Biomass Conversion Technologies: Heat, Electricity, and Liquid Fuels

Woody Biomass Workshop

Tulare, CA

May 5, 2009

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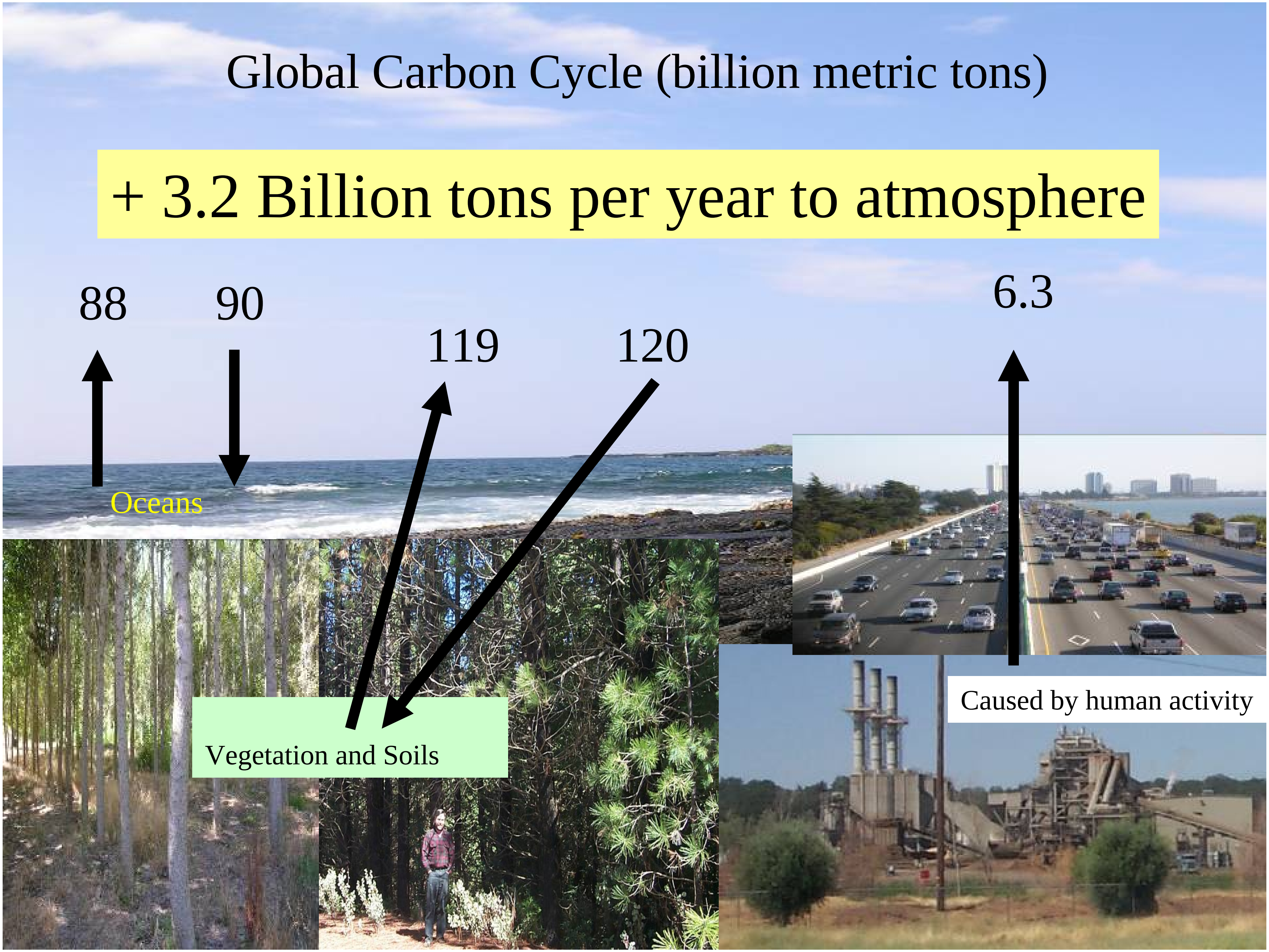
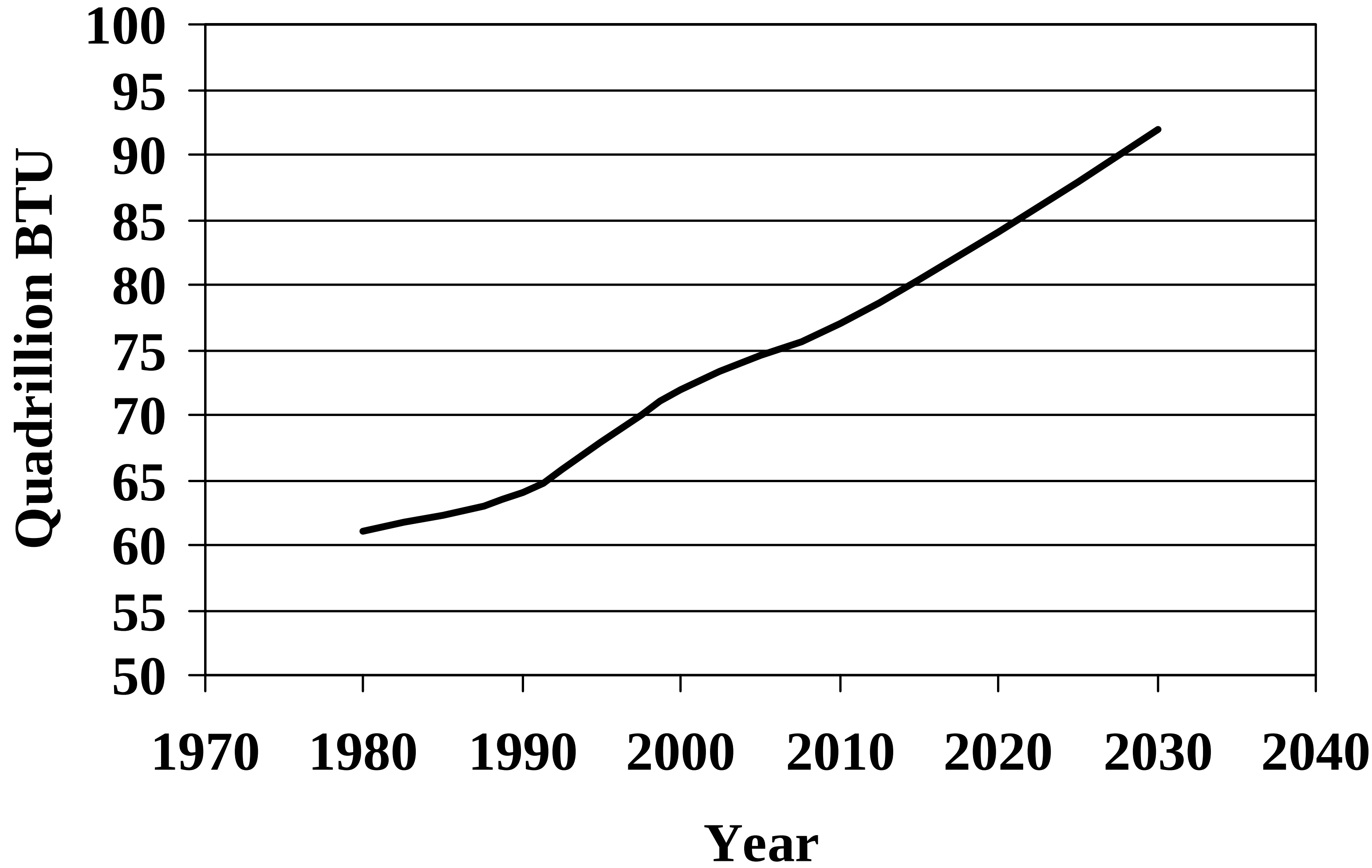
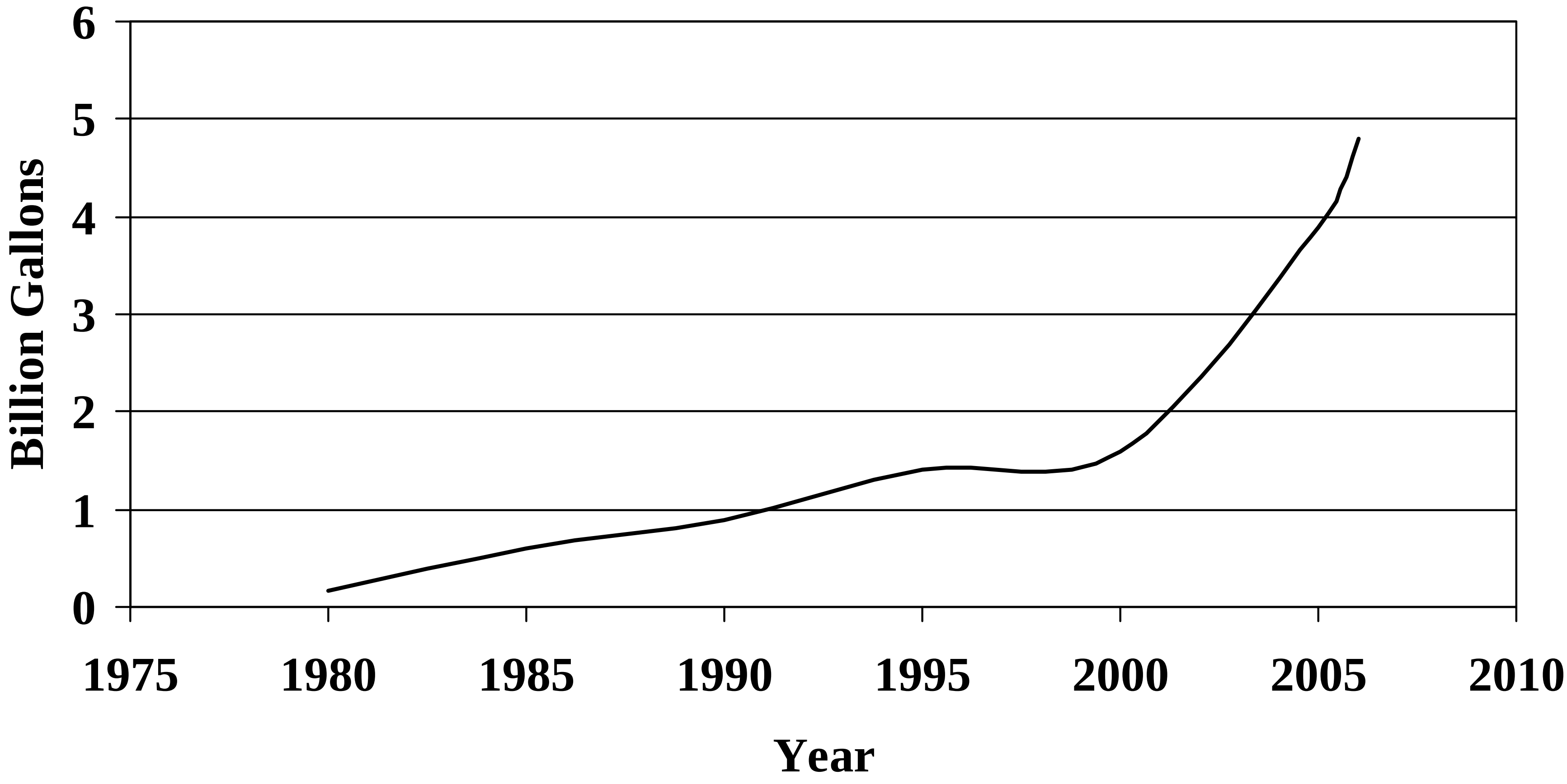

