# Biomass Conversion to Electricity:
## Stand Alone Power Plants, Co-Generation, and Combined Heat and Power (CHP)

*Woody Biomass Workshop*

*Ukiah, CA*

*December 2, 2010*

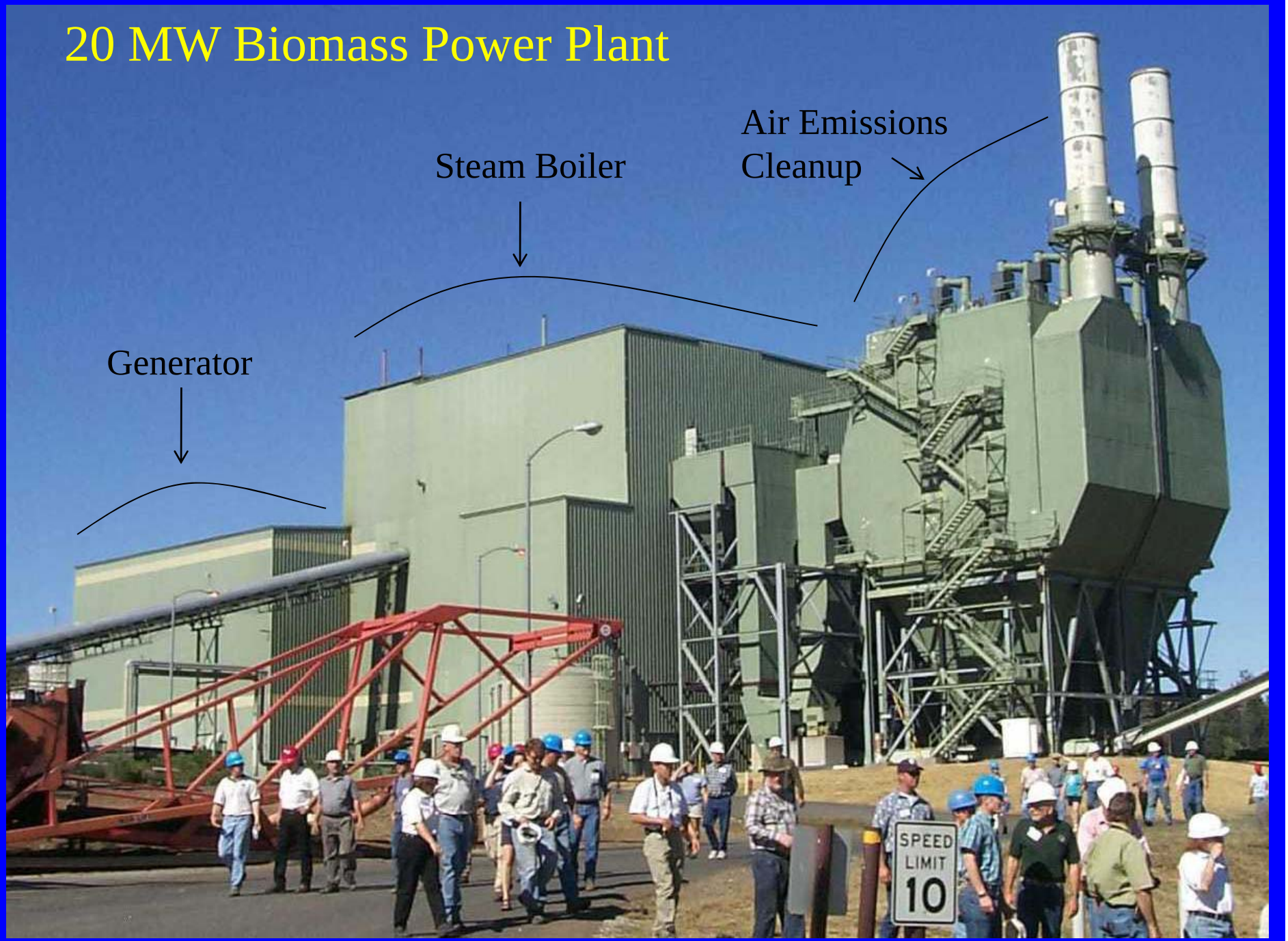
John R. Shelly
UC Cooperative Extension
University of California, Berkeley

