ALGAE BIOMASS SUMMIT
2012

Hydrothermal Processing of Algae

Fuels and Recycled Plant Nutrients

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Hydrothermal Processing

- **Hydrothermal processing uses water, temperature and pressure to convert organic feedstock into fuel**
- **Wet process with no additional solvents**
- **Best combination of cost and performance is in subcritical region—water remains liquid**
- **Current process conditions are wet slurry at 20% dry solids in 80% water, 350°C, 200 bar**

Primary Process Steps

- **(1) Liquefaction converts portion of organic content to oil—usually about 50% by mass**
- **(2) Gasification converts residue to methane**
- **(3) Preliminary upgrading converts oil to form acceptable for refining**
- **Gasification and preliminary upgrading use catalyst, but no catalyst is used in liquefaction step**
- **Plant nutrients are recycled**

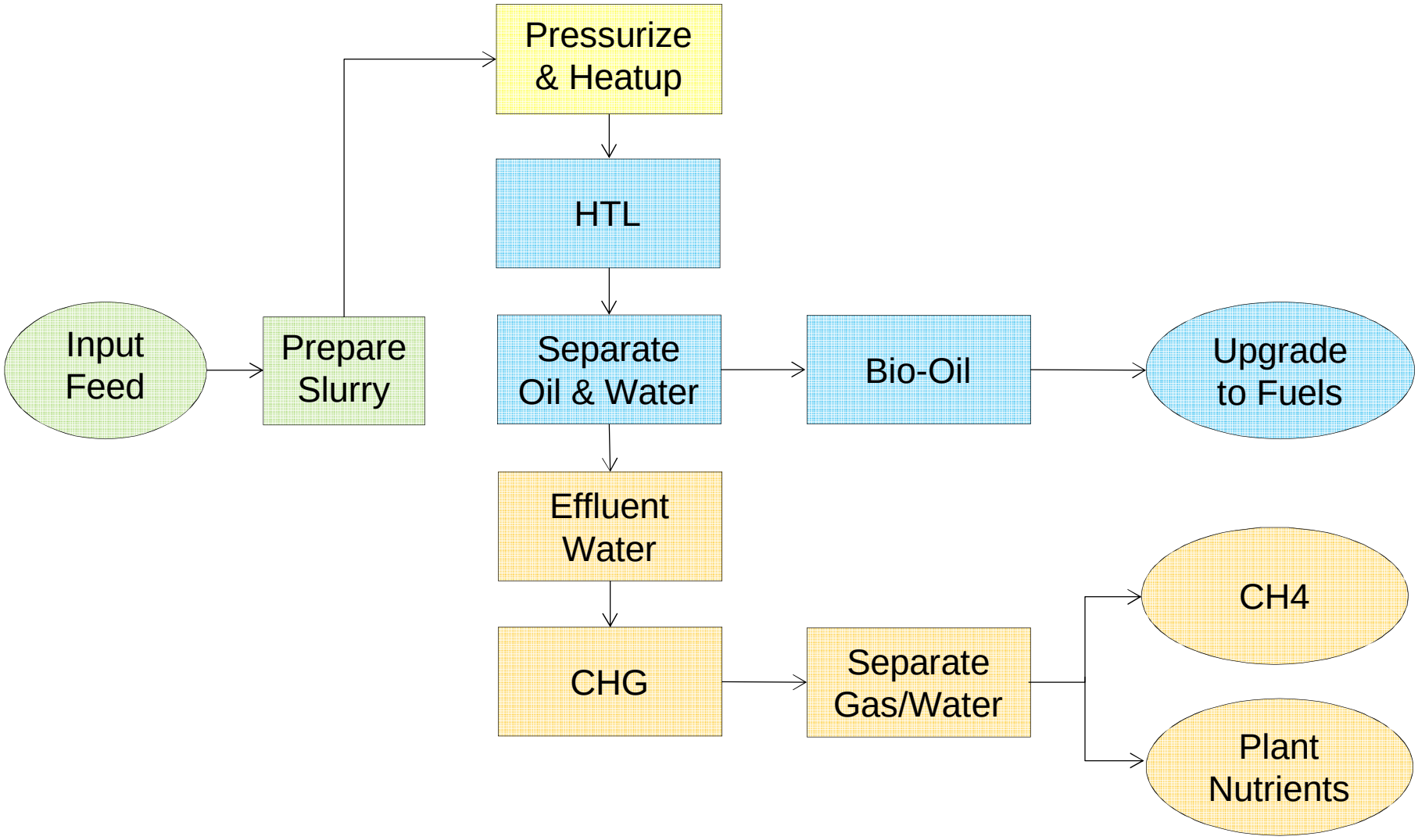
Advantages of Hydrothermal Processing

- **Clean, simple process with almost no waste**
- **Carbon conversion to fuel as high as 85%**
- **Conventional technology and materials**
- **High efficiency—heat recovery reduces energy use to app. 12%**
- **Near zero emissions—output water is clean, clear, and sterile**
- **Algae is the perfect feedstock—easy to make into slurry, high yield, fast processing**
- **Simple nutrient recycle—return to the algae water**

Names Used in Presentation

- **Hydrothermal Liquefaction = HTL**
- **Catalytic Hydrothermal Gasification = CHG**
- **Preliminary upgrading = Catalytic Hydrotreating**
- **Raw output oil = bio-oil**
- **Oil after preliminary upgrading = green crude**

Combined HTL-CHG Process Flow



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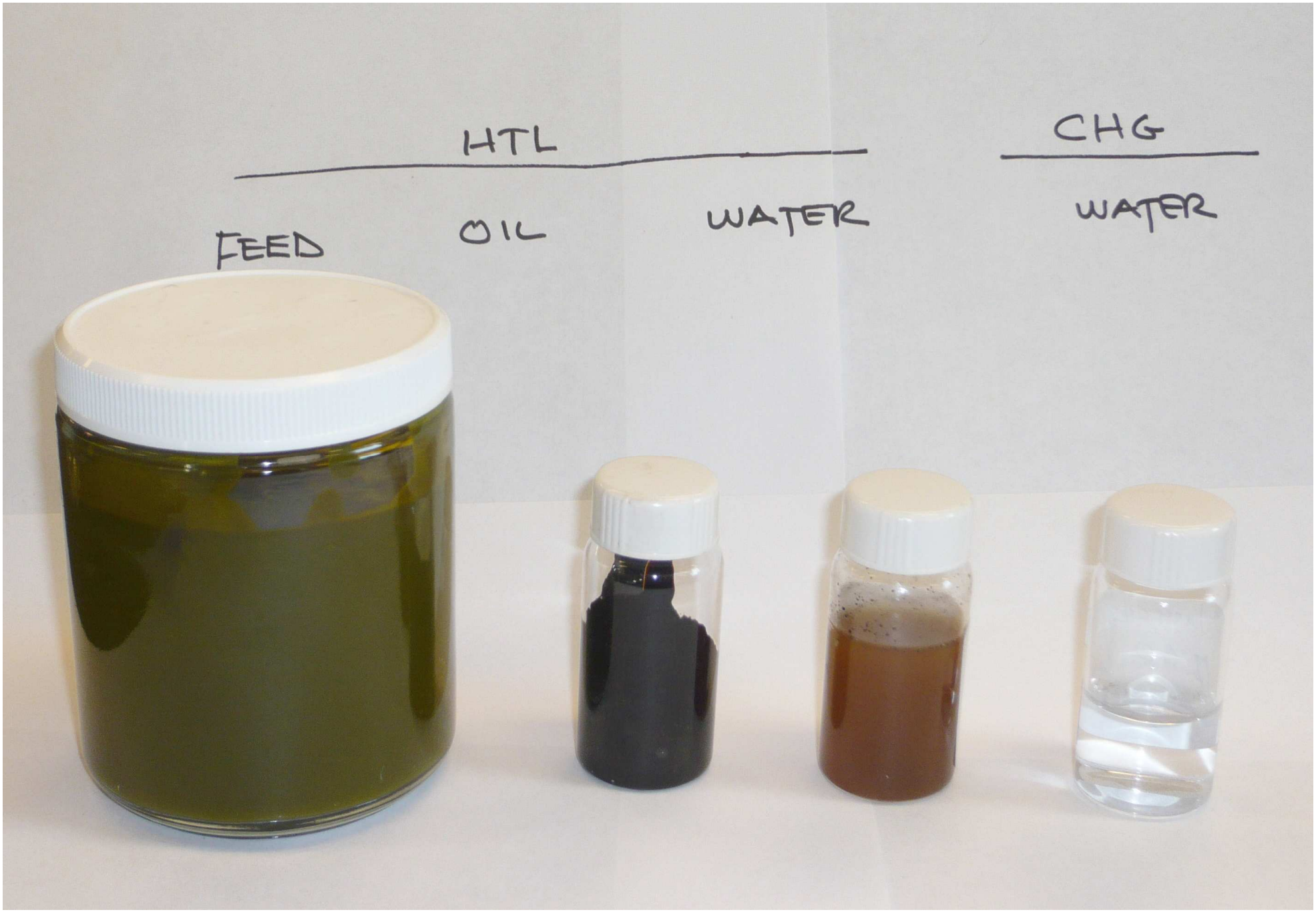
Combined HTL-CHG Inputs & Outputs



