

# Woody Biomass for Biofuels

*Woody Biomass Workshop*

*Ukiah, CA*

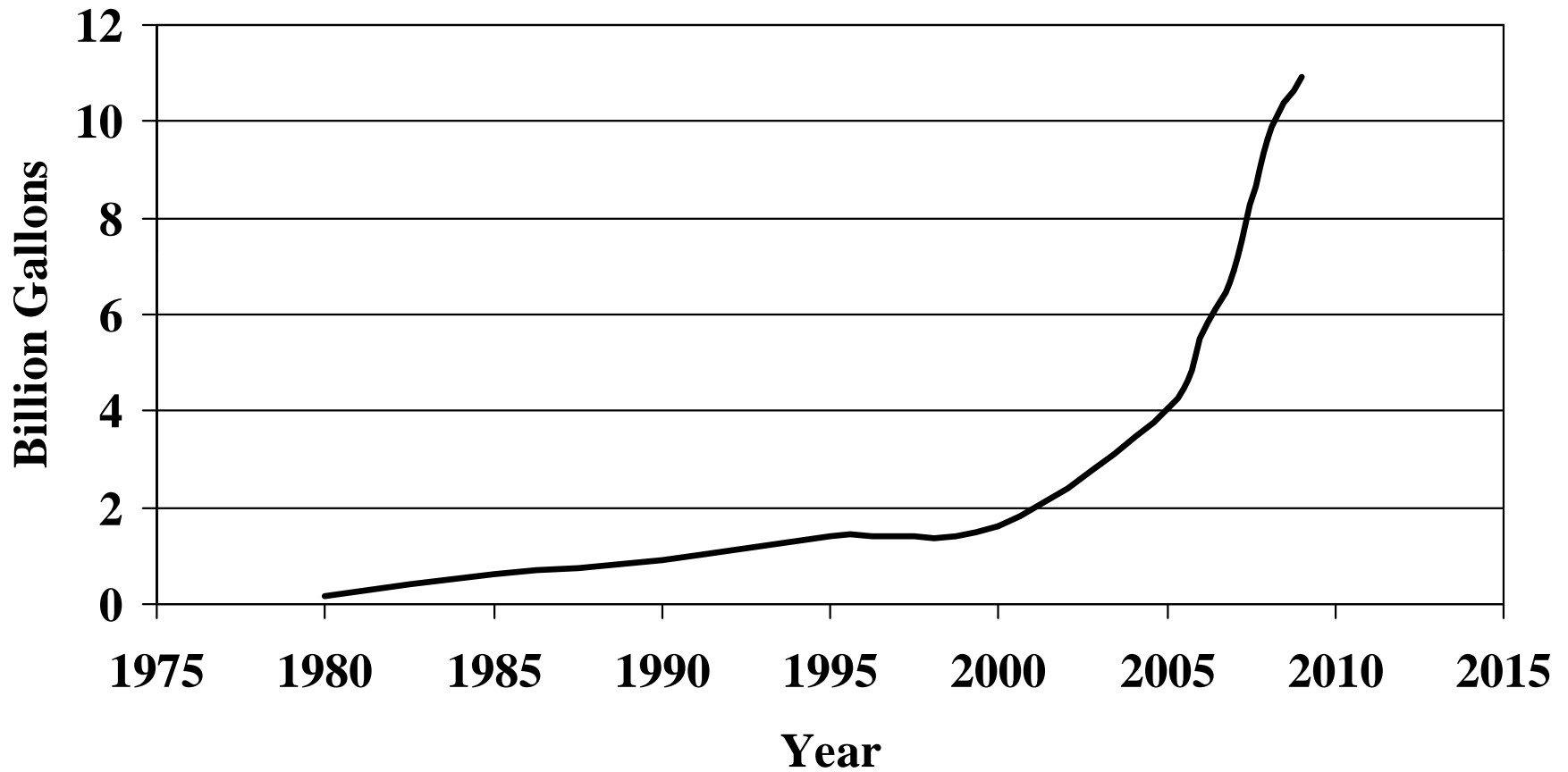
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# US Renewable Fuel Demand



