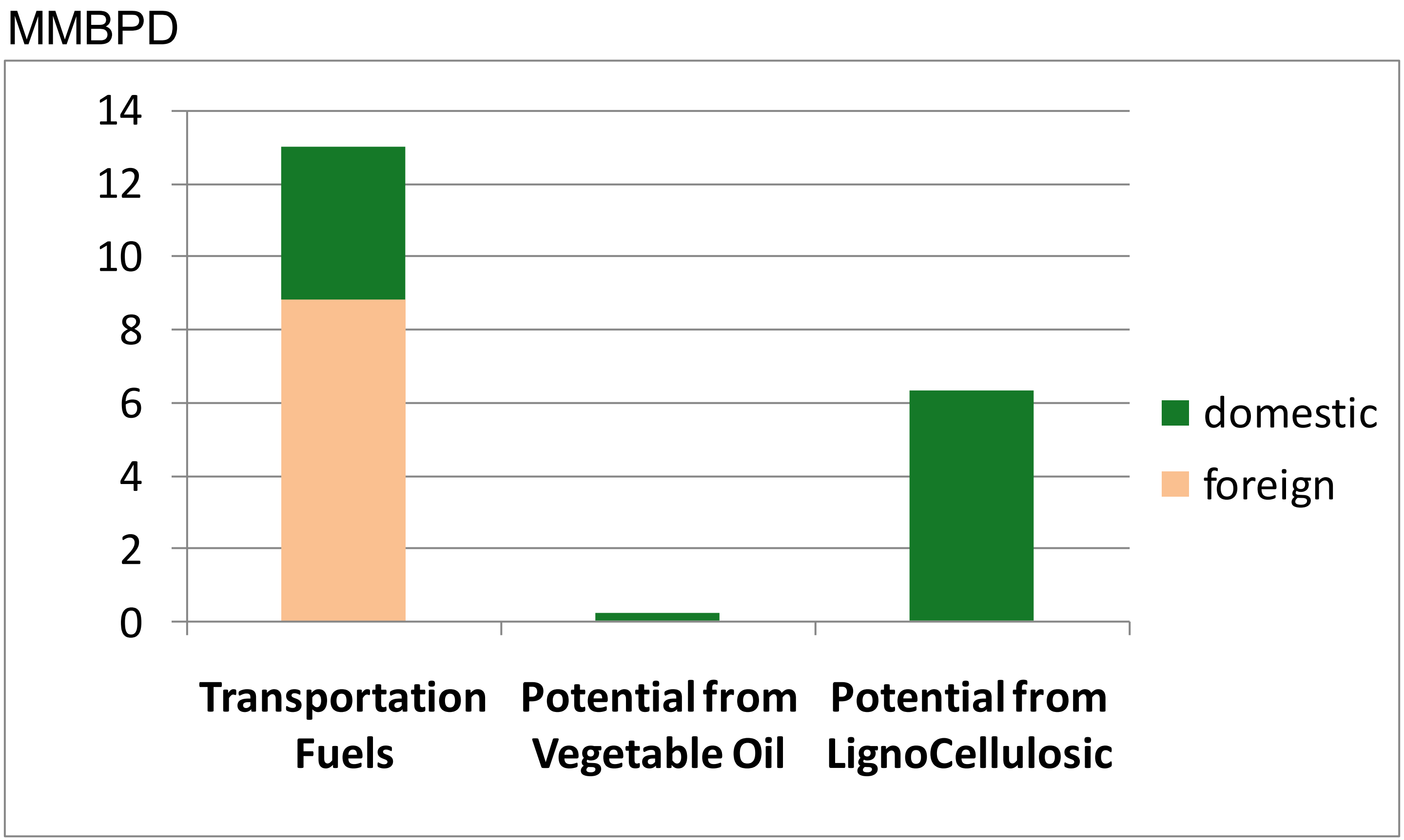
Integrated Hydropyrolysis and Hydroconversion (IH2) Process for Direct Production of Gasoline and Diesel Fuel from Biomass

