

## Integrated, Non-Catalytic Process for the Production of High Value Chemicals from Low Rank Coal by Oxidative Hydrothermal Dissolution (OHD)

*Francois Botha, Ken Anderson, Derek Perry and Madhav Soti*

*Thermaquatica, Inc., Carbondale, Illinois, U.S.A.*

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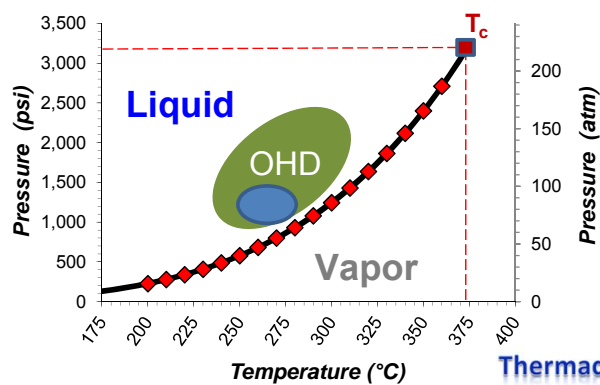
1

## What is Oxidative Hydrothermal Dissolution (OHD)?

OHD is a novel, continuous, hydrothermal process to convert macromolecular organic solids into low molecular weight chemicals, using only elevated temperature (200-370°C), high pressure, liquid water (subcritical) and molecular oxygen.

### Important Parameters:

- ✓ Temperature (coals: 250-300 °C)
  - ✓ Oxidant Loading
  - ✓ No gas phase
  - ✓ Continuous flow
  - ❖ Pressure
- } reaction  
} process



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2

## OHD is Environmentally Friendly

- 🔥 Uses only water and oxygen.
- 🔥 Requires no exotic solvents, enzymes or catalysts, nor pretreatment of the feed.
- 🔥 Moisture content of the feed is irrelevant – great for lignites.
- 🔥 Typical reaction times (pulverized feed) are of the order of a few 10s of seconds.
- 🔥 Readily achieves very high conversion of the solid.
- 🔥 High recovery (typically 75-90+%) of the products as solubilized, low molecular weight chemicals.
- 🔥 Produces very little CO<sub>2</sub> or other gases.

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3

## What is Oxidative Hydrothermal Dissolution (OHD)?

- 🔥 OHD proven on various feeds:
  - 🔥 coal (all ranks)
  - 🔥 biomass (cellulosic & lignin)
  - 🔥 oil sands and oil shales
  - 🔥 organic-containing “waste” streams
- 🔥 Products can be used in multiple areas:
  - 🔥 Agricultural (fulvate-type biostimulants and fertilizer)
  - 🔥 Platform chemicals
  - 🔥 Liquid fuels (alcoholic and oxygenated)
- 🔥 Product distribution depends on feed and OHD conditions.

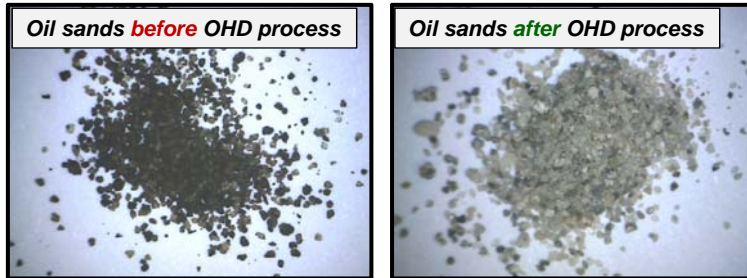


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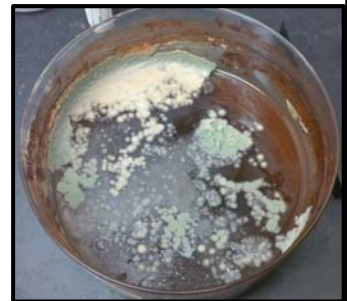
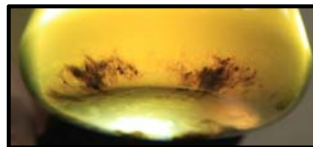
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## And on Another Note....

- Mineral matter passes through the process unaltered.



