Advanced Clean Technology for Biomass Conversion to Bioenergy, Fuels, and Chemicals

Clean Syngas for Drop-in Fuels: It starts in the gasifier

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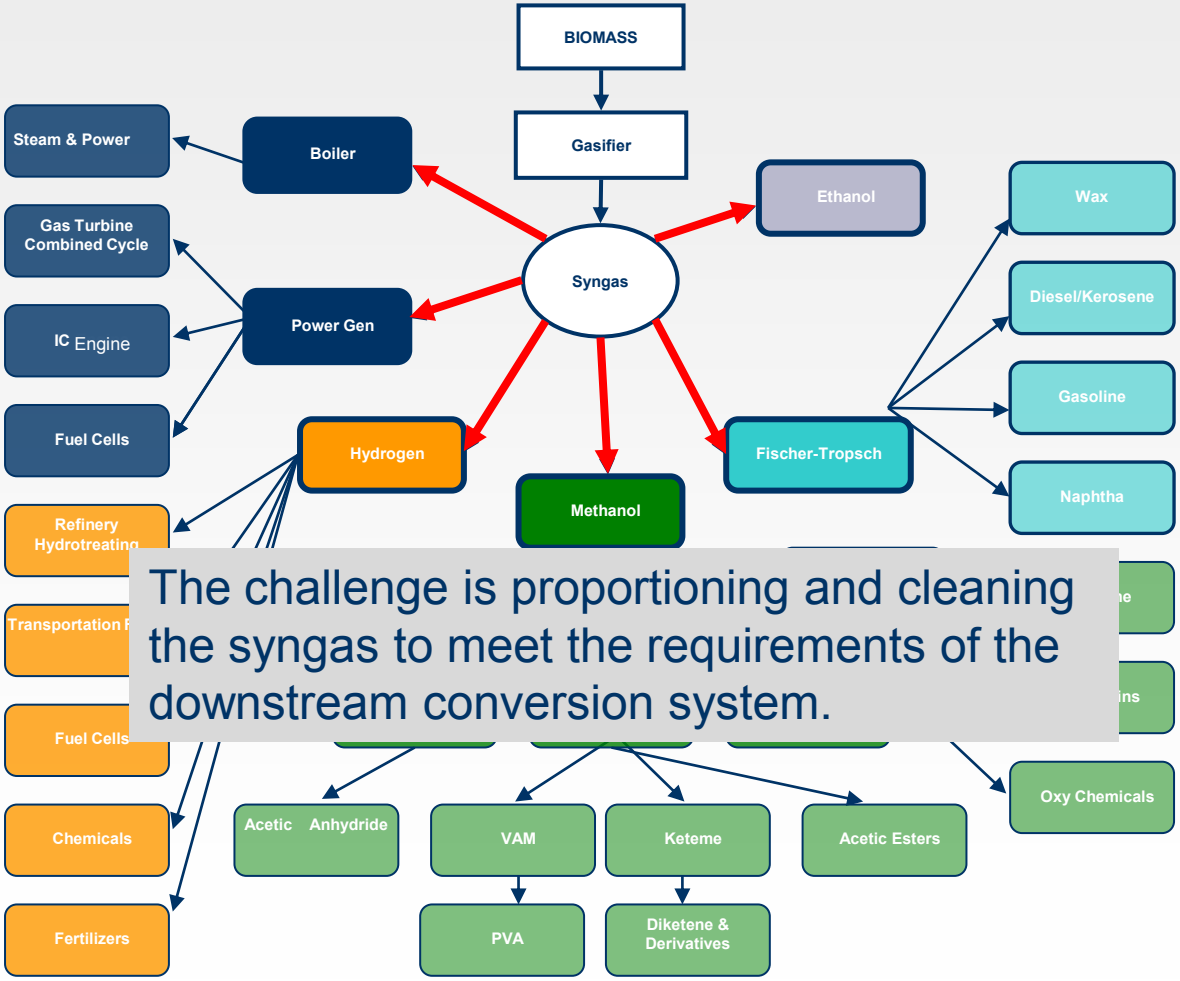
www.tri-inc.net

Syngas - the flexible intermediate



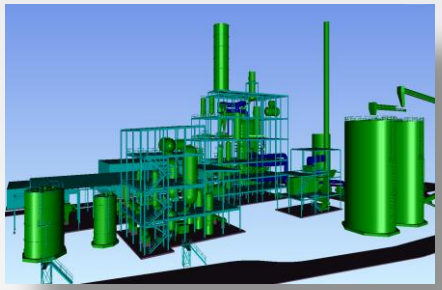
The challenge is proportioning and cleaning the syngas to meet the requirements of the downstream conversion system.

Corporate Overview

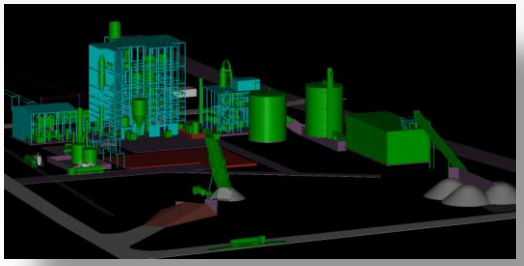
- TRI - Advanced technologies for the conversion of biomass to bio-fuels, bio-chemicals and renewable power
  - Formed in 1996
  - Proprietary steam reforming gasification system developed with over $80 million of R&D investment
  - Research facilities in Durham, NC and Utah
  - Commercial scale on black liquor
  - Commercializing the Integrated Biorefinery Platform
    - Flambeau River Biofuels – 1,000 TPD woody biomass to FT
    - NewPage – 500 TPD woody biomass to FT

DOE Supported IBR's

- Flambeau River Biofuels, Park Falls, WI
  - 1000 dtpd forest waste biomass
  - 9.5 million gallons per year diesel fuel
  - 7.6 million gallons per year paraffin wax
  - 5.3 MW green electricity
  - 160,000 pph steam to paper mill