Global Carbon Cycle (billion metric tons)
+ 3.2 Billion tons per year to atmosphere
88
90
119
120
6.3
Oceans
Vegetation and Soils
Caused by human activity

US Energy Demand



Source: Energy Information Administration: Annual Energy Outlook 2007

US Renewable Fuel Demand



Source: Renewable Fuels Association 2007

Biomass ?

- Animal related
- Plant related – lignocellulosic materials
  - Woody – More than 10% lignin

    stems and branches of trees and shrubs
  - Non-Woody – less than 10% lignin

    grasses, non-tree agricultural crops

Woody Biomass – more than just small trees

- Forest-based, non merchantable trees and residues
- Urban Wood Waste stream
  - Construction and demolition wood
  - Post-consumer use wood products
  - Tree removals and trimmings
- Chaparral
- Energy plantations?

Commercial Timberland - Biomass ?

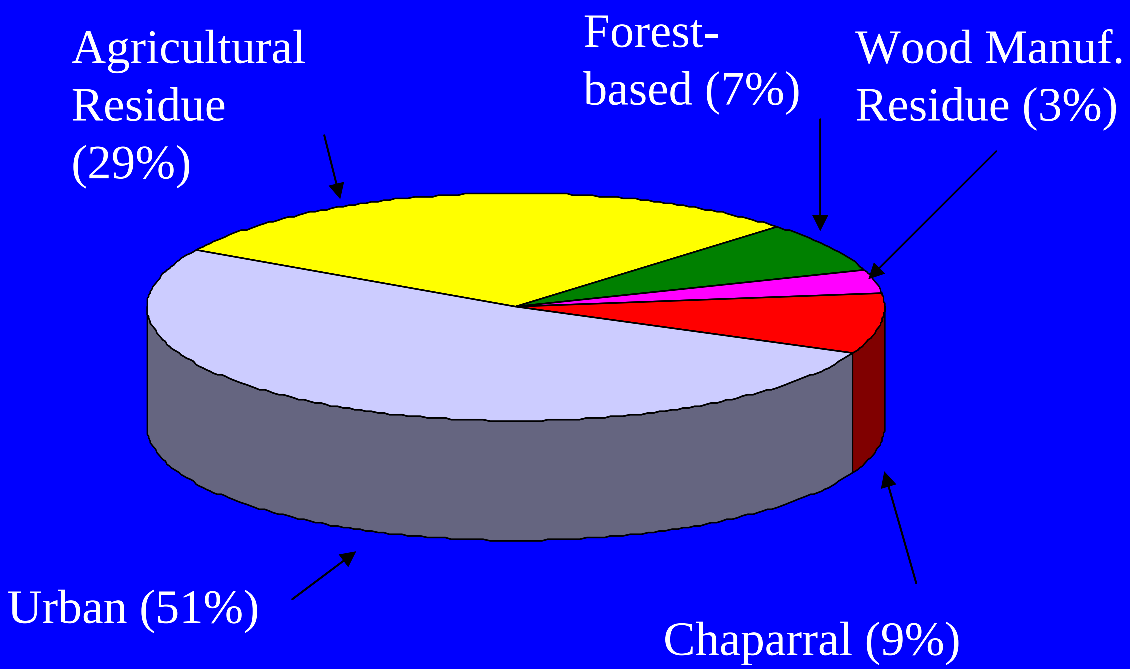
Harvesting Residues

Idyllwild, CA – Population ~ 4,000

Dense Stand of Small Diameter Trees

Urban Woody Waste

California Biomass in 2005



Available

million BDT

AR = 9

F = 12

WM = 2

C = 0

U = 8

Total = 31

Gross Total = 80 million BDT/year

Source: California Biomass Collaborative Forum, 2005

What Role Will Biomass Play in Helping Meet the Ever-Growing Demand for Energy?

