# A Hybrid Catalytic Route to Fuels from Biomass Syngas

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Gasification
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# Project Goal

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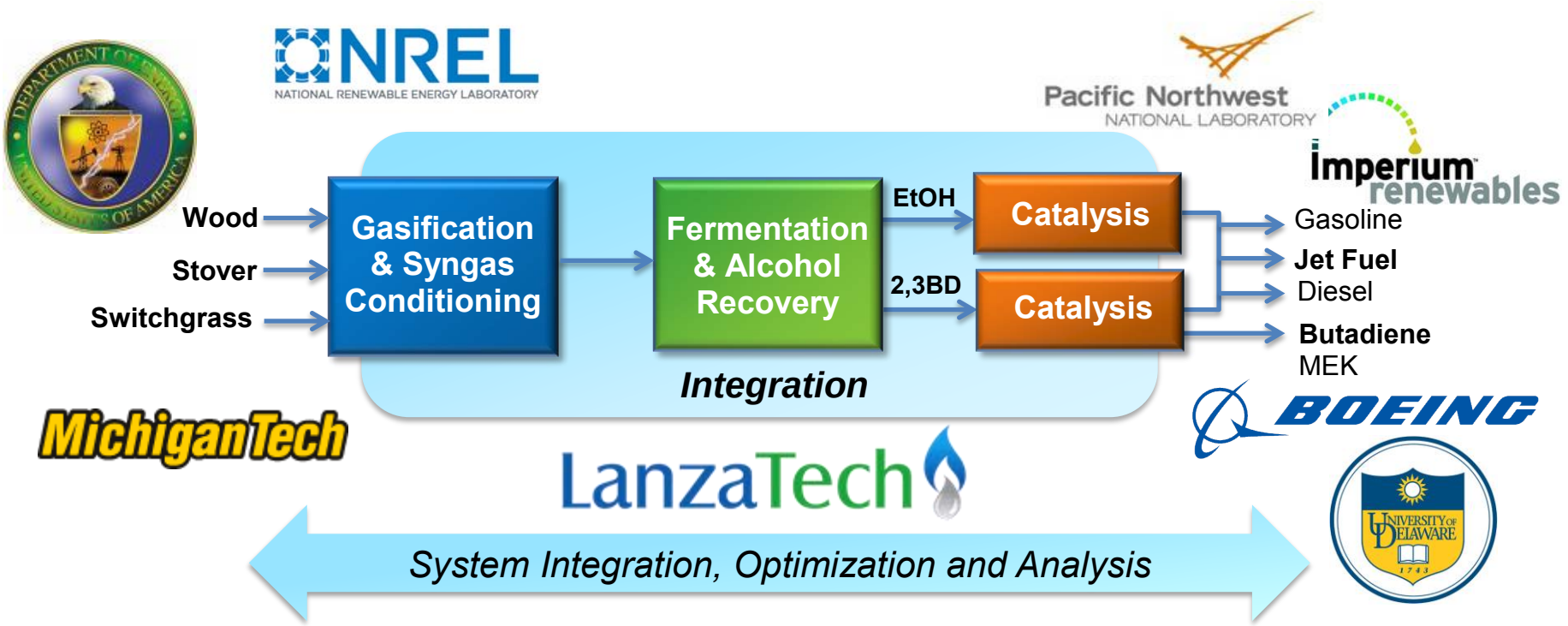
**A hybrid biorefinery design that enables the production of jet fuel and other hydrocarbon fuels from waste biomass**




