Transportation Fuels from Biomass via IH^2 Technology

IEA Bioenergy Conference
Vienna Austria
November 13-14, 2012

Presented by CRI Catalyst Company

RENEW. REFINE. REFUEL.

Disclaimer

The information contained in this material is intended to be general in nature and must not be relied on as specific advice in connection with any decisions you may make. None of CRI/Criterion Inc or any of its affiliated companies are liable for any action you may take as a result of you relying on such material or for any loss or damage suffered by you as a result of you taking this action. Furthermore, these materials do not in any way constitute an offer to provide specific products or services. Some products or services may not be available in certain countries or political subdivisions thereof.

Agenda

- Introduction to CRI and GTI
- IH^2 Technology Overview
- Economics
- Deployment

Technology Heritage - CRI Snapshot

- Evolution of Shell Catalyst Business with > 45 year history
- Global business headquartered in Houston
- Business Units
  - EO
  - ECS
  - Performance Products (CRI KataLeuna)
  - Upstream & Renewables
- Research Facilities
  - STCA 1000 staff using > 80,000 m^2 building space
  - SBL > 70 staff using ~3 acre temporary site, to relocate to 40 acre campus
  - STCH (Westhollow) 1200 staff using > 1mln sq.ft. building space
- Manufacturing Facilities in US, Germany, Belgium
- CRI and GTI have Joint Development and Commercial agreements in place

Technology Heritage - GTI Snapshot

- Not-for-profit gas research & services organization with a 70 year history
- Capabilities that span the natural gas value chain
- Energy Solutions
- Facilities
  - 18 acre Chicago campus
  - 28 specialized labs totaling 200,000 sq ft
- Staff of 250
- >1,200 patents
- >750 products taken to market