Terry Marker, Martin Linck, Larry Felix

BIOMASS 2010 – March 30-31, 2010

Potential for U.S. Liquid Fuels from Lignocellulosic Feed



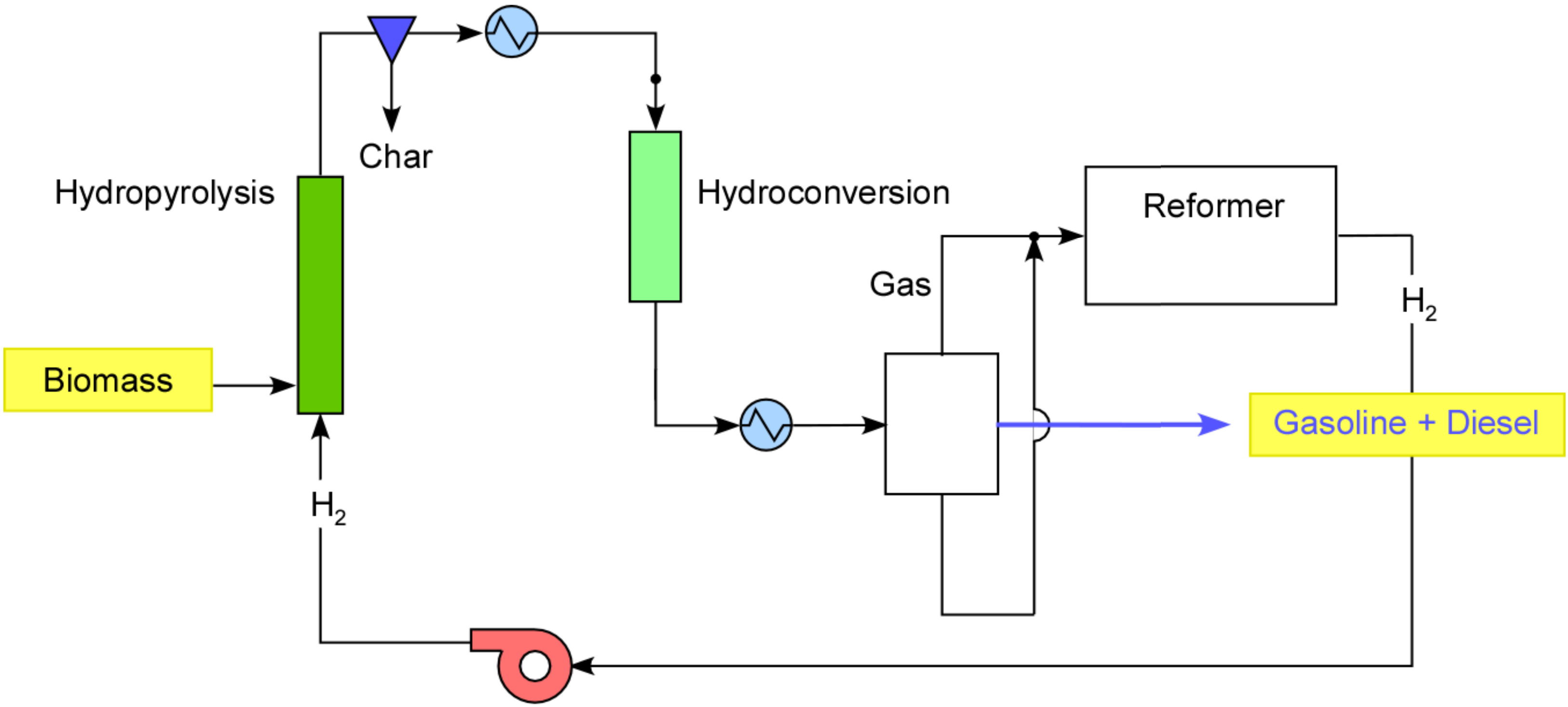
Based on billion ton per year of biomass and 28wt% conversion to liquid

Challenges for Pyrolysis or Pyrolysis Plus Upgrading

- >Undesirable Pyrolysis Oil Properties
  - > Limited demand
  - > Expensive to transport
  - > Incompatible with oil refinery metallurgy

