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A Honeywell Company

Rapid Thermal Processing (RTP™): A Proven Pathway to Renewable Liquid Fuel

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Agenda

- Introduction
- Rapid Thermal Processing (RTP™) Technology
- Applications
- Project Development
- Summary

Envergent Technologies LLC – UOP / Ensyn Joint Venture

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- **Formed in October 2008**
- **Provides pyrolysis oil technology for fuel oil substitution and electricity generation**
- **Development of technology for upgrading pyrolysis oil to transportation fuels**

UOP A Honeywell Company

- **Leading process technology licensor~$2 billion in sales, 3000 employees**
- **Nearly 100 years of refining technology development, scale-up and design**
- **Modular process unit supplier**
- **Global reach via Honeywell & UOP sales channels**

ENSYN

- **Over twenty 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

Lignocellulosic Biomass Processing Options

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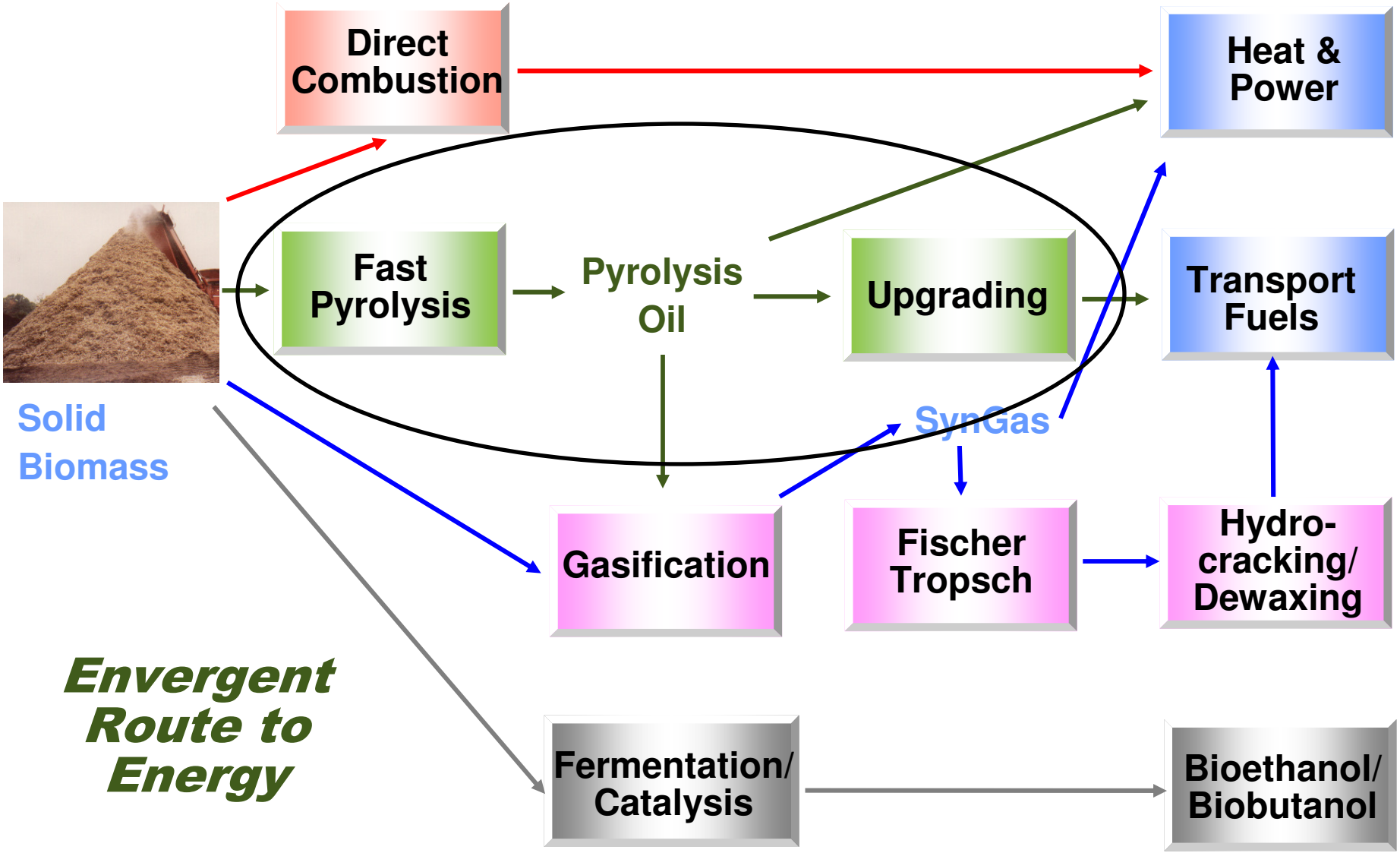