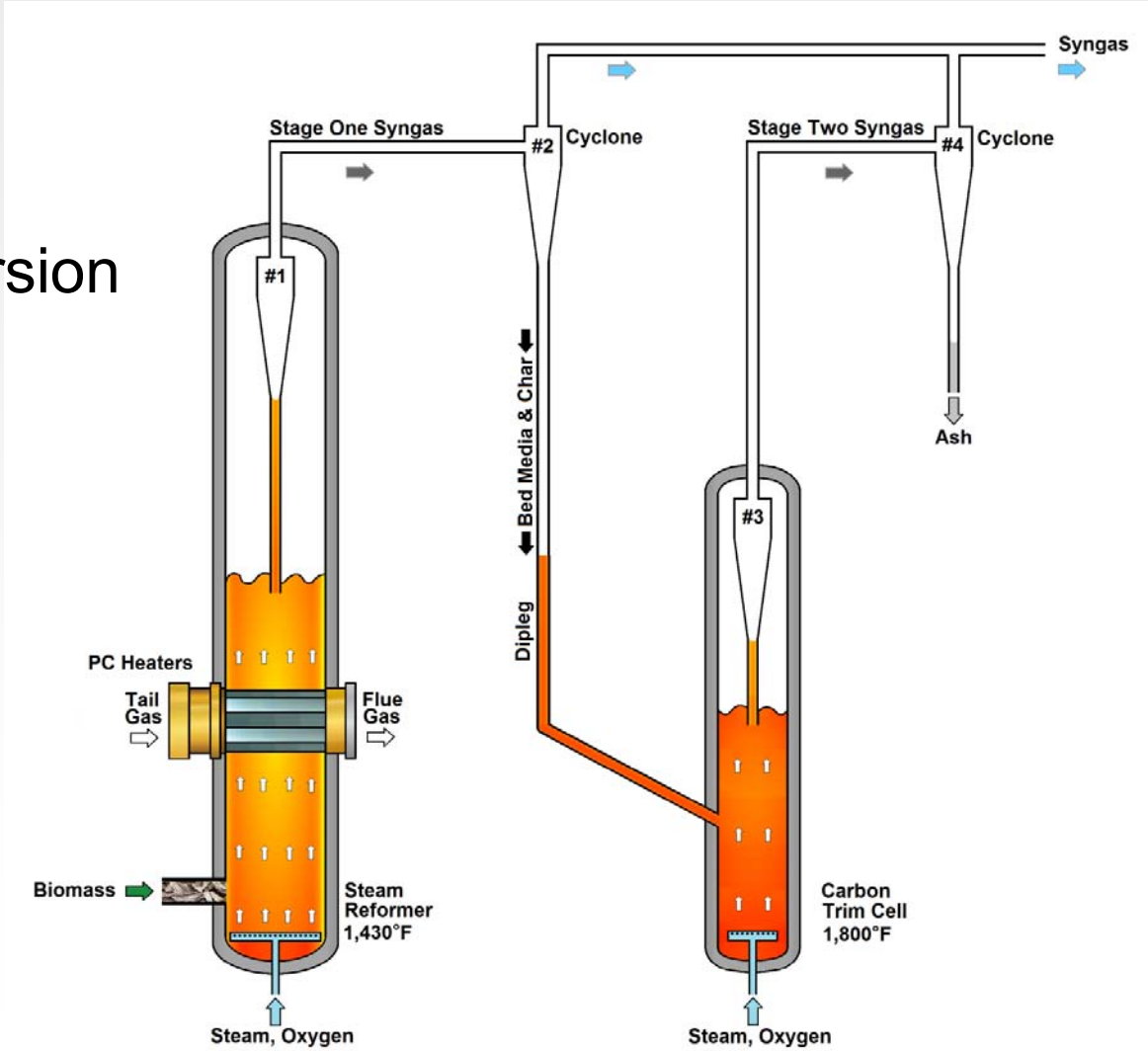


- NewPage, Wisconsin Rapids, WI
  - 500 dry tons per day waste wood biomass
  - 5.5-8.5 million gallons per year FT liquids
  - Up to 92 MMBTU/HR tail gas to lime kiln
  - Steam and hot water to paper mill

