2015 DOE Bioenergy Technologies Office Project Peer Review

Gridley Biofuels Project
Technology Area Review: Thermochemical Conversion

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Alexandria, VA
March 26, 2015

A Rice Field near the Sutter Butte Mountains in Northern CA

Gridley Biofuels Project

Gridley is Centrally Located in the Northern Sacramento Valley

Goal Statement

Project Goal

The primary goal of this final phase (BP2) of the Gridley Biofuels Project during 2015 is to design a 240 daft/day commercial scale integrated biorefinery (IBR), as based upon the results from the Gridley BP1 and DOE IBR projects, for the conversion of rice harvest waste (and other local agricultural wastes) into premium diesel fuel, reformulated gasoline blendstocks, biopower and biochar with an average internal rate of return (IRR) of more than 10% over the plant lifetime. The general process diagram for this plant is shown in the next slide.

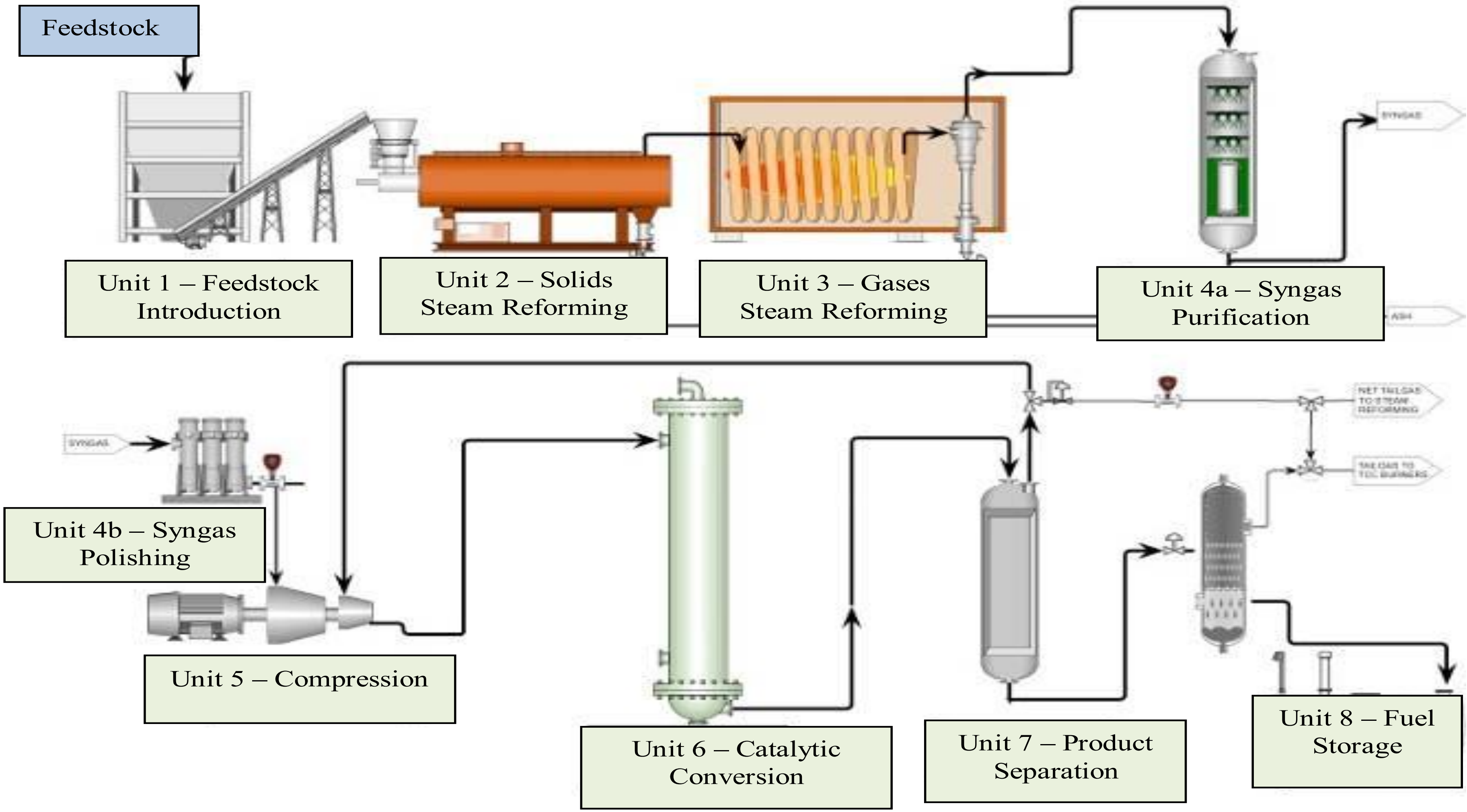
Project Meets the Current Goals & Objectives of DOE BETO

This next-generation thermochemical technology has a high probability of:

- ✓ Economically produce high-quality “drop-in” fuels with environmental benefits
- ✓ Helping support the goals of the Renewable Fuel Standard (RFS)
- ✓ Increasing biopower generating capacity
- ✓ Helping the U.S. move toward a more secure, sustainable and economically sound future

Goal Statement

General Process Diagram for the Proposed Gridley 240 daft/day IBR Plant



Quad Chart Overview

Project Start Dates

Budget Period 1 (2nd Qtr. 2003)
Budget Period 2 (March 6, 2015)

Project End Dates

Budget Period 1 (1st Qtr. 2008)
Budget Period 2 (March 31, 2016)

Budget ($MM)