Envergent Route to Energy

Pyrolysis Oil to Energy & Fuels Vision

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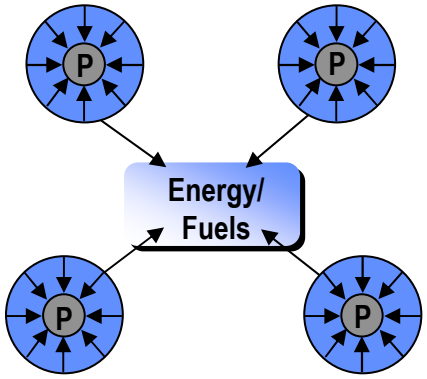
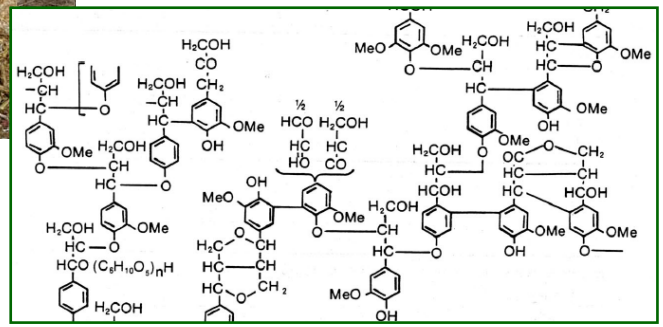


Biomass → Fast Pyrolysis → Pyrolysis Oil



Pyrolysis Oil →

- Electricity Production
- Fuel Oil Substitution

Available for Sale

- Transport Fuels (Gasoline, Jet, Diesel)

Commercially available in 2012

Phased Commercialization

Rapid Thermal Processing (RTP™) Technology

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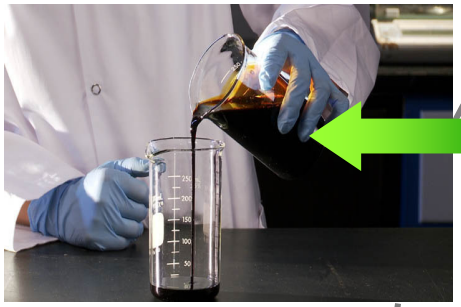
Pyrolysis Oil



