Fractional Multistage Hydrothermal Liquefaction of Biomass and Catalytic Conversion into Hydrocarbons

26 March, 2015

Technology Area Review: Thermochemical Conversion

Randy Cortright PhD

Virent, Inc

WBS: 2.5.5.401

VIRENT

Goal Statement

Project Goal – Develop a novel Multistage Hydrothermal Liquefaction (HTL) of biomass and integrate with Virent's Catalytic BioForming® Process to efficiently produce cost effective "drop-in" fuels from woody biomass and corn stover, with particular focus in maximizing jet fuel and diesel yields.

- **Developing commercially Viable Bioenergy Technology**
  - **Improve pretreatment strategies**
  - **Improve fuel yields**
- **Reduction of Greenhouse Gas Emission**
  - **Non-Food Feedstock** – Woody Biomass, Corn Stover
  - **Improve fuel yields**
- **Process Generates "Direct Replacement" Hydrocarbons compatible with today's transportation infrastructure**
  - **Distillate Range Products** for use as either jet fuel or diesel fuel
  - **"Advantaged" Jet and Diesel Fuels**
- **Relevance and Tangible Outcomes for the United States**
  - **Promotes National Security**
  - **Growing a Sustainable future**
  - **Generating green jobs**

Quad Chart Overview

Timeline

- Project Start: October 2013
- Project End: September 2016
- Percent complete: ~50%

Budget

	FY10 –FY12 Costs	FY13 Costs	FY14 Costs	FY15-End Costs
DOE Funded	$0	$0	$451,831	$2,948,169
Virent Cost Share	$0	$0	$158,751	$1,035,843

Barriers

- Tt-B: Feeding Wet Biomass
- Tt-D: Biomass Pretreatment
- Tt-F: Deconstruction of Biomass to Form Bio-Oil Intermediates
- Tt-J: Catalytic Upgrading of Bio-Oil Intermediates to Fuels and Chemicals

Partners

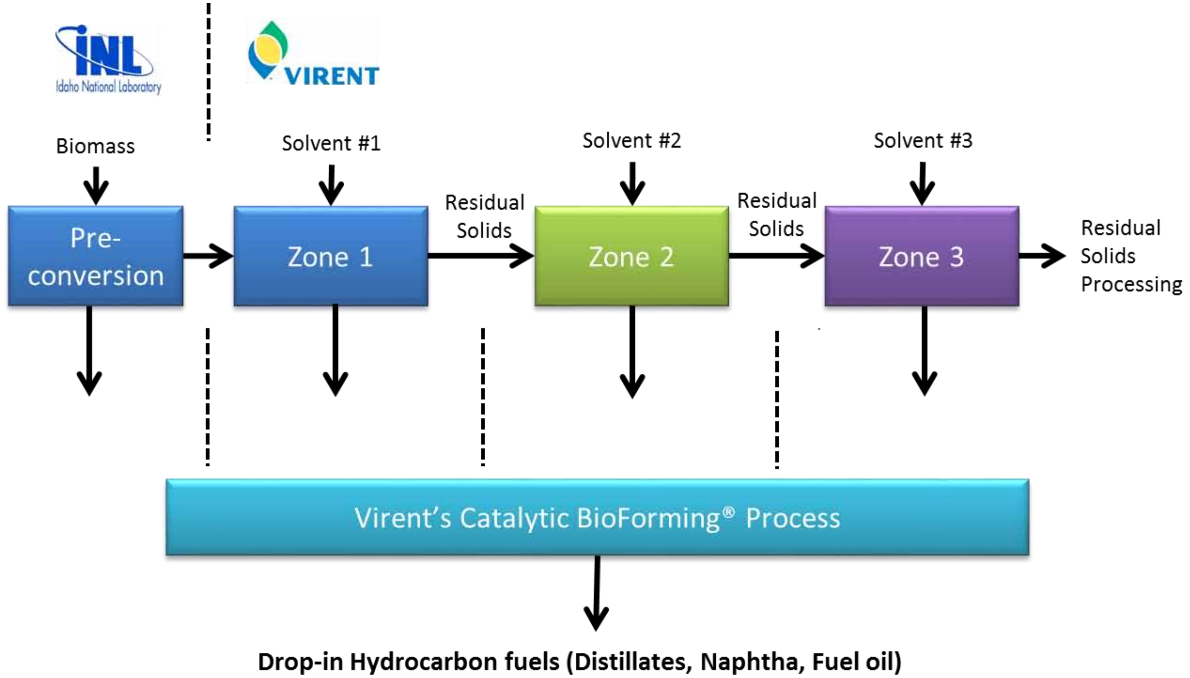
- Idaho National Laboratory
  - Feedstock Supply
  - Biomass Pretreatment

