2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

NC A&T Renewable Energy Center

-Production of High-Quality Syngas via Biomass Gasification for Catalytic Synthesis of Liquid Fuels and Combined Heat and Power Generation

May 21st 2013

Technology Area Review: Biomass Gasification

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Goal Statement

The major goal of this project is to develop an efficient gasification system in order to convert woody biomass and agricultural residue from North Carolina to synthesis gas (syngas). Then, convert syngas into liquid fuel through catalytic process and heat and power through a gas turbine.

Quad Chart Overview

Timeline

- Project start date: 01/01/2012
- Project end date: 09/30/2015
- Percent complete: 30%

Budget

- Funding for FY 2012: 300K/0
- Funding for FY 2013: 192K/61K
- FY 2014 projected budget: 91K/110K
- Years the project has been funded/average annual funding: 1.5 years

Barriers

- Barriers addressed
  - Tt-C. Gasification of Wood, Biorefinery Residue Streams and Low Sugar Content Biomass
  - Tt.-F. Syngas Cleanup and Conditioning
  - Tt- Validation of Syngas Quality
  - It-E. Engineering Modeling Tools

Partners

- N/A

Project Overview

1. Uncover biomass gasification chemistry
2. Computer aided design and analysis of a fluidized bed gasifier
3. Novel biomass-based syngas cleaning technology
4. Catalytic synthesis of liquid fuels from biomass derived syngas
5. Combined heat and power generation from residual syngas

1 – Approach

-I. Uncover Biomass Gasification Chemistry

Study 1: Characterize the physical and chemical properties of raw and pretreated biomass

Crop residues, energy crops, and woody biomass are characterized as feedstocks. Pretreatment methods including drying, shredding, densification and torrefaction are used to improve the characteristics of these biomass materials prior to gasification. A database are established to manage all experimental data.

Study 2: Develop a structured biomass gasification kinetic model

Experimental techniques including micro-pyrolysis reactor-FTIR/GC-MS, TGA-DSC-MS, and elemental analyzer are used to uncover the reaction pathways, rates and heat during biomass gasification. A structured kinetic model will be developed using the experimental data.

1 – Approach

-II. Computer Aided Design and Analysis of a fluidized bed gasifier

- Study 1: CFD modeling of multiphase reactive gas-particle flow
- Study 2: Experimental study of the multiphase gas-particle flow
- Study 3: Design, operate and control an externally heated, fluidized bed gasifier for the production of high-quality syngas with a favorable H_2 to CO ratio.

1 – Approach

-III. Novel Hot Syngas Cleaning Technology

- Study 1: Investigation of the synergic cleaning of hot syngas and production of high-quality biochar

- Study 2: Design and analysis of a novel biomass-based syngas cleaning technology.

1 – Approach

-IV. Catalytic Synthesis of Liquid Fuels from Syngas

Study 1: Fisher-Tropsch catalysts

- Catalysts: Earth abundant elements such as Fe and Cu
- Supports: Carbon-based support such as carbon nanotube and activated carbon
- Promoters such as platinum

Study 2: Design and analysis of a Fisher-Tropsch reaction system

Coupling F-T synthetic reaction (exothermic) with water reforming reaction (endothermic) to improve:

- heat transfer
- H_2/CO ratio
- Selectivity of C5-C11

1 – Approach

-V Combined heat and power generation

Study 1: Combustion characteristics of syngas and residual syngas

Study 2: Design and analysis of a combined heat and power generation unit

Study 3: Integration of biomass gasification, Fisher-Tropsch synthesis, and CHP (Biomass to biofuels and biopower through thermodynamic integration)