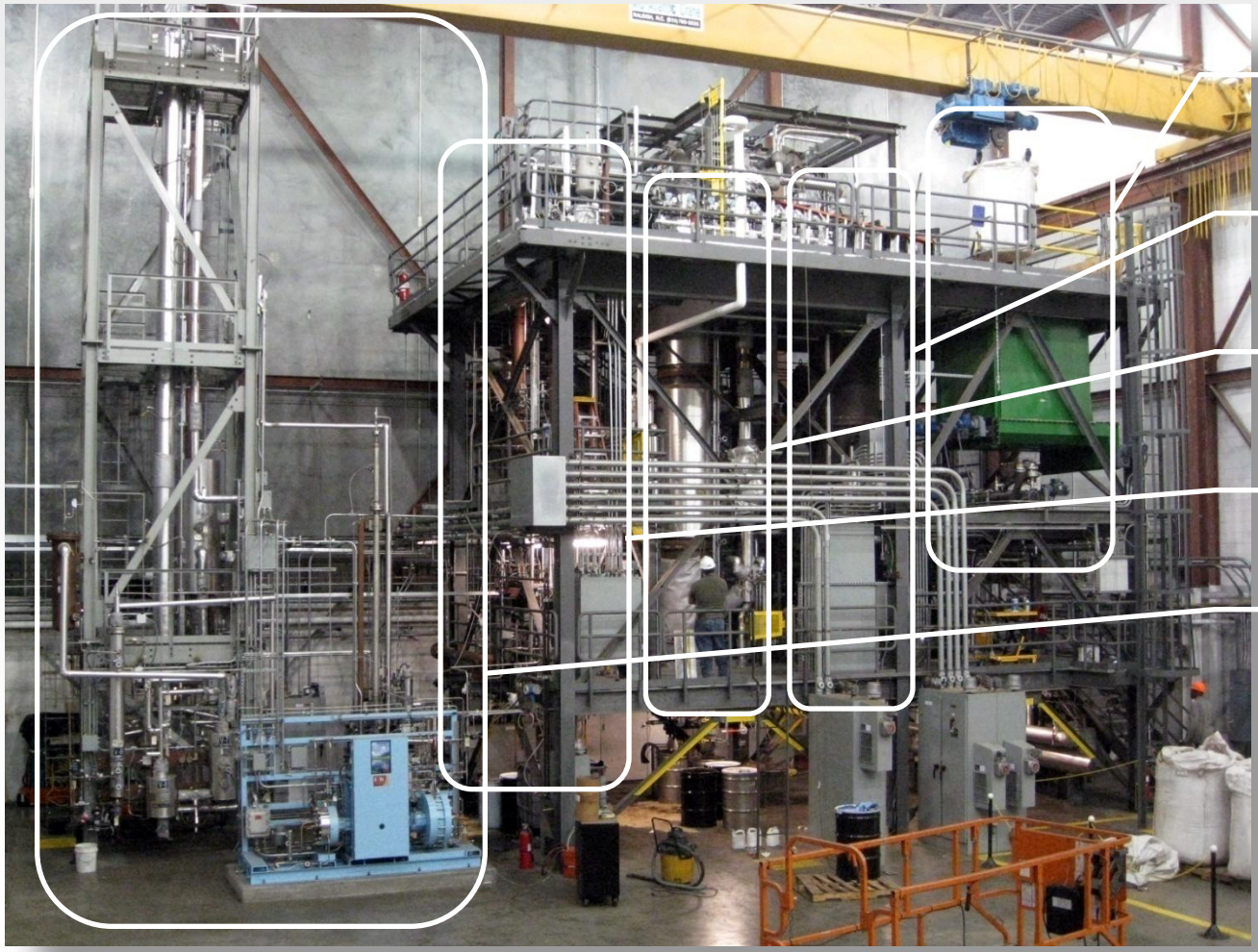


TRI's Steam Reforming of Biomass Technology and Attributes

- Unique two stage gasification system
- High carbon conversion
- Customize syngas quality



TRI's Pilot Plant



Biomass Feed System

Steam Reformer

Carbon Trim Cell

Gas Clean Up System

FT GTL

Technology Key Accomplishments

Pilot Demonstration Successfully completed

- Integrated Biorefinery trial met or exceeded performance criteria
- Generated high quality F-T products for off-take testing
- Non-detect level of contaminants after gas clean-up
- No observable F-T catalyst deactivation

Extensive Run Time

- 7,500 hrs on gasification
- 4,000 hrs on FT GTL
  - 2,800 hrs on biomass syngas
  - 1200 hrs on trailer syngas

Pilot Plant Capabilities

- **Stable consistent gasification**
  - Reliable feed system
  - Efficient two stage gasification with low tars generation and consistent H_2:CO ratio
- **Effective Primary and Secondary Gas Clean-up**
  - Non detect levels of all contaminants – at or below ppb threshold for analytical methods. (Enhanced analytical methods implemented)
  - Effective capture and recovery of tars, benzene, toluene, etc
- **Efficient conversion of Syngas to F-T Fuels and Waxes**
  - High CO conversion rates with good catalyst productivity
  - High quality F-T products generated for off-take agreements
  - Very low catalyst deactivation rates observed – good catalyst life
  - Zero contaminants detected on catalyst elemental analysis

