Biomass Conversion to Heat, Power & Fuels

Rapid Thermal Processing (RTP™) And Pyrolysis Oil Upgrading

USDA-ARSTeleseminar Series on Chemical Conversion Technologies, October 11th, 2011

UOP
A Honeywell Company

Honeywell Corporate Overview

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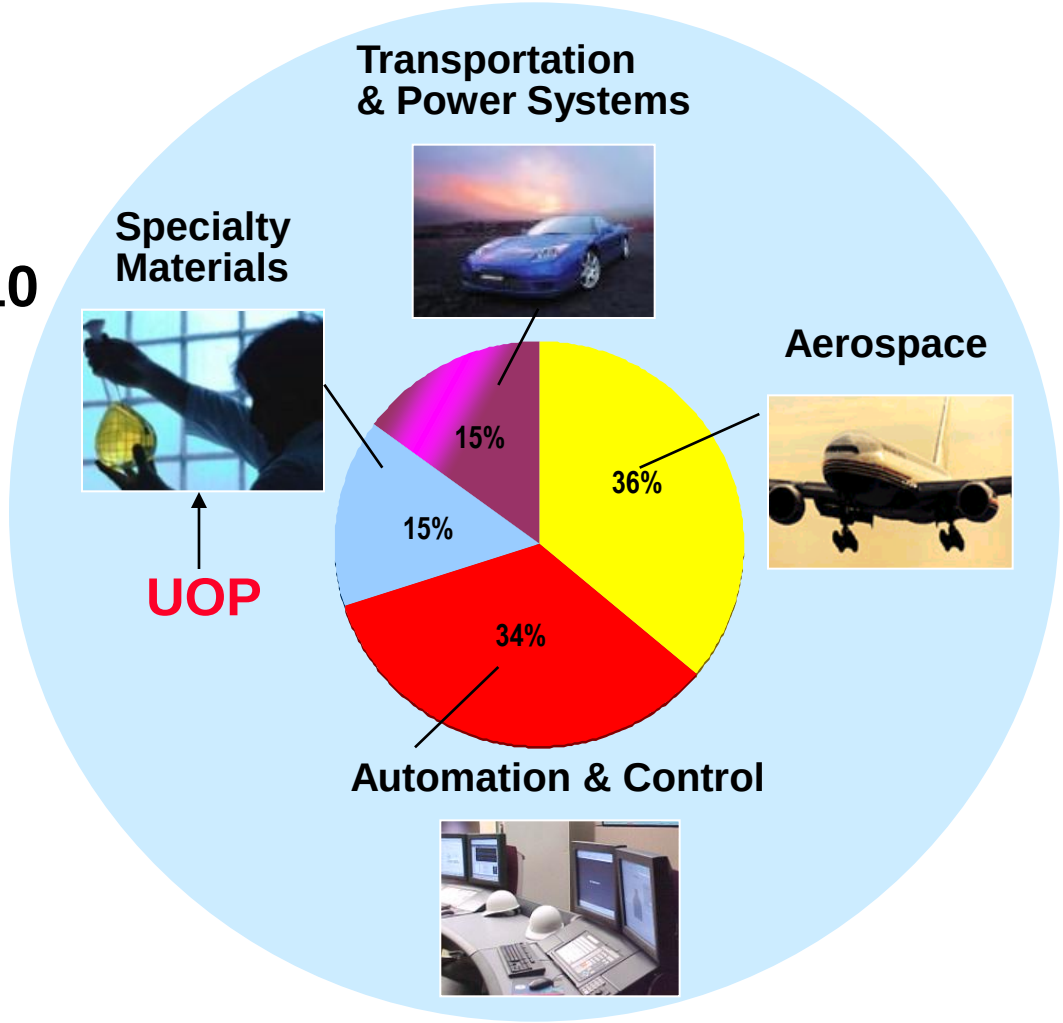
- 125,000 employees in more than 100 countries
- A Fortune 100 company – sales of $33.4 billion in 2010
- Global leader in advanced technology products, services and solutions



Honeywell

UOP Overview

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- Since 2005, a Honeywell Company – part of Specialty Materials business unit
- Leading supplier and licensor of processing technology, catalysts, adsorbents, process plants, and technical services to the petroleum refining, petrochemical, and gas processing industries.
- UOP Technology Furnishes:
  - 60% of the world's gasoline
  - 85% of the world's biodegradable detergents
  - 60% of the world's *para*-xylene.
- 3400 employees worldwide.
- 2008 Financials: $1.9 billion in sales.
- Strong relationships with leading refining and petrochemical customers worldwide.

