U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Bioenergy Technologies Office

TRI Technology Update & IDL R&D Needs

March 20, 2014

TRI

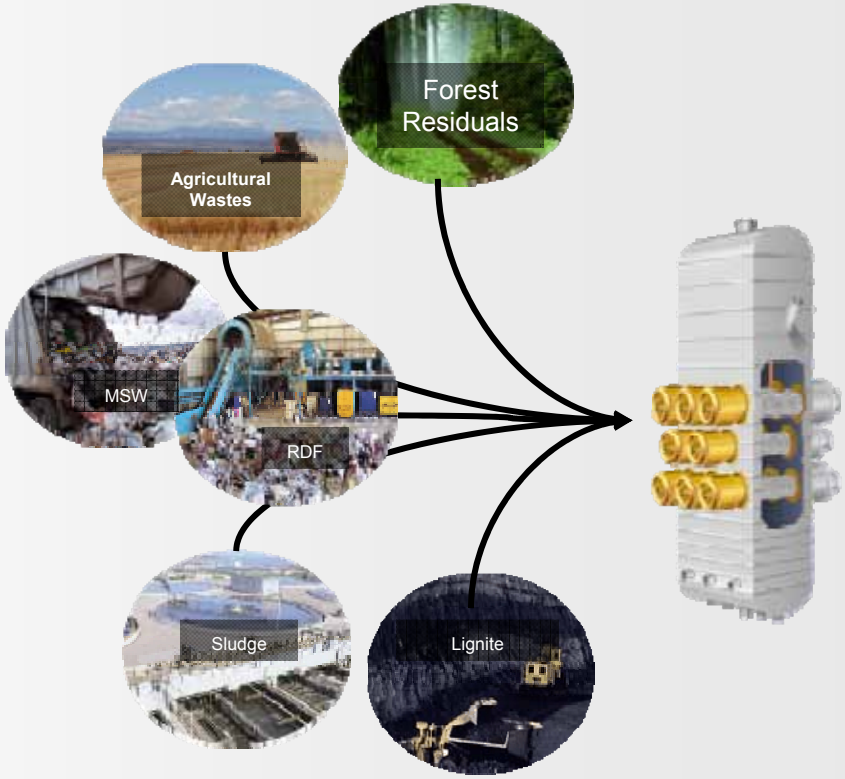
Topics List

1. TRI Overview
2. PDU capabilities and results
3. IDL R&D needs

Our Technology

TRI's steam reforming technology is the foundation of the integrated Thermochemical Biorefinery and Power Plant

- Processes a **wide range of waste and biomass feedstocks** for improved economics
- Suitable for **greenfield or can be integrated with host** to maximize thermal efficiency and capitalize on existing infrastructure
- **End product can be augmented** at a later date to respond to changing market conditions with modest capital investment, e.g. adding a catalytic or fermentation fuels module to the existing plant.