# Combustion of Woody Biomass to produce heat and/or power

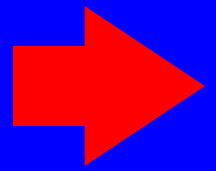
*Small scale (50 kWh to 1 MWh) – units are available for space or process heat. Combined heat and power may be feasible*

*Large scale (5MWh to 50 MWh) – California has biomass power plants that consume 1 ton of woody biomass per hour for each MWh produced*

# 20 MW Biomass Power Plant



# Combustion of Wood

**Wood + Air + Ignition** 

$CO_2 + H_2O + O_2 + N_2$

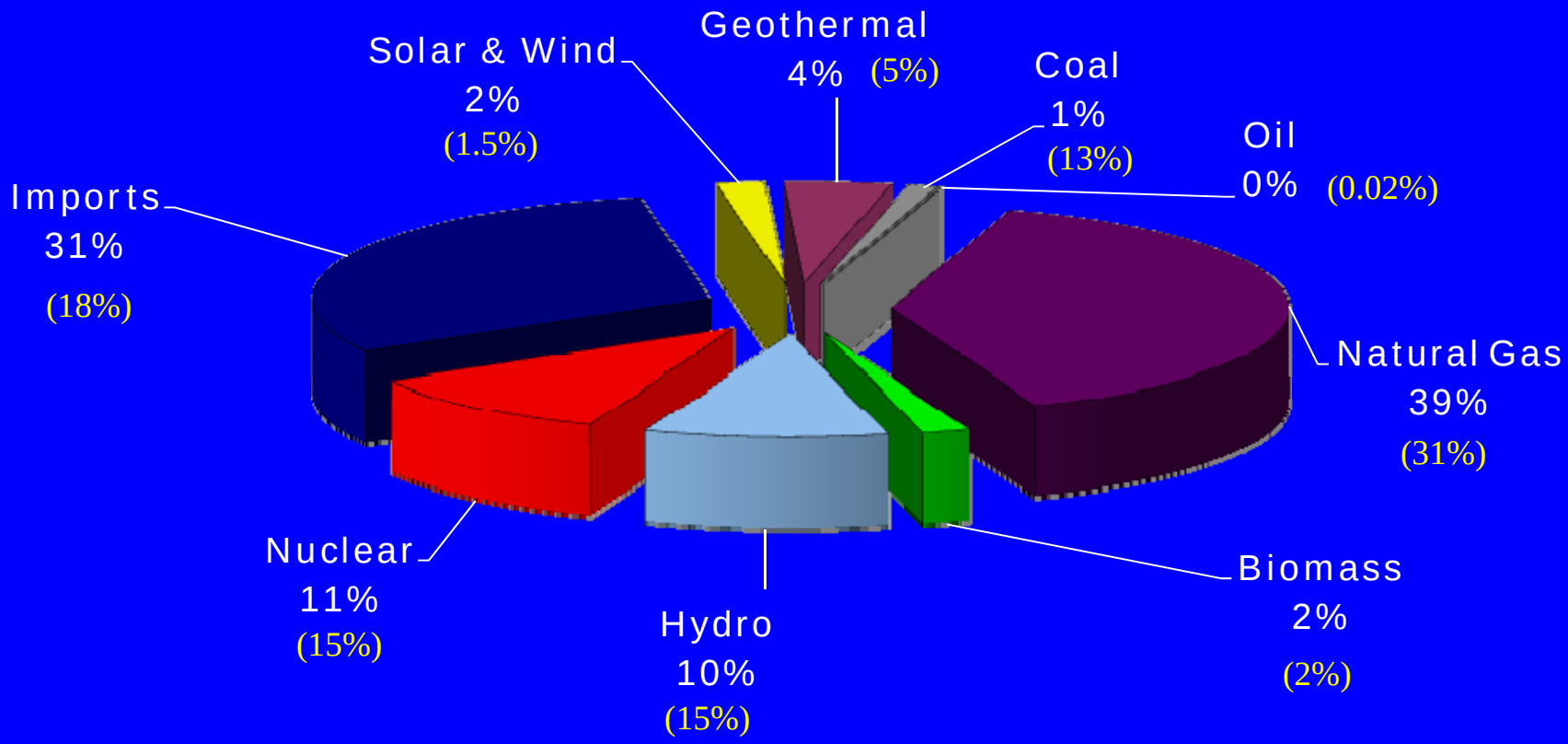
+ **Heat**

+ **Ash**

+ **Emissions**

**particulates, Nox, Sox, etc.**

# 2008 CA Electricity Production



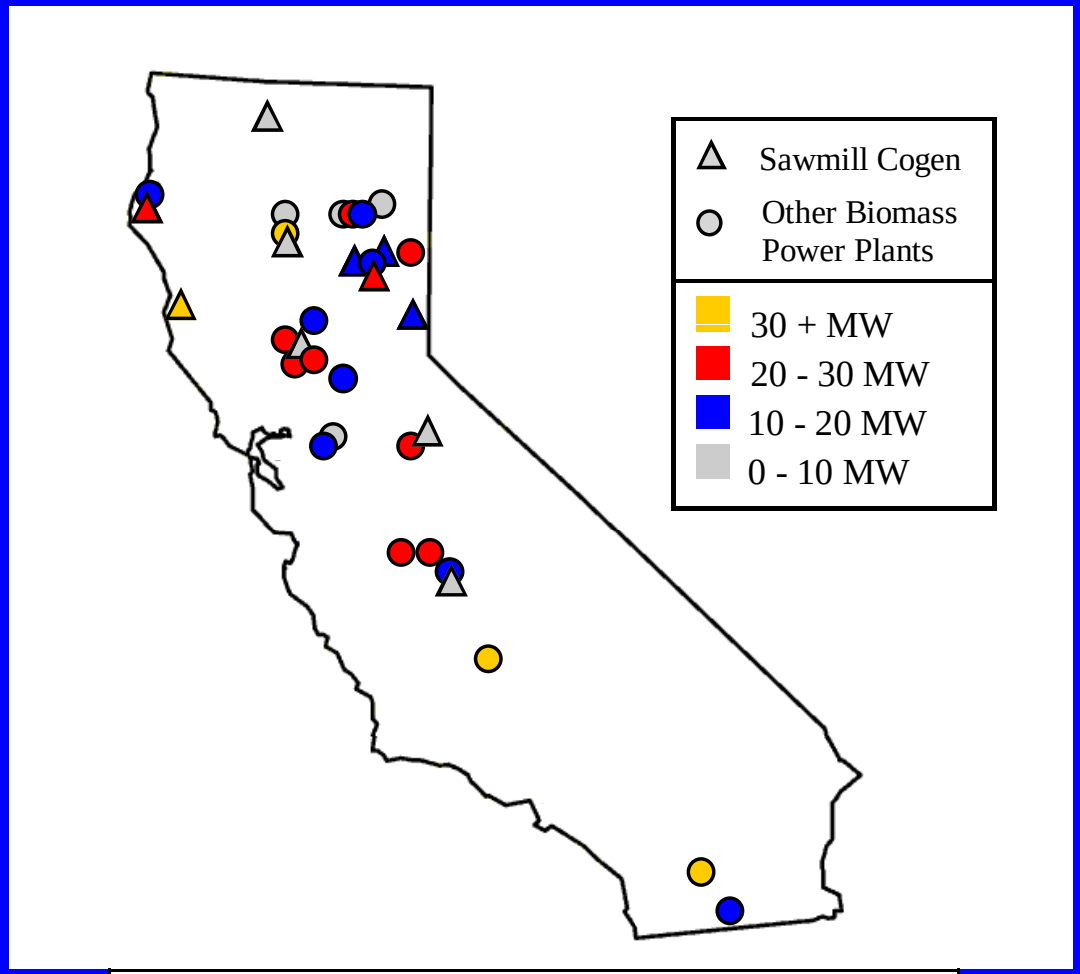

**Total Production: 296,819 GWh**

**Biomass: 5, 685 GWh**

Source: CA Energy Commission

(values in parenthesis are for year 1999)

# California Biomass Energy Facilities




A 10 MW (megawatt) generator can supply electricity to about 10,000 homes.