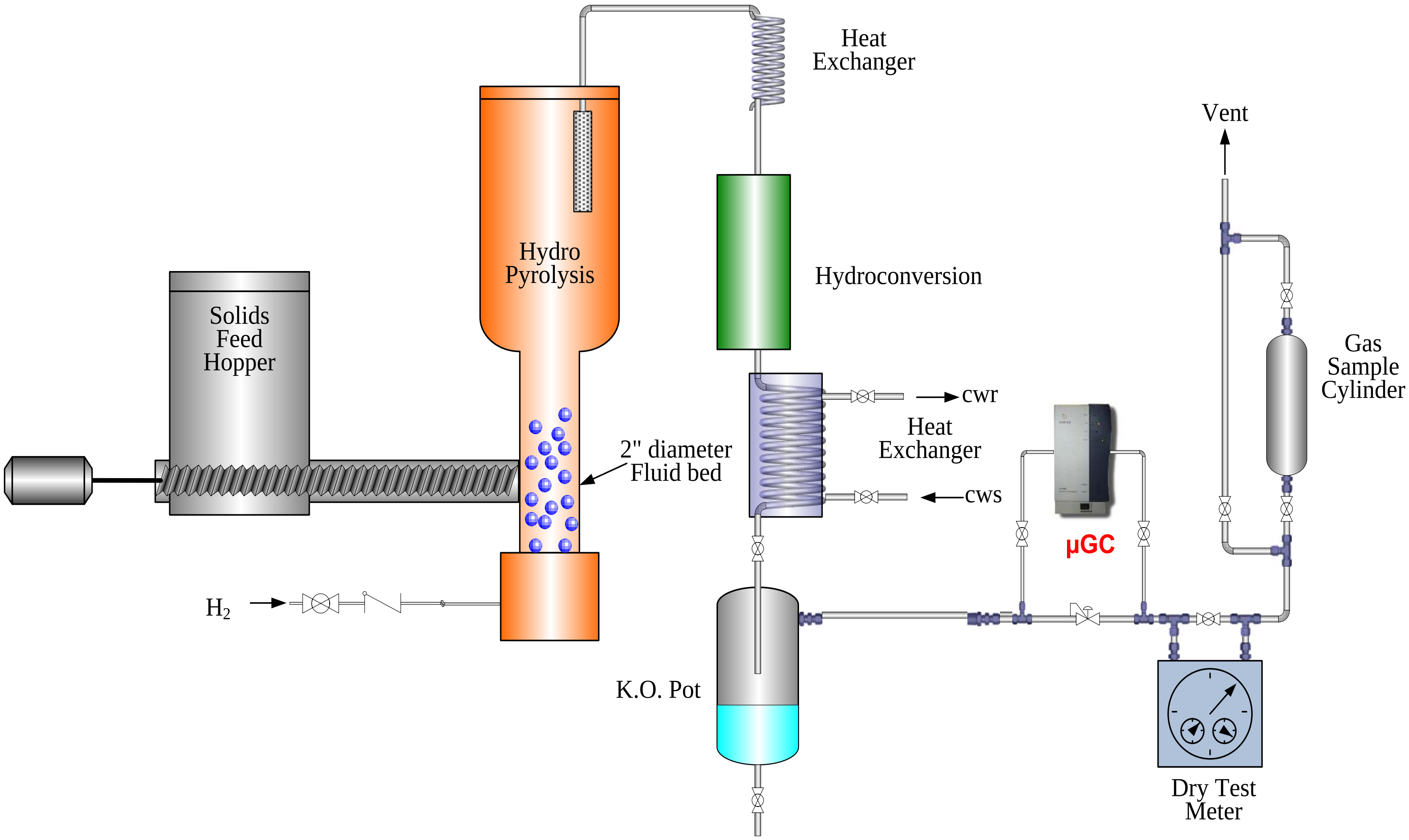
- >Expensive Upgrading to Make Fungible Fuels
  - > High H_2 requirements
  - > Severe conditions (low LHSV, high pressures)