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

ENV 5233-04

RTP™ Flow Diagram

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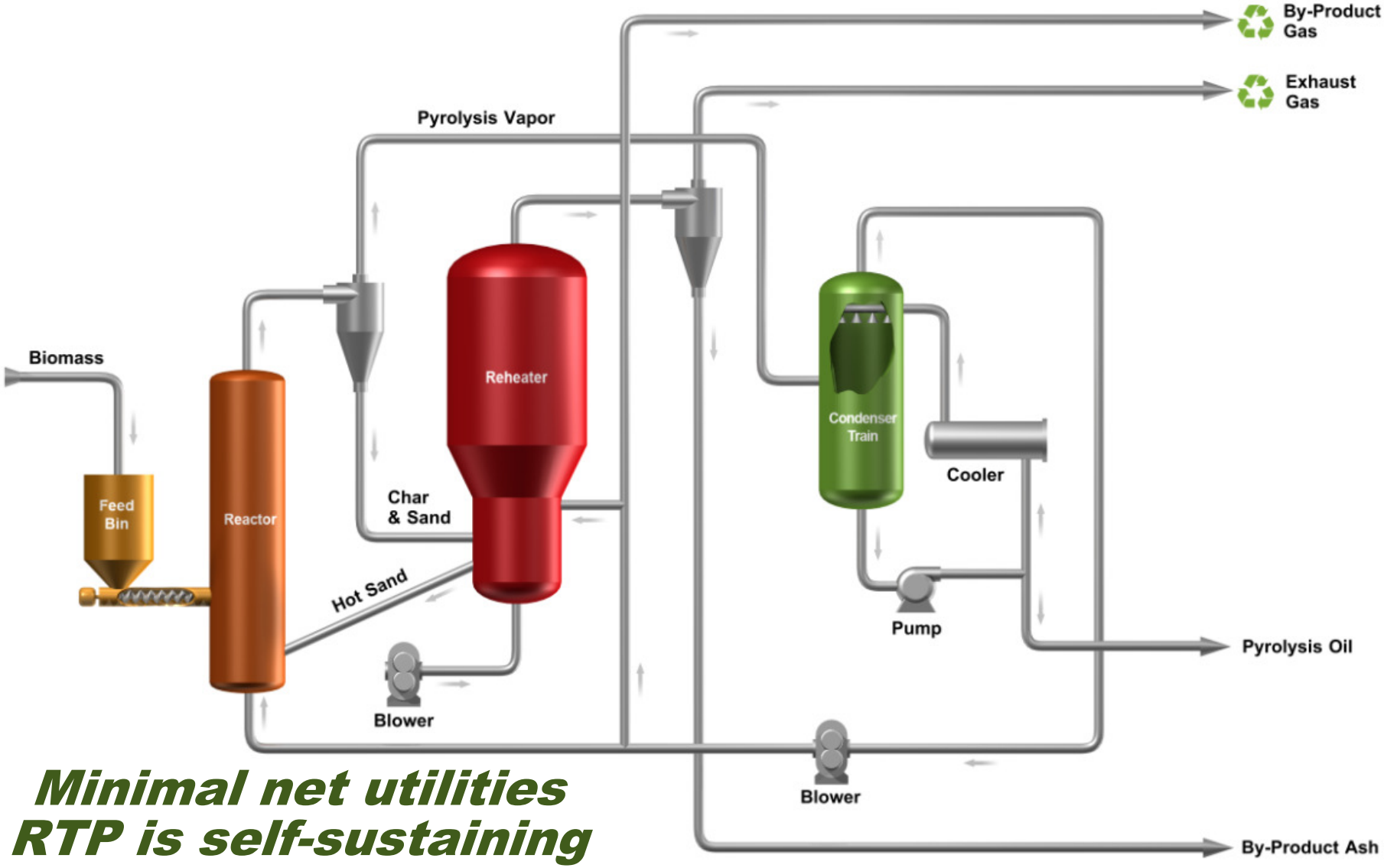

Minimal net utilities
RTP is self-sustaining process

RTP™ Operating History & Commercial Experience

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- **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**

Note: design basis for wood based plants assumes feedstocks with 6 wt% moisture content.

