2013 DOE Bioenergy Technologies Office (BETO) IBR Project Peer Review

Demonstration of a Pilot Integrated Biorefinery for the Economical Conversion of Biomass to Synthetic Diesel Fuel

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and

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W. Sacramento, CA and Toledo, OH

Project Description

REII Headquarters:	Sacramento, CA
Project Location:	Toledo, OH
Feedstock:	Wood (0.15”-1.00” chips) and Rice Hulls (whole)
Feedstock Input:	25 dry ash free ton (daft)/day
Product Output:	54 gallons/daft of premium synthetic diesel fuel
GHG Reduction:	89% (field to engine use)

Rice Harvest Residues

Wood Residues

Thermochemical Conversion (TCC)

Biomass Pyrolysis & Steam Reforming

RED LION BIO-ENERGY

Syngas

Liquid Fuel Production (LFP)

Direct Fuel Production

PACIFIC RENEWABLE FUELS

Premium, Synthetic Diesel Fuel

Project Description

25 tpd Integrated Biorefinery (IBR) Plant [Construction Completed (3/2012)]

Project Overview – Quad Chart

Timeline

Project Start Dates

BP-1: 2nd Quarter 2010
BP-2: 2nd Quarter 2011
BP-3: N/A

Project End Dates

Plant Construction:	3/2012
Plant Test/Validation:	4/2012-7/2013
IE Test:	6/2013
Final Report:	9/2013

Project Development

Testing and Validation:	75% Completed
Project Costs:	On Track
Project Schedule:	6 Month Extension
Project Scope:	On Scope
Project Completion:	09/30/13

Budget

DOE Share: $19.6 M
Contractor Share: $5.8 M
2010 Budget: $1.06M; 2012 Budget: $8.21M
2011 Budget: $6.61M; 2013 Budget: $3.72M

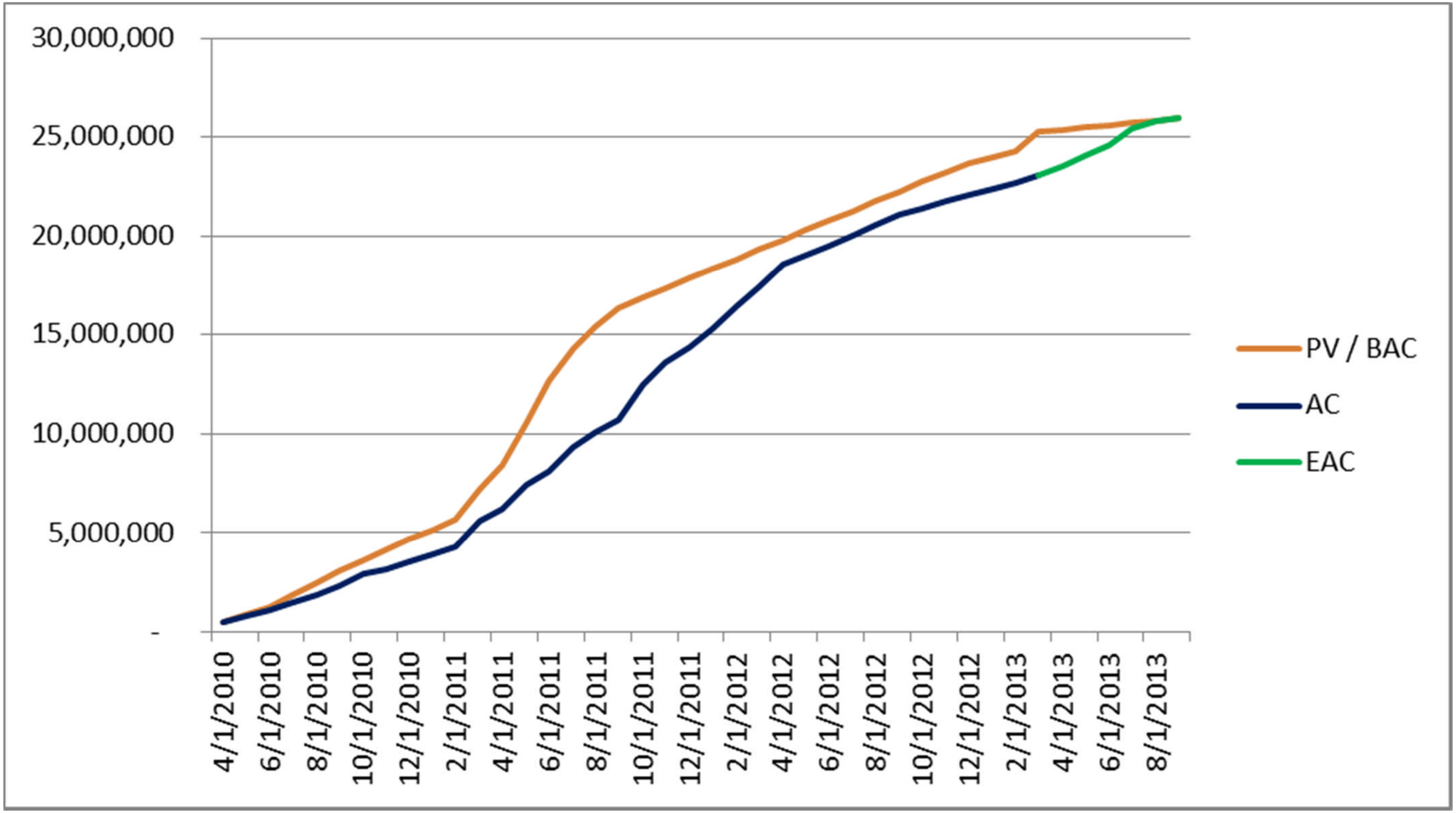
Project Participants

Interactions/collaborations: (**see next slide**)
IP Licenses: Red Lion Bio-Energy (RLB) & Pacific Renewable Fuels (PRF)
Project Management: REII
Construction Management: RLB and REII
Start-up & Commissioning: REII, RLB and PRF
Operations: REII, RLB and PRF