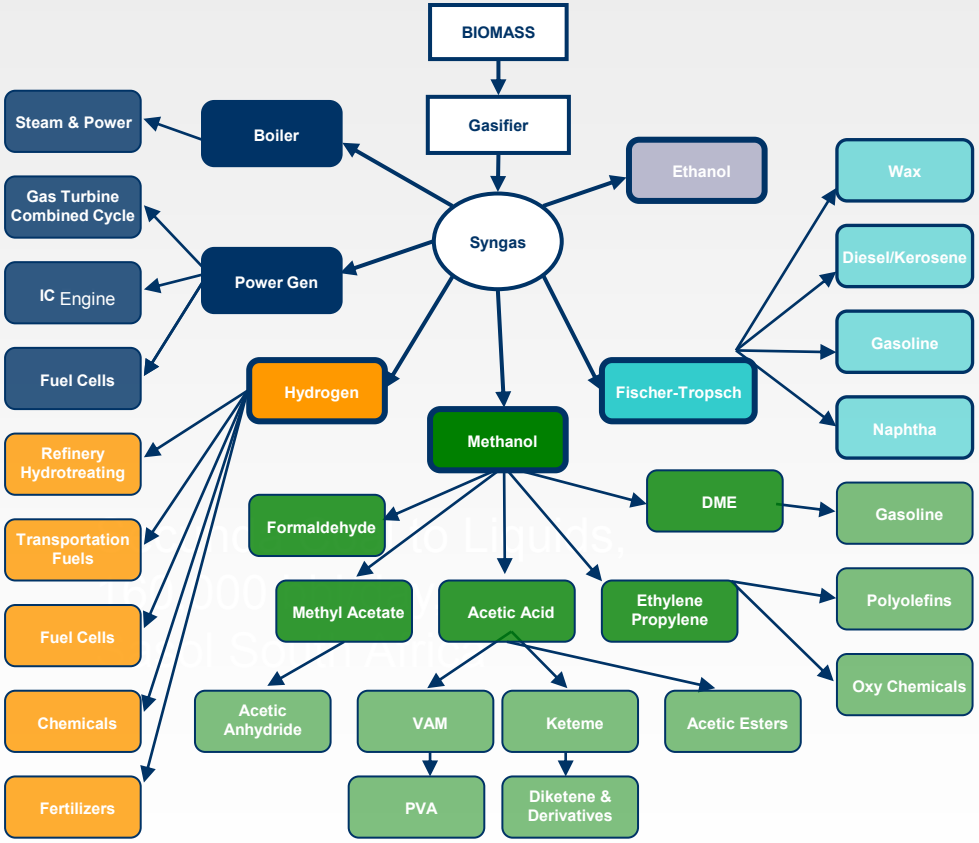
Optimal IBR

- Processes a wide range of biomass feedstocks, i.e. "lowest delivered cost of carbon to the gate"
- Integrated with host to maximize thermal efficiency and capitalize on installed infrastructure
- Produces some or all of its own power
- Is economically scale-able

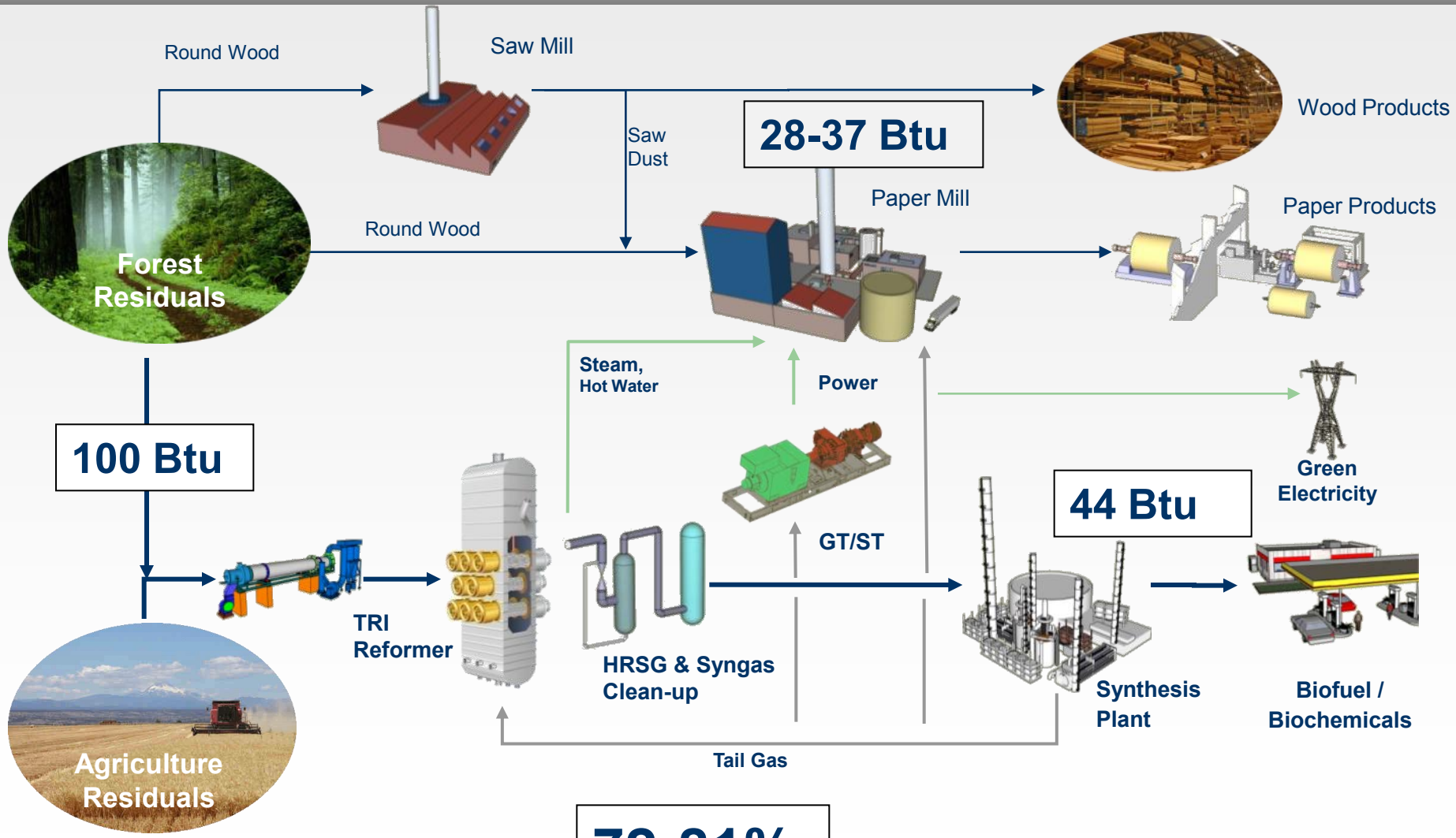
Biomass gasification is the foundation of the platform

Optimal IBR Product Optionality

- Product Optionality to maximize regional economic performance
- Flexibility to respond to market changes by changing the products produced while maintaining the front end (the majority of the asset base)