Significant Commercial Experience

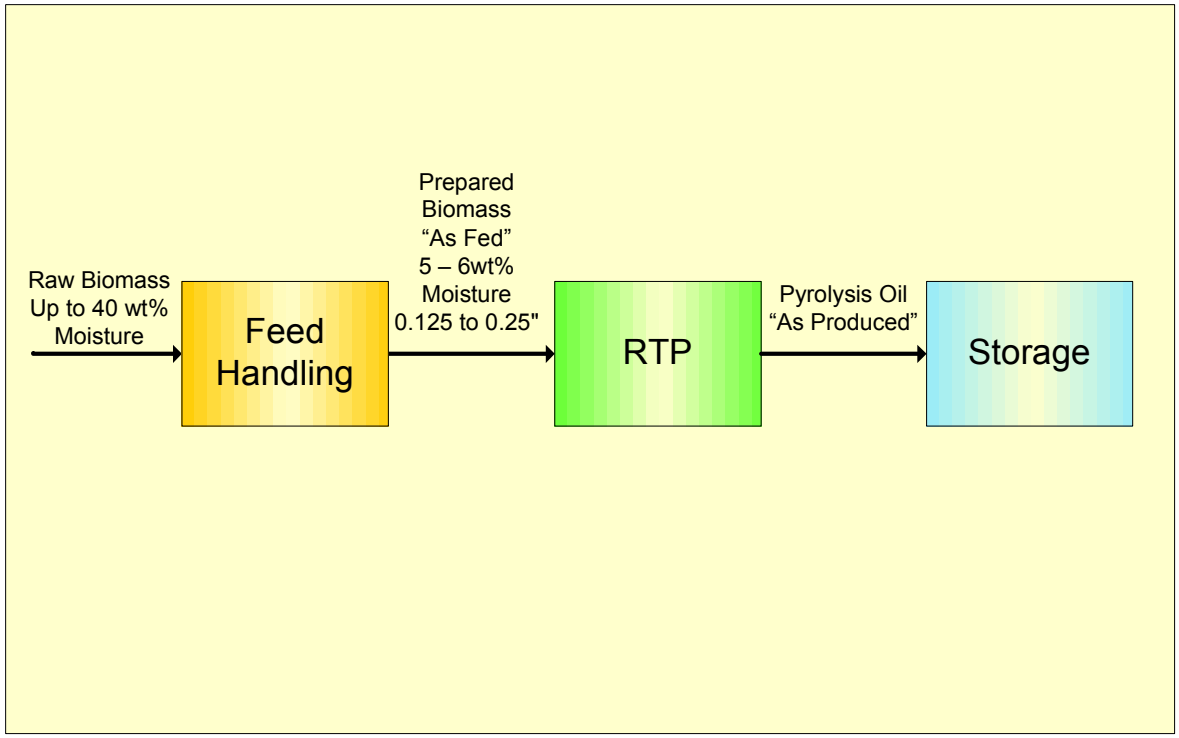
Feedstock Sources

- **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, 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

Feed Handling / Preparation

- **Water is a heat sink**
  - Dried to 5-6 wt% moisture content for efficient RTP™ reactor operation
- **Size impacts heat transfer**
  - Biomass sized to 0.125-0.25 inch (3-6 mm)
- **Capacity of unit expressed on bone dry feed basis**
  - BDMTPD
  - Zero water content



RTP is Self-Sustaining – Excess Heat Dries Raw Biomass

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

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

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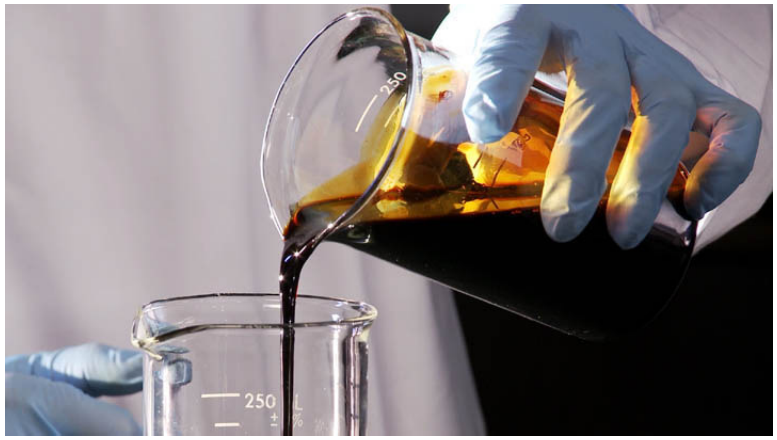
- **Pourable, storable and transportable liquid fuel**
- **Energy densification relative to biomass**
- **Contains approximately 50-55% energy content of fossil fuel**
- **Stainless steel piping, tankage and equipment required due to acidity**
- **Requires separate storage from fossil fuels**