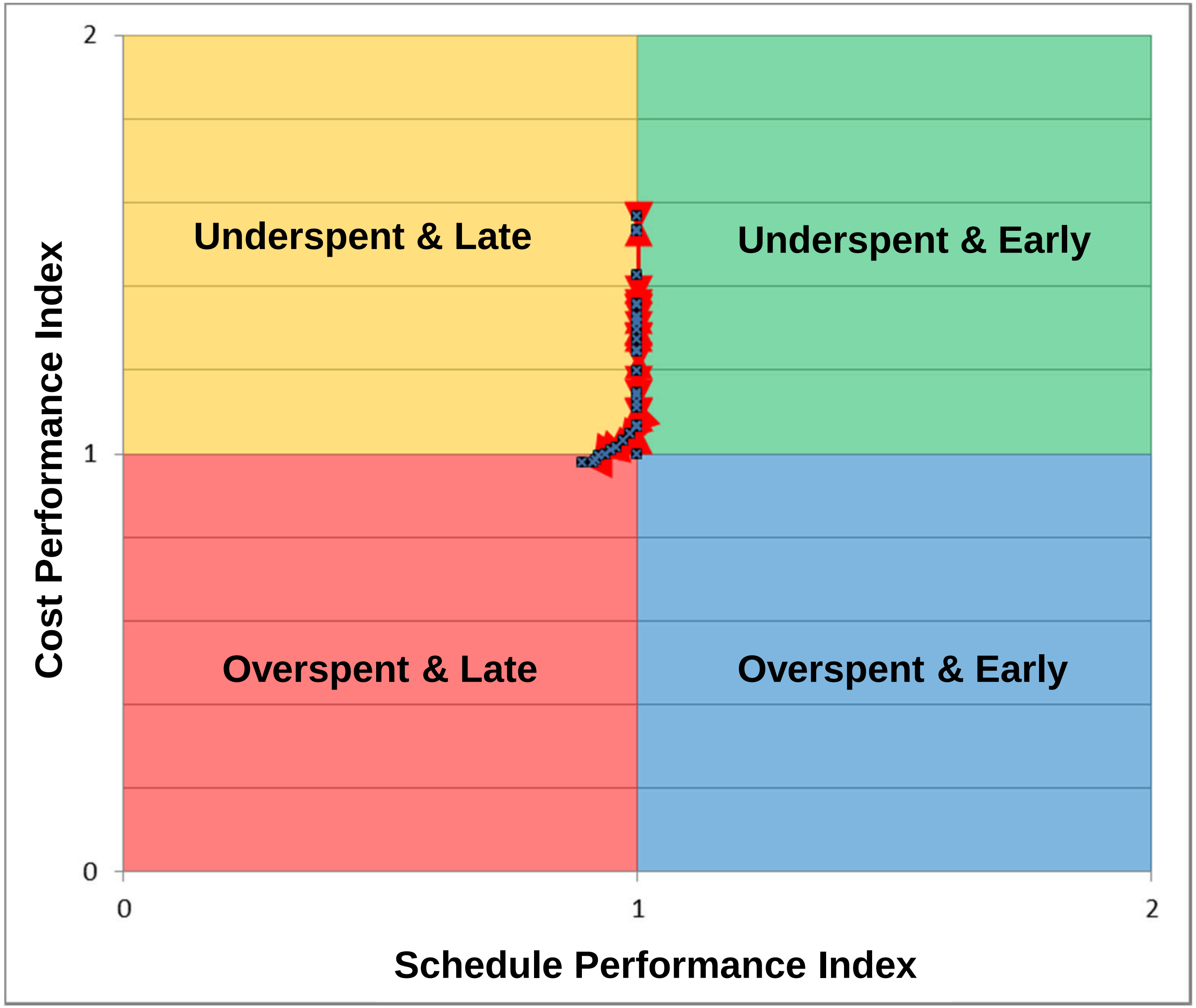
Key Project Interactions/Collaborations

Project Participants	Responsibility
Renewable Energy Institute (REII)	IBR Project Management and Technical Oversight
Red Lion Bio-Energy (RLB)	Manage Design, Procurement, Construction & Operations
Pacific Renewable Fuels (PRF)	Manage Design, Procurement, Construction & Operations
Synterra Energy (RLB/PRF JV)	Commercialization of IBR Technology
Midwest Terminals (MT)	Biomass Storage
Labyrinth (LAB)	Permitting Support
Worley Parsons (WP)	Engineering Support
Desert Research Institute (DRI)	Characterization of Syngas & Catalytic Reactor Products
National Renewable Energy (NREL)	Real-Time Analysis of Syngas
Bureau Veritas (BV)	Characterization of Syngas, Wastewater and Ash
Solar Turbines (ST)	Power Generation for Commercial Facilities
University of Toledo (UT)	Optimization of Biomass Pyrolysis Operating Conditions
Quanta Services (QS)	Commercialization Partner

Cost and Schedule Performance (Spend Plan)

