Biomass Gasification in a Dry Grind Ethanol Facility:
Benefits and Challenges

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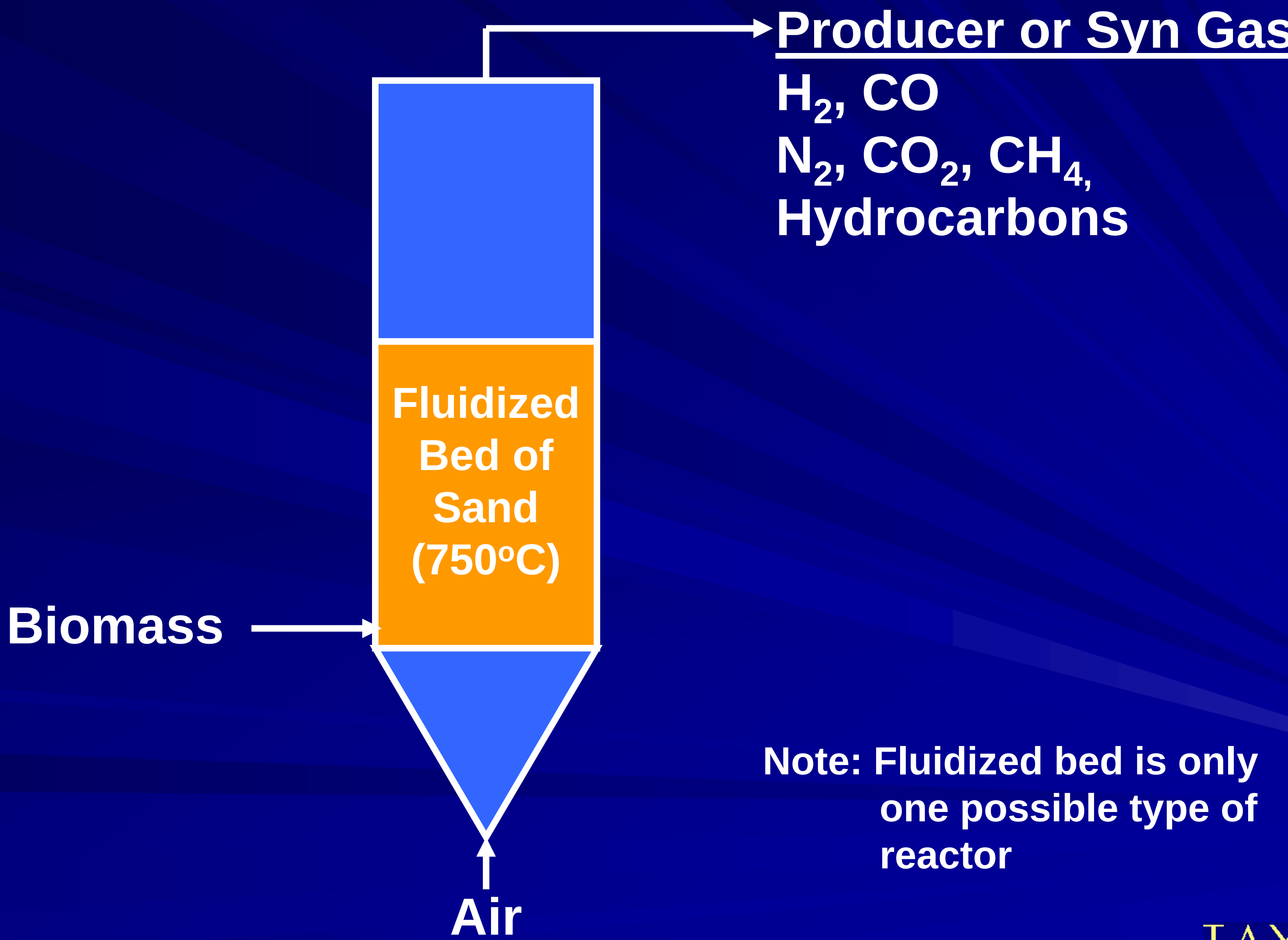
Fluidized Bed Biomass Gasifier



Note: Fluidized bed is only one possible type of reactor

Biomass Gasification: Reactions

Two Simultaneous Reaction Types

```
            H  H H H
            |  |  |  |
Pyrolysis: -C-C-C-C- + Heat → H2 + CH4 + hydrocarbons (endothermic)
            |  | |  |
            H H H H
```

Pyrolysis: -C-C-C-C- + Heat → H_2 + CH_4 + hydrocarbons (endothermic)

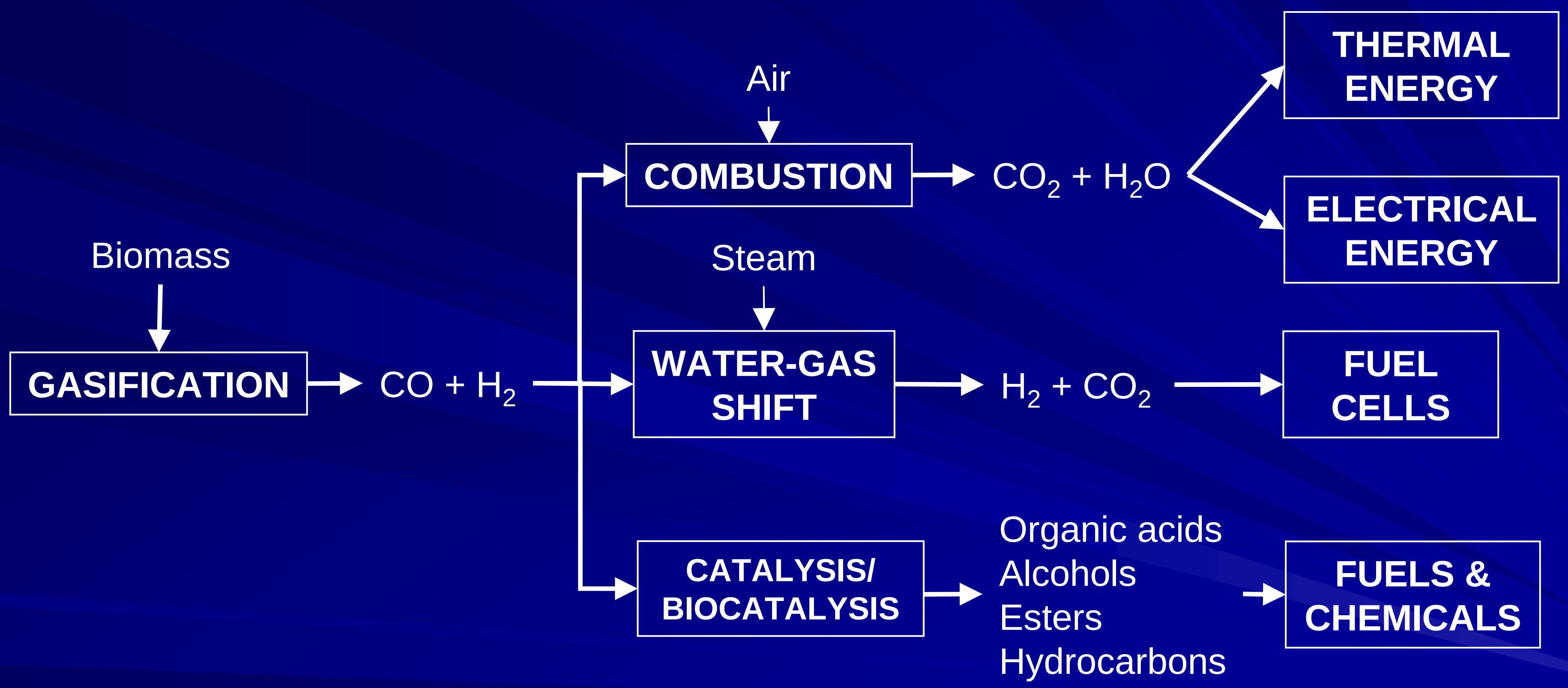
Combustion: C + O2 → CO2 + Heat (exothermic)