Bench-Scale Hydrothermal System

Mobile Hydrothermal System

HTL

HTL Described

- **HTL is both an extraction and a conversion process**
  - Because the hydrocarbon structure of lipids is almost completely recovered, HTL can replace other lipid extraction methods such as solvent or acid/alkali
  - In addition, a portion of proteins and carbohydrates are converted to oil
  - The total oil yield is higher than other known extractions
- **Since HTL uses only water, no solvent recovery is needed and oil is removed from water by simple oil/water separator**

HTL and Algae Growth

- **Because HTL produces oil from the whole cell, it is not mandatory to grow high-TAG algae**
  - The tradeoff is that TAGs are recovered almost completely, increasing the total HTL oil yield
  - In addition, oil quality is higher with higher TAGs—less oxygen and acid, and easier upgrading of the bio-oil
- **HTL can change the focus of algae growth—not as important to achieve maximum TAG yield or select only high-lipid algae**

Upgrading of HTL Oil

- **HTL bio-oil is not directly usable as a fuel**
  - Quality is much better than pyrolysis oil, but still contains O, N, S and is slightly acidic
- **For fuel production, the bio-oil is first "pre-treated" and then sent to an existing refinery to be processed along with fossil crude**
  - The pre-treatment consists of catalytic hydrotreating, similar to but not identical to petroleum processes
- **This "pre-treat" removes oxygen, sulfur, and nitrogen from the bio-oil**

Nutrient recovery

- **Both HTL and CHG have nutrient recovery, allowing for nutrient recycle to the algae ponds**
- **All major nutrients (NPK) as well as micro-nutrients (iron, magnesium, copper, boron, etc.) are recovered**
- **When used together, the nutrient recycle is almost a "closed-loop" system**
- **Carbon dioxide may also be recovered and recycled**

CHG

CHG Described

- **CHG produces methane gas rather than oil because of the gasification catalyst**
- **HTL organic residue is in the water and is sent to CHG to recover all the mass not converted to oil**
  - Depending on the algae, app. 50% of the dry mass will go to oil and 50% to methane
  - HTL effluent is not a good feedstock for anaerobic digestion but is easily processed by CHG
- **CHG processing yields additional fuel and also neatly disposes of organic waste residue from HTL**

Uses for CHG Output Gas

- **Can burn directly to make electricity**
- **CHG gas can also be made into CNG vehicle fuel—already at CNG pressure**
  - Under RFS2, renewable CNG is eligible for RINs with current value of $10 per MMBTU, compared to current wholesale CNG price < $3 per MMBTU
- **Most CNG vehicles in US are heavy trucks and buses—nearly 25% of municipal buses are CNG**
- **CNG costs are half or less compared to diesel**