Integrated Hydropyrolysis and Hydroconversion

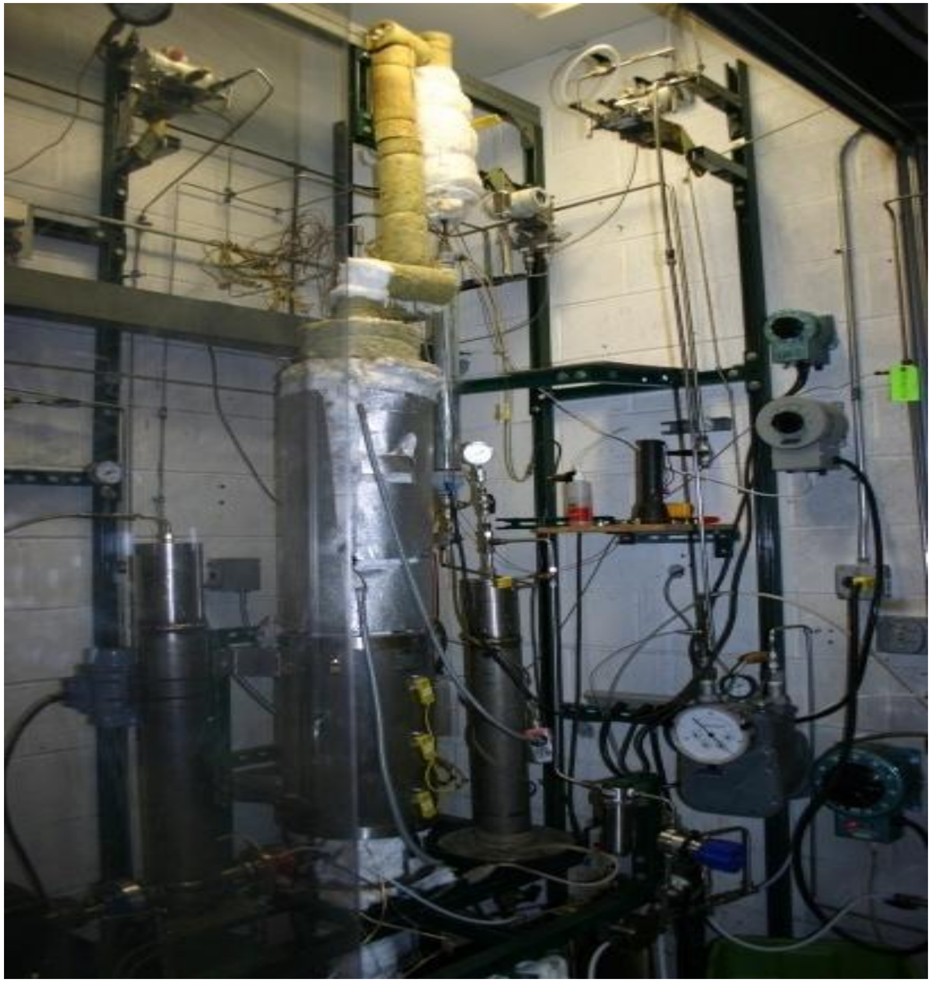


- Directly make desired products
- Run all steps at moderate hydrogen pressure (100-500 psi)
- Utilize C_1-C_3 gas to make all hydrogen required
- Avoid making “bad stuff” made in pyrolysis – PNA, free radicals

IH2 Proof of Principle Unit



GTI IH2 Equipment



- Hydrogen pressures of 100-500 psi
- Fast heat up of continuously fed biomass
- Specially designed feeder
- Well fluidized bed of catalyst for hydropyrolysis
- No sign of bed agglomeration
- No signs of coking or pressure buildup across hot internal filter
- Integrated fixed bed hydro-treating – using CRI/Criterion Inc. CoMo catalyst
- Hydrocarbon product floats on top of *separate* water phase

IH2 Feedstock Flexibility

	Wood	Lemna (Minor Duckweed)
% C	49.7	46.3
%H	5.8	5.8
%O	43.9	35.7
%N	0.11	3.7
%S	0.03	0.3
% Ash	0.5	8.2
Cellulose	40	
Hemicellulose	32	
Lignin	28	
Carbohydrate		52.2
Protein		28.7
Lipid		1.0
Fiber		6.0
% C_4 + Liquid Yield (MAF)	23-30	23-30
% Oxygen	<1%	<1%