1 - Project Overview

- Convert lignocellulosic feedstocks to drop-in liquid fuels
- Multistage Hydrothermal Liquefaction
  - Develop multistage HTL utilizing appropriate solvent and process conditions to convert woody biomass and corn stover to liquid intermediates that can be catalytically upgraded to “direct replacement” hydrocarbons
  - Progress from Applied Research to Preliminary Investigation
  - Focus on integration with Virent BioForming platform
- Pilot Build
  - Design, build, and operate a continuous pilot for multistage HTL technology
- Catalytic Upgrading
  - Integrate HTL technology with Virent BioForming catalytic upgrading to produce “direct-replacement” hydrocarbon liquid fuels
  - Focus on distillate fuels – jet fuel and diesel
- TEA and LCA
  - Complete Techno-Economic Analysis and Life Cycle Analysis

2 – Approach (Technical)

- Overall Technical Approach



- Each zone will target solubilizing a specific biomass fraction (hemicellulose, cellulose, or lignin) with an appropriate solvent
- Solvents may be internally generated or economically obtained

- Critical Success Factors – Feedstock, Biomass Pretreatment, Deconstruction, Hydrolysate Conditioning, Catalytic Conversion, Product Certification, Overall Process Economics
- Potential Challenges – Biomass to usable carbon, HTL product integration into catalytic upgrading, Intensify process by eliminating processing steps

2 – Approach (Technical)

- **Critical Success Factors**
  - **Ash Removal**
    - Necessary to Reduce Potential Catalyst Poisons
  - **Carbon Recovery**
    - Maximize carbon recovery from hemicellulose and cellulose
    - Maximize the solubilization and conversion of lignin components
    - Maximize carbon conversion in the catalytic conversion to desired liquid hydrocarbon
  - **Process Economics** – Reduction in capital and operating cost of biomass to jet fuel distillate

- **Potential Challenges**
  - **Improve yields** of "convertible carbon" intermediate streams through HTL process optimization
  - **Removal** of ash components in preconversion and processing steps.
  - **Process Intensification** through the potential elimination of HTL and/or catalytic processing steps

2 – Approach (Technical)

INL Tasks

- Supply formatted loblolly pine to Virent upon request (up to three shipments)
  - Characterize with proximate/ultimate, ash composition and calorific analyses
- Perform chemical preconversions on corn stover using the Chemical Preconversion System and subsequent bench top extractions/washes
  - Characterize ash and nitrogen removal and changes to ash composition
    - SiO_2, alkali metals, alkaline earth metals and nitrogen
  - Supply samples to Virent for testing
- Optimize chemical preconversion process using sequential alkali/acid treatments and extractions/washes based on Virent's input for desired results

2 – Approach (Technical)

Why Is Ash A Quality Issue?

