GHG Impact of Using Fast Pyrolysis Oil for Electricity and Biofuel Generation

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UOP 5398A-01

Presentation Overview

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- **Introduction**
  - RTP™ Rapid Thermal Processing Technology
  - Heat, Power and Fuel Applications
- **Life Cycle GHG Assessments**
  - Pyrolysis Oil from Forest Biomass
  - Electricity via Pyrolysis Oil Combustion
  - Gasoline via Pyrolysis Oil Conversion
- **Summary & Technology Benefits**

Rapid Thermal Processing Technology

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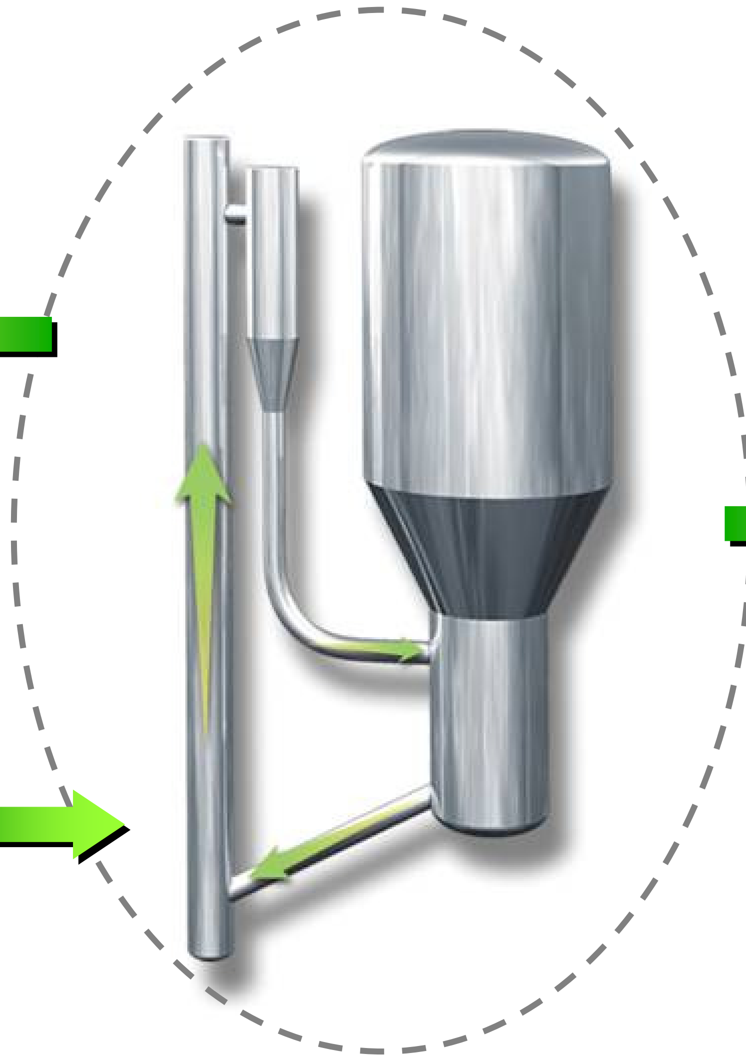
Pyrolysis Oil

Solid Biomass



- 510℃, <2 seconds
- Biomass converted to liquid pyrolysis oil
- Fast fluidized bed, sand as heat carrier

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plus

ENSYN

Commercially Proven Patented Technology

Feedstock Sources

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- **Forestry and Pulp and Paper**
  - Wood chips, sawdust, bark
  - Forest & mill residues, short rotation crops
- **Agricultural**
  - Residues – corn stover, expended fruit bunches from palm (EFB), bagasse
  - Purpose-grown energy crops – miscanthus, elephant grass
- **Post-consumer**
  - Construction and Demolition Waste, Categories 1&2
  - Municipal solid waste (future)
- **DoE study 2005 - > 1 billion ton per year available in United States alone**

Cellulosic Feedstocks Widely Available

RTP^{TM} Pyrolysis Oil Properties

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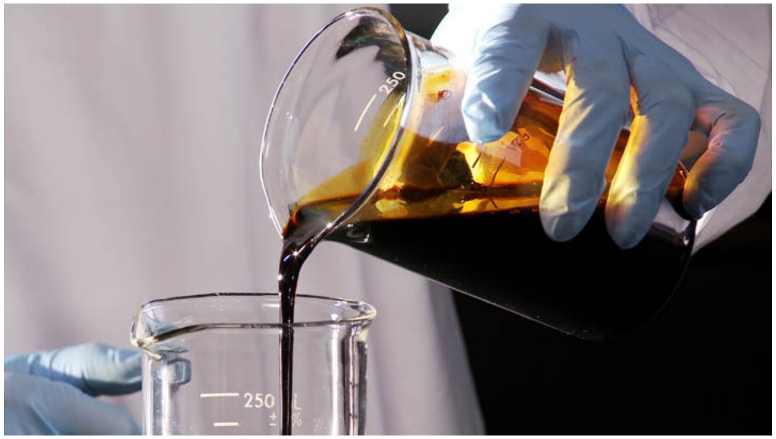
- **Pourable, storable and transportable liquid fuel**
- **Energy densification relative to biomass**
- **Contains approximately 50-55% energy content of fossil fuel**
- **Stainless steel piping, tankage and equipment required due to acidity**
- **Requires separate storage from fossil fuels**



Comparison of Heating Value of Pyrolysis Oil and Typical Fuels

Fuel	MJ / Litre	BTU / US Gallon
Methanol	17.5	62,500
Pyrolysis Oil	**19.9**	**71,500**
Ethanol	23.5	84,000
Light Fuel Oil (#2)	38.9	139,400