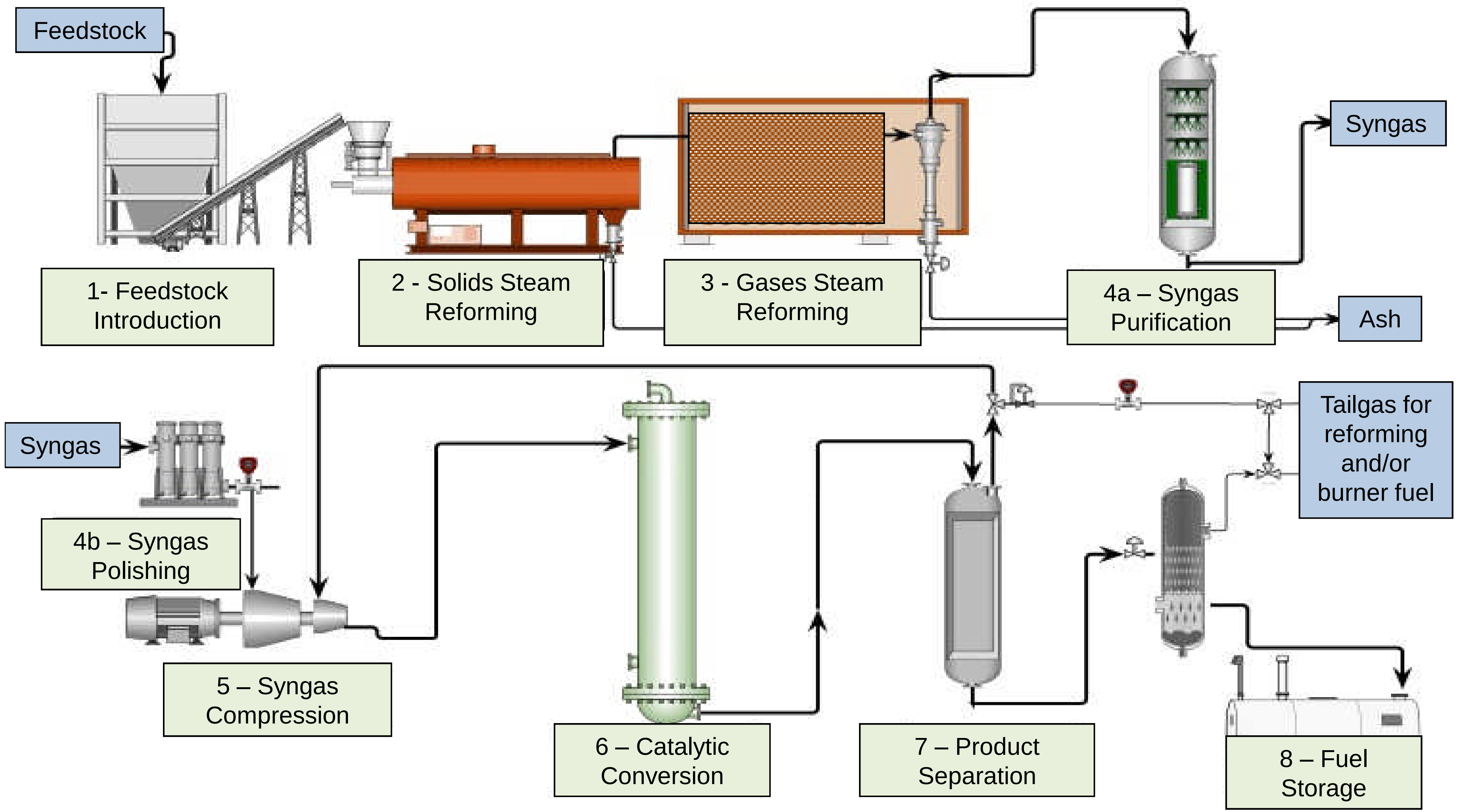


Cost and Schedule Performance (Earned Value)



- ✓ This project will be completed within the original scope and original budget provided by DOE
- ✓ The project recently received a project extension to 9/2013
- ✓ The project will have contributed more than the required cost share to the project by the close-out of the contract.

Project Overview
Key Unit Operations



Project Overview
Key Unit Operations

Thermochemical Conversion (TCC) System (Unit Processes #1-4A)

Project Overview
Key Unit Operations

Wood to Syngas Production
Chemical Processes Determined from Plant Validation Tests

Unit Process #2 (Slow Pyrolysis)

$C_8H_{14}O_5 = C_7H_8O_2 + H_2 + CO + 2\ H_2O$ (Eq. 1)

($C_8H_{14}O_5$: Wood Elemental Composition)
(*$C_7H_8O_2$: Guaiacol Molecular Composition*)

Unit Process #3 (Steam Reforming of Gas-Phase Organics)

$C_7H_8O_2 + 5\ H_2O = 5\ H_2 + 3\ CO + 2\ CO_2 + 2\ CH_4$ (Eq. 2)
$CO + H_2O = CO_2 + H_2$ (Eq. 3)

Overall Process Reaction Stoichiometry (Combine Eq. 1-3)

$C_8H_{14}O_5 + 4\ H_2O = 7\ H_2 + 3\ CO + 3\ CO_2 + 2\ CH_4$ (Eq. 4)

Project Overview
Key Unit Operations

Liquid Fuel Production System (Unit Processes #4b – #8)

Project Overview
Key Unit Operations

Liquid Fuel Production System (Unit Process # 6- Catalytic Reactors)

Project Overview
Key Unit Operations

Diesel Fuel Production from Syngas
(example for Decane)

$$21\ H_2 + 10\ CO = CH_3\text{-}(CH_2)_8\text{-}CH_3 + 10\ H_2O$$

Primary Product

Diesel Fuel (C_8-C_{24} HC's)

Minor Products

Wax (C_{24} – C_{45} HC's)

Tailgas (C_1-C_7 HC's)

1 – Project Management
Technical Approach

Performance Tests and Plant Process Verification

1. Run IBR plant under a wide variety of operating conditions
2. Determine syngas purification efficiencies
3. Determine carbon conversion efficiencies
4. Determine syngas composition and contaminant levels
5. Characterize and quantify waste products (e.g. ash)
6. Determine catalyst efficiencies and determine catalyst durability and life
7. Determine fuel production under various plant operating conditions
8. Determine co-products under various plant operating conditions
9. Quantify air emissions and water effluents

1 – Project Management
Technical Approach

Performance Tests and Plant Process Verification

10. Determine the physical & chemical properties of the synthetic diesel fuel

11. Carry out engine performance testing of the fuel

12. Use the above performance data for:
    - ✓ Assessing potential flaws in major unit processes, minor components, control systems and instrumentation
    - ✓ Determining optimum plant operating parameters
    - ✓ Developing chemical and engineering process models
    - ✓ Design of the first commercial scale IBR plant
    - ✓ Training future plant operations personnel

1 – Project Management
Management Approach

IBR Project Management

Weekly team technical and safety meetings;
Project reporting to DOE and IE every two weeks
Budgeting and accounting
Concurrent engineering
Value engineering
Design for manufacturing
Plant design (P&ID's)
Failure mode and effects analysis (FMEA)
Process hazards assessments
Risk management planning
Life-cycle assessments (LCA's)

1 – Project Management
Management Approach

Management of Commercial Deployment of IBR Technology

Commercial plant design (P&ID’s)
Design for manufacturing
Failure mode and effects analysis (FMEA)
Process hazards assessments
Risk management planning
Feedstock resource assessments
Market analysis (product off-take)
Techno-economic analysis

2 – Technical Accomplishments
Progress/Results

1. Plant performance and validation tests were initiated on May 9, 2012

   - ✓ No severe problems (showstoppers) have been encountered
   - ✓ Moderate process problems were encountered during tests (e.g. leaks, bearing failure, flow meter reading errors, etc.) and repairs successfully made

2. Fourteen test campaigns have been carried out successfully to date

   - ✓ The plant has been operated for a total of > 650 hours
   - ✓ A vast body of performance data has been generated
   - ✓ This data has been evaluated using thermodynamic and statistical models
   - ✓ Optimum plant operating conditions were derived from these models.
   - ✓ Subsequent validation tests verified these models

2 – Technical Accomplishments

<u>Significant Results</u>

It has been demonstrated from testing and validation of this IBR plant that:

- The unit processes selected for integration are entirely capable of efficiently and economically converting most biomass feedstocks to premium 'drop-in' diesel fuel at the commercial scale.