BP1: DOE (1.67); Cost Share (4.62)
BP2: DOE (3.62); Cost Share (3.42)

Primary Technology Developers

Greyrock Energy & Red Lion Bioenergy

Other Collaborations (2015 Interactions)

National Renewable Energy Laboratory
CA Energy Commission
Butte County EPA
R.W. Beck/SAIC
Desert Research Institute
PACCAR Trucks
World Bank
Health Effects Institute
Thailand NSDA
Northern CA Power Agency (NCPA)
California State University – Sacramento
Chicago Bridge and Iron

Argonne National Laboratory
California EPA
Colusa County EPA
Worley Parsons
Bureau Veritas
Caterpillar (Solar Turbines)
Venture Capital Organizations
U.S. EPA
pH Matter Laboratory
An Oil and Gas Company
PetroTex
Surface Combustion

Quad Chart Overview

Technical Barriers

The biomass introduction system needs to be redesigned to eliminate plugging and degradation of seals.

The capacity of the ash removal system needs to be increased to efficiently collect ash from feedstocks with high ash content (e.g. rice hulls & rice straw).

The steam reformer design for conversion of the biomass pyrolysis products needs to be modified to reduce capital costs and O&M costs and to help guarantee a 20 year life.

Economic Barriers

The recent drop in oil prices has resulted in a reduction in the wholesale value of diesel and gasoline fuels, and a concurrent reduction in natural gas and coal prices has reduced the wholesale value of electricity.

As a result, the internal rate of return (IRR) is not acceptable (near zero) for the current, preliminary commercial scale plant design [*see RS #1*].

1. Project Overview

Project History and Context

Gridley was chosen for this Congressionally Directed Project (CDP) in 2003 since it is an ideal, agriculture based town that is representative of many U.S. towns.

A wide variety of agriculture products are produced within 35 miles of Gridley (*see reference slide #2 for preliminary quantities and costs [see RS #2]*). The harvesting and processing of these products produces millions of tons of waste biomass each year. These biomass residues are ideal feedstocks for the production of fuels and power, which can provide additional revenue.

During Budget Period 1 (BP1) (2003-2007), the most promising thermochemical technology, capable of efficiently converting rice harvest waste directly into “drop-in” biofuels and bioenergy, was identified and tested at the laboratory, PDU, and small pilot scales with promising results.

1. Project Overview

Project History and Context

Budget Period 2 (BP2) was initiated in January, 2008 to track and assess the capabilities of a ~5 ton/day Red Lion Biofuels (RLB) 5 ton/day Thermochemical Conversion (TCC) system and a 1 ton/day (equivalent) Greyrock Energy Fuel Production System (FPS).

As a result of the Gridley effort, REII was awarded an ARRA integrated biorefinery (IBR) project in Dec. 2009 (see next slide). DOE recommended that the effort on Budget Period 2 (BP2) of the Gridley project be postponed until 2015 so that REII and its partner's could focus on the DOE IBR project.

1. Project Overview

Press Conference (Dec. 2009) to announce the DOE IBR Project Award

Left to Right: Dr. S. Chu, U.S. Sec. of Energy; Dr. D. Schuetzle, REII; Congresswoman M. Kaptur; Dr. T. Vilsack, U.S. Sec. of Agriculture

1. Project Overview

Project History and Context

The major focus of the DOE IBR award was to utilize the results from the Gridley Biofuels Project R&D studies to design, deploy, test and validate a 25 dry ash free ton (daft) per day Integrated Bio-Refinery (IBR) during 2010-14.

The demonstration of this IBR technology has been successfully completed and the final DOE project report was published in March 2015.

The key technical accomplishments and results from the Gridley BP1 and the first phase of BP2 are summarized in Section 3 (*Technical Accomplishments, Progress and Results*).

2. Approach

A Gridley Area Farming Family (with faithful dog)

2. Approach (Technical)

As based upon the next generation thermochemical technology identified in BP1, tested during the first phase of BP2, and validated under the DOE IBR project, complete a detailed, final design for the 240 daft/day commercial scale plant which meets the requirements of reliability, environmental stewardship, and economic feasibility (> 10% IRR).

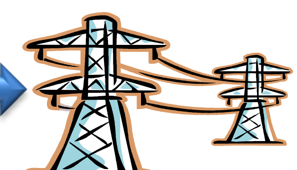
Thermochemical Conversion (TCC)
Biomass Pyrolysis & Steam Reforming

Liquid Fuel Production (LFP)
Direct Fuel Production

Rice Harvest Residues

Wood Residues

Syngas



RED LION BIO-ENERGY

GREYROCK ENERGY

2. Approach (Technical)

The information generated from the last phase of the BP2 and IBR project efforts will be used to support the final conceptual design for deployment of an economically viable, commercial scale plant in the Gridley area including:

- ✓ Process flow description
- ✓ Process flow diagram
- ✓ Site plan/equipment layout
- ✓ Capital cost
- ✓ Operating and maintenance cost
- ✓ Products and product yields
- ✓ Emissions and waste products