Suitable for Energy Applications

Pyrolysis Oil to Energy & Fuels Vision

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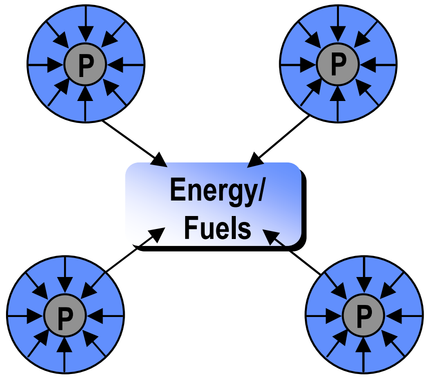
Forest Fiber



Biomass → **Fast Pyrolysis** → Pyrolysis Oil

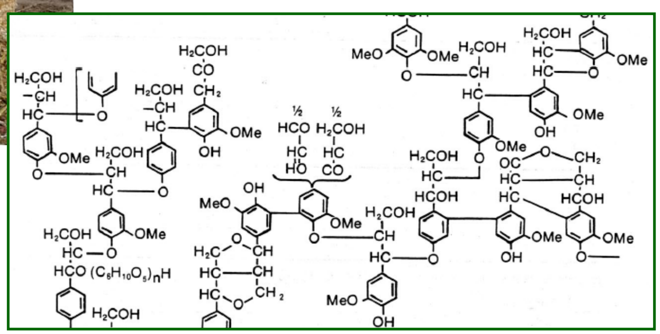
- **Electricity Production**
- **Fuel Oil Substitution**

Available for Sale

- **Transport Fuels (Gasoline, Jet, Diesel)**

Commercially available in 2012

Ag Residue



Phased Commercialization

Pyrolysis Oil as a Fuel Oil Substitute

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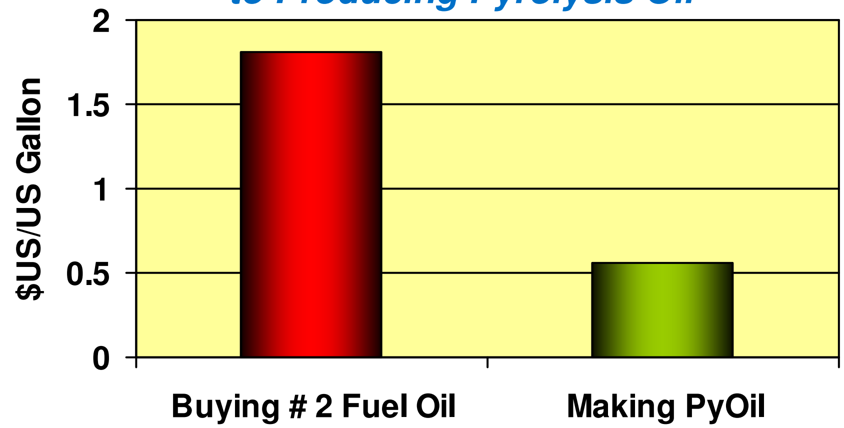
- **Specialized burner tips improve flame/burning**
- **Low emissions (GHG, NOx, SOx)**
- **Fuel consistency - *ASTM D7544***
- **Flexibility to decouple pyrolysis oil production from energy generation (location and time)**
- **Low cost liquid biofuel**
  - **~40% cheaper to make and use pyrolysis oil than to purchase #2 fuel oil on an equivalent energy basis**
    - 400 BDMTPD RTP Unit
    - Assumes 60 $US/bbl crude
    - Includes RTP operating cost and 15-yr straight line depreciation of CAPEX
    - 330 Days per Year

Comparison of Cost of Buying #2 Fuel Oil to Producing Pyrolysis Oil



~ 8 $US Million per Year Savings

Pyrolysis Oil to Green Electricity

- Compatible with specialized turbines
- Green electricity production cost is ~0.12 $US/kWh
  - Includes RTP operating cost and depreciation of CAPEX (including gas turbine)
- Experience in stationary diesel engine as blend with fossil fuel
  - Operation with 100% pyrolysis oil under development

Pyrolysis Oil to Green Transportation Fuels

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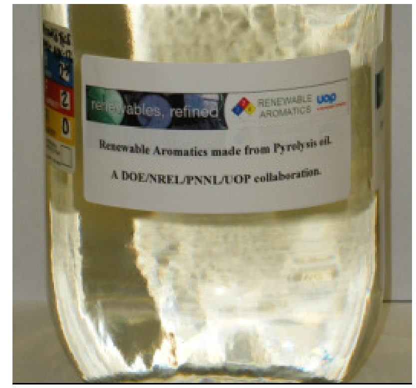
- Conversion Objectives
  - Remove oxygen atoms
  - Reduce acidity and viscosity
  - Shape molecules to match gasoline and diesel/jet fuel hydrocarbons
  - Commercialization expected in 2012
- Solution
  - Thermochemical upgrading; leverage UOP's extensive hydroprocessing experience
  - Continuous, reliable guaranteed process, per current refinery standards



Achieved in Lab, Working on Scale-up

LCA Study Overview

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- Conducted to ISO 14040 standards
- LCA software employed SimaPro 7.1 Cumulative Energy Demand & IPCC GWP 100a methodologies
- Functional unit for power = 1 kWh electricity generated
- Functional unit for biofuel = 1 MJ of fuel energy
- System boundaries:
  Raw material extraction (cultivation) through either electricity production or fuel combustion (WTW for biofuel)
- Primary Focus: Emission of GHGs
- Several feedstocks considered
  - Logging residues
  - Hybrid poplar
  - Hybrid willow
  - Sawmill waste

LCA study team included:
Dr. David Shonnard, Professor MTU
Jiqing Fan, Ph.D. Candidate
Matthew Alward, Undergraduate Researcher
Jordan Klinger, Undergraduate Researcher
Adam Sadevandi, Undergraduate Researcher