Biochemical Potential

	Softwoods	Hardwoods
Cellulose	40-44 %	43-47 %
Hemicellulose	25-29	25-35
Lignin	25-31	16-24
Extractives	1-5	2-8
Ash	< 1	< 1

Organic Chemicals from Biomass

Many Valuable Chemicals can be Made from Wood

- Pharmaceuticals -- Extraction
- Fragrances -- Extraction
- Charcoal, phenolic oils, -- Pyrolysis
- Alcohols - Thermochemical, Hydrolysis/Fermentation
- Bio-Gases (low BTU, high CO) -- Gasification
- Levulinic and Lactic acid ("building blocks") –
  - Hydrolysis/Conversion

Conversion Pathways

Combustion

→ Heat
Electricity

Biochemical

- Anaerobic digestion
- Hydrolysis/Fermentation

→ Alcohol
Other organic chemicals

Thermochemical

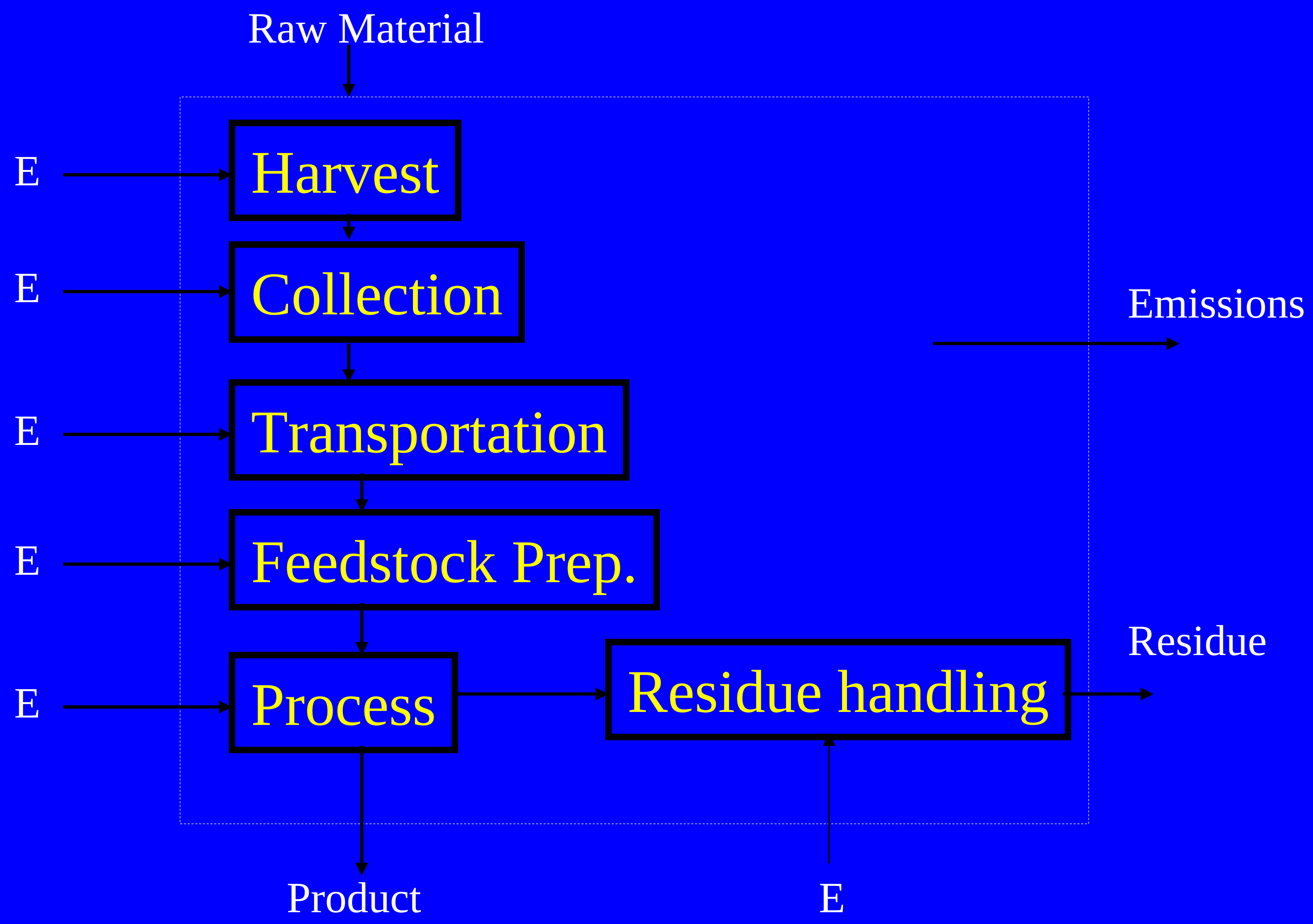
- Pyrolysis
- Gasification

→ Heat
Electricity
Bio-diesel
Alcohol
Other organic chemicals

So What’s the Problem?

- Resource Availability
- Processing Cost
  - Harvesting, raw material prep, manufacturing
- Product Quality

Life Cycle Inventory Analysis



Combustion of Woody Biomass to produce heat and/or power

Small scale – units are available for space or process heat. Combined heat and power may be feasible

Large scale – California has biomass power plants that consume large quantities of woody biomass