2 - Technical Accomplishments/ Progress/Results

-I. Physical and Chemical Properties of Selected Biomass Materials

Properties		Corn Stover	Wet distillers grains	Fresh cattle manure
Moisture content (%, wet basis)		9.4	68.3	70.7
Ash content (%, dry basis)		8.1	5.8	37.2
Bulk density after drying (kg/m^3)		180	525	780
Heating value (MJ/kg, dry basis)		18.9	22.5	13.3
Volatile (%, dry basis)		71.6	78.0	52.0
Elemental analysis (%, dry and ash-free basis)	C	51.89	49.93	49.38
	H	5.45	7.26	6.46
	O	41.48	36.45	39.79
	N	0.84	5.31	3.33
	S	0.34	1.04	1.05
Chemical formula		$CH_{1.251}O_{0.600}N_{0.014}S_{0.002}$	$CH_{1.733}O_{0.548}N_{0.091}S_{0.008}$	$CH_{1.559}O_{0.605}N_{0.058}S_{0.008}$

2 - Technical Accomplishments/ Progress/Results

-II. General Chemical Formulas of Different Biomass Materials

Biomass $C_xH_yO_zN_mS_n$

If the ultimate analysis of a specific biomass materials is not available, the following chemical formulas which were obtained by statistically analyzing the data of the ultimate analyses of different biomass materials can be used

- **Grasses: $CH_{1.488}O_{0.666}N_{0.016}S_{0.001}$**
- **Crop residues: $CH_{1.482}O_{0.656}N_{0.021}S_{0.001}$**
- **Woody biomass: $CH_{1.428}O_{0.593}N_{0.007}S_{0.001}$**

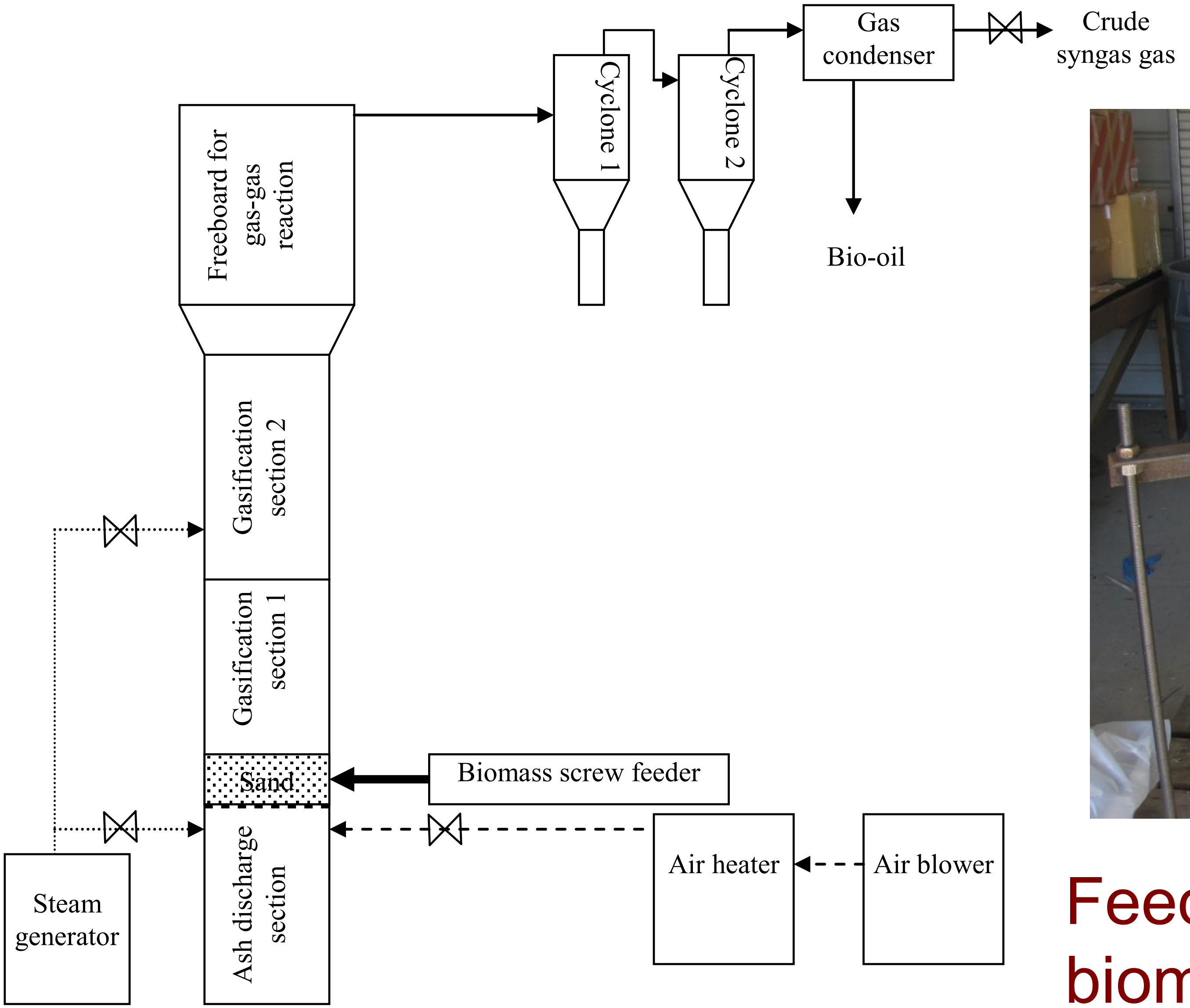
2 - Technical Accomplishments/ Progress/Results