RTP™ Mass & Energy Balance

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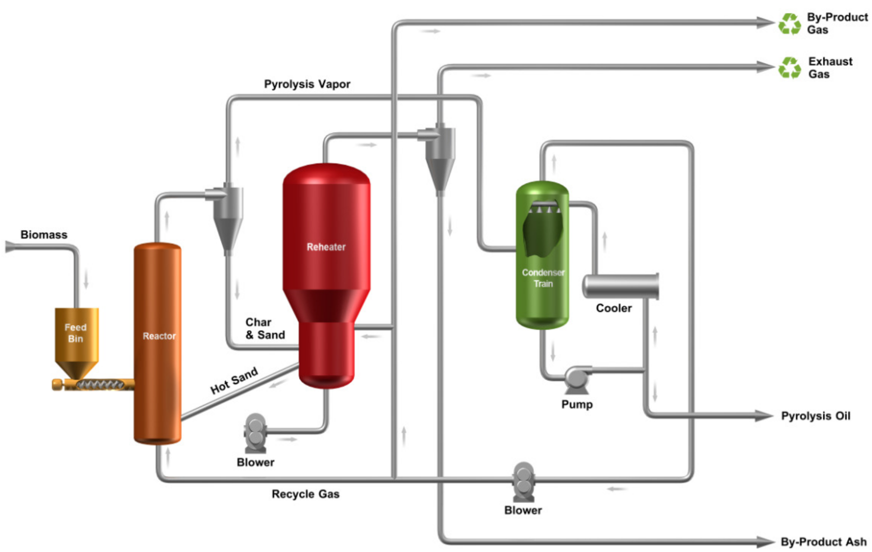
400 BDMTPD of Hardwood Whitewood

Feed, wt%	
Hardwood Whitewood	100
Typical Yields, wt% Dry Feed	
Pyrolysis Oil	70
By-Product Vapor	15
Char	15

Yields For Various Feeds

Biomass Feedstock Type	**Typical Pyrolysis Oil Yield, wt% of Dry Feedstock**
Hardwood	70 – 75
Softwood	70 – 80
Hardwood Bark	60 – 65
Softwood Bark	55 – 65
Corn Fiber	65 – 75
Bagasse	70 – 75
Waste Paper	60 – 80

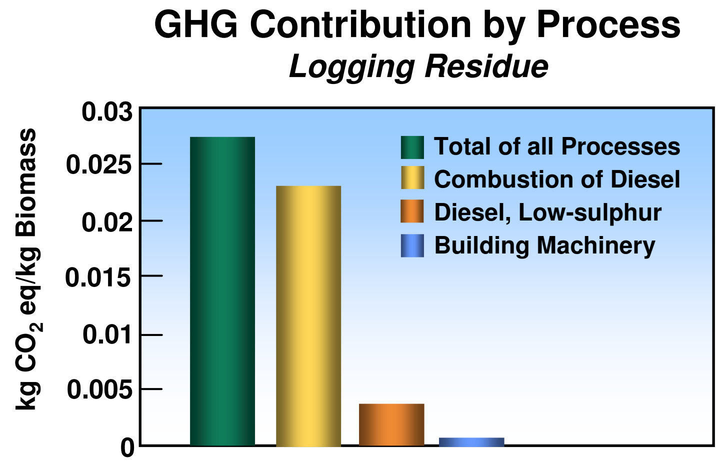


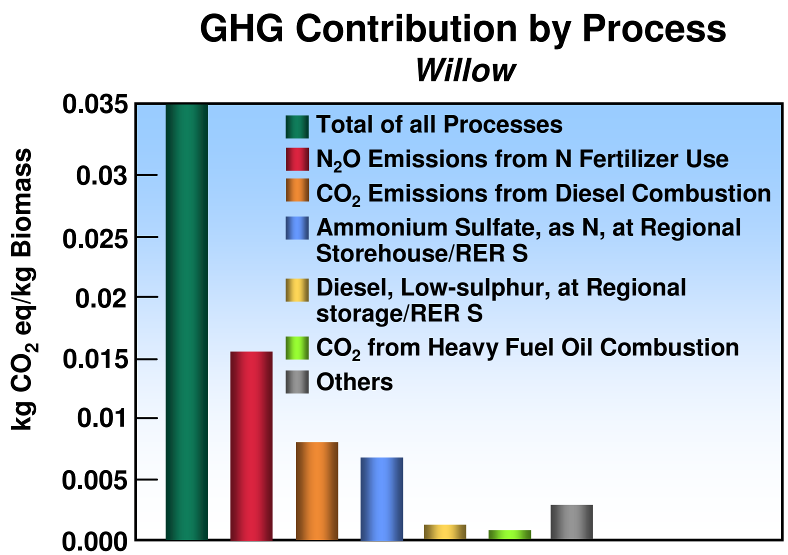
- *Cellulosic Feedstock Flexible*
- *High Yields of Pyrolysis Oil, Co-products provide Process Energy*
- *Minimal Net Utilities (primarily electrical power)*