2003 National Medal of Technology Recipient

Refining | **Gas Processing** | **Petrochemicals** | **Renewable Energy**

Bridging Feedstocks Today, but Focus on 2nd Generation

Honeywell/UOP Renewable Fuels Vision

- Building on 96 years of petrochemical industry technology and expertise
- Produce real “drop-in” fuels instead of fuel additives/blends
- Leverage existing refining, transportation, energy, biomass handling infrastructure to lower capital costs, minimize value chain disruptions, and reduce investment risk
- Focus on path toward second generation feed stocks and chemicals

Oxygenated Biofuels

Ethanol | **Biodiesel**

Renewable Energy

Fuel & Power

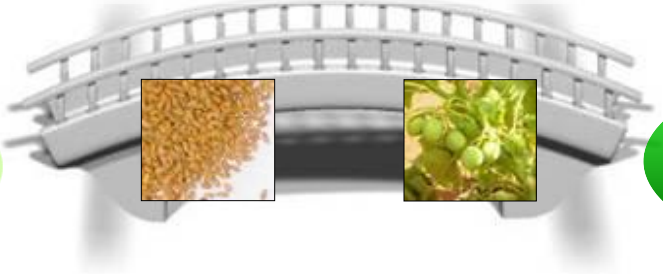
Hydrocarbon Biofuels

Diesel | **Jet** | **Gasoline**

First Generation

Natural Oils From Vegetables and Greases

“Other” Oils: Camelina, Jatropha

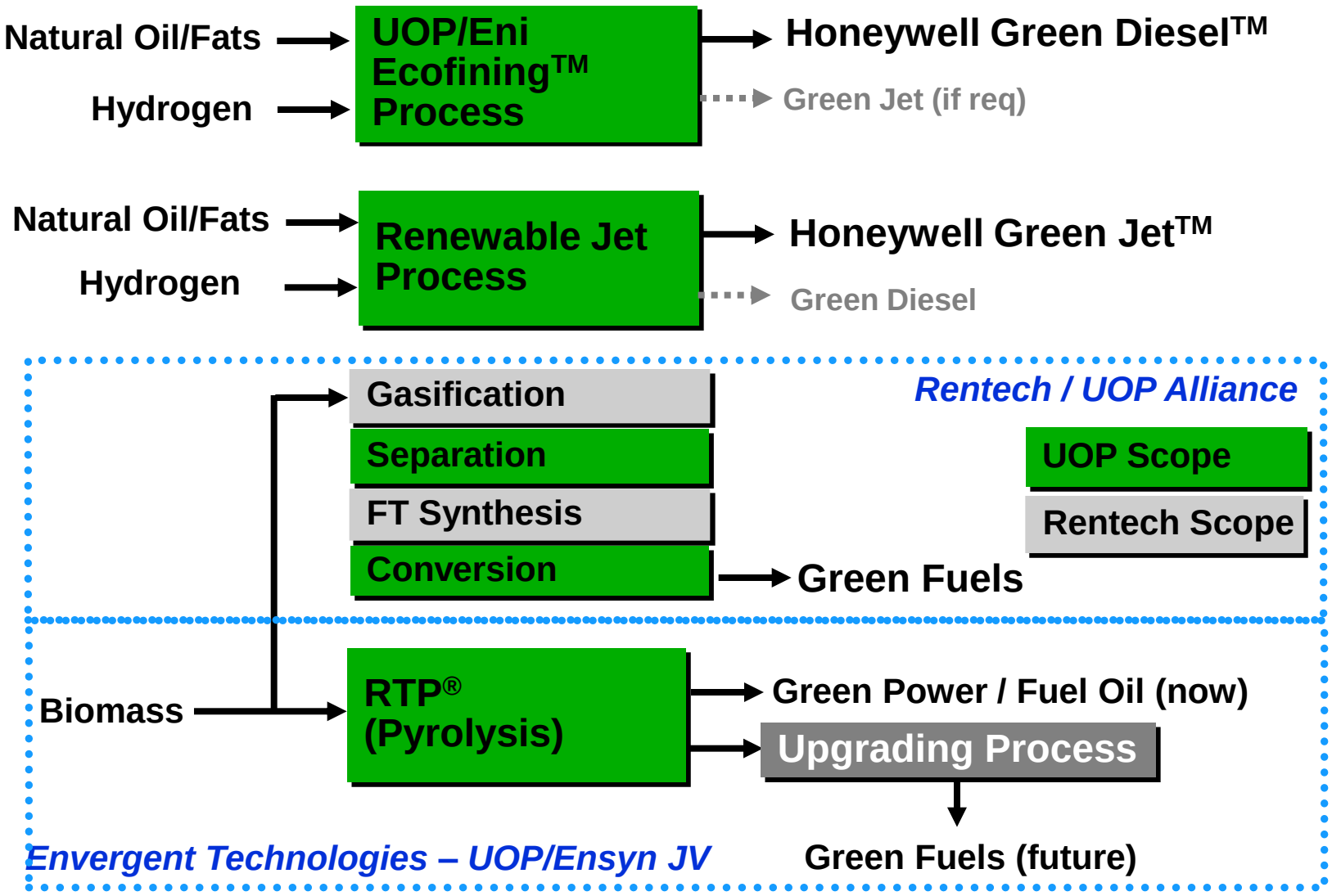


Second Generation

Lignocellulosic Biomass, Algal Oils

Bridging Feedstocks Today, but Focus on 2nd Generation

UOP Renewable Fuel & Energy Technologies



Technologies for converting the whole plant – oil and biomass

Envergent Technologies LLC – UOP / Ensyn Joint Venture

- Formed in October 2008
- Provides pyrolysis oil technology for fuel oil substitution and electricity generation
- Channel for UOP R&D program to upgrade pyrolysis oil to transportation fuels

UOP A Honeywell Company

- Leading process technology licensor ~$2 billion in sales, 3000 employees
- Co-inventor of FCC technology
- Modular process unit supplier
- Global reach via Honeywell & UOP sales channels

ENSYN

- Over 20 years of commercial fast pyrolysis operating experience
- Developers of innovative RTP™ fast pyrolysis process
- Seven commercial RTP units designed and operated

