2013 DOE Bioenergy Technologies Office (BETO) Project Peer Review

Long Term Processing using Integrated Hydropyrolysis plus Hydroconversion (IH^2) for Production of Gasoline and Diesel from Biomass

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Bio-Oil Technology Area Review

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GTI

Big Picture Goals and Objectives

- ***Demonstrate a new game changing technology, IH^2, in a continuous pilot plant which***
  - **Solves the current technical and economic issues for biomass conversion to fungible fuel**
  - **Directly makes high quality fungible hydrocarbon fuels from biomass**
  - **Works for all biomass feeds tested**
  - **Integrates nicely with existing forest product or agricultural residue processing**
  - **Projected < $2.00/gallon product cost (2000t/d)**
  - **80 gal/ton gasoline + diesel product yield from wood**
  - **Environmental sustainability = Extremely good (more than 90% greenhouse gas reduction)**

Project Goal/Objective Statement

- Demonstrate continuous testing of the IH^2 process in a 50kg/d Pilot Plant
- Show Catalyst Stability
- Produce Gasoline and Diesel fuels directly from biomass containing less than 1% oxygen that can be blended into petroleum fuels or further upgraded in a petroleum refinery
- Provide detailed characterization of gasoline and diesel fuels produced
- Produce Yield and Material Balances for the IH2 Products

Awarded from FOA DE-FOA-0000342 Upgrading of Biomass Fast Pyrolysis Oil (Bio-oil)

Project Quad Chart Overview

Timeline

- Aug 2011
- May 2013
- 99.9% - final report will issue shortly

Barriers

- Barriers addressed
  - Pyrolysis of Biomass and Bio-Oil Stabilization

Budget

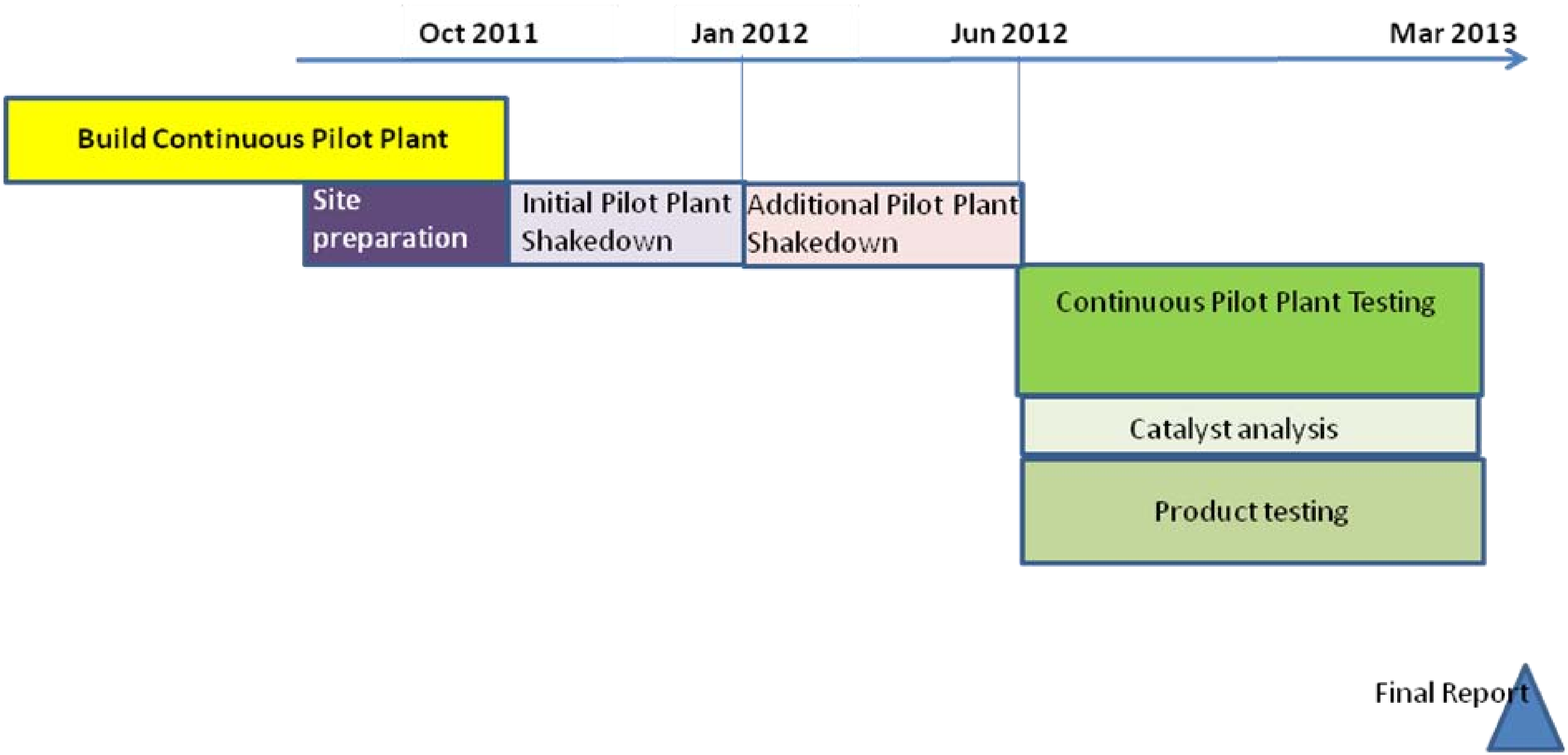
- Total $3.8MM, $2.9MM DOE,$.97MM CS
- 2011 $1.7MM, $1.16MM DOE.$.51MM CS
- 2012 $2.1MM. $1.66MM FOE,$.45 MM CS
- 2013 $72K, $63K DOE, $9K CS
- 3 years funding,$1.2MM/year