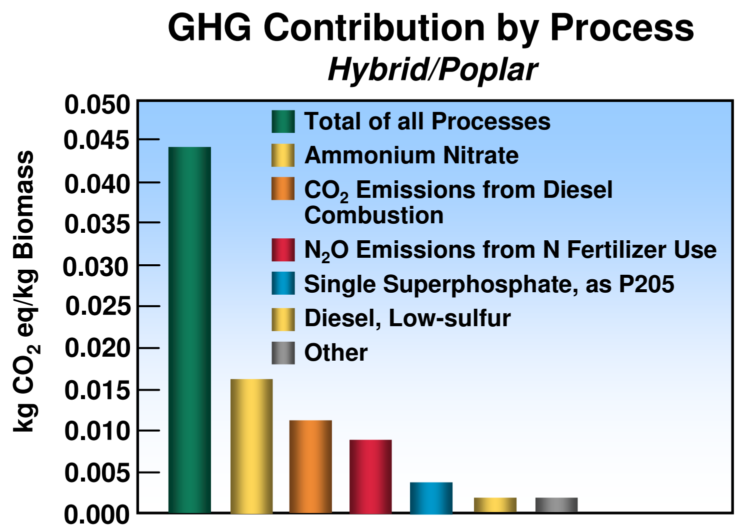
Feedstock GHG Emissions

Cultivation and Harvesting

	Residue	SRF Crops	
	Logging	Willow	Poplar
Biomass Yield			
odt/ha/yr	**0.62**	**11.95**	**13.50**
GHG			
kg CO_2-eq/kg dry Biomass	**0.027**	**0.035**	**0.044**







Pyrolysis Oil Production

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Life Cycle GHG Emissions

$g\,CO_2$ eq /MJ	PyOil Logging Residue	PyOil Willow	PyOil Poplar	PyOil Waste
Biomass Cultivation and Harvesting	2.1	2.4	4.0	0
Biomass Transportation	3.8	0.9	0.8	0
Pyrolysis	8.6	8.6	8.6	8.6
Total	14.5	11.9	13.4	8.6

$$r_{circle} = \frac{2}{3} * \tau * \sqrt{\frac{F}{\pi * Y * f}}$$ (Wright et. al.)

t: the tortuosity factor of the road
f : fraction of land devoted to biomass crops
F: feedstock biomass required in (short ton / acre / year)
Y: yield of biomass (short tons / acre)

GHG Sensitivity to Transport & Energy Source

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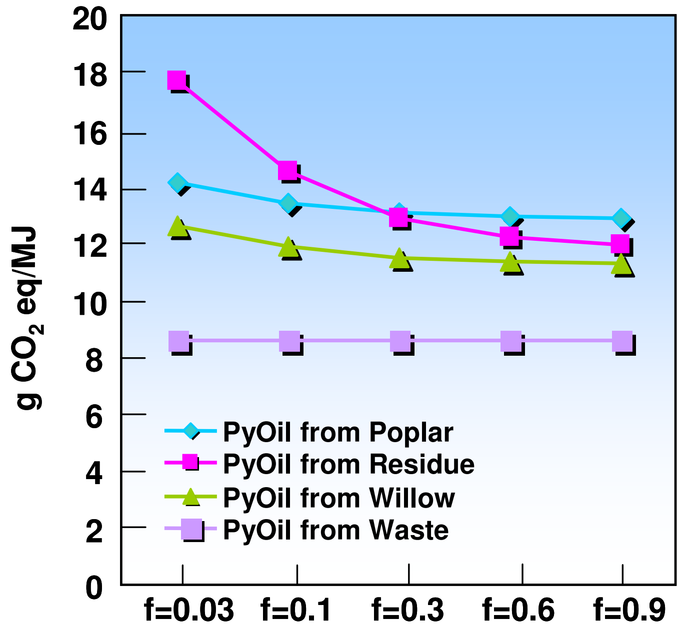
Pyrolysis Oil GHG Emissions vs f



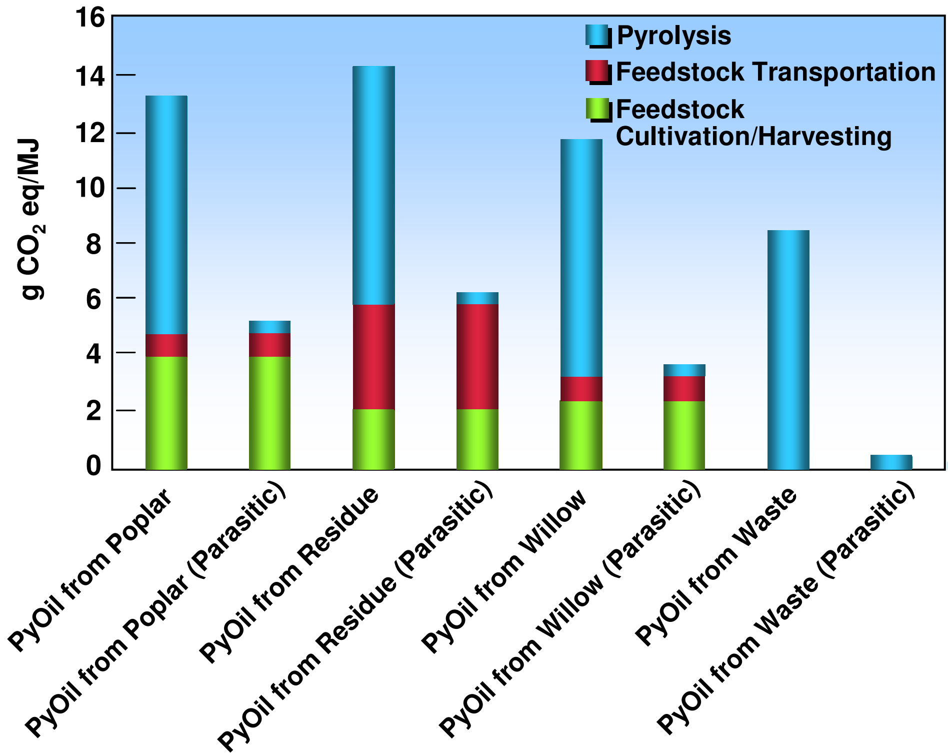
f Value = Fraction of Land in Cultivation

	f=0.03	*f=0.1*	*f=0.3*	*f=0.6*	*f=0.9*
r_{circle} (miles) Poplar	20.05	10.98	6.34	4.48	3.66
r_{circle} (miles) Willow	21.34	11.69	6.75	4.77	3.90
r_{circle} (miles) Residue	93.74	51.34	29.64	20.96	17.11