Second Generation Renewable Energy Company – Global Reach

Rapid Thermal Processing (RTP™) Technology

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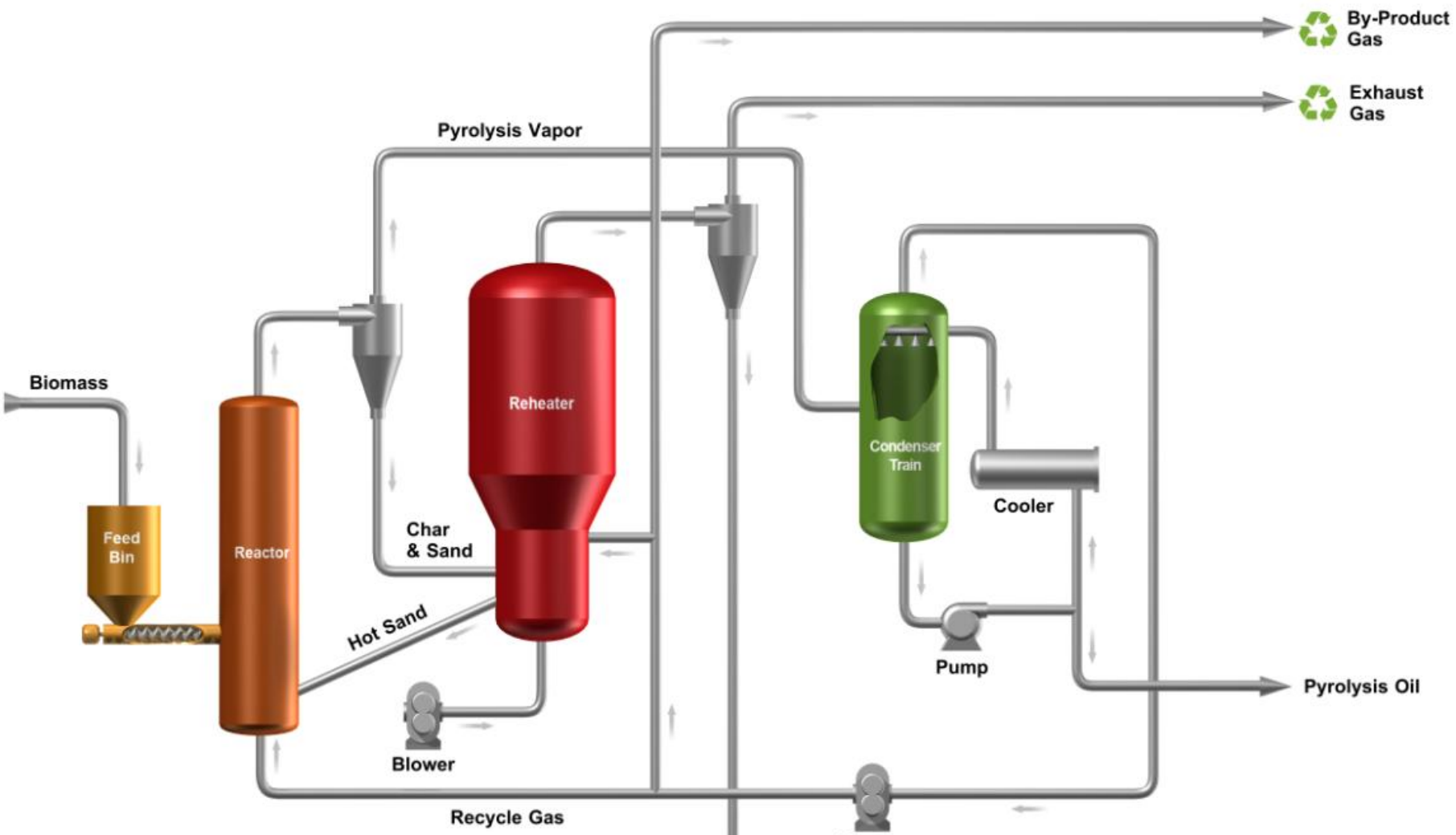
Pyrolysis Oil

Solid Biomass

- 510°C, <2 seconds
- Biomass converted to liquid pyrolysis oil
- Fast fluidized bed, sand as heat carrier
- High yields; >70 wt% liquid on woody biomass

Commercially Proven Patented Technology

RTP™ Flow Diagram



Minimal net utilities RTP is self-sustaining process

History and Commercial Experience

- **Commercialized in the 1980's**
- **7 units designed and operated in the US & Canada**
- **Continuous process with >90% availability**

Plant	*Year Built*	*Operating Capacity (Metric Tonnes Per Day)*	*Location*
Manitowoc RTP™ – 1	1993	30	Manitowoc, WI, USA
Rhinelander RTP™ – 1	1995	35	Rhinelander, WI, USA
Rhinelander Chemical #2	1995	2	Rhinelander, WI, USA
Rhinelander RTP™ – 2	2001	45	Rhinelander, WI, USA
Rhinelander Chemical #3	2003	1	Rhinelander, WI, USA
Petroleum Demo # 1	2005	300 barrels per day	Bakersfield, CA, USA
Renfrew RTP™ – 1 (Owned and operated by Ensyn)	**2007**	**100**	**Renfrew, Ontario, Canada**

New Projects:

Year of Project	*Technology*	*Location*	*Customer*	*Size (TPD)*
2009	**RTP**	**Italy**	**INDI**	**150**
2010	**RTP**	**North America**	**High North**	**400**
2010	**RTP**	**Malaysia**	**Premium**	**400**
2010	**RTP**	**Sweden**	**--**	**2 x 400**
2011	**RTP**	**Canada**	**--**	**400**

Feedstock Sources

- **Forestry and Pulp and Paper**
  - Wood chips, sawdust, bark
  - Forestry residues
- **Agricultural**
  - Residues – corn stover, expended fruit bunches from palm (EFB), bagasse
  - Purpose-grown energy crops – miscanthus, Switchgrass
- **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™ Product Yields

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400 BDMTPD of Hardwood Whitewood

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

* Char is utilized as fuel for the re-heater section of the RTP™. No net char is generated. Ash is produced as by-product.

