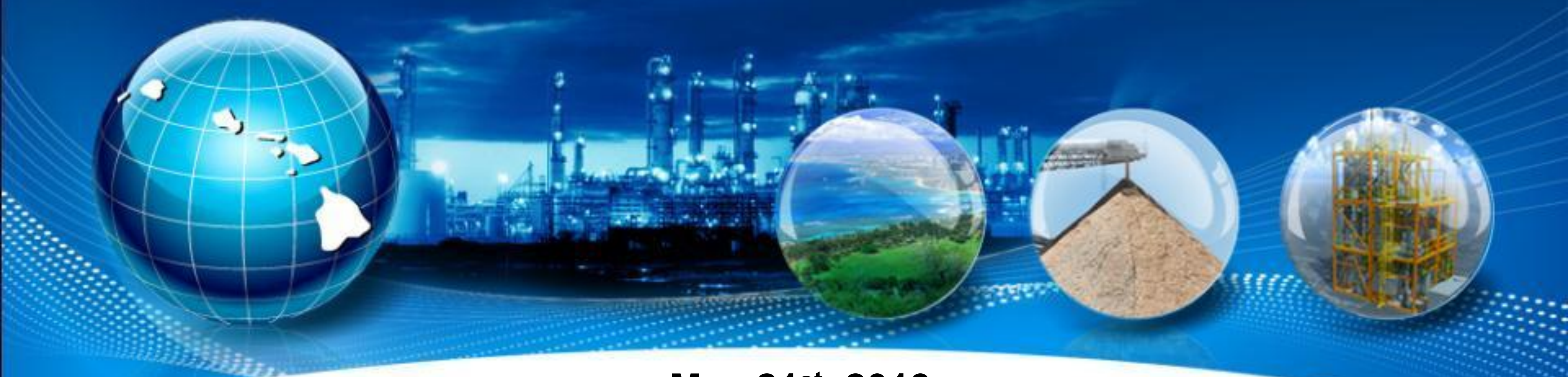
2013 DOE Bioenergy Technologies Office (BETO) IBR Project Peer Review

Sustainable Transport Fuels from Biomass and Algal Residues via Integrated Pyrolysis and Catalytic Hydroconversion



May 21st, 2013

Steve Lupton
Principal Investigator

Honeywell

IBR Scope Block Flow Diagram

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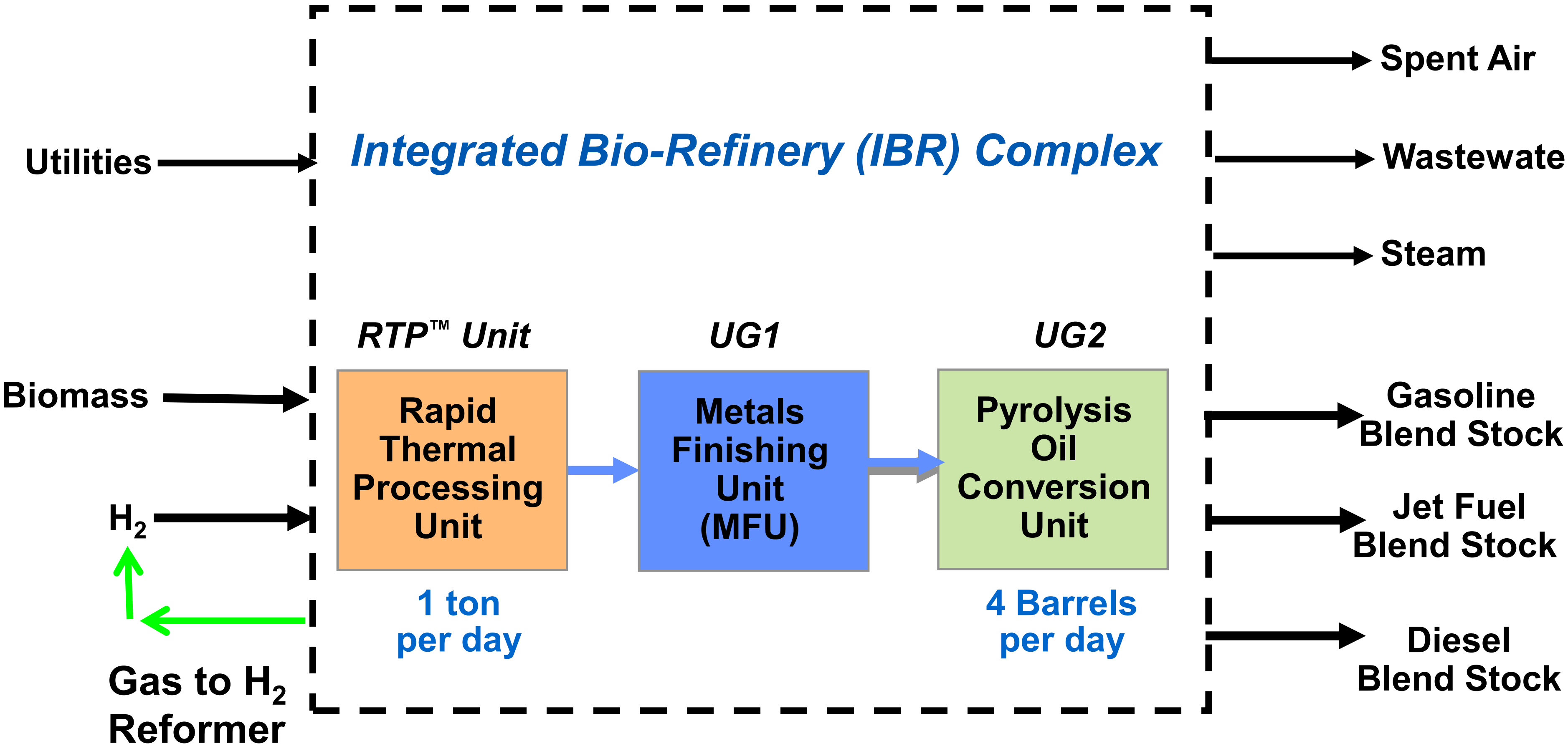

Located at Tesoro Kapolei Refinery and Operated by UOP

Integrated BioRefinery Pilot Plant- Biomass to Transport Fuels

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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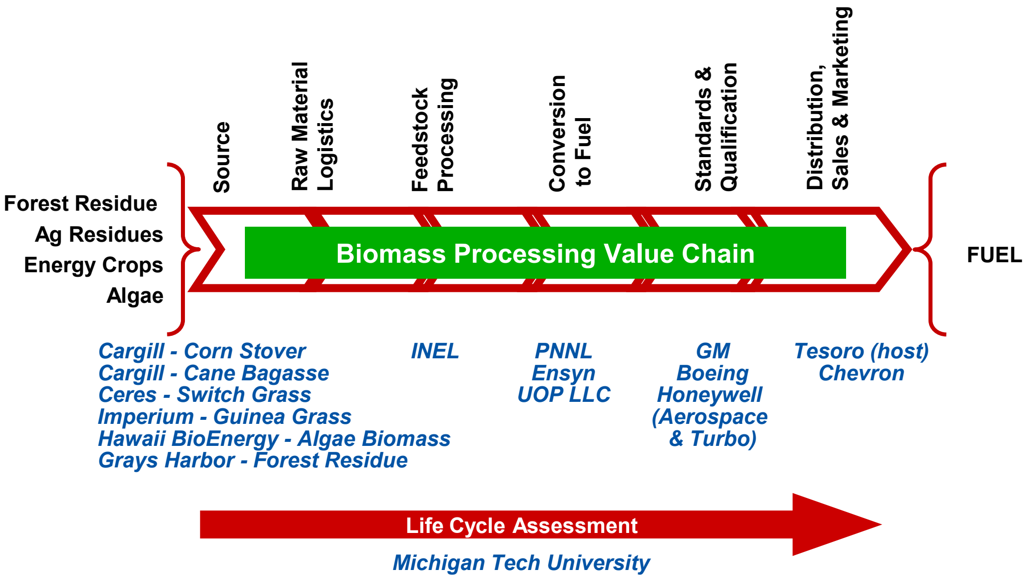
- **$25M Pilot Scale (1 ton/day) Project under the DOE Energy Efficiency and Renewable Energy program and partially funded under the American Recovery and Reinvestment Act.**
- **Plant located at Tesoro/Hawaii refinery, operated by UOP**
- **Commercially relevant biomass feedstocks**
- **Phase I: RTP pyrolysis & RTP Green Fuel stabilization units commissioned in 2012**
- **Phase II: Hydroprocessing Unit, Product Fractionation Unit, &PNNL Catalytic Hydrothermal Gasification Unit commissioning targeted for 2015**



Commercialization Strategy:
Create Bridges Across the Biomass Supply Chain

Project Quad Chart

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Timeline

- Project start date
  - BP 1: Q2, 2010
  - BP 2: Q1, 2011
- Project end date
  - RTP Commissioned 2012
  - Start-up Planned 2015
- Percent complete
  - 50%

Budget

Total Project Funding

Federal	$ 25,000,000
UOP	$ 13,000,000
Total	**$ 38,000,000**

Planned UOP Cost Share 34%

Project Development

Project Status

- Project schedule has slipped 12 months
- Project scope remains unchanged
- Project will be complete by September, 2015

Project Participants

- UOP will Operate Units
- Fabrication of RTP & Upgrader Units by Zeton
- Installation by Ambitech