Combustion

Fuel + Air →

$CO_2 + H_2O + O_2 + N_2$

+ Ash

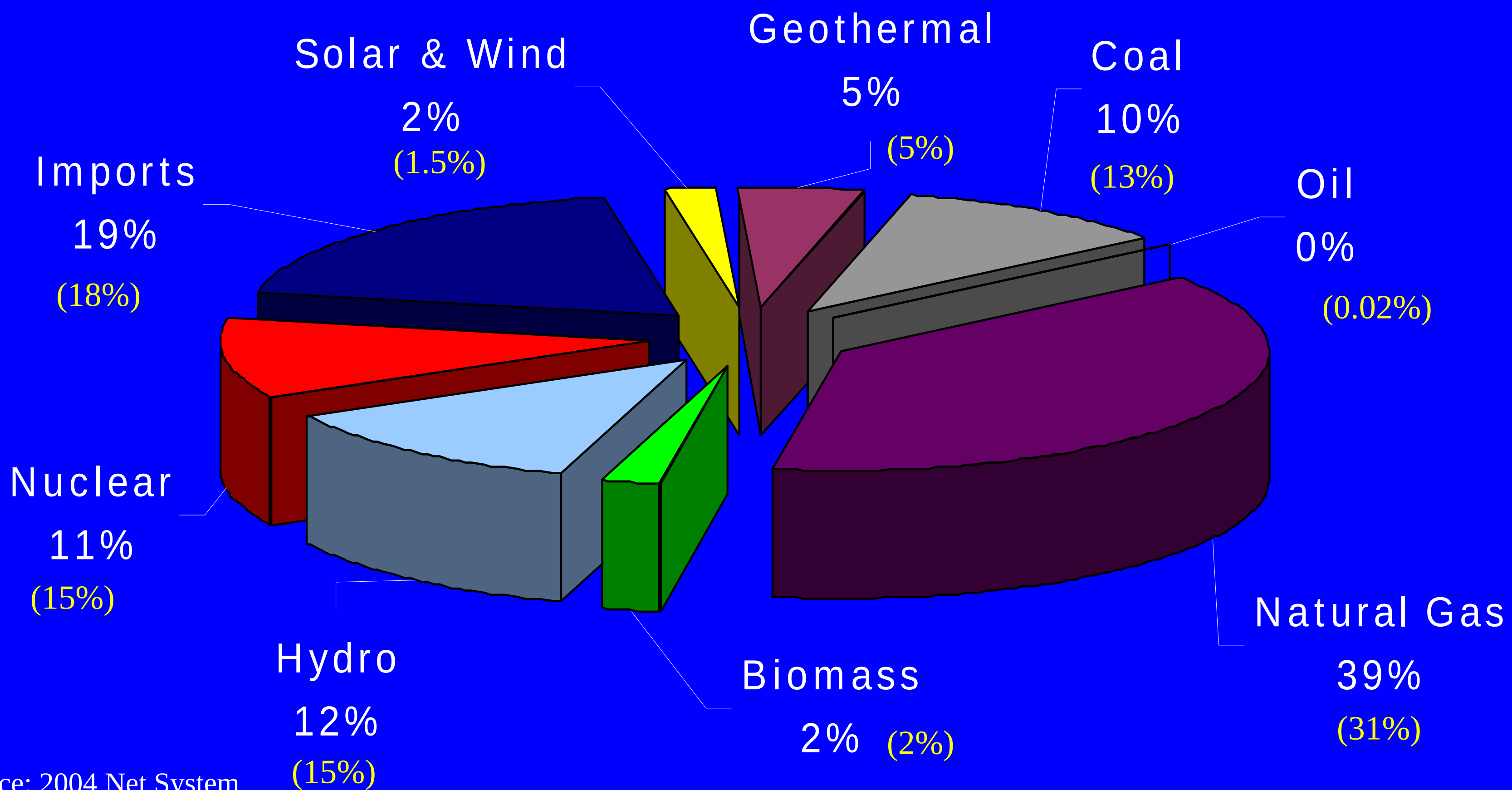
+ Heat

+ Pollutants


SPEED
LIMIT
10

Residential Pellet Stove ????

2004 CA Electricity Production

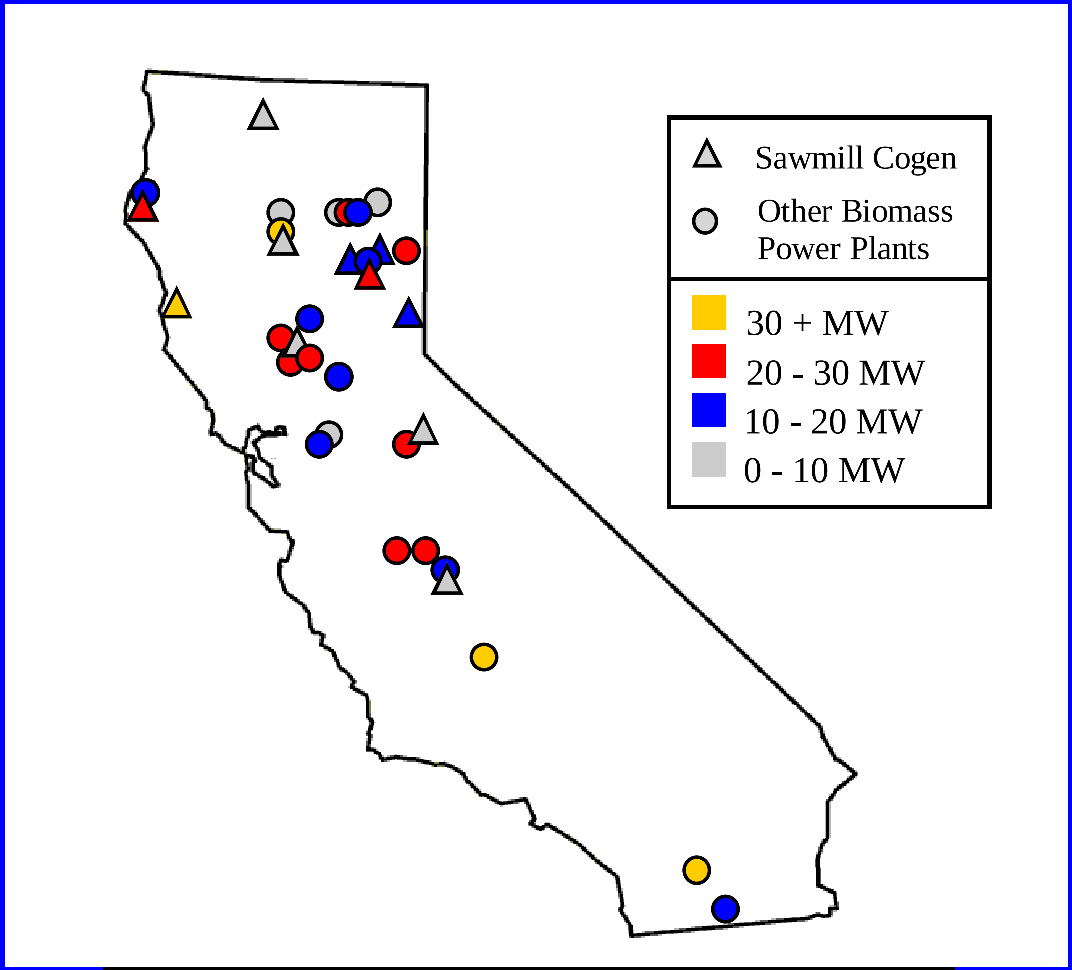


Source: 2004 Net System Power Calculation Report, CEC-300-2005-004, CA Energy Commission

Total Production: 275,091 GWh
Biomass: 5, 997 GWh

(values in parenthesis are for year 1999)

California Biomass Energy Facilities



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

Total capacity of about 626 MW using 4.5 million bone dry tons of biomass per year