The 7 cogeneration facilities are co-located with sawmills

27 facilities with total capacity of about 626 MW using 4.5 million bone dry tons of biomass per year

- 22% forest-based
- 29 % manuf. residue
- 28% landfill diverted
- 21% ag residue

About 15% of total biomass available and about 12% of forest-based biomass available

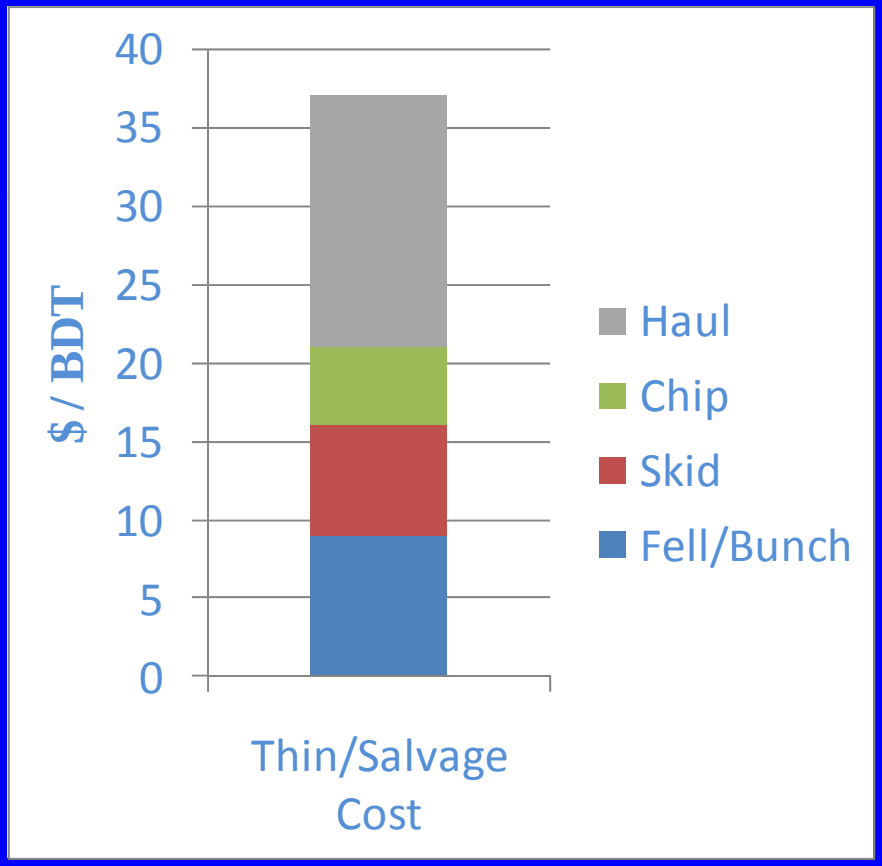
# Typical Biomass-Fired Powerplant

- 20 MW capacity, combustion/steam turbine
- Installed cost = $1700 - $3500 per kW
- Processes 140 - 200 thousand tons/yr (1BDT/MW/hour)
- Biomass transported up to 50 miles
- Delivered biomass valued at $15 - 60 per BDT
- Average production cost ~ $0.07 - $0.10/kWh