Note: 1. Actual reaction scheme is very complicated

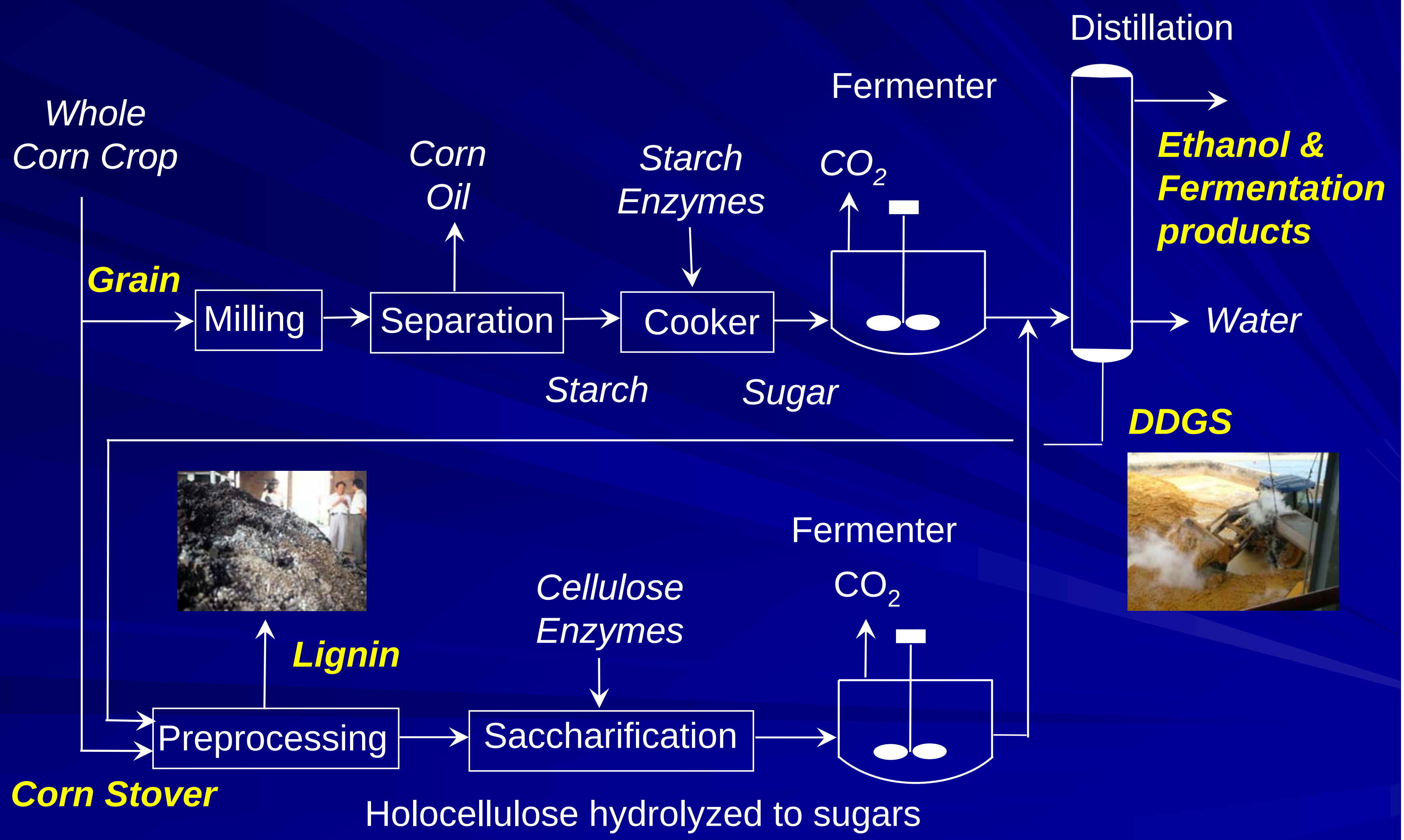
2. $C + H_2O$ + heat → $CO + H_2$ is a source of CO and H_2

3. $CO + H_2O$ → $CO_2 + H_2$ is a source of H_2 (water-gas shift)

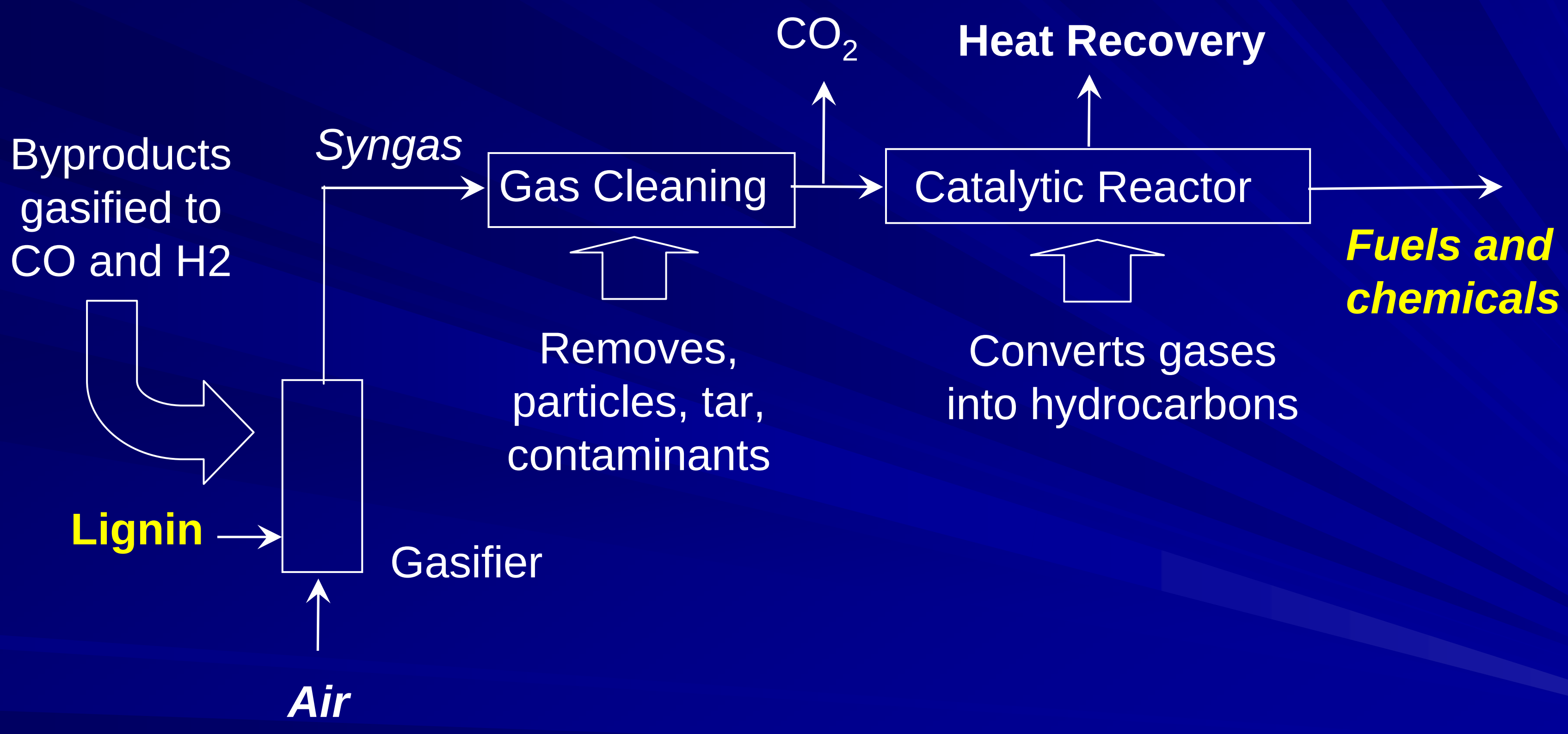
Why Gasification?



