

# Energy Performance
## (Typical Combustion Units in US)

Common Assumptions

- 70% Energy Conversion efficiency (useful heat in water/wood energy input)
- 8200 Btu/dry-lb (Higher heating value of dry wood)
- 5700 Btu/lb for wood at 30% moisture



# 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
- Energy prices, GHG policies, use of district heat, all contribute to many biomass gasification for combined heat and power (CHP) installations in Europe

**“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

# 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 |

# 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