Hydrothermal Processing of Wet Wastes

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Q: What is possible with Waste-to-Energy (WTE)?

A: Up to 25% of US Liquid Fuel Supply.

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25% Sounds High—Is That Possible?

- **Available technology and wet wastes can start toward this goal now**
- **285,000 barrels of oil per day by 2025**
  - 3.3 million bbl/d by 2045 (17% of US demand); also produces more than 6 million MCF/d of methane
  - Continue growing to 25% of US demand by adding more feedstocks (chart shown later)
- **Using wastes solves environmental disposal problems, reduces or eliminates feedstock cost, and produces significant renewable energy**

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Hydrothermal Processing

- **Advanced process efficiently converts wet wastes to biofuels and clean water**
  - Can produce bio-crude oil, natural gas, or both together
  - More than 99% of organic matter is converted
- **Process perfected by US Department of Energy at PNNL over 35-year period with extensive testing**
- **"Solving Two Problems at Once" ™**
  - Solves wet waste disposal problems
  - Profitably produces renewable energy—key factor is low or negative cost of wet waste

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Process Concepts

- **Process is similar to fossil fuel formation, but faster**
  - "Does in 30 min. what nature does in 30 million years"
  - Bio-crude and gas are similar to fossil equivalents
- **Best technology available for converting wet wastes to hydrocarbon fuels**
- **Equipment is compact and highly scalable**
- **Tested on more than 100 feedstocks**
- **Fuels produced are drop-in replacements using existing infrastructure**

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Partial List of Tested Feedstocks

Waste	Dairy Manure, Poultry Manure, Pig Manure, Municipal Solid Waste, Pulp and Paper Mill Waste, Plastic Bottles
Aquatic	Water Hyacinths, Kelp (Marine), Red Algae (Marine), Green Algae (Brackish), Green Algae (Marine), Green Algae (Fresh), Diatoms, Cyanobacteria
Ligno-Cellulosic	Wood Slash, Sawdust, Corn Stover, Poplar Fermentation Residuals, Wood Gasification Residuals, Cellulosic Fermentation Residuals
Herbaceous	Napier Grass, Sorghum, Sunflowers, Corn Stover, Marigolds
Food Processing	Potato Waste, Corn Ethanol Bottoms (DWG), Grape Pomace (Wine Making), Cranberry Pomace, Digester Sludge, Kraft Paper Black Liquor, Cheese Whey, Coffee Grounds, Spent Distillers Grain, Vinegar, Olive Wash Water, Chicken Processing Waste, Fish Processing Waste, Gelatin Mfg. Waste, Rum Vinasse, Soda Pulp Wastewater, Soft Drink Factory Waste, Potato Processing Crumbs, Shrimp Waste, Potato Peels, Dairy Waste, Onions, Corn Canning DAF, Apple Pomace, Beer Waste
Chemical Waste	Nylon Wastewater, Acrylonitrile Wastewater, Fatty Acid Waste, Metal Chelate Solution, Sodium Cyanide Waste, Polyol Wastewater, Vitamin Fermentation Broth, Paint Booth Wash, Methyl Ethyl Ketone, Propylene Glycol, Carbon Tetrachloride, many other chemical compounds

The Problem and the Opportunity

- **Wet waste materials are everywhere, with huge quantities worldwide, and will always be there**
- **Wet waste treatment often means large-scale dumping into landfills, watersheds or oceans, squandering fresh water, energy and fertilizers**
- **Worldwide regulations are increasingly requiring more complete and expensive treatments, and will continue to trend in this direction**
- **Demand and value for renewable energy and biofuels are expanding rapidly**