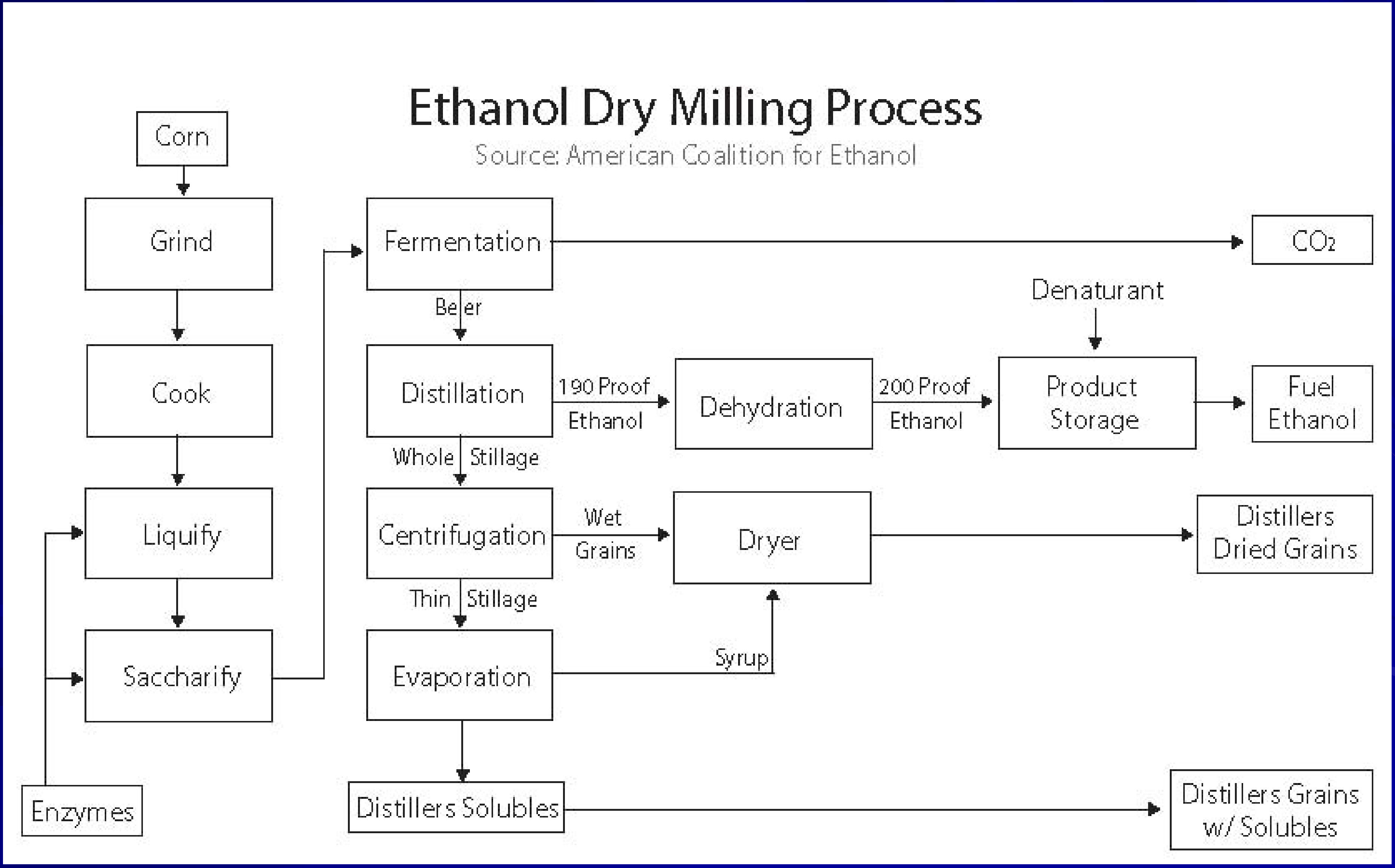
Whole Crop Biorefinery



What to Do With the Byproducts of Biorefinery?



Drymill Ethanol Process



Ethanol Production – Energy Costs

$8/MM Btu for Natural Gas

↓

$0.24/gal of Ethanol (30,000 Btu/gal)

↓

$11.5 million/yr for Central Indiana Ethanol
(48M gal/yr capacity)

Reducing natural gas → Cost Savings!

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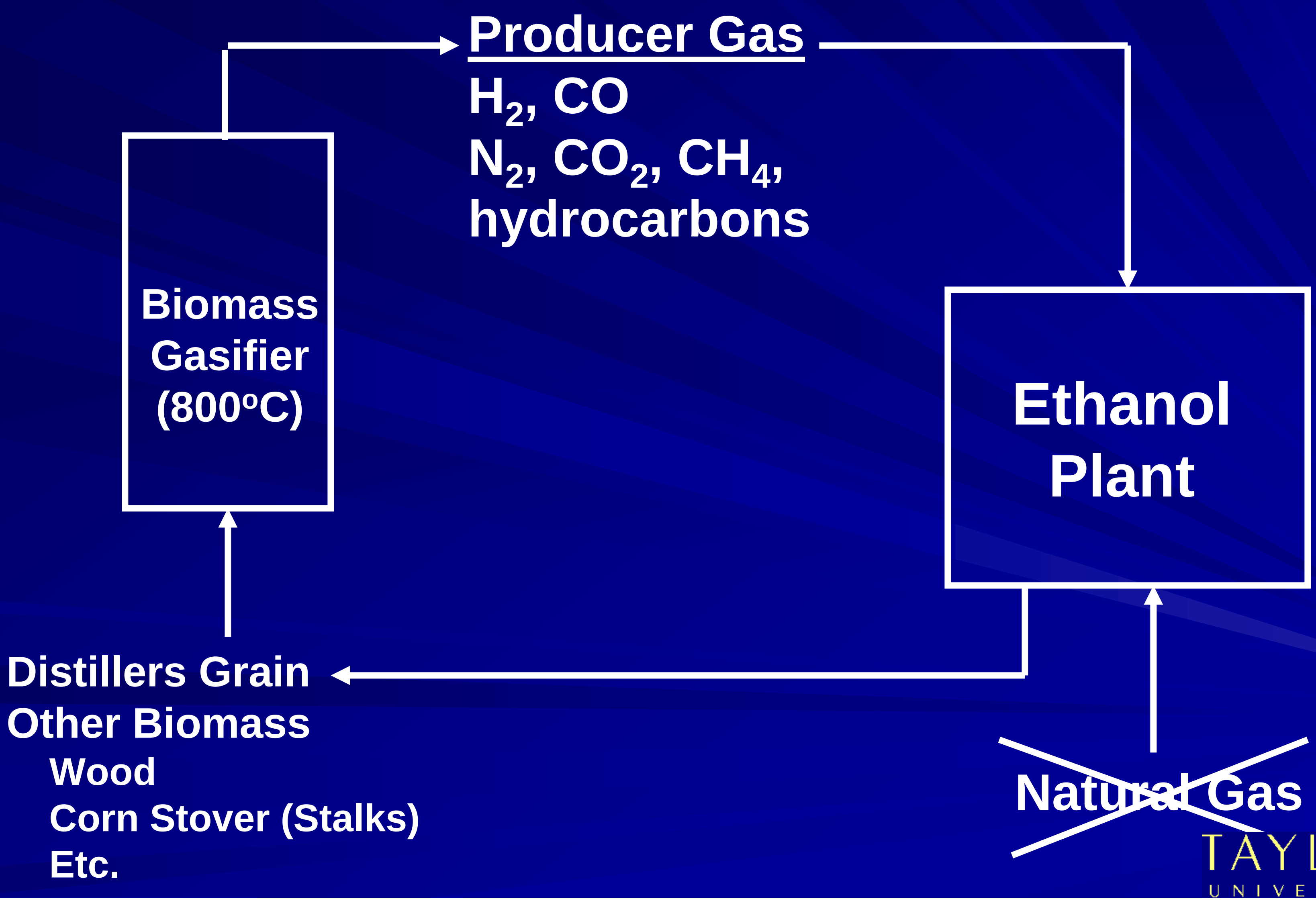
Biomass Gasification Replaces Natural Gas