Source: Renewable Fuels Association 2010

# Conversion Pathways

Combustion

Heat  
Electricity

Biochemical

- Anaerobic digestion
- Hydrolysis/Fermentation

Alcohol  
Other organic chemicals

Thermochemical

- Pyrolysis
- Gasification

Heat  
Electricity  
Bio-oil  
Alcohol  
Other organic chemicals

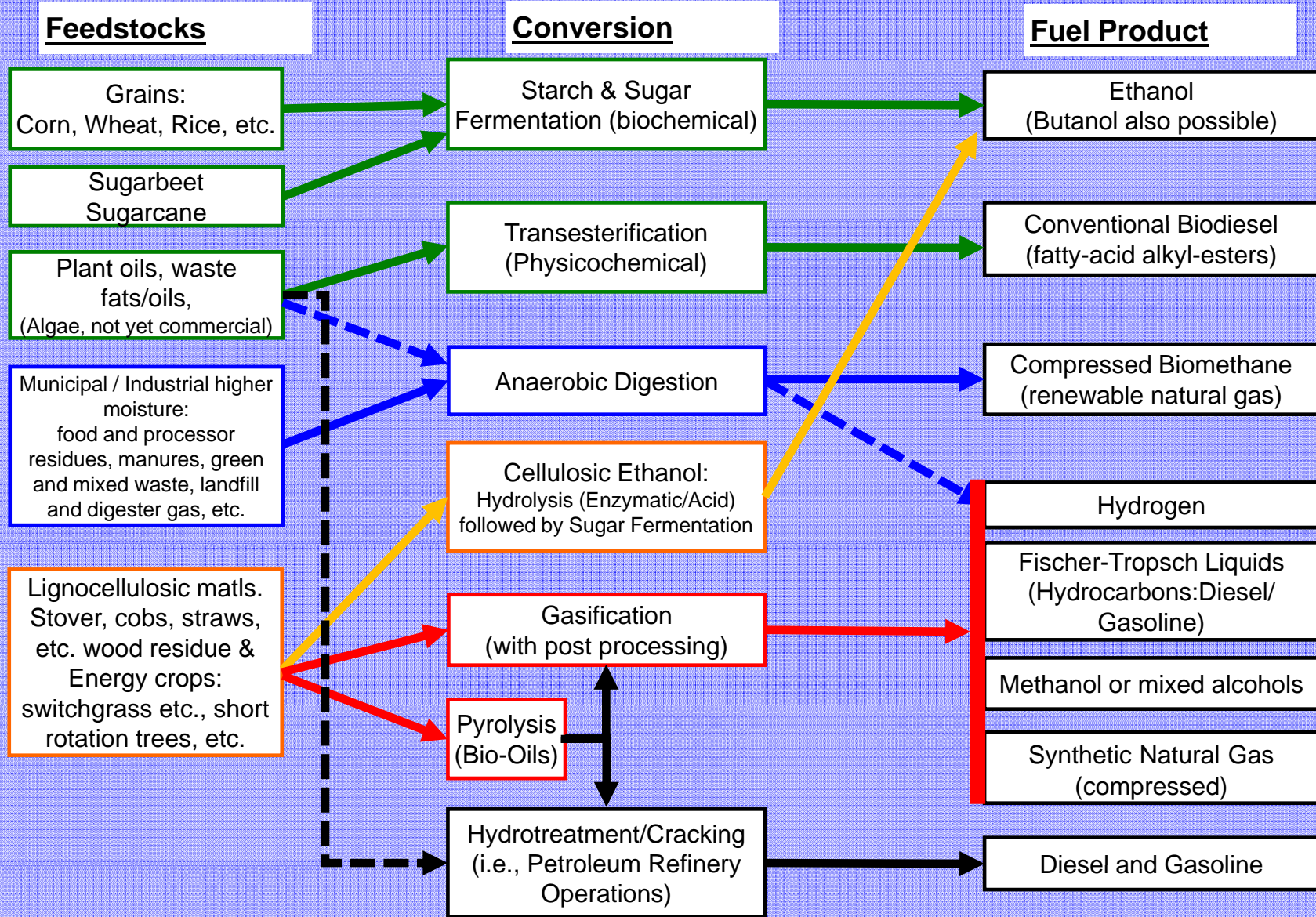
# Biochemical Potential

	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

# Biofuels

- **Solid**
  - Wood (chips, chunks, densified)
  - Charcoal
  - Lignin residues
- **Liquid**
  - Bio-oil (low viscosity tar)
  - Bio- diesel
  - Ethanol (Ethyl alcohol)
  - Methanol (methyl alcohol)
  - Biobutanol (butyl alcohol)
- **Gaseous**
  - Producer gas (syngas)

# Biofuel Pathways



## Competing Cellulosic Feedstocks for Biofuels

	Cellulose	Hemi-Cellulose	Energy Content (BTU/lb)	Yield (tons/acre)	Bulk Den. (kg/m <sup>3</sup> )	Conversion ratio
Switch-grass	45%	45%	7,000	20	108	5
Miscanthus	45	24	7,700	60	80	5
Corn Stover	35	25	7,300		40	< 1-1.2
Bagasse	40	22	7,500		60	
Wood	42	25	8,000	10	450	0.8 - 1

transportation costs and energy conversion ratio are impt.