- Biomass contains both introduced soil ash and endogenous ash
- Endogenous ash is comprised of structural and non-structural physiological ash
- Ash is comprised of metals and heteroatoms that may be
  - Inert
  - Destructive to conversion products
  - Fouling agents for conversion catalysts
  - Sources of pollutants
  - Damaging to equipment
- This increases processing costs and/or reduces product yields
- Knowing the chemical form, function and plant tissue location of specific ash components aids in identifying effective reduction methods

2 – Approach (Management)

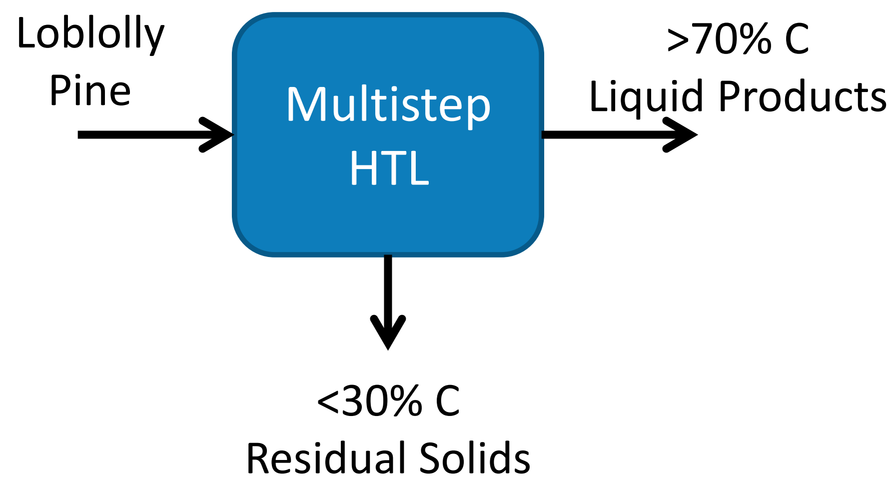
- *Critical Market and Business Success factors*
  - *Establish Cost and Technical Targets for Catalytic derived hydrocarbon fuels based on TEA*
  - *Market Size and Opportunity*
- *Potential Market and Business Challenges*
  - *Biomass Cost, Crude Oil Prices, Financing of Plant, Government Policy*
- *Management approach*
  - *Gantt Chart for 3 year project*
  - *Key Milestones*
    - *TRL-2 Milestones (September 2014)*
    - *TRL-3 Milestones (September 2015)*
    - *Stage Gate Review   (September 2015)*
    - *TRL-4 Milestones (September 2016)*

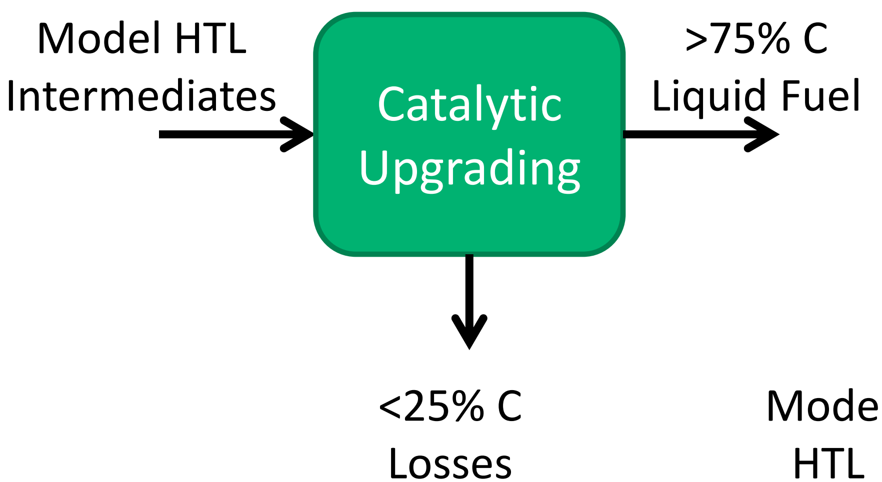
3 – Technical Accomplishments/ Progress/Results