- 22% forest base
- 29 % manuf. residue
- 28% Urban woody
- 21% Ag residue

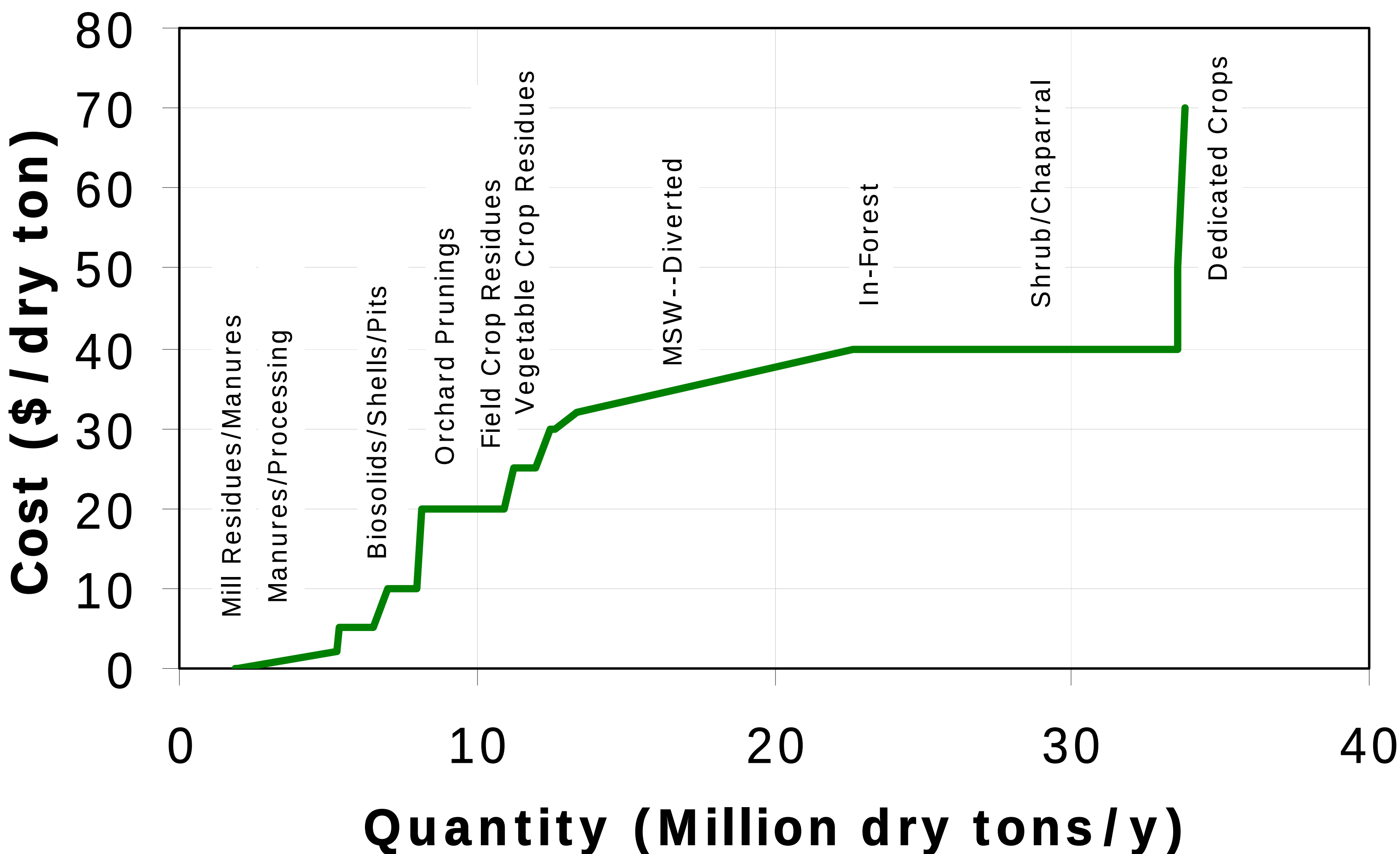
Using less than 10% of total biomass available

and about 20% of forest based biomass available

Typical CA Biomass Powerplant

- 20 MW plant produces about 130 GW/yr
- New plant construction cost = $65 million +
- Processes 140 - 200 thousand tons/yr (1BDT/MW/hour)
- Biomass transported up to 50 miles
- Delivered Biomass valued at $15 - 25 per ton
- Average production cost ~ $0.05 - $0.07/kWh

California Statewide Resource Supply Curve



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)

Problems in Biomass and Waste Combustion

- Inorganic (ash) transformations lead to fouling of fireside surfaces in furnaces and boilers
- Fouling rate depends on composition and concentration of ash in fuel
- Slag formation on grates/Agglomeration in Fluid Beds
- Increased corrosion/acid gas and potential toxics emissions
- Increased maintenance, reduced capacity, reduced efficiency, reduced availability

Alkali + silica
+ sulfur
+chlorine
+ organics

→

Complex Alkali-silicates, sulfates, chlorides, carbonates

Environmental Impact

Air Emissions	Open Field Burning	Biomass Fueled Boiler	Natural Gas Boiler
	lb/Million Btu		
CO	6.89	2.267	0.058
CO_2 fossil		0	114.6
CO_2 non fossil	100 - 350	350.0	0
NO_x	0.36	0.250	0.301
SO_x	0.03	0.013	0.073
VOC	0.74	0	0.009
Methane		0	0.003
Particulates	0.66	0.028	0.009

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

	PM- 2.5	NO_x	CO	VOC	N_2O
Industrial (dry fuel)	0.7 – 6.5	8.8	10.8	0.31	0.23
Industrial (wet fuel)	0.4 – 5.0				
Residential Stove	6 - 23	45 – 100	2 – 14		
Prescribed Burn	12 - 34	3	300	19.0	0.46
Wildfire	17	4.0	140	12 - 24	0.46

Competing Cellulosic Feedstocks

	Cellulose	Hemi-Cellulose	Energy Cont ent (BTU/lb)	Yield (tons/acre)	Bulk Den. (kg/m^3)	Million BTU/m^3	Conversn ratio
Switch-grass	45%	45%	7,000	20	108	1.7	
Miscanthus	45	24	7,700	60	80	1.4	5
Corn Stover	35	25	7,300				< 1
Bagasse	40	22	7,500		60	1	
Wood	42	25	8,000	10	450	8	2 – 5
Coal			10,000		800	17.6	

transportation costs and energy conversion ratio are impt.

Pyrolysis Process

Biomass plus heat (about 500 C) (limited or no Oxygen) → Tars, liquid hydrocarbons, bio-oil, bio-crude