The Problem: Wet Wastes

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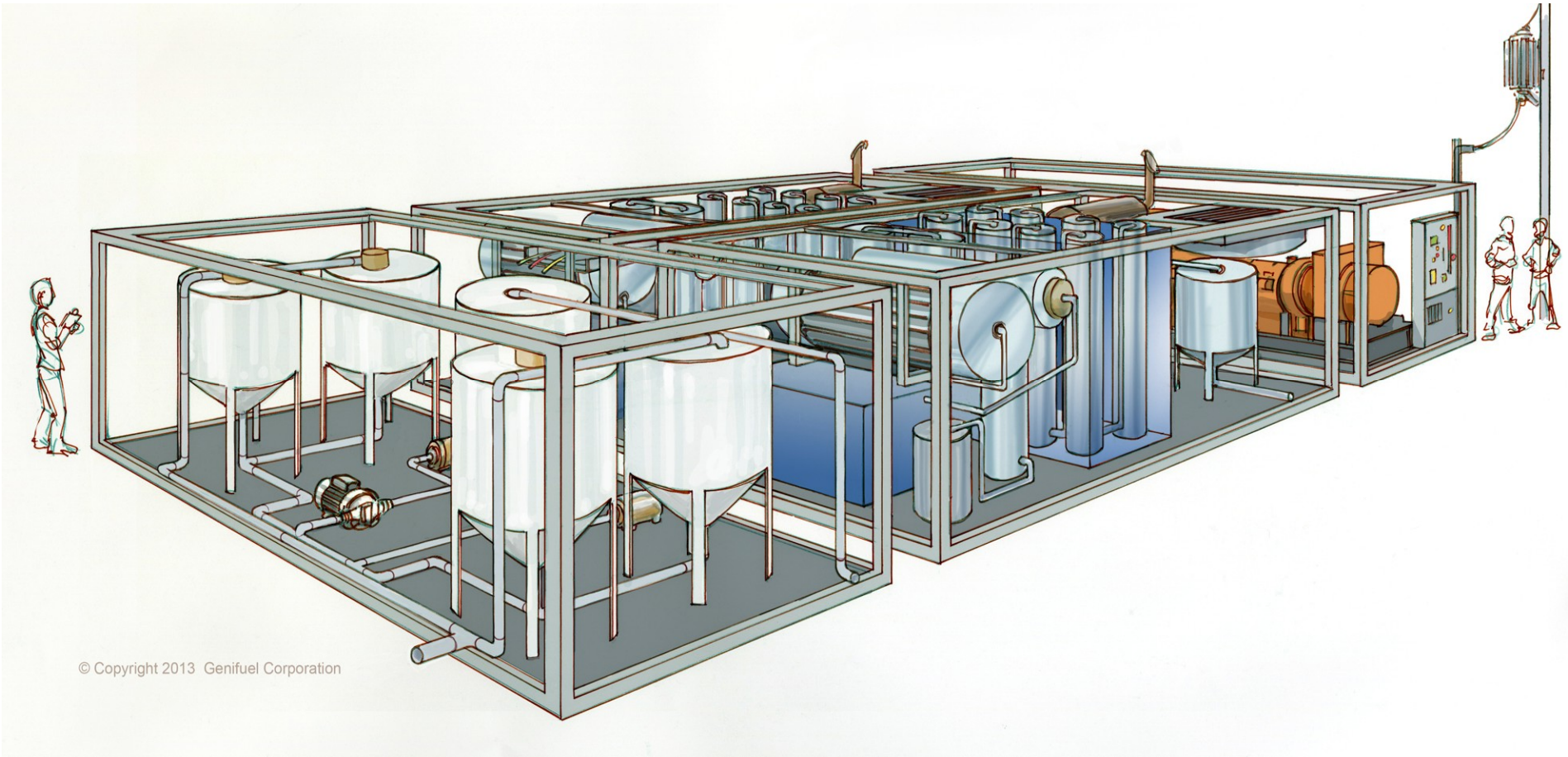
The Solution: Wet Waste to Fuel



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How It Works

- **Hydrothermal Processing (HTP) uses only pressurized hot water--no solvents**
- **Wet feedstock is made into water slurry with 15% to 35% dry equivalent solids (not actually dried)**
- **Process is NOT supercritical, which is important to the overall economics and success of HTP**
  - 350°C and 207 bar (662°F and 3,000 psi)
- **Continuous process converts more than 99% of the feedstock organic content in 30-45 minutes**
- **Process is efficient--uses 12% of energy (88% free)**

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Products

- **Bio-crude can be used as is, or upgraded to refined fuels in a conventional refinery**
  - May need small pre-treater depending on refinery
- **Methane can be used several ways**
  - Use as fuel for generator to make electricity and heat
  - Remove CO_2 , then inject into natural gas pipeline or use locally as CNG
  - Gas is clean (no sulfur, phosphorus, siloxanes)
- **Most feedstocks produce fuels and power which are eligible for renewable incentives internationally**

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Products are Crude Oil, Methane Gas, or Both