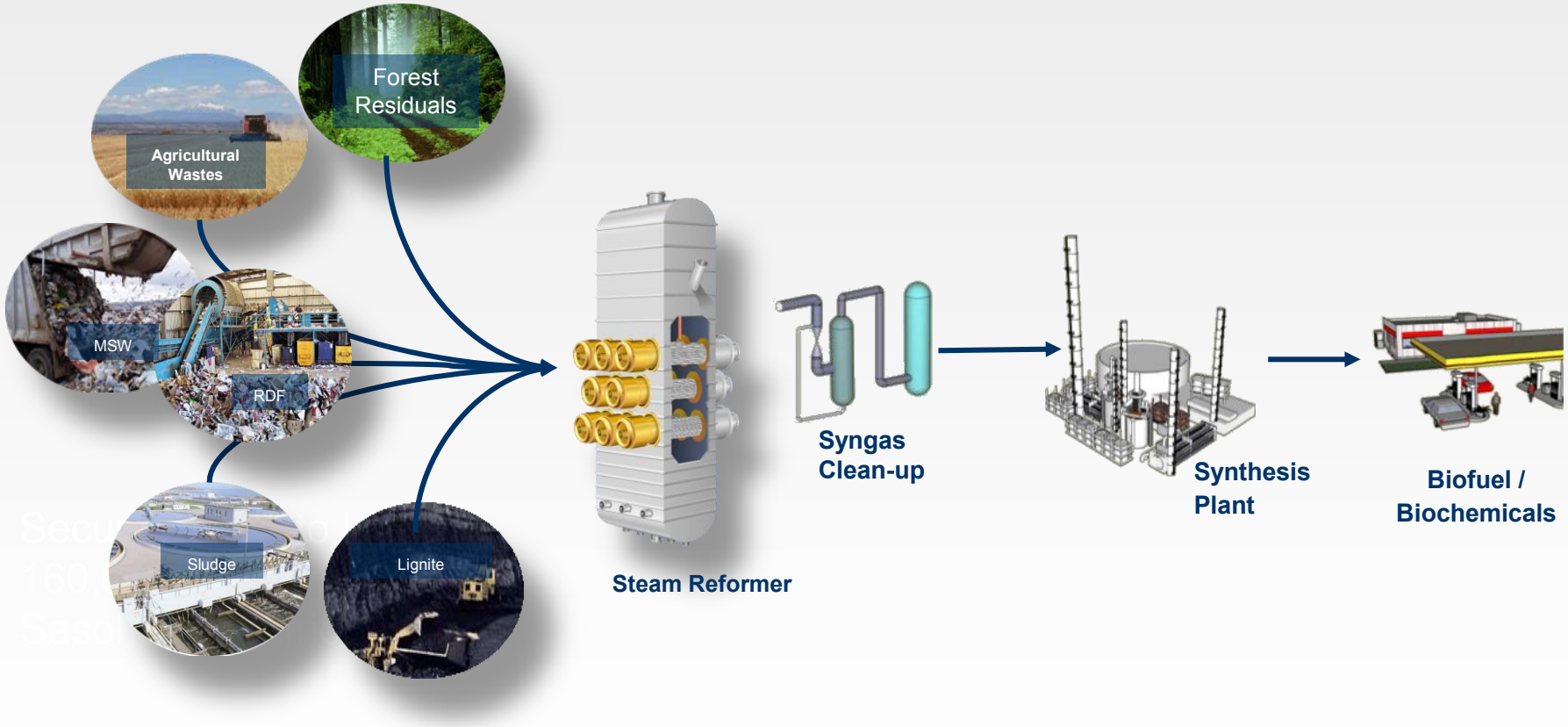


Integration Advantages of IBR

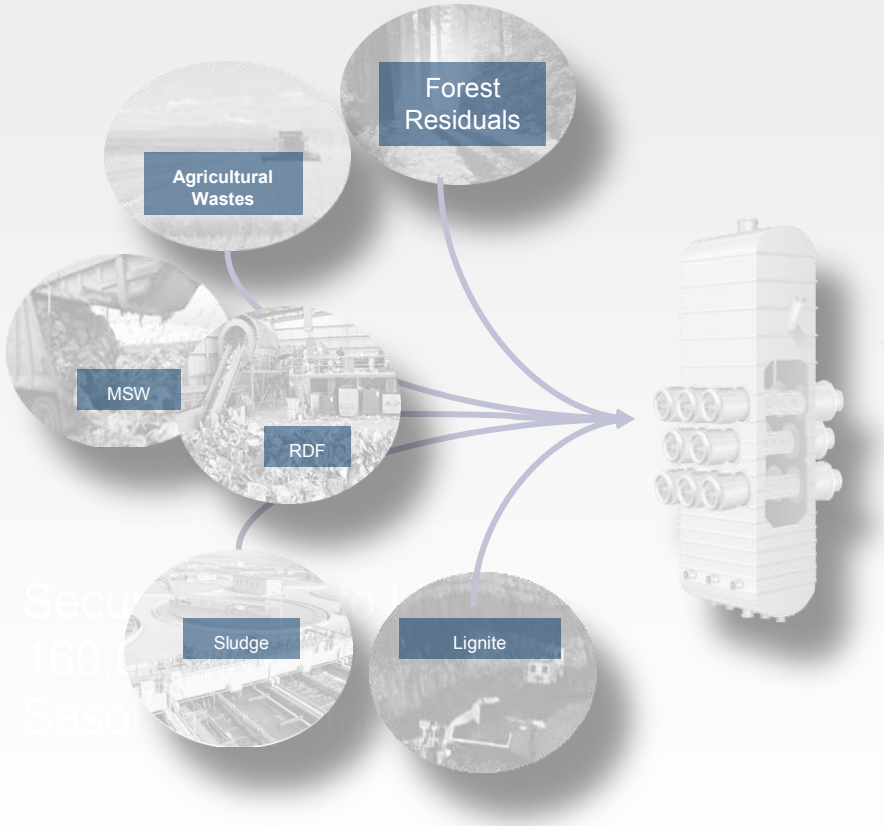


72-81%

Thermochemical Biorefinery

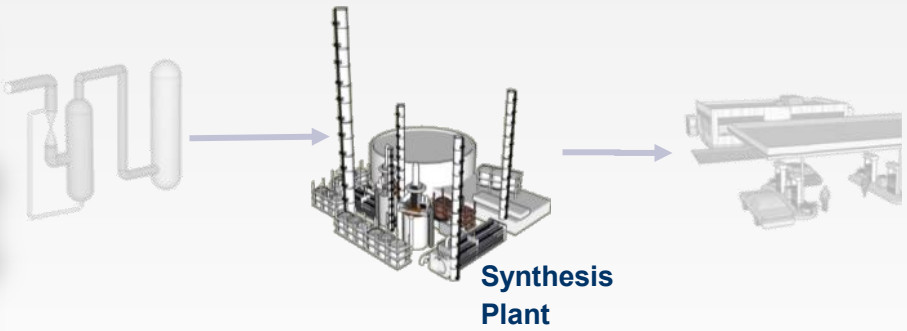


Thermochemical Biorefinery



Commercial F-T technology

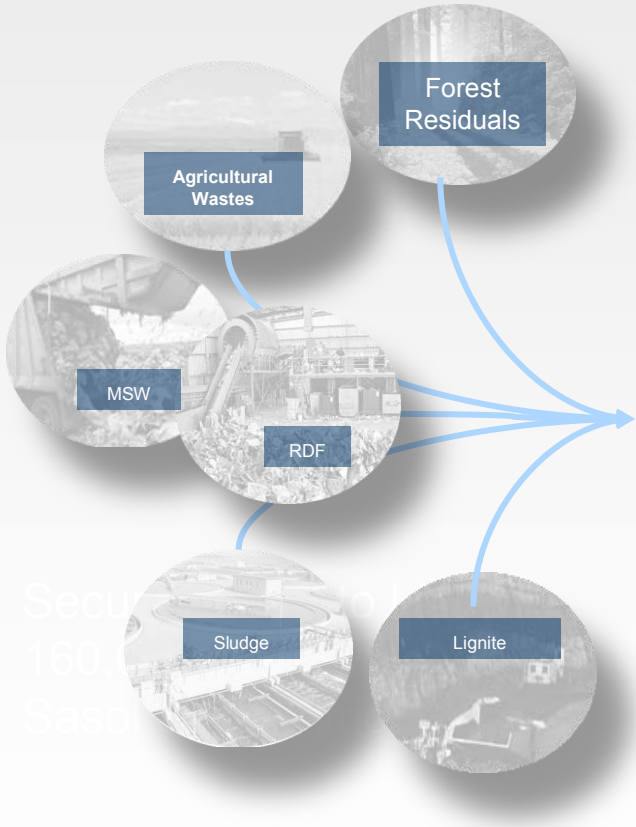
Fixed bed scales well for biomass



Requires “Utility Grade” Syngas

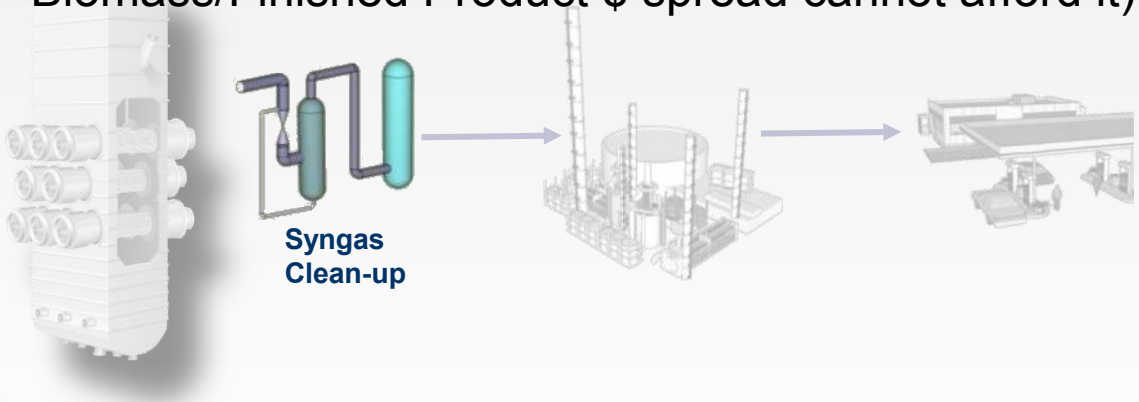
- ppb quality
- consistent supply

Thermochemical Biorefinery



Commercial GCU sub-systems

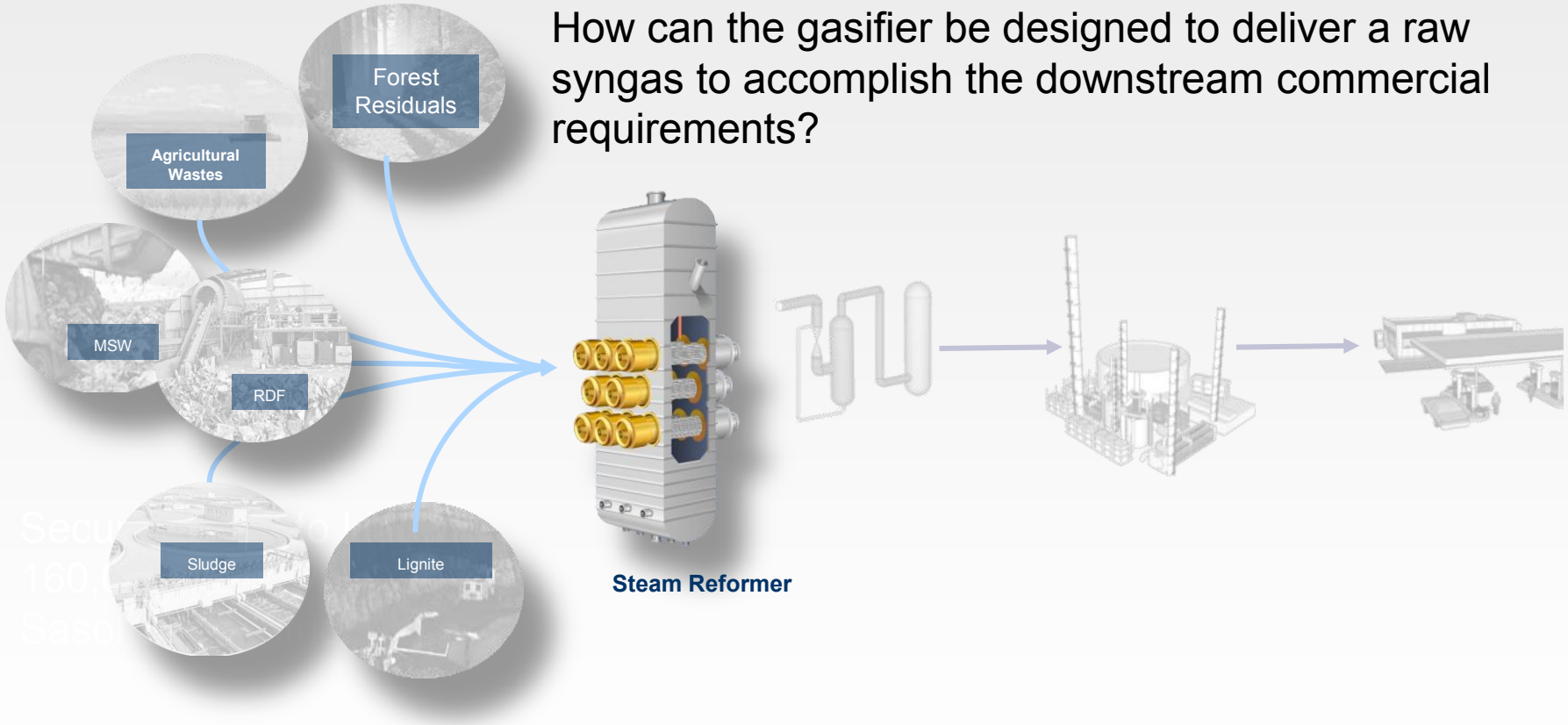