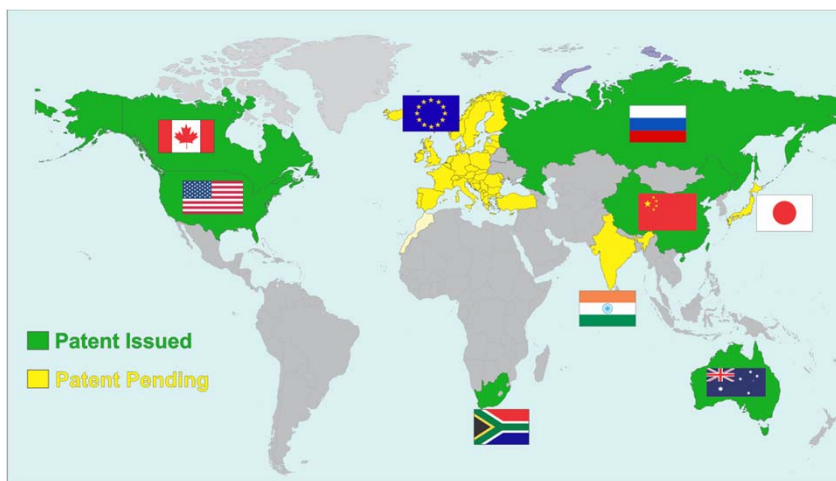
- It has been observed that products from the OHD process are readily biodegradable...



5

## Intellectual Property Status

- Thermaquatica holds exclusive license to OHD patents as well as rights for additional developments.



Status June 2016

Issued:

USA  
Canada  
Australia  
South Africa  
China  
Russia

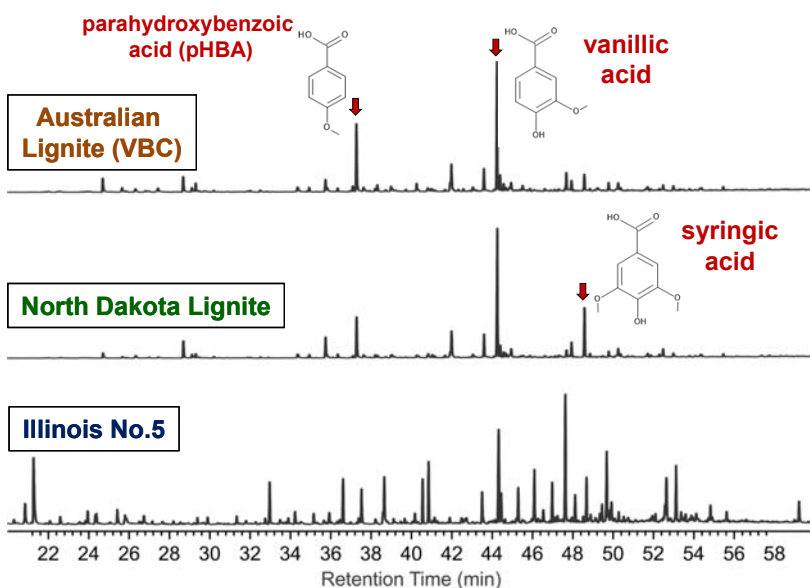
Pending:

EU  
India  
Japan

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6

## Coal-derived OHD Products



Coal-derived OHD products are dominated by:

- 🔥 aromatic acids and phenols (dominate from humic components)
- 🔥 aliphatic acids, diacids and keto acids (dominate from sapropellic components)
- 🔥 Most products are di- or poly-functionalized; functionality increasing with increasing rank

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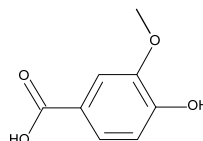
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## OHD Products

- 🔥 Main products are platform chemicals:
  - 🔥 a platform chemical acts as a building block
  - 🔥 can subsequently be converted to a number of high-value chemicals or materials

**Example:**

**Platform chemical:** vanillic acid



**Target material:** polyethylene vanillate (PEV).

- 🔥 PEV is a biopolymer that is functionally equivalent to petroleum-based polyethylene terephthalate (PET).
- 🔥 Significant technical and commercial interest for mimics that are NOT derived from petroleum.