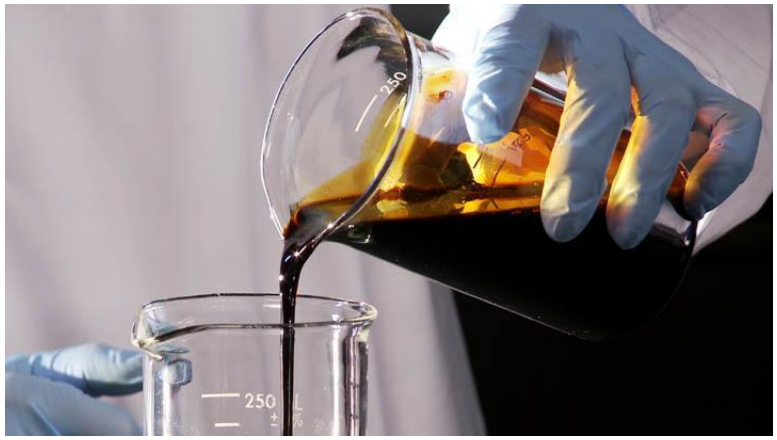
Yields For Various Feeds

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 With High Yields of Pyrolysis Oil

RTP™ Pyrolysis Oil Properties

- **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**

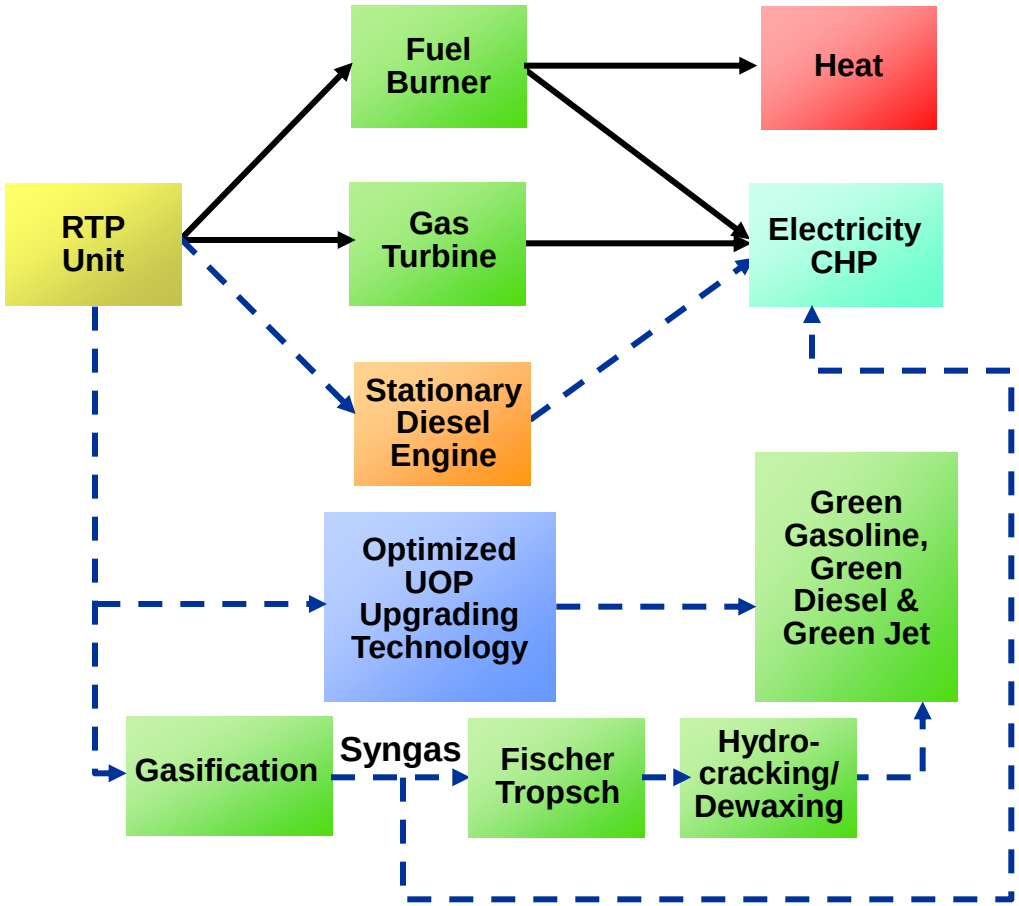


Comparison of Heating Value of Pyrolysis Oil and Typical Fuels

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 Energy Applications



- **Replacement of fossil fuel for heat/steam generation**
- **Production of green electricity**
- **Future upgrading to transportation fuels**