Project Schedule Versus Baseline

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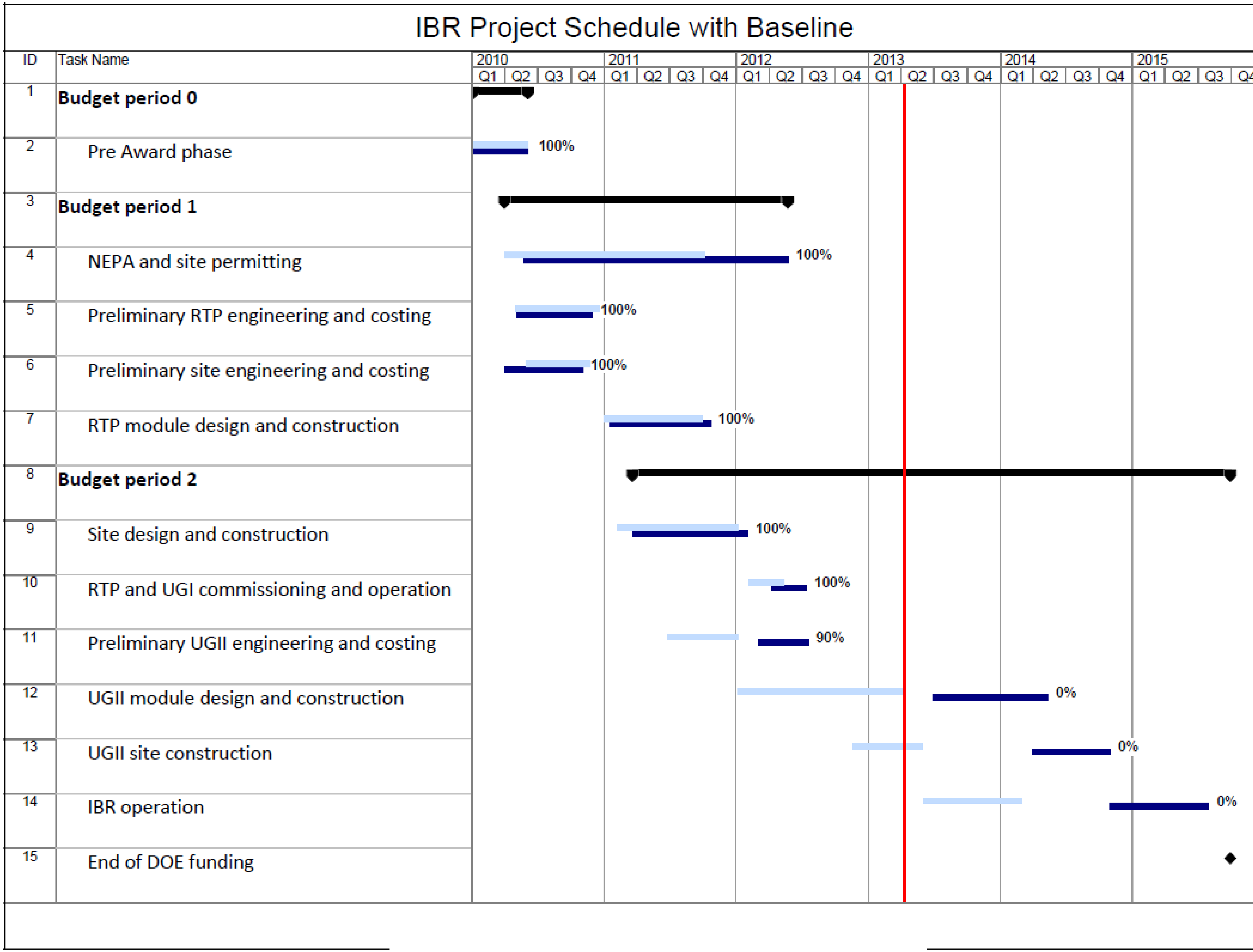

Cost Performance – Federal Funds

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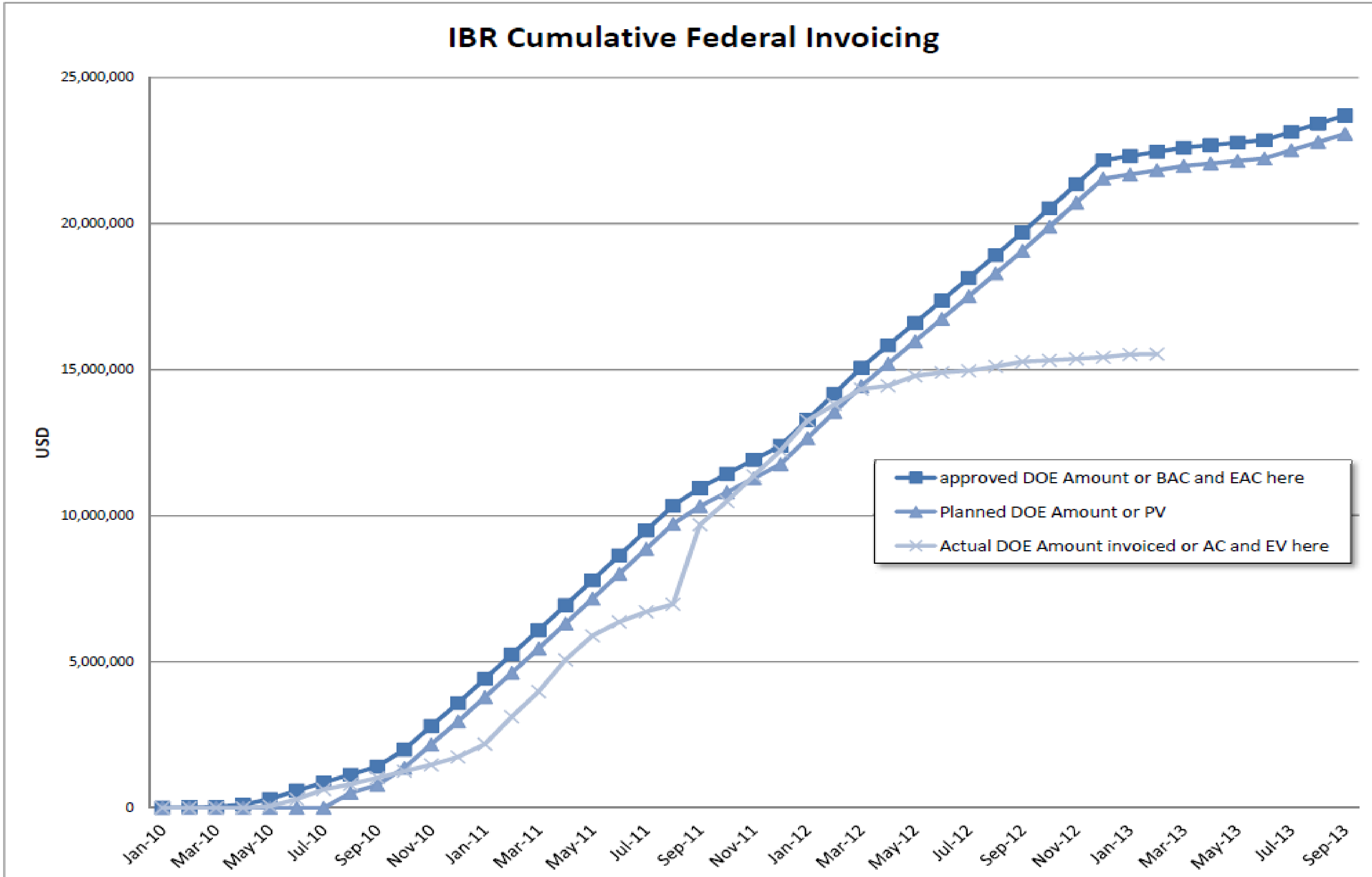

Cost Performance – UOP Cost Share

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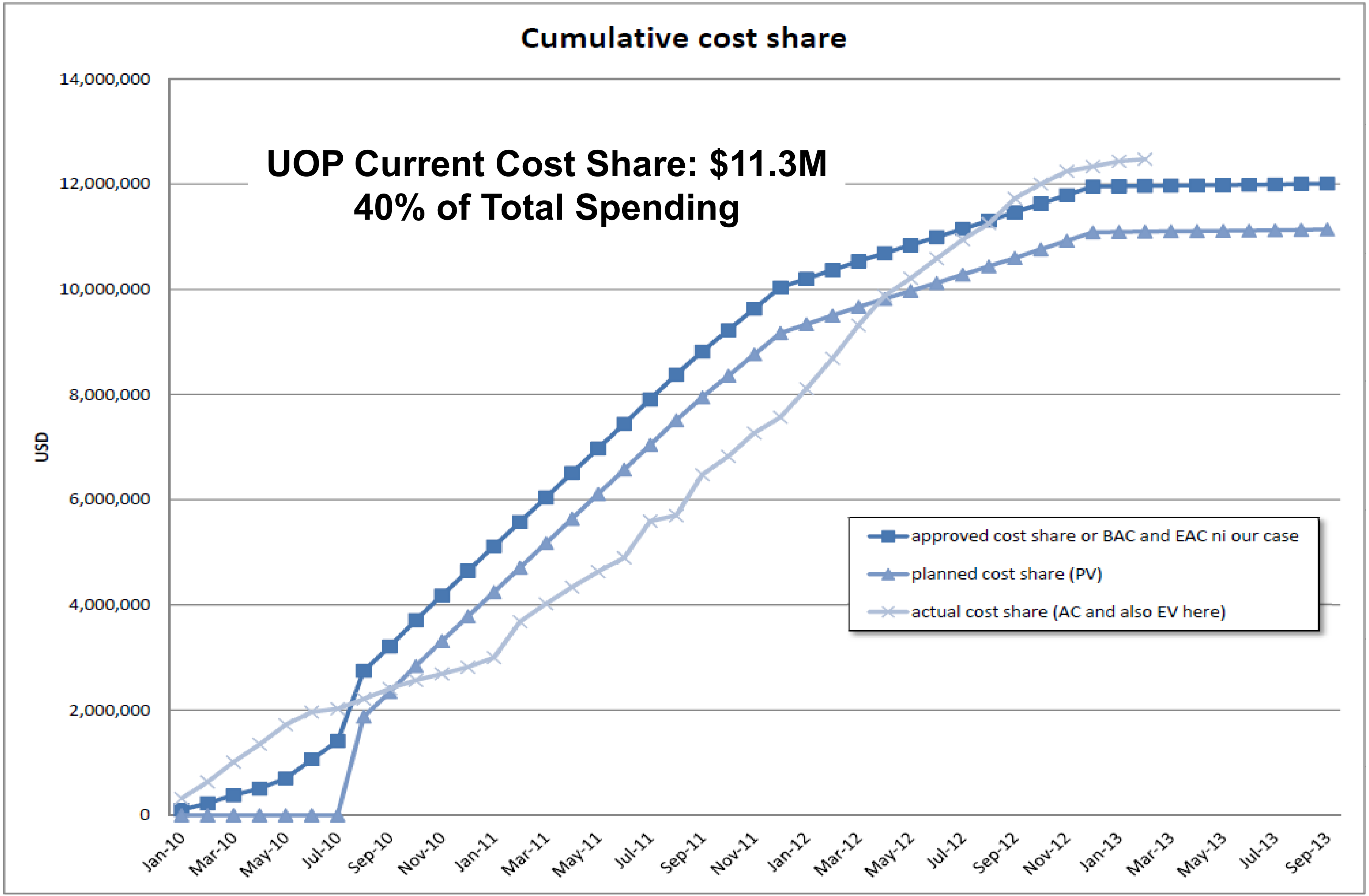