Partners & Roles

- GTI,CRI Catalyst, Shell Global Solutions, Johnson Timber, Cargill, Parabel

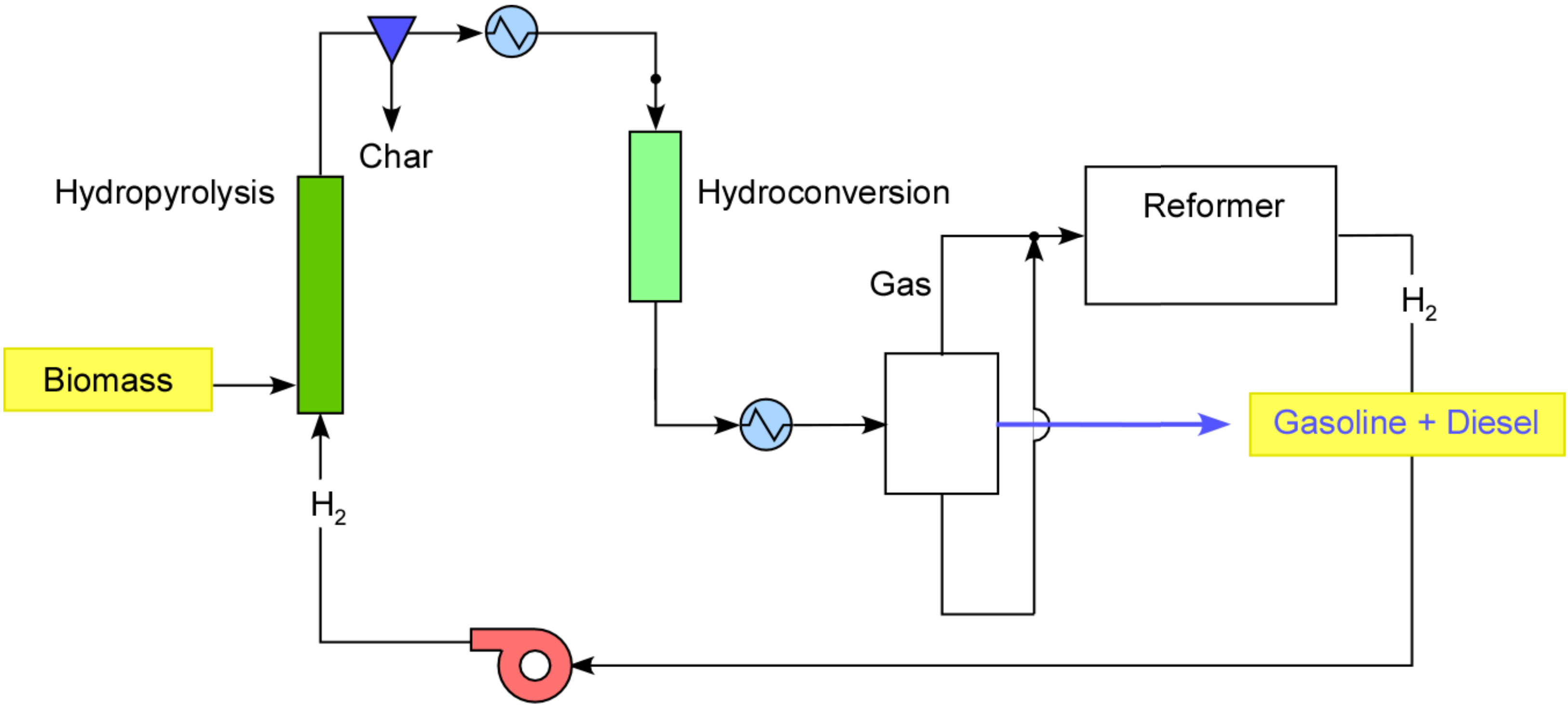
U.S. DOE Award DE-EE-0004390

Long Term Processing Using IH^2



Project Partners are GTI, CRI Catalyst, Shell Global Solutions, Cargill, Johnson Timber, Parabel

Integrated Hydropyrolysis and Hydroconversion (IH²)

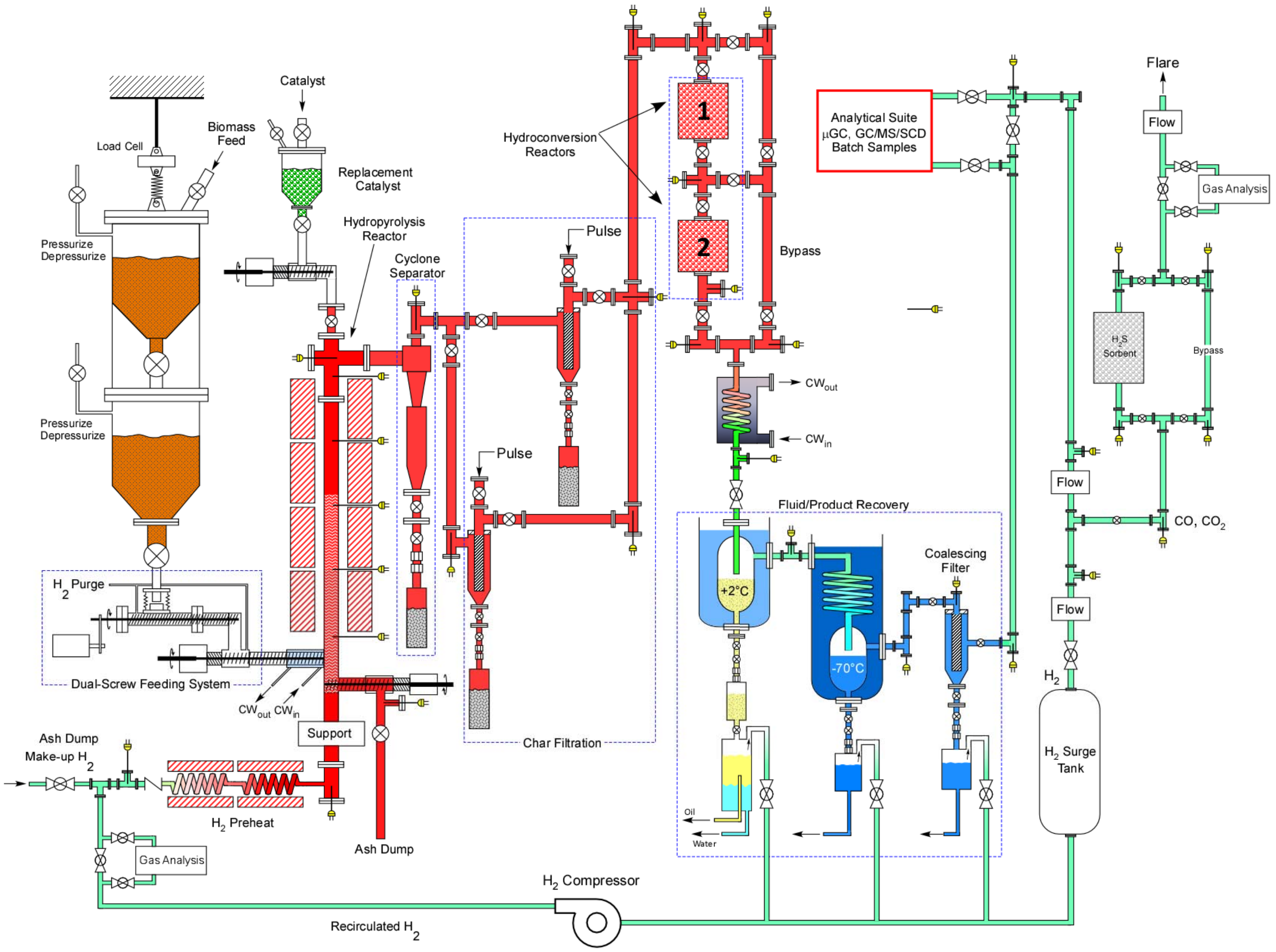


- Directly make desired products
- Run all steps at moderate hydrogen pressure (200-500 psi)
- Utilize C_1-C_3 gas to make all hydrogen required
- Avoid making "bad stuff" made in pyrolysis – PNA, free radicals

IH^2 50 kg/d Continuous Pilot Plant

- Only Continuous IH^2 Pilot Plant in the world

Schematic Diagram of Continuous IH² Process Unit



- 2 kg/hr of biomass feed
- Continuous char-catalyst separation
- Continuous operation

Long Term Processing using IH^2 Accomplishments

Continuous Testing in IH2-50 50kg/d Pilot Plant

- Demonstrate Long term Operability – **750 Hours on Stream (HOS)**
- Show Catalyst Stability **- Good Stability**
- Produce Gasoline and Diesel fuels containing less than 1% oxygen **-High quality drop in gasoline,**
- Detailed characterization of gasoline and diesel fuels produced – **Lots of detailed data**
- Yield and Material balances of IH2 Products – **daily yields and material balances**

•Project Complete except Final Report under review – should issue shortly.