Transportation Distance vs. f

Pyrolysis Oil GHG Emissions vs Power Source

Imported Power (US Grid Mix) vs. Parasitic System



In parasitic system, a portion of the electricty generated from pyrolysis oil is used to operate RTP and Biomass pretreat units

Pyrolysis Oil as a Fuel Oil

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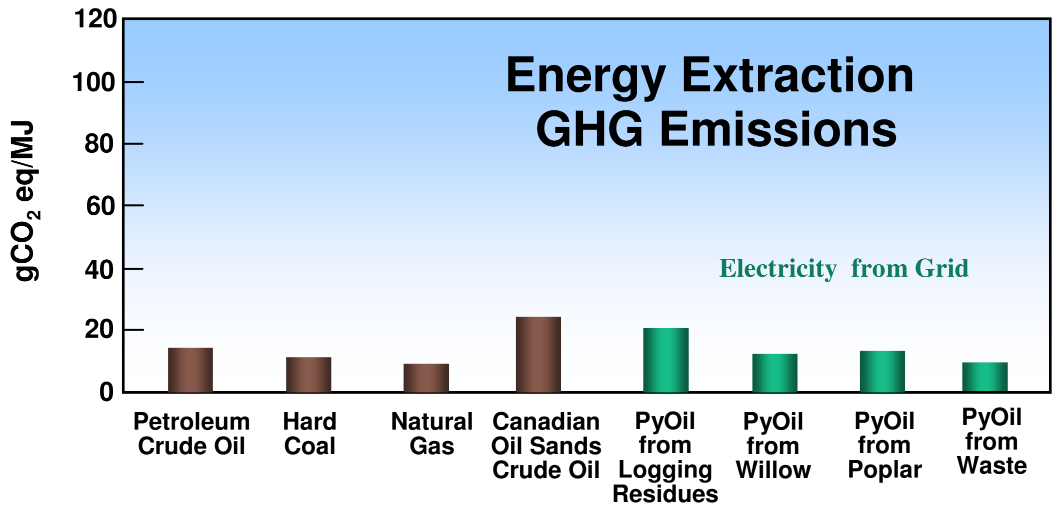
Comparison of GHG Emissions
Cradle to Delivered Energy

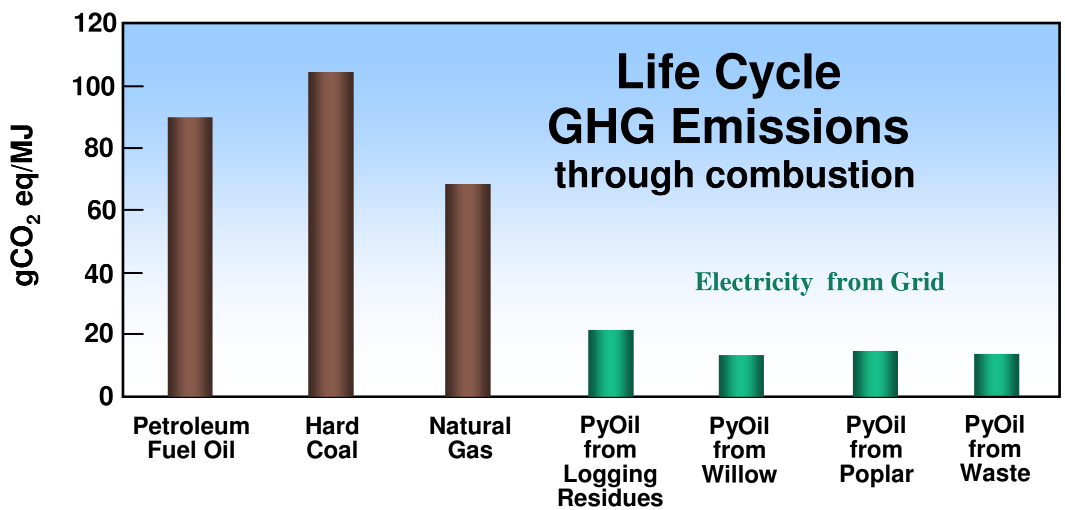


Pyrolysis Oil Production foot print similar to other energy alternatives

Assumed biomass transport distances

- 200 km for logging residues
- 25 km for short rotation forest crops
- 0 km for sawmill residues (waste)

Comparison of GHG Emissions
Cradle to Delivered Energy, and Burned



Pyrolysis Oil *Life Cycle* foot print *Greener* than other alternatives

- 70-90% lower GHG emission
- SO_x emission similar to Natural Gas

LC-GHG for Pyrolysis Oil Green Electricity

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Multiple Scenarios Evaluated

- Co-firing Cases *(lowest capital)*
  - Fuel Oil Power Plant
  - Coal Power Plant
  - Natural Gas Power Plant
- Advanced Power Facilities *(highest efficiency)*
  - Gas Turbine Combined Cycle (GTCC) with heat recovery
  - Distributed Diesel Generator located at site
  - Parasitic Electric Power Supply
- Comparison to Direct Biomass Combustion (BC)
  - Dedicated facility at 18% efficiency (existing BC1)
  - Dedicated facility at 25% efficiency (modern BC2)

Comparisons of LC-GHG Emissions with Direct Biomass Combustion (BC)