# Biomass Combustion Concerns

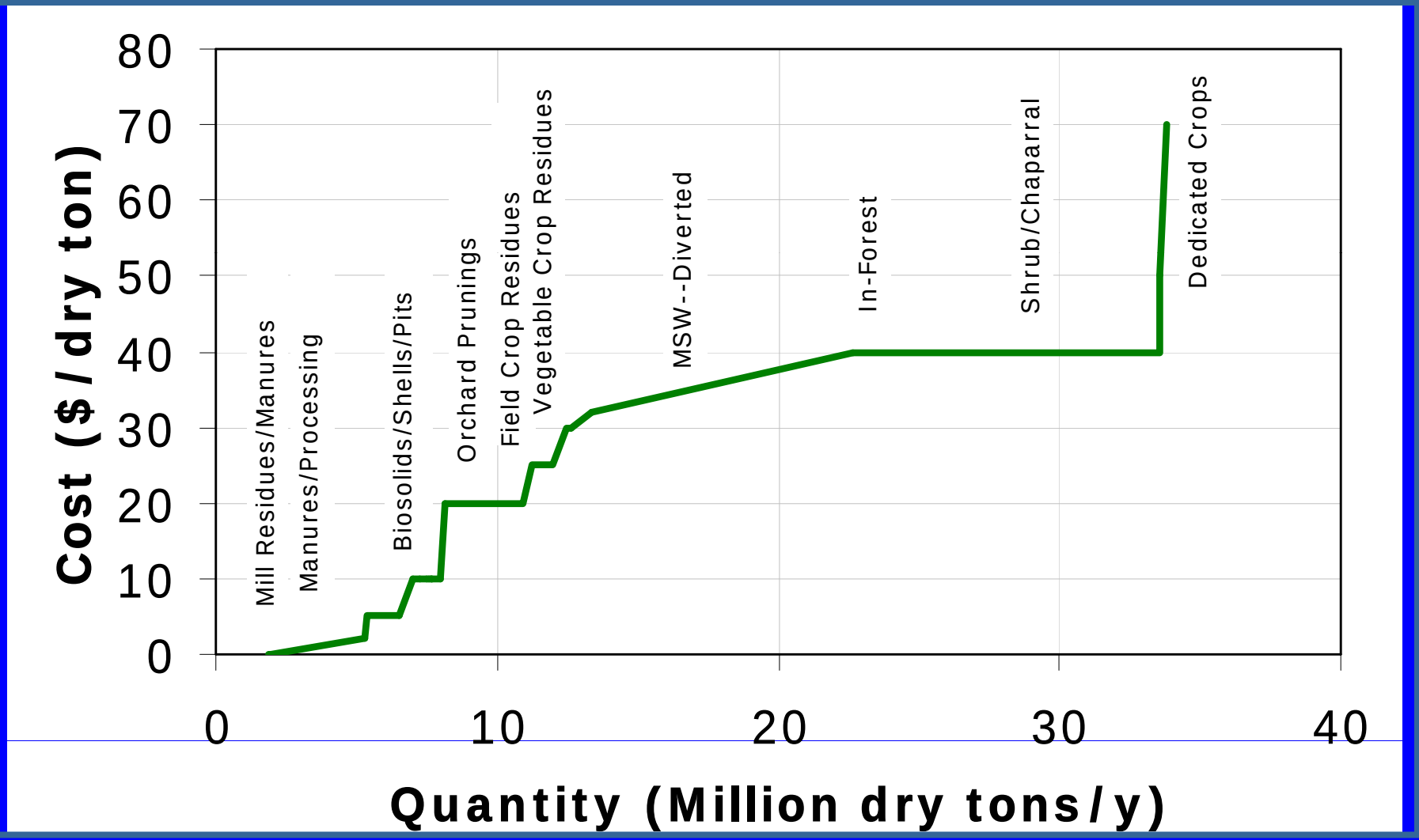
- Availability and cost of Fuel
- Emissions
- Higher maintenance compared to other fuel types
  - Inorganic (ash) transformations lead to fouling of combustion chamber surfaces and slag formation on bottom
  - Increased corrosion from acidic gases
- Maintenance issues can lead to reduced capacity and efficiency

# Example of Costs of Forest Thinning or Salvage Operations with a 50 Mile Haul




Value of biomass delivered to a powerplant ranges from about $15 - $40 per BDT

# California Statewide Resource Supply Curve




Source: California Biomass Collaborative

# Emissions by type of Combustion in pounds emitted per ton of Woody Biomass consumed

| | PM- 2.5 (lb/ton) | $No_x$ (lb/ton) | CO (lb/ton) | VOC (lb/ton) | $CO_2$ (lb/ton) |
|---|---|---|---|---|---|
| Industrial (dry fuel) [1] | 0.7 – 6.5 | 8.8 | 10.8 | 0.31 | 3120 |
| Residential Stove [2] | 6 - 23 | 2 - 14 | 46 - 160 | 10 - 44 | ~ 2800 |
| Prescribed Burn [3] | 12 - 34 | 6 | 167 | 19.0 | ~ 2700 |
| Wildfire [3] | ~ 30 | 4 | 140 | 12 - 24 | ~ 2600 |


Sources: 1. US EPA. AP42, Fifth Edition, Volume 1, Chapter 1
2. McDonald et. al. 2000. Environmental Science and Technology (34:2080-2091)
3. USDA Forest Service, various reports