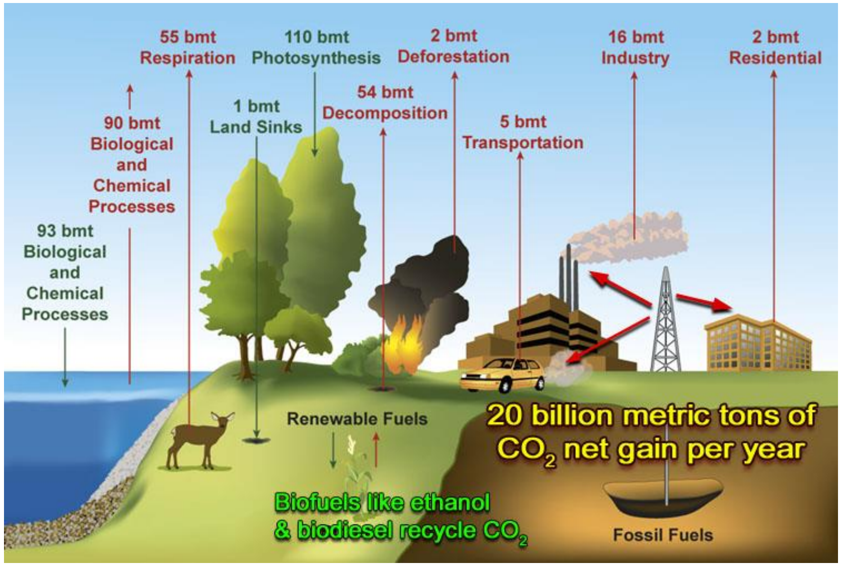
It will be determined how the current plant processes will be modified/upgraded to help insure that the commercial plant will be reliable and efficient over the 20+ year life of the plant.

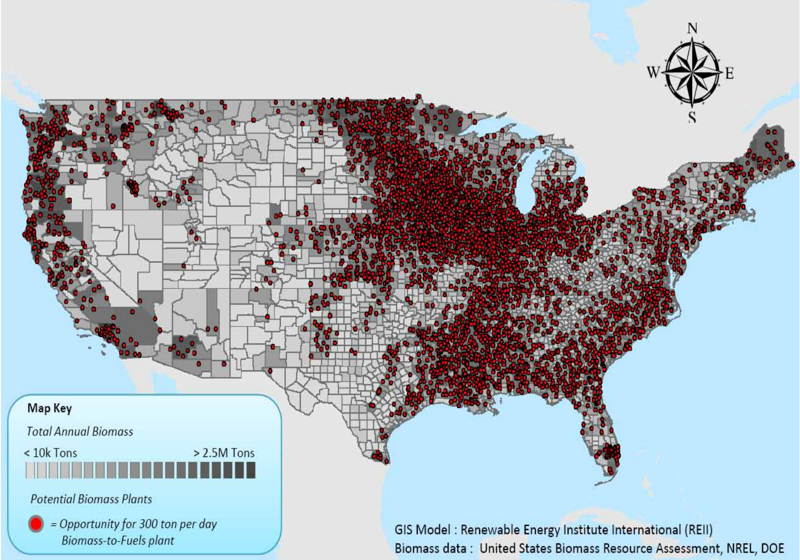
2. Approach (Technical)

Determine the least costly and most reliable sources of rice harvest waste residues available within a 35 mile radius of the plant (see RS #2 for the preliminary estimates).

Carry out environmental assessments on potential air, water and solid waste effluents, and green-house gas emissions

Use REII's TEA and GIS models, to determine where similar plants can be deployed economically throughout the U.S.





2. Approach (Processes)

Management Processes

Budgeting and Accounting; Market Analysis; Environmental Assessments; Document Control; Project Reporting; Feedstock Resource Studies

Engineering Processes

Concurrent Engineering; Value Engineering; Design for Manufacturing; Plant Design (P&ID's), Failure Mode and Effects Analysis (FMEA); Process Hazards Assessments; Risk Management Planning; Techno-Economic Analysis; Life-Cycle Assessments (LCA's)

Commercial Deployment Assessments (REII "5E" Model)

(E1) - **E**valuations that assess the scientific and engineering feasibility/practicality of each unit processes in terms of chemistry, chemical engineering, systems engineering and other technically relevant processes

(E2) - **E**nergy and mass conversion balances and efficiencies

(E3) - **E**nvironmental impact assessments

(E4) - **E**conomic analyses

(E5) - **E**ffectiveness of the proposed socio-political processes needed to obtain government and private stakeholder support

2. Approach (Management)

Critical Success Factors

The recent drop in oil prices has resulted in a reduction in the wholesale value of diesel and gasoline fuels. In addition, a concurrent reduction in natural gas and coal prices has reduced the wholesale cost of electricity.

As a result, the capital, O&M, and other costs need to be reduced and process improvements (e.g. fuel and power production efficiencies) will be needed as outlined in RS #1. Our technical and business teams believe that these technical and business objectives can be met.

Potential Challenges

Since there have been major technical and business failures recently with respect to the commercial deployment of technologies to economically produce "drop-in" fuels from biomass materials, some members of the investment community are not willing to provide further equity investments for the deployment of bio-refineries.

An objective of this effort in 2015 will be to help convince certain equity investors that this next-generation technology approach is sound and that the financial returns will be positive.