Cost Performance – SPI

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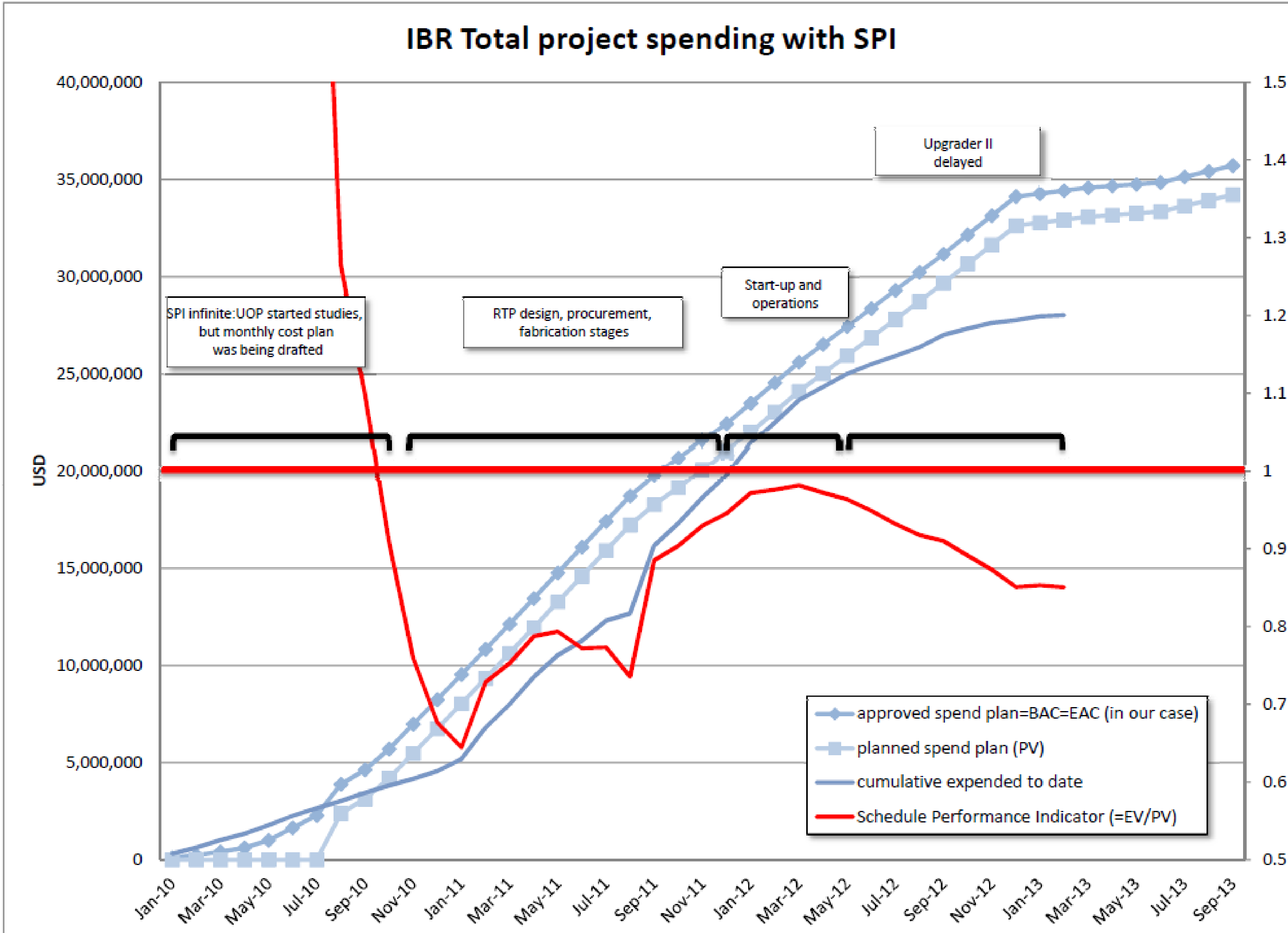

Project Overview

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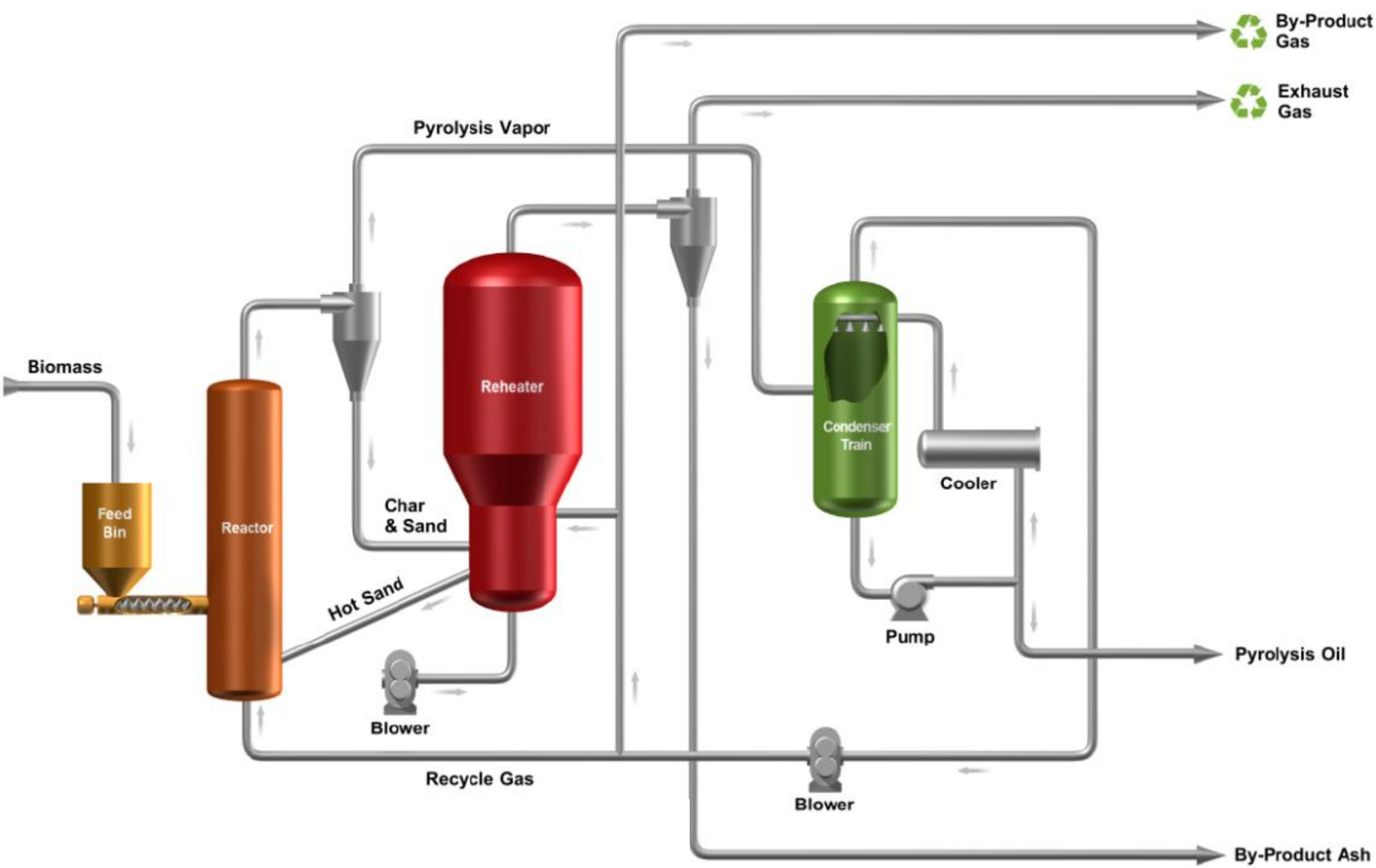
- RTP unit was commissioned and operated in 2012
- During commissioning a number of mechanical and process issues were identified and rectified prior to successful operation of the RTP unit.
- Pre-commissioning work on UG1 (metals removal) was also completed during 2012. Operation of the UG1 is scheduled for later in 2013. Minor modifications were made to the UG1 to correct minor piping issues.
- QA/QC Lab was operational during the RTP commissioning and operation and was able to analyze basic pyrolysis oil samples
- Both Lab and Pilot testing of the UG2 process have identified issues that have prevented us from issuing a final process design to Zeton so they can provide a firm price for the design and construction of UGII
- Closure of Tesoro Refining Operations requires new source of hydrogen

Project Overview

Honeywell



Rapid Thermal Processing (RTP™)

Project Overview

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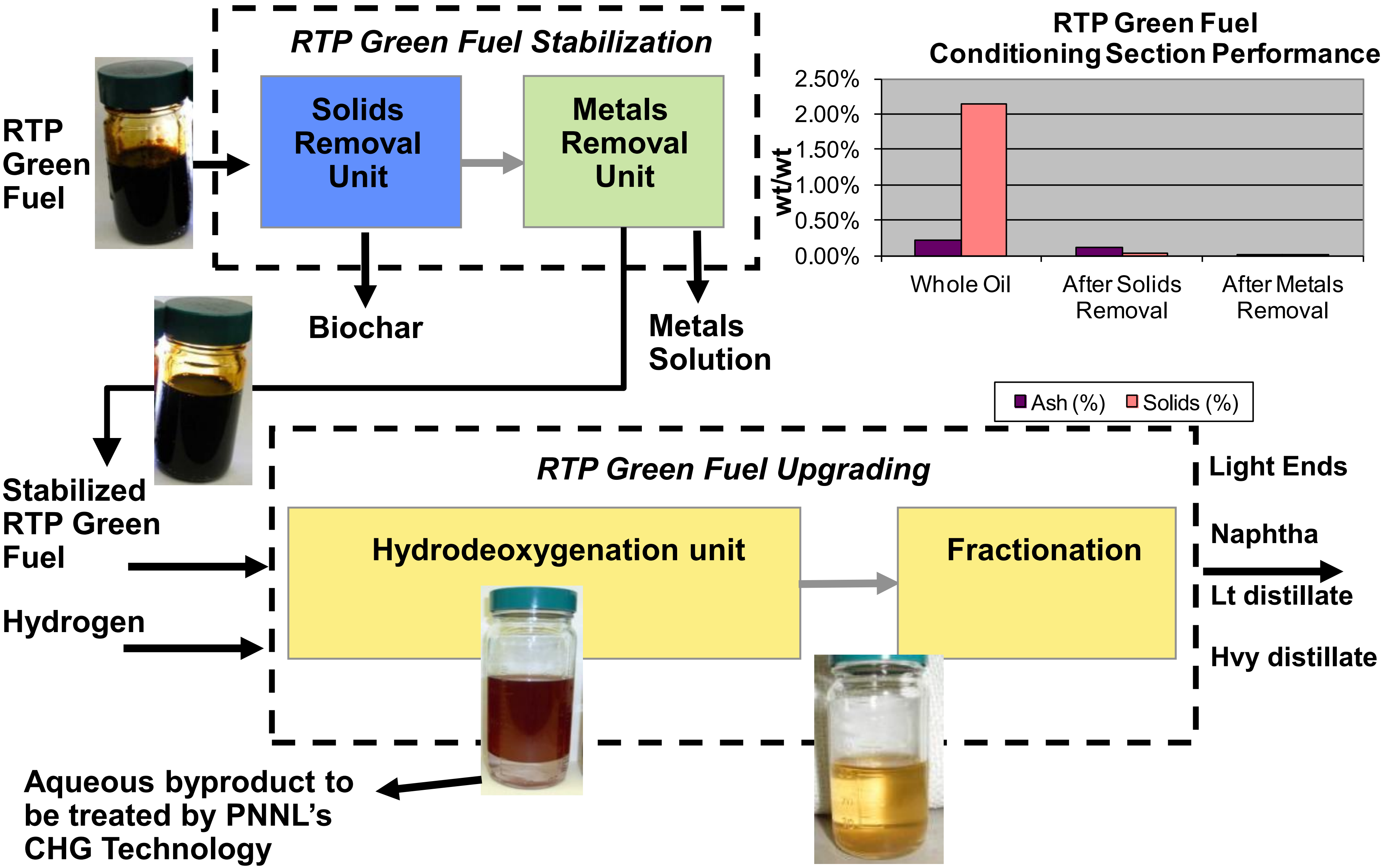
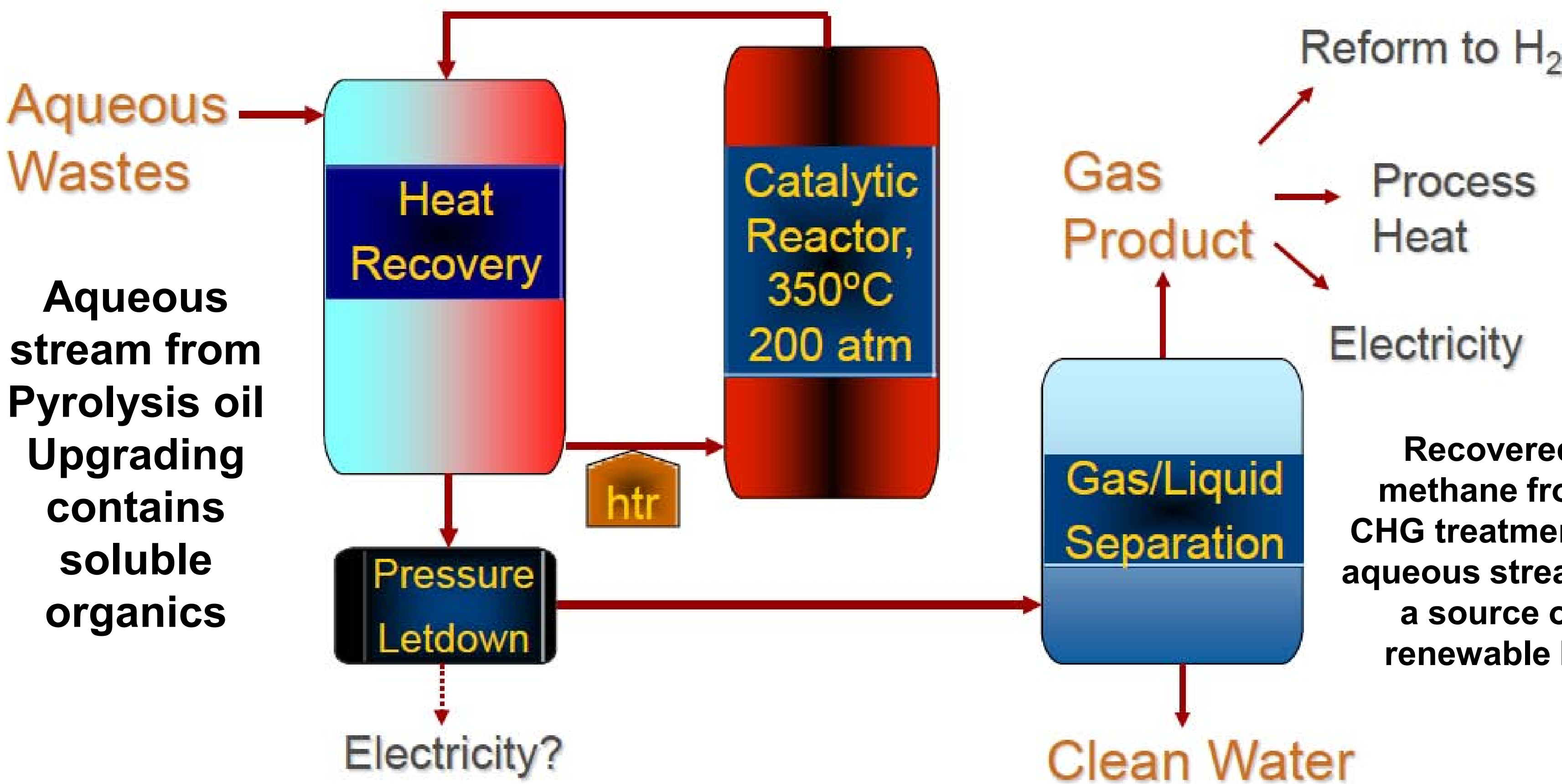