***Improve Economics and Process Sustainability***

# Quad Chart Overview

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| Timeline | Barriers (Specific to Gaseous Intermediates Pathway) |
|---|---|
| **Project Start:** April 2012<br>**Project End:** April 2015<br>**Percent Complete:** 25% | **Gt.-F. Gas Cleanup and Conditioning:** NREL and LanzaTech investigating minimum necessary gas cleanup and conditioning requirements for syngas fermentation<br>**Gt.-G. Fuel Synthesis and Upgrading:** Ethanol and 2,3-BDO being upgraded to jet fuel and butadiene. PNNL and Imperium developing catalyst technologies for upgrading alcohols to high value chemicals and hydrocarbon fuels.<br>**Gt.-K. Gaseous Intermediates Process Integration:** Direct integration at NREL between primary unit operations – gasification and fermentation – , with upgrading performed at PNNL. Modeling of integrated process informs commercial viability. |
| **Budget** | **Partners** |
| **Total Budget:** $5.2M<br>DOE: $4M Cost Share: $1.2M<br>**Funding for FY2012:**<br>PNNL: $445K<br>LT DOE:$299K Cost Share: $98K<br>**Funding for FY2013:**<br>PNNL: $183K NREL: $644K<br>LT DOE: $377K Cost Share: $554K<br>**Projected for FY2014:**<br>PNNL: $750K NREL: $277K<br>LT DOE: $336K Cost Share: $543K<br>**Projected for FY2015:**<br>PNNL: $607K NREL: $23K<br>LT DOE: $54K Cost Share: $52K | **LanzaTech:** Project Lead and Management, Integrated TEA, Syngas Fermentation Lead, Commercialization Partner, Analysis Support<br>**NREL:** Syngas Production Lead, Syngas Cleanup and Integration with Fermentation<br>**PNNL:** Catalytic Alcohol Conversion Lead, Catalyst-Fermentation Integration, TEA Modeling, Fuel Quality Measurements<br>**The Boeing Company:** Fuel Quality and Aviation Industry Analysis<br>**Imperium Renewables:** Commercialization, Market and Engineering Analysis<br>**Orochem Technologies:** Advanced Alcohol Recovery<br>**Michigan Technological University:** Life Cycle Assessment<br>**University of Delaware:** Alcohol Conversion Catalyst Fundamentals |

# Technical Approach

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- LanzaTech leading project management and technoeconomics
- Integrated approach to manage all aspects of technology development through lifetime of project
- Technoeconomics informs commercial viability

Determine impacts of syngas contaminants on fermentation productivity and stability, with the goal of optimizing syngas cleanup costs

Optimize alcohol upgrading catalyst and process conditions through screening and mechanistic/kinetic studies coupled with computation

Determine impact of water and other impurities in the fermentation broth on catalyst stability and product yield, with the goal of optimizing alcohol recovery cost

Validate process stability through extended operations and detailed catalyst characterization

Design an integrated process that optimizes the performance of each step, as well as material and energy integration between steps, producing a globally optimized process design

# Project Task Structure

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**Task A: Gasification Fermentation Interface**
**NREL / LanzaTech**

**Task B: Prepare Alcohol Intermediates**
**Production: LanzaTech**
**Separations: Orochem (2,3-BDO) / NREL (Ethanol)**

**Task C: Catalytic Upgrading**
**PNNL / Imperium Aviation Fuels (IAF)**

**Task D: Catalyst Fundamentals**
**Univ. of Delaware / PNNL**

**Task E: Production of Hydrocarbon Fuels**
**PNNL / LanzaTech**

**Task F: Product Evaluation**
**PNNL / Boeing / IAF / LanzaTech**

**Task G: Techno-Economics & Life Cycle Analysis**
**LanzaTech / MTU / NREL / PNNL / Boeing**

# Project Tasks Objectives

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- **Task A - Gasification-Fermentation Interface**

  Develop and demonstrate an integrated gasification and fermentation process for commercial jet fuel production

- **Task B - Prepare Alcohol Intermediates**

  Produce 2,3BDO and ethanol samples for upgrading

- **Task C - Catalytic Upgrading of Alcohol Intermediates**

  Develop and demonstrate catalytic conversion of alcohols to chemicals and hydrocarbon fuels

- **Task D - Catalyst Fundamentals**

  Develop mechanistic understanding of conversion catalysts to improve performance

- **Task E - Production of Hydrocarbon Fuels**

  Produce hydrocarbon fuels for analysis and fit-for-purpose testing

- **Task F - Product Evaluation**

  Validate jet fuel properties from hybrid processing route

- **Task G - Techno Economics and Life Cycle**

  Identify additional integration opportunities. Estimate the input requirements, costs, and environmental impact of the integrated process.