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 Energy Applications

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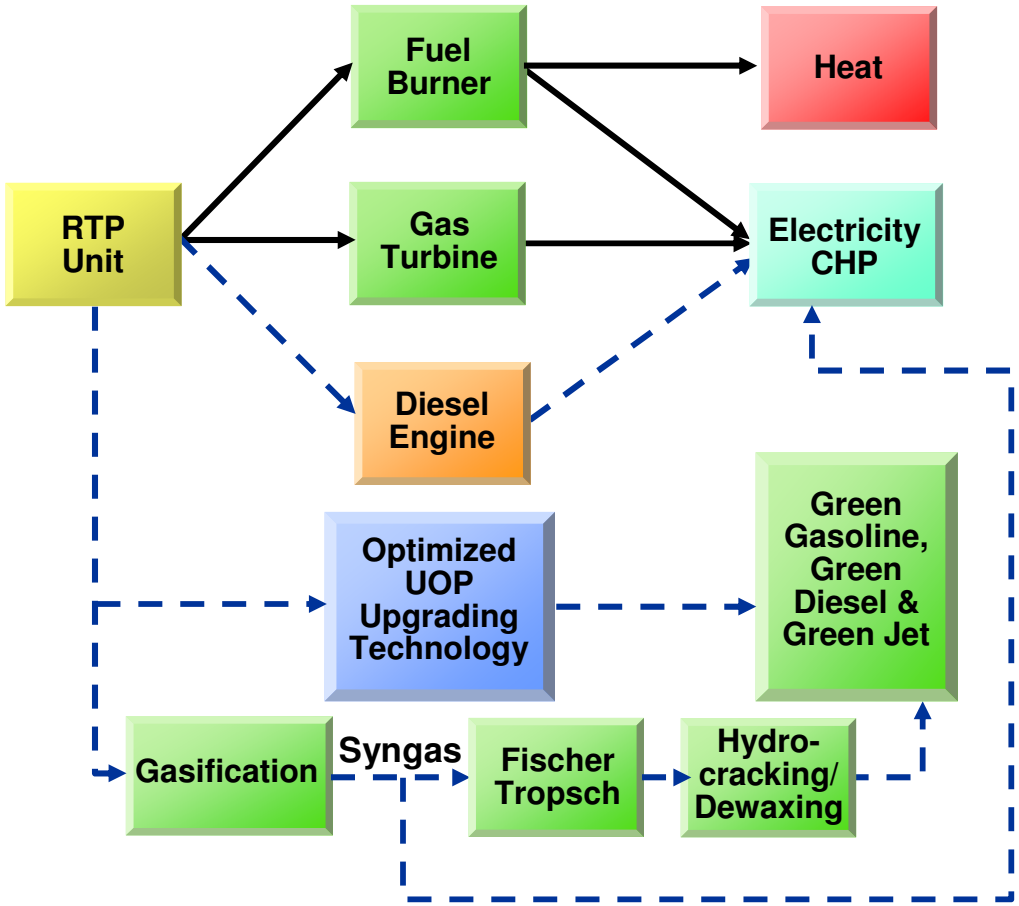
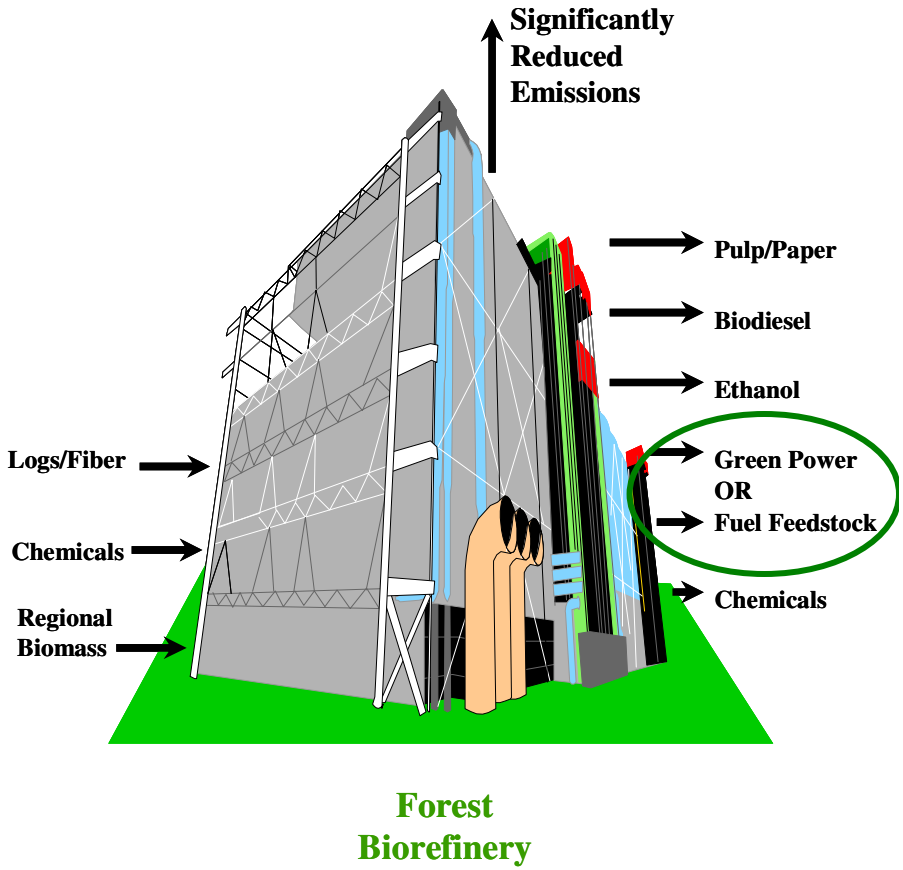