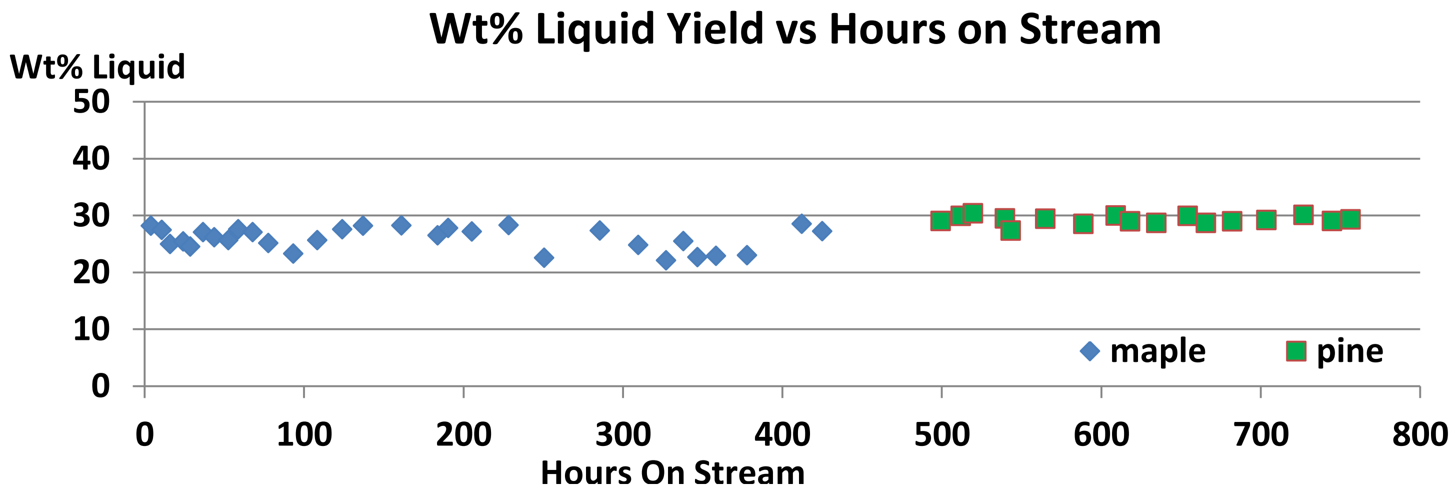
Comparison of Lab & Pilot Yields

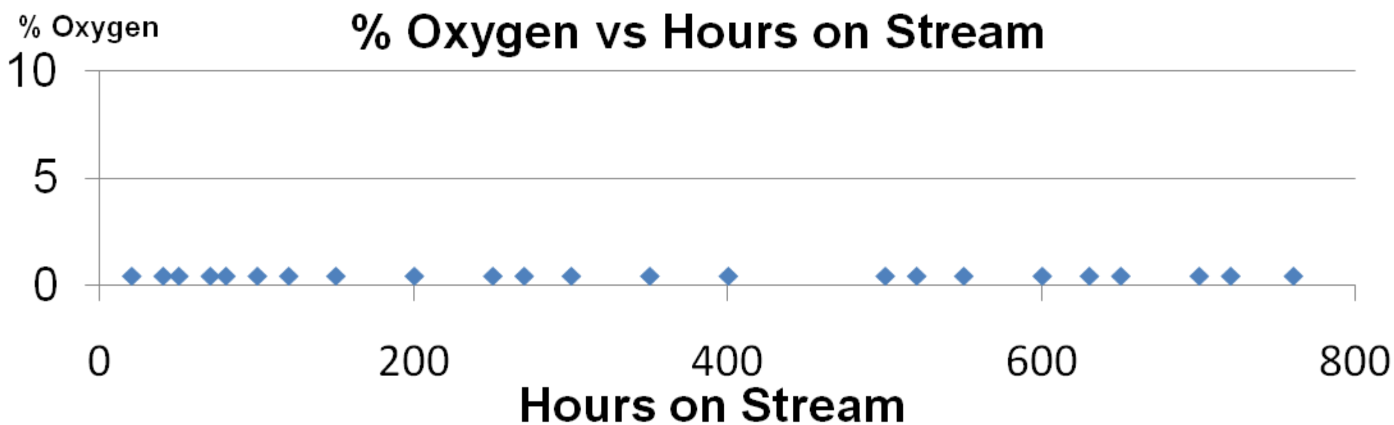
- Yields in wt% of biomass feed (wood) on a moisture and ash free basis

	Lab	Pilot
Gasoline + Diesel	**26**	**27**
char +ash	13	15
water	36	37
$CO+CO_2$	17	12
C1-C3	13	14
TOTAL*	105	105

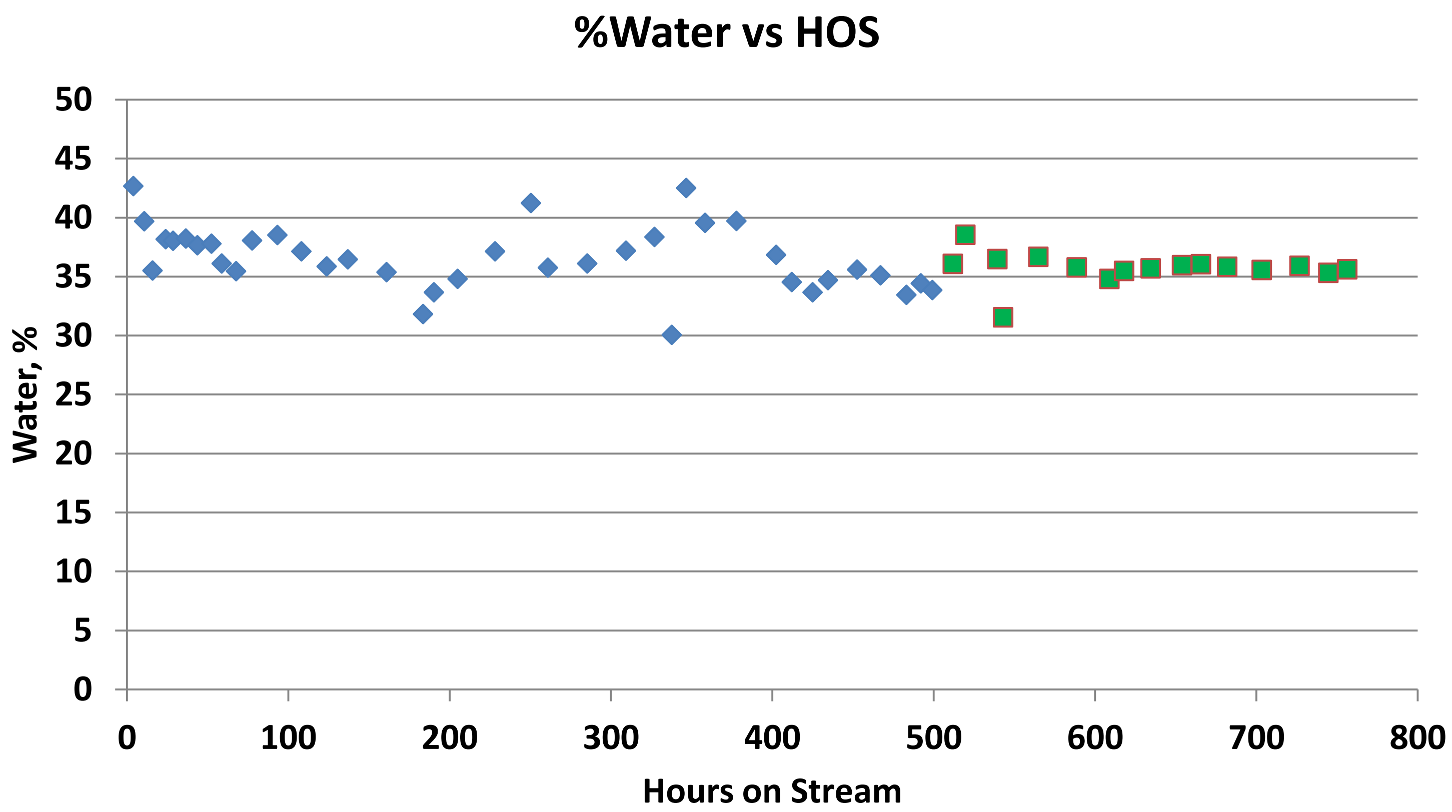
* Total greater than 100% due to hydrogen uptake