Offices& Labs

Pilot Scale Gasification Campus

Energy & Environmental Technology Center

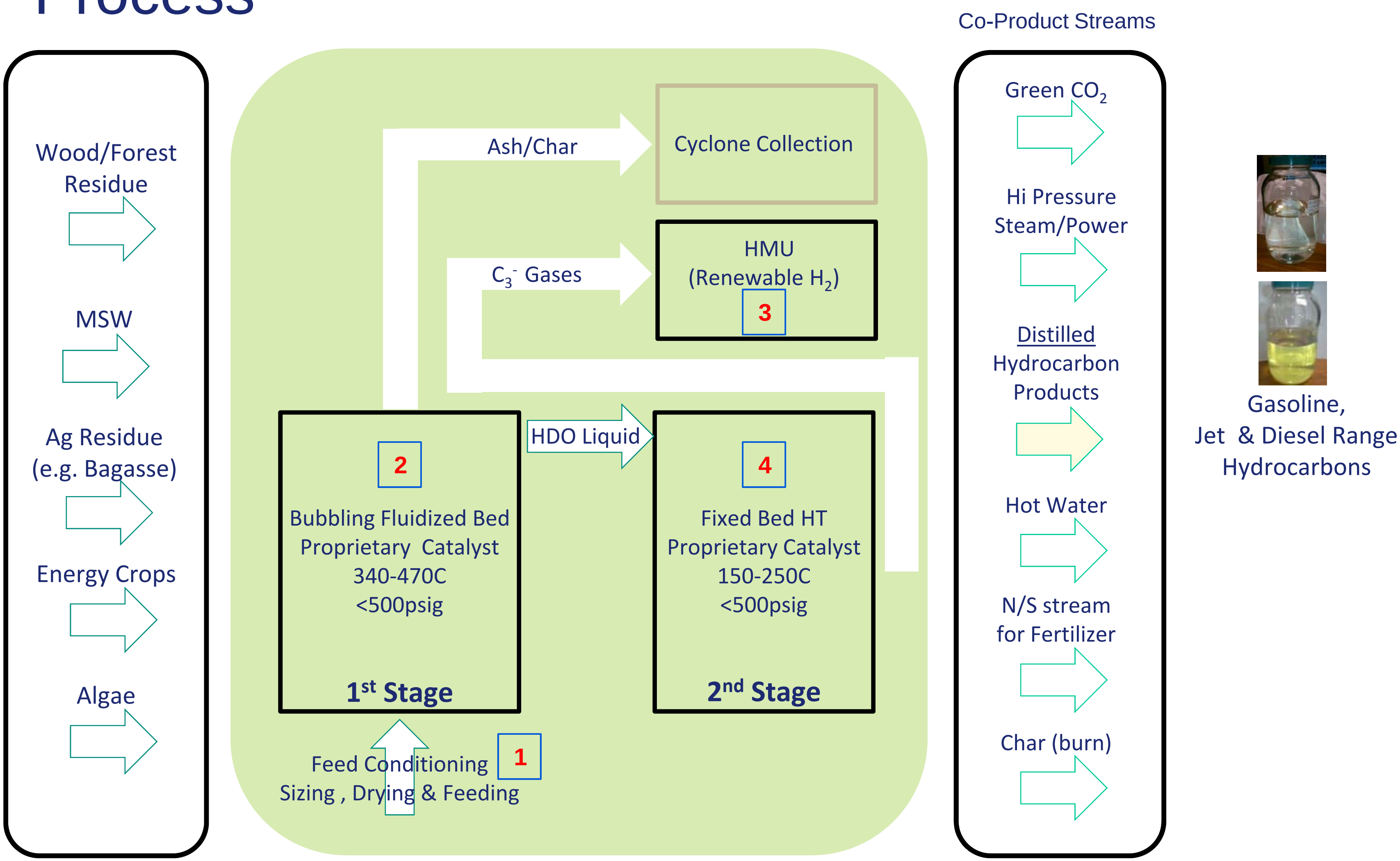
Design Principles

- Produce fungible hydrocarbon fuel/blend stock from a broad range of inedible/residual biomass feed at low cost

- *Require* no infrastructure other than road/rail transport into and out of the production. Can be integrated with existing mills or refineries for even better economics

- Have minimal unsustainable impact on the surrounding environment

IH^2 Process


Wood/Forest Residue
MSW
Ag Residue (e.g. Bagasse)
Energy Crops
Algae
Ash/Char
Cyclone Collection
C_3^- Gases
HMU (Renewable H_2)
3
HDO Liquid
2
Bubbling Fluidized Bed
Proprietary Catalyst
340-470C
<500psig
1st Stage
4
Fixed Bed HT
Proprietary Catalyst
150-250C
<500psig
2nd Stage
Feed Conditioning
Sizing , Drying & Feeding
1
Co-Product Streams
Green CO_2
Hi Pressure Steam/Power
Distilled Hydrocarbon Products
Hot Water
N/S stream for Fertilizer
Char (burn)
Gasoline, Jet & Diesel Range Hydrocarbons