3 – Technical Accomplishments

A Rice Processing Plant in the Northern Sacramento Valley

3 – Technical Accomplishments

City of Gridley

REII — Ecological, Economical and Efficient

Thermochemical Conversion (TCC)
Biomass Pyrolysis & Steam Reforming

Liquid Fuel Production (LFP)
Direct Catalytic Fuel Production

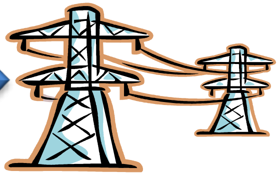
Rice Harvest Waste

Other Agriculture Waste

RED LION BIO-ENERGY

Syngas

GREYROCK ENERGY



It is a non-combustion process that efficiently converts biomass feedstock to high-value products.
It has been validated by over 3 years of testing at the pilot/demonstration scale.
It is more energy efficient and environmental friendly than a NG power plant [see RS #3].
The diesel fuel will reduce vehicle emissions and improve engine life [see RS #4 & RS #5]
The fuel and power is expected to be cost competitive without government incentives or subsidies

3 – Technical Accomplishments

- ✓ The thermochemical process efficiently converts any type of biomass to clean syngas with a H_2/CO ratio of ~2.0/1.0, which is the proper stoichiometric ratio needed for direct conversion to fuel [see RS #6].
- ✓ Biomass up to 2.0”- 2.5” in size, with water content up to 35 wgt. %, and ash content up to 30 wgt. % is acceptable.
- ✓ Tar production is reduced by 100-1,000 times, compared to traditional thermochemical conversion processes, which significantly reduces the need for extensive syngas purification processes.
- ✓ An average of about 15% of the carbon in the biomass is converted to biochar. This biochar has been demonstrated to increase crop yields and reduce water requirements [see RS #7].
- ✓ The syngas is converted directly into “drop-in” fuels using a one-step catalytic process (this is a leap-frog technology over past approaches) [see RS #8].

3 – Technical Accomplishments

- ✓ It has been demonstrated that this IBR process efficiently converts syngas into liquid fuels with an average of 57.6 +/- 3.0 gallons/daft for rice hulls and wood [see RS #8].
- ✓ No decrease in fuel productivity was observed as a result of 8,000 hrs. of laboratory testing and 1,212 hours of IBR plant operation. The projected catalyst life is more than 3 years.
- ✓ Since comprehensive analytical measurements were made during the IBR plant tests, it was possible to achieve a complete plant C mass balance for the IBR plant [see RS #9].
- ✓ The diesel fuel has been tested in current model diesel engines which demonstrates the premium properties of the diesel fuel [see RS #11 & #12]
- ✓ The GHG reduction for biomass collection to fuel use is about 160% [see RS #14 - 2014 collaborative REII, NREL & ANL modeling project].

3 – Technical Accomplishments

Premium Diesel and Reformulated Gasoline Blendstock Product Specifications

Synthetic Diesel Fuel *[see RS #8 & #9]*

Ideal as a blend (20-90%) with petroleum diesel, or as a neat fuel (100%)

It is compatible with in-use, current model and next-generation vehicles

High Cetane (68-72) and contains no sulfur or aromatics

Excellent storage stability (> 3 years without alteration)

Improves fuel economy by up to 0.8% at the 20 volume % blend level

Provides excellent lubricity which improves engine performance & life

Reduces tailpipe emissions from 3-20% from 2014-15 model vehicles

Reduces tailpipe emissions by 50% or more from “in-use” and off-road vehicles

Reformulated Gasoline Blendstock (RGB)

Meets or exceeds all ASTM specifications except for octane

Ideal as a 20 Vol.% blend with petroleum gasoline

4 – Relevance

An Orchard in the Northern Sacramento Valley

4 – Relevance

[Contributions to the BETO Multi-Year Program Plan (MYPP) (11/2014)]

This technology pathway exceeds the current DOE 2017 MYPP objectives of:

- ✓ $3.00/GGE (2011 economics) for the Gridley plant biofuel with GHG emissions reduction of 50% or more (*compared with petroleum fuel*) as based upon $85-$100/barrel of oil (2011-14 average)
- ✓ Feedstock cost below $80/dry ton

Since the wholesale price of diesel and gasoline has dropped significantly during 2015, REII has established a more aggressive objective to sustain an IRR of >10%:

- ✓ $2.48/GGE (2015 economics) for the Gridley plant biofuel with GHG emissions reduction of 50% or more as based upon $50-$60/barrel of oil (2015-16 projected average) (RS #13)
- ✓ Feedstock cost below $40/dry ton

Toledo, OH Station
March 8, 2015

4 – Relevance

Contributions to the BETO Multi-Year Program Plan (MYPP) (11/2014)
Thermochemical Conversion (TCC) R&D Technical Challenges and Barriers

Tt-A: Feedstock Feeding (Barriers Overcome)

Biomass can be feed effectively with the following specifications:

- ✓ 0.20”-2.50” in diameter
- ✓ Water content up to 35%
- ✓ Ash content up to 25%

Tt-A: Feedstock Feeding (Barriers Remaining)

- ✓ The introduction system seals need to be upgraded to improve durability.
- ✓ Ground rice straw tends to form matts since its surface is rough like Velcro.

Tt-B: Feeding of Wet Biomass

- ✓ Feedstocks are efficiently fed and converted when dried to about 35 wgt. % water. Higher levels of water reduce the energy efficient of the plant.

Tt-C: Relationship between Feedstock Properties & Conversion (Barriers Overcome)

- ✓ Feedstock composition does not effect the quality and quantity of syngas produced (no barriers remain).

4 – Relevance

Contributions to the BETO Multi-Year Program Plan (MYPP) (11/2014)
Thermochemical Conversion (TCC) R&D Technical Challenges and Barriers

Tt-D: Biomass Pre-Treatment (Barriers Overcome)

- ✓ Biomass is acceptable with the properties specified in Tt-A (*no barriers remain*).

Tt-E: Deconstruction to Form Gaseous Intermediates (Barriers Overcome)

- ✓ Significant advances have been made on understanding the chemistry of biomass gasification (see RS #14-#17 for publications) (*no significant barriers remain*).