- This integrated bio-refinery eliminates several unit processes that competing technologies typically deploy. This reduction in complexity results in lower Capex and operating costs for commercial scale plants.

- This thermochemical conversion process significantly reduces the production of tars typically found in traditional air-blown, oxygen blown or plasma processes. As a result, the need for costly syngas purification processes is significantly reduced.

2 – Technical Accomplishments

Significant Results

It has been demonstrated from testing and validation of this IBR plant that:

- Syngas is produced directly at the proper stoichiometric ratio for H_2/CO of ~2.1/1.0 (ideal for diesel fuel production) without requiring water gas shift, hydrogen addition, membrane gas enrichment or other process augmentation. This advancement results in a significant reduction of Capex and operating costs for commercial scale plants.

- The liquid fuel production (LFP) system is able to directly produce premium, synthetic diesel fuel using next generation, “designer” catalyst (patented) and high efficiency catalytic reactors. This direct fuel production process eliminates major capital and operating expenses associated with the traditional production of wax from syngas and the refinery-type processing of that wax to produce fuel.

- The LFP system is able to directly produce diesel fuel from many other feedstocks (e.g. natural gas, glycerol, natural gas liquids) that can be effectively converted to clean syngas using alternative thermochemical processes.

2 – Technical Accomplishments

Other Noteworthy Results

1. Optimum plant operating conditions quantified for the efficient thermochemical conversion of wood to clean syngas (ref. slides #1).

2. Feedstock carbon converted to syngas carbon with 85% mass efficiency (ref. slide #2)

3. Syngas directly produced at the optimum H_2/CO ratio of ~2/1 (ref. slide #3)

4. The concentration of tars generated from the process were found to be 100-1,000 times lower than tars typically generated from other more traditional thermochemical processes (technical journal paper in press)

5. The purification system reduces syngas contaminants to levels which do not adversely effect the productivity and durability of the fuel production process (ref. slide #4)

6. Principal chemical processes have been developed and validated for the thermochemical conversion of wood to syngas (ref. slide #5)

2 – Technical Accomplishments

Other Noteworthy Results

7. Optimum catalyst operating conditions have been established for the direct conversion of clean syngas to drop-in, synthetic diesel fuel (slide #6).

8. Substantial quantities of synthetic diesel fuel have been stored for future fuel, engine and vehicle studies.

9. The synthetic diesel is a premium product that utilizes the current diesel fuel infrastructure for in-use and current light-duty and heavy-duty diesel engines, off-road vehicles, military vehicles and stationary diesels (ref. slide #7)

10. Engine dynamometer tests indicate that this fuel can reduce engine-out emissions and improve engine life for most in-use, new and next-generation diesel engines.

11. Unlike ethanol, bio-diesel and other alternative fuels, this synthetic diesel can be used directly in currently available transportation fuel systems, such as pipelines, fuel storage tanks and fuel distribution systems, without any detrimental effects.

2 – Technical Performance
Benchmark of Results Achieved vs. Original Targets

Volume of Syngas Produced	Original Targets	Results Achieved
Volume (SCF/daft) (without recycle)	60,000	56,000 ± 7,000
Volume (SCF/daft) (with tailgas recycle)	74,000	TBD
Syngas Constituents (volume %)		
Carbon Monoxide (CO)	23 ± 3	21 ± 2.0
Hydrogen (H_2)	47 ± 3	46 ± 2.0
Carbon Dioxide (CO_2)	18 ± 3	21 ± 1.5
Methane (CH_4)	12 ± 3	13 ± 1.0
Nitrogen (N_2)	<1.0	<1.0
Syngas (H_2/CO ratio)	2.1 ± 0.3	2.2 ± 0.2

3 - Relevance

The IBR Technology is Environmentally Friendly

Water Use

- Minimal net external water required when using biomass feedstock containing ~20 weight% water.