IH2 works with a variety of feedstocks

GTI IH2 Proof of Principle Experimental Results

Feedstock	Wood	Lemna
C_4 + Liquid yields (MAF) wt%	23-30%	23-30%
% Oxygen in liquid	<1%	<1%
% Gasoline boiling range in liquid product	54-75	55-72
% Diesel boiling range in liquid product	25-46	28-45
% Char	7-10	3-15
% CO_X	13-23	2-20
% C_1-C_3	10-14	4-16
% Water	31-35	30-40

Adjustment of process conditions (temperature, pressure catalyst) – adjusts yield structure - further optimization likely

Product Property Comparisons

	Fast Pyrolysis Oil	IH2 product
% Oxygen	50	<1.0%
% Water	20	<0.1%
TAN	200	<2
Stability	poor	Good
Heating value (Btu/lb)	6560	18000
% Gasoline	Non-distillable	54-75
% Diesel	Non-distillable	23-46
Compatibility with crude oil or refinery products	No	Excellent
Relative transportation cost	1.0	0.3

It is easier to find a market for desirable products than undesirable ones.

Recipe for Hydrogen Self Sufficiency

1. Utilizing the C_1-C_3 gas for making hydrogen in steam reformer (usually burned in pyrolysis)
2. Balanced CO_X and H_2O production in the IH2 process with catalyst and conditions:
   - Too much H_2O production uses too much hydrogen
   - Too much CO_X reduces liquid yields
   - After water gas shift <60% oxygen to water
3. Water gas shift in hydroconversion reactor or reformer to make hydrogen from water

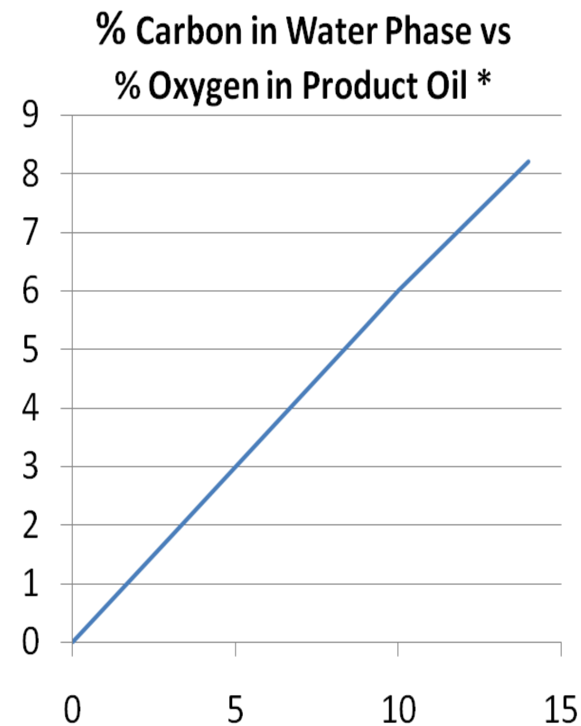
$$CO + H_2O \rightarrow CO_2 + H_2$$

Technology Comparison

	Fast Pyrolysis	Distributed Pyrolysis + Upgrading	IH2
Product properties	Poor	Excellent	**Excellent**
External hydrogen required	None	3-4%	**None**
Capital costs	Medium	High	**Medium**
Hot filtering	Difficult	Difficult	**Straightforward**
Heat of reaction	Endothermic 300J/g	Pyrolysis = Endothermic Upgrading = Exothermic	**Both Stages Exothermic**
Integration with upgrading	None	No	**Yes**
Transportation costs	Medium	High	**Low**

Advantages of Directly Making Hydrocarbon Products – Rather than Oxygenated Intermediates

