THE OHIO STATE UNIVERSITY

Biomass Gasification for Chemicals Production Using Chemical Looping Techniques

Liang-Shih Fan (PI), **Andrew Tong (Co-PI)**

Department of Chemical and Biomolecular Engineering

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Bioenergy Technologies Office (BETO)

2017 Project Peer Review | Thermochemical Conversion Session

Project Goal

- To demonstrate the capability of the biomass to syngas chemical looping (BTS) process for continuous 2:1 ratio (H_2:CO) syngas production at the 10 kW_{th} biomass processing capacity using a scalable reactor design
  - Cold flow model studies of non-mechanical CFB design will be tested to verify the sizing of the non-mechanical interconnecting reactor components for gas sealing and solid circulation control
  - Multiple biomass feedstocks will be tested as part of the project. Woody biomass will be the major focus of the extended reactor studies
- Develop a process model and economic assessment of the BTS process integrated with a methanol synthesis plant to determine the required selling process in comparison with a reference plant case. Two project outcomes:
  - Identify market potential of the BTS process based on the relative cost savings achievable compared to existing processes
  - Sensitivity analysis performed on key process components and operating conditions will identify areas of research focus that can maximize the profitability of the technology

Quad Chart Overview

Timeline

- Start Date: 10/1/2016
- End Date: 9/30/2019
- Percentage Complete: 8%

Barriers

- Barriers
  - Continuous operation of the BTS reactor system using a scalable reactor design
  - Comprehensive techno-economic analysis of biomass gasification unit integrated with a chemical/product synthesis plant.
- Technical Targets:
  - Year 1: Detailed design of 10 kW_{th} reactor system complete and ready to fabricate
  - Year 2: Completion of reactor installation and commissioning
  - Year 3: Completion of techno-economic analysis and 10 kW_{th} unit testing

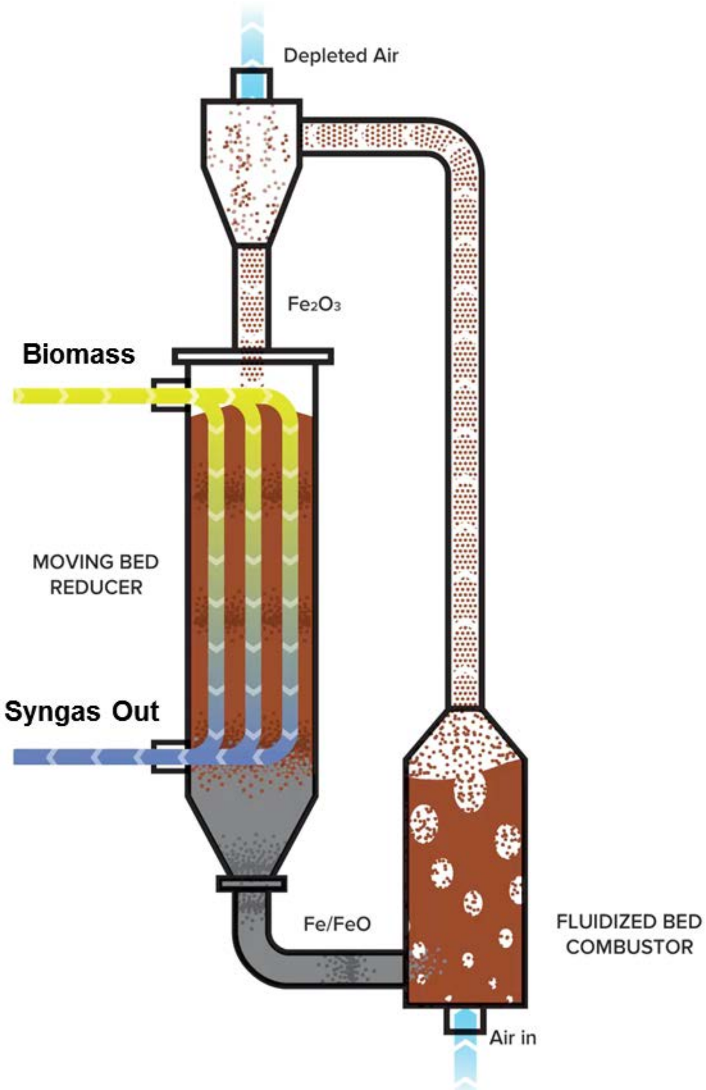
Budget

	FY 17 Costs	FY 18 Costs	FY 19 Costs
DOE Funded	$561,078	$469,020	$469,902
OSU	$84,862	$87,949	$91,188
CAAFI	$8,667	$8,667	$8,667
AdvanceBio	$15,000	$15,000	$15,000
CPC	$25,000	$25,000	$25,000
Kurtz Brothers	$15,000	$15,000	$15,000
Peloton	$15,000	$15,000	$15,000