Multiple Applications for Pyrolysis Oil, a Renewable Fuel Available Today

Pyrolysis Oil to Energy & Fuels Vision

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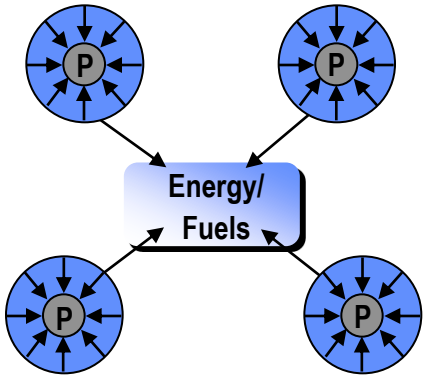
Forest Fiber



Biomass → Fast Pyrolysis → Pyrolysis Oil

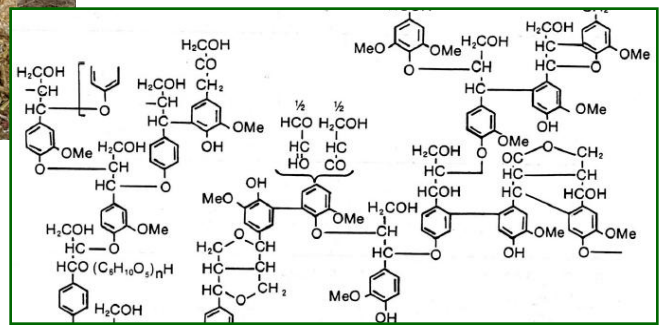
- Electricity Production
- Fuel Oil Substitution

Available for Sale

- Transport Fuels (Gasoline, Jet, Diesel)

Commercially available in 2013

Ag Residue



Phased Commercialization

Pyrolysis Oil: Replacement of Fossil Fuels to Generate Heat

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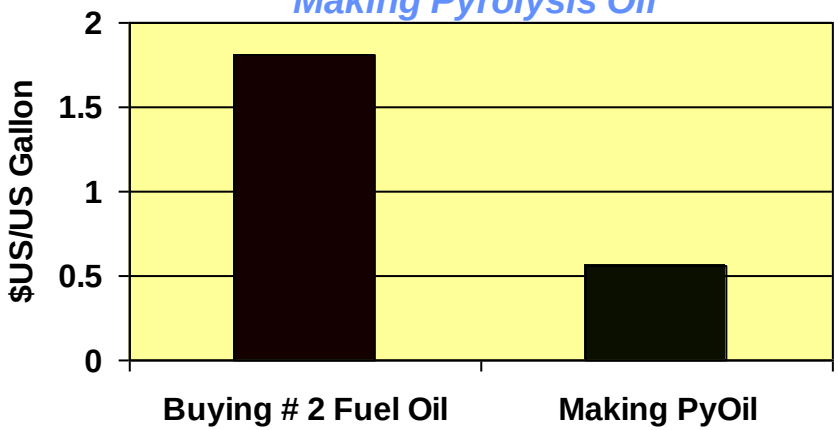
- Specialized burner tips improve flame/burning
- Low emissions (NOx, SOx)
- Fuel consistency
  - *ASTM D7544*
- Flexibility to decouple pyrolysis oil production from energy generation (location and time)
- GHG emission reduction of 70-90%
- Low cost liquid biofuel
  - ~40% cheaper to make and use pyrolysis 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 vs. Making Pyrolysis Oil



~ 8 $US Million per Year Savings

Applications for RTP Green Fuel

Replacement of fossil fuel to generate heat

- Low emissions (NOx, SOx)
- Fuel consistency
  - *ASTM standard*
- GHG emission reduction of 70-90%
- Favorable economics versus purchased fuel oil

Production of green electricity

- Stationary diesel engine operation with 100% RTP Green Fuel in final development
- The most efficient route for biomass conversion to electric power
  - Up to 40% energy conversion efficiency versus direct combustion at 16-26%