Differentiators

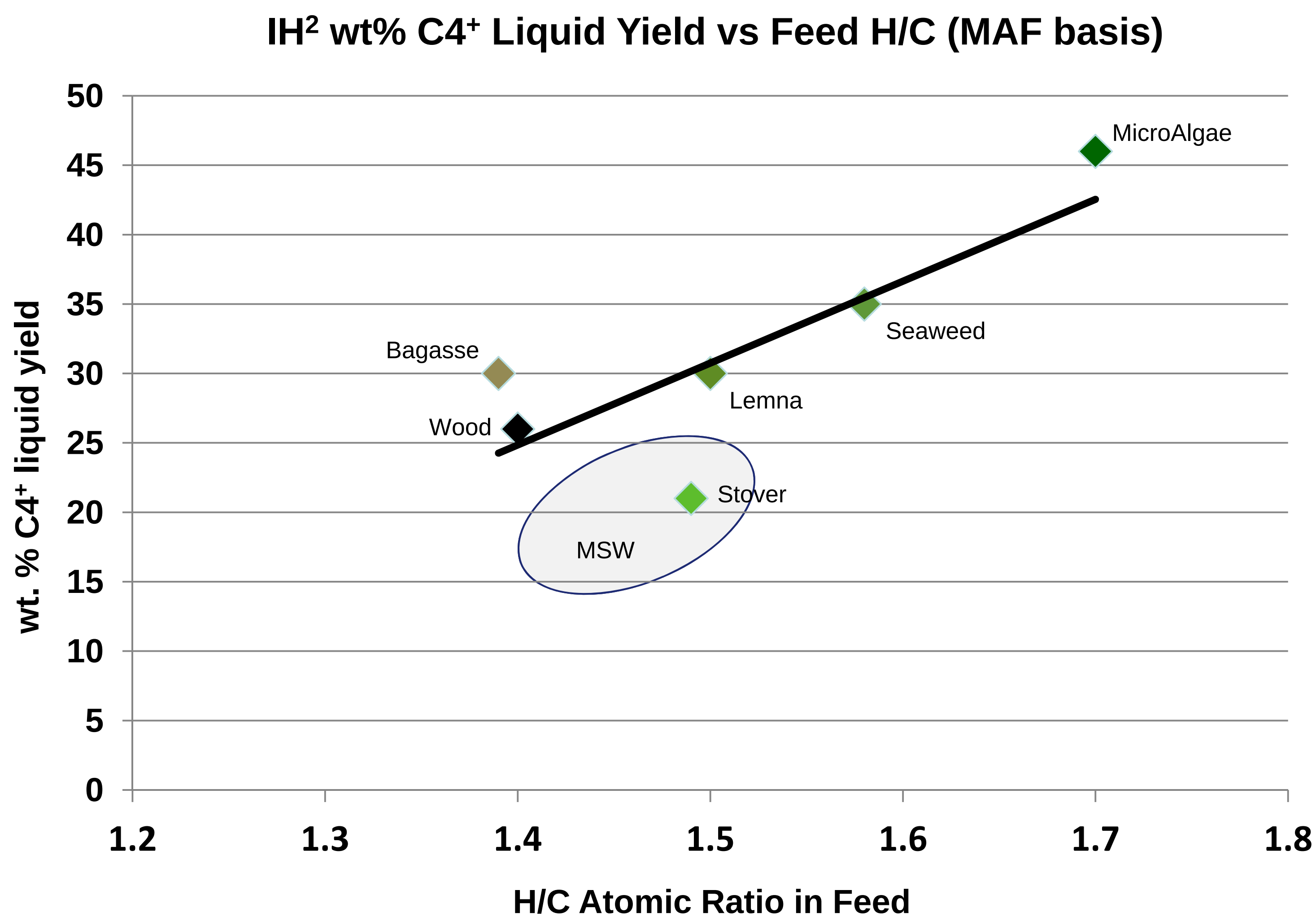
- Feedstock flexibility with yields 67-157 gal/dry, ash-free ton of feed
- Energy recovery >72% (wood, commercial scale, 45% moisture)
- Attractive economics
  - Low capex (low pressure system, non-corrosive materials, simple process)
  - Low opex (predominated by feed cost)
  - Fully profited manufacturing costs under $2.00/gal at 2000mt/d scale
- Both stages exothermic, able to export steam or electricity
- Fungible, high purity hydrocarbon product
  - High energy density (i.e. 18 kBTU/lb)
  - Replaces 'whole barrel' gas/jet/diesel with *same molecules* as fossil fuels
  - O below detection limit
- Self-sufficient internal "green" H_2
  - Eases logistical constraints
  - >94% GHG reduction (Professor David Shonnard, MTU)
- Integrates existing technologies for fast implementation
- Proprietary CRI catalysts play critical role

1st Gen Liquid Yields and Feedstock Flexibility

Parameter	UoM	Wood	Parabel Lemna	Aquaflow MicroAlgae	Bagasse	Blue Marble Seaweed	Corn Stover
Feed Carbon Content	wt%	49.7	46.3	43.1	43.1	34.0	40.2
Feed Hydrogen Content	wt%	5.8	5.8	6.1	5.0	4.43	5.0
Feed oxygen content	wt%	43.9	35.7	20.4	35.3	23.6	35.7
Feed nitrogen content	wt%	0.11	3.7	6.5	0.34	4.6	1.0
Feed sulfur content	wt%	0.03	0.3	0.7	0.10	1.9	0.05
Feed ash content	wt%	0.5	8.2	23.1	16.2	29.4	18.1
Feed H/C atomic ratio		1.40	1.50	1.70	1.39	1.56	1.49
C_4^+ liquid yield (MAF)	wt%	28	30	46	30	35	21
(Gasoline/Diesel)	wt/wt	62/38	65/35	50/50	76/24	76/24	62/38
C_4+ liquid yield	Gallons/ton	92	100	157	100	119	67
Product Oxygen		b d l	b d l	b d l	b d l	b d l	b d l
Product TAN	mg KOH/g	<0.05	<0.05	<0.5	<0.05	<0.05	<0.05

b d l = below detection limit

Liquid Yields and Feedstock Flexibility



Approach

- Initial focus upon motor transportation fuels gasoline, diesel
  - initial look at 1st gen gasoline and diesel to set catalyst development targets
  - demonstrate product improvements via catalyst improvements
  - ASTM D4814 and D975
  - EN 228 and EN 590

- Examine aviation turbine fuel quality second as greater quantities of fuel become available from pilot plant

- Entered EPA registration process
- Began ASTM fuel qualification program
- Begin OEM interaction