Energy Demand

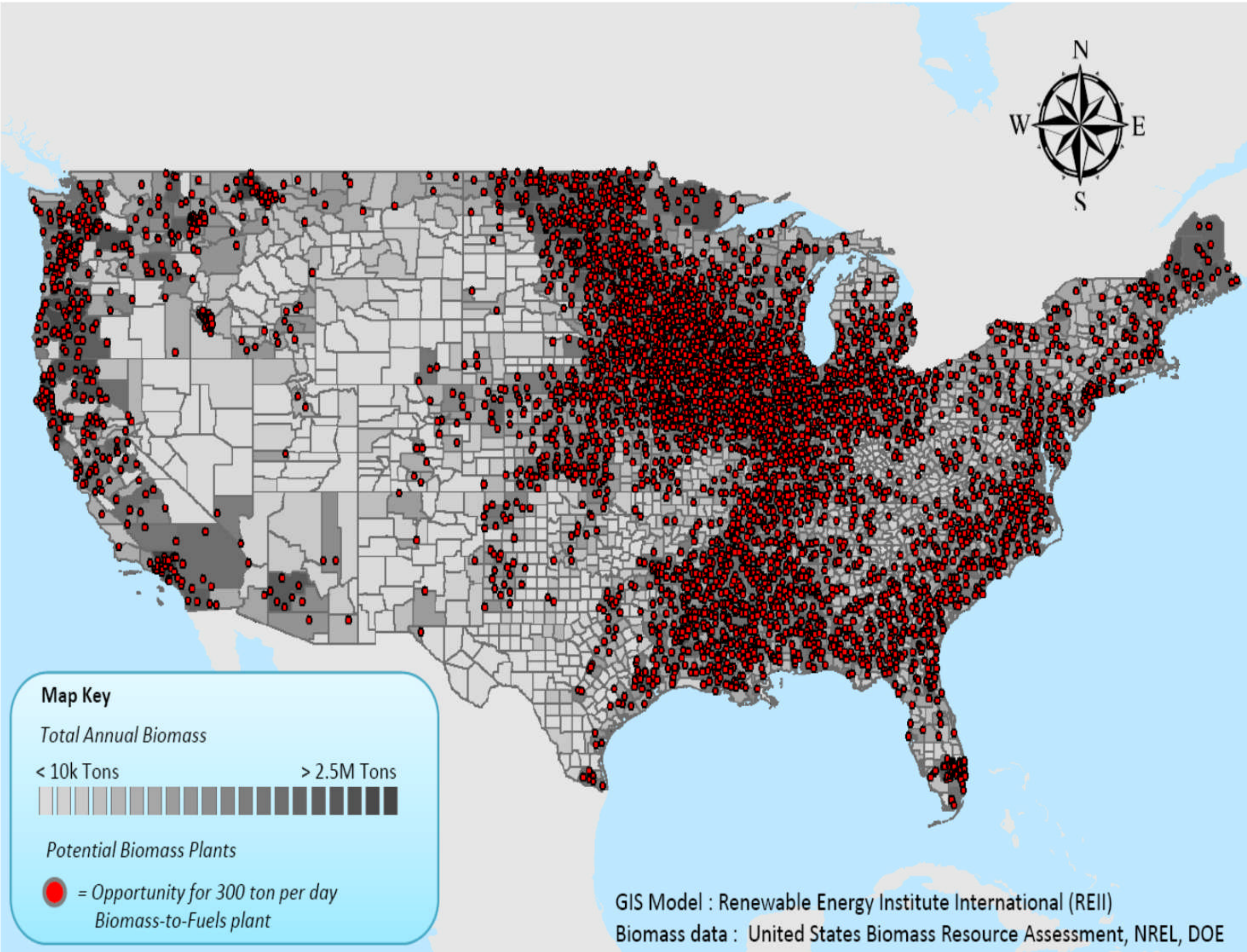
- Natural gas (NG) required (3,420 BTU/gallon)
- Electricity required (0.16 kWh/gallon)
- 42% plant energy efficiency for diesel fuel production

Environmental Sustainability

- 89% reduction in greenhouse gas emissions compared to petroleum gasoline (Argonne Greet model)
- Up to 50% reduction in CO, HC and particulate diesel emissions and 5-10 % reduction in NOx diesel emissions compared to standard CA #2 diesel fuel
- Ash products from forest and agriculture biomass residues are non-toxic
- Plant criteria pollutant emissions are significantly less than that from current natural gas power plants

3 - Relevance

Potential U.S. Locations for 240 daft/day Commercial Biomass to Synthetic Diesel Plants



- Thousands of biomass to synthetic diesel fuel plants are possible based on this IBR technology resulting in the potential production of several billion gallons of diesel fuel per year and creating over 1 million long-term jobs by 2030.
- This premium drop-in diesel fuel is ideal for in-use, current and future vehicles.

4 – Critical Success Factors

Critical Success Factors that define Technical and Commercial Viability

✓ Successful re-design and validation of a more robust feedstock introduction and ash removal system to insure long-term, effective operation

✓ Effective updating of the IBR commercial design with the above major modifications as well as minor changes to insure plant reliability (e.g. expansion joints where vibration may create stress in unit process connectors).

✓ Securing equity financing from farmer's co-operatives and debt financing from farmer's banks for deployment of the first commercial plant in Northern CA's agriculture communities.

✓ Deploying the first commercial plant at a location that meet the following requirements:

- An abundant year-round supply of feedstocks at $40/daft or less
- An appropriate plant site with a good transportation infrastructure for feedstock delivery and product off-take
- A high level of support from local residents and government organizations

4 – Critical Success Factors

Top Challenges to Achieving Successful Commercialization

- ✓ The current adverse equity market for commercial financing of biomass to fuel plants due to the failure of technologies that were not ready for commercialization
- ✓ The proper choice of competent engineering firms to support procurement, construction and training
- ✓ The right selection and sourcing of all minor and major components to insure robust operation 24/7 for many years of plant operation.

Risks Successfully Mitigated

- ✓ Upgrading of biomass introduction and ash removal systems to improve reliability
- ✓ Thermal insulation of sensitive components to prevent freezing during very cold climate conditions.

5. Future Work

The Key Remaining Milestones for the IBR Project

- ✓ Finish last phase (#3) of plant testing/validation
- ✓ Carry out Independent Engineer (IE) test
- ✓ Complete data analysis and final report
- ✓ Project Completion (9/30/2013)