- Compatible with specialized turbines
- Specialized burner tips improve flame/burning
- Convert to steam to use existing infrastructure
- Use as a blend in diesel engines
- Upgradable to hydrocarbon fuels

Multiple Applications for Pyrolysis Oil, a Renewable Fuel Available Today

Benefits and Uses of Pyrolysis Oil

- **Benefits**
  - Energy densification relative to biomass (i.e. forest residue)
  - Fuel consistency – ASTM D7544
  - Flexibility to process biomass in one location and economically ship/store pyrolysis oil for use at other place/time
  - GHG emission reduction of 70-90% relative to fossil fuels
- **Uses**
  - Internal replacement of fossil fuel for heat/steam generation
  - Production of electricity for internal use
  - Alternate revenue stream from external sale
  - Future upgrading to green transportation fuels



RTP™ Plays a Key Role in the Biorefinery

Pyrolysis Oil: Replacement of Fossil Fuels to Generate Heat

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- **Consistent quality/improved operations**
  - ASTM D7544, Standard Specification for Pyrolysis Liquid Biofuel, established last month
- **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 unit
    - Assumes 60 $US/bbl crude
    - Includes RTP operating cost and 15-yr straight line depreciation of CAPEX
    - 330 Days per Year

Property	*Value*	*Test Method*
Gross Heat of Combustion, MJ/kg Point, °C	15 min	ASTM D240
Pyrolysis Solids Content, wt%	2.5 max	ASTM D7544, Annex I
Water Content, wt%	30 max	ASTM E203
pH	report	ASTM E70
Kinematic Viscosity, cSt @ 40 °C	125 max	ASTM D445
Density, kg/dm^3 @ 20 °C	1.1 – 1.3	ASTM D4052
Sulfur Content, wt%	0.05 max	ASTM 4294
Ash Content, wt%	0.25 max	ASTM 482
Flash Point, °C	45 min	ASTM D93, Procedure B
Pour Point, °C	-9 max	ASTM D97