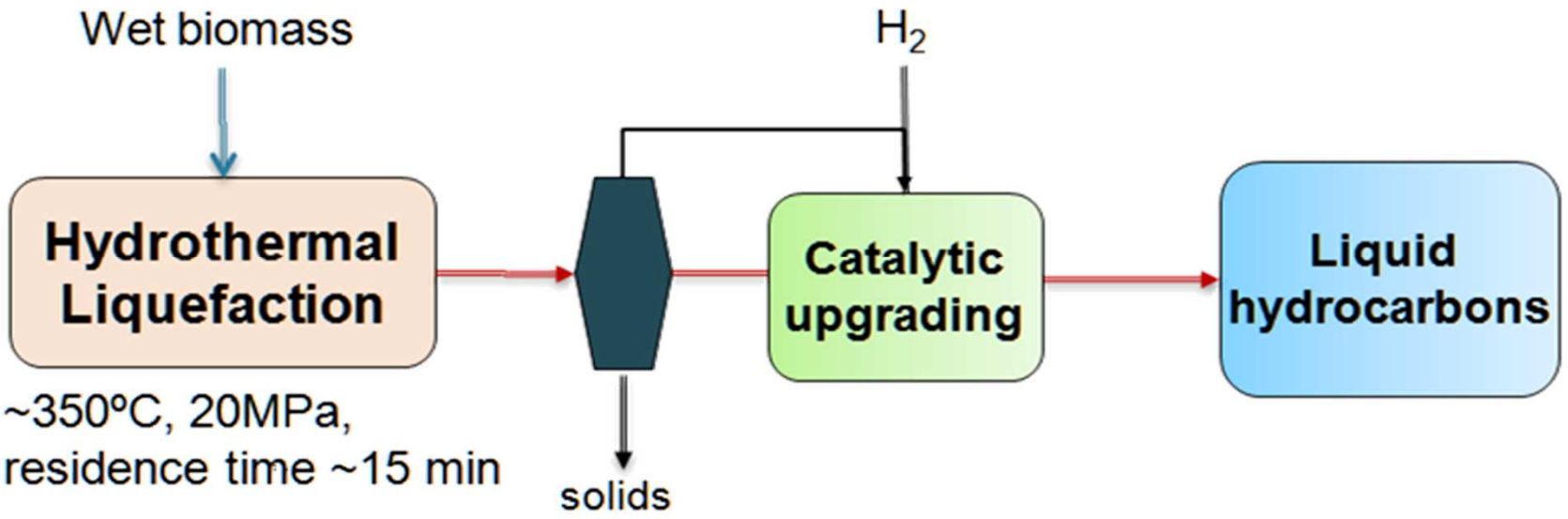
Combined HTL & CHG

Test Summary: HTL + CHG of Algae

ITEM	DATA
Lipid content of whole algae	33%
Bio-oil from HTL as % algae mass	58%
Bio-oil from HTL as % algae AFDW	64%
% of algae carbon in HTL oil	69%
Mass of organic residual in effluent water	34%
% of organic in effluent converted to CH_4	50%
Total carbon recovery as fuel (oil + CH_4)	86%