Catalysts Are Key

- <u>1st generation hydrocarbon products had deficiencies</u>
  - low conversion, residual N/S, low diesel cetane, etc
  - advanced catalysts developed to address many of these issues

- 2nd – 3rd generation catalyst packages
  - increased liquid yields (demonstrated)
  - shifted jet/diesel product into gasoline (demonstrated)
  - increased hydrogen / carbon ratio (demonstrated)
  - maximized fuel by converting heavy ends (demonstrated)
  - decreased aromatic content (demonstrated)
  - decreased product N and S (demonstrated)
  - improved product visual appearance/color (demonstrated)

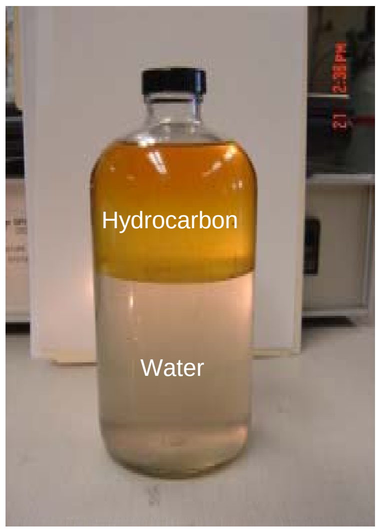
- 4th generation catalyst packages
  - increase diesel cetane (work in progress)
  - shift gasoline into jet/diesel (work in progress)

IH^2 Liquid Products (Wood)

Advanced catalysts improve product appearance and quality

Total Liquid Product
1st Gen Catalyst MBU

Total Liquid Product
2nd Gen Catalyst MBU



Gas/Jet/Diesel Product
3rd Gen Catalyst MBU

Gasoline Product
3rd Gen Catalyst ex
IH^2 50 Pilot Plant

Jet/Diesel Product
3rd Gen Catalyst ex
IH^2 50 Pilot Plant

Water Product
3rd Gen Catalyst ex
IH^2 50 Pilot Plant

"B5" Quality → "B25" Quality → "B60+" Quality →

"GOAL"
Drop In
Stand
Alone
"B100"

GRI

IH^2 50 kg/d Continuous Pilot Plant

Comparison of Lab and Pilot Units

	Pilot plant	Laboratory unit
Mode of operation	Continuous	Semi-continuous
Amount of biomass feed	2000 g/h	360 g/h
Automation/control system	Yes - Complete	Partial
Lock hopper – continuous feed	Yes	No (Batch)
Continuous char removal	Yes	No (Batch)
Compressor/recycle gas	Yes	No (Once-through)
Automated valves/interlocks	Yes	No
Primary reactor diameter	2.5x	1.0x
Cyclone separation	Yes	No
Gas velocity in primary Rx	2.0x	1.0x

Yield Comparison between Pilot Plant and Lab Unit

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

	Pilot plant	Laboratory unit
Liquid hydrocarbon product	24-26	26
Char	11-14	13
Water	39-42	36
$CO + CO_2$	7-8	17
C1-C3 gases	12-15	13
Total*	105	105

*Total greater than 100% due to hydrogen uptake

Comparison of Liquid Quality from Woody Biomass

	Pilot plant	Laboratory unit
		
% Carbon	88.20	88.40
% Hydrogen	11.60	11.00
% Sulfur	0.02	0.02
% Nitrogen	<0.10	<0.10
% Oxygen	BDL	BDL
Total acid number, mg KOH/g	<0.05	<0.05