WBS	Milestone Title	Description	Deliverable	Complete?
1.2.2	Develop Initial Kinetic Model	Develop an initial kinetic model based on preliminary investigation	Report initial Kinetic Model results in the quarterly report	✓
1.2.1	TRL-2: Applied Research Demonstrated HTL Yield	Demonstrate carbon efficiency of >60% for HTL from biomass to soluble carbon in batch tube experiments.	Report carbon efficiency in the quarterly report	✓
1.2.3	TRL-2: Applied Research Catalytic Upgrading Demonstrated Yield	Demonstrate >65% yield to liquid fuel products with model feeds	Report carbon efficiency in the quarterly report	✓

3 – Technical Results – Yield

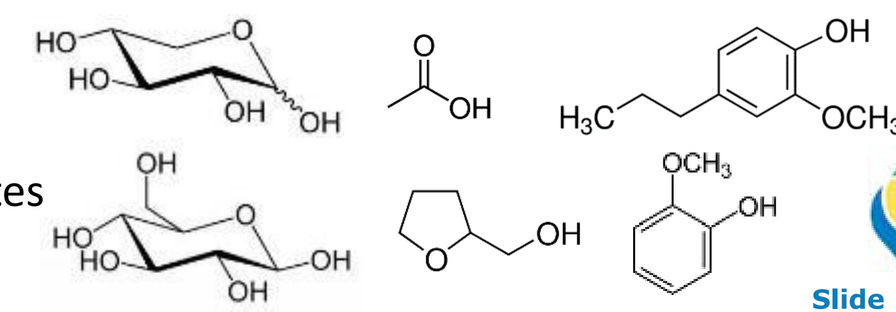
- Milestone of >60% C to liquid products from real feedstock demonstrated
- Hemicellulose, cellulose, and lignin liquefied





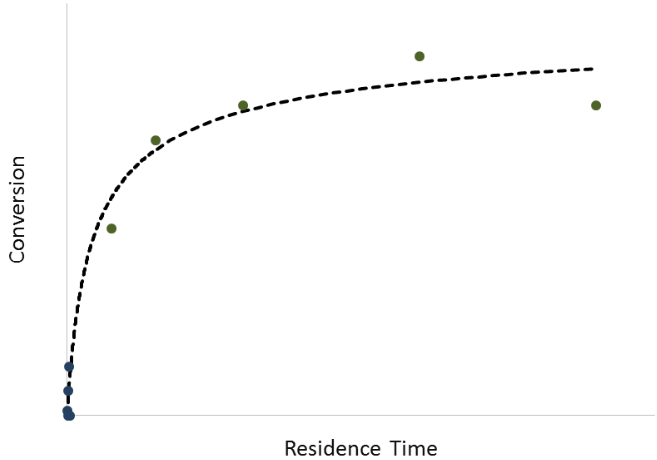
- Milestone of >65% C to liquid fuels from model HTL intermediates demonstrated
- Finished fuel meets jet fuel and diesel specifications