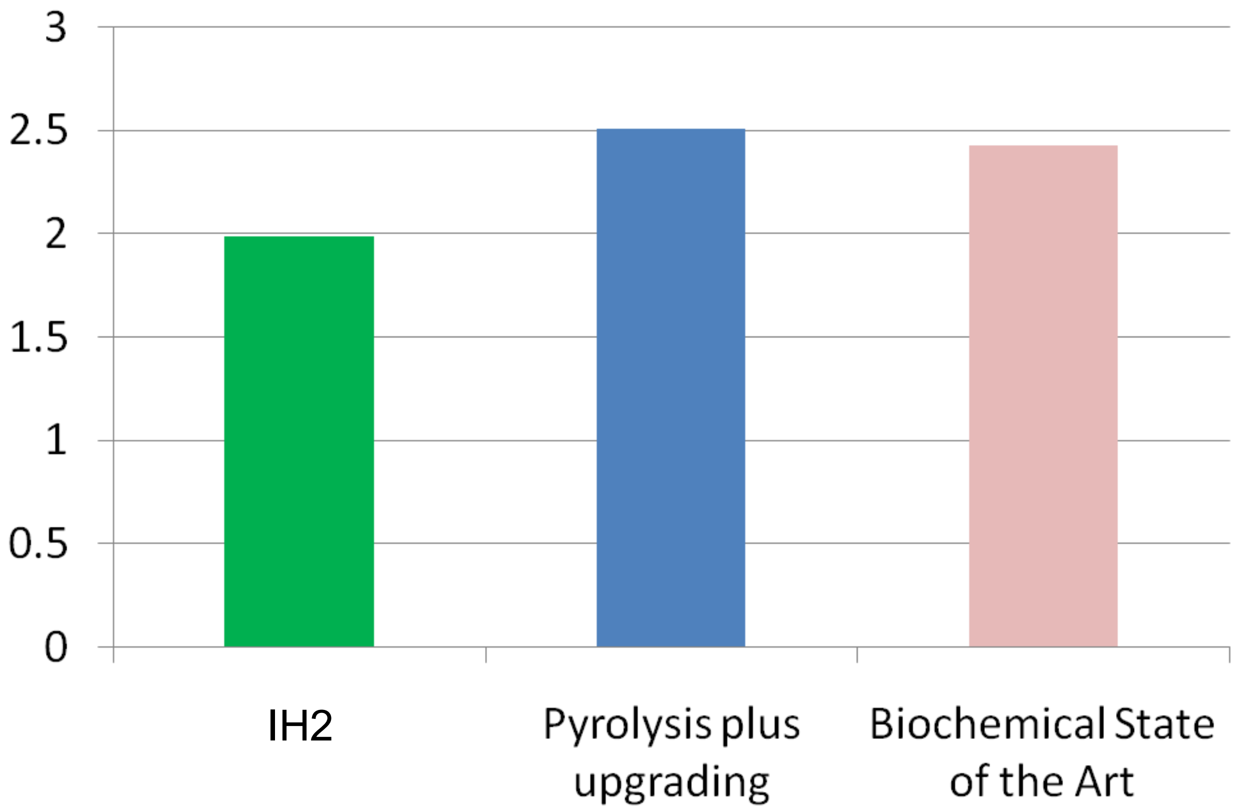
- Lower transportation costs
- No water cleanup problems
- Minimal loss of carbon to water
- Lower capital costs (add one vessel with some catalyst)
- Easier and simpler design
- Eliminate hydrogen costs and capital costs at refinery



Refiners will be happy to receive a better product !