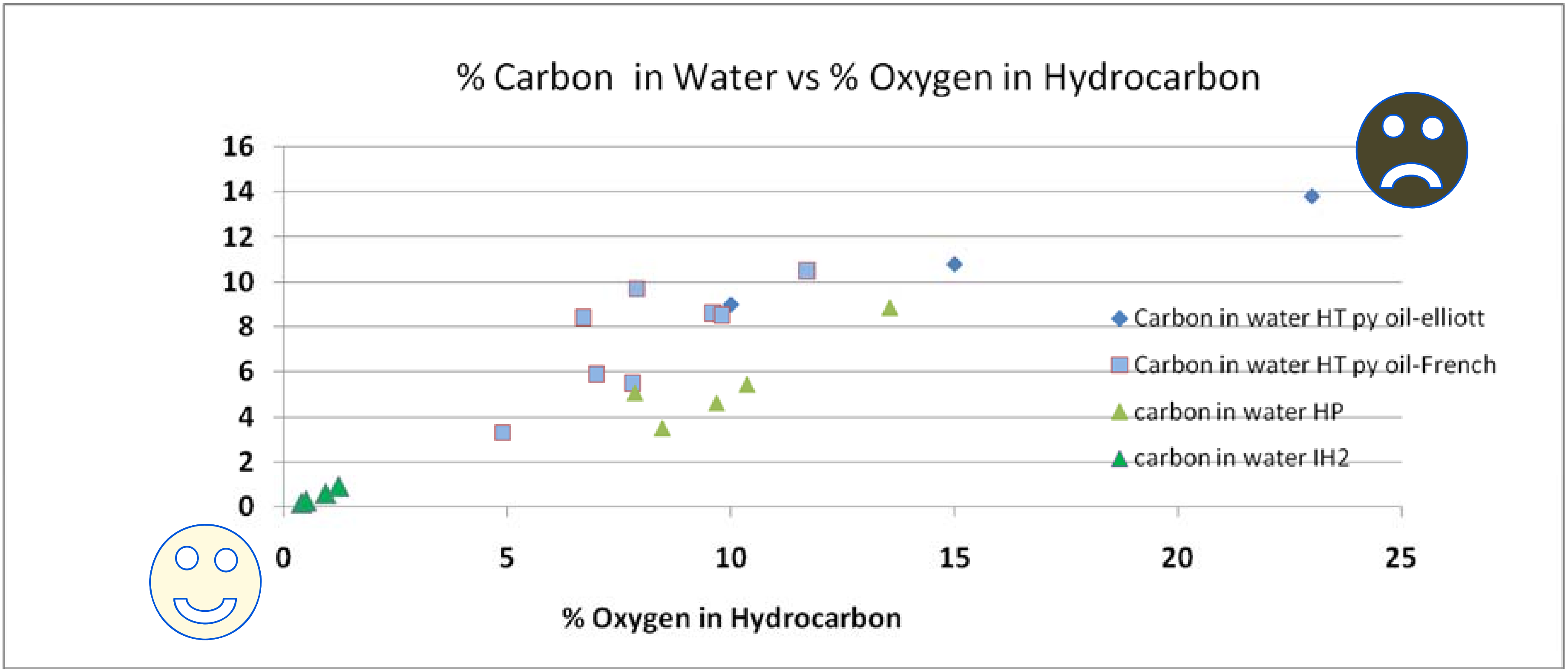
IH^2 Liquid Products (Wood)

- 3rd generation gasoline from IH^2-50 Pilot Plant
  - Distilled 5 gallons
  - Passed all D-4814-10b unleaded gasoline specifications as B100
  - Except Cu strip (2A vs 1) & Ag strip (4 vs 1)
  - Active S related, improved 2nd stage catalyst(s)

- 3rd generation jet from IH^2-50 Pilot Plant
  - Distilled 2 gallons
  - Extensive specifications

- 3rd generation diesel from IH^2-50 Pilot Plant
  - Distilled 2 gallons
  - Passed all D-975-11 as No 2, general purpose middle distillate fuel as B100
  - Except Cetane Index & Viscosity

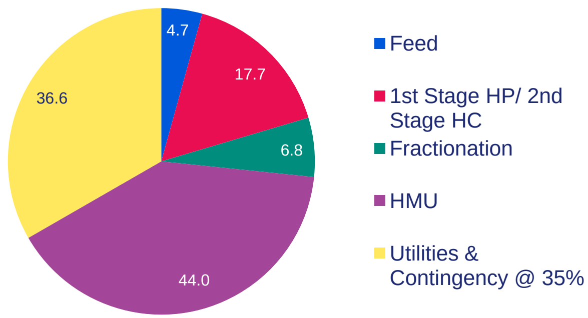
IH2 Water is Clean!



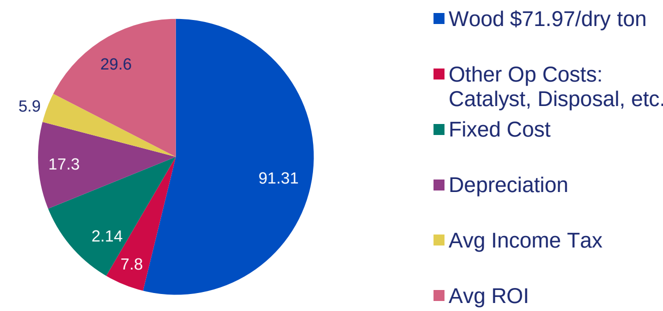
1 Elliott, Doug, Hart, Todd, Neuenschwander,Leslie, Zacher, Alan " Catalytic Hydropyrolysis Biomass Fast Pyrolysis Bio-Oil to Produce Hydrocarbon Products, Environmental Progress & Sustainable Energy",Aug 2009
2 French, Richard , Stunkel, Jim, Baldwin, Robert " Mild-Hydrotreating of Bio Oil: Effect of Reaction Severity and Fate of Oxygenated Species" , Energy and Fuels. Vol. 25(7) 21 July 2011