# Technical Accomplishments - Task A Gasification-Fermentation Interface

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- **Objective**
  - Develop and demonstrate an integrated gasification and fermentation process for commercial jet fuel production.
- **Accomplishments to date**
  - Dual 3-10L fermentation system installed and operated
  - 100L fermentation system installed and commissioned
  - Gasification –fermentation integrated
  - LT demonstrated stable operation on simulated syngas
  - NREL demonstrated stable biomass gasification operations
  - Stable integrated operations in progress

# Technical Accomplishments – Task C
# Catalytic Upgrading of Alcohol Intermediates

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- **Objective**
  - Develop and demonstrate catalytic conversion of alcohols to chemicals and hydrocarbon fuels
- **Accomplishments to date**
  - PNNL's catalyst development is on schedule
  - Produced about 3 liters of jet fuel in lab-scale testing
    - Product is a distribution of primarily branched hydrocarbons, very low in cyclic and no aromatic compounds detected
    - Product requires a light hydrotreatment and distillation of jet-range fraction
  - Catalyst is *easily regenerated*
    - Improved catalyst prepared on a commercial support
    - Regenerated twice during extended catalyst lifetime studies (>2000 hours time on stream, catalyst returns to original activity)
    - Determined the effect of $H_2O$ on catalyst activity – *$H_2O$ deactivates the catalyst – several existing mitigation techniques for this catalyst deactivation*

# Anticipated Results

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- Reduced cost of gasification by integrating with a fermentation process that reduces gas clean-up requirements, specifically related to sulfur and ammonia species in the syngas (i.e. assessing effects of crude syngas impurities on downstream processes.)
- Reduced separations cost through integration of minimally treated fermentation process streams with catalyst steps.
- Reduced costs of catalytic conversion by providing a clean, consistent biomass-derived intermediate for conversion to jet fuel, also improving catalyst lifetime and viability.
- Reduced energy demands through heat integration to use process heat for distillation and power requirements.

# Relevance

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- This project directly supports the overall goal of the Bioenergy Technologies Office (BETO) and the specific goals identified within the Gaseous Intermediates Pathways R&D technology area (MYPP):
  - "The Gaseous Intermediates Pathways R&D strategic goal is to develop commercially viable technologies for converting biomass feedstocks into energy dense, fungible liquid fuels, such as, renewable gasoline, jet fuel, and diesel, bioproducts and chemical intermediates, and bioenergy."
- The project's new hybrid catalytic route will reduce risk and enable the program to meet its 2022 R&D performance goals to make cellulosic biofuels cost competitive with petroleum based fuels, achieving a modeled cost for mature technology of $3/gallon hydrocarbon fuel ($2011).
- In addition, this project will support the milestones below by incorporating techno-economics and an integrated conversion process for woody biomass to hydrocarbon fuels (gasoline, jet, diesel). Milestones towards accomplishment of those performance goals include:
  - "By 2014 establish out-year cost goals and technical targets, based on completed techno-economic analysis, for at least one gaseous intermediate conversion to hydrocarbon fuels pathway."
  - "By 2022 validate integrated conversion process for woody biomass to renewable gasoline or diesel via conversion of gaseous intermediates at a scale sufficient for transfer to pilot-scale operation."

# Critical Success Factors

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- To be successful, this project needs to accomplish the following:
  - Define syngas cleanup protocol
  - Validate integrated operations
  - Produce and deliver alcohol samples suitable for upgrading
  - Define separations scheme
  - Achieve commercially relevant upgrading selectivity with industrially relevant catalyst
  - Produce and deliver jet fuel samples
- The project's main challenges are:
  1. Integration of process technologies (gasification, fermentation, separations, catalytic upgrading, product testing)
  2. Coordination of all project partners to achieve integrated process success