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Savings Via Distillers Grains Gasification

Savings in $M/yr for Central Indiana Ethanol Plant (48M gal/yr)
(Capital costs not included)

	$70/ton Distillers Grains	$80/ton Distillers Grains	$90/ton Distillers Grains
$5/MMBtu Nat. Gas	$0.2 M/yr	-$0.8 M/yr	-$1.8 M/yr
$6/MMBtu Nat. Gas	$1.7	$0.7	-$0.4
$7/MMBtu Nat. Gas	$3.2	$2.1	$1.1
$8/MMBtu Nat. Gas	$4.5	$3.5	$2.5
$9/MMBtu Nat. Gas	$6.0	$5.0	$4.0

Gasification Hurdles in the Ethanol Industry

- Process Integration
- Feedstock Handling
- Capital Cost
- Policy/Permitting

Process Integration

Problem	Solution
Tars & ash in producer gas ➔ Equipment fouling	Gas cleanup technologies being developed (Integrated systems –thermal oxidation and ash removal)
Btu/Volume: Producer Gas < Natural Gas	Dedicated boiler and oxidation systems to handle increased gas flow through the burner and system.
Uninterrupted feedstock needed to avoid process upsets.	Biomass harvest, storage and supply systems needed

Capital Cost

- $12M-15M gasification system needed for a typical ethanol facility
  - Central Indiana Ethanol is a $64M Plant
- The 2005 energy bill provides significant tax relief.

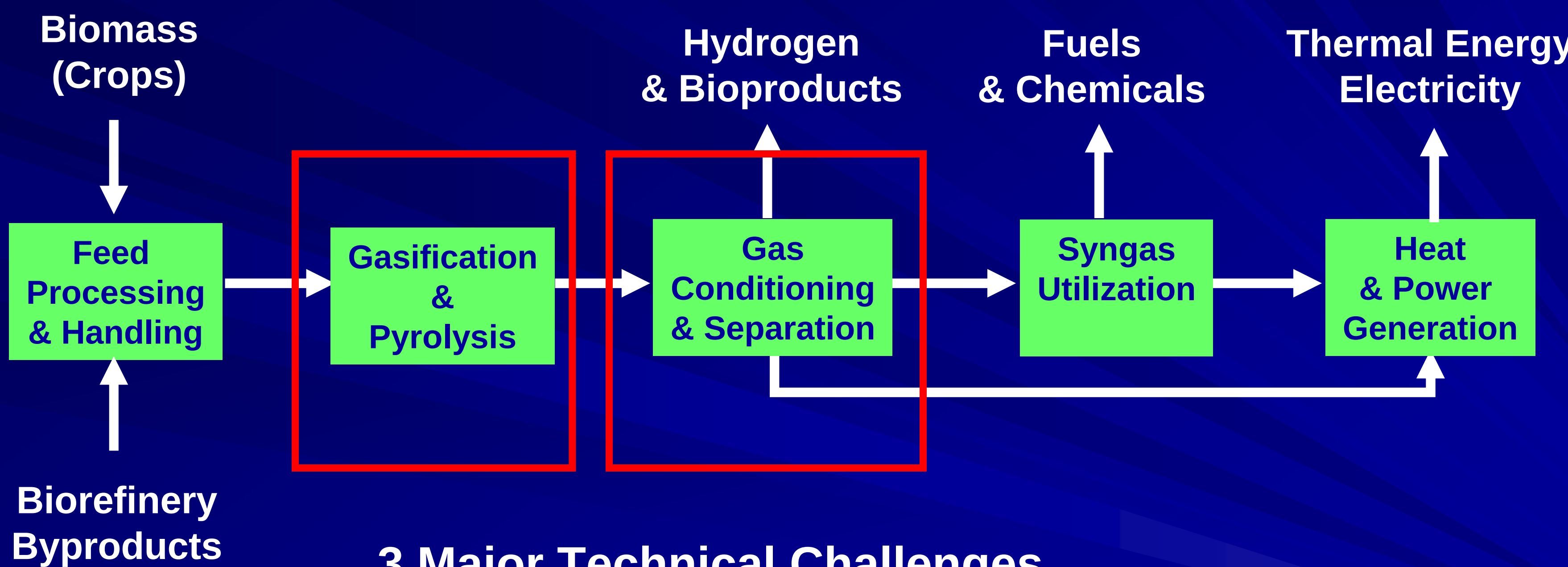
Feedstock Handling

- **Problems**
  - Typical Ethanol production facility (50M gal/yr) would need ~350 tons/day of dry biomass
  - No storage techniques available for dry biomass on that scale (wood waste is an exception)
  - Feeding corn stover into a reactor above atmospheric pressure
- **Solutions**
  - Ethanol plants can utilize in-house feedstock such as syrup and DDGS.
  - Innovation is key to making large scale biomass handling and storage commercially viable.

Policy/Permitting

- Policy is key for implementing new concepts in industry.
- Biomass production and/or utilization incentives needed on the state and federal levels.
- Policy makers need to be involved.
- Air permitting is new territory because state pollution control agencies deal with coal or natural gas combustion.
- Months to years needed to permit new gasification systems on an industrial scale.