-III. Advantages and technical challenges of Different Gasifying Agents

	Main advantages	Main technical challenges
Air	1. Partial combustion for heat supply of gasification 2. Moderate char and tar content	1. Low heating value (3 – 6 MJ Nm^{-3}) 2. Large amount of N_2 in syngas (e.g., >50% by volume) 3. Difficult determination of ER (usually 0.2 – 0.4)
Steam	1. High heating value syngas (10 – 15 MJ Nm^{-3}) 2. H_2-rich syngas (e.g., >50% by volume)	1. Require indirect or external heat supply for gasification 2. High tar content in syngas 3. Require catalytic tar reforming
Carbon dioxide	1. High heating value syngas 2. High H_2 and CO in syngas and low CO_2 in syngas	1. Require indirect or external heat supply 2. Required catalytic tar reforming

2 - Technical Accomplishments/ Progress/Results

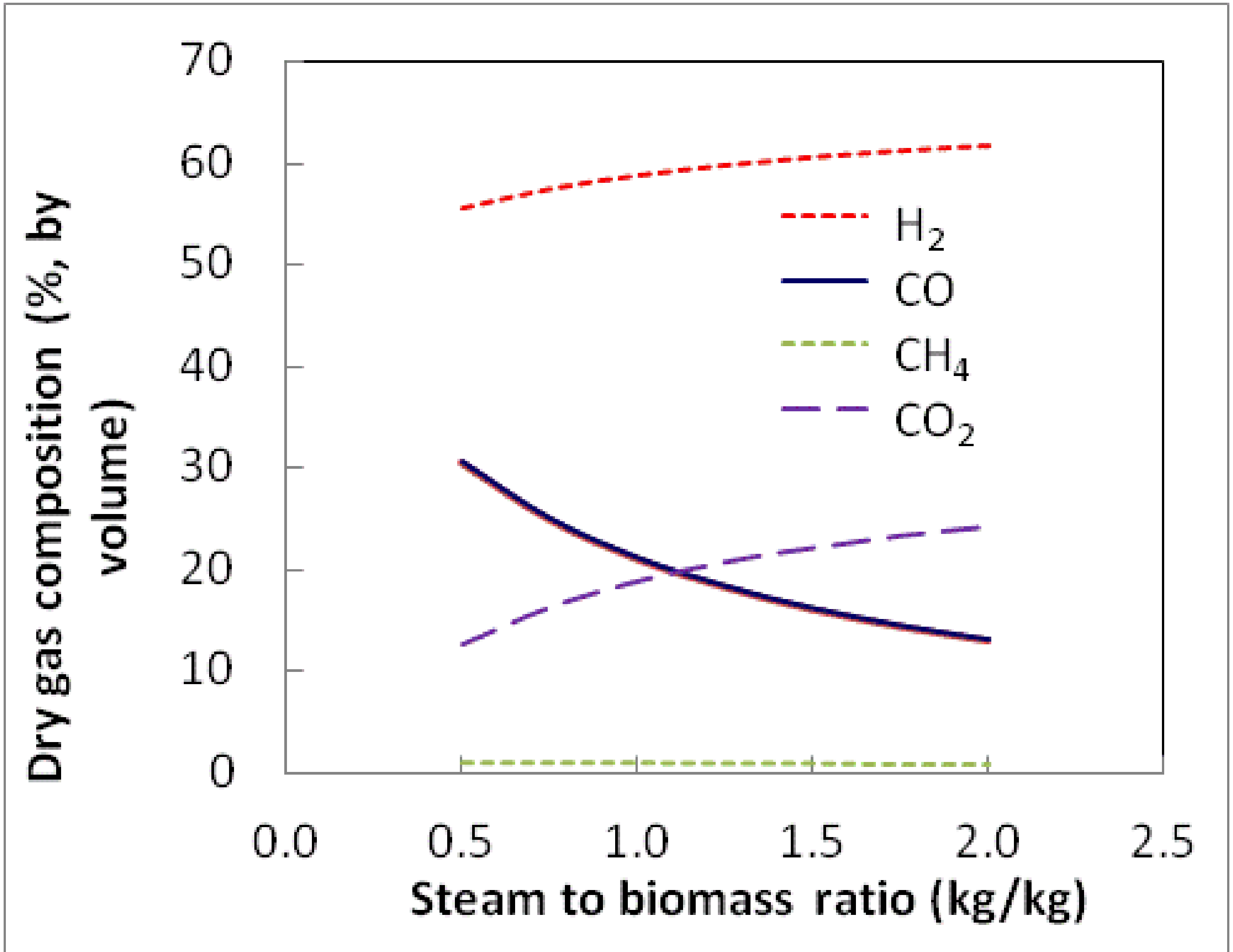
-IV: Advance the design and operation of a lab scale fluidized bed gasifier