Pyrolysis Oil: Production of Green Electricity

- **Compatible with specialized turbines**
- **Green electricity production cost is 0.10 $US/kW-h**
  - Includes RTP operating cost and 15-yr straight line 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: Upgrading to Green Transportation Fuels

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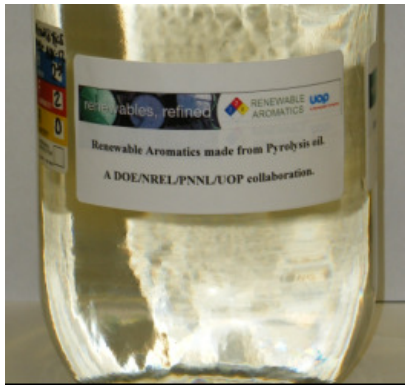
- **Objectives**
  - Remove oxygen molecules
  - Reduce acidity and viscosity
  - Break up molecules to make gasoline and diesel/jet precursors
  - Commercialization expected in 2012
- **Solution**
  - Thermochemical upgrading; leverage UOP's extensive hydroprocessing experience
  - Continuous, reliable guaranteed process, per current refinery standards



Achieved in Lab, Working on Scale-up

Delivery & Scope of Supply

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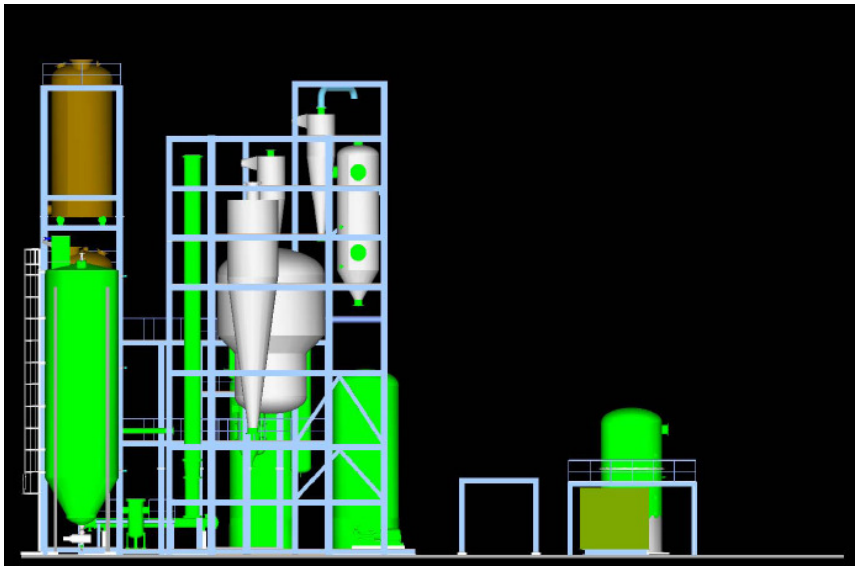
- **Standard sized modular units offered**
  - 100, 200, 400 and 1000 Bone Dry Metric Tons per Day (BDMTPD)
  - Design adjusted to meet site specific requirements
- **Design based on hardwood whitewood**
  - If alternate feedstock being processed, unit performance to be re-rated
  - Unit performance is *guaranteed*
- **Broad modular experience in refining, petrochemical and oil & gas industries**



Modular Delivery Provides Faster Execution and Higher Reliability

RTP™ Project Execution – Envergent Scope

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- **Three-phase work process**
  - Develops project specific scope
  - Enhances capital figures to reduce uncertainty

	Project Scoping	Detailed RTP Development	RTP Project Execution
Key Goals	•+/- 40% project specific RTP estimate •Define project – Inside Battery Limits (ISBL) •Understand likely delivery model	•Project-specific RTP design and implementation plan •Feedstock verification testing •Outside Battery Limits (OSBL) duty specifications •RTP firm price proposal	•Detailed RTP engineering •Build RTP modules / pre-fab •Procure equipment •Ready to ship •Envergent interfaces with client's OSBL contractor
Duration	•8-12 weeks	•6 months	•12-18 months

Equipment Delivery – Guaranteed Performance

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 2012