Technical Barriers

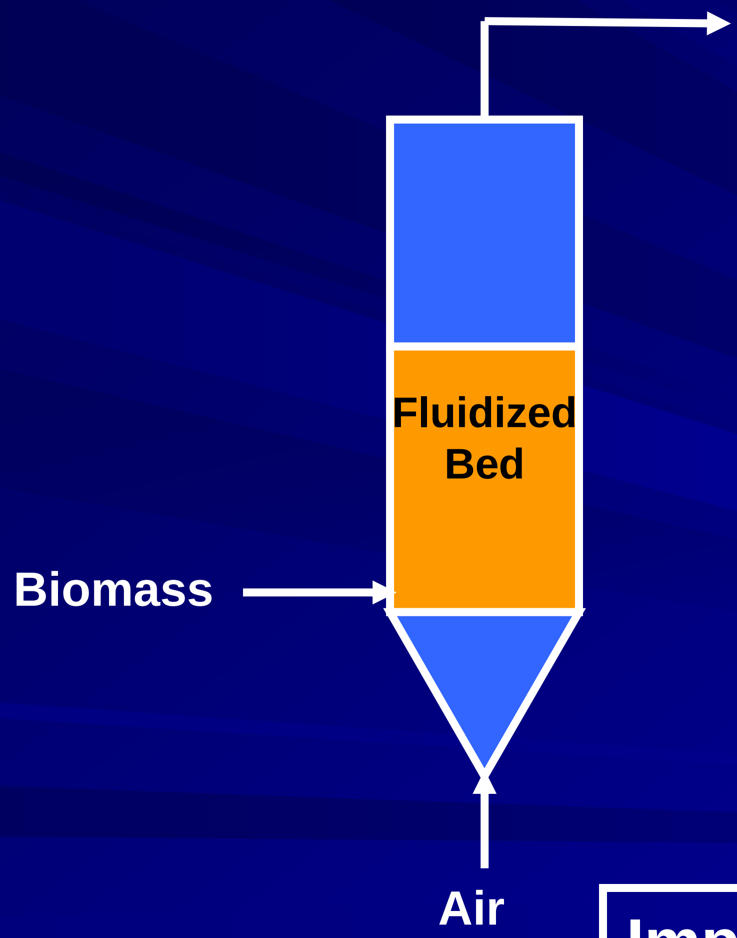


3 Major Technical Challenges

1. **Producer Gas Contaminants**
2. **Incomplete Carbon Conversion**
3. **Agglomeration in Fluidized Bed**

Source: National Renewable Energy Laboratory

Producer Gas Contaminants
(Unique to Biomass Gasification)



- **Alkali Compounds**
  (from Biomass)
  - Solids: Ash Particulates
  - Gases → Downstream Deposition
- **Char Particulates**
  (unreacted biomass)
- **Tar**
  - Hydrocarbons, M.W. > Benzene

Impact on Downstream Technologies

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End Use Impact of Contaminants

Difficulty of Implementing Biomass Gasification ↓

	Alkali Compound	Char	Tar	Sulfur	CO/H_2 Ratio
Thermal Energy	Minimal	Minimal	Minimal	No	No
Electrical Energy (turbine)	Yes	Yes	Yes	No	No
Fuels & Chemicals	Yes	Yes	Yes	Yes	Yes
Fuel Cells	Yes	Yes	Yes	Yes	Yes

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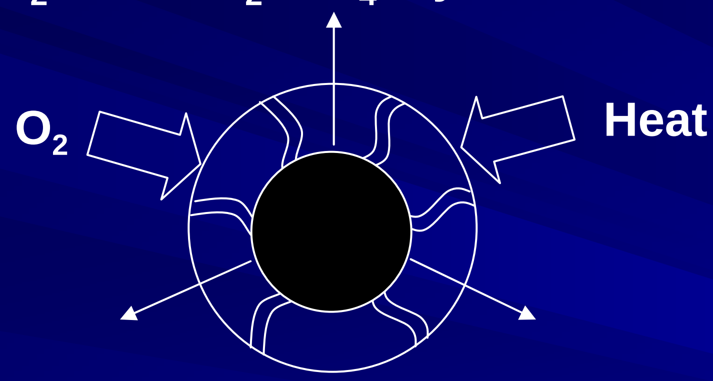
Elutriation of Char Particles