Model HTL Intermediates



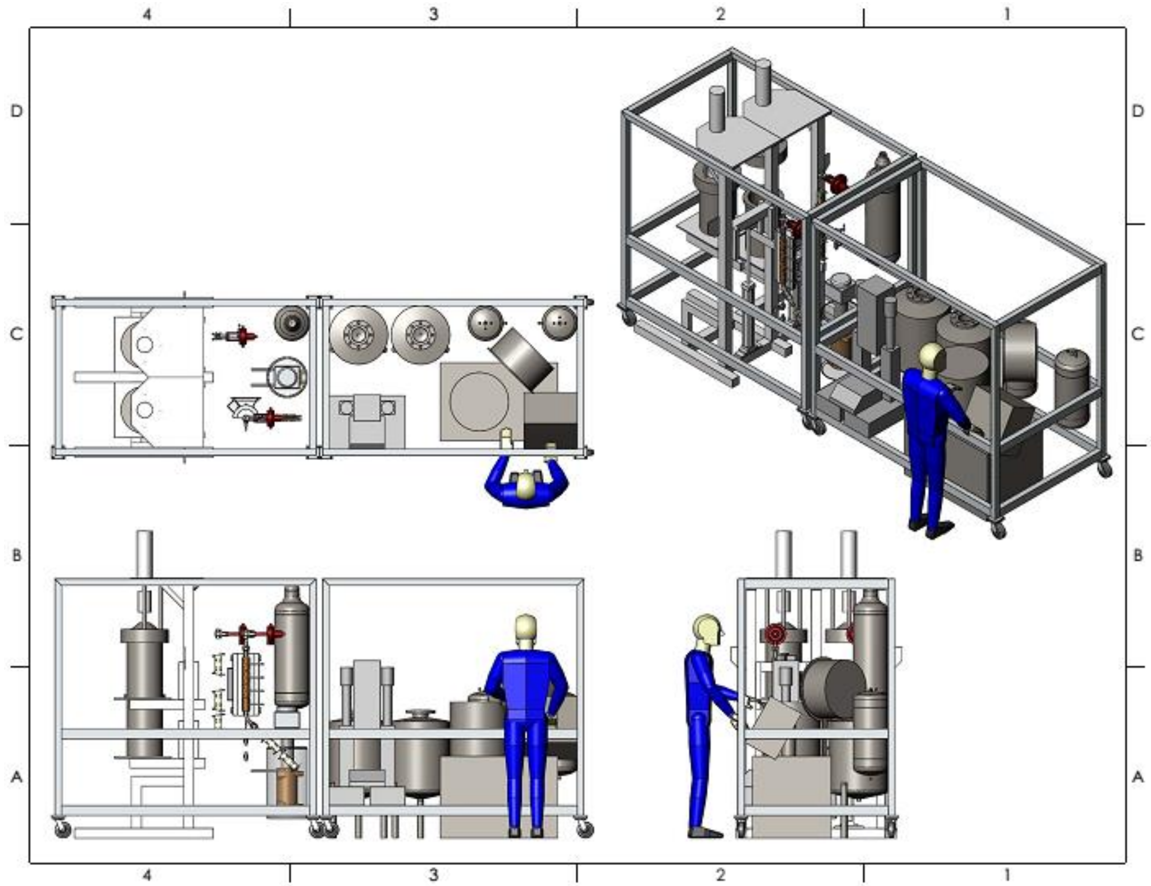
3 – Technical Results – Kinetic Model

- Initial kinetic milestone met
- Use of flow through system to accurately capture kinetics to apply to pilot design
- Model will be verified, expanded, and refined with pilot



3 – Technical Results – Pilot Build

- Initial design of continuous HTL pilot complete
  - Feed System, HTL Reactor, Solid/Liquid Separation, Product Collection
- All major equipment identified, utilizing scalable and economical process design
- Build to be completed mid-2015



4 – Relevance

- *Contributions to meeting the platform goals and objectives of the BETO Multi-Year Program Plan*
  - If successful, project would address the strategic goal to develop commercially viable technologies for converting biomass into energy-dense, fungible finished liquid fuels, such as renewable jet and diesel.
  - This project utilizes analysis interface through the use of TEA and LCA to inform feed collection methods and processing steps.
  - Working with INL will investigate feedstock supply, preconversion technologies, and logistics interfaces.
  - Biofuels distribution infrastructure interface will be addressed through ASTM certification of resulting jet fuel, and diesel product qualification.
  - Addresses barriers such as
    - Tt-B Feeding Wet Biomass
    - Tt-C Biomass Pretreatment
    - Tt-F Deconstruction of Biomass to Form Bio-Oil Intermediates
    - Tt-J Catalytic Upgrading of Bio-Oil Intermediates to Fuels and Chemicals
    - Tt-K Product Finishing
    - Tt-L Knowledge Gaps in Chemical Processes