Tt-G: Gaseous Intermediate Cleanup and Conditioning (Barriers Overcome)

- ✓ The process has been optimized resulting in the reduction of tars by 100-1,000 times compared to traditional thermochemical conversion processes (see RS #14-#17 for publications) (*no significant barriers remain*).

Tt-I: Catalytic Upgrading of Gaseous Intermediates to Fuels and Chemicals

- ✓ Syngas is converted directly into "drop-in" fuels using a one-step catalytic process (this is a leap-frog technology over past F-T processes) *(see next slide) (no significant barriers remain).*

4 – Relevance (Summary)

Premium Diesel (41 gallons/daft)

+

Reformulated Gasoline (16 gallons/daft)

+

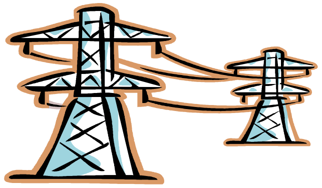
Biochar (300 pds./daft)

International Biochar Initiative

+

Potential Production of Ceramics from Biochar

Electricity (28,200 kwh/daft



4 – Relevance

Contributions to the 2015 BETO Multi-Year Program Plan (MYPP)
Thermochemical Conversion (TCC) R&D Technical Challenges and Barriers

Tt-L: Knowledge Gaps in Chemical Processes (Barriers Overcome)
Significant advancements have been made in understanding the fundamental chemical and physical processes as follows (see RS #14 for publications):

1. The effect of the following processes on biomass deconstruction
   - ✓ Slow pyrolysis reactor design and operating conditions
   - ✓ Steam reforming reactor design and operating conditions
2. The effect of the following processes on direct fuel production
   - ✓ The chemical and physical properties of the catalyst
   - ✓ Catalytic reactor design

Tt-NP: Wastewater Treatment (Barriers Overcome)
The water produced from the syngas scrubbers is typically acceptable for discharge into standard city wastewater treatment plants and the water produced from the catalytic process is recycled back to the TCC system *(no significant barriers remain).*

4 – Relevance

Contributions to the 2015 BETO Multi-Year Program Plan (MYPP)
Thermochemical Conversion (TCC) R&D Technical Challenges and Barriers

Tt-O: Separations Efficiency (Barriers Overcome)
The fuel produced directly is separated using standard distillation process (*no significant barriers remain).*

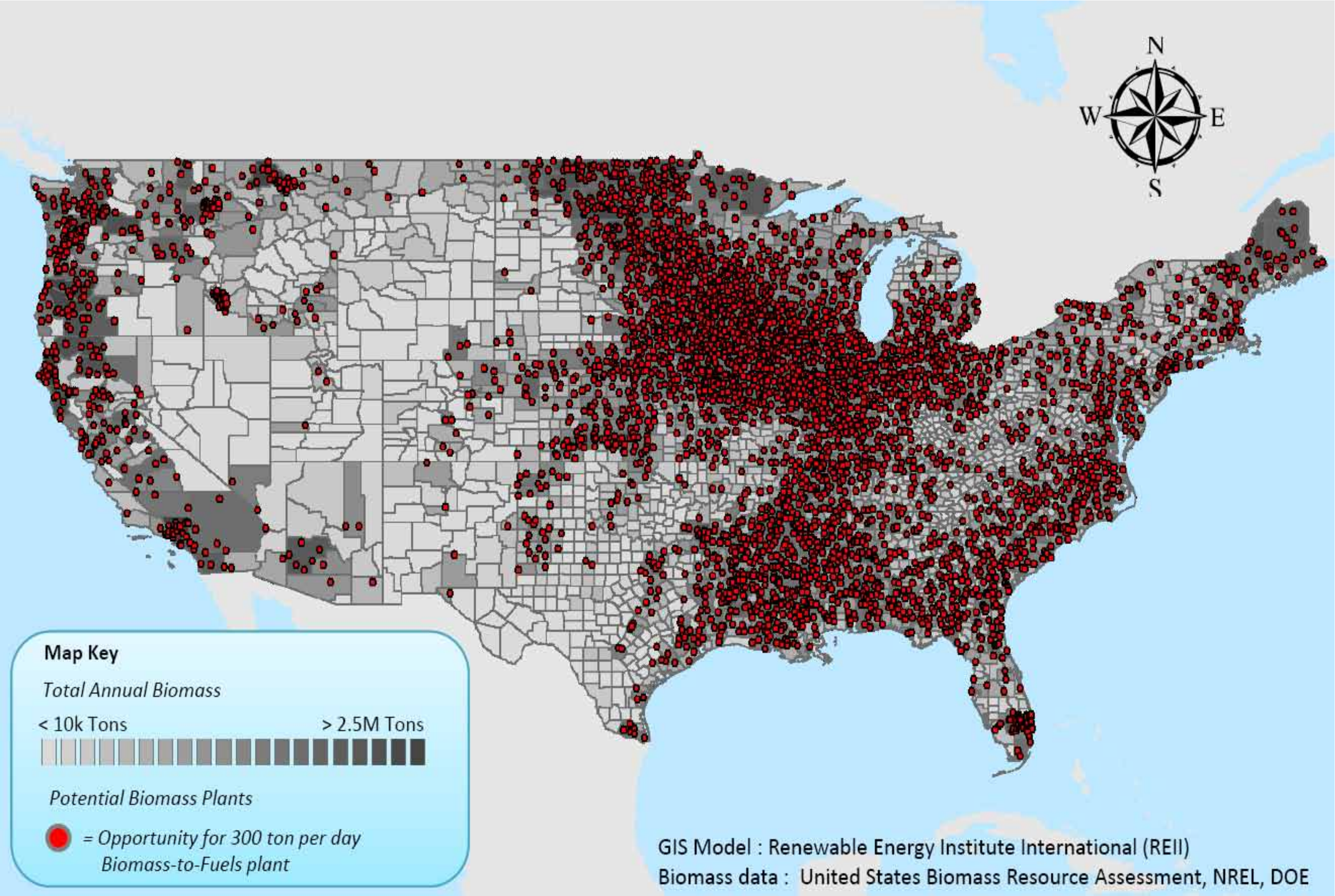
Tt-P: Materials Compatibility (Barriers Overcome)
Materials that have been chosen for the commercial IBR plant that are robust and are expected to have a 20 year lifetime (*no significant barriers remain)*.