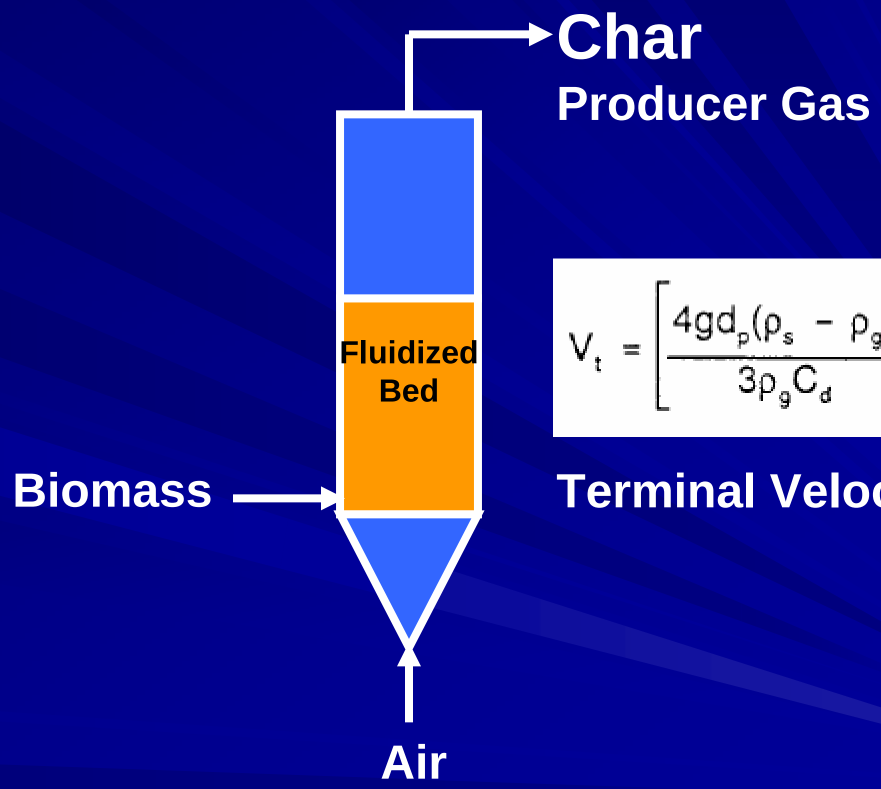
Char Formation

H_2, CO, CO_2, CH_4, hydrocarbons



Porosity increases
Weight decreases
Less reactive with time

Elutriation of Char



$$V_t = \left[\frac{4gd_p(\rho_s - \rho_g)}{3\rho_g C_d}\right]^{1/2}$$

Terminal Velocity

Reduced Conversion of Carbon

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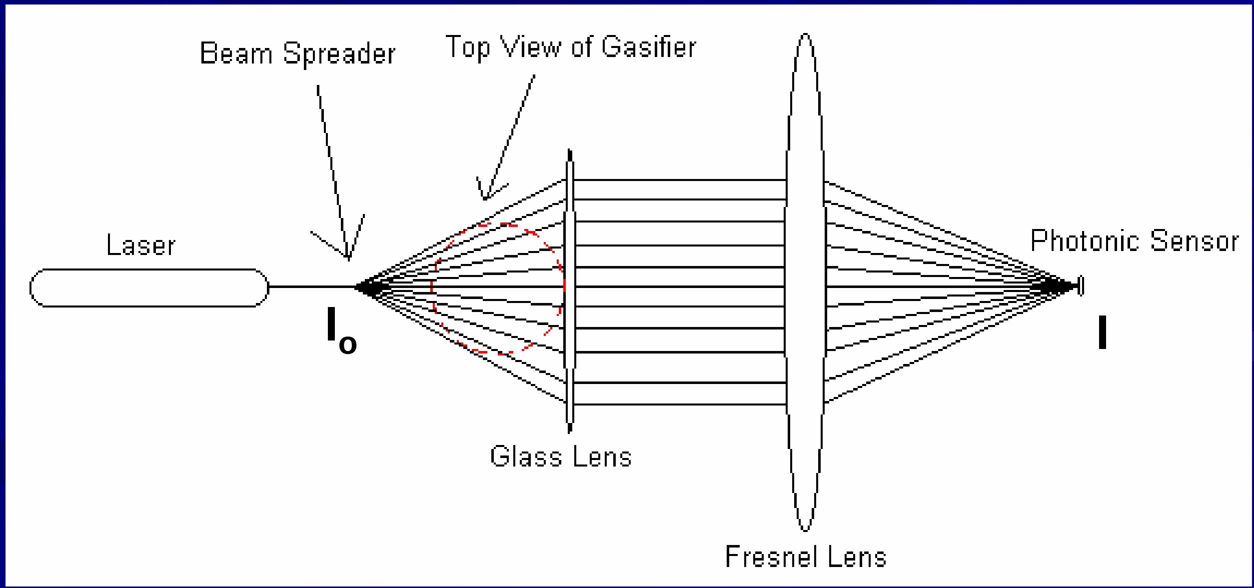
Elutriation Rate Measurement Laser Method

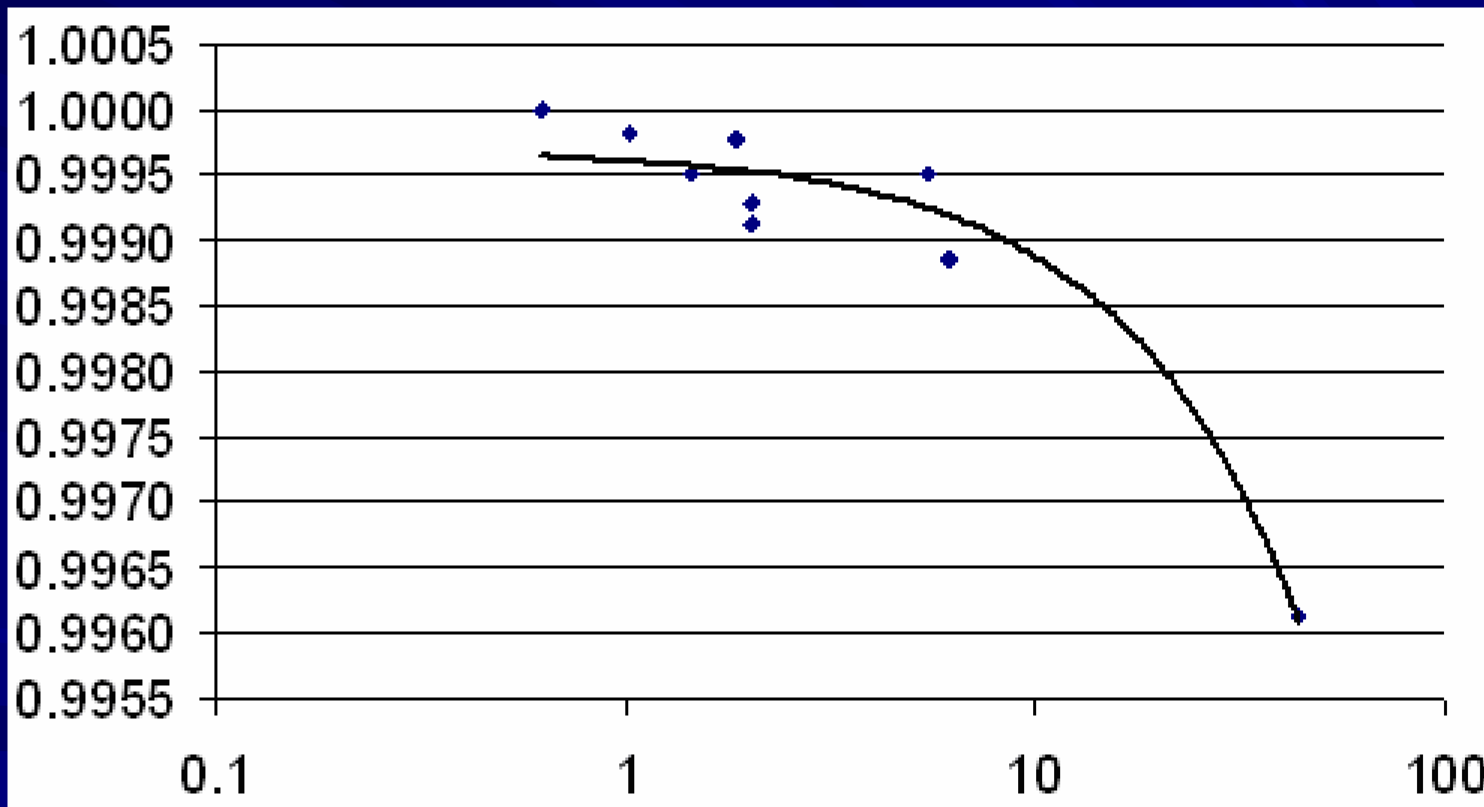
- Taylor – Iowa State Collaboration
- Measurement is essential
  - Understand elutriation
  - Increase Carbon conversion



Laser System for measuring particle concentration

Laser Method: Initial Results

Response vs Concentration



I/I_o

Particle Concentration (g/m^3)