Continuous Pilot Plant Yields and Quality

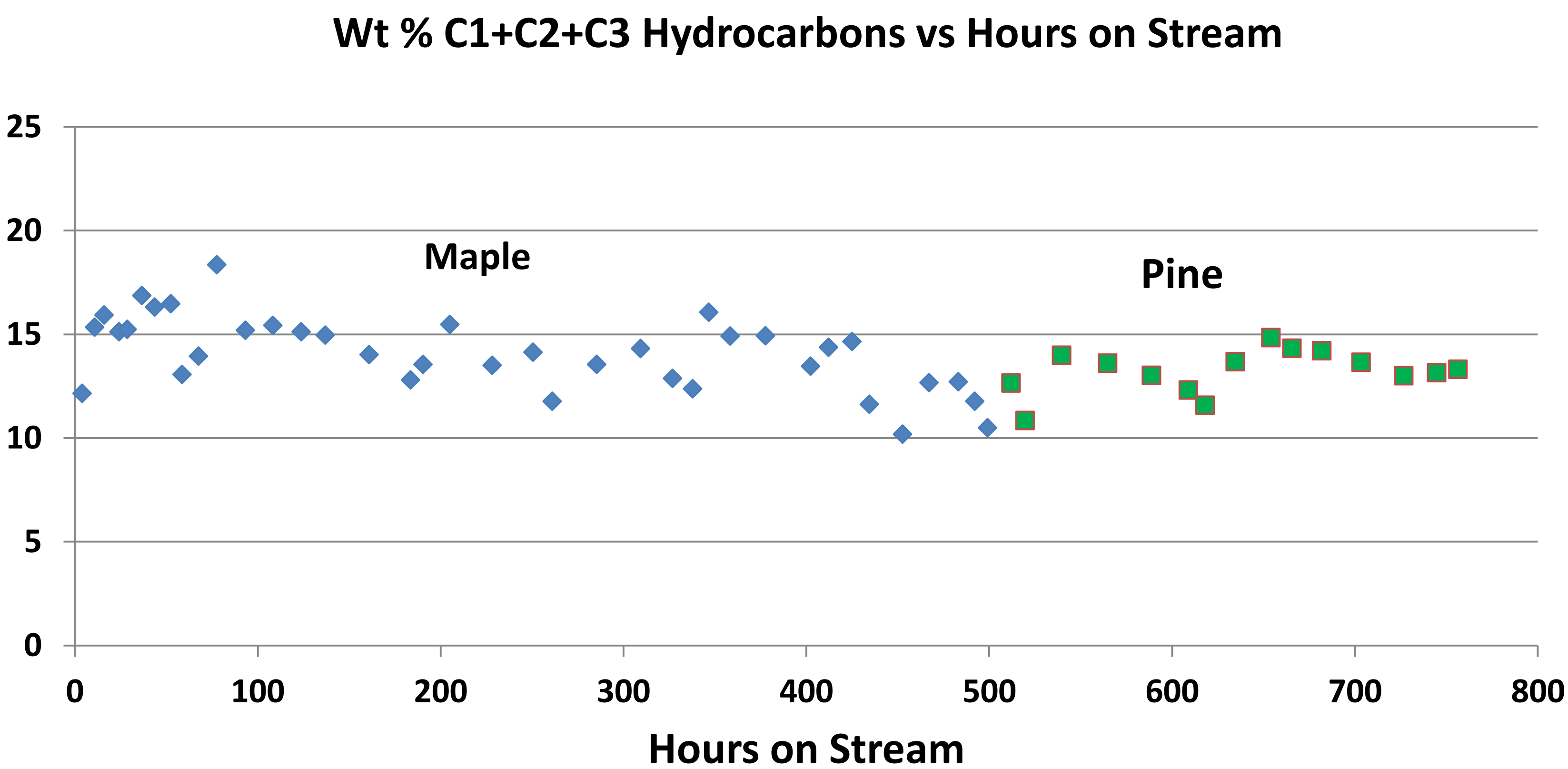




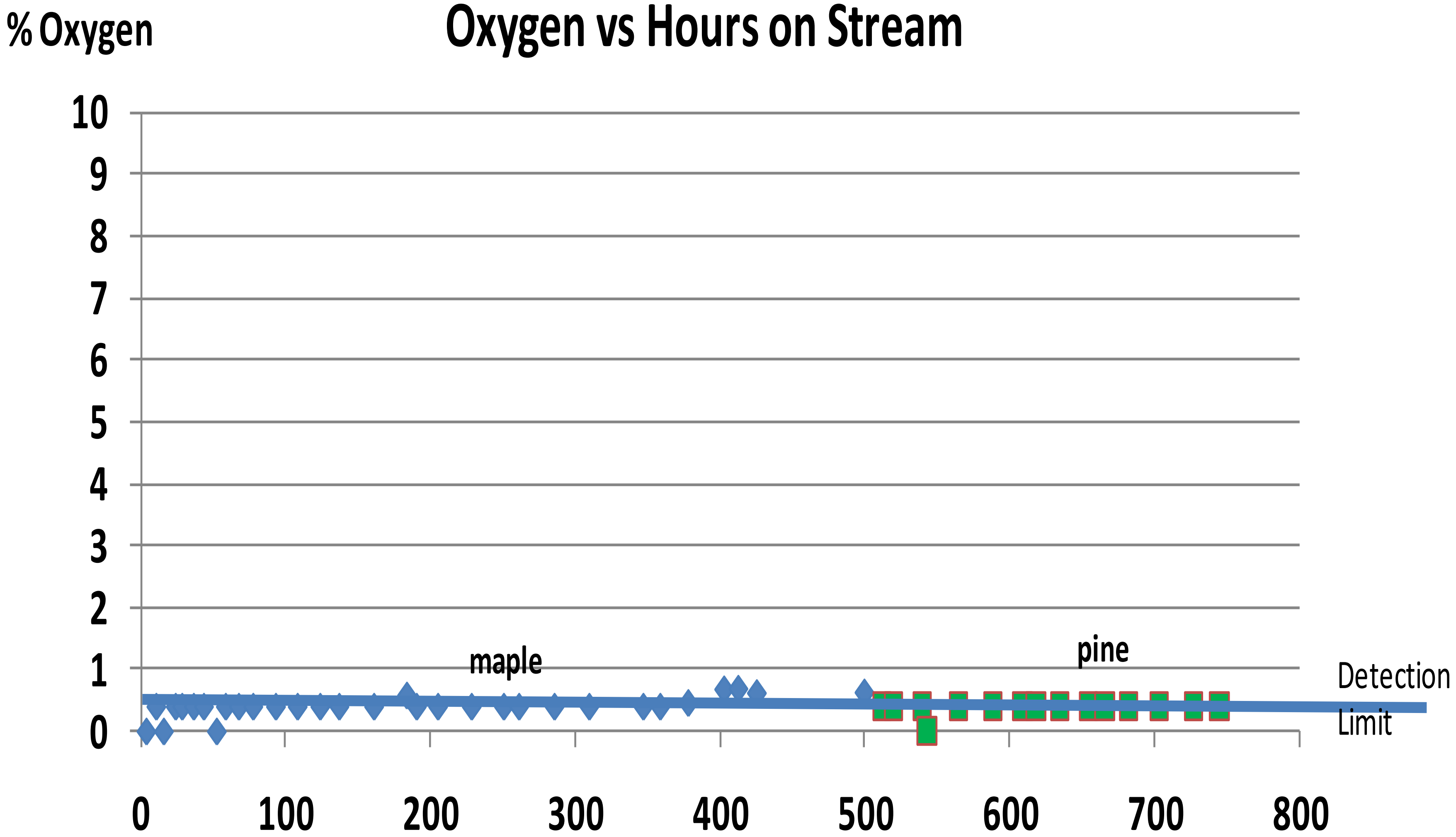
Wt %Water Produced vs Hours on Stream