Feed rate of biomass into the gasifier: 5-10 kg/h

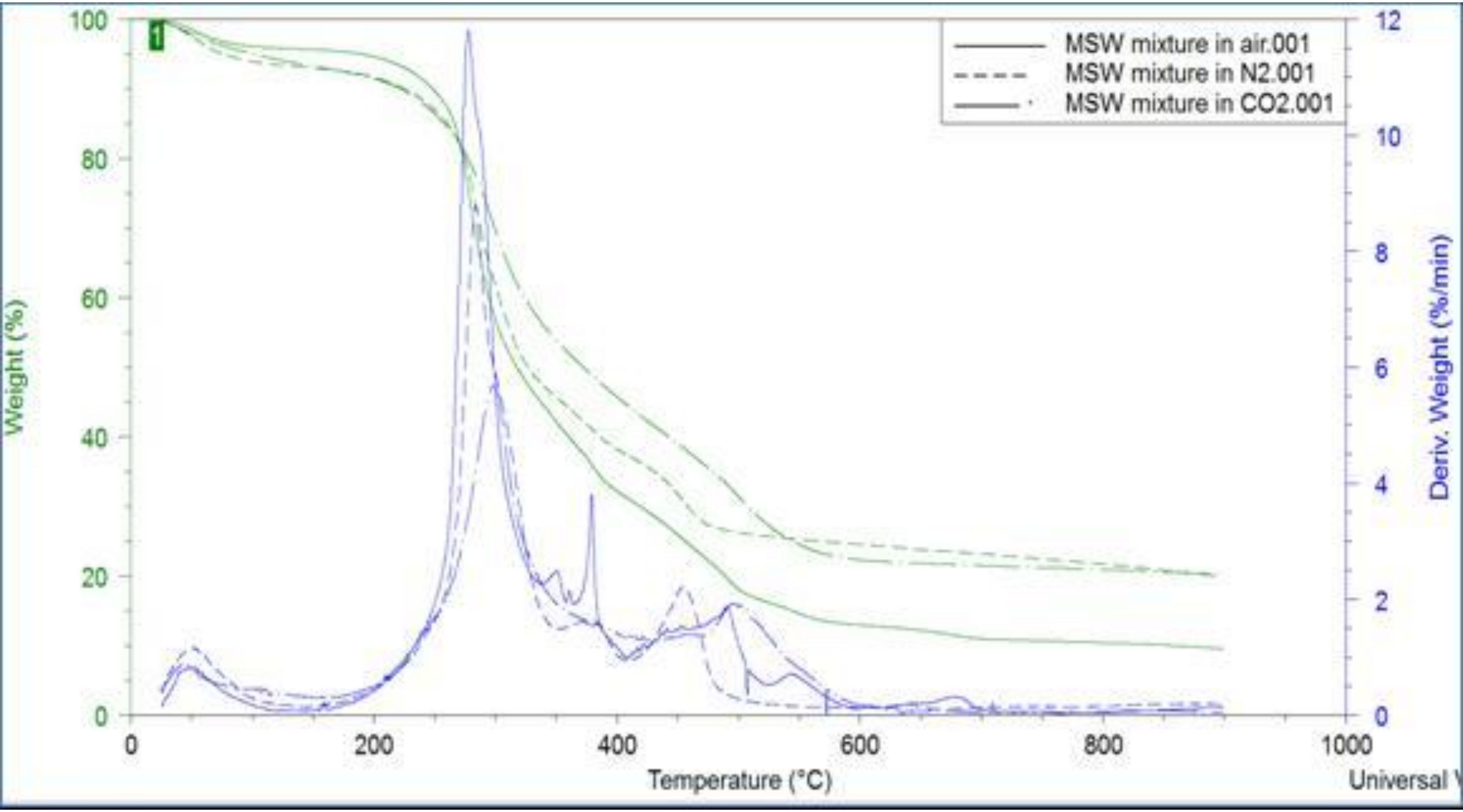
2 - Technical Accomplishments/ Progress/Results

-V. Composition of Dry Syngas During Steam Gasification of Corn Stover at 850ºC Predicted by a Mathematical Model



2 - Technical Accomplishments/ Progress/Results

-VI. Thermal degradation characteristics of biomass in different gasifying agents