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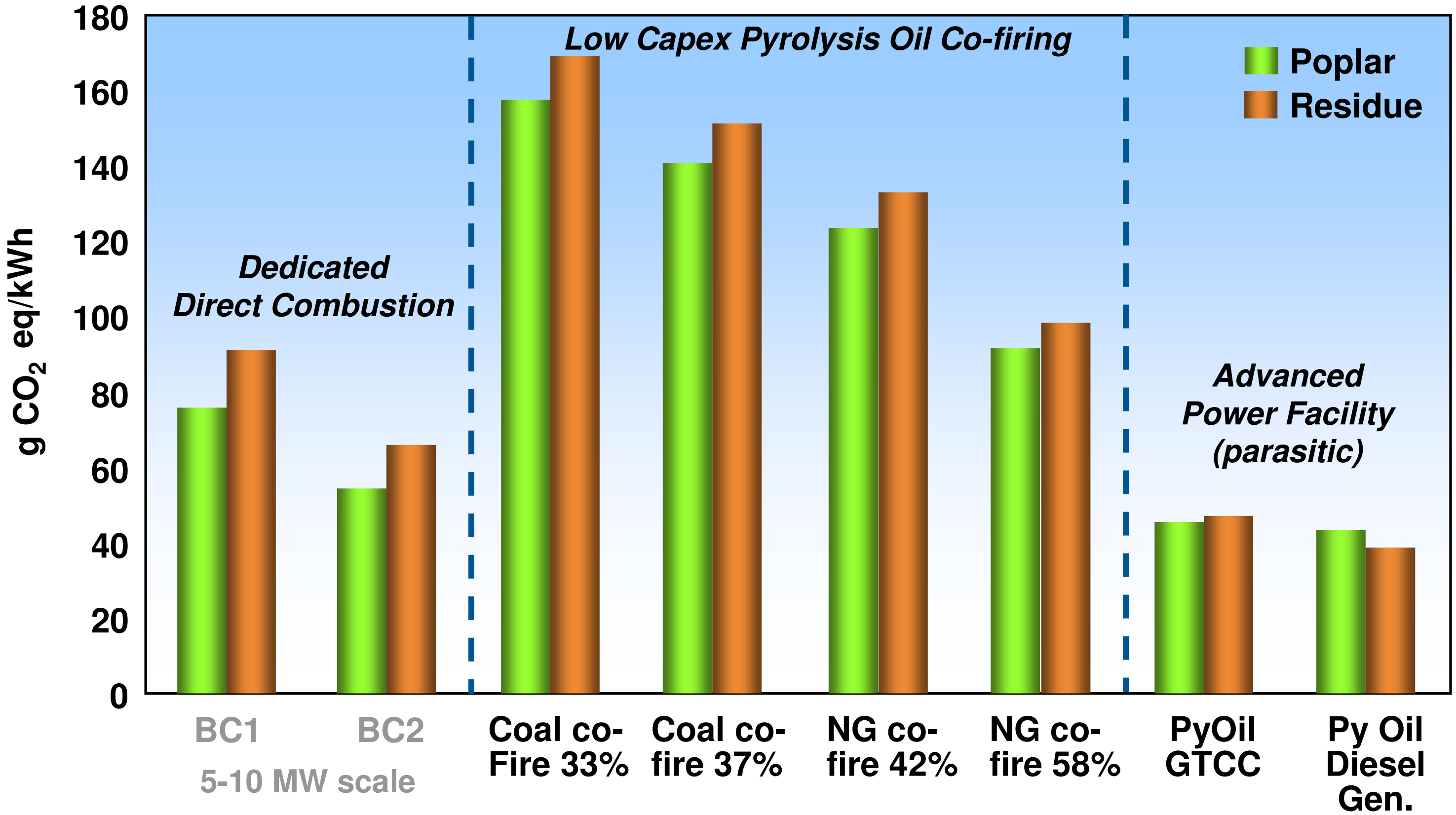
BC1= existing combustion/steam turbine unit at 18% efficiency
BC2= modern combustion/steam turbine at 25% efficiency



Typical Fossil Electricity GHG Values in g/CO_2eq/kWh
Coal~1000, Oil ~820, Natural Gas ~550

Pyrolysis Oil Pathway to Renewable Electricity Generation

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- Pyrolysis Oil co-firing maximizes use of existing power plant infrastructure
  - No new solids storage or solids handling systems required
  - Avoids issues associated with co-firing solid biomass (e.g. NO_x catalyst fouling, Use of ash as cement additive)
- Enables wider use of biomass in co-firing applications
  - Compatibility with existing NG, Oil, and Coal facilities demonstrated
- Reduces GHG produced during biomass transport
  - Up to 4 x higher energy density per unit volume shipped
- Future application to high efficiency power generation in distributed stand-alone facilities
  - GTCC or Stationary Diesel Power Generators