Tt-Q: Sensors and Controls (Barriers Overcome)
The instruments and controls for the commercial IBR plant have been developed and sufficiently tested (*no significant barriers remain).*

Tt-R & Tt-T Process Integration and Heat/Power Generation (Barriers Overcome)
Preliminary designs for process integration and heat and power generation have been completed (a final plant design will be completed in 2015).

4 – Relevance

This Map shows the Opportunity for the Deployment of Similar *Gridley IBR Plants in Other U.S. Farming Communities*



5 – Future Work

Fall Harvest in the Northern Sacramento Valley

5 – Future Work

Work to be Completed by Project End (Dec. 31, 2015)

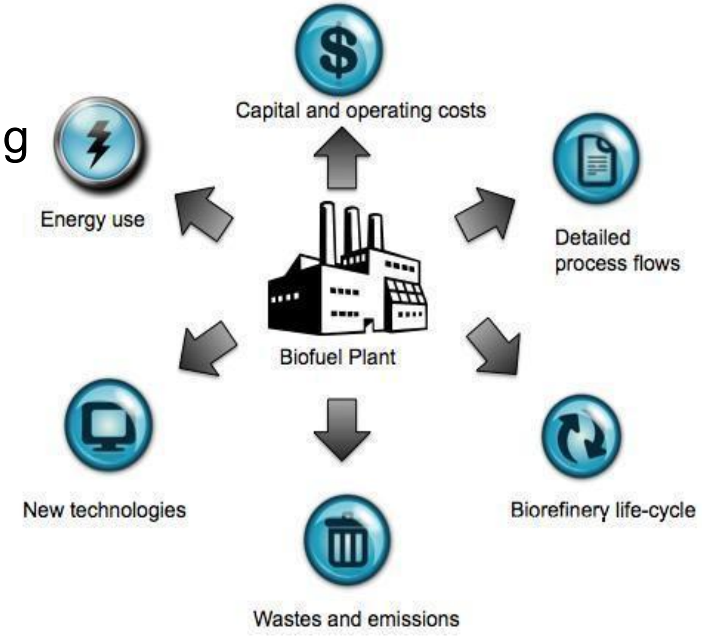
Complete the final, detailed conceptual design for the Gridley plant including:

- Process flow descriptions
- Process flow diagrams
- Site plan/equipment layouts
- Capital and O&M costs

REII's techno-economic models will be employed to determine the IRR for the commercial scale plant though the utilization of a "design for manufacturing" process to reduce capital and O&M costs and to improve plant performance while meeting the project's financial goals of an IRR of greater then 10% of the life of the plant.

In order to minimize the capital and O&M costs for the Gridley plant, major components will be designed using the "design for manufacturing process" as follows:

- ✓ Mass manufactured to reduce component costs
- ✓ Modular and deliverable to nearly any site by truck
- ✓ Easy to install, minimizing field work
- ✓ Similar designs used to eliminate re-engineering
- ✓ Tested to assure the quality of each modular unit



5 – Future Work

Identify the Best Site for the First Plant

Some potential sites under consideration include:
- ✓ A local waste-water treatment plant
- ✓ Gridley industrial Park
- ✓ Nearby local food processing plants
- ✓ Former food processing plants

Rice hulls, rice straw, wood and other agriculture waste resources will be transported to the plant from up to a 35 mile radius.

5 – Future Work

Fuel Properties and Off-Take

Complete testing of mixtures of the reformulated gasoline blendstock with petroleum fuels. Select local distributors for the fuels.

Environmental Assessments

Assess environmental data associated with the construction and operations of the plant and identify potential federal, state and local permits.

Commercial Readiness Plan

Complete a commercial readiness plan

Funding for Plant Deployment

Prepare a funding proposal for potential investors.

City, County and State Approvals

Determine what government approvals will be necessary for deployment of the plant.

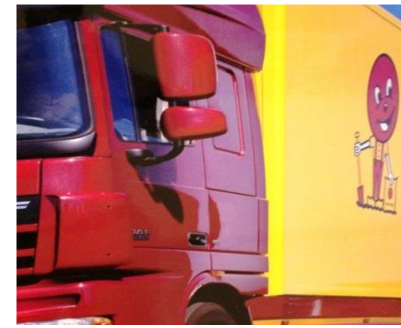
Summary

Diego Rivera – The Harvest

Summary

Next Generation Integrated Bio-Refinery

This next-generation, distributed, IBR technology has the potential of economically converting biomass feedstocks directly to “drop-in” fuels, power and high-value products.