IH² Process Estimates

Installed Equipment Costs $112.6mln

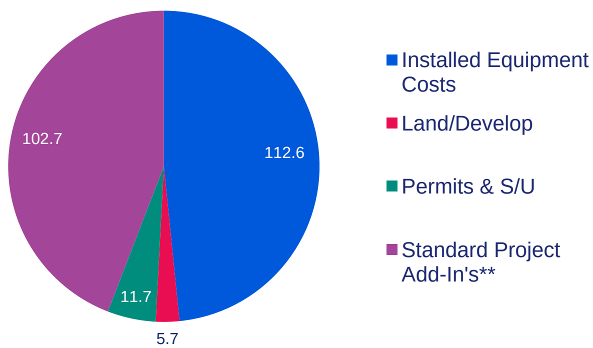


Operating Costs Total $1.60/gal*



*Includes $0.093/gal coproduct credit

Total Capital Investment $232.8mln



** Prorated Expense (10%), H O & Construction (20%), Field Expense (10%), Working Capital (10%) , Project Contingency (30%)

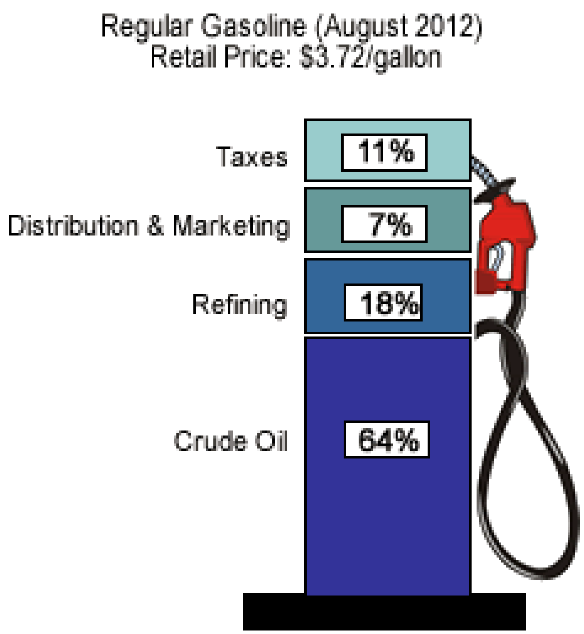
- 2000mt/d wood (50% moisture fed, dried to 10% moisture at 1st stage)
- Land acquisition & development costs included
- Equipment cost - HMU is largest @ $44mln ~40% TIC
- Total Capital ~Double Installed Equipment
- Feed Stock ~55% of Operating Cost
- **Minimum Fuel Selling Price – $1.60/gal (2007) $1.76 (2012)**

- Refinery Synergy w/Refinery H_2 Supply
  - Reduces Capital Cost ~44.0MM$
  - **Estimated MSP $1.36/gal (2007) $1.49 (2012)**

- NREL capex validated by KBR
- NREL used early liquid yields (79 vs 92 gal/t)

Title: Techno-economic Analysis of the Integrated Hydropyrolysis and Hydroconversion Process for the Production of Gasoline and Diesel Fuels from Biomass
Author: Eric C. D. Tan Platform: Analysis Report Date: May 23, 2011