- *Applications of the expected outputs in the emerging bioenergy industry*
  - Results from this project provide technical viability of combining a biochemical conversion technology frontend with a chemical (catalytic) conversion technology to generate “direct replacement” hydrocarbons from a lignocellulosic feedstock.
  - Project has resulted in 1 US Patent application

5 – Future Work

WBS	Milestone Title	Description	Deliverable	Estimated Completion
2.2.3	Refine Kinetic Model	Refine kinetic model using liquefaction data from the prototype unit	Report the refined Kinetic Model in the quarterly report	8/4/15
2.3	TRL-3: Proof of Concept Demonstrated Yield	Demonstrate >50% yield to liquid fuel products from biomass- 70% recovery in HTL and 70% in catalytic step	Report the results in this the quarterly report	9/30/15
2.4	TEA and LCA	Complete intermediate TEA and LCA on the process configuration . Demonstrate >60% GHG reduction in LCA	Stage Gate TEA and LCA Report	9/30/15
4.2	Stage Gate Review	Hold Stage Gate review to assess TRL-3 status and determine if the project should proceed to TRL-4	Go/No-Go Decision	9/30/15
3.3	TRL-4: Preliminary Integration Demonstrated Yield	Demonstrate >60% yield to liquid fuel products from biomass, with 75% recovery in catalytic step	Report the results in this the quarterly report	9/30/16
3.4	Final TEA and LCA	Complete TEA and LCA on the final process configuration.	Final TEA and LCA Report	9/30/16

Summary

1. Overview
   - Convert lignocellulosic feedstocks to drop-in liquid fuels
   - Develop novel Multistage Liquefaction and integrate with Virent's BioForming Catalytic Upgrading
2. Approach
   - Progress from TRL-2 Applied Research to TRL-4 Preliminary Integration
3. Technical Results
   - TRL-2 Applied Research completed: yield milestones met, initial kinetic model developed, pilot design completed
4. Relevance
   - Demonstrate technical and economic viability of process
5. Future Work
   - Complete pilot build, meet TRL-3 Proof-of-Concept and TRL-4 Preliminary Integration milestones

Additional Slides

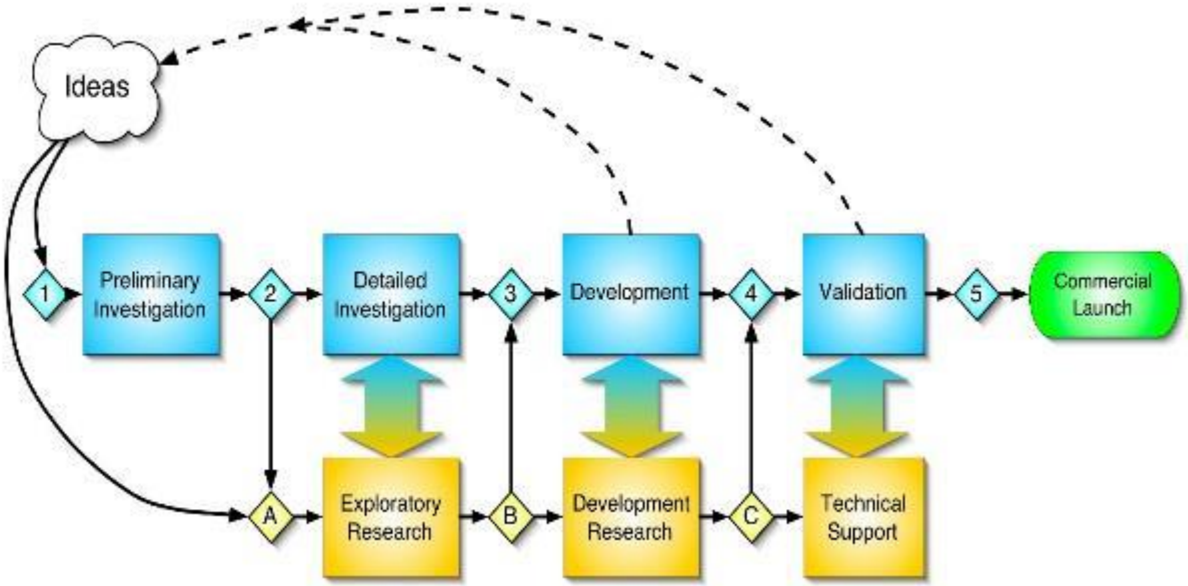
Responses to Previous Reviewers' Comments