# Environmental Impact

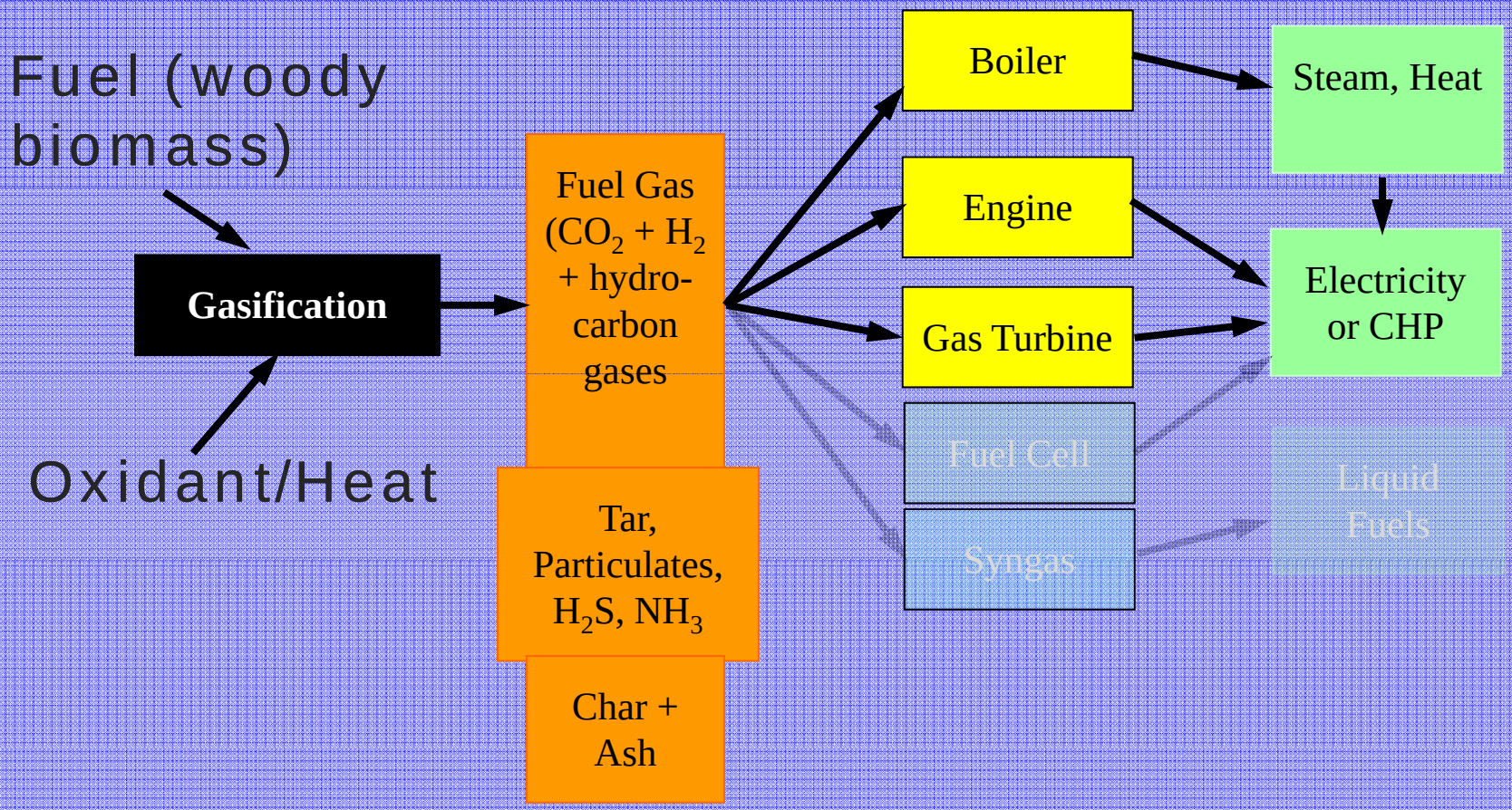
| Air Emissions | Coal Fueled Boiler (lb/Million Btu) | Biomass Fueled Boiler (lb/Million Btu) | Natural Gas Boiler (lb/Million Btu) |
|---|---|---|---|
| CO | 0.02 – 0.67 | 0.60 | 0.058 |
| $CO_2$ fossil | 178 - 231 | 0 | 117.6 |
| $CO_2$ non fossil | 0 | 195.0 | 0 |
| $NO_x$ | 0.27 – 1.15 | 0.22 – 0.49 | 0.031 – 0.27 |
| $SO_x$ | 1.3 | 0.025 | 0.0005 |
| VOC | 0.002 – 0.048 | 0.017 | 0.005 |
| Methane | 0.002 | 0.021 | 0.002 |
| Particulates | 0.37 – 2.4 | 0.05 – 0.56 | 0.007 |

Source: US EPA. AP42, Fifth Edition, Volume 1, Chapter 1

# Power Plant Efficiency

| | Heat Rate (Btu/kWh) | Efficiency (%) |
|---|---|---|
| Natural gas combined-cycle | 7,500 | 45.5 |
| Coal-fired steam/electricity | 10,000 | 34.1 |
| Biomass-fired steam/electricity | 15,000 | 22.7 |
| Biomass-fired, combined heat and power (co-gen) | 8,500 | 70.0 |

# Biomass Gasification to Electricity




Gasification is the "Partial Oxidation" (controlled amount of air or oxygen) to produce a combustible, gaseous mixture (producer gas) of many compounds that can be used directly as a low BTU fuel gas or cleaned and used to produce higher value products (syngas).