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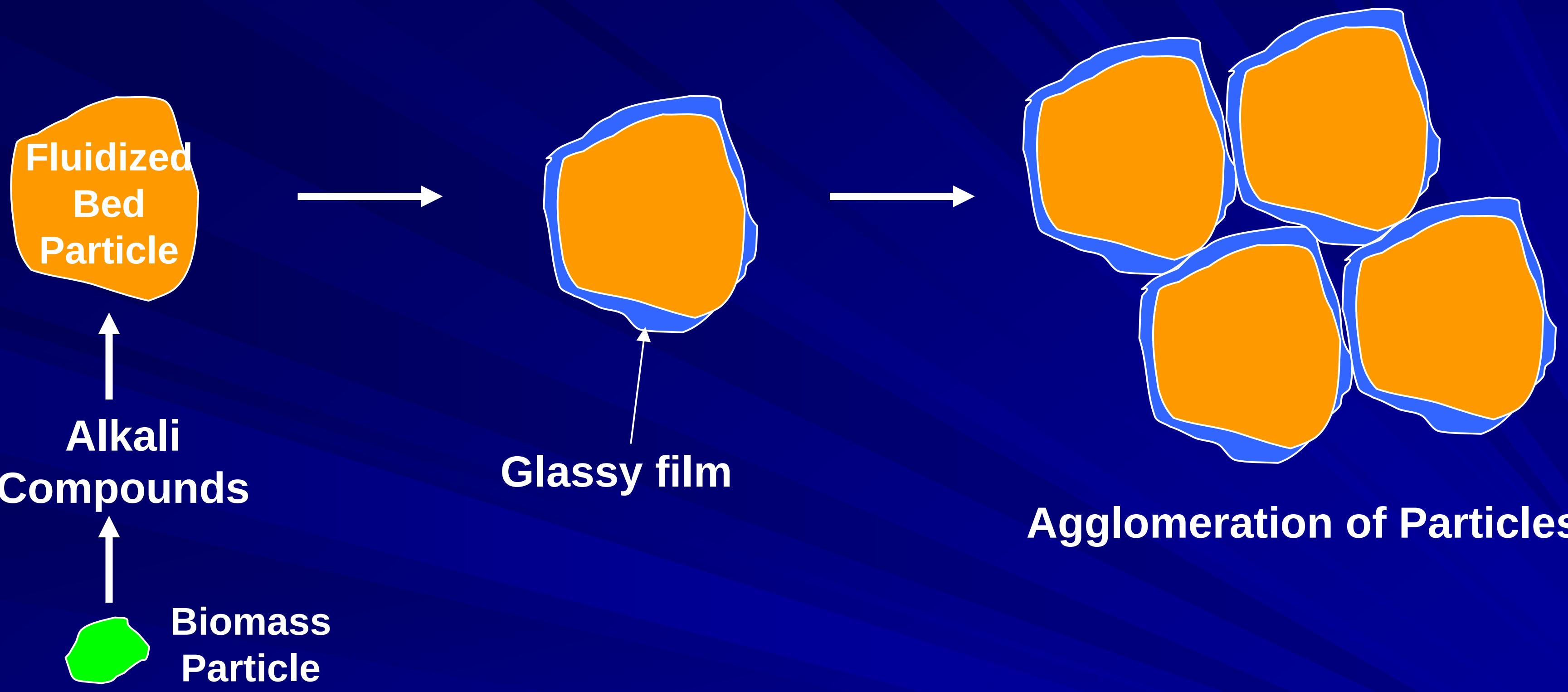
Agglomeration in Fluidized Bed



Alkali Compounds: K (fertilizer), Na, SiO_2 (soil), Ca, Mg, etc.

Fluidization Ceases & Reactor Fails

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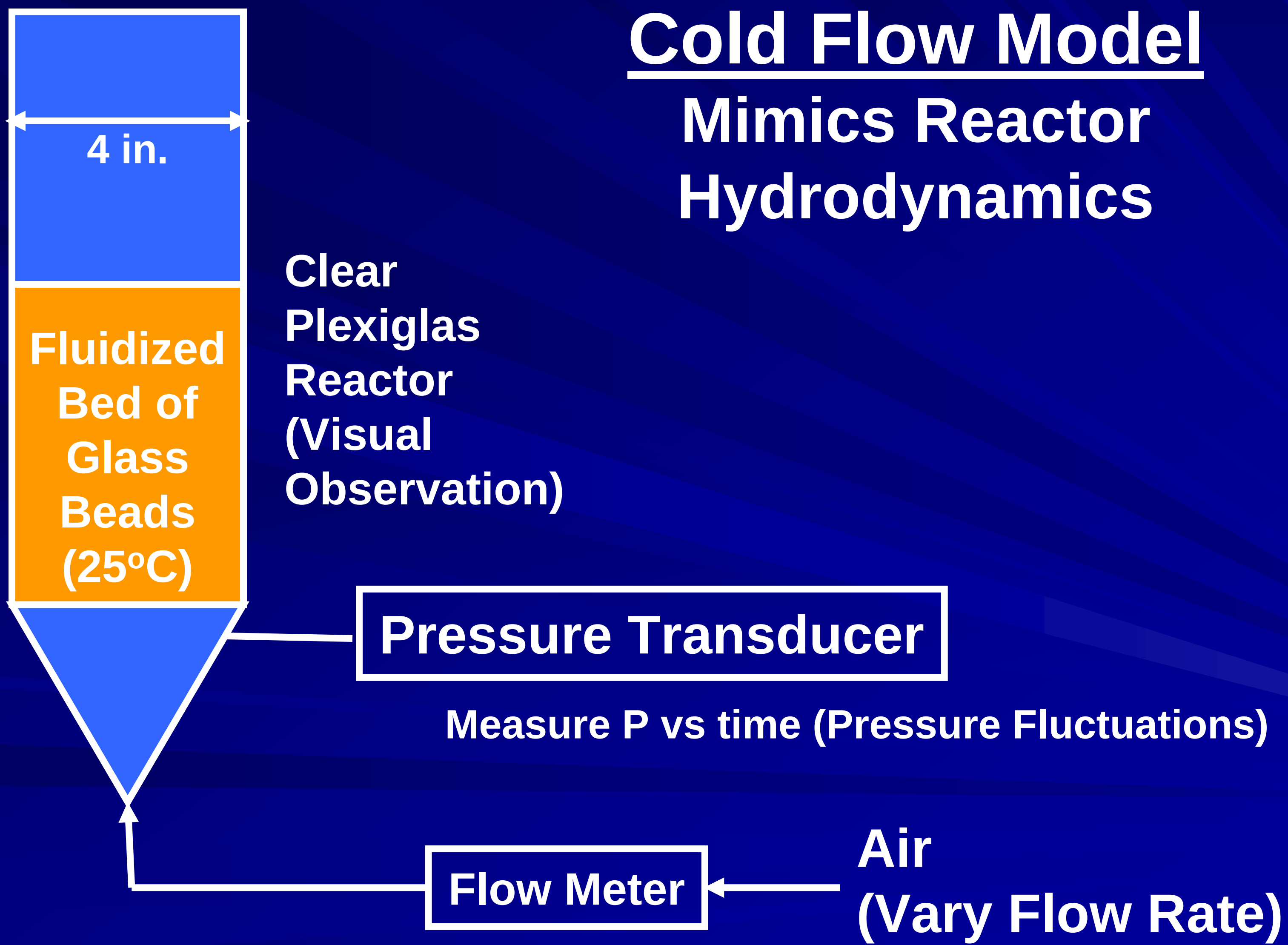
Taylor-Iowa State Pressure Fluctuation Study