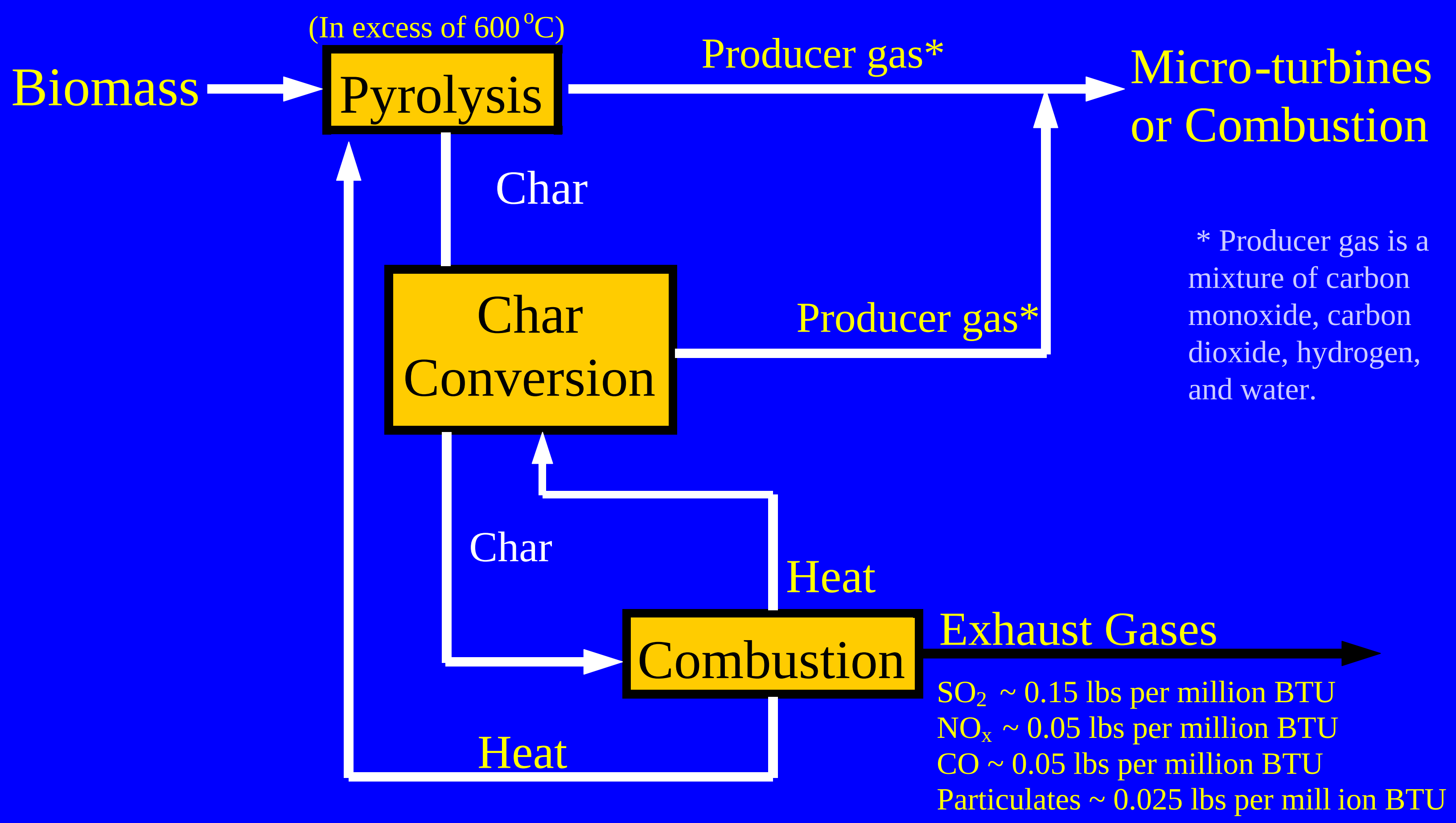
↓

Char

Changing process parameters leads to different products

…Fast pyrolysis, Advanced Pyrolysis, Toreification

Gasification Process




Power Production Module

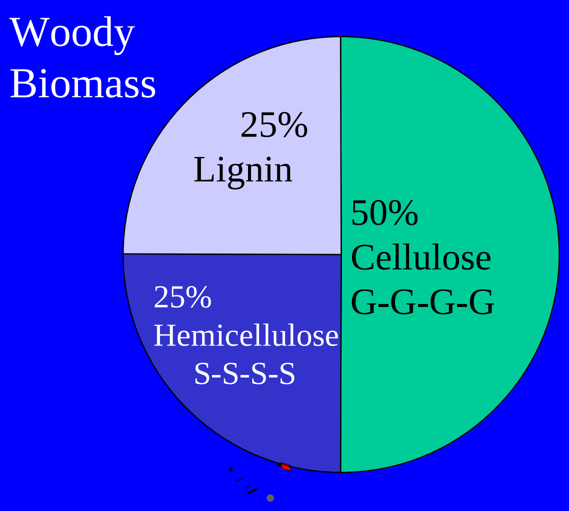
Biomass to ETOH Technologies

- Hydrolysis/Fermentation
  - Concentrated Sulfuric Acid
  - Dilute Sulfuric Acid
  - Dilute Nitric Acid
  - Enzymatic
- Thermal Reduction/Chemical Conversion
  - Gasification/Catalytic Conversion (Fischer-Tropsch)

Hydrolysis/Fermentation

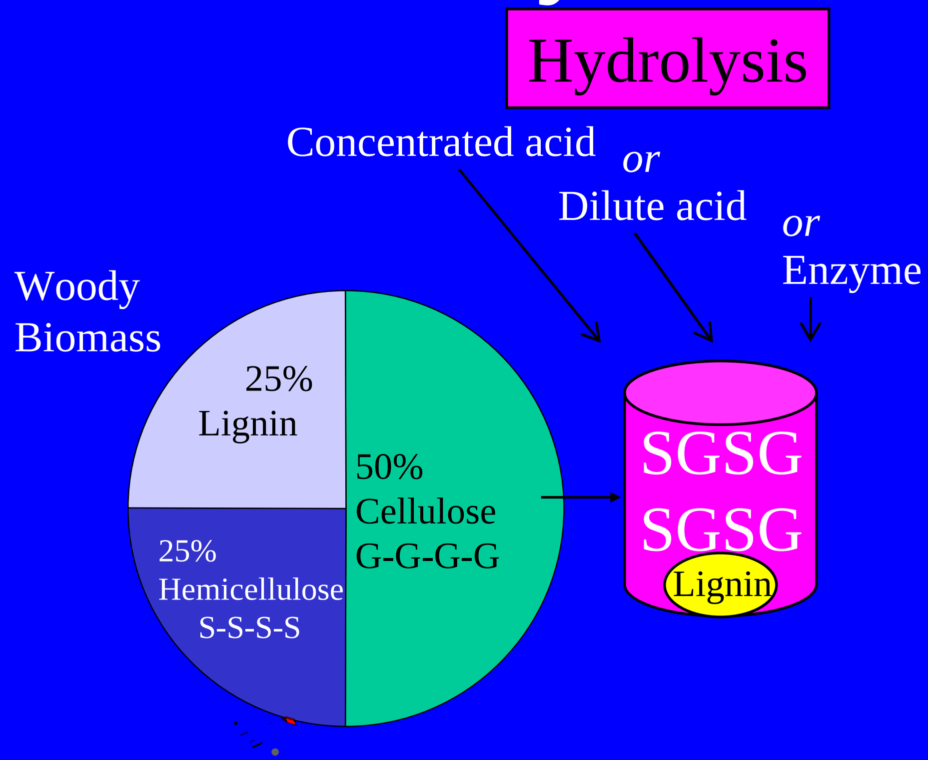
- Dilute nitric acid hydrolysis
  - Separates the 5 and 6 carbon sugars from the lignin
- Yeast Fermentation
  - Converts sugars to alcohol