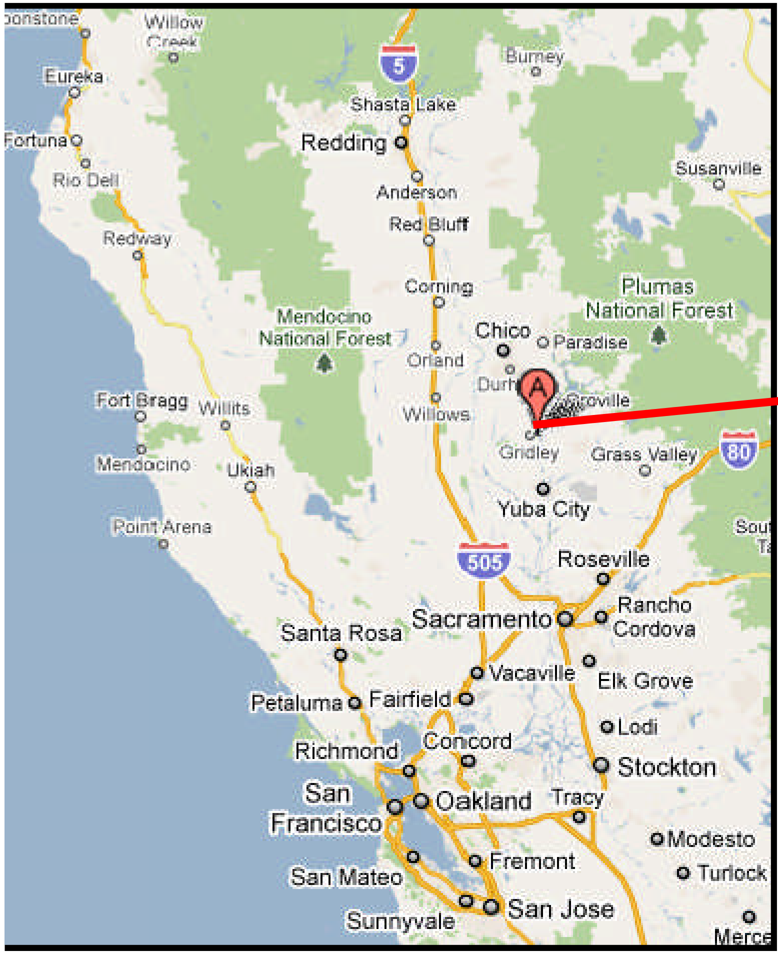
Commercialization of IBR Technology

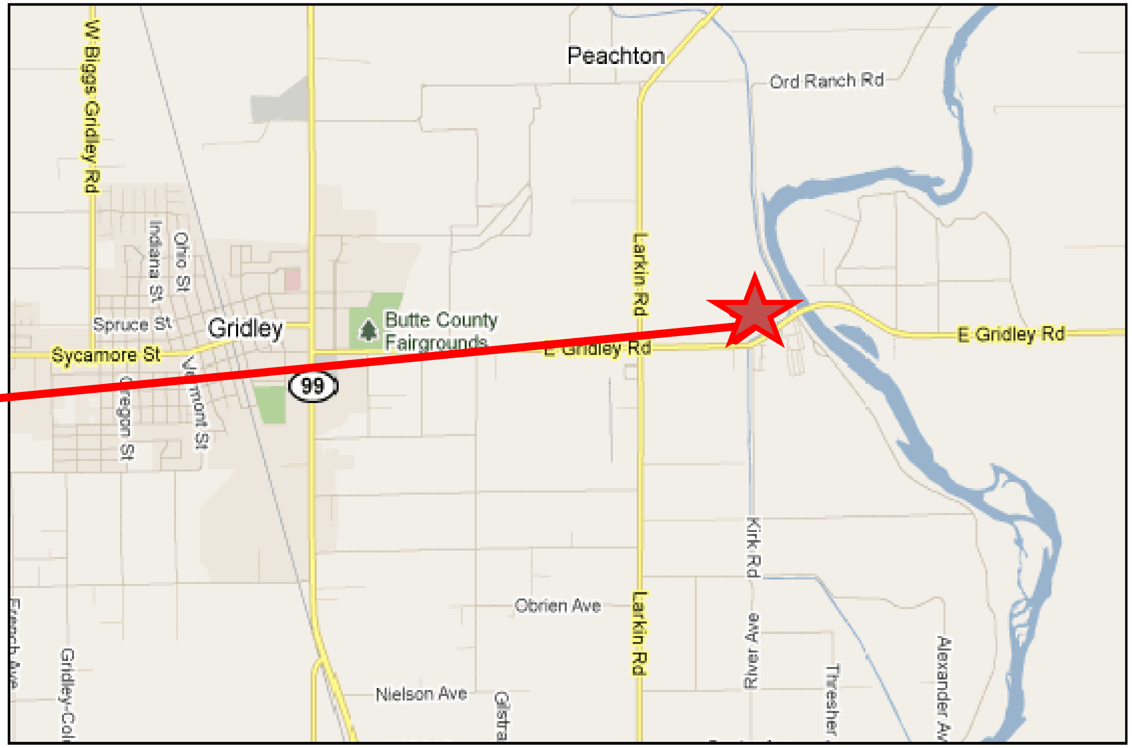
Synterra Energy Corporation has been formed as a 50/50 venture between PRF and RLB to commercialize the IBR technology for conversion of renewable feedstocks to synthetic diesel fuel.

- ✓ The Synterra team has gathered enough technical information from this IBR project to effectively design and deploy the first commercial plant
- ✓ Commercialization business plan developed
- ✓ Comprehensive competitive analysis completed
- ✓ Northern CA has been chosen as the preferred site for the first commercial IBR plant.

5 – Future Work
Commercialization of IBR Technology

Proposed Gridley, CA Plant Location - Adjacent to Wastewater Treatment Plant





IBR Commercial Plant Capacity 240 daft/day

Feedstock: rice harvest waste and other local agriculture, wild-land and forest residues

5 – Future Work
Commercialization of IBR Technology

Feedstocks available within a 50 mile radius of the Gridley plant site*

Fruit processing wastes: 10-15 Kt./yr. @ $10-$20/daft

Rice hulls: 50-100 Kt./yr. @ $15-$20/daft

Rice straw: 500-1,000 Kt./yr. @ $30-35/daft

Nut shells: 500-1,000 Kt./yr. @ $40-45/daft

Orchard wood waste: 15-25 Kt./yr. @ $40-45/daft

Wild-land and forest wood: 50-100 Kt./yr. @ $55-$65/daft

* *Primary query from peer reviewers at 2011 presentation*

5 – Future Work
Commercialization of IBR Technology

California Supporting Organizations and Projects

City of Gridley and Butte County, California

Gridley Biofuels Project (2002 Congressional Appropriation)

Butte County Rice Growers Associations

California Farmers Rice Cooperative

California Department of Agriculture

California Department of Forestry and Fire Protection

California Energy Commission (2008-2011 Project)