Project Overview

Catalytic Hydrothermal Gasification (CHG)

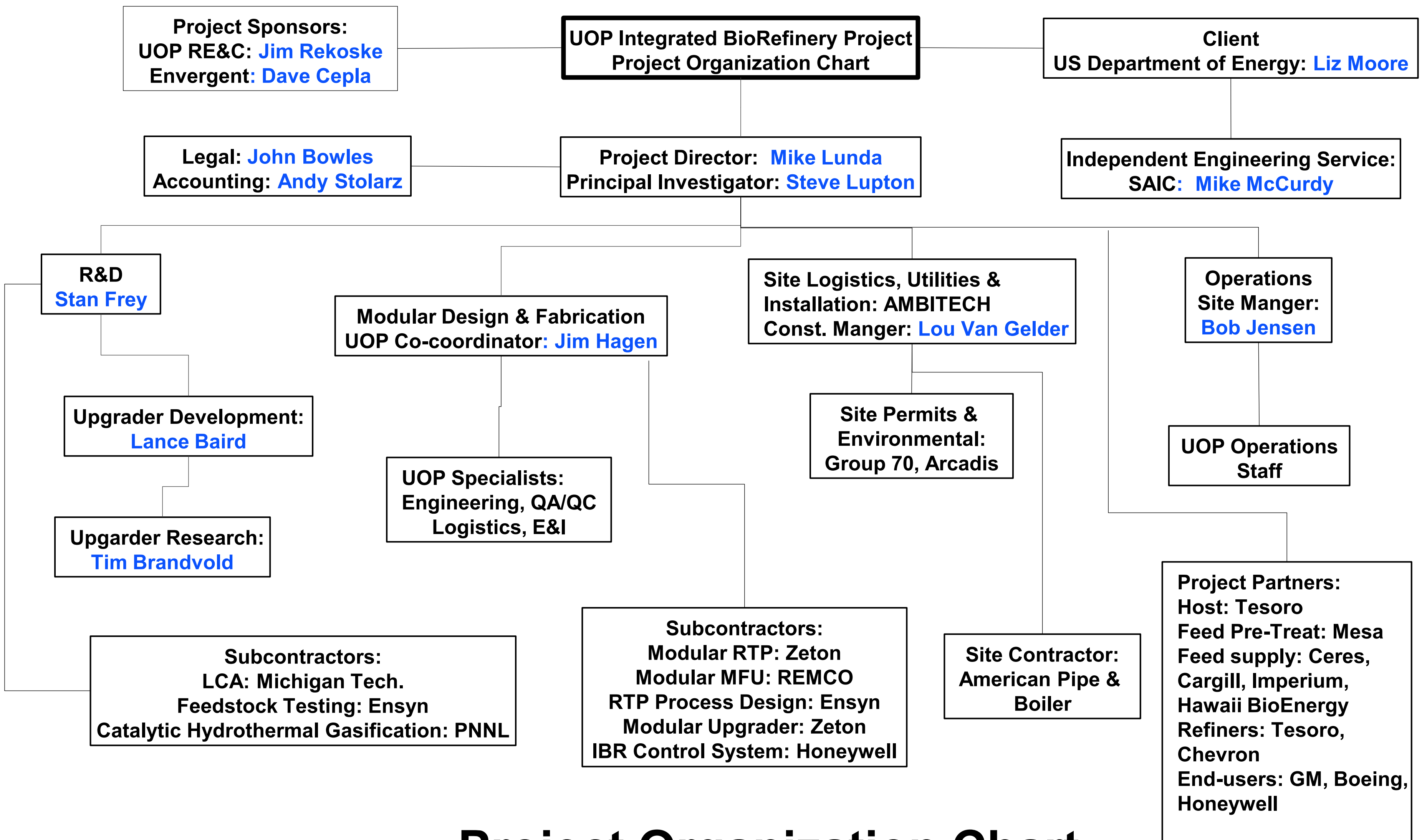
Technology Developed by PNNL

Aqueous stream from Pyrolysis oil Upgrading contains soluble organics



Recovered methane from CHG treatment of aqueous stream is a source of renewable H_2

1 – Project Management



Project Organization Chart

2 - Technical Accomplishments/ Progress/ Results

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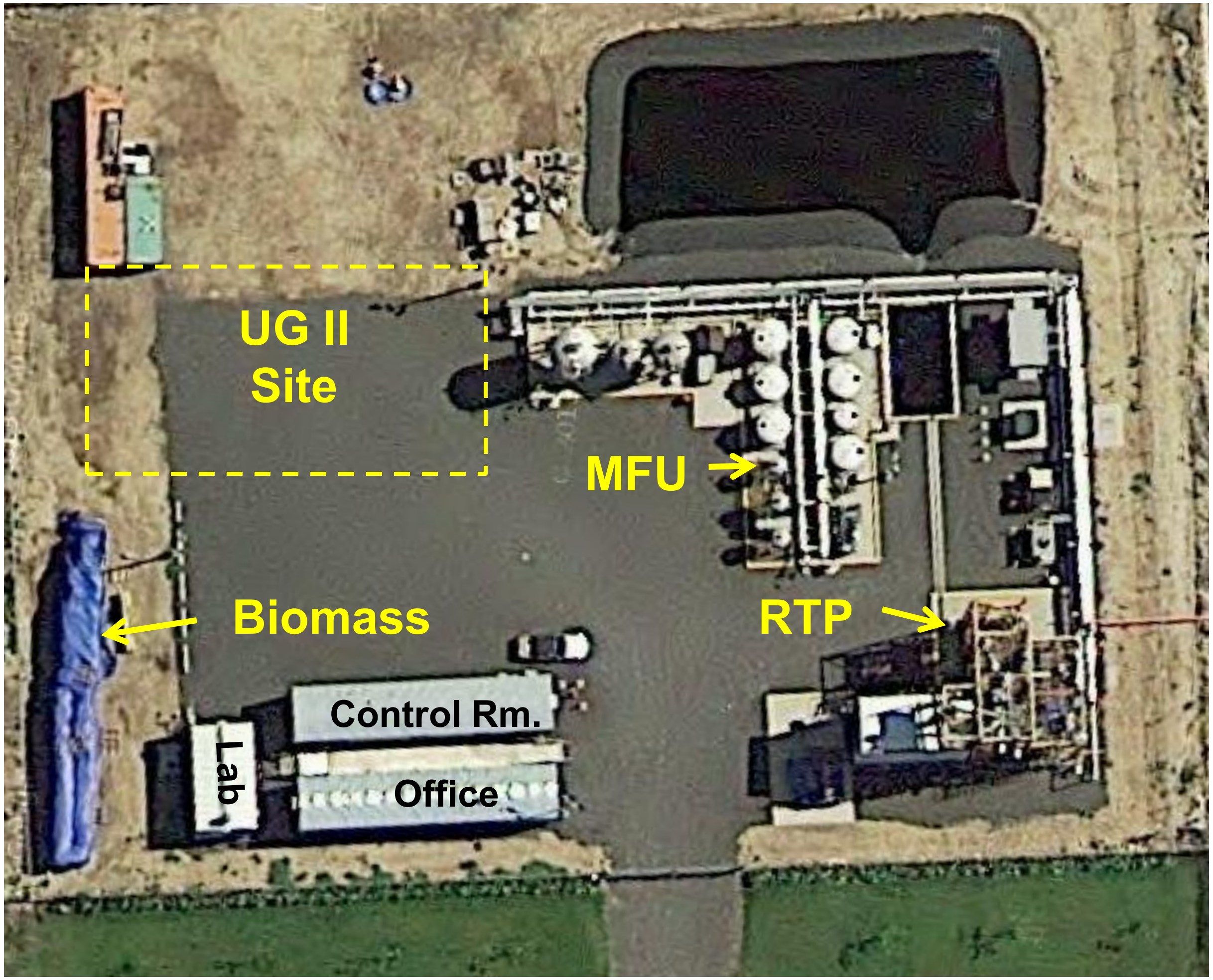