# Biomass to ETOH Technologies

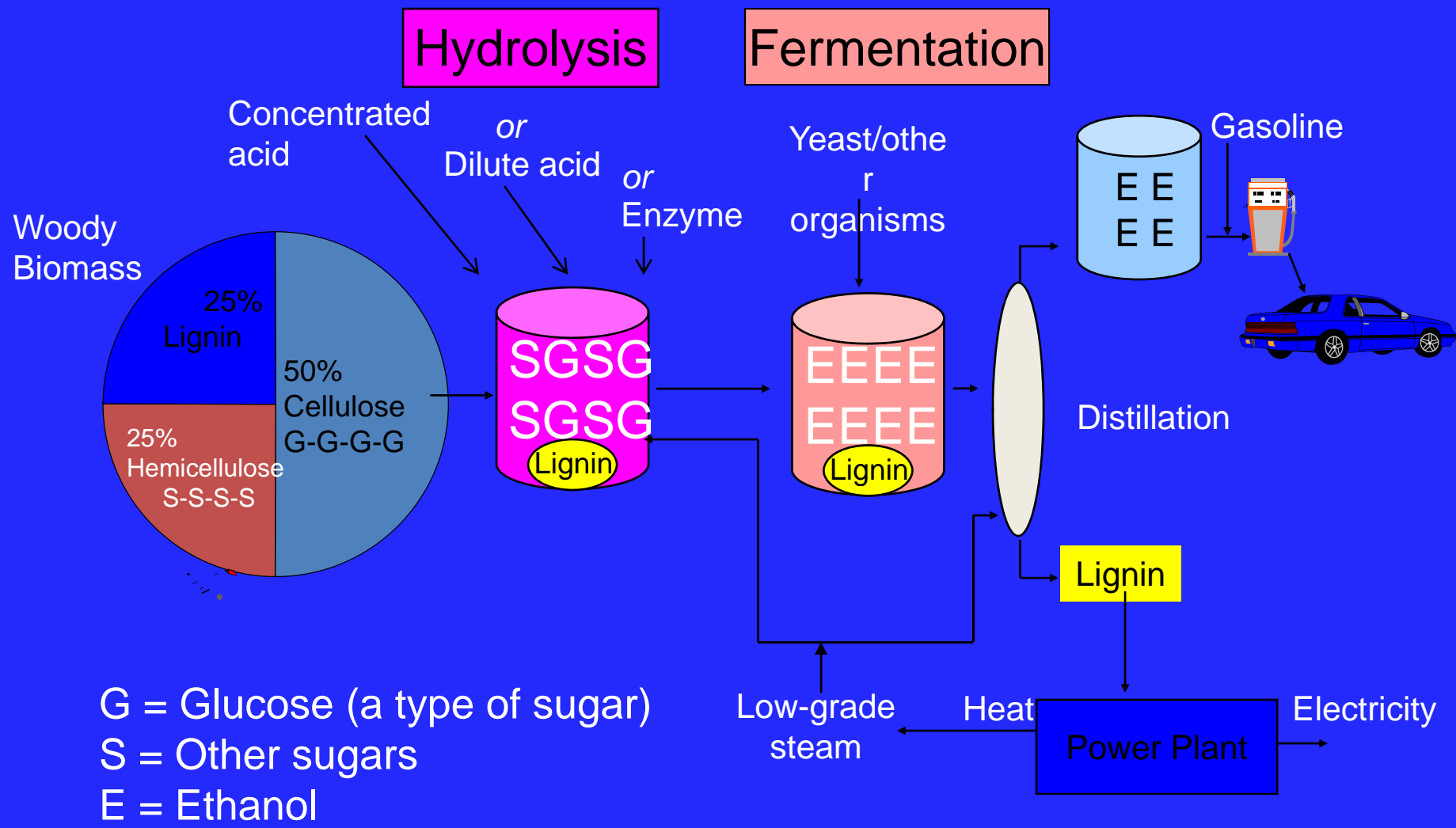
- Hydrolysis/Fermentation
  - Concentrated Sulfuric Acid
  - Dilute Sulfuric Acid
  - Dilute Nitric Acid
  - Enzymatic
- Thermal Reduction/Chemical Conversion
  - Gasification/Catalytic Conversion (Fischer-Tropsch)