Partners

- Nexant, Inc (11%)
- Industrial Review Committee members
  - Commercial Aviation Alternative Fuel (CAAFI)
  - AdvanceBio
  - Community Power Corporation (CPC)
  - Kurtz Brothers
  - Peloton

1 - Project Overview

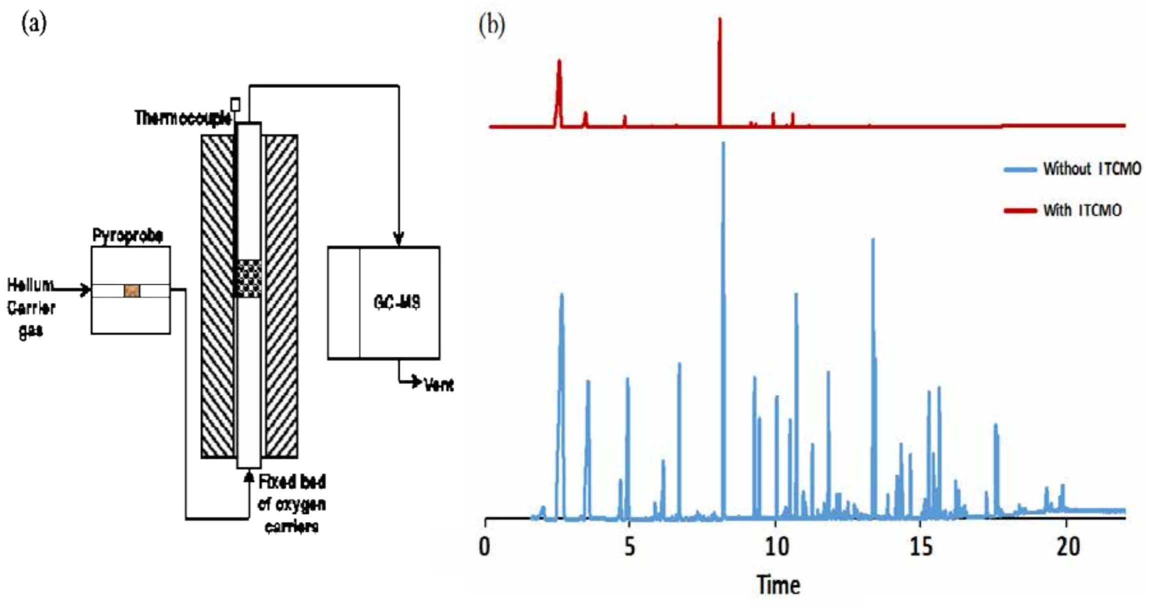


Main reactions:

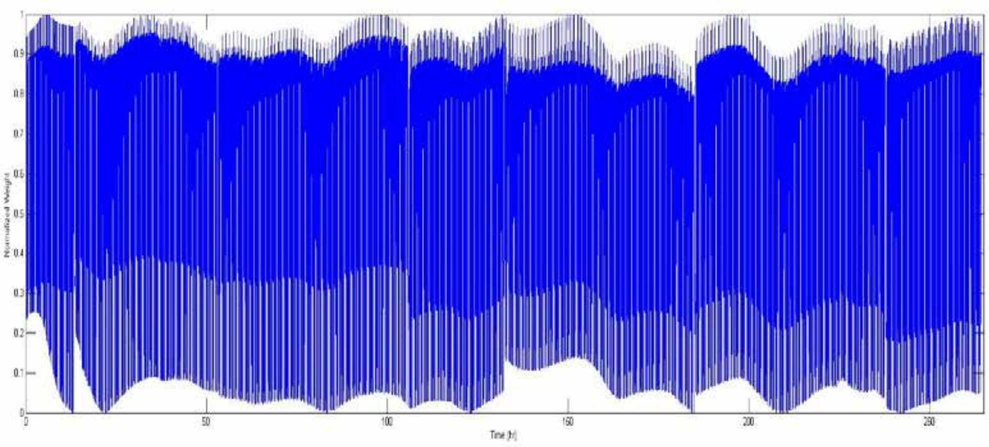
Reducer:	Biomass + H_2O + Fe_2O_3 → CO + H_2 + Fe/FeO
Combustor:	Fe/FeO + O_2 (Air) → Fe_2O_3 + Q
Net:	Biomass + H_2O + O_2 (Air) → CO + H_2 + Q