- This project has not been previously presented for Peer Review

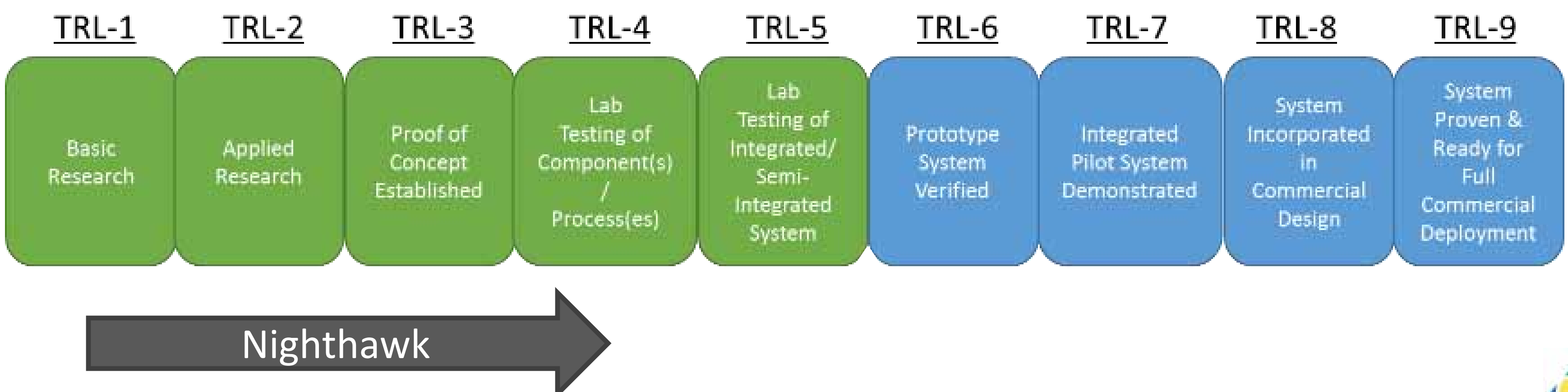
Publications, Patents, Presentations, Awards, and Commercialization

- Patent Application
- Multi-Stage Biomass Liquefaction
- Nelson et al.
- US 62/009,500
- 6/9/2014
- Status – Pending

2. Approach (Technical)
Current State of Technologies



- Currently the Nighthawk project is mid Stage 2 which correlates to TRL-3.
- Completion of this project would put the project at the end of Stage 3 and ready to advance to TRL-5.



Large Addressable Market Sizes

The ultimate market for any biofuel is the national and global refined product markets, which collectively represents over a trillion dollar business. In these markets, the US consumes significant amounts of liquid transportation fuels with a large portion derived from imported crude oil.