Cover Art,  
*Green Chemistry*  
12(10) 2010

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8

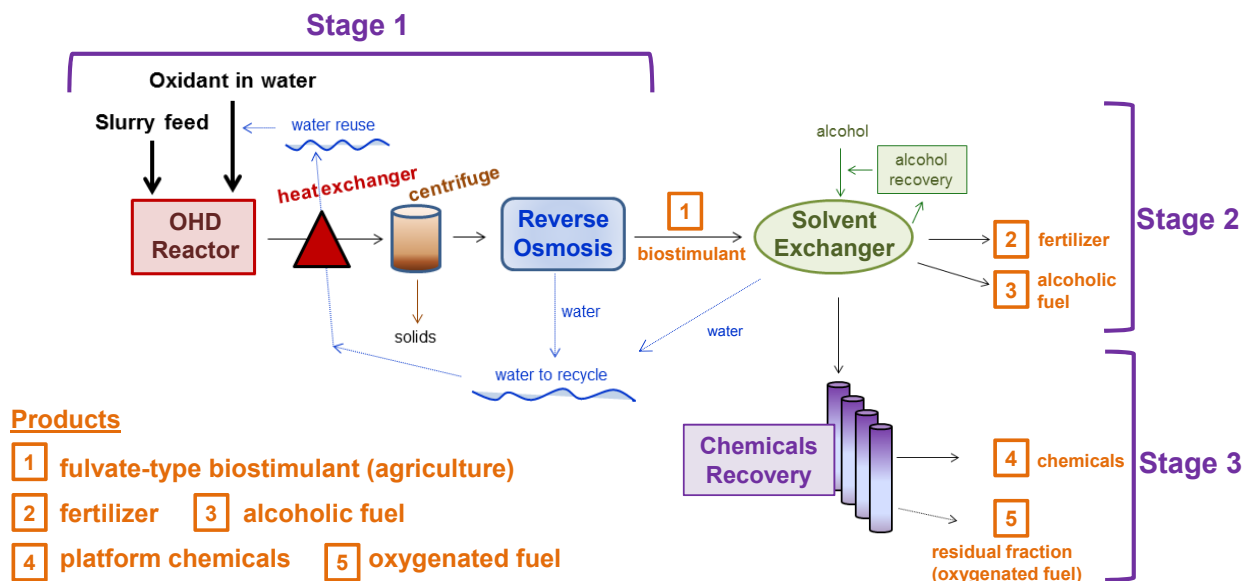
## Technology Status

- 🔥 **Laboratory Scale proof-of-concept – Complete.**
  - Semi-continuous and continuous reactor systems.
  - Regularly used for “quick” runs and establishing initial process parameters.
- 🔥 **Process Development Unit (PDU)**
  - Fully operational, small engineering scale.
  - Up to 5 kg/hour capacity (feedstock in 10% - 20% aqueous slurry) used in process refinement and economics.
- 🔥 **Innovative downstream product recovery strategy developed and tested.**