Upgrading

Hydrotreating HTL Oil



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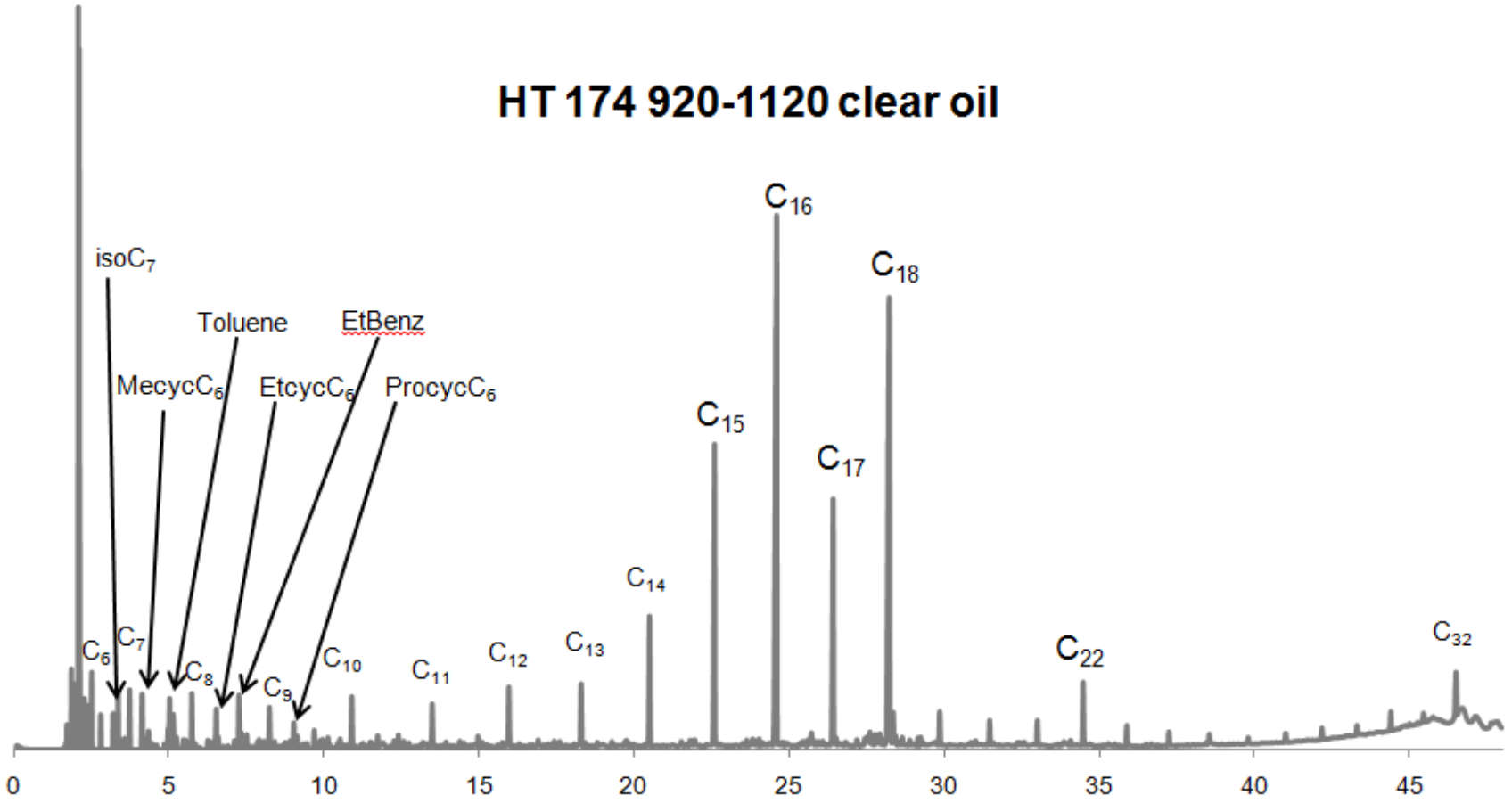
Upgrading Via Hydrotreating

- **Easy to hydrotreat, less H_2 needed vs. fast pyrolysis bio-oil**
- **Commercial catalyst**
- **Hydrotreated product ~ 95% of bio-oil volume**
- **Primarily long-chain hydrocarbons (from lipids) and smaller chains plus cyclics (from protein and carbs)**
- **Final step is standard refinery processing including isomerization, cracking, and distillation to produce finished fuels**

Analysis of Hydrotreated Oil



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Jet, Diesel, and “Heavies” from HT Oil

Hydrotreated Oil

Fractionated Oil

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80% in Diesel Range

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Conclusion

Conclusion

- **Hydrothermal processing is a highly efficient method of producing fuel from algae, which is an excellent feedstock**
- **HTL produces high yields of bio-oil from both lipid-producing and non-lipid-producing algae**
- **CHG produces methane from HTL effluent**
- **Nutrients can be recovered for recycle to algae growth ponds**
- **Oil can be upgraded and refined to yield high-quality drop-in fuels**

Credits

- John Holladay, Doug Elliott, Todd Hart—PNNL
- Pete Lammers, Tanner Schaub—NMSU
- Bryan McCarty, Rich Crowell—Solix Biofuels

A portion of this work was performed under the NAABB contract, funded under the DOE Office of Biomass Production, DE-EE0003046

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