(Amine technologies do not scale well and the Biomass/Finished Product $ spread cannot afford it)



TRI's KASyn System - Medium Temperature Aqueous system is ideal

Thermochemical Biorefinery

How can the gasifier be designed to deliver a raw syngas to accomplish the downstream commercial requirements?



Why Steam Reform Biomass

Steam reforming takes advantage of the unique chemistry of biomass

- **Stable system maximizes uptime/reliability**
  - Low reforming temperatures eliminates agglomeration, increasing reliability
  - Endothermic reactions improve reactor stability and process controls
- **Unique reformer environment results in hi-quality syngas**
  - Generates a cleaner syngas with a high hydrogen content good for catalysis
  - High steam/hydrogen partial pressures
  - Hydrogenated contaminants have improved water solubility

Reactions in Reformer

Fluid bed with gas tight feeder = fast pyrolysis

Example Pyrolysis Products

Acetic Acid

$C_2H_2O_2 + 2H_2O \rightarrow 4H_2 + 2CO_2$

($\Delta H = +32.21$ kJ/mol)

Acetone

$C_3H_6O + 5H_2O \rightarrow 8H_2 + 3CO_2$

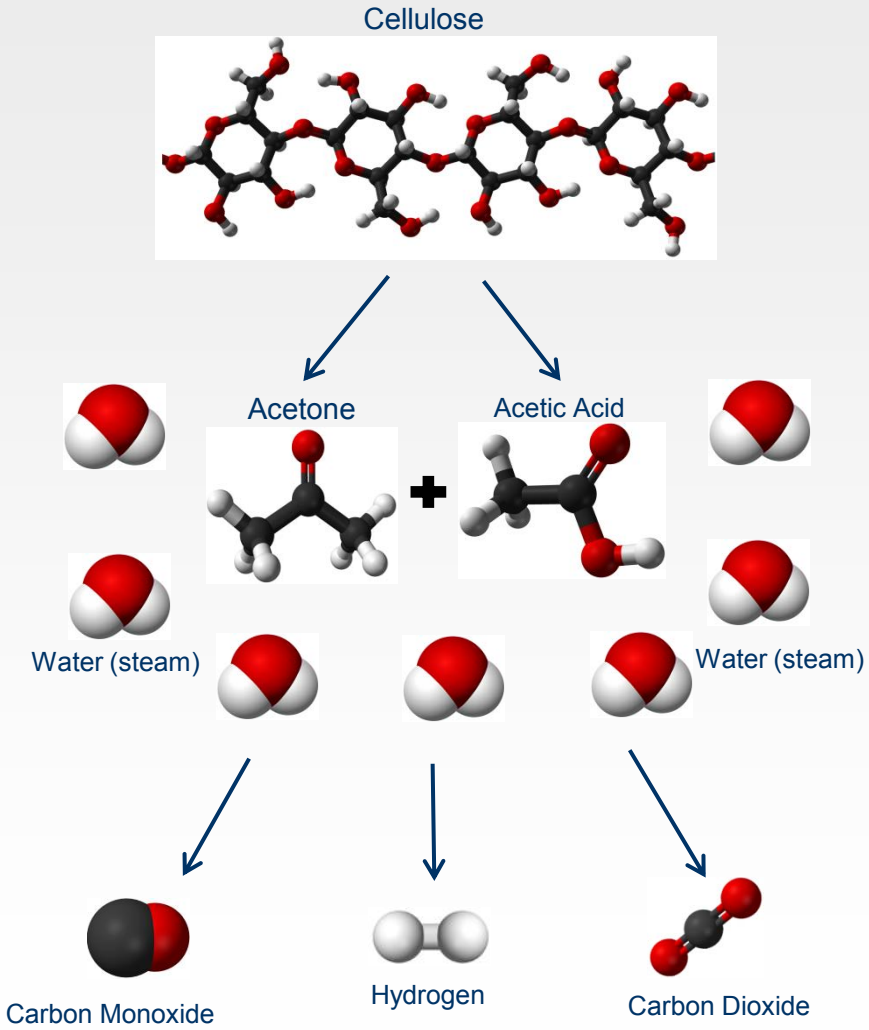
($\Delta H = +58.62$ kJ/mol)