Fuel Type	Current Consumption in 2012 (MMGPY)[1]	Projected Consumption in 2040 (MMGPY)	CAGR (%) 2012 – 2040
Motor Gasoline	133,378	101,373	(1.00%)
Jet Fuel	21,845	24,369	0.50%
Distillate Fuel Oil	59,772	70,836	0.80%

DOD Fuel Requirements[2]	FY 2012 (MMGPY)	Product Cost ($MM)
Jet Fuel	3,521	11,842
Distillates and Diesel	865	2,764
Totals	**4,386**	**14,606**

1) EIA Annual Energy Outlook 2014 Early Release Reference Case
2) DLA Fiscal Year 2012 Energy Facts. http://www.energy.dla.mil/library/Pages/Publications.aspx

2. Approach (Management)
(Market/Business Challenges)

Business Risk	Mitigation Strategy
Biomass Price Escalation and Sourcing	Continue to work with groups like INL to determine costs of harvesting biomass. Continue to work on improving yields to lower effect of biomass price volatility on final fuel product.
Prolonged Depression of Crude Oil Prices	Strive to be the low cost producer of cellulosic hydrocarbon biofuels. Optimize byproduct streams for use as chemical/petrochemical to increase co-product value.
Financing	Financing will be determined by projected cost of production, profitability, capital risk, and optimal site location.
Policy Uncertainty	Continue promoting efforts and participation in groups like Advanced Biofuels Association (ABFA) and others.
Emerging Competitive Technologies	Monitor competitive landscape and continue to expand IP portfolio.

Approach – Management

Project Gantt Chart with Milestones

Task Name	Duration	Start	Finish
DE-EE0006286	767 days	Tue 10/1/13	Thu 10/13/16
TRL-2 Applied Research	482 days	Tue 10/1/13	Thu 8/27/15
TRL -2 Preconversion	482 days	Tue 10/1/13	Thu 8/27/15
TRL -2 Liquefaction	430 days	Thu 10/31/13	Thu 7/16/15
Develop Initial Kinetic Model	0 days	Thu 8/28/14	Thu 8/28/14
TRL-2 Demonstrated Carbon Efficiency	0 days	Tue 9/30/14	Tue 9/30/14
TRL -2 Catalytic Upgrading	415 days	Mon 12/2/13	Thu 7/23/15
TRL-2 Catalytic Upgrading Demonstrated Yield	0 days	Tue 9/30/14	Tue 9/30/14
TRL -3 Proof Of Concept	323 days	Mon 6/23/14	Wed 9/30/15
TRL -3 Preconversion	268 days	Wed 9/10/14	Wed 9/30/15
TRL -3 Liquefaction	285 days	Mon 6/23/14	Thu 8/6/15
Complete Liquefaction Prototype Skid	0 days	Mon 1/5/15	Mon 1/5/15
Refine Kinetic Model	0 days	Tue 8/4/15	Tue 8/4/15
TRL-3 Demonstrated Carbon Efficiency	0 days	Wed 9/30/15	Wed 9/30/15
TRL -3 Catalytic Upgrading	100 days	Thu 4/2/15	Thu 8/20/15
TRL-3 Catalytic Upgrading Demonstrated Yield	0 days	Wed 9/30/15	Wed 9/30/15
TEA / LCA	295 days	Mon 6/23/14	Thu 8/20/15
TEA / LCA Completed	0 days	Wed 9/30/15	Wed 9/30/15
TRL -4 Preliminary Integration	252 days	Thu 10/1/15	Fri 9/30/16
TRL -4 Preconversion	240 days	Thu 10/1/15	Tue 9/13/16
TRL -4 Liquefaction	205 days	Thu 10/1/15	Mon 7/25/16
TRL -4 Demonstrated Carbon Efficiency	0 days	Fri 9/30/16	Fri 9/30/16
TRL -4 Catalytic Upgrading	150 days	Mon 12/21/15	Mon 7/25/16
TRL -4 Catalytic Upgrading Demonstrated Yield	0 days	Fri 9/30/16	Fri 9/30/16
TEA / LCA	50 days	Fri 7/8/16	Fri 9/16/16
Final TEA / LCA	0 days	Fri 9/30/16	Fri 9/30/16
Project Management	767 days	Tue 10/1/13	Thu 10/13/16
Reporting	767 days	Tue 10/1/13	Thu 10/13/16
Stage Gate	3 days	Mon 9/28/15	Wed 9/30/15