# 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

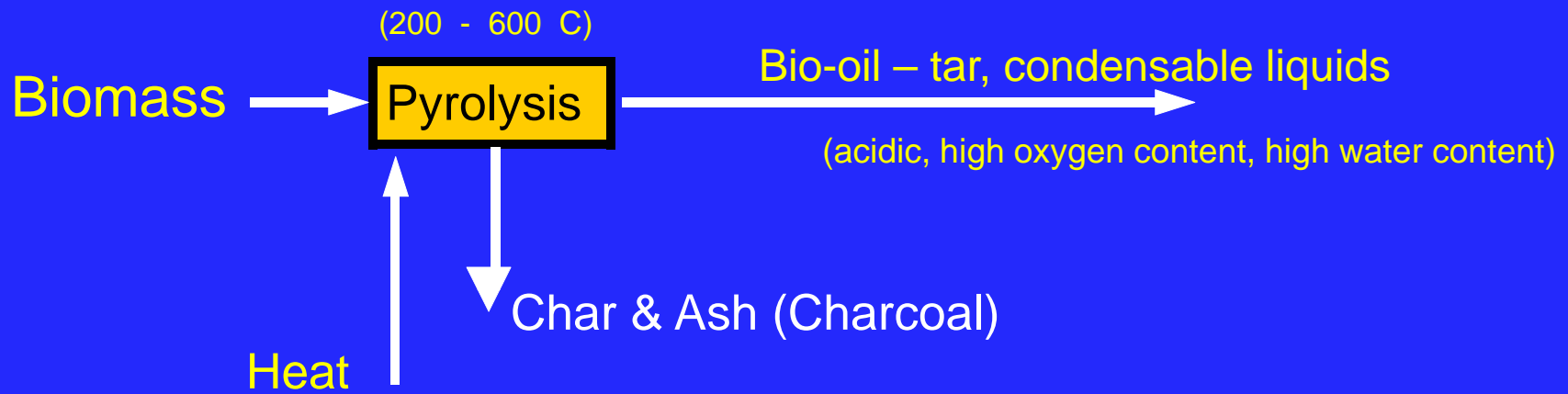


Modified from source slide supplied by USDOE NREL

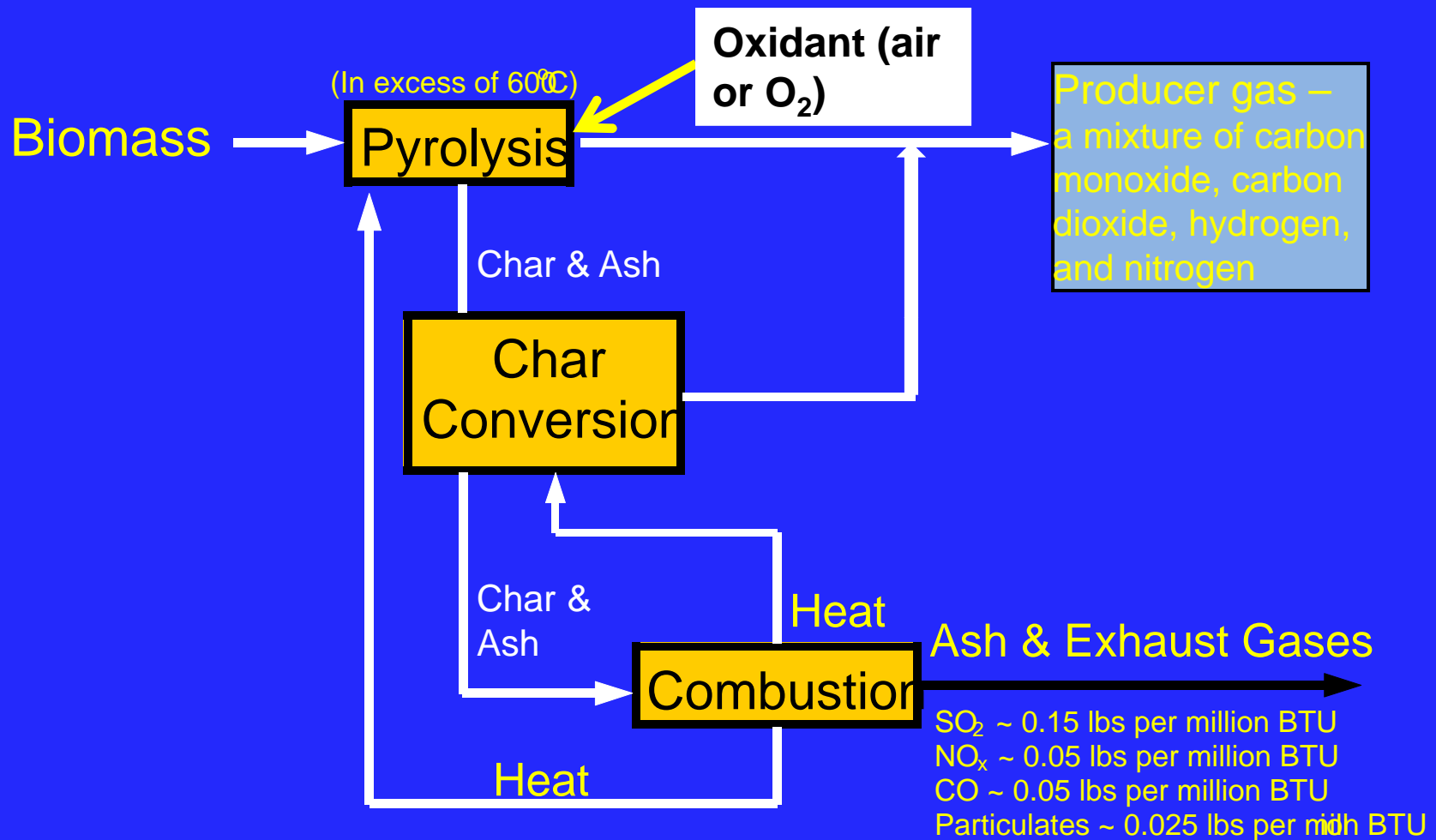
# Ethanol

- First Generation Biofuel
- What is the best feedstock?
  - Corn
  - Corn Cellulose (stover)
  - Switchgrass
  - Miscanthus
  - Woody Biomass
  - Bagasse
  - Others?