Water Gas Reactions with pyrolysis products result in syngas

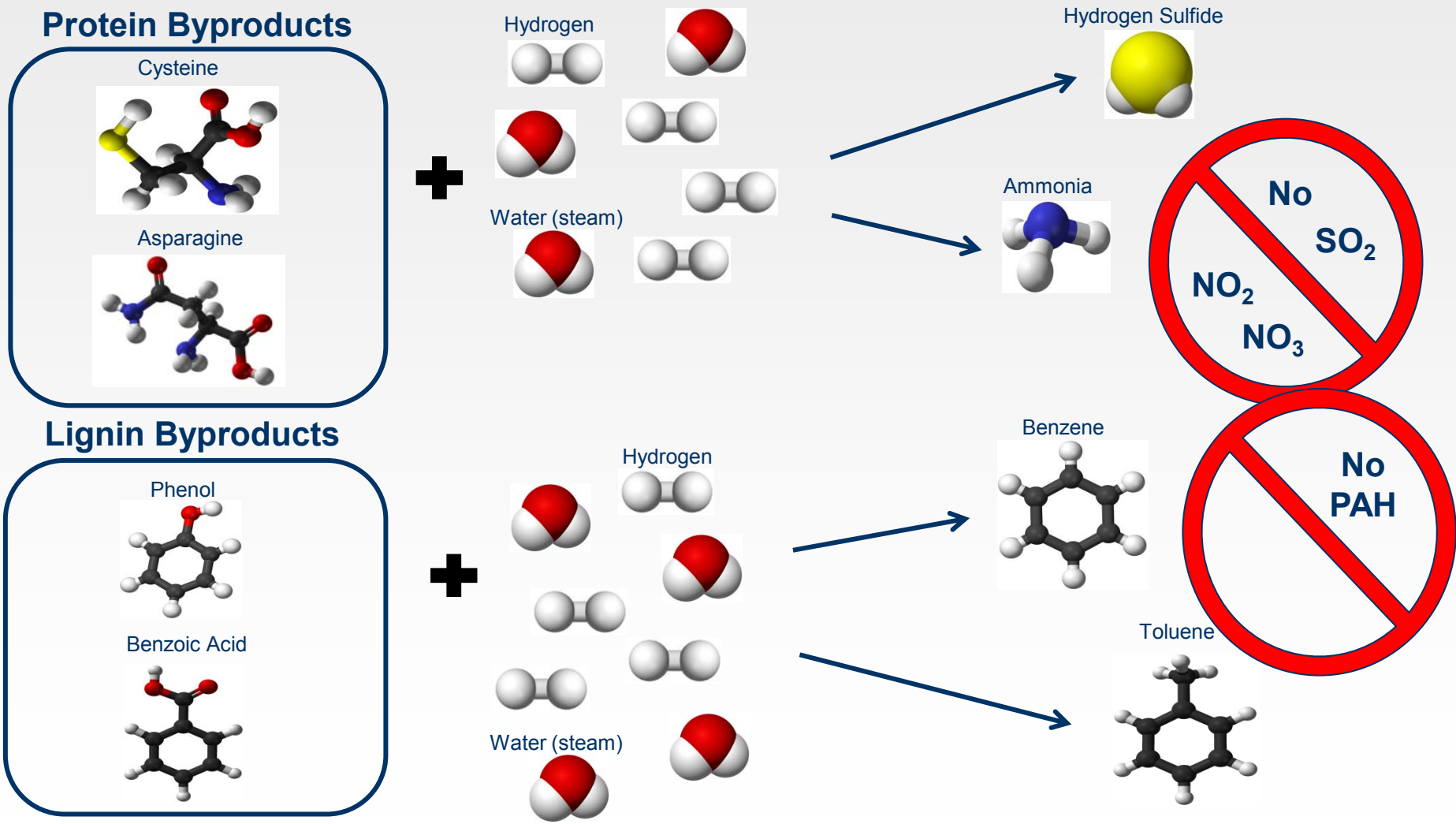
Char is reformed to more syngas

$C + H_2O \rightarrow H_2 + CO$

($\Delta H = +131$ kJ/mol)



Hydrogenation of Tars and Contaminants



Advantages of Pulse Heaters

Indirect heating (allothermal) at high efficiencies

- **Optimizes Efficiency and Quality**
  - Convert all the biomass to syngas
  - Integrated with downstream GTL to utilize tail gas for endothermic energy
  - Eliminates nitrogen dilution and oxygen by-products

- **Enhances Uptime and Stability**
  - No risk of runaways or hotspots
  - Exceptional heat transfer efficiencies from unique indirect heaters
  - Notably improved control of reactor conditions

TRI Steam Reforming Summary

- **System provides optionality in GTL arena**
  - Ability to process a wide range of feed stocks; No process limits on feedstock type: moisture, density or energy content
  - Ability to dial-in H_2:CO ratio for catalysis, fermentation, etc
  - Ability to provide excess hydrogen for upgrading product streams
  - Syngas purity supports wide range of catalytic synthesis (fuels, chemicals)
- **Entire KASyn gas cleanup process is composed of commercial, mid-temp aqueous processes**
- **Produce drop-in diesel and jet fuel through F-T**
  - Fischer-Tropsch generates straight chain paraffin
  - Excess hydrogen available to hydrocrack waxes to increase the yield of diesel and jet fuel – energy content equivalent to fossil fuels
- **Ready for commercialization**

Discussion/Questions