UOP IBR Site, Kapolei, Oahu, Hawaii

2 - Technical Accomplishments/ Progress/ Results

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UG-I Tanks

Control Room

IBR Site - Looking South to Tesoro Refinery

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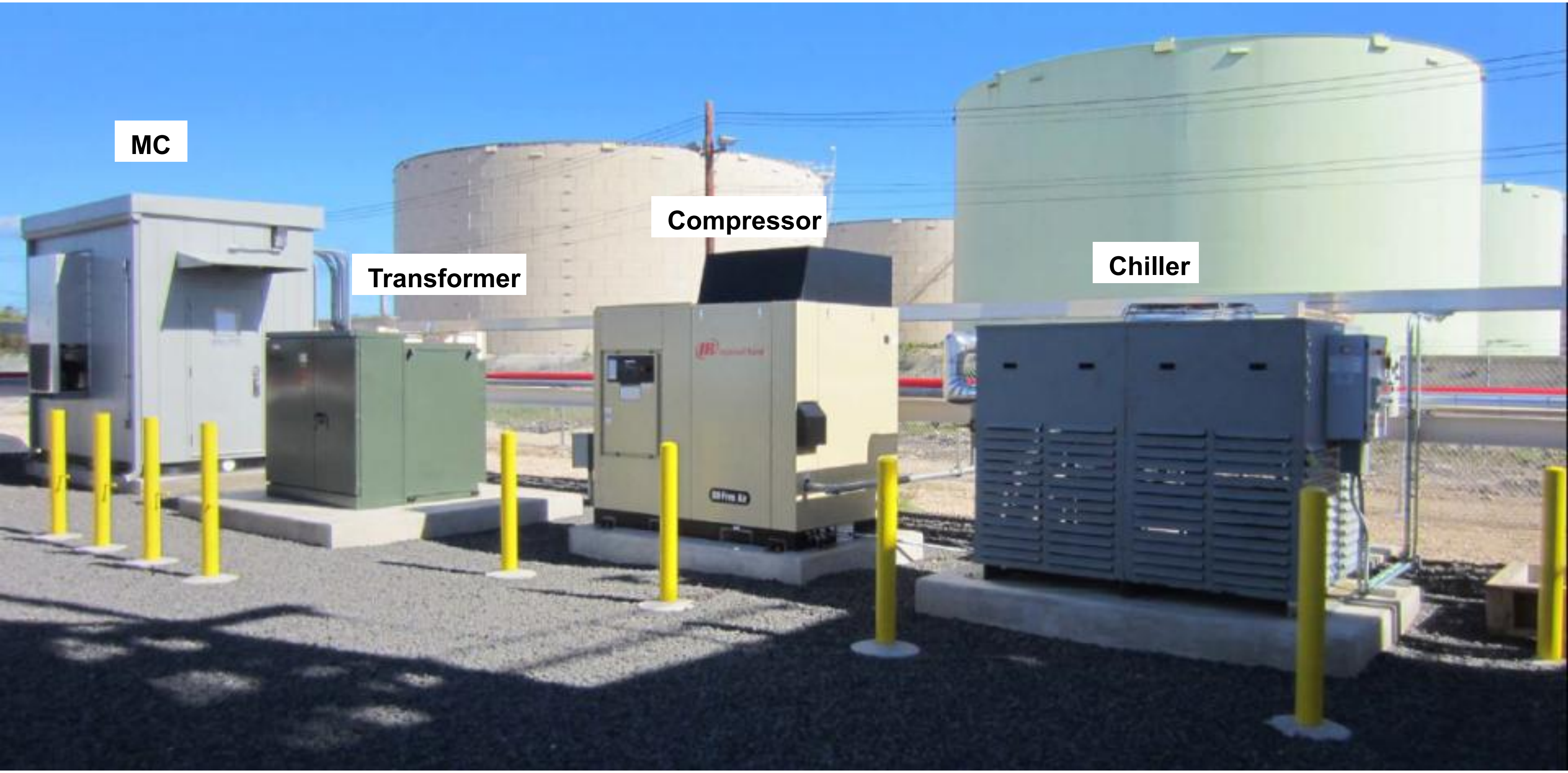
Motor Control, Transformer, Compressor and Chiller



2 - Technical Accomplishments/ Progress/ Results

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UG-I System (MFU & Tanks)

2 - Technical Accomplishments/ Progress/ Results

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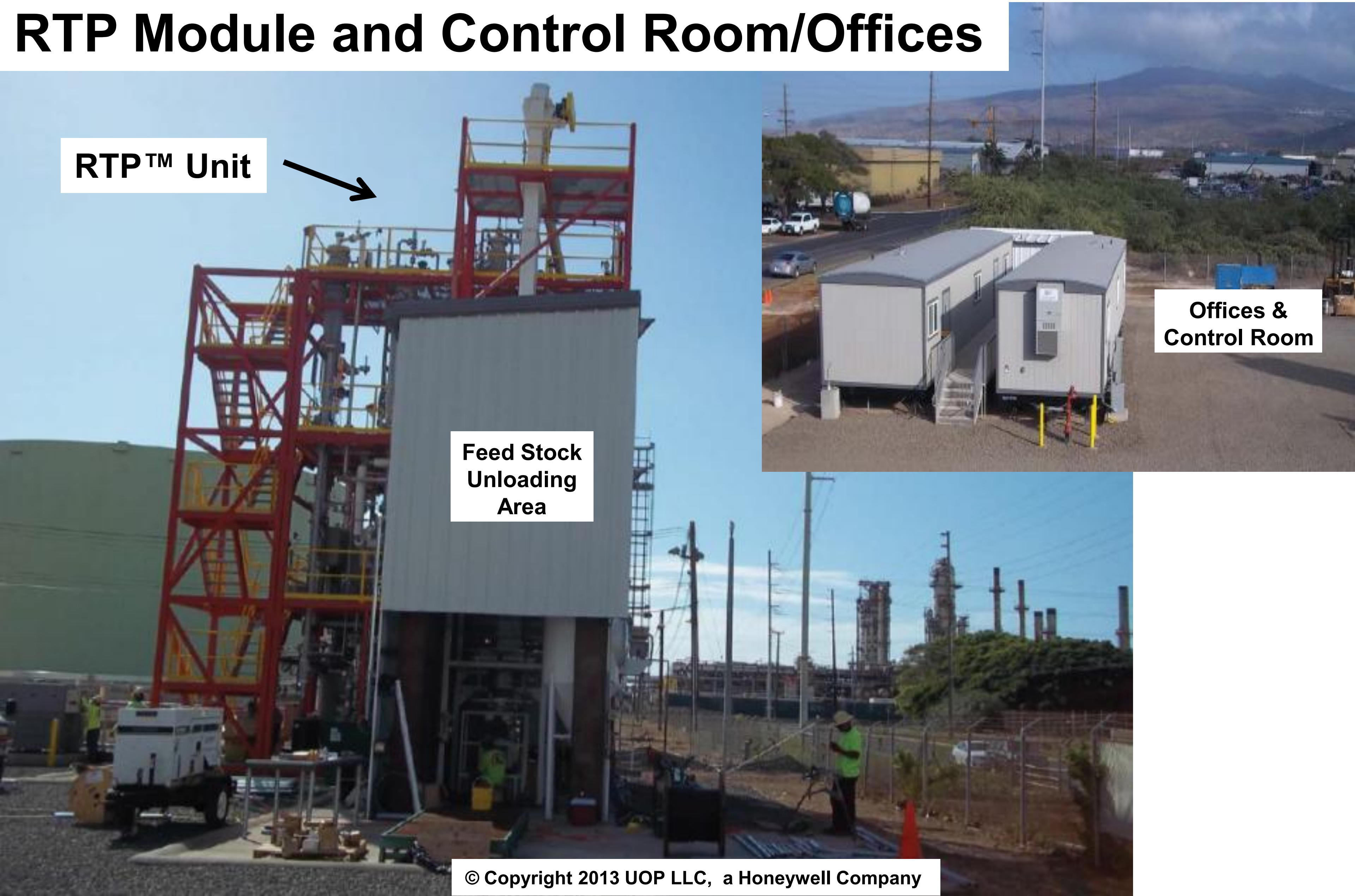
RTP Module and Control Room/Offices



2 - Technical Accomplishments/ Progress/ Results

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IBR Site Lab

2 - Technical Accomplishments/ Progress/ Results

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Operations Crew

RTP™ Unit shakedown occurred under the supervision of UOP Field Service Engineers and local operators trained by UOP

Control Room

RTP™ Unit Shakedown, 2012

2 - Technical Accomplishments/ Progress/ Results

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Bulk Properties of Hydrogenated Product From Lab Scale Upgrading

Elemental and Physical Properties	
Oxygen, mass%	<0.03
Carbon %	88.7
Hydrogen %	11
Nitrogen %	<0.10
Density	0.86
Degree API	33.2
Water, wppm	53

GCxGC, wt%	**Gasoline**	**Kerosene/ Jet**	**Diesel + Fuel Oil**
Paraffin	2.7	0.9	0.3
Isoparaffin	1.6	2.0	0.1
Naphthene	75.4	50.9	21.6
Aromatic	20.2	46.2	78.0
Estimated Fractions by SimDist D2887, wt%	~55	~23 - 31	~23 - 46

3 - Relevance

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ASTM D7566 Certification

***D7566:* Standard Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons**

Annex for each class of synthetic blending component (up to 50%)

- Annex 1: Fischer-Tropsch hydroprocessed SPK (FT-SPK, 2009)
- Annex 2: Hydroprocessed esters and fatty acids SPK (HEFA-SPK/HRJ/bio-SPK July 2011)
- *Future annex: Pyrolysis Oil to Jet – Hydroprocessed Depolymerized Cellulosic Jet (HDCJ) – sample sent to AFRL for evaluation and testing*