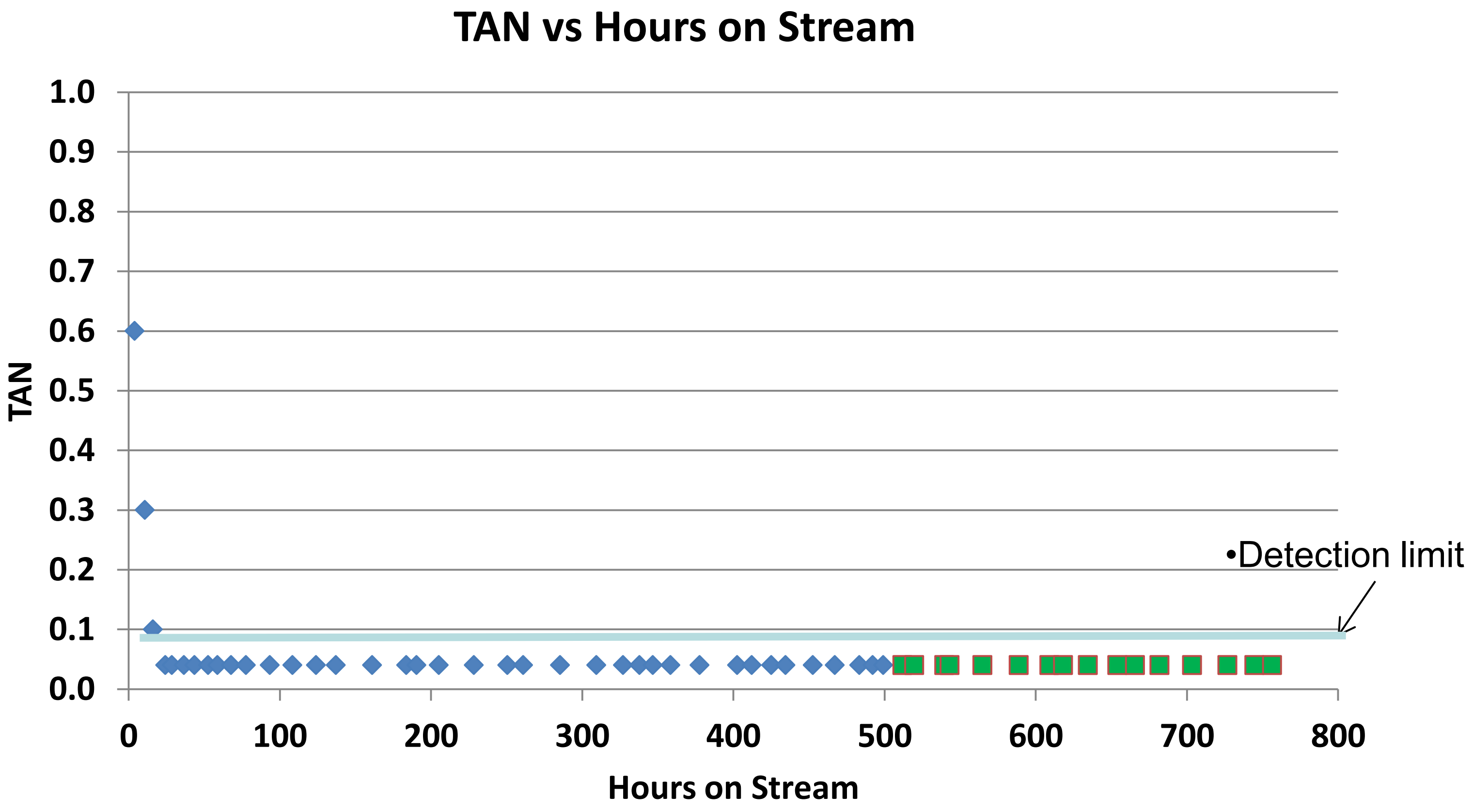
Wt% Light Ends vs Hours on Stream



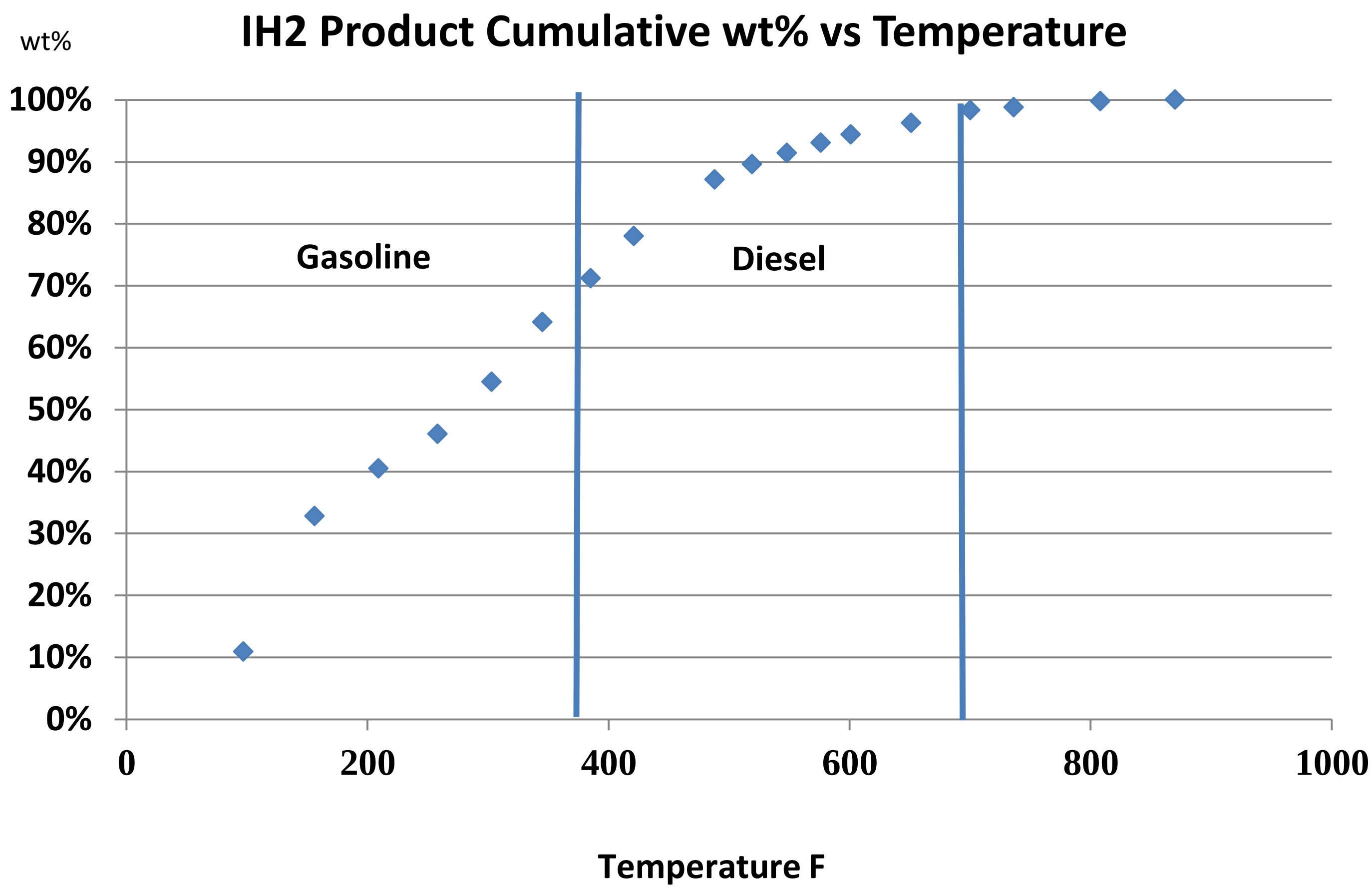
% Oxygen in Hydrocarbon Product Below Detection Limit