# Pyrolysis Process

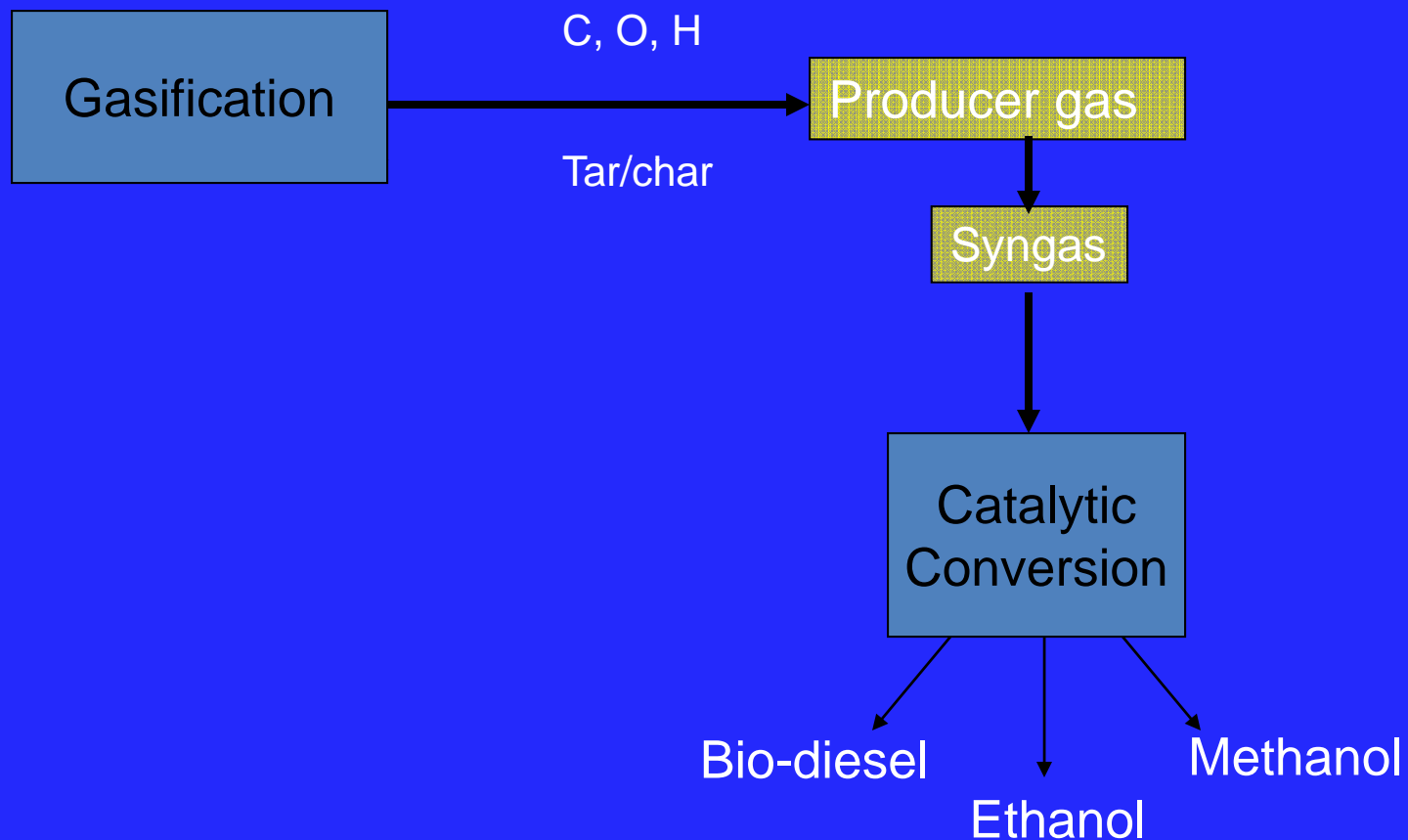


# Gasification Process



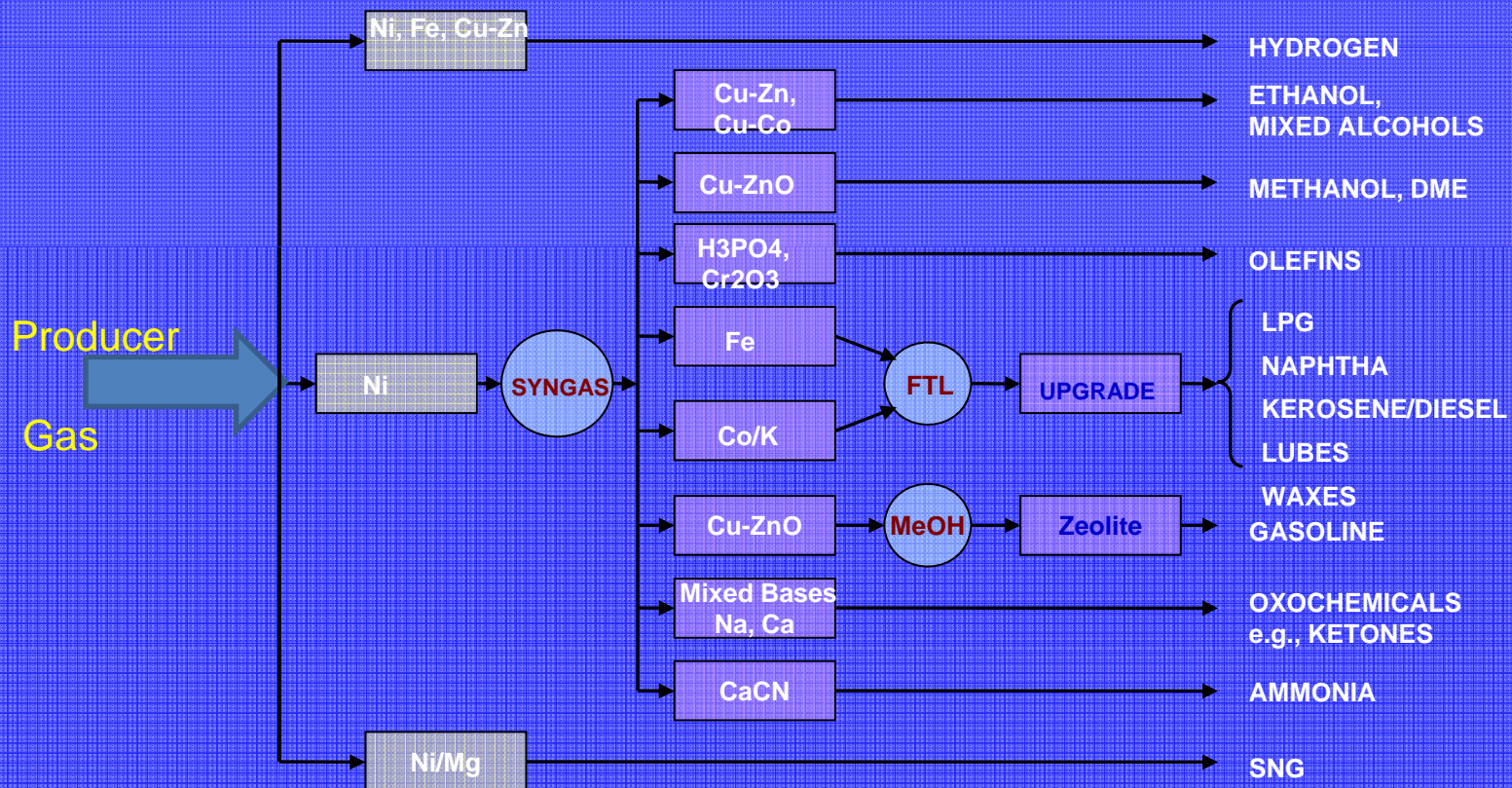
Gasification -- "Partial Oxidation" (controlled amount of air or oxygen) to produce a combustible, gaseous mixture (producer gas) of many compounds that can be used directly as a low BTU fuel gas or cleaned and used to produce higher value products (syngas).