IH^2 Process Economics: US Retail Price Build Up



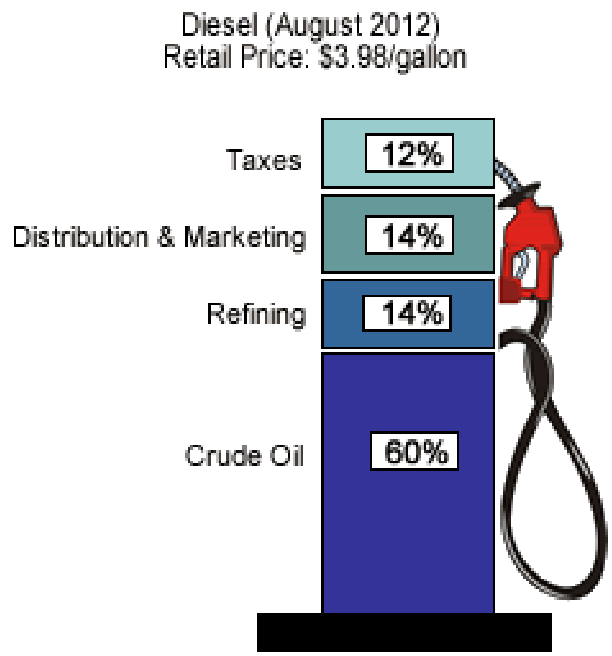
Fossil

$0.41/gal	$0.48/gal
$0.26/gal	$0.56/gal
$0.67/gal	$0.56/gal
$2.38/gal	$2.39/gal
$3.72/gal	$3.98/gal

$100.14/bbl

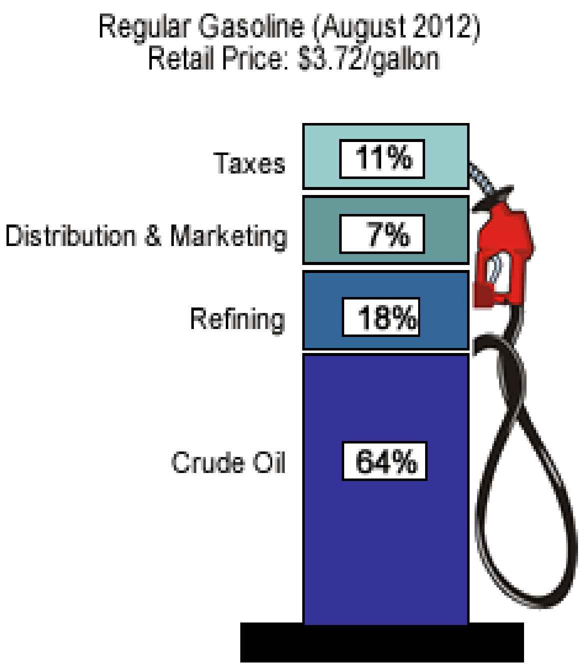
$3.05/gal	$2.95/gal

(crude + refining only)



source: http://www.eia.gov/petroleum/gasdiesel/ 10/3/2102

Breakeven Crude Price Simplified Estimate

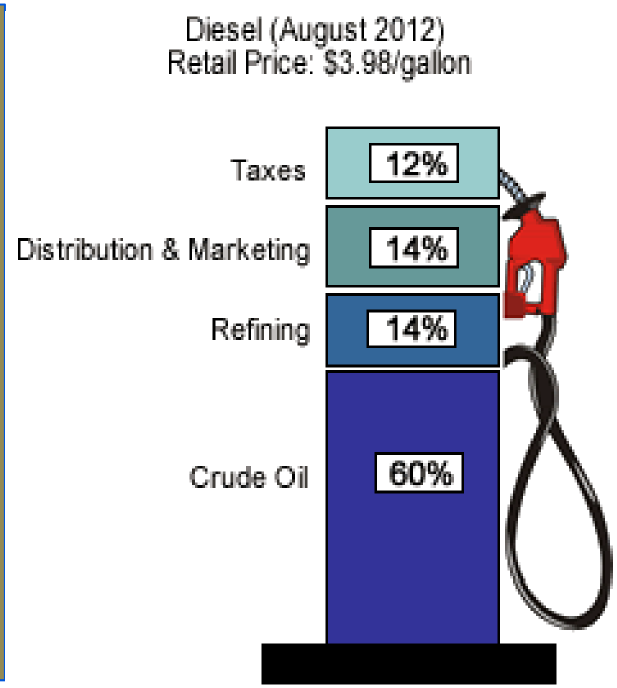


Fossil

$0.41/gal $0.48/gal
$0.26/gal $0.56/gal
$0.67/gal $0.56/gal
$2.38/gal $2.39/gal
$3.72/gal $3.98/gal

$100.14/bbl

$3.05/gal $2.95/gal
(crude + refining only)