California Department of Conservation

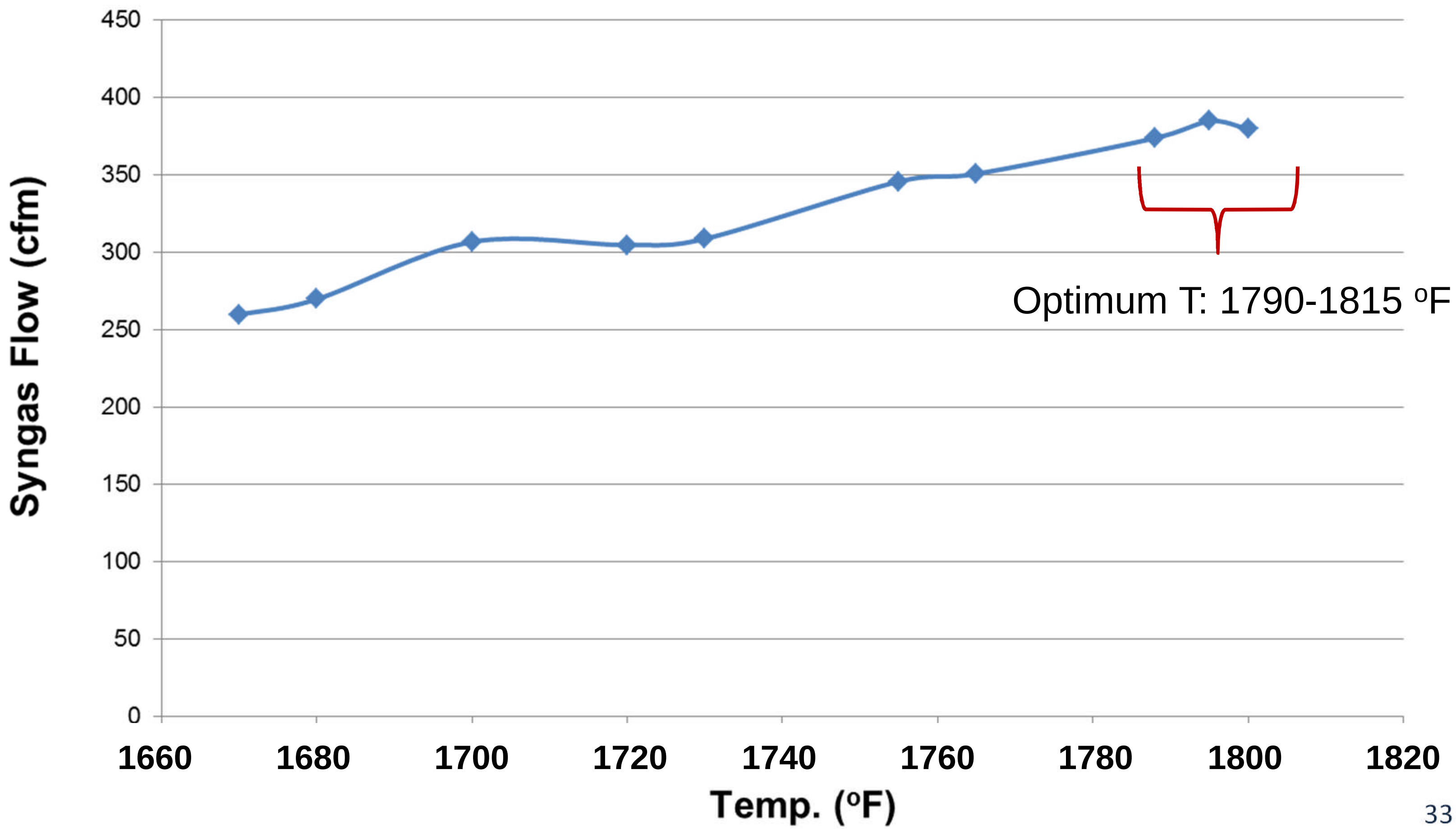
California Air Resources Board

Reference Slides

(background for peer reviewers
& not intended for presentation)