Wet Waste

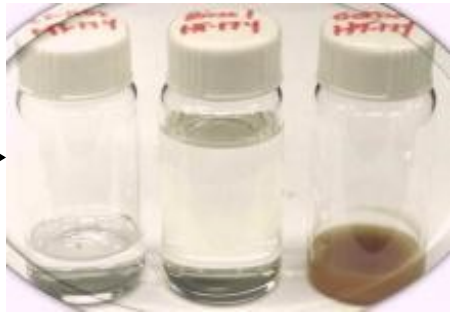
Step 1 (HTL)

HTL Bio-oil

HYDROTREAT

Upgraded Oil

FRACTIONATE



Clean Fuels

Jet Diesel Heavy

HTL Effluent Water

Step 2 (CHG)

Clean Effluent Water

Renewable Natural Gas

HTL = Hydrothermal Liquefaction
CHG = Catalytic Hydrothermal Gasification

Status: Finish Fabrication in August

Feedstocks Available for Hydrothermal Processing

Feedstock	World Million t/y	USA Million t/y
Non-Dairy Cattle Manure	2,510	396
Food Processing Waste	2,397	422
Pig Manure	2,154	340
Algae	1,260	270
Cellulosic Ethanol Bottoms	1,260	270
Muni Solid Waste (paper and organics only)	819	225
Dairy Cow Manure	747	53
Wastewater Treatment Solids	66	24
Beer Production	27	5
All Other	1,686	301
TOTAL	12,926	2,305

1. All amounts shown as metric tons of wet slurry @ 20% solids.
2. All amounts are actual amounts for 2010 except algae and cellulosic ethanol, which are estimated at 5% of transportation fuel supply.
3. Assumes 54% of available feedstocks are ultimately recovered worldwide.
4. "All Other" includes waste from pulp and paper processing, water and landfill remediation, organic chemical waste, poultry manure,etc.
5. Data do not include wood or agricultural waste except as ethanol bottoms.

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Fuel Potential from Chart: >15%

- **Chart assumes 54% of available wet wastes are actually collected and processed**
- **Algae is not counted, since timing of high-volume algae production is unclear**
- **Wood and agricultural waste (e.g. corn stover) are not counted except as residuals from cellulosic ethanol production**
  - If fully counted would significantly increase results
- **Conclusion is that wet wastes could supply more than 15% of US liquid fuel (3.1 out of 19 million barrels per day) by 2045**

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Other Biomass to Fuel Technologies

- **Anaerobic Digestion (AD) is most widely known**
  - Biological process, more than 2,000 years old
  - Slow and incomplete conversion--app. 50% in 20 days vs. 99% in 30 minutes for hydrothermal
- **Cellulosic ethanol production**
  - 35% of carbon goes to fuel, vs. 85% for hydrothermal
  - Alcohol lower value than hydrocarbon fuels
- **Another technology—high-temperature pyrolysis—is not practical for wet materials**
  - 40% of the energy is lost drying the material
  - Output oil is lower energy and higher cost to refine

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Example: Eliminate Wastewater Sludge

- Can process either primary or secondary sludge with no digester (preferred)
- Can also process post-digester sludge
- Either way: Renewable fuel and no solids left

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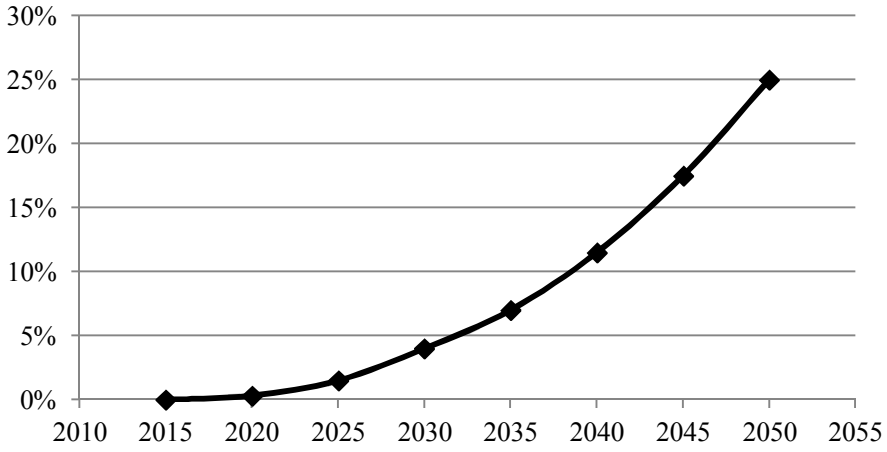