# Dixon Ridge Farms – Winters, CA

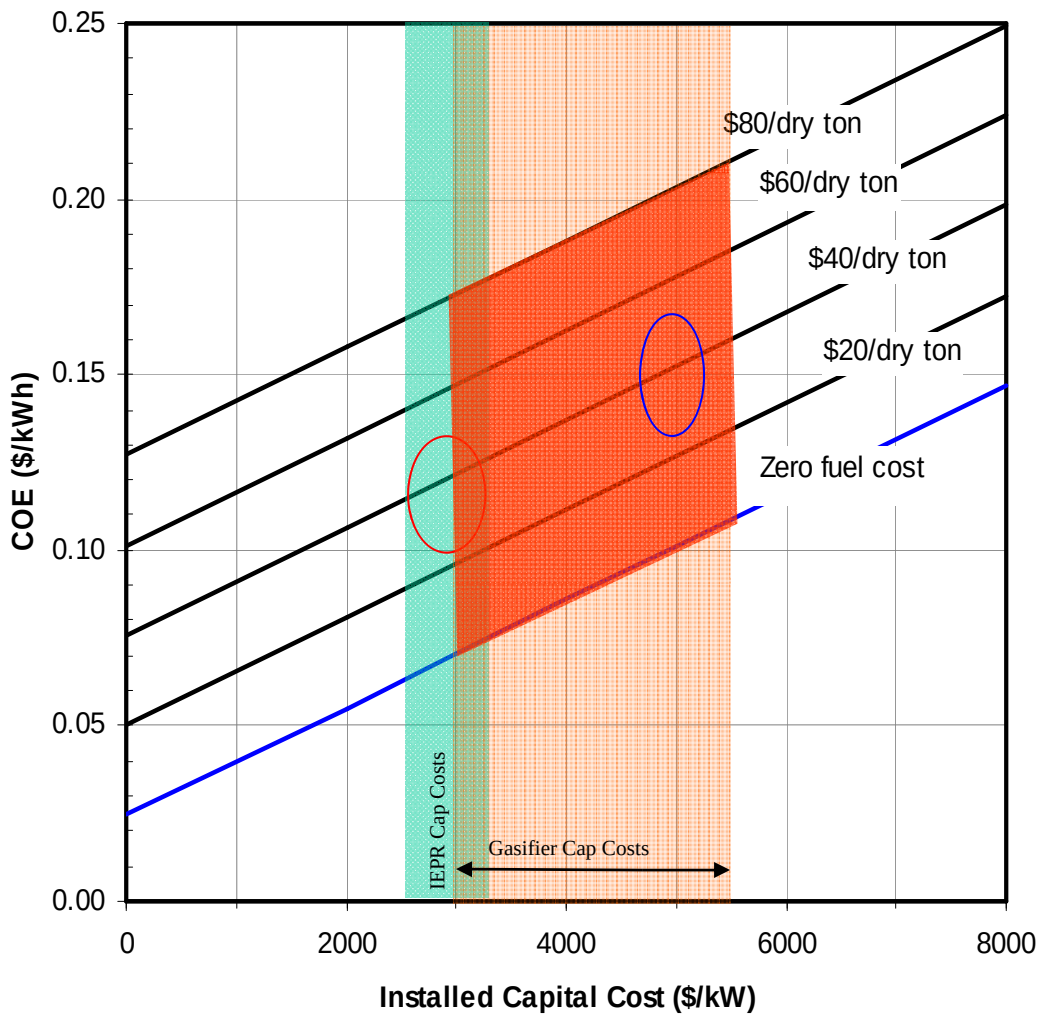
Moderate Scale Combined Heat and Power (CHP) Gasification Unit.

Designed to produce 50 kW of electricity and 200,000 Btu of heat per hour.