Product From the UOP IBR Will Support Certification of HDCJ Fuel

3 - Relevance

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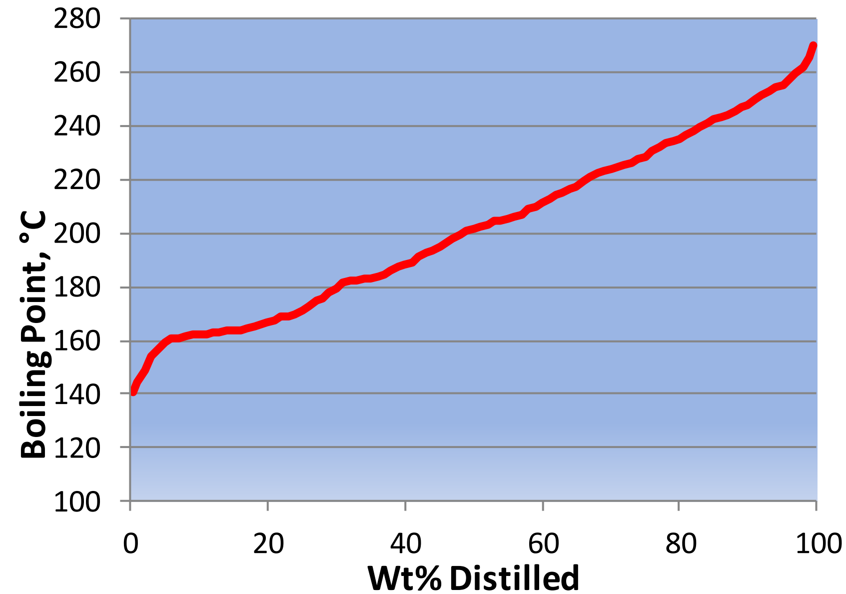
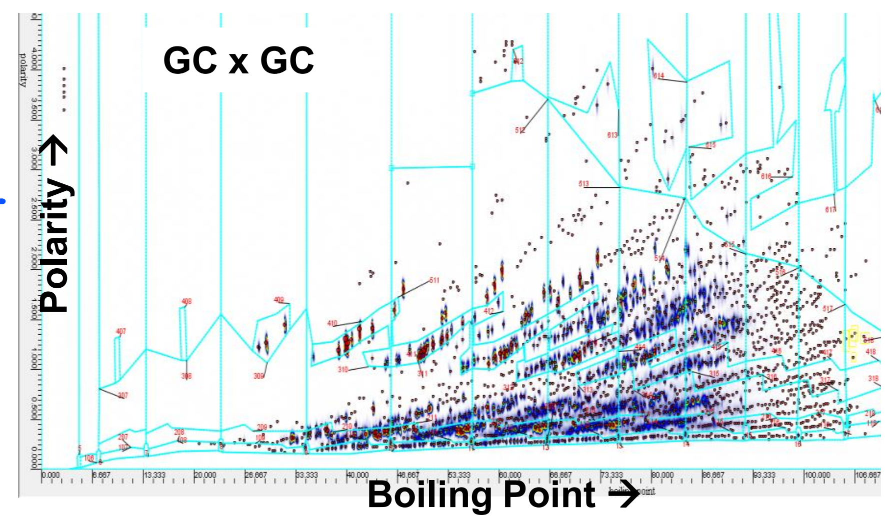
Upgraded Jet Fuel Cut Properties to HDCJ Committee

Test	Value	Unit
Density Relative D4052	0.8622	g/mL
Freeze Point D7153	< -80	°C
Flash Point D7094	56.6	°C
Trace metals U389	< 0.6	wppm
Chloride D7539	0.3	wppm
Nitrogen D4629	< 0.2	wppm
Oxygen U730	< 0.03	wppm
Sulfur D2622	1	wppm
n-paraffins	0.8	wt%
isoparaffins	2.8	wt%
Monocycloparaffins	22.7	wt%
Dicycloparaffins	13.2	wt%
Single ring aromatics	40.1	wt%
Indans/ tetralins	20.1	wt%
Naphthalenes	0.3	wt%





3 - Relevance

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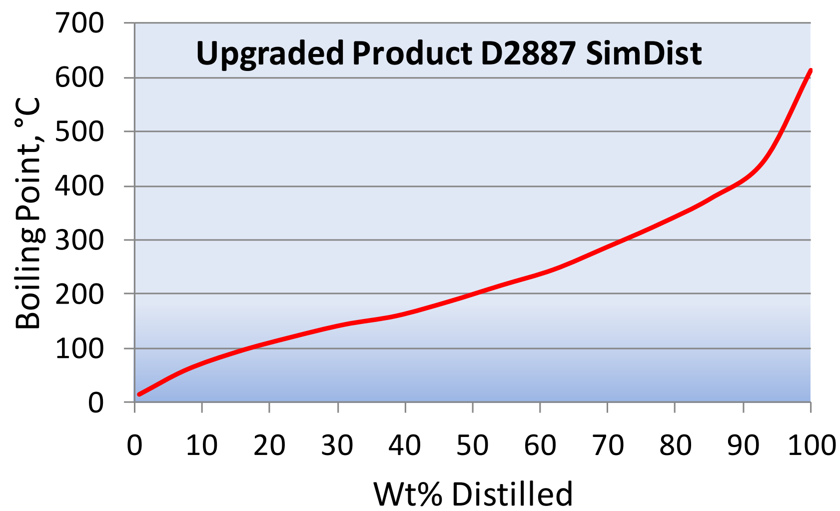
Pyrolysis Oil Feed to Fuels Feed/Product Analysis			
	Pyrolysis Oil	Upgraded Fuel	Gasoline Requirements
Water, %	~25	0.03	<0.1
O, %	51	<0.1	<2.0
TAN, meq/g	91	<0.1	<0.1



Pyrolysis Oil Feed to Fuel Transportation Fuel Yield[1]	
	Overall Yield, % of Pyrolysis Oil
Mass	41
Volume	60[2]

1. Demonstrated yield from at multiple equipment scales.
2. Equals > 90 gallons per dry MT for woody biomass.

~50% of material in gasoline boiling range 40-200°C

RON of gasoline ~80-89

~40% of material in distillate boiling range

Upgraded Pyrolysis Oil Products

3 - Relevance

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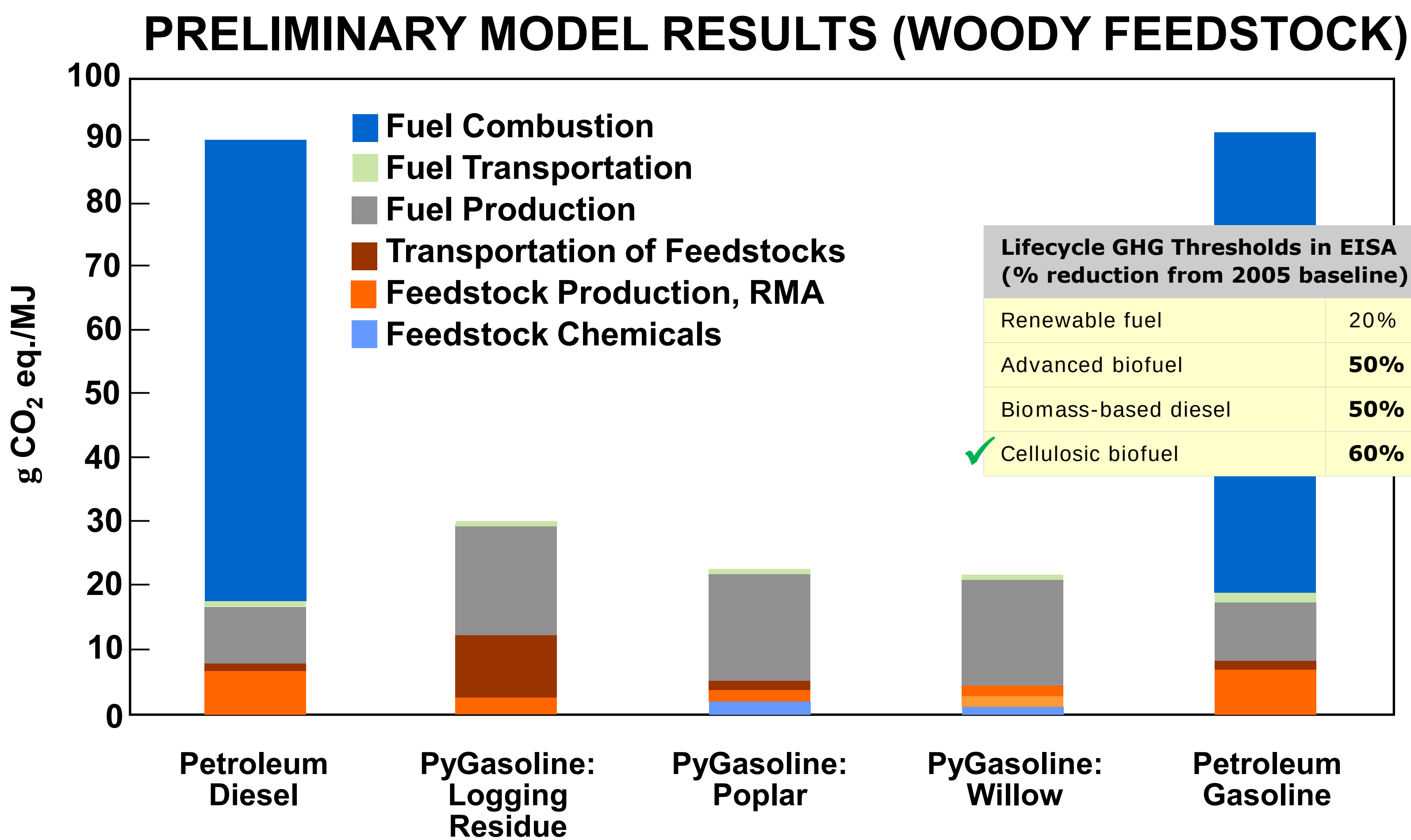
Renewable Gasoline GHG Emissions



Lifecycle GHG Thresholds in EISA (% reduction from 2005 baseline)	
Renewable fuel	20%
Advanced biofuel	**50%**
Biomass-based diesel	**50%**
✓ Cellulosic biofuel	**60%**