These synthetic bio-fuels can be produced and marketed at a price that is economically competitive with petroleum fuels, even at $50-$60/barrel oil.

Relevance for Gridley and Other Rural Community Towns

Will provide a local, affordable fuel for diesel trucks and off-road diesel vehicles which will reduce emissions, improve engine performance and help decrease U.S. dependence on foreign oil.

Will reduce costs for electricity rate payers which will encourage food processing plants and other agriculture based business to locate in these communities resulting in the creation of jobs and improving the economy vitality of these agriculture communities.

City of Gridley

Gridley Biofuels Project

REII
Ecological, Economical and Efficient

Reference Slides (RS)

A Rice Straw Baler Near the City of Gridley

Reference Slide #1

Current Commercial Plant Metrics and 2015 BP2 Project Goals

Metric	Current Metrics	BP2 Goal
Biomass Input (dry ash free tons/day)	240	240
Natural Gas Input (million scf/day)	0.75	0.75
“Drop-in” Fuel Production (millions gallons)	4.40	4.62
Wholesale Fuel Sales ($/gallon)	3.08	**2.48**
Biochar Sales ($/dry ton)	100	125
Process Capital Cost ($ millions)	31.3	26.6
Site Development Cost ($ millions)	4.6	3.9
Assembly & Validation Cost ($ millions)	4.5	3.8
Total Capital Cost ($ millions)	40.4	34.3
Capex ($/gallon) (*first full year of operation*)	9.18	**7.42**
Plant O&M Costs (excludes feedstock) ($ millions/year)	4.21	**3.79**
Feedstock Cost (50% rice hulls & 50% wood ($/daft))	35.00	30.00
Personnel (FTE’s)	13	13
Financing Assumptions (% Equity)	100%	100%
Internal Rate of Return (IRR)	- 0.2%	**11.6%**

Reference Slide #2

Waste Agriculture Materials available within a 35 mile Radius of Gridley

Waste Agriculture Materials	Average Quantity Available (kiloton/year)	Estimated Cost ($/dry ton)
Rice hulls	332	20
Rice straw	910	35
Orchard and domestic wood residues	170	30
Nut shells	460	40
Wild land remediation wood residues	120	55
Fruit Processing Residues	80	15

Reference Slide #3

Gridley Commercial Plant (current metrics)

Inputs

Wood Biomass
240 daf Tons/day
249.2 dry Tons/day
300 Tons/day (20 wt.% H_2O)
8,586 Btu/daf lb.

Electricity
45,000 kWh/day

Nat Gas (NG)
0.75 MM scf/day

Water (Steam) 47,154 Gal/day

Tail Gas to Burners 4.99 MMScf/day

Outputs

Diesel Fuel
9,677 Gal/day
40.32 Gal/daft wood
123,800 Btu/gal

Gasoline Blendstock
3,782 Gal/day
15.68 Gal/daft wood
116,243 Btu/gal

Biochar
36.0 Tons/day
14,700 Btu/lb.

Wax
67.3 Gal/day
127,000 Btu/Gal.

Water Discharge
12,391 Gal/day
(suitable for Ag use)

Air Emissions (*tons/day*)
0.053 CO   0.009 PM
192.3 CO_2 0.0092 NOx(SCR)

Energy Efficiency
45%

C Conversion Efficiency
53%

Reference Slide #4

City of Gridley

REII Ecological, Economical and Efficient

Heavy Duty Diesel Engine Performance Tests

Reference Slide #5

The % Difference in 2014 Heavy-Duty Engine Emissions for the 20% Synthetic Diesel Blend with EPA/CARB Certification Fuel Compared to a 100% EPA/CARB Certification Fuel

Emission Species	THC	CH_4	NM HC	NOx	CO	CO_2	PM
Units	Grams/KW-hr						
Engine Out Emissions (% Difference)	-9.5	-9.2	-9.5	No Diff.	-11.3	-0.8	-21.1
Tail-Pipe Emissions (after control) (% Difference)	-9.7	No Diff.	-9.7	Below 0.20 EPA std.	-9.5	-1.0	Near zero[1]

[1] *The concentrations of these tail-pipe emission species were near zero and therefore any differences between the 20% blend and certification fuel could not be accurately determined.*

Reference Slide #6

Predicted and Validated Plant Performance Specifications for the Conversion of Wood to Fuel

Average Plant Inputs & Outputs (Thermochemical Conversion)	Gridley BP1 Predicted Values	IBR Plant Validated Values
Slow pyrolysis temperature (ºF)	1,450	1,505 $\pm$ 25
Gas steam reforming temperature (ºF)	1,800	1,803 $\pm$ 12
Operating pressure (psia)	45	30
Air & O_2 usage (lb./daft)	0	0
Steam usage (lb. steam / lb. feed C)	2.0 / 1.0	1.4 / 1.0
Syngas production (scf / daft)	45,000	44,660 $\pm$ 2,100
CO production (scf / daft)	9,450	10,260 $\pm$ 440
H_2 / CO (molar ratio)	2.0	2.00 $\pm$ 0.15

Reference Slide #7

Predicted and Validated Plant Performance Specifications for the Conversion of Wood to Fuel