Woody Biomass-to-Ethanol



G = Glucose (a type of sugar)
S = Other sugars
E = Ethanol

Woody Biomass-to-Ethanol



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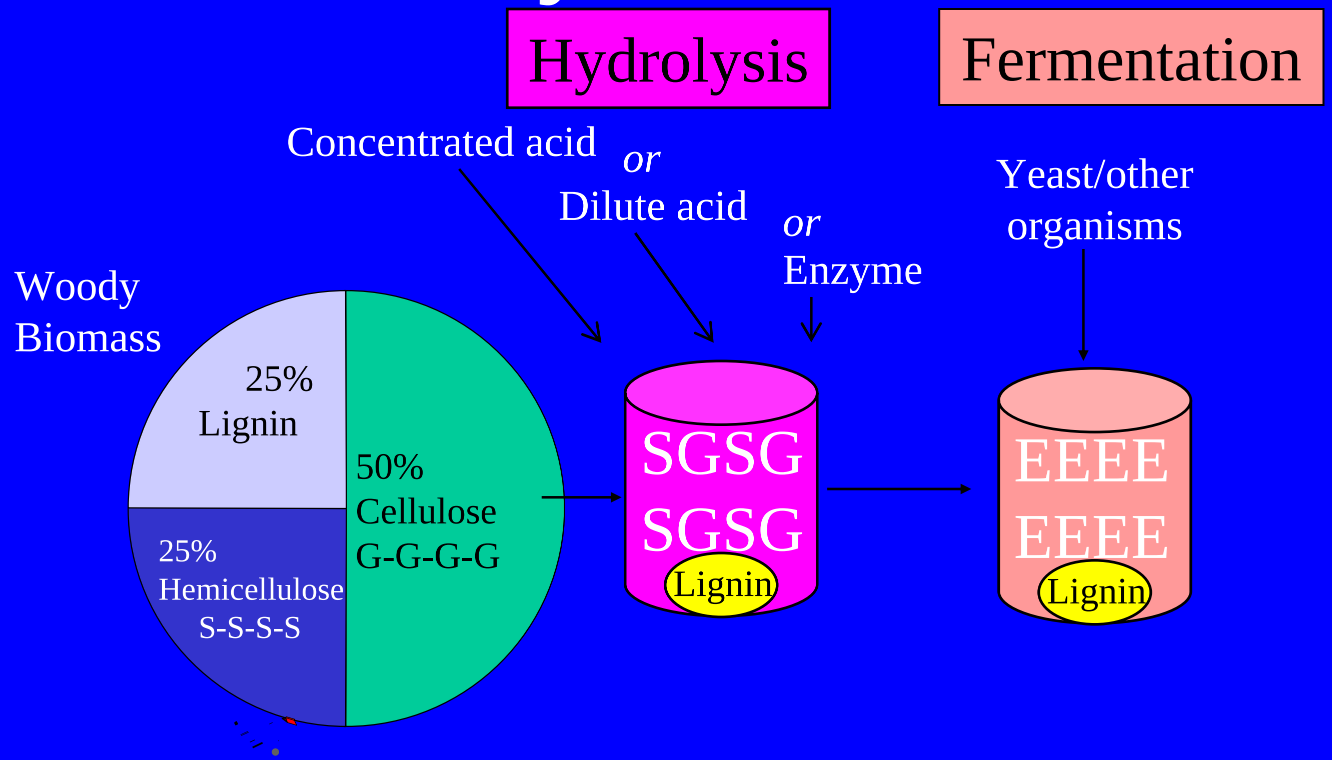

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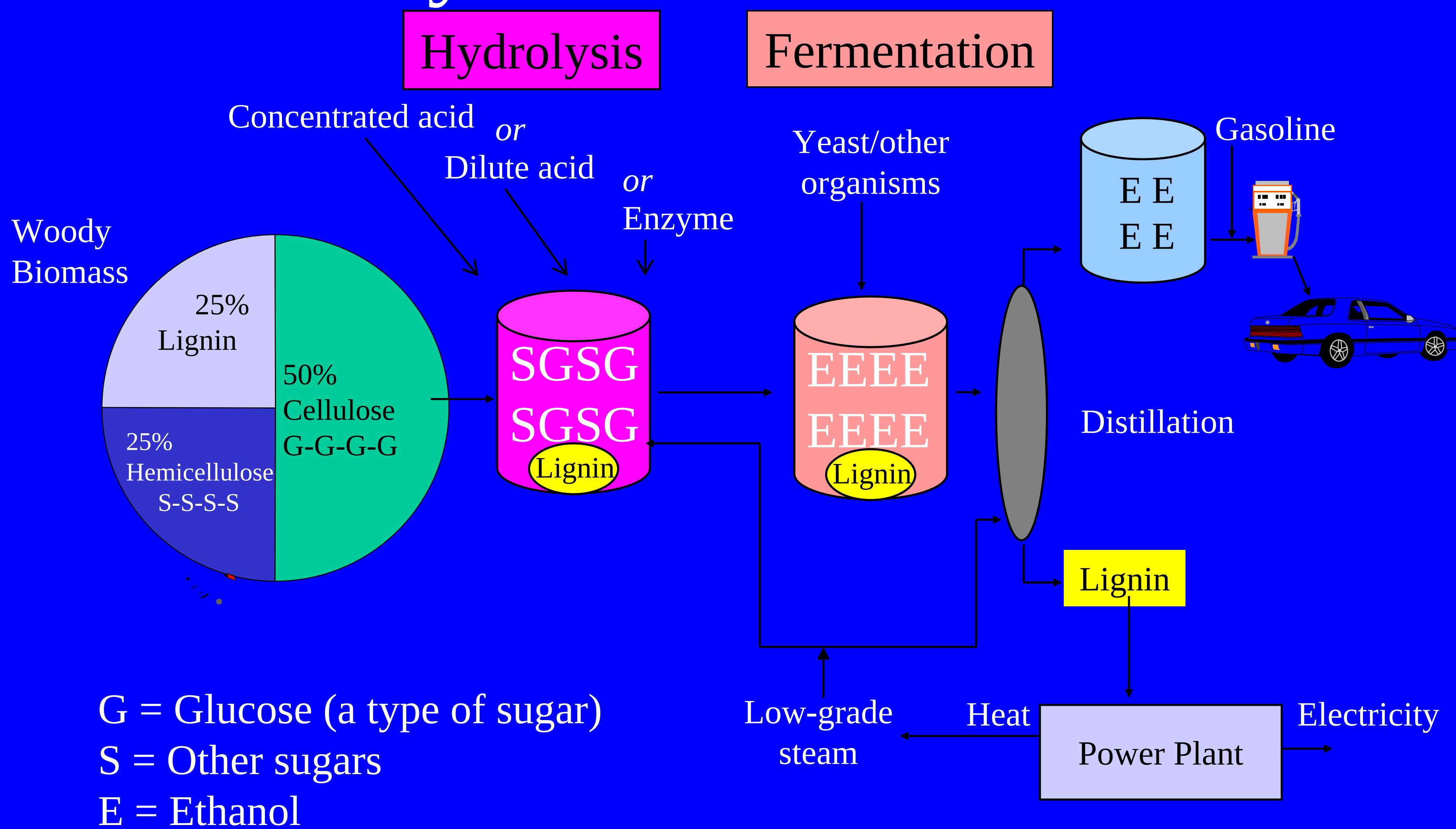
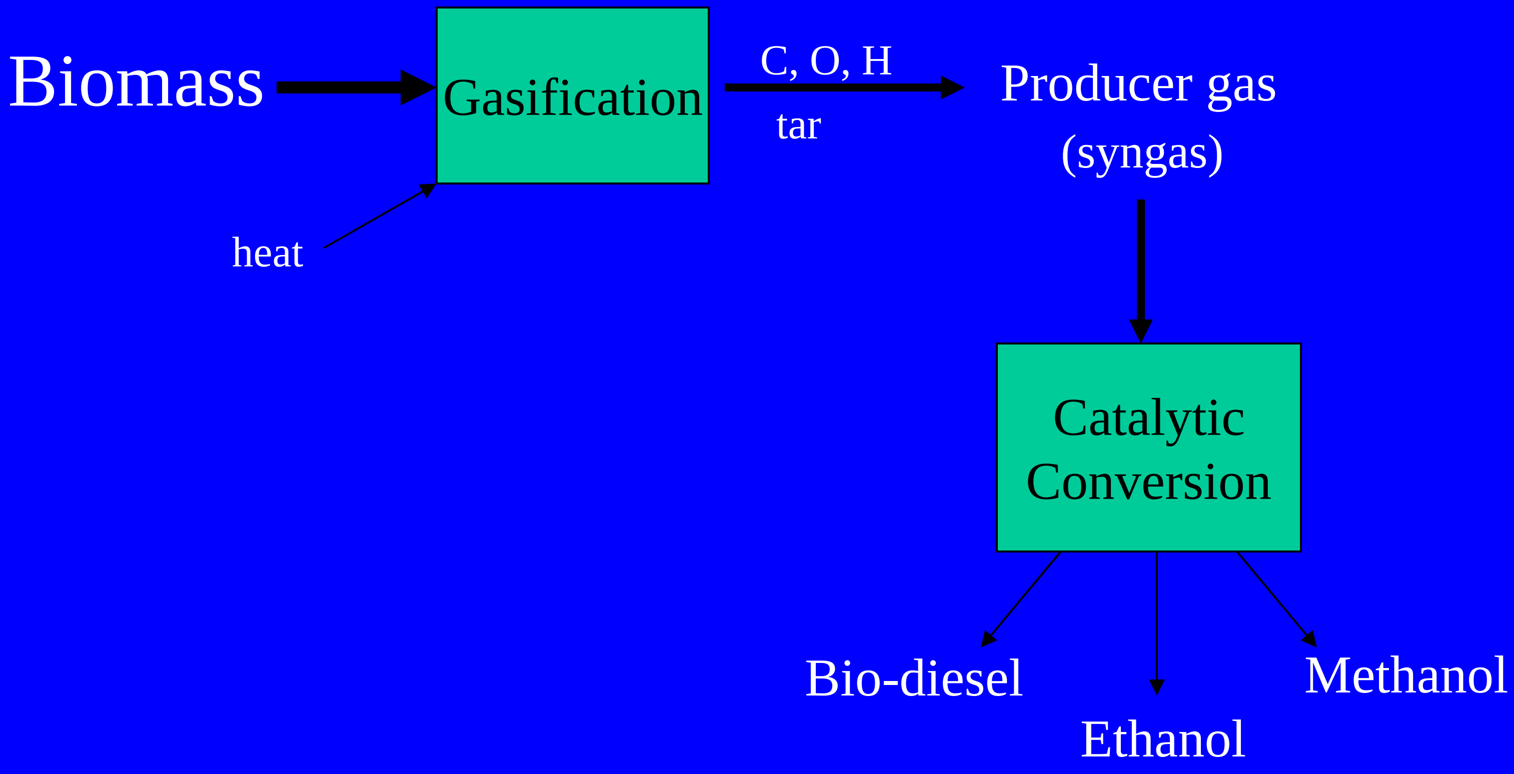