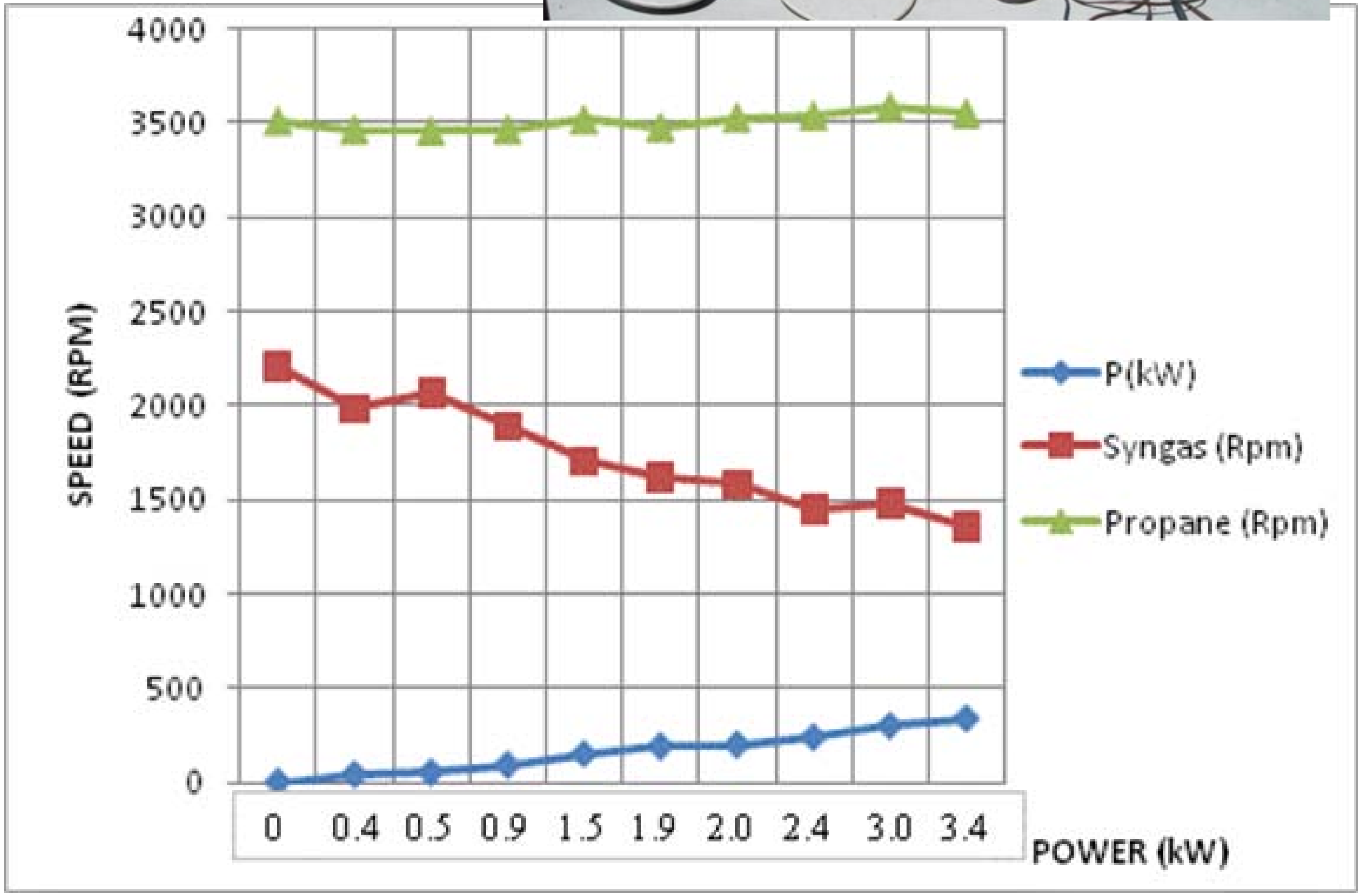


2 - Technical Accomplishments/ Progress/Results

–VII. *The relationship between the speed and load of generator, using syngas and propane as fuels*

10 KW Down-draft gasifier

Tri-gas generator



3 - Relevance

- M6.11.1 Develop cost effective gasification designs for syngas production at appropriate scale
- M6.13.1 Produce non-ethanol fuel from syngas
- M6.16.1 Verify fuel gas quality to levels necessary for CHP or clean cold gas consuming equipment

4 - Critical Success Factors

(1) Biomass gasification: Proper design, operation and control of a fluidized bed gasifier is critical to produce high-quality syngas from biomass for the catalytic synthesis of liquid fuels from the syngas.

(2) Fisher-Tropsch synthesis: Coupling F-T synthetic reaction (exothermic) with water reforming reaction (endothermic) and corresponding catalysts are critical to improve:

- Heat transfer
- H_2/CO ratio
- Selectivity of C_5-C_{11}

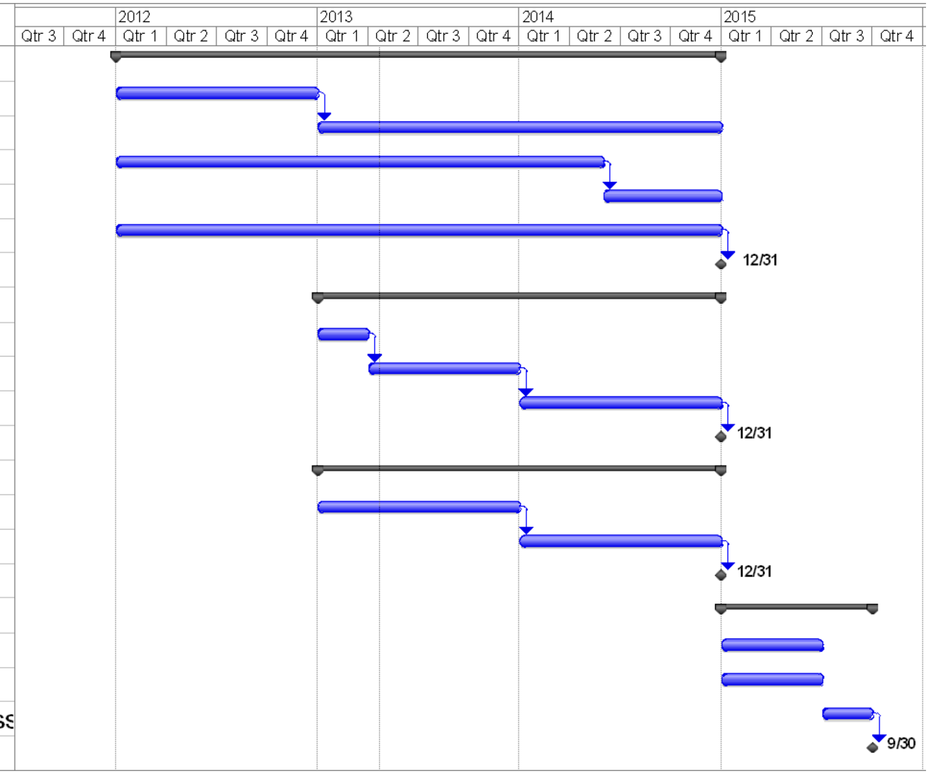
5. Future Work
-Research activities

- Computational fluid dynamics simulation of multiphase reactive gas-particle flow in a biomass fluidized bed gasifier: Ph.D. student, Samuel Agyemang, Computational Science and Engineering Dept.
- Catalytic synthesis of liquid fuels from biomass derived syngas: Ph.D. student, Mohammad Rafati, Energy and Environmental Systems Dept.
- Biomass gasification mechanism and reaction kinetics: Ph.D. student, John K. Eshun, EES Dept.
- Novel hot syngas cleaning technology: Ph.D. student, Rui Li, Nanoengineering Dept.

5. Future Work

-Timeline

ID	Task Name
1	**Study 1 Biomas gasification**
2	1.1 Biomass characterization and preparation
3	1.2 Analysis of biomass gasification chemistry
4	1.3 Study of reactive particle flow in a fluidized bed gasifier
5	1.4 Advance gasifier design and operation
6	1.5 Study of novel syngas cleaning technology
7	1.6 Milestone 1: Technology to produce high-quality syngas
8	**Study 2. Fisher-Tropsch synthesis of liquid fuels from syngas**
9	2.1 Screening catalysts for F-T syntehsis
10	2.2 Catalysts preparation, characterization and evaluation
11	2.3 F-T reactor design and analysis
12	2.4 Milestone 2: Efficient and economic F-T synthetic technology
13	**Study 3. Combined heat and power generation**
14	3.1 Combustion characteristics of syngas and residual syngas
15	3.2 CHP design and analysis
16	3.3 Milestone 3: A syngas-based CHP technology
17	**Study 4. Process integration**
18	4.1 Integrate the physical units
19	4.2 Mathematical modeling of the integrated process
20	4.3 Economic analysis and life cycle assessment of the integrated process
21	4.4 Milestone 4: A gasification-based biorefinery



Summary

- ***Approach:*** A combination of basic and applied science aimed at developing an efficient gasification technology for producing biofuels and biopower.
- ***Technical Accomplishments***: Project is 30% complete. All the resources in place to complete the balance of the project.
- ***Relevance***: this project is in line with three majors goals (M6-11.1, M6-13.1, and M6-16.1)of the DOE BETO program.
- ***Critical Success factors and challenges***: CFD modeling, Syngas cleaning, F-T reaction, and CHP are major challenges.
- ***Future work***: Gasifier optimization, syngas cleaning, CFD modeling, F-T process and CHP system.
- ***Technology transfer***: Close collaboration with TT office

Research Group

Thermochemical Research Lab