LC-GHG for Pyrolysis Oil Gasoline

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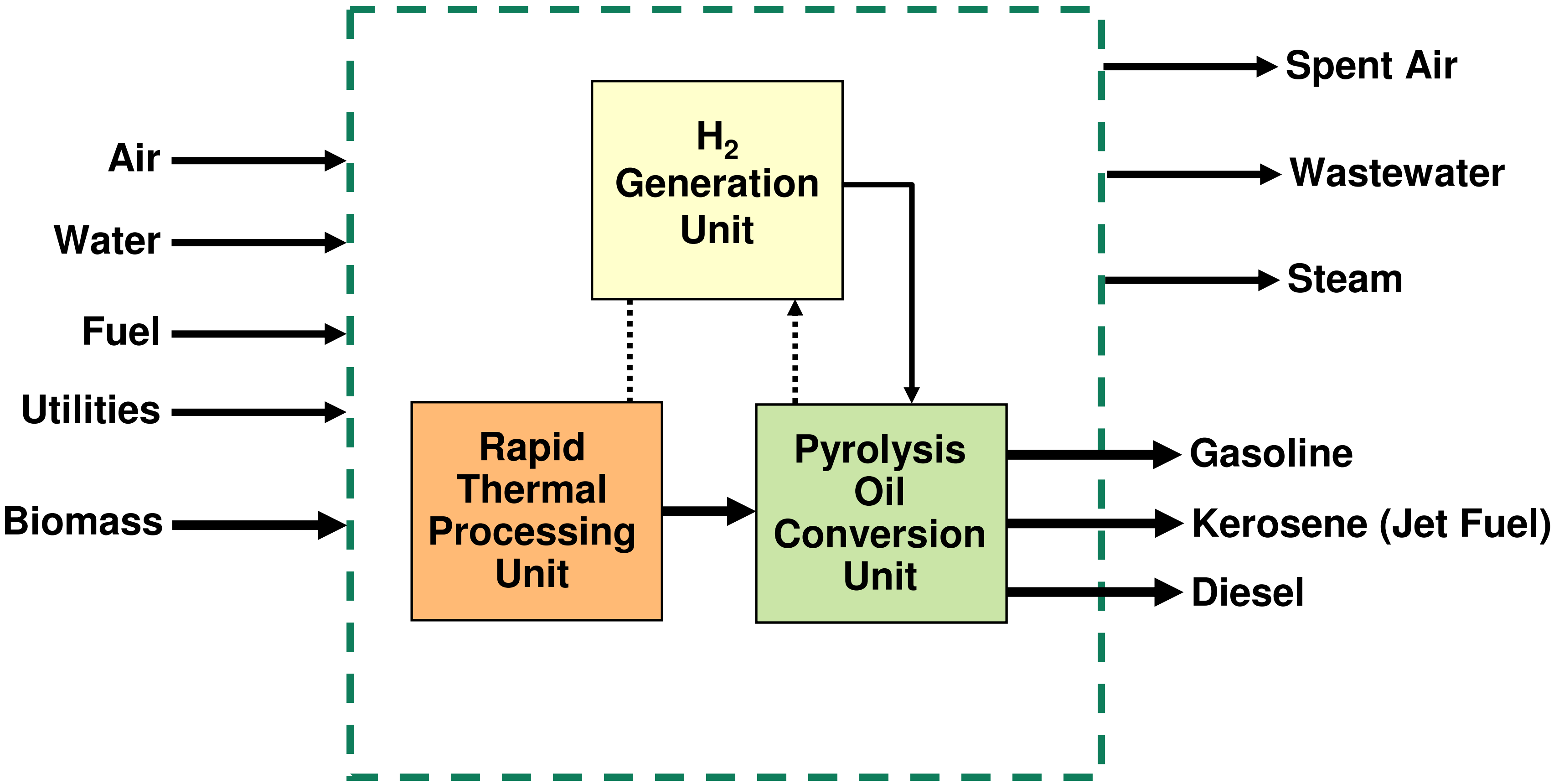
Preliminary Configuration for Integrated Bio-Refinery (IBR) Complex



(Py)Gasoline is Primary Product

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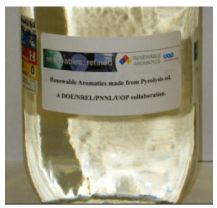
Basis: Bench Scale Production*

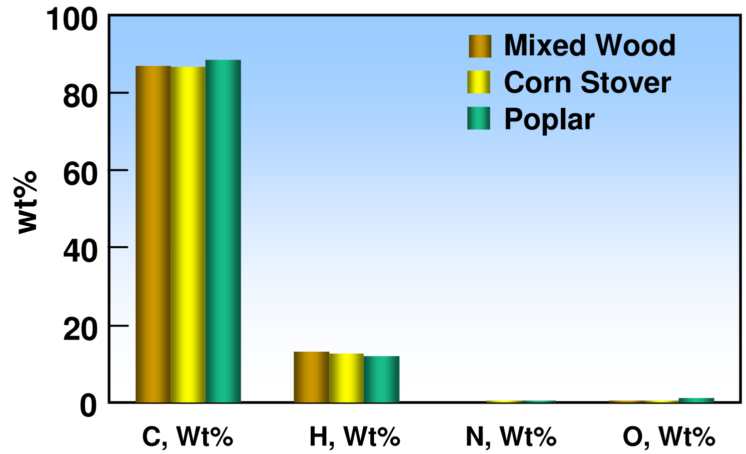
Several Biomass Feeds Processed
- Mixed Wood
- Corn Stover
- Poplar

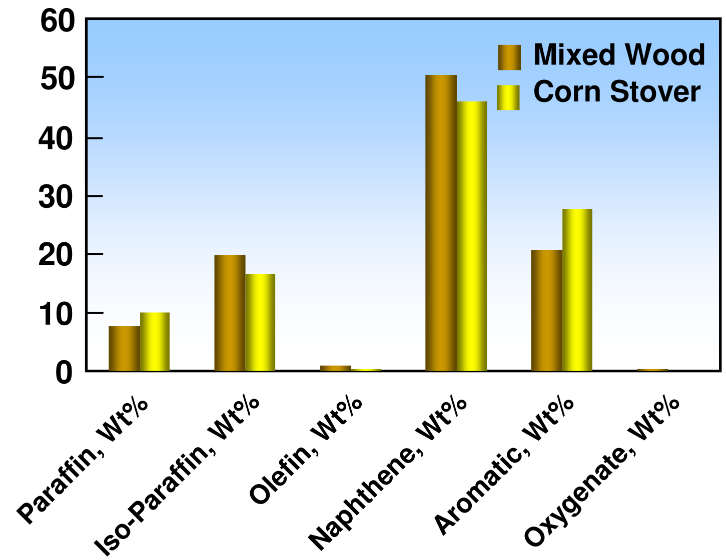
Liquid Product is a HC mixture of
- Gasoline
- Kerosene
- Diesel



Quality similar to Petroleum Fuel
- 99.5+% Hydrocarbon
- LHV ~43 MJ/kg
- 70% Naphthenes & Aromatics
- High Octane Value