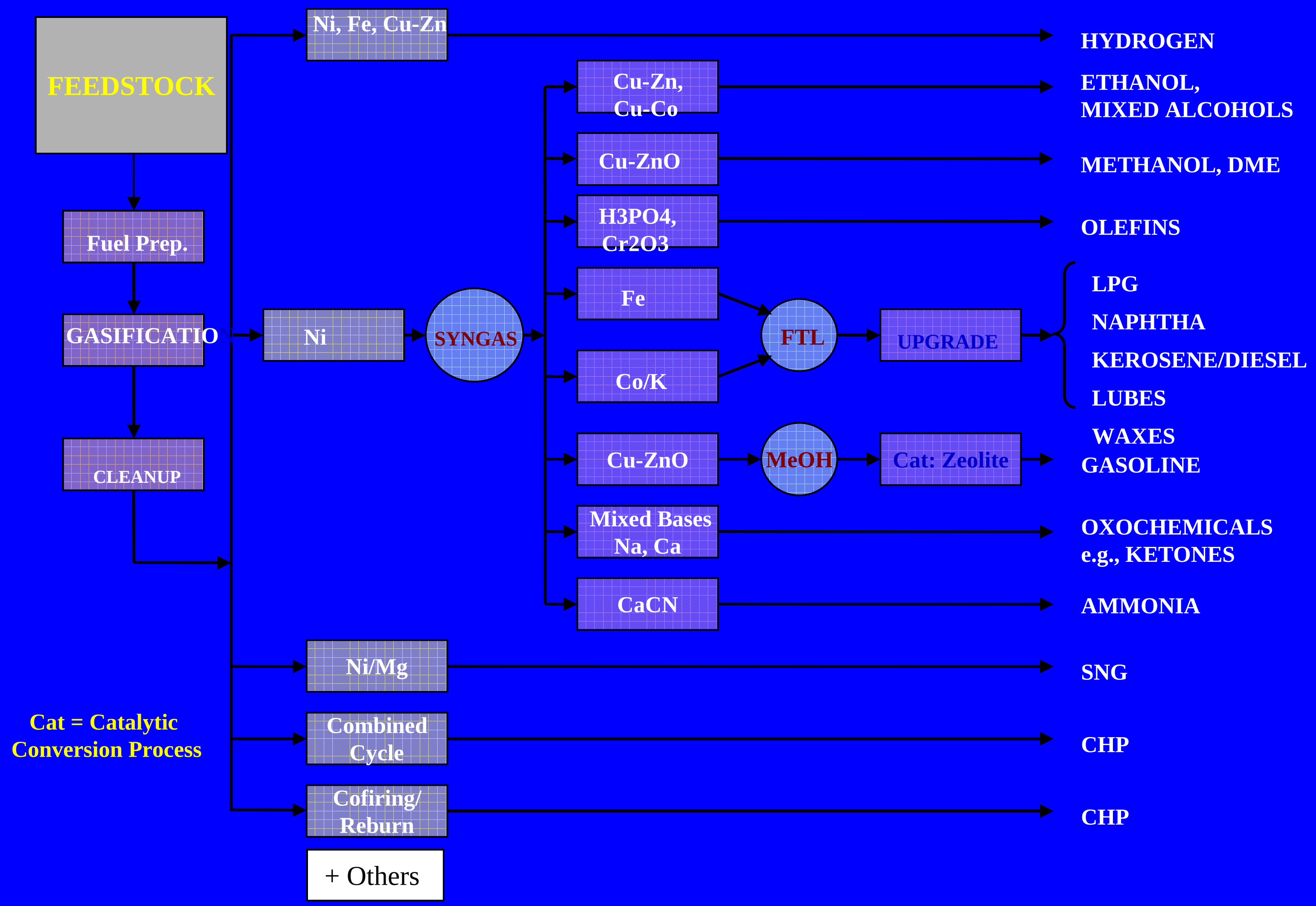
Modified from source slide supplied by USDOE NREL

Thermal Reduction/Catalytic Conversion



Thermochemical Processing

Catalytic Conversion Options



Source: NREL

The Ethanol Issue

- ETOH replaced MTBE as an Oxygenate
- What is the social value of renewable fuels?
- CA demand ~ 600 million gal/year
- What is the best feedstock?
  - Corn
  - Switchgrass
  - Woody Bomass
  - Others?
- Will ETOH be the transportation of the future?

Challenges for Manufacturing Biomass-Based Products

- Insure a Long-Term Supply of Biomass Raw Material
- Overcome Material Property Limitations (biomass is a low quality raw material)
- Improve Processing Knowledge
- Develop New Markets or Market Share
- Encourage Research Funding and Investment Capital
- Make it Economical -- Reduce the High Handling and Production Costs

Future Biomass and Small Tree Innovation

1. Reduce handling and processing costs
2. Improve conventional technology
3. Improve conversion efficiency
4. Develop new processes
5. Develop new products
6. Develop new markets
7. Educate public to benefits of utilization

Summary

- Many woody biomass utilization challenges
  - Raw material quality, economics, markets
- Slim Profit Margins – little room for mistakes
- Small-Scale can’t compete in commodity markets
- Biomass Power Plants are important to CA
  - Encourage development in greater energy efficiency
- Demand for renewable fuels continues to grow
- Social value for using biomass can offset high costs of gathering and transporting biomass
- What is the best use?