# Catalytic Conversion of Syngas

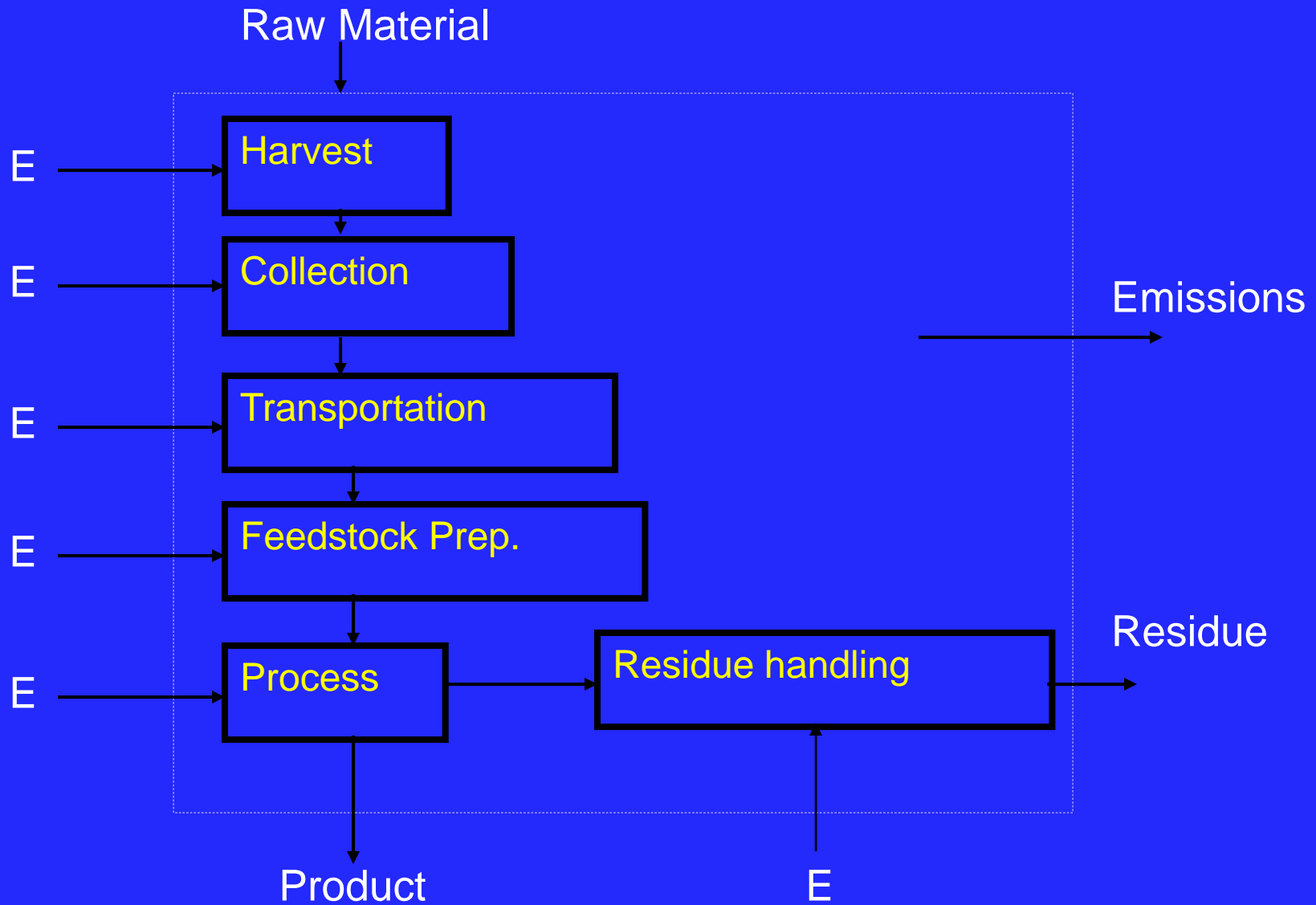


# Thermochemical Processing

## Catalytic Conversion Options

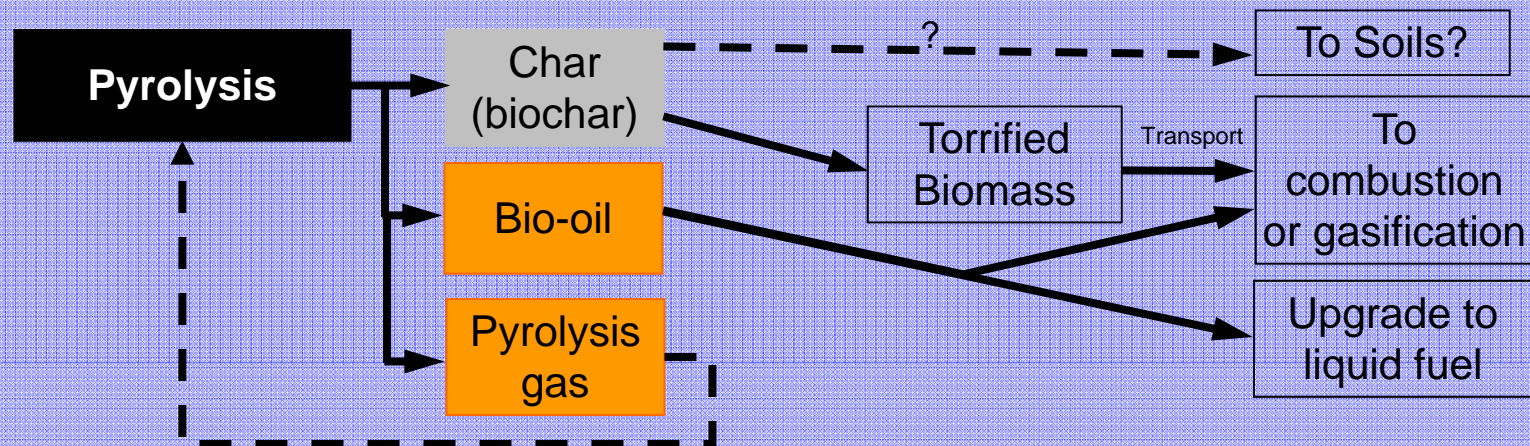


# Life Cycle Inventory Analysis



# 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.



# Hydrolysis and Fermentation

## PROS

- Mature technology (think vodka)
- Adaptable to many feedstocks
- Supported by subsidies

## CONS

- Not an ideal transportation fuel (absorbs water, difficult to transport)
- Potential to compete with food resources
- Can be energy negative

# Gasification

## PROS

- Produces a versatile fuel gas that can be:
  - used directly or stored
  - combusted to produce heat
  - Used to synthesize other chemicals
- Lower emissions than combustion

## CONS

- Lower BTU value than natural gas or LPG
- High production costs (capital and operating)
- Tar contaminates the gas and must be cleaned for higher value uses
- Char ash may be a disposal problem

# Pyrolysis

## PROS

- Can produce hydrocarbon gases, liquids, and a solid char product (e.g. charcoal)
- Solid char has properties similar to that of coal and can be used to co-fire coal combustion units
- Relatively low costs

## CONS

- Bio-oils have a high moisture content and a complex mix of organic chemicals and are not very compatible with other fuel oils
- Markets for products are untested

# Energy to Deliver 1 million BTU from Source to Vehicle Fuel Tank

Fuel	Total Energy (BTU)	Fossil Energy (BTU)
Gasoline	240,000	240,000
ETOH (corn starch)	500,000	500,000
ETOH (corn cellulose, stover)	1,230,000	230,000
ETOH (herbaceous)	1,200,000	100,000
ETOH (Wood)	800,000 - 1,600,000	100,000

Source: Argonne National Laboratory, 2001

# A Wood Scientist's Opinion

*The importance of woody biomass as a raw material will increase dramatically through the 21<sup>st</sup> century becoming the choice for many carbon-based materials, including part of the solution to replacing fossil fuels for transportation.*

*The challenge remains to do it economically with a positive energy balance.*