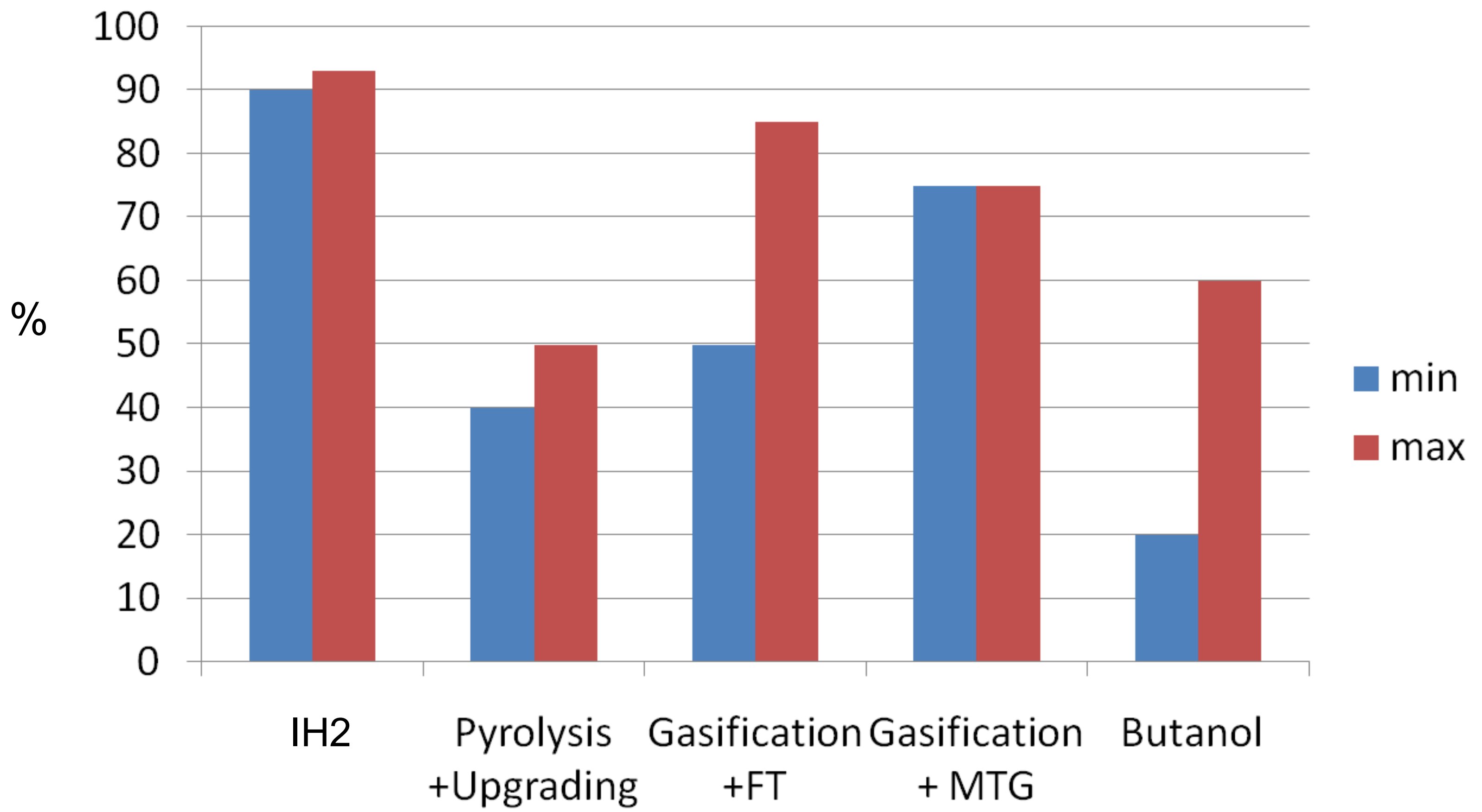
Economic Comparison

FCOP +ROI - $/gal



Based on 2000 t/d of biomass feed

Preliminary Estimate of Greenhouse Gas Reduction



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

gti

Typical IH2 Product Quality – PIANO Analysis of C_6+

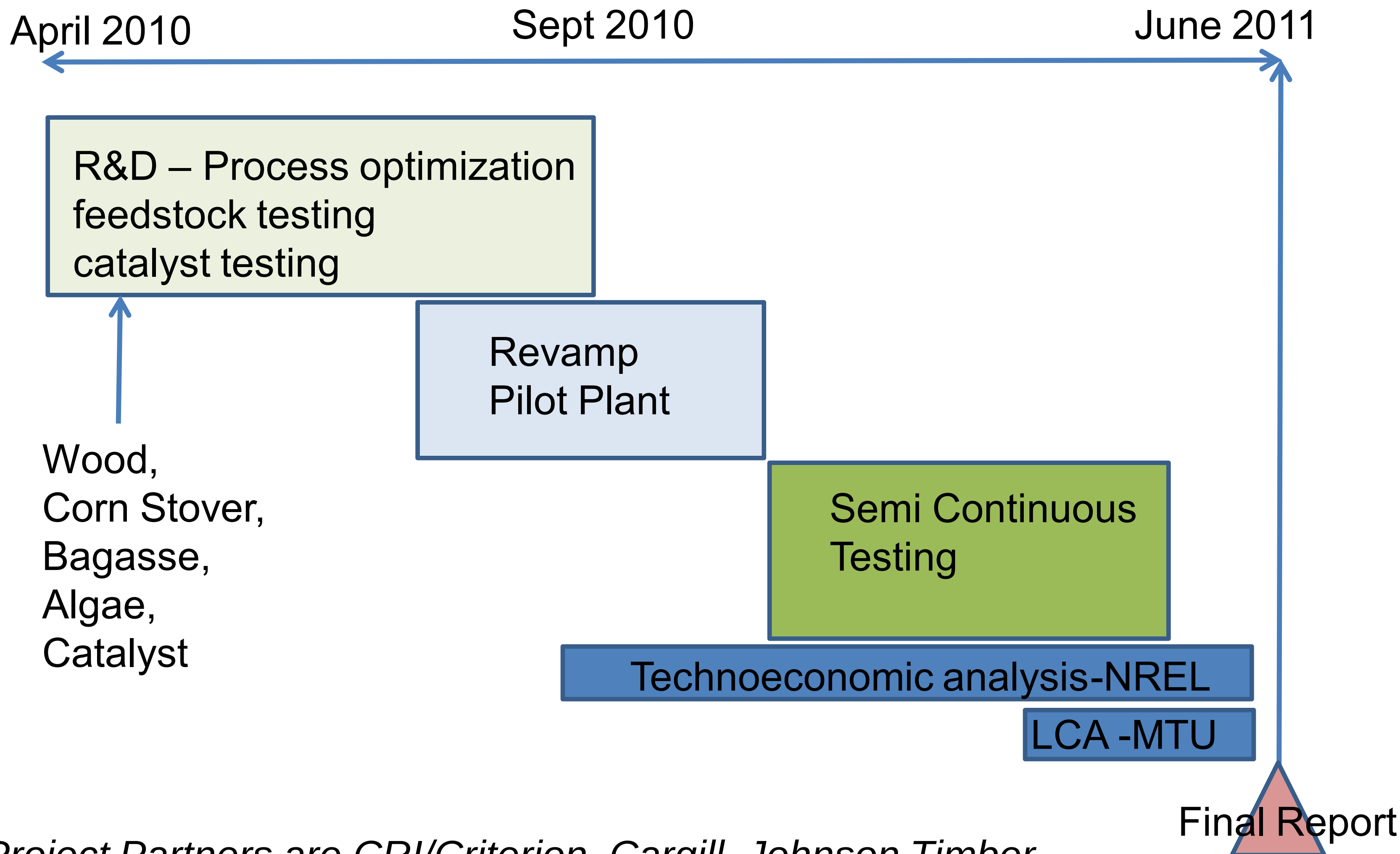
	IH2 (Lemna)	IH2 (Wood)	Pyrolysis + Upgrading (Wood)
Paraffins	24.4	10.3	12-36 (I+N)
Isoparaffins	35.5	37.0	
Naphthenes	13.5	5.2	68-36
Aromatics	22.1	47.3	12-27
Olefins	2.7	0.3	
RON of gasoline	84	90	

Wood makes more aromatics than lemna since it has lignin while lemna has protein

Pyrolysis plus upgrading saturates the aromatics and makes naphthenes (because of high pressure) which should reduce octane compared to the IH2 process

New IH2 DOE Project Plans

14 Month Project - $3.1 MM



Project Partners are CRI/Criterion, Cargill, Johnson Timber, Blue Marble Energy, Aquaflow, NREL and MTU

Conclusions and Future Work

- IH2 is a promising new technology approach with excellent LCA, economics, potential
- 3 Years to commercialization with proper funding !
  - Will allow feedstock providers to produce valuable hydrocarbon products for refiners
  - Will produce products which can be easily used by refiners
- If successfully developed, could result in significant shift in source of U.S. transportation fuel
- *Lots of work left to be done!*
  - *Optimal conditions and catalyst*
  - *Catalyst stability*

Acknowledgements

- CRI/Criterion Inc.
  - Catalyst was key to project success and supplied IH2 catalyst
- Prof David Shonnard of MTU
  - LCA analysis