Upgrading RTP Green Fuel Makes Cellulosic Biofuels

4 - Critical Success Factors

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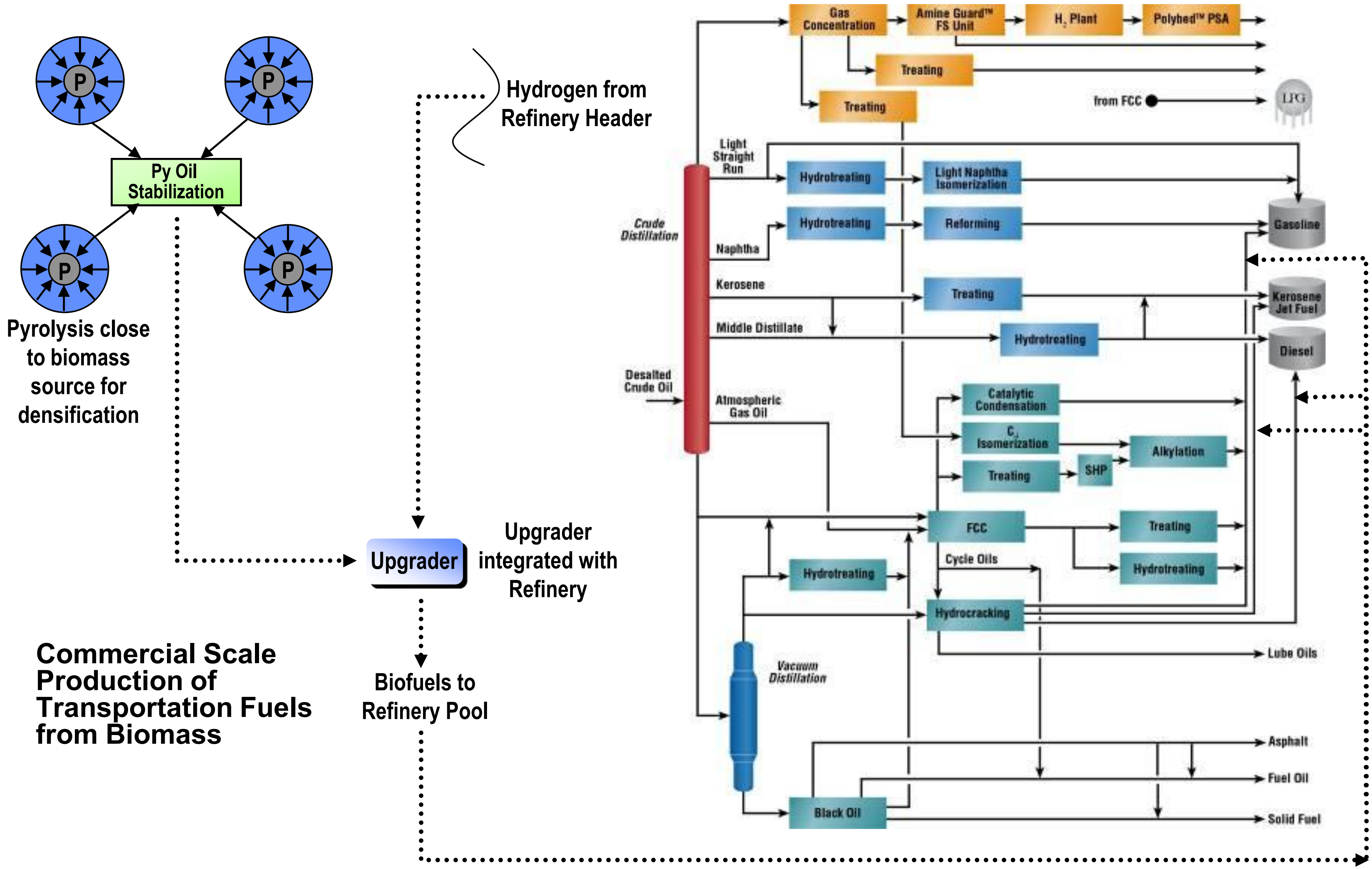

Commercial Scale Production of Transportation Fuels from Biomass

Commercial Application is Distributed Model

4 - Critical Success Factors

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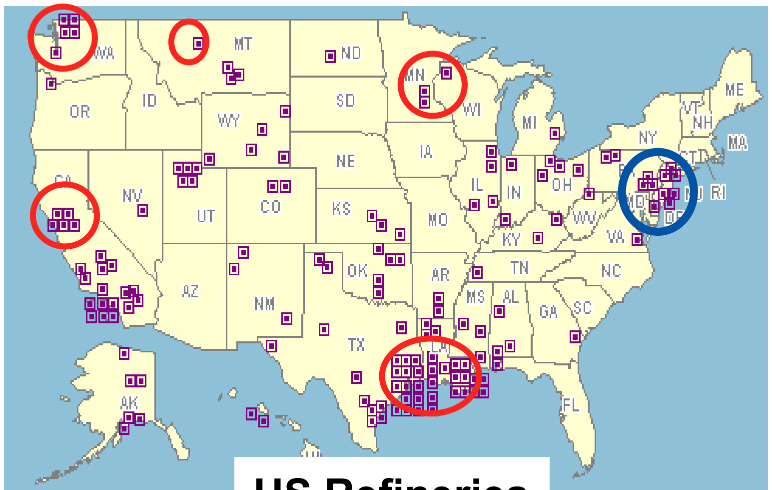
Co-location of US refineries with Major Forestry Resources



US Refineries

>18,000,000 metric ton (MT)/year of Forestry Residue in close proximity to US refineries

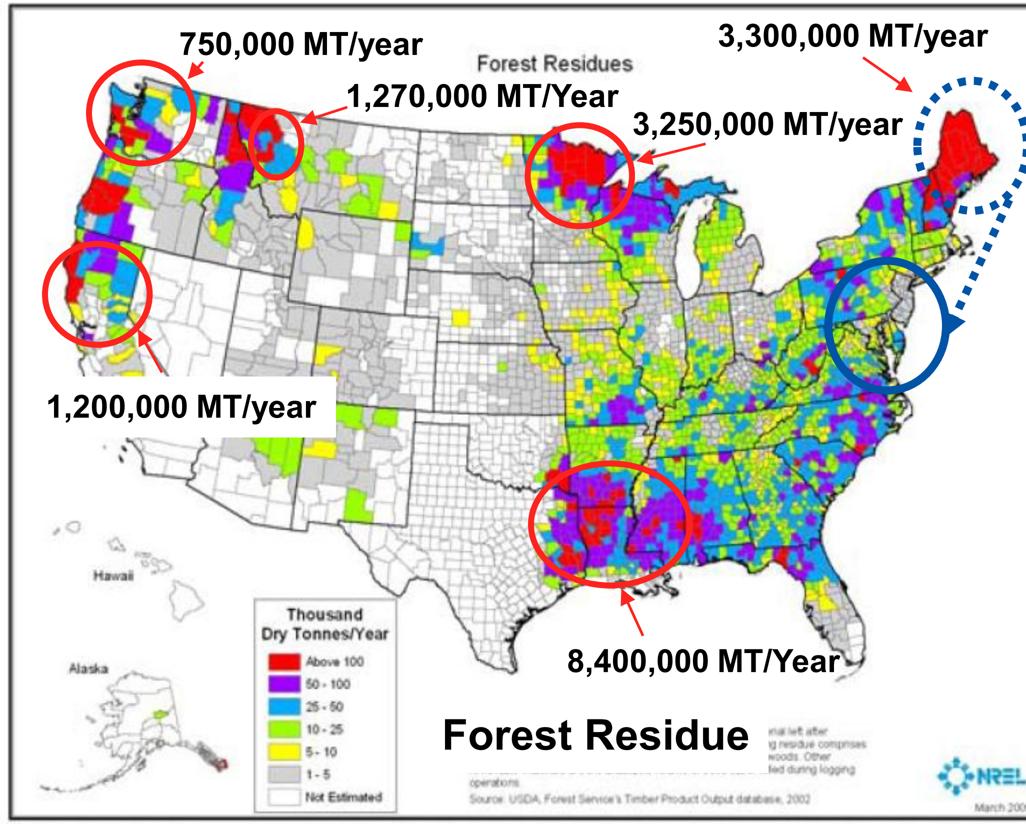


Figure 13 Estimated Forest Residues by County

There is sufficient forestry residue alone co-located with refining assets to support commercialization
Additional feedstocks are available on a regional basis

5. Future Work

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- Resolve hydrogen supply issues resulting from closure of Tesoro refining operations
- Shakedown of UG I in June, 2013
- Finalize design for UG II, August, 2013
- Construct and Install UG II at Kapolei site, Q4, 2014
- Conduct Independent Engineer Evaluation, Q1 – Q2, 2015

Summary

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- Pyrolysis oil has been upgraded at bench scale into transportation fuel blend stocks
- A process is to be installed to convert biomass to cellulosic biofuel suitable for transportation fuel at high yield at the 1 ton/day scale.
- Some scale-up issues still need to be resolved prior to fabrication and installation of Upgrader at site

Acknowledgements

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- The authors wish to acknowledge the support of:
  - The Honeywell - UOP Renewable Energy and Chemicals R&D groups
  - The broad Honeywell-UOP technical community
  - the Honeywell-UOP Renewable Energy and Chemicals business group, Envergent Technologies, and Ensyn Corporation
  - The group of Dr. Doug Elliott at Pacific Northwest National Laboratories for past and ongoing collaborations on biomass pyrolysis oil upgrading and Catalytic Hydrothermal Gasification
  - The group of Prof. David Shonnard, Michigan Technological Univ., for ongoing LCA collaborations
- The material presented is based in-part upon work supported by the Department of Energy, Energy Efficiency & Renewable Energy, Biomass Program, under Award Number DE-EE0002879, Recovery Act - Pilot Scale BioRefinery: Sustainable Transport Fuels From Biomass And Algal Residue Via Integrated Pyrolysis And Catalytic Upgrading.

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Additional Slides

Response to Past PEER Review Comments

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<table>
<tr><th>Project Approach</th><th>UOP Response</th></tr>
<tr><td>Sound plan to build and implement plant using successful UOP practices and suppliers.</td><td></td></tr>
<tr><td>Project is being performed in two stages. DOE requested acceleration. Phase 1 is RTP and UG1. Same UOP approach as commercial plants. Modules fabricated offsite and transported to project site. Large number of project participants. Could be difficult to coordinate.</td><td rowspan="5">Technical data from lab and pilot testing on feedstocks is proprietary and business sensitive information so it is not possible to present this data in a public forum such as the Peer Review. This data was presented to DoE staff as part of the comprehensive project review which is held with DoE and the Independent Engineering Group.

The selection of the Hawaiian site was largely driven by UOP’s refinery partner for this project, Tesoro. Tesoro was willing to provide a site for the pilot only at this location. Tesoro has since ceased operations at the site but the expense of removing the installed equipment to a new location is prohibitory expensive.

There are certain unique logistics issues situated with strategic supply of transportation fuels in the State of Hawaii which support the location of the IBR project at that location</td></tr>
<tr><td>High appreciation of the need for feed stock flexibility, does add complexity to pilot operations. Process robustness will be proven with further successful operations. Location at refinery in HI adds unnecessary logistics and shipping issues so one to four 55 gallon drums of product/day is available on-site for refining. Care will need to be taken to ship and store feedstocks.</td></tr>
<tr><td>biomass into pyrolysis oil to a funguble hydrocarbon fuel scale - 1T/day or 4 barrels per day of hydrocarbon product unit operation at an existing plant integrate into other refinery infrastructure - and what is the best way to do that finally slide 8 - seems like the approach is all about operations; no early in the talk specifics about research, demo, deployment and the like. - the first dig into feedstocks and LCA came on the 11th slide under accomplishments/progress/results</td></tr>
<tr><td>As expected, this project's strategic, technical, and management teams possess the right skills and have the right experience to implement a solid PMP. The implementation of the PMP met the milestones. Overall, given the project team, this reviewer has solid confidence the PMP will continue to effective. A weakness was the absence of a summary of pilot results which could be used by reviewers to gauge roughly the soundness of the technical approach. This especially applies to the performance or piloting of the Ensyn’s pyrolysis unit and data related to upgrading the py-oil, so this reviewer reduced scoring on this criteria by one mark.</td></tr>
<tr><td>UOP has a technically sound approach to project execution, but the timeline presented does not include planned versus actual progress, so it isn’t possible to measure how they’re doing versus what they planned.</td></tr>
</table>