# Future Work

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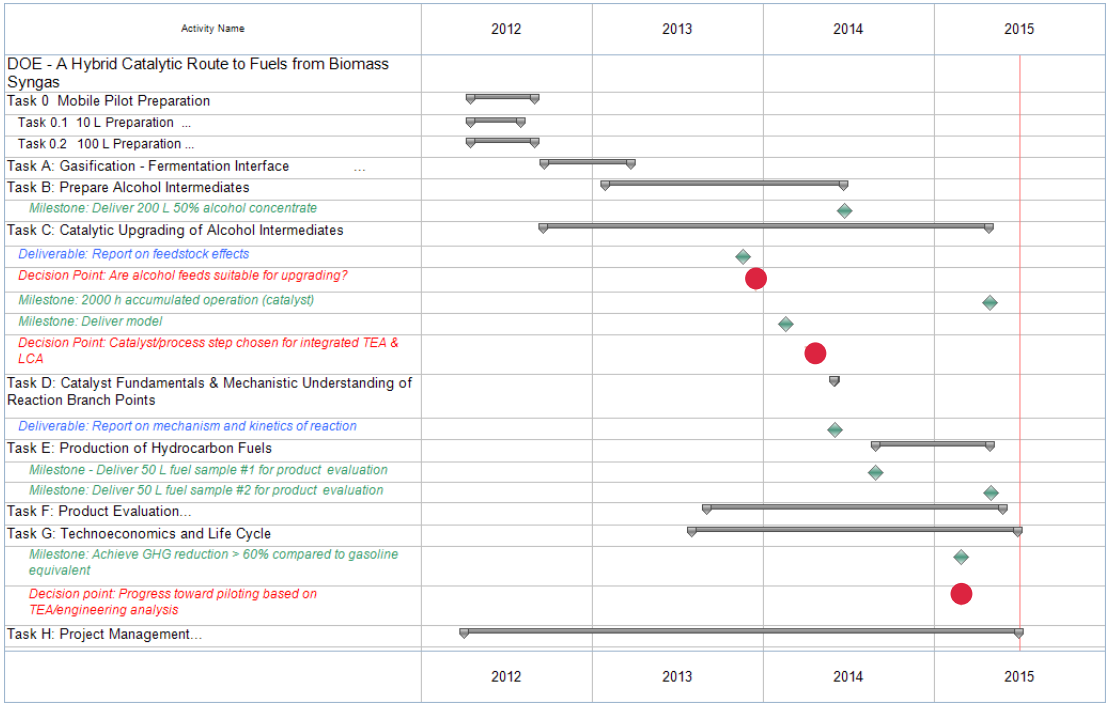


Decision points:

- Are alcohol feeds suitable for upgrading?
- Catalyst/process step chose for integrated TEA & LCA
- Progress toward piloting based on TEA/engineering analysis

- Reinitiate production of syngas from NREL TCPDU and produce ethanol and 2,3-butandiol from LT syngas fermentation
- Catalyst development work on-going at PNNL
- Upgrading of alcohols to be performed by PNNL (jet fuel and butadiene)
- Catalyst fundamentals modeling work on-going at PNNL and Delaware
- Imperium and Boeing supporting commercialization and fuels testing

# Summary

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- Development of a hybrid catalytic route to fuels as an integrated process:
  - Residual biomass gasification
  - Syngas fermentation to intermediate fuels and chemicals
  - Catalytic upgrading to hydrocarbon fuels and commercial chemical products
  - Focus on *jet fuel* production
- Techno-economic and life-cycle analyses will be used to quantify and compare process economics and sustainability respect to conventional processes.
  - Identification of additional research needs and synergistic opportunities to enable fuel cost reductions.

**This work will lead to a hybrid biorefinery design that enables the production of jet and other hydrocarbon fuels from biomass in an environmentally sustainable, cost-effective manner that will facilitate reduction in imports of foreign oil and improve the U.S. competitive advantage in renewable technologies.**

# Commercial Relevance
# A Place To Transfer Learnings

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***Aerial View of Freedom Pines, Soperton, Georgia***
***125 TPD Infrastructure in Place***
***to Process Woody Biomass***

# Publications/Presentations

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- PNNL and Imperium Aviation Fuels were interviewed for an on-line article in Physics Today which highlighted the LanzaTech led DOE CRADA project. http://www.physicstoday.org/daily_edition/down_to_earth/flying_high_on_biomass
- PNNL gave an invited presentation at the Future Energy Conference, Northwest Bioenergy Research Symposium in Seattle WA on November 13, 2012. The title of the presentation was "Northwest Efforts Toward Producing Aviation Fuels Using Hybrid Approaches."