Internal Combustion Engine and 50 kWe Generator

Community Power Corporation downdraft gasifier – 100 lb biomass/hr produces about 5,000 $ft^3$ of gas (rated at 130 $Btu/ft^3$)

# Levelized Cost of Electricity- Biomass Power




**Capital Costs of Gasifiers***

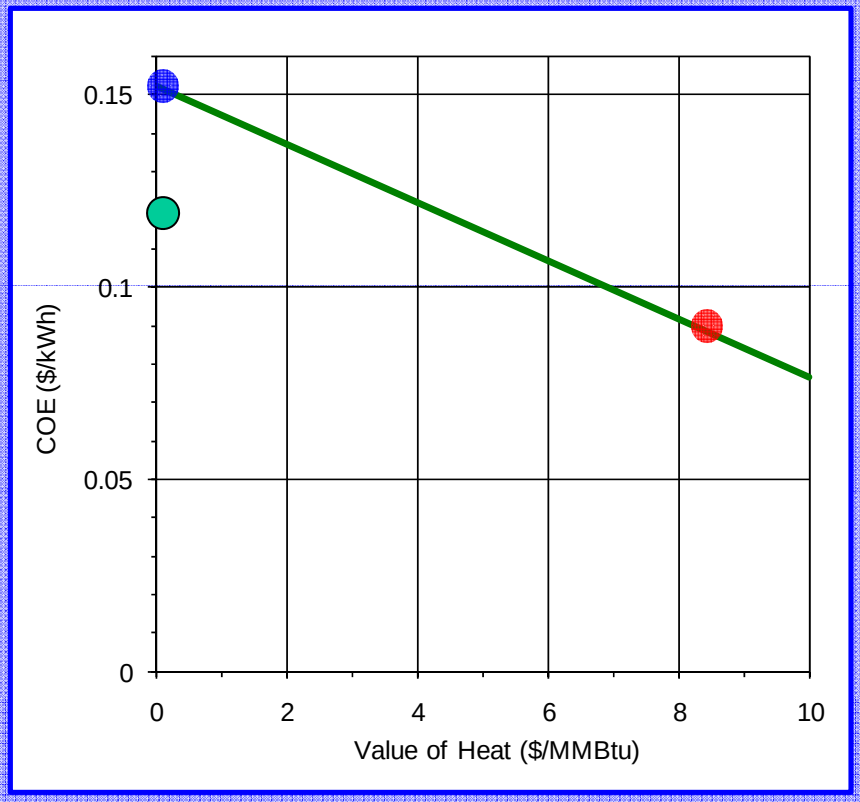
- Proposals ranging from 3300 -5500 $/kW installed (maybe as high as $10,000/kW - CPC??)
- Those that are built seem to come in at ~ 5000 $/kW
- Target is
  - 3000 $/kW for elect. only
  - 5000 – 6000 $/kW for CHP

**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

# The case for Combined Heat and Power
# Influence of Heat sales on COE




## Assumptions:

- $5000/kW capital cost
- Fuel cost ~$40/dry ton
- 70% overall energy efficiency
  - 23% fuel-to-electricity efficiency
  - 47% fuel-to-heat recovery efficiency
- Value of heat = $8/million BTU
  - Based on industrial heat produced from natural gas

- Cost of Electricity ($.12) in Biomass power plant
- Cost of Electricity ($.15) in CHP plant with no heat use
- Cost of Electricity ($.09) in CHP with heat valued at 8$/MM BTU

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

# Barriers to Increasing Biomass Use for Electricity Production

- Emissions
- Grid Interconnect
- Fuel Availability

# The Future of Biomass Power Plants Depends on …

- Biomass utilization policies
- Relative price of natural gas and electricity
- Environmental issues
  - Emissions – particulates, $CO_2$
  - Carbon Accounting -- does biomass $CO_2$ have a zero emission impact?
- Societal value placed on biomass disposal/use (e.g. reducing wildfire hazards)

# How Can We Increase Woody Biomass-Produced Electricity?

- Offset high costs of processing in thinning and salvage operations
  - Assign values to environmental and social benefits
  - Apply economic incentives
- Educate public to the value of well managed, sustainable, and productive forests
- Improve the conversion efficiency of powerplants
- Compare life cycle assessments of various energy alternatives
- Encourage policies and incentives that level the playing field with other fuels