Response to Past PEER Review Comments

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<table>
<tr><th>Benefits and Expected Outcomes</th><th>UOP Response</th></tr>
<tr><td>Very expensive $36MM for 1 tpd and 4 barrels/day demonstration plant. Commercial plant would be 1600 tpd and 6,400 barrels/day at an unknown cost. No additional data provided.</td><td rowspan="6">The economics associated with the UOP technology is business sensitive information and cannot be disclosed in a public forum. This is reviewed in depth each year during the comprehensive project review with DoE and the Independent Engineers</td></tr>
<tr><td>Specific performance parameters not provided. General benefits targeted toward refinery applications. Project will have to be scaled about 400 times for7 commercial application.</td></tr>
<tr><td>No disclosure according to the mandated format. Even a hint would have been nice.</td></tr>
<tr><td>DOE
Fuels Consumers
Refinery Host
UOP LLC Ensyn
Auto manuf
Farming
Pulp and Paper
Developers of new energy crops incl algae
none of the following was addressed:
a, b, c, d, e, f, from above</td></tr>
<tr><td>Data from operations will benefit from refinery location and partner experience in motor fuel production. Program will demonstrate process and provide economic data for scale-up. If all six feedstocks are tested significant data will be developed.</td></tr>
<tr><td>No economics presented</td></tr>
</table>

Response to Past PEER Review Comments

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<table>
<tr><th>Critical Success Factors</th><th>UOP Response</th></tr>
<tr><td>Yes, they listed -many critical success factors and have highlighted sub-topics in each area that will be examined and evaluated when the project is operational. Ascertaining the impact of each critical factor in the project implementation was difficult but they have moved to the purchase stage so clearly have overcome most/all known hurdles. It was unclear, for example, if catalyst stability was an issue that they had overcome, or was one that they intended to overcome once the project is operational. For commercialization of this system, feedstock supply and associated deployment of distributed pyrolysis units remains a significant issue and this has been evident in other Platform projects involving ag-waste feedstock. The project cost ($36 MM total money) seems extraordinarily high for a pioneer demo-scale plant, even in Hawaii. This reviewer assumes the DOE has examined this closely.</td><td rowspan="6">The demonstration of multiple feedstocks in the UOP process shows the versatility of the process and shows that the technology is not dependent on any one source or type of feedstock such as agricultural wastes or energy crops.

The RTP™ Unit was fabricated, delivered and installed on schedule and on budget. Shakedown occurred in 2012 and minor equipment changes were made. Pyrolysis oil was successfully produced.

UOP learned from permitting process and expects upgrader permitting to be less onerous. The project costs have been closely monitored by DoE and the project has been subjected to yearly detailed audits by independent auditors.</td></tr>
<tr><td>The presentation identified-critical success factors for commercialization and described actions being taken in the pilot plant to address these factors.</td></tr>
<tr><td>Project has a local partner for permits and applications are submitted, slated for May 2011 issuance.- NEPA is completed.- Site layout and equipment selection has occurred.- Construction start planned for July 2011.- Modules for pilot unit are being constructed by Zeton in Burlington, Ontario, Canada.- While an renowned pilot plant constructor, long shipping route.</td></tr>
<tr><td>Plan is to use plant data to determine the parameters for process success.</td></tr>
<tr><td>LCA
feedstock supply contracts
establish refinery partnerships
commercial size units
establish customer off-take agreements
fair detail in summary, but only outlined the contribution from the pilot project; no discussion of any problems or expected critical path</td></tr>
<tr><td>Success factors clearly identified, but not a very good explanation of how the pilot plant will achieve them other than to say that it will.</td></tr>
</table>

Response to Past PEER Review Comments

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<table>
<tr><th>Technical Progress and Accomplishments</th><th>UOP Response</th></tr>
<tr><td>Wide range of feedstocks used in process development. Good progress overall toward the project.</td><td rowspan="5">Project schedule is shown in this presentation. Budget Period 1 was on schedule and on budget. There has been some slip in schedule for BP2 due to closing of the Tesoro Refining operations and with scale up issues for the uprader but overall project progress is in alignment with the project schedule.

Again, the details cannot be shared in a public presentation. However, project execution and schedule reviews by DoE's independent engineer and the DOE Project Officer are being conducted on a bi-weekly basis.</td></tr>
<tr><td>Site partners and location is well defined.0 Scope of work is largely not defined as bench scale work appears yet to be performed for many of the feedstocks other than wood which shows promise for gasoline. Location adds logistics complexity which seems to be affecting the schedule progress and cost of the project.</td></tr>
<tr><td>Issuance of purchase orders is a major step towards project implementation and demonstrates the maturity of the engineering work. Project was correct in emphasizing the complexity of implementing a project within a refinery footprint and this acknowledge should help put a stop to the casual assumption that placing pyrolysis/reformer plant at a refinery is an easy thing to do. Specifically they mentioned the impact of refinery standards and performance inside the refinery fence line. Testing of various feedstocks is beneficial at this stage but eventually, the pioneer commercial project will focus on only one or two feedstocks.</td></tr>
<tr><td>BP1 to be completed 7/11.0 BP2 to start 7/11. Fuel products will be released into the refinery process Basic engineering, preliminary detail design and equipment sourcing complete for RTP and UG1. NEPA determination (CX) and environmental permits are underway.</td></tr>
<tr><td>Progress is apparently being made on both permitting and technical fronts. The claim is made that equipment design and procurement is on schedule, but that schedule is not shown. Also, the explanation of technical accomplishments is quite sketchy. It would be very useful to have some more technical detail regarding experimental results to date rather than just the broad brushstroke verbal overviews.</td></tr>
</table>

Response to Past PEER Review Comments

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<table>
<tr><th>Project Relevance</th><th>UOP Response</th></tr>
<tr><td>see slide 12 - appears to relevant to the DOE mission regarding at least feedstocks, crop processing and the algal pathway</td><td rowspan="6">UOP feels that the integration of the biomass pyrolysis /upgrading technology piloted in the IBR project has certain synergies when co-located with traditional petroleum refining operations for the following reasons:

1. Refineries have the appropriate outside battery limit (OSBL) infrastructure, such as supply of hydrogen gas that support the UOP IBR process units (upgrader).

2. The hydrocarbon fuel products that will be produced by the IBR make blending components that are quite fungible with existing petroleum fuel products and may enhance the properties of these existing fuels.

3. Refineries have incentives, under the RFS regulations, to produce a portion of their fuels that are both fungible with existing petroleum fuel products but which have the required GHG savings mandated under the RFS.</td></tr>
<tr><td>Relevance somewhat limited by the UOP plan to target refinery customers.</td></tr>
<tr><td>Project provides pathway to renewable gasoline that potentially will integrate well with existing refining infrastructure. Relevant specifically to HI to help develop a state-specific renewable component. Replication at mainland locations may be significantly different.</td></tr>
<tr><td>Presentation identified relevance to DOE Biomass Pathway Milestones.
Looking at feedstock that is relevant to rest of US</td></tr>
<tr><td>Fits well with MYPP.
Addresses the underlying area3of pyrolysis oil utilization at a refinery.</td></tr>
<tr><td>This project is directly relevant to the MYPP goals. Integration of BioRefinery concepts into petroleum refineries is a key to the long term advancement of the biofuels industry.</td></tr>
</table>

Response to Past PEER Review Comments

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<table>
<tr><th>Technology Transfer and Collaborations</th><th>UOP Response</th></tr>
<tr><td>UOP experience in IP for refining industry will help successes to be developed.) Project partners and refinery host for project are benefits for increased tech transfer.</td><td rowspan="7">It was also explained that UOP is an open licensor of technology and that the existing worldwide refining base represents major potential customers for the upgrading component of the technology whereas forest products companies, pulp & paper companies, farming co-operatives, etc, may be an existing customer base for the pyrolysis component of the technology.

It may be quite possible that a refinery may licensing the py-oil upgrading component of the technology but the forest products and/or biomass producing companies may license the pyrolysis component with off-take agreements with the refineries.</td></tr>
<tr><td>UOP experience in IP for refining industry will help successes to be developed.) Project partners and refinery host for project are benefits for increased tech transfer.</td></tr>
<tr><td>Technology transfer and collaboration beyond the immediate project team was not discussed.</td></tr>
<tr><td>Not addressed in presentation</td></tr>
<tr><td>No information presented.</td></tr>
<tr><td>no discussion - went straight to the summary slide</td></tr>
<tr><td>Many collaborators identified – very good. Technology transfer to the refinery sector will be crucial in the long term, so that's a very favorable approach.</td></tr>
</table>

Response to Past PEER Review Comments

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Overall Impressions	UOP Response
Very expensive project with solid program plan and partners.) Potential for significant fuel volume contributions is very far into the future.	The $36M project costs were flagged by some reviewers as high compared to other projects. A detailed breakdown of the project costs could not be presented in this public format. However, a detailed breakdown of the project costs show that the equipment costs are very similar to many of the other projects. The overall project has a considerable amount of process development costs borne by UOP at its own expense that are not directly related to equipment fabrication and installation at the Hawaii site. Also, many of the costs, such as environmental and construction permitting are independent of the size of equipment being fabricated and installed and are the same for this project as for a 1000 ton/day BioRefinery project. Likewise operations are even more complex and expensive to run this 1 t/day pilot than for a full-scale commercial plant due to the fact that at the pilot scale there are more manual tasks required than for full-scale plants which are more integrated. Likewise, HS&E considerations are just as complex and requires just as much attention at pilot scale as for full-scale. It is true that the logistics associated with the demonstration in Hawaii do added significantly greater transportation costs for both equipment and feedstocks
Overall, this is a good project with a solid team. If it goes well they will go a long way to proving the basics of their chosen technology platform, but more importantly, they will provide the basis to assess the practicality behind distributed pyrolysis units and refinery based py-oil upgrading.	
Approach and progress appear to be good. Information on commercial plant was missing.	
Well formulated project making good progress but with limited application to refineries.	
20M dollars with a small pilot plant - pretty expensive for a pilot 36M with UOP Honeywell scale of commercial plant is 6400bbl/day unit with feedstock at -1600 tpd with few cost pieces feedstock integrity means they are dried.	
This appears to be a good project. My concern is the project cost. It appears that the total cost will be about $36 million for a one ton per day pilot plant. I'd sure like to see what the pro-forma economics look like for a commercial plant. The capital cost per ton of feedstock will have to be several orders of magnitude lower.	

Presentations & Patents

Honeywell

Ten (10) US patent applications and four (4) Foreign applications have been submitted covering py-oil upgrading to hydrocarbon fuels covering both process designs and catalyst composition

- ***Integrated BioRefinery*, Mike Lunda, 2012 Asia Pacific Clean Energy Summit and Expo, August 13-15, 2012, Honolulu, Hawaii**
- ***Solid Biomass Conversion to Transportation Fuels with UOP RTP™ Upgrading Technology* , Jim Rekoske, Advanced Biofuels Leaders Conference, April 3, 2012, Washington, D.C.**
- ***The UOP Integrated BioRefinery (IBR) project,* Steve Lupton, IEA Pyrolysis Newsletter, December Issue, 2012**
- ***Transportation Fuels From the Catalytic Hydrodeoxygenation of Biomass Pyrolysis Oil*, Lance Baird, 2013 AIChE Spring Meeting & 9th Global Congress on Process Safety, May 2nd, 2013**