Pyrolysis Oil: Upgrading to Green Transportation Fuels

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- **Objectives**
  - Remove oxygen
  - Reduce acidity and viscosity
  - Break up molecules to make gasoline and diesel/jet precursors

- **Solution**
  - Thermochemical upgrading; leverage UOP's extensive hydroprocessing experience
  - Continuous, reliable guaranteed process, per current refinery standards

Achieved in Lab, Working on Scale-up

Integrated Biorefinery Demo - Biomass to Transport Fuels

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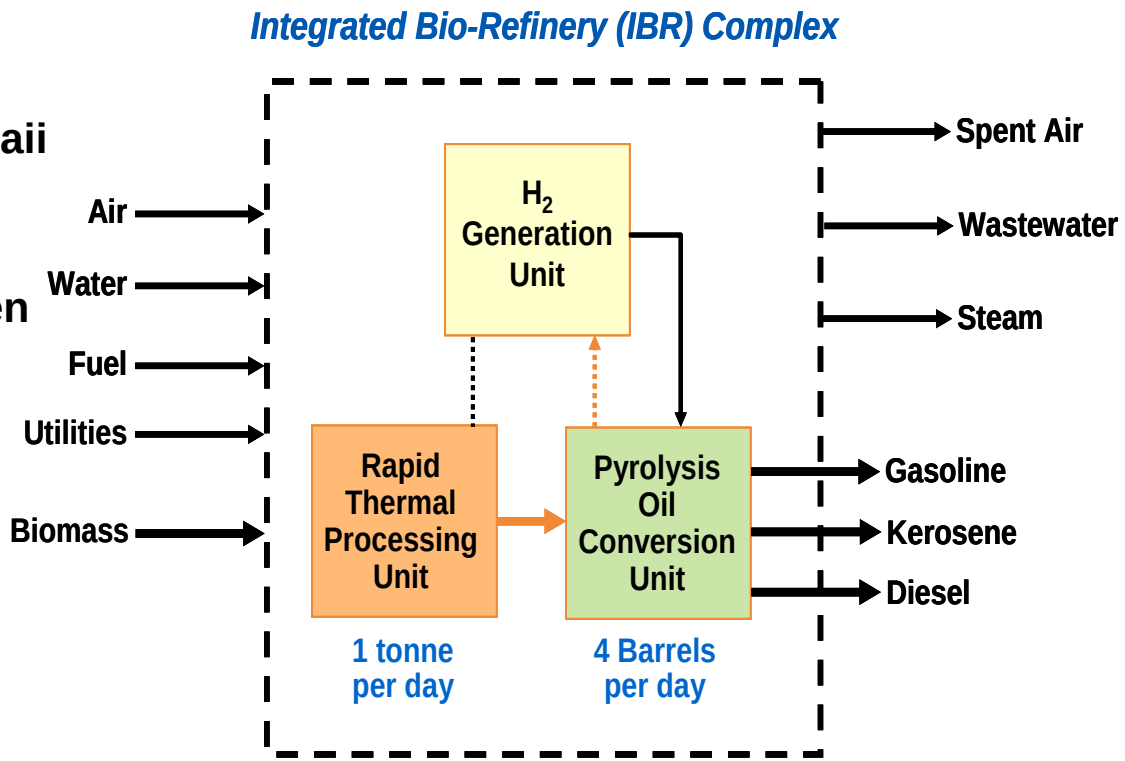
- UOP received $25M DOE grant
- Plant to be built at Tesoro/Hawaii refinery, operated by UOP
- Will include RTP and RTP Green Fuel upgrading
- 2nd Generation feedstocks to include
  - Corn Stover
  - Cane Bagasse
  - Switch Grass
  - Guinea Grass
  - Algae Biomass
  - Forest Residue
- Demonstration to be complete in three years



RTP™ Summary

- **Commercially proven technology: 7 units designed and operated**
- **Reliable operation with 90% on-line availability**
- **Designed to maximize pyrolysis oil yield, 70 wt% based on hardwood whitewood feed**
- **Performance guaranteed**
- **Cost-competitive with fossil fuels**
- **GHG emission reduction of 70-90%**
- **Engineering and modular delivery by world-renowned industry leader**
- **Technology for upgrading to transportation fuels expected to be available in 2013**


Q&A