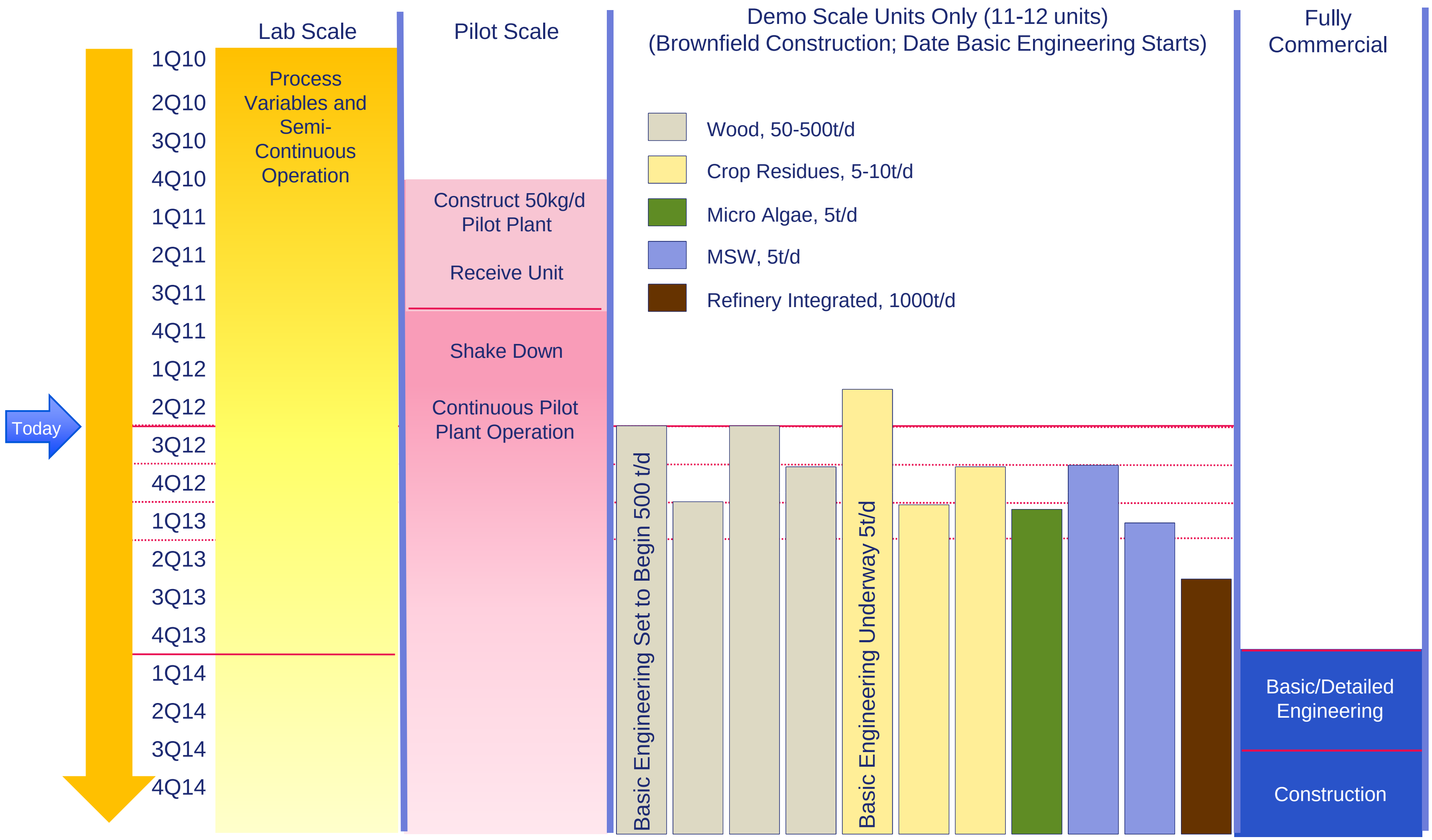
IH2 RENEW. REFINE. REFUEL.

$1.76/gal $1.76/gal wood + refining
$1.25/gal $1.25/gal no “refining”

source: http://www.eia.gov/petroleum/gasdiesel/ 10/3/2102

$60/bbl estimated breakeven (wood)

Commercial Timeline, Current Status



Conclusions

- The IH^2 technology is
  - a cost-effective catalytic thermochemical process that converts biomass directly to hydrocarbon fuels / blend stocks
  - self-sufficient and self-sustaining with little impact on the surrounding environment needing only transport in/out of the site
  - feedstock agnostic, able to consume broad range of biomass straight, mixed and varied feeds including MSW and algae
  - not gasification/FT based
  - scalable from 40 to ≥3000mt/d feed
  - nearly carbon-neutral (LCA ≥94% GHG* reduction)
  - currently in basic engineering for multiple feed demonstrations
  - available exclusively from CRI

Thank You

Learn more at
www.cricatalyst.com/renewables