TAN vs Hours on Stream



IH2 Product Simulated Distillation (from Wood)



- 70% gasoline,30% diesel

Liquid Products Collected from Recent Continuous IH^2-50 Testing with Wood

Gasoline-Range Hydrocarbons

Diesel/Jet-Range Hydrocarbons

Aqueous Product

Liquid Product Quality Excellent from both pilot plant units

	Semi continuous	Continuous
		
%C	88.40	88.20
%H	11.00	11.60
%S	0.02	0.02
%N	<0.1	<0.1
%O	<0.5 (BDL)	<0.5 (BDL)
TAN	<1	<1

- 100% gasoline + diesel

IH^2 Pilot Plant Gasoline Cut v ASTM D-4814-10b

Spec Name	ASTM D 4814-10b	Test Method Used	IH^2 Gasoline Hydrocarbon
Property			
• Antiknock index (MON+RON)/2, calculated, min			86.2
Sulfur, ppm, max	80	ASTM D 5453	40
RVP @ 37.8°C (100°F), kPa, max	103	ASTM D 5191	67.4
Distillation		ASTM D 86	
IBP, °C, max			33.6
T10, °C, max	70		50.9
T30, °C, max			67.6
T50, °C, max	121		88.7
T90, °C, max	190		172.9
FBP, °C, max	225		195.1
Residue, vol%, max	2		1
Oxidation stability (Induction period), minutes, min	240	ASTM D 525	960+
Copper corrosion, 3hr @ 50°C, merit (class)	1	ASTM D 130	2A

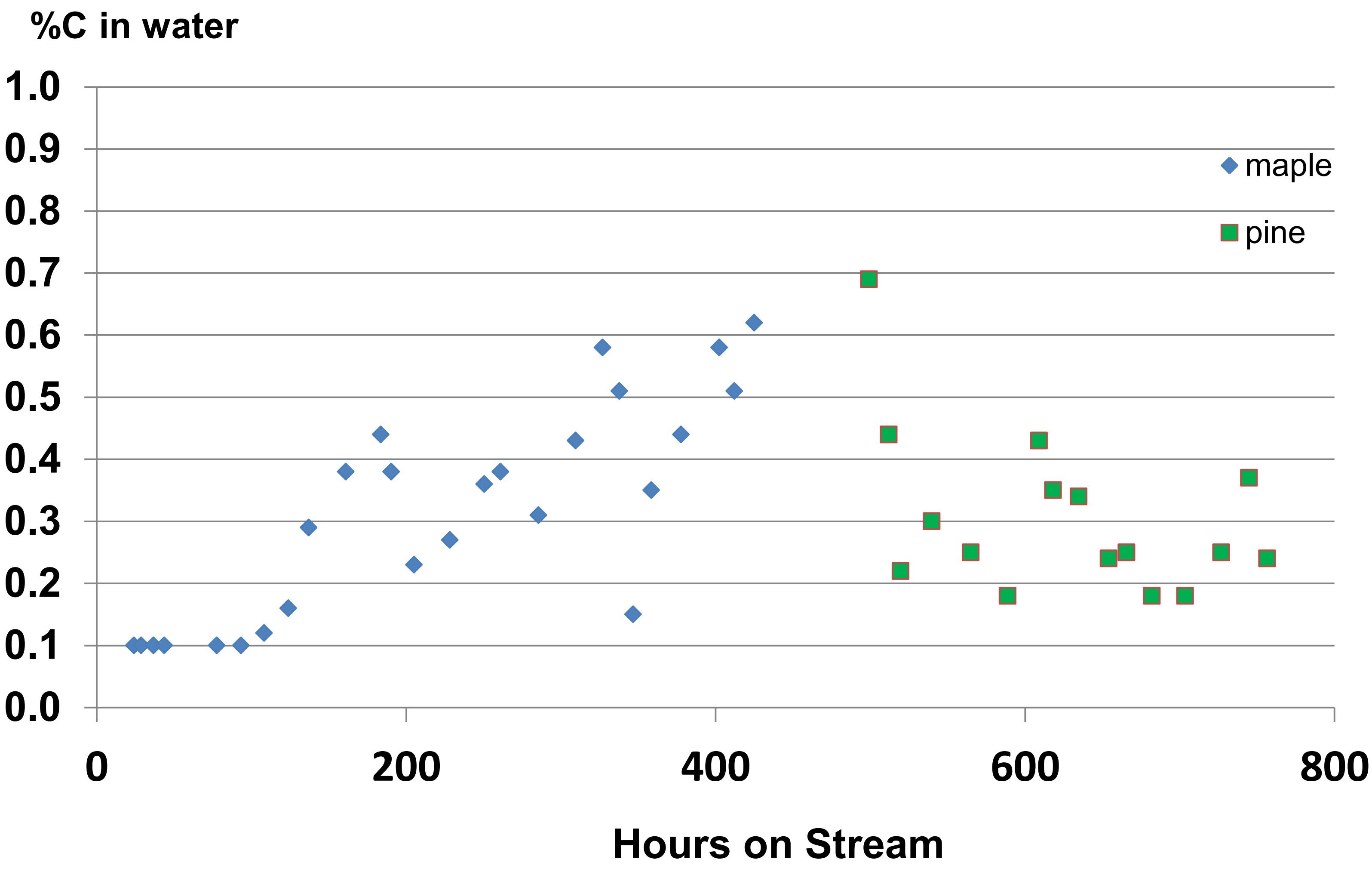
- High quality gasoline – almost 100% drop in gasoline