Average Plant Inputs & Outputs (Thermochemical Conversion)	Gridley BP1 Predicted Values	IBR Plant Validated Values
H_2 (volume %) (dry)	45	46 $\pm$ 2.0
CO (volume %) (dry)	22	23 $\pm$ 1.3
CO_2 (volume %) (dry)	20	18.0 $\pm$ 1.2
CH_4 (volume %) (dry)	12	12 $\pm$ 0.8
$C_2 – C_6$ (volume %) (dry)	1	0.15 $\pm$ 0.10
O_2 (ppm) (dry)	< 500	< 500
Particulates ($\mu g/m^3$)	< 500	440 $\pm$ 140
Benzene (ppm)	not determined	4,600 $\pm$ 850

Reference Slide #8

Predicted and Validated Plant Performance
Specifications for the Conversion of Wood to Fuel

Average Plant Inputs & Outputs (Thermochemical Conversion)	Gridley BP1 Predicted Values	IBR Plant Validated Values
"Drop-in" fuel (gal/daft) (without wax and tailgas recycle) (70% diesel & 30% reformulated gasoline blendstock)	44	57.6 $\pm$ 3.0
Wax side-product (gal/daft)	6.6	0.25 $\pm$ 0.2
Biochar (lbs./daft)	not determined	297
Tailgas side-product (scf/daft) (used for plant gas burners)	12,000	12,200 $\pm$ 1,300
Commercial plant energy efficiency (%)	40	44.8 $\pm$ 1.5
Commercial plant carbon conversion efficiency (%)	40	53.1 $\pm$ 1.2

Reference Slide #9

Carbon Balance for Conversion of
1,000 lbs. (dry, ash free) of Biomass (B) to Products

Components	Lbs. of C in TCC Products	Lbs. of C for the Integrated Plant
H_2	0.0	0.0
CO	417.0	38.4
CH_4	285.0	345.5
CO_2	122.6	97.4
C_2-C_5 HCs	4.2	42.5
Fuels (C_5-C_{24} HC's)	0.0	396.6
C_1-C_4 Alcohols in LFP Water	0.0	8.8
Wax	0.0	4.0
Biochar	135.5	135.5
Tars	1.6	1.6
C in Scrubber Water	13.0	13.0
Total Lbs. Carbon	979	1079
% C Conversion Efficiency	Biomass to CO & Biochar (56%)	Biomass to Fuels & Biochar (53%)

Reference Slide #10

Energy Balance Data for the IBR Plant

Plant Inputs	Plant Energy Input (Billion BTU/day)	% of Total Energy Input
Biomass	4.12	82.07
Natural Gas	0.75	14.94
Electricity	0.15	2.99
Total	5.02	100.00
Plant Outputs	Plant Energy Output (Billion BTU/day)	Energy Efficiency (%)
Diesel Fuel	1.20	23.90
Gasoline	0.44	8.76
Biochar	0.62	12.35
Wax	0.0085	0.17
Total	2.27	45.19

Reference Slide #11

Synthetic Diesel Fuel Properties

(Improved Properties compared to Petroleum Diesel)

Fuel Specifications (ASTM Test #)	Greyrock Synthetic Diesel	US #1 Diesel	US #2 Diesel
Cetane Index (D 976)	**70**	40	40
Fuel Energy Content (BTU/gallon)	123,500	122,300	128,700
Fuel Energy Content (MJ/kg)	**45.3**	43.2	43.1
Flash Point (^{o}F) (D 93)	105-125	100	125
Cloud Point (^{o}F) (D 2500)	28	-54	7
Density (g/mL)(68 ^{o}F)	**0.76**	0.81	0.84
Lubricity (HFRR)(D 6079)	**371**	520	520
Viscosity (mm^2/s) (cSt)(D 445)	2.0	1.9	2.6
Copper Corrosion (D 130)	Class 1a	Class 1a	Class 1a
Oxidative Stability (D 2274)	**0.1**	1.5	1.5
High Temp. Stability (D 6468)	99	99	99

Reference Slide #12

Synthetic Diesel Fuel Properties

(*Improved Properties compared to Petroleum Diesel*)

Fuel Specifications (ASTM Test #)	Greyrock Synthetic Diesel	US #1 Diesel	US #2 Diesel
Sulfur (ppm)	**< 0.1**	15	15
Aromatics (%)	**< 0.3**	21	20
Benzene (%)	**< 0.1**	< 0.1	< 0.1
Olefins (%)	6	2	13
Oxygen Content (%)	**0.21**	ND	ND
Methanol / Ethanol Content (%)	< 0.1	< 0.1	< 0.1
Initial Boiling Point (IBP)(D86)	266	275	360
5 % Point (D86)	342	336	363
50 % Point (D86)	478	412	504
90 % Point (D86)	636	482	640
Final Boiling Point (FBP)(D86)	696	523	689
Recovery (%)	98.5	98.2	98.0

Reference Slide #13

Life Cycle GHG Emission Results for Biomass to Liquid Fuel Production (g CO_2/MJ) for the 240 daft BTL Plant

Scenario	Life Cycle GHG Emissions (g CO_2/MJ)						% GHG Reduction (compared to Diesel)
	Biogenic CO_2 in Fuel	Biochar Use	Feedstock Production	Fuel Production	Fuel Transport & Use	Well to Wheels	
Oil to Gasoline	0.0	0.0	8.1	12.7	73.3	94.1	--
Oil to Diesel	0.0	0.0	8.1	12.5	75.0	95.6	0.0
Wood to Fuel (a)	-78.4	-46.7	25.3	-31.2	80.2	-50.8	-153
Wood to Fuel (b)	-78.4	-46.7	17.2	-31.2	79.8	-59.2	-162
Rice Hulls to Fuel	-79.1	-46.4	12.0	-17.3	80.9	-49.9	-152

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