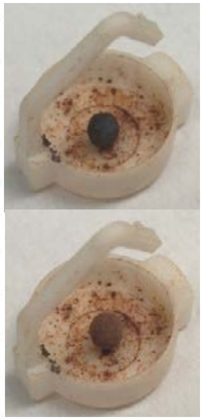
- Co-current moving bed reducer design
  - Tight control of gas-solid flow
  - High fuel conversion to syngas
- No tar reforming required
- H_2/CO molar ratio reach 2.12 while syngas purity is 70.4%
- Syngas generation and conditioning 44% cost reduction
- Total plant cost 22% reduction

1 - Project Overview: ITCMO Performance



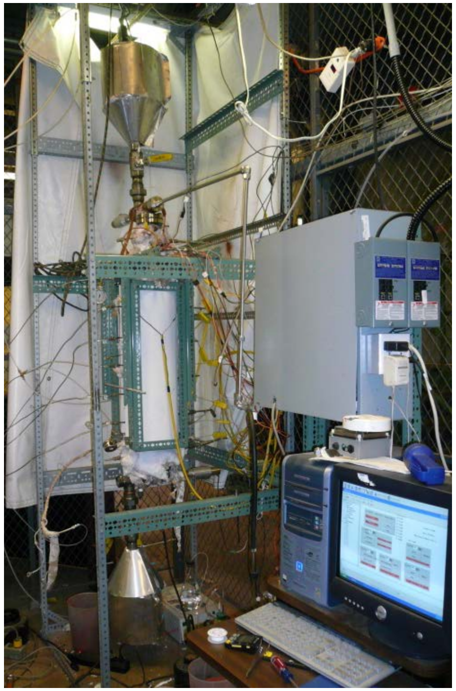
ITCMO oxygen carrier able to crack tar constituents in biomass

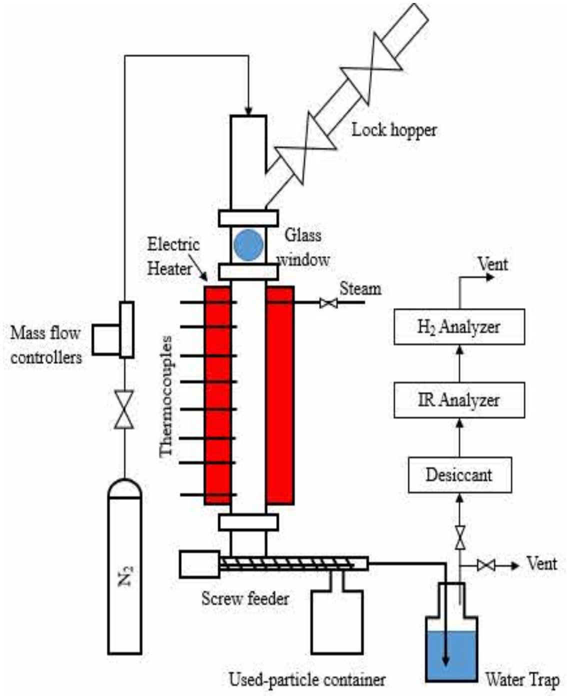


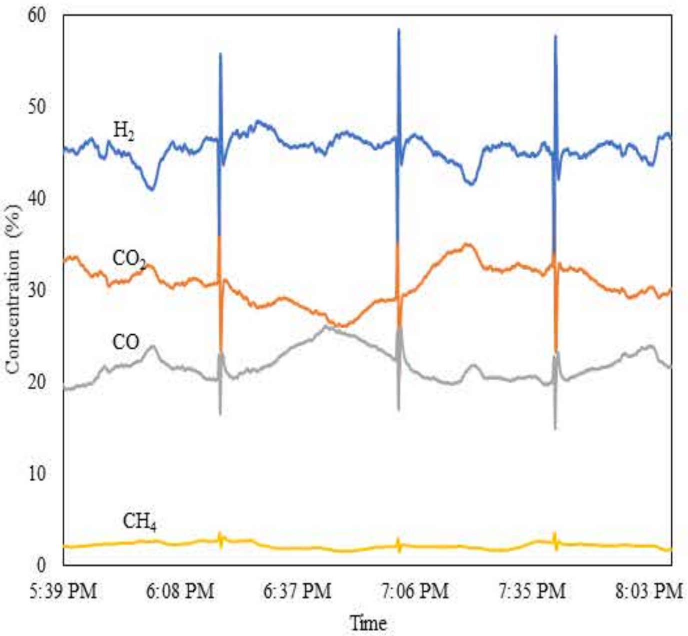


>1,000 redox cycles completed without loss in reactivity, recyclability, or strength