IH^2 Pilot Plant Diesel Cut v ASTM D-975-11

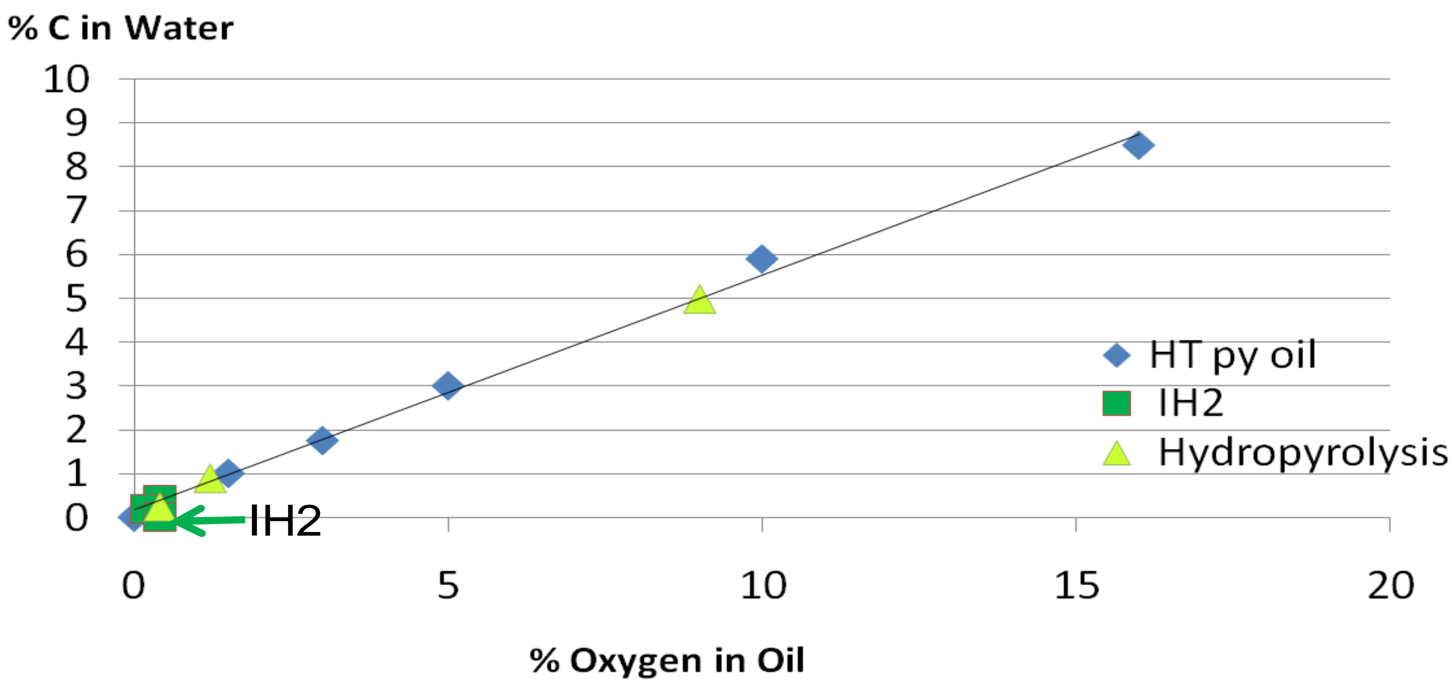
Spec Name	No.2-D S15	Test Method Used	Pilot Plant Wood Based
Cetane index, min	40	ASTM D 976	27
Sulfur, ppm, max	15	ASTM D 5453	9.1
Viscosity @ 40°C, cSt, max	4.1	ASTM D 445	7.61
Distillation			
T90, °C, max	338	ASTM D 86	340.6
Flash Point, °C, min	52	ASTM D 93	156.1
Carbon residue 10%, wt%, max	0.35	ASTM D 524	0.25
Water and sediment, vol%, max	0.05	ASTM D 2709	<0.005
Ash, wt%, max	0.01	ASTM D 482	<0.001
Lubricity, diam @ 60°C, micron, max	520	ASTM D 6079	330
Copper corrosion, 3hr @ 50°C, max	No. 3	ASTM D 130	1A

LCO like Diesel from wood, but CRI Catalyst has shown mild upgrading produces diesel product meeting 40 cetane spec

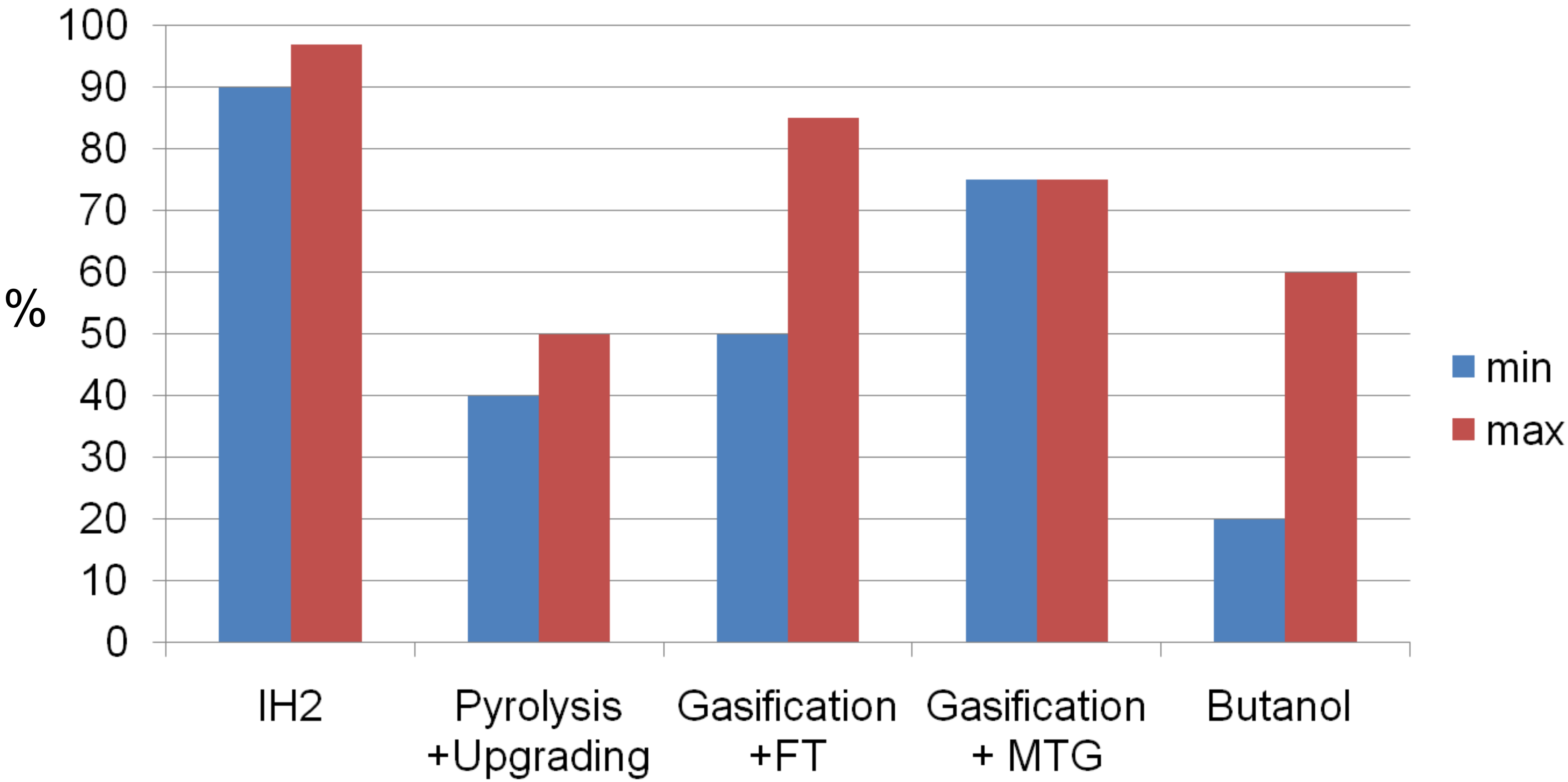
%C in Water vs Hours on Stream



Carbon Content of Water vs Oxygen Content of Oil



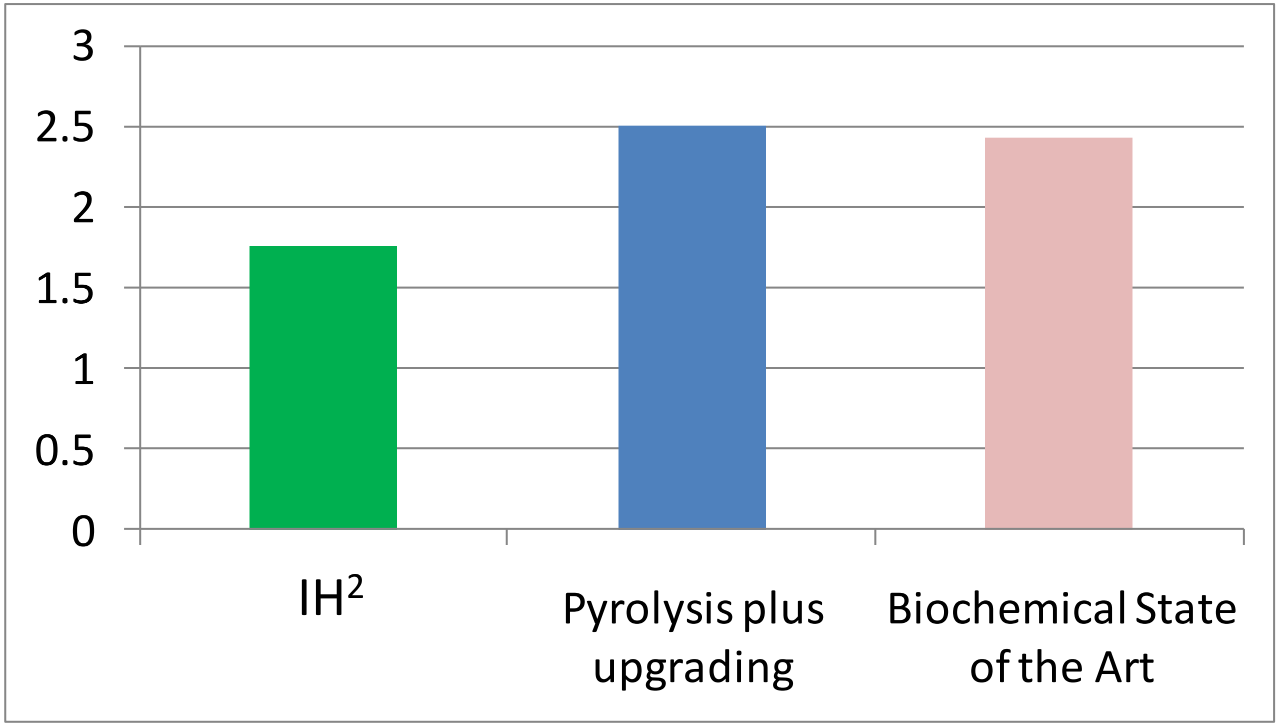
Comparison of Greenhouse Gas Reduction- by Technology