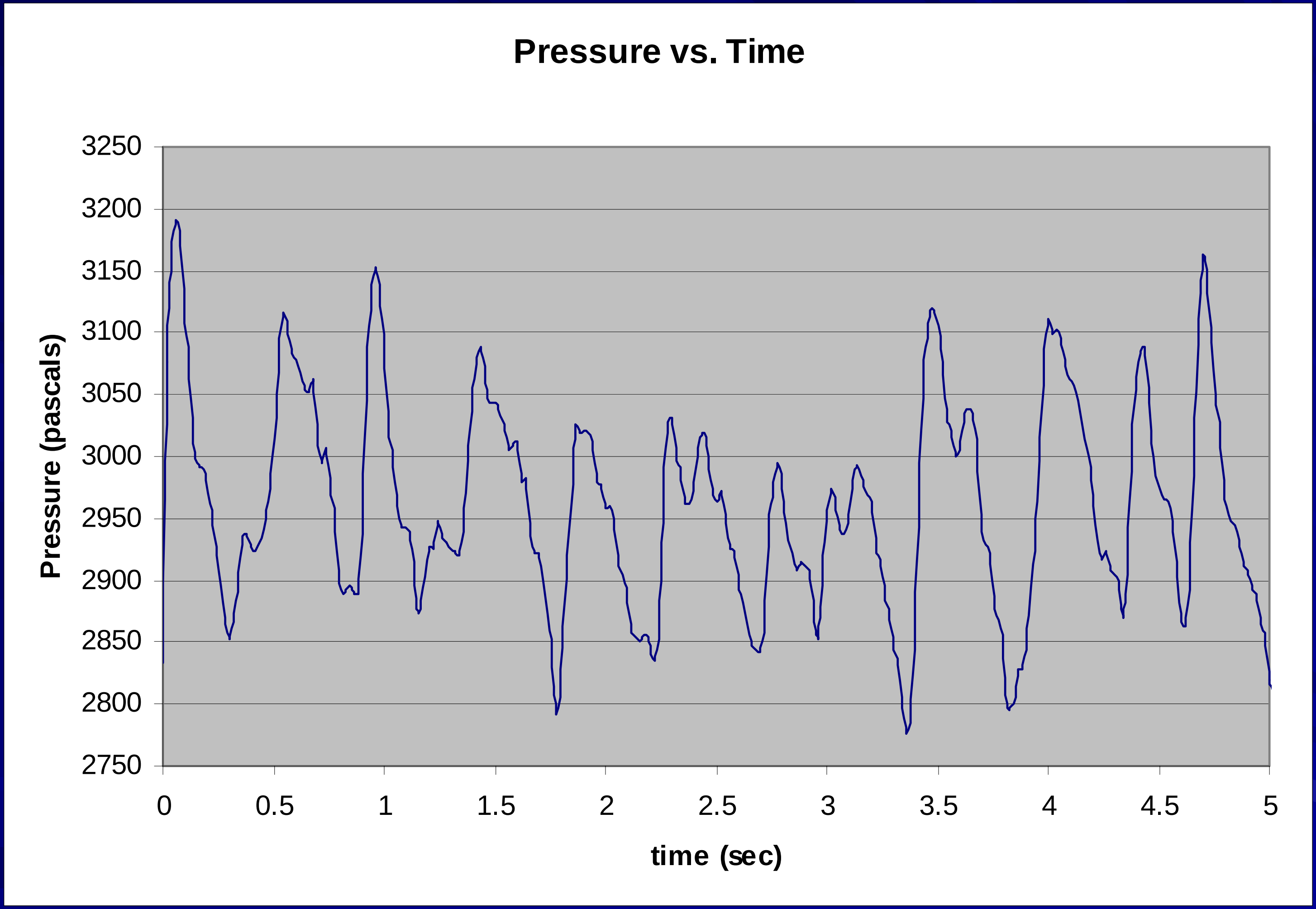
Cold Flow Model

Mimics Reactor Hydrodynamics



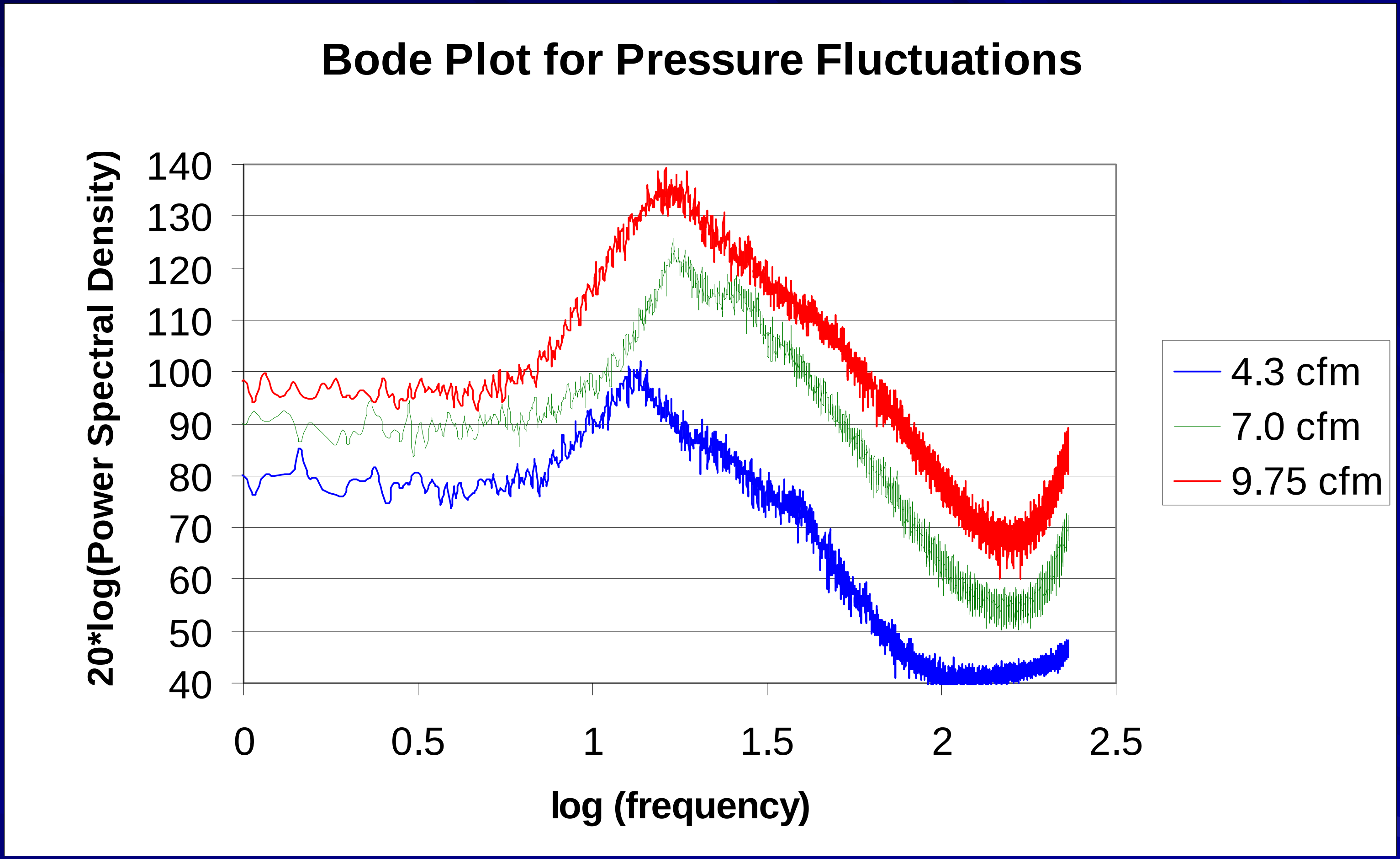
Taylor Cold Flow Model Gasifier

Pressure Fluctuation in Bed



- 0.05 psi fluctuations
- Is it meaningful?

Bode Plot Analysis



- **Fluidized Beds yield characteristic Bode Plots**
- **Bode Plots correlate with Hydrodynamics?**
- **Potential diagnostic tool for bed agglomeration**

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Future Research

- Background:
  - Scale-up from lab to commercial reactor is difficult
  - Mathematical model would help significantly
    - CFD (Computational Fluid Dynamics) is available
- Issue:
  - CFD model has not been compared to Experimental Data
- Solution:
  - Cold Flow Model
    - Gather data and compare to CFD results

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Variables to Compare

CFD Model		Cold Flow Model
Pressure Fluctuations vs Flow Rate	↔	Pressure Fluctuations vs Flow Rate
Elutriation Rate vs Flow Rate	↔	Elutriation Rate vs Flow Rate
Other Variables?	↔	Other Variables?

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