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9

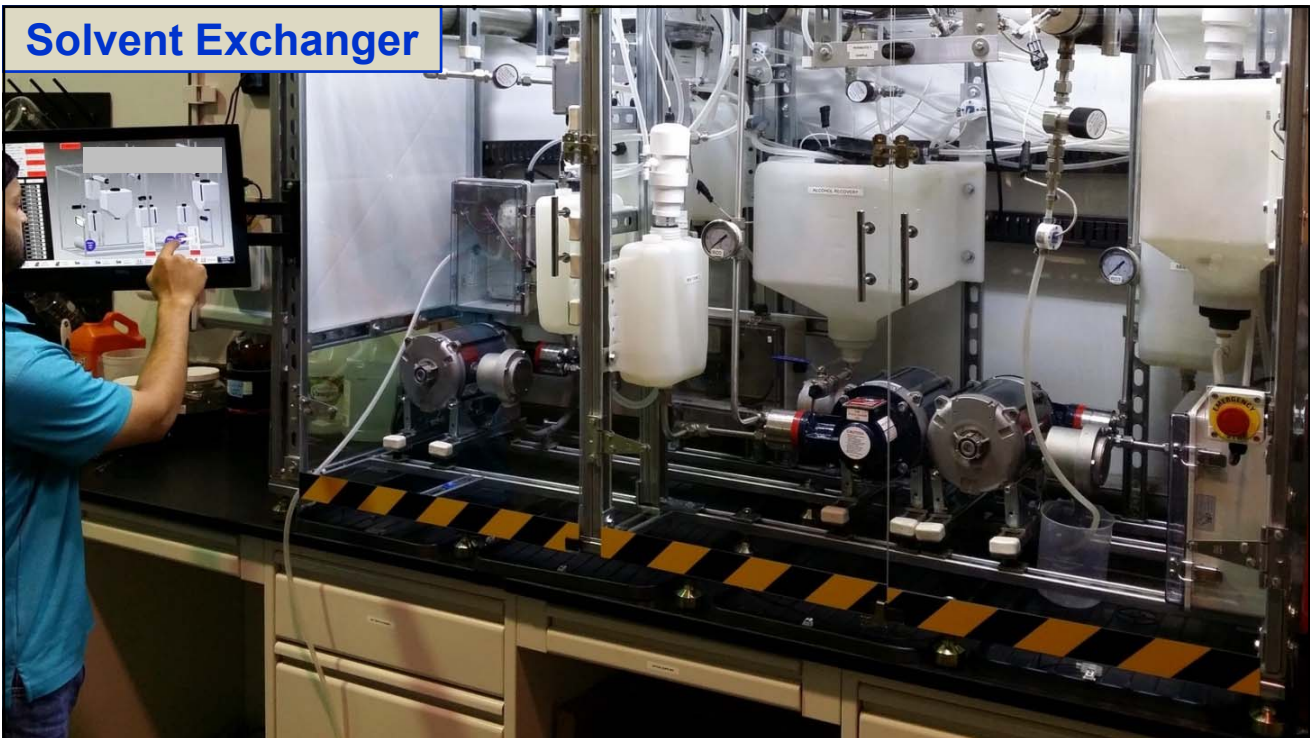
## Complete Process – OHD to Products



**Process Design Unit (PDU)**



**Solvent Exchanger**



## Commercialization and R&D Activities

- 🔥 RD&D agreement with Australian energy producer GreenPower for OHD processing of Australian lignite (Victorian Brown Coal - VBC).
- 🔥 Anticipated construction of a Stage 1, 20 tonne/day OHD Australian demonstration facility to commence 2017.
- 🔥 Massachusetts-based IMPACT Technology Development completed an OHD process GAP analysis, and an economic analysis for VBC 20 t/day pilot and a 1,000 t/day commercial plant.
- 🔥 Ongoing agricultural studies on OHD biostimulant at Monash University (Melbourne, Australia).
- 🔥 Ongoing downstream R&D for Stage 3 chemical recovery.






13

## Economic Analysis

- 🔥 20 tonne VBC/day **profitable** OHD demonstration facility
  - 🔥 Stage 1: \$7.5 million
- 🔥 Stage 1; main product is OHD biostimulant:



	OHD Biostimulant Cost of Production	US Competitor Pricing, Liquids		
		Bulk Fulvic Acid (1,000 gallons)	Retail Liquid, 1 Gallon	
			Fulvic Acid	(Compost Tea)
 \$/gallon	0.26	9.00	30.00	15.00
 \$/l	0.07	2.40	7.94	3.97
 €/l	0.06	2.07	6.90	3.45

- 🔥 Advanced R&D for producing a dry, solid product.



14

## Economic Analysis

- 🔥 20 tonne VBC/day **profitable** OHD demonstration facility
  - 🔥 Stage 1: \$7.5 million    Stage 3: \$15-20 million
- 🔥 Stage 3: First pass model shows that chemicals can be produced cost-effectively even with current (low) oil prices.
- 🔥 Client specific - depends on:
  - 🔥 feed and targeted chemicals.
  - 🔥 number of chemicals recovered (pHBA and vanillic acid for VBC case).
  - 🔥 process integration improvements.



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15

## Summary

- 🔥 OHD is a non-gasification, commercially feasible and environmentally friendly process to convert macromolecular organic solids into low molecular weight chemicals.
- 🔥 Thermaquatica is interested in expanding R&D and commercialization activities:
  - 🔥 European Lignites (Germany, Poland, Turkey)
  - 🔥 Chinese and Indian Coals
  - 🔥 Industrial organic-containing “waste” streams (e.g. black liquor)
  - 🔥 Oil sands remediation
  - 🔥 Biomass (forest and agricultural wastes)

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16



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**Thank You!**

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