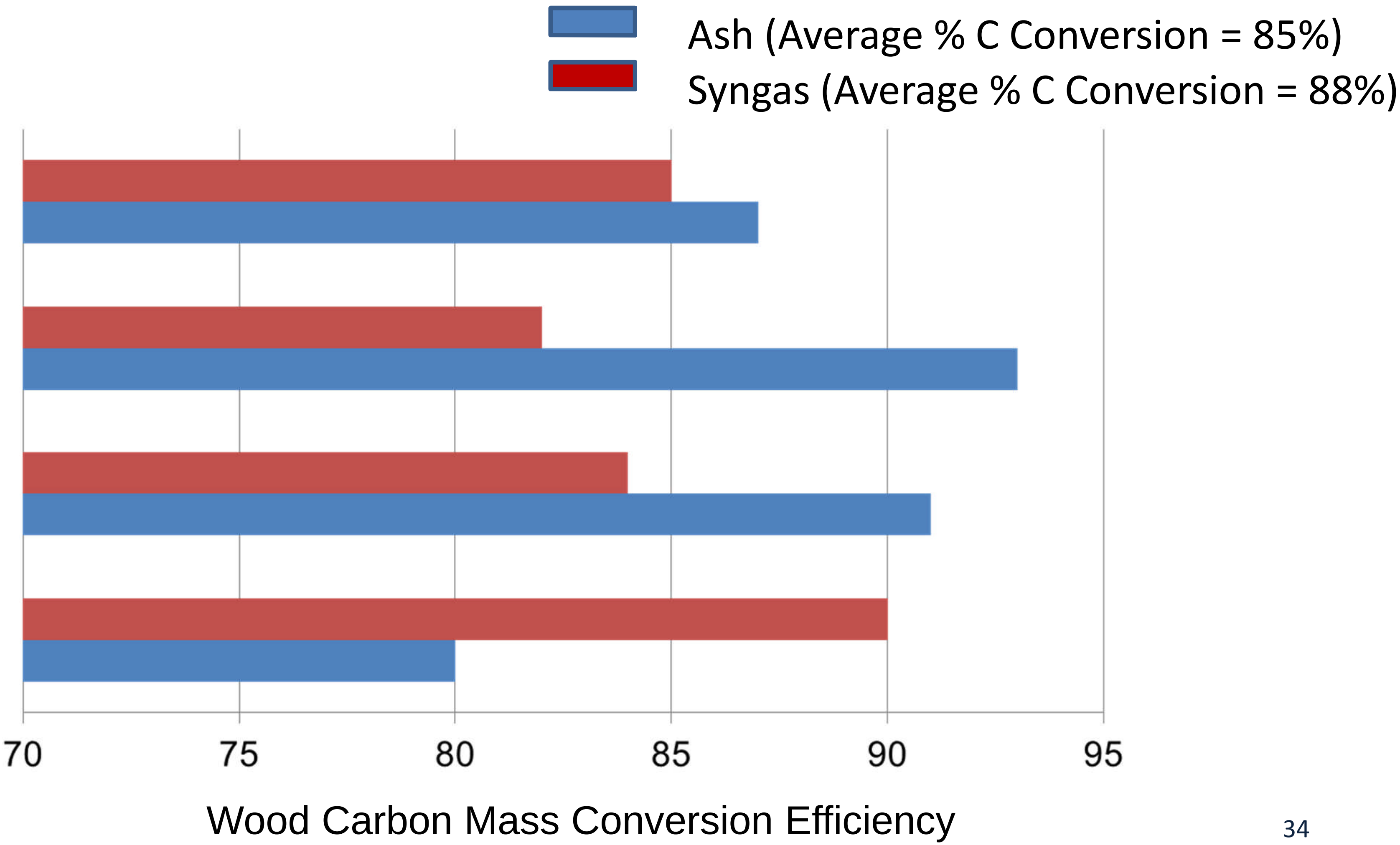
Reference Slide #1

Effect of Unit Process #3 Temperature on Syngas Production (with Unit Process #2 @ 1520 ^{o}F)



Reference Slide #2

Conversion Efficiency of Feedstock Carbon to Syngas Carbon



Reference Slide #3

Syngas Directly Produced at the Optimum H_2 / CO Ratio

Volume of Syngas Produced	Original Target	Results Achieved
Volume (SCF/daft) (without recycle)	60,000	56,000 ± 7,000
Volume (SCF/daft) (with tailgas recycle)	74,000	TBD
Syngas Constituents (volume %)		
Carbon Monoxide (CO)	23 ± 3	21 ± 2.0
Hydrogen (H_2)	47 ± 3	46 ± 2.0
Carbon Dioxide (CO_2)	18 ± 3	21 ± 1.5
Methane (CH_4)	12 ± 3	13 ± 1.0
Nitrogen (N_2)	<1.0	<1.0
Syngas (H_2/CO ratio)	2.1 ± 0.3	2.2 ± 0.2

Reference Slide #4

Concentrations of Contaminants in the Syngas (before syngas scrubbing)

Syngas Contaminants	Average Concentrations
Particulates (including tars)	2,600 ug/m^3
Ammonia	85 ppb
Organic Alcohols & Acids	370 ppb
Phenol	4 ppb

Concentrations of Contaminants in the Syngas (after syngas scrubbing)

	Average Concentrations	
Syngas Contaminants	**IBR Target**	**Results Achieved**
Particulates (including tars)	< 500 ug/m^3	23 ug/m^3
Ammonia	50 ppb	<20 ppb
Hydrogen Sulfide	20 ppb	<5 ppb

Reference Slide #5

Average Reaction Stoichiometry for Syngas Production from Wood

$$C_8H_{14}O_5 + 4\ H_2O = 7\ H_2 + 3\ CO + 3\ CO_2 + 2\ CH_4$$

Comparison of Average Reaction Stoichiometry with IBR Plant Results

Results	**Syngas Composition (Volume %)**				
Syngas Component	**H_2**	**CO**	**CH_4**	**CO_2**	**H_2/CO**
Reaction Stoichiometry (from above equation)	47	20	13	20	2.35
IBR Plant Tests	46	21	13	21	2.19

Reference Slide #6

Optimization of Fuel Production System (LFP)

Parametric studies were carried out to determine the optimum operating conditions for the LFP by varying the following IBR plant conditions during extended test periods

- ✓ Syngas H_2/CO ratios
- ✓ Syngas Gas Hourly Space Velocity (GHSV)
- ✓ Catalyst Operating Temperature

A model was developed from the extensive data set and this model was used to establish the optimum operating conditions for the LFP.

Reference Slide #7
Synthetic Diesel Fuel Properties

Fuel Specifications (ASTM Test #)	***100 % Synthetic Diesel Fuel***	***20 Vol. % Synthetic Diesel Fuel Blend with CA #2 Diesel***	***CA #2 Diesel Fuel***
Cetane Number (D 976)	71	52	45
Fuel Energy Content (BTU/gallon)	123,500	127,600	128,700
Lubricity (HFRR test) (D 6079)	420	404	520
Average Viscosity (D445)	2.2	2.4	2.6
Flashpoint ^oC (max) (D 93)	>68	>58	>52
Pour Point (^oF) (D 97)	34	10 (-4)*	6
Copper Corrosion (122 ^oF) (D 130)	<1.0	<1.0	<1.0
High Temperature Stability (D 6468)	99	99	99
Density (g/ml) (20 ^oC)	0.75	0.79	0.81
Sulfur (ppm)	<0.1	12	15
Aromatics (%)	1-2%	8	10
Olefins (%)	1.5%	10	13
ASTM D 86 Distillation Test [% Fuel Recovered as a Function of T (^oC)]			
5% Recovered	170 ^oC	184 ^oC	180 ^oC
90% Recovered	358 ^oC	326 ^oC	325 ^oC
Distillation End Point	369 ^oC	368 ^oC	365 ^oC
Recovery (%)	98.5	98.0	98.0
Residue (%)	0.5	1.0	1.0

**Pour point reduced as indicated with addition of commercially available pour point additive @ <$0.01/gallon*

Reference Slide # 8
Patents, Awards, Publications & Presentations

- Presided over press conference with Secretaries Chu and Vilsack
- Presentation at the International Energy Agency/DOE Annual Meeting
- Article in Comstock's Business Magazine
- Article in Renewable Energy World
- Published overview of Low Carbon Fuel Standard
- Published overview of the Renewable Fuel Standard
- Presentation to the Sierra Business Council
- Presentation at the West Coast Biomass Conference
- Presentations to the Gridley City Government and Citizens
- Presentation to the Sacramento Science Center
- California Energy Commission Publication
- Several IBR Project Overviews presented to Congressional Representatives
- Patent issued for Direct Production of Diesel Fuel from Syngas
- Paper published in Biomass and Biorefinery Journal
- Paper published in Frontiers of Environmental Science & Engineering Journal