•Other technologies LCA from David Hsu "Biofuels Beyond Ethanol" Sept 9, 2008

Economic Comparison

- FCOP +ROI - $/gal



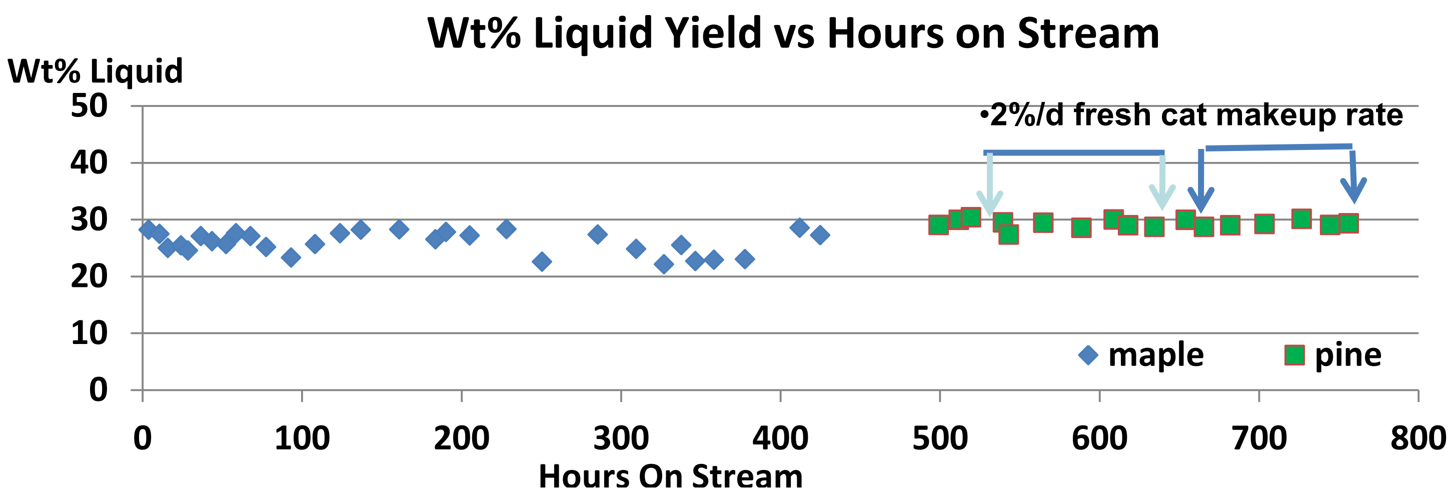
Based on 2000 t/d of biomass feed

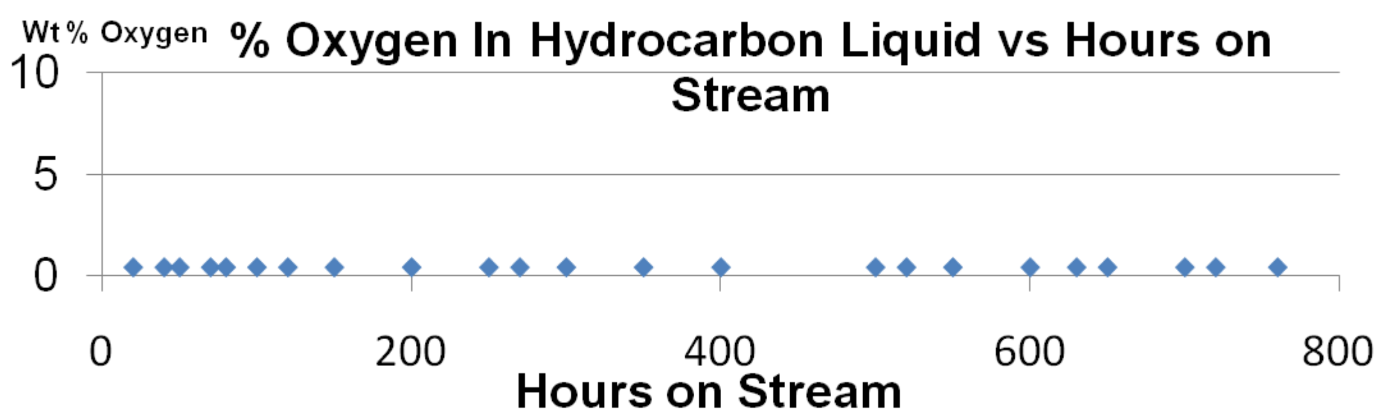
Conclusions and Future Work

- **IH^2 is a Game Changing Biomass Conversion Process**
  - **Produce valuable fuel products *directly* from biomass feedstocks**
  - **Self-sufficiency produces fuels with excellent life cycle carbon benefits (>90% lower than fossil fuels)**
  - **Excellent economics of production (estimated <$2/gallon minimum selling cost)**
- **Remaining work to be done - in future projects**
  - **More continuous testing studies, using additional feeds,**
  - **Larger size feeds must be tested next**
  - **Fundamental studies/modeling needed for hydropyrolysis reactor design**
  - **Scale up - larger demonstrations**

Backup slides

Continuous Pilot Plant Yields and Quality





MBU Test Results: IH² Liquid Yields and Feedstock Flexibility

	Wood	Lemna	Aquaflow Micro Algae	Bagasse	Blue Marble Macro Algae	Corn Stover
Feed % C	49.7	46.3	43.1	43.1	34.0	40.2
Feed %H	5.8	5.8	6.1	5.0	4.43	5.0
Feed %O	43.9	35.7	20.4	35.3	23.6	35.7
Feed %N	0.11	3.7	6.5	.34	4.6	1.0
Feed %S	0.03	0.3	0.7	.10	1.9	0.05
Feed % Ash	0.5	8.2	23.1	16.2	29.4	18.1
Feed H/C	1.40	1.50	1.70	1.39	1.56	1.49
Typical % C_4 + Liquid Yield (MAF)	**25-28**	**30**	**46**	**30**	**35**	**21**
C_4+ Gallon/Ton MAF	**82**	**100**	**157**	**100**	**119**	**67**
% Oxygen	**(BDL)**	**(BDL)**	**(BDL)**	**(BDL)**	**(BDL)**	**(BDL)**
TAN #	**<1**	**<1**	**<1**	**<1**	**<1**	**<1**