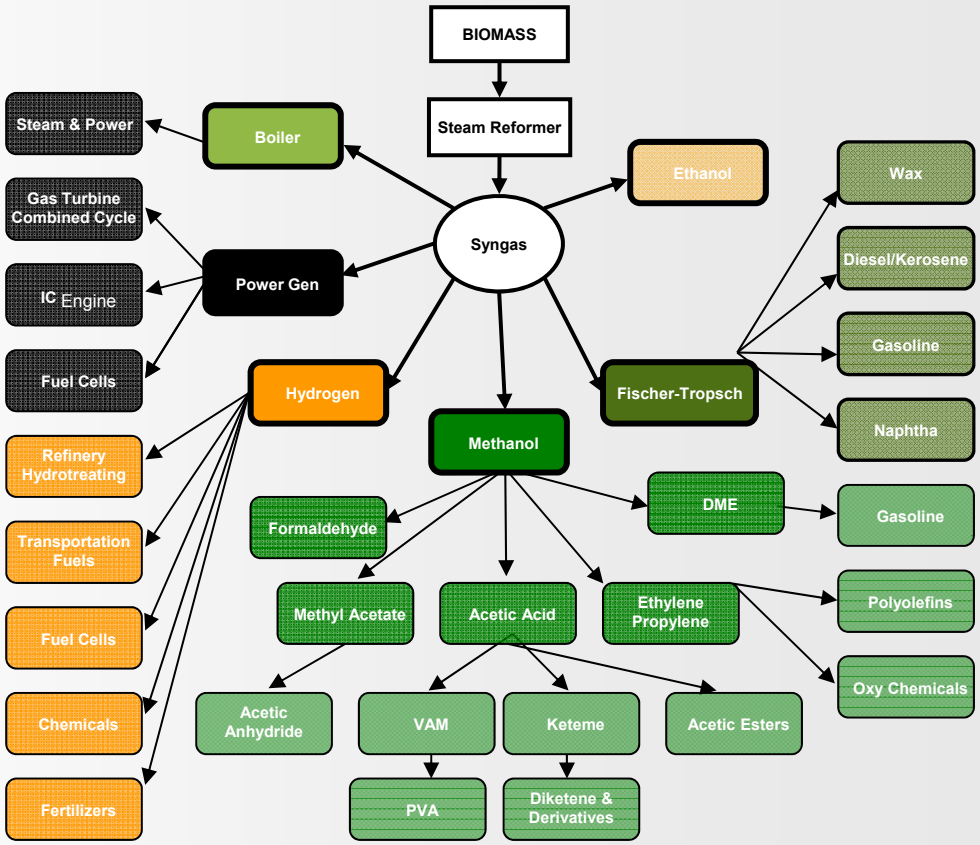


- Is **sustainable** for maximum economic life
- **Low emissions profile** for enhanced environmental performance

Our Technology

TRI's proprietary technology produces a clean, high-quality syngas - the key to a wide range of product options

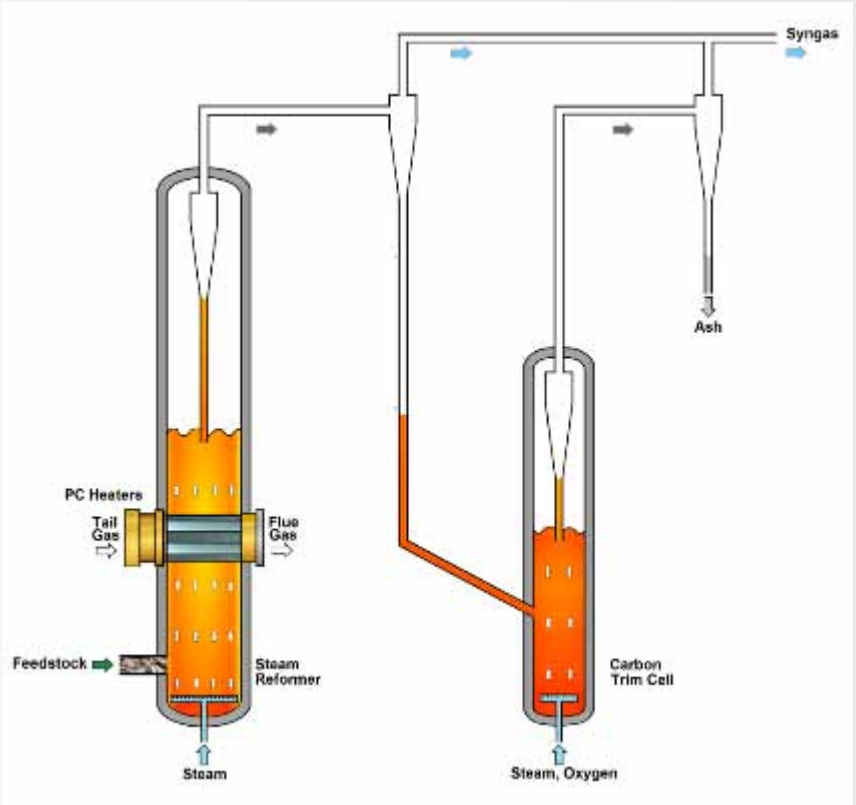
- **Fuels**
  Customizable H_2:CO ratio suited to catalytic and fermentation fuels pathways
- **Chemicals**
  Ideal for chemical production via the methanol pathway
- **Power**
  Suitable for high efficiency combined cycle power production



TRI's Proprietary Steam Reforming Process

How it works and why it excels

- **Unique two stage gasification system** that provides process flexibility for a wide range of feedstocks
  - High carbon conversion to maximize yields
  - Capable of customizing syngas H_2:CO ratio ranging from 1:1 to 3.5:1
  - Contaminants are kept dry for easy removal
- **Deep fluidized bed** first stage where feedstock undergoes drying, pyrolysis and steam reforming in a reducing environment to produce a high value syngas
  - Indirectly-heated steam reforming process operates at medium temperature and low pressure which is well suited for contaminant laden feedstocks
- **3 inputs and 3 outputs**
  - In - Feedstock, steam and fuel for pulse heaters (typically tail gas from downstream syngas conversion processes)
  - Out - Syngas, clean flue gas for heat recovery and dry solids for contaminant removal



TRI's Proprietary Steam Reforming Process

The process takes advantage of the chemistry of the feedstock to produce a high quality syngas that can be cost effectively cleaned

Unique reformer environment results in hi-quality syngas

- Generates a syngas with high hydrogen content for catalysis
- High steam/hydrogen partial pressures to promote beneficial reactions for cost effective gas clean up
  - The steam and hydrogen rich environment reform simple pyrolysis products, like acetic acid, to syngas
  - More complex pyrolysis products, like protein and lignin byproducts, are hydrogentated to contaminants that are easily removed via aqueous based clean-up systems

Stable system maximizes uptime/reliability

- Low reforming temperature avoids agglomeration and increases reliability
- Endothermic reactions improve reactor stability and process controls

TRI Pilot and Testing Facilities and Gas Processing Services

A complete range of testing and validation facilities to support development

- Bench scale steam reformer (4” diameter) at UofU
- Feedstock screening tests to determine optimum operating conditions including temperature and pressure, eutectics, etc.

- Mid scale pilot steam reformer (50 lb/hr) at UofU
- Steam reforming concept testing
- Feedstock testing
- Process concept testing

- Large scale integrated biorefinery pilot (4 dry tons/day)
- Integration validation testing for complete systems
- Feedstock and process validation in support of commercial scale designs
- Gas Processing Services using TRI’s KASyn™ brand Gas Clean-up and Conditioning system

TRI Integrated Biorefinery Pilot Plant

State of the art pilot facility to validate feedstocks and products

- **Located in Durham, NC**
- **Capacity: 4 dtpd biomass**
  1MW thermal
- **Scope**
  - Biomass feed
  - Biomass gasification
  - Primary syngas clean-up
  - Compression and secondary gas clean-up
  - FT liquids production

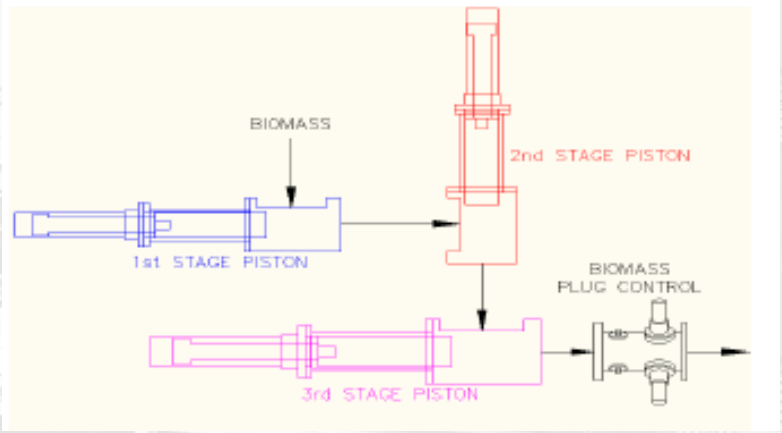
- **Capable of providing high value, clean syngas to essentially any downstream catalytic process**

TRI Process Demonstration Unit (PDU)

Original PDU scope – Gasification only

TRI Process Demonstration Unit (PDU)

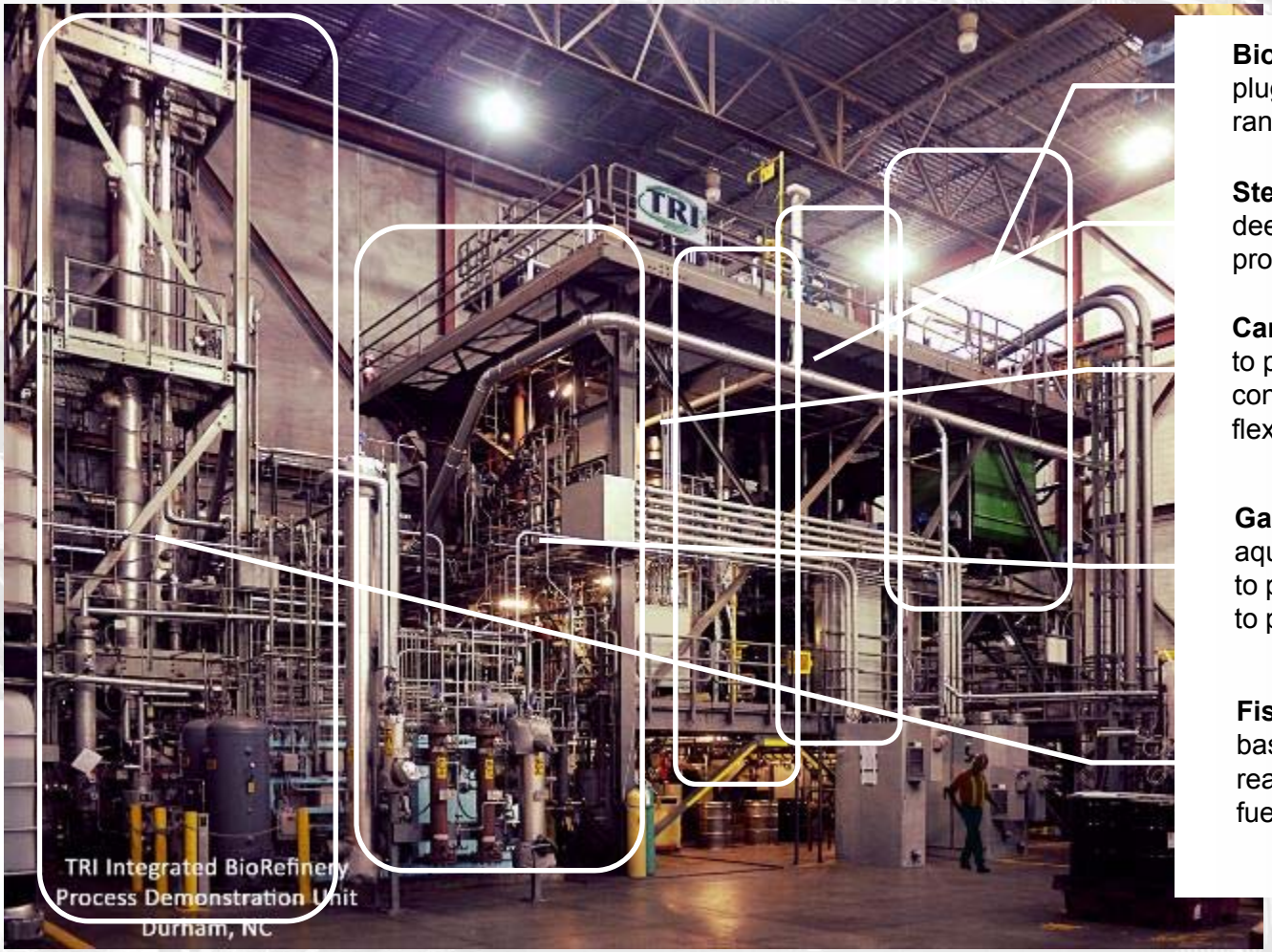
TRI's Proprietary Three Stage Plug feeder



- Positive handling of biomass
- Creates pressure boundary over a wide range of densities
- Has never had a syngas blowback event in over 8,850 hours of operation

TRI Pilot Plant

Every process needed in a commercial biorefinery is replicated here



Biomass Feed System – multistage plug feeder capable of feeding wide range of biomass feedstocks

Steam Reformer – Proprietary deep bed fluidization of biomass to produce high value syngas

Carbon Trim Cell – Second stage to provide complete carbon conversion and provide process flexibility to alter the H_2:CO ratio

Gas Clean Up – Proprietary aqueous based system (KASyn) to prepare syngas for conversion to power, fuels and chemicals

Fischer-Tropsch GTL – Cobalt based commercial scale 3 tube reactor to convert clean syngas to fuels and waxes

TRI Pilot Plant

Feedstocks tested to date

- **Woody biomass**
  Logging residuals, chips and saw dust
- **Ag Residuals**
  Corn Stover, wheat straw
  Swine waste, Poultry litter
  Rice hulls, switch grass
  Grape plant pruning's
  Pistachio nut shells
  Olive waste

- **Low Rank Coal**
  Lignite, sub bituminous
- **Wastes**
  Refuse Derived Fuel
  Municipal and mill sludge

- **Spent Liquors**
  Kraft
  Sulfite
  Soda
  Straw
  Distillery spent wash

Example Fischer-Tropsch Products

Drop-in fuels for the strategic domestic market

Feedstock Challenges

- **Woody feedstocks are easy but costly and long term contracts are problematic**
- **Waste based feedstocks have better cost and supply characteristics, BUT**
  - Can have 1-2 orders of magnitude more contaminant concentrations
  - Can have a wider range of contaminants
  - Low density, high ash, very high tramp
  - Can be very heterogeneous both short and long term
  - Can have severe implications for thermochemical processes, like agglomeration
- **The challenge is to be able to process these low cost feedstocks with minimum additional capex and opex primarily in Gas Clean Up and Gas Conditioning**

R&D Needs

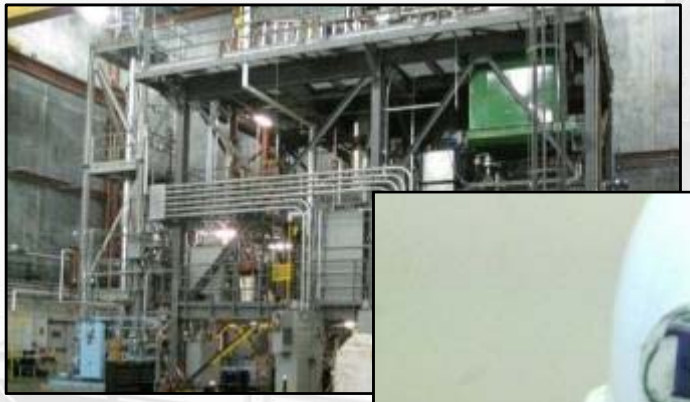
- **Gas Conditioning - Catalytic HC reforming**
  - Warm temp
  - High temp
  - Contaminant tolerant
  - Affordable catalysts (catalyst cost and life)
- **Gas Clean Up – Process Intensification**
  - Simultaneous removal of multiple contaminants
  - Higher temperature processes
  - CO_2 removal to improve energy density
  - Low cost adsorption/absorption systems

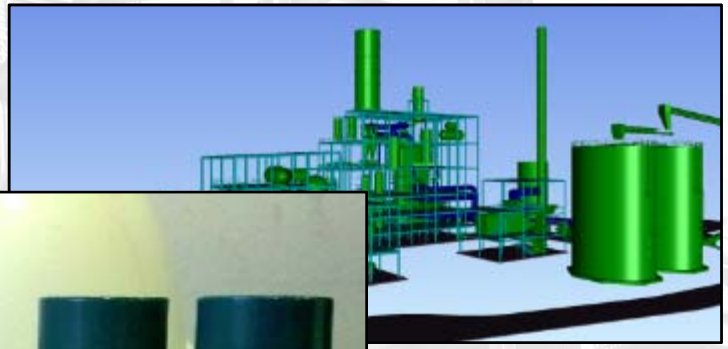
R&D Needs

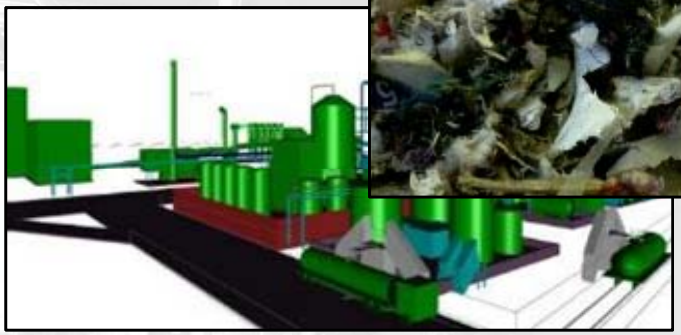
- **Real time syngas analytics**
  - Robust syngas analysis with reliable ppb detection of contaminants
  - Simultaneously track multiple syngas components and contaminants in real time
  - Applied at various points in the process to enable rapid response for protection of downstream systems
  - Affordable for PDUs and for commercial scale
- **GTL**
  - Lower pressure GTL systems
  - Better contaminant tolerance
  - Lower cost catalysts/longer life

Advanced Green Power, Bio-fuels and Bio-chemicals

TRI – leading the way to Biopower and Biorefineries







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