1 - Project Overview: 1 kW_{th} Bench Unit Operation

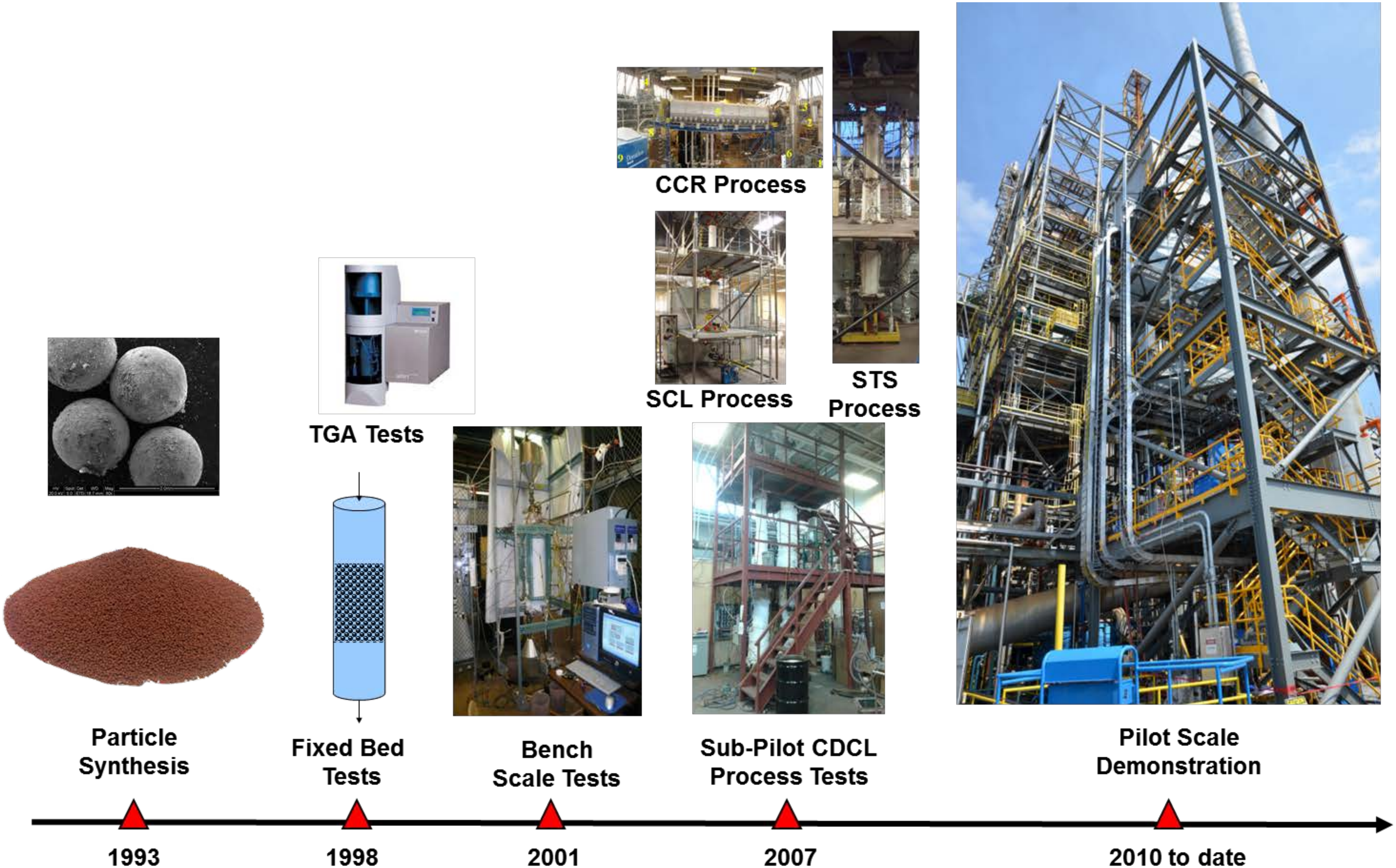






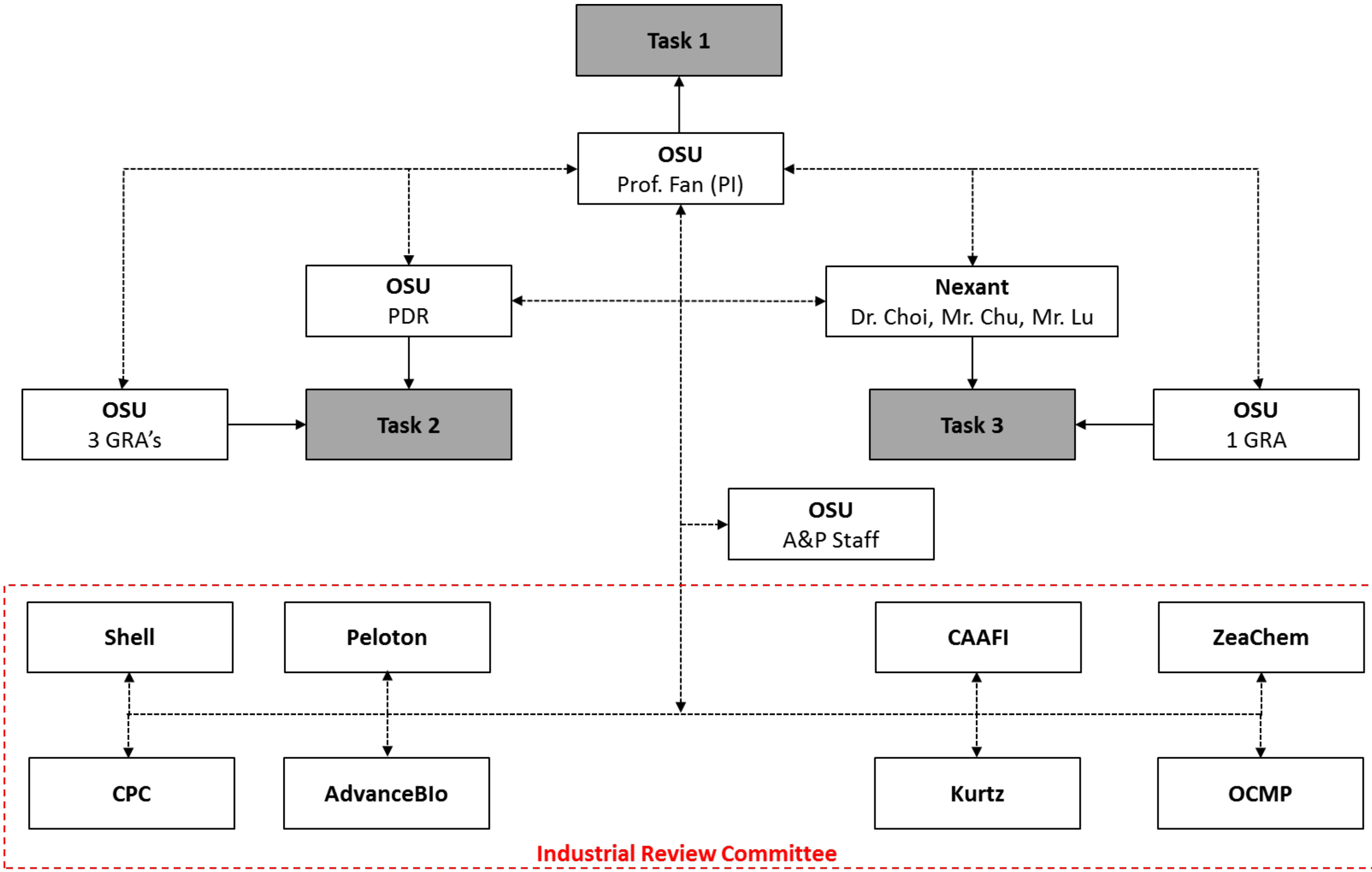
Condition	1		2		3		4	
Feedstock	Methane		Methane		Woody Biomass		Woody Biomass	
Temperature	960 ^oC		975 ^oC		1000 ^oC		1000 ^oC	
$[O]:C_{Feed}$	2.5		2.2		2.0		1.7	
$H_2O:C_{Feed}$	0		0		1.59		1.55	
Concentration (dry base)	Exp.	Sim.	Exp.	Sim.	Exp.	Sim.	Exp.	Sim.