* UOP experience in commercial hydroprocessing process scale-up and design





LC-GHG for Pyrolysis Oil Derived Gasoline

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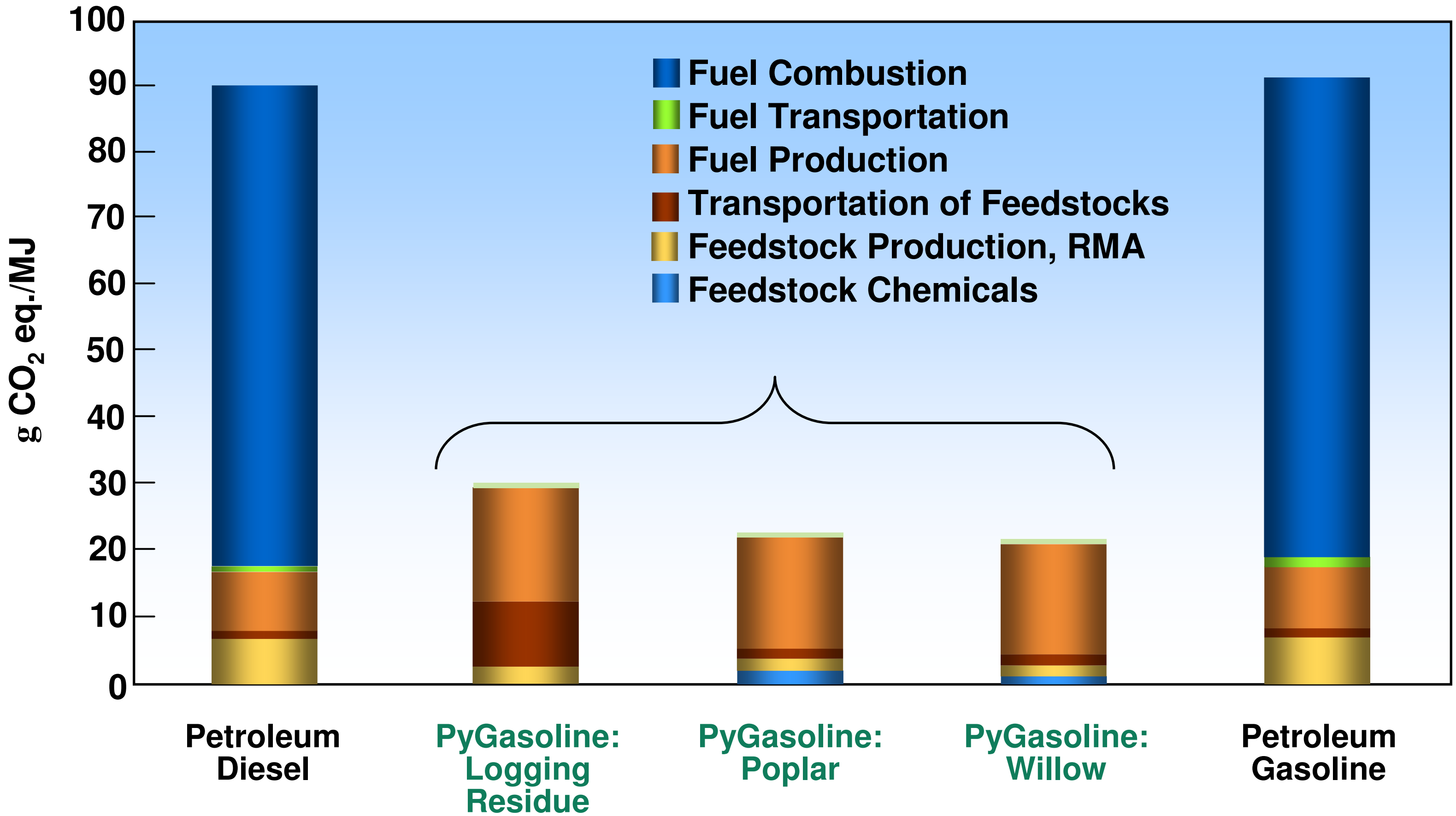
68-77% Lower WTW GHG Emissions



Energy Allocation for Co-products

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Summary

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- A variety of biomass feedstocks can be converted to pyrolysis bio-oil using RTP process technology
  - Cost competitive with petroleum fuels
  - GHG emissions are 70-90% lower than fossil alternatives
- Pyrolysis bio-oil can be utilized by a wider spectrum of power generation technologies compared to biomass combustion
  - Biomass combustion: limited to co-firing with coal
  - Pyrolysis bio-oil: compatible with NG, coal, and oil systems
- Greenhouse gas emissions of pyrolysis bio-oil electricity
  - Savings of GHG emissions between 77 – 99% possible for pyrolysis oil electricity compared to US Grid electricity
  - High efficiency applications for pyrolysis -oil electricity are more favorable compared to direct biomass combustion electricity
- Greenhouse gas emissions of pyrolysis bio-oil transportation fuel
  - Savings of GHG emissions between 68 – 77% is achieved for pyrolysis oil gasoline compared to petroleum baseline
  - Hydrocarbon based composition is compatible with existing fuel infrastructure. “Blend wall” hurdles not expected to be an issue.

RTP Technology Benefits

Economics

- **Economic solution for renewable energy**
- **Competitive relative to fossil fuels**
- **Leverages existing assets**
- **Provides alternate revenue stream**

Technical

- **Proven application**
- **Feedstock flexibility**
- **Minimal net utilities**
- **Storable product allows decoupling from end user**

Environment & Social

- **Reduction of greenhouse gases and emissions**
- Waste disposal
- Minimum environmental Impact
- Agriculture development
- Employment

Energy Security

- **Energy diversification**
- **Reduction of fossil energy requirements**

Pyrolysis to Energy Now – Transport Fuels in 2012

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Q&A