H_2 (%)	62.69	63.81	63.53	63.84	46.28	46.88	46.99	46.56
CO (%)	33.89	33.41	33.62	33.42	20.74	26.52	28.29	26.67
CO_2 (%)	3.42	2.78	2.85	2.74	32.98	26.60	24.72	26.77
$H_2:CO$	1.85	1.91	1.89	1.91	2.23	1.77	1.66	1.75

Evolution of OSU Chemical Looping Technology



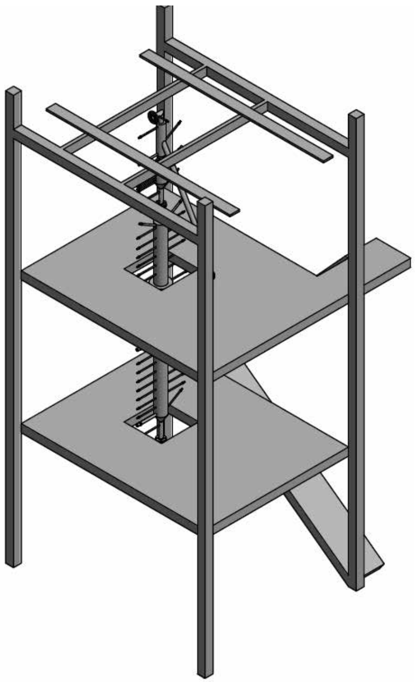
Fan, L.-S., Zeng, L., Luo, S. *AIChE Journal*. 2015.

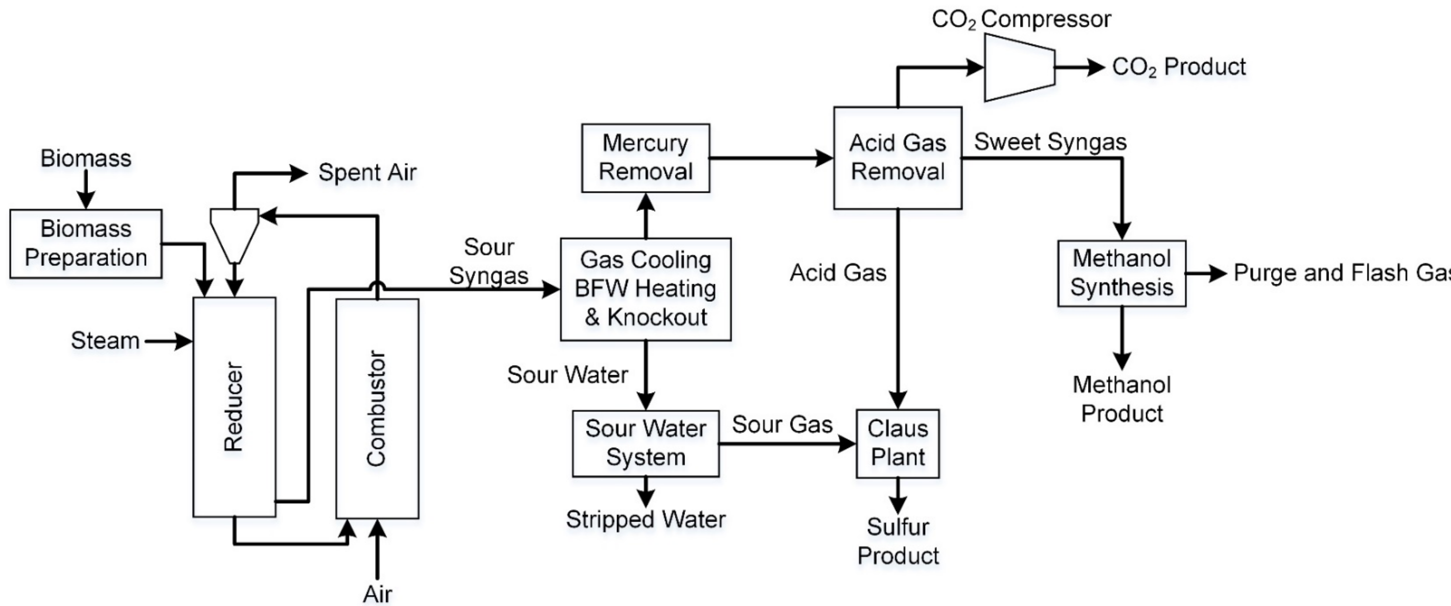
2 – Technical Approach (Management)



2 – Technical Approach (Technical)

1. **Design, Construction, and Operation of the 10 kW_{th} BTS Sub-Pilot System**
2. **BTS Process Techno-Economic Analysis for Methanol Production Application**





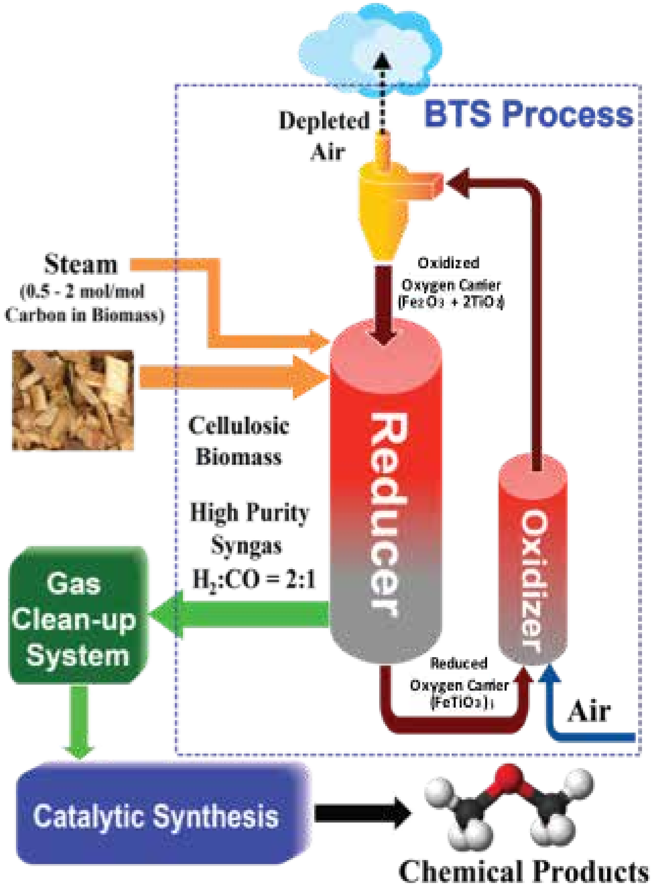
Technical Challenges

- Integrated reactor system design: Cold flow studies performed to be performed in Year 1
- Sub-pilot reactor costs: existing sub-pilot facility available resources and equipment will minimize process costs
- Methanol plant integration with BTS process: Nexant support will ensure task completion

3 – Technical Accomplishments

- Project kickoff meeting with industrial review committee members
- Reactor sizing to commence cold flow model design and fabrication
- Reference case selection for economic model assessment

4 – Relevance

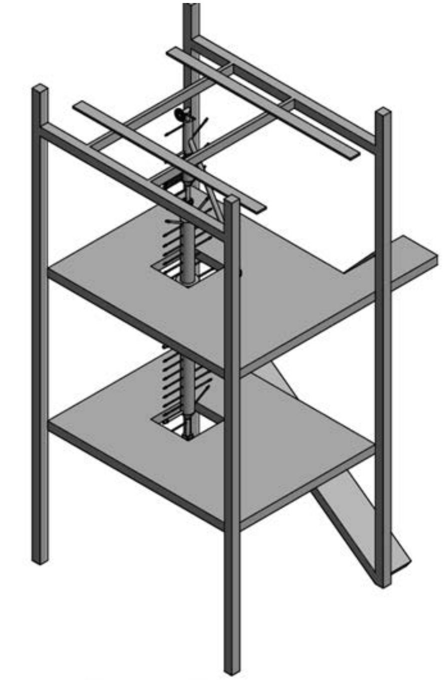


	Indirectly Heated Gasifier Outlet	Reducer Outlet
Biomass (mtpd)	4000	4000
H_2/CO molar ratio	0.92	2.12
H_2 (lbmol/hr)	3156.2	7134.7
CO (lbmol/hr)	3440.1	3358.1
CO_2 (lbmol/hr)	817.5	4345.8
Hydrocarbons (lbmol/hr)	952.2	33.5

- Directly Supports BETO's Mission:
  - "Develop and transform our renewable biomass resources into commercially viable high performance biofuels"
- Project driven by TEA – verify reactor sizing/capital cost based on continuous process performance results
- BTS process considered process intensification approach to biomass gasification:
  - Eliminates tar reformer and air separation unit
  - Flexible H2/CO ratio production
  - High carbon efficiency to syngas

5 – Future Work: Year 1

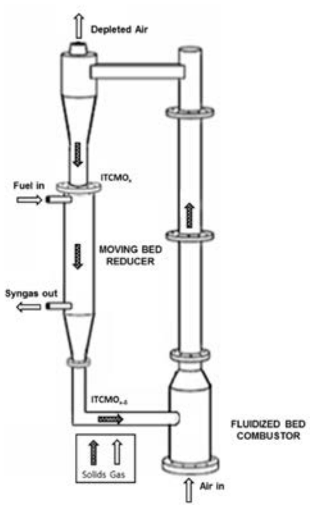
- 10 kW_{th} Sub-Pilot BTS Reactor
    - Cold Flow Model Studies
        - Internal and interconnecting component sizing (HMB)
        - Test condition studies based on varying operating capacities
    - Sub-pilot design
        - P&ID specifications
        - Controls specifications
        - Process Safety Review
        - Detailed reactor design and costing
- TEA economic studies
    - Design basis report development with selected reference cases
    - Process modeling of BTS-Methanol plant and reference case
    - Initial economic assessment
- IRC Review Meetings



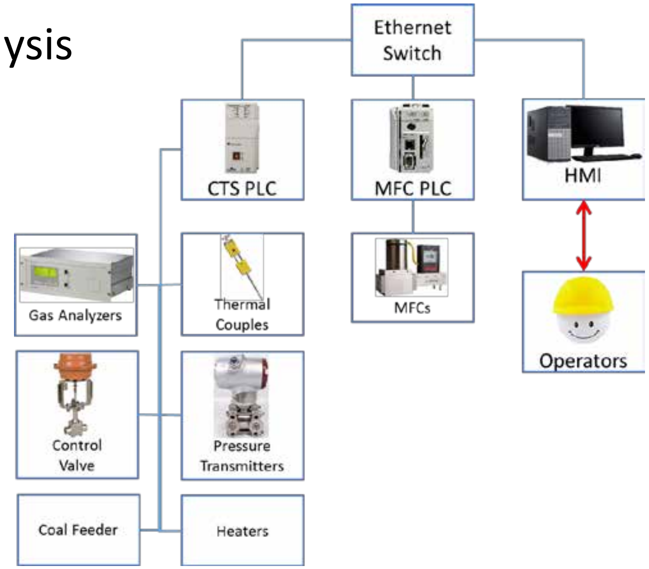
5 – Future Work: Year 2

- 10 kW_{th} Sub-Pilot BTS Reactor
  - Test site preparation – equipment removal and structure preparation
  - Reactor fabrication and installation
  - Piping and electrical
  - Process commissioning – verify controlled solid circulation and heat up achievable
  - Control Programming
- TEA economic studies
  - Initial sensitivity analysis
- IRC Review Meetings

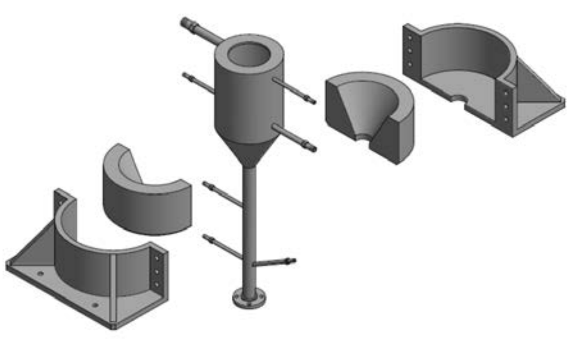
Site Preparation/ Student Training



System Control

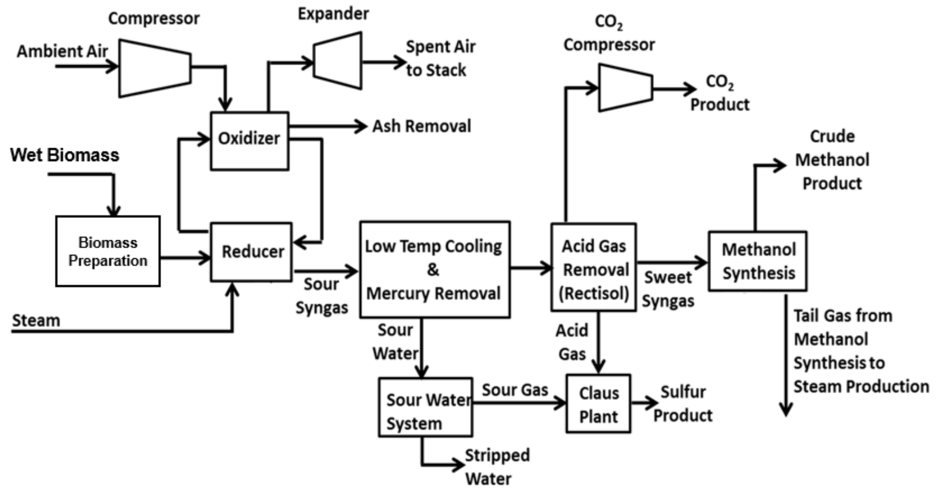


Structural Support Design/Installation



5 – Future Work: Year 3

- 10 kW_{th} Sub-Pilot BTS Reactor
  - Sub-pilot parametric studies: biomass feed rate and type, operation temperature, steam/CO_2 feed input
  - Extended continuous operations – verify particle reactivity and attrition resist and non-mechanical reactor performance
  - Data reduction/analysis
- TEA economic studies
  - Update process model based on experimental results
  - Complete sensitivity analysis and report to IRC members
  - Deliver TEA final report
- IRC Review Meetings



Summary

- The BTS process is capable of substantial cost savings due to its process intensification attributes (i.e. gasifier, tar reformer, and ASU combined operation) and high carbon conversion efficiency. Proof of concept studies verified the sustained reactivity and strength of the ITCMO oxygen carrier and the moving bed reactor performance for high purity syngas production
- The project will address the continuous operation of the BTS reactor system in a sub-pilot test unit and perform a comprehensive TEA of a BTS-Methanol plant
- Year 1&2 activities focused on sub-pilot design and construction while Year 3 is for extended unit operations
- IRC members will guide the direction of TEA and serve to market technology for continued scale-up
- BTS process meets BETO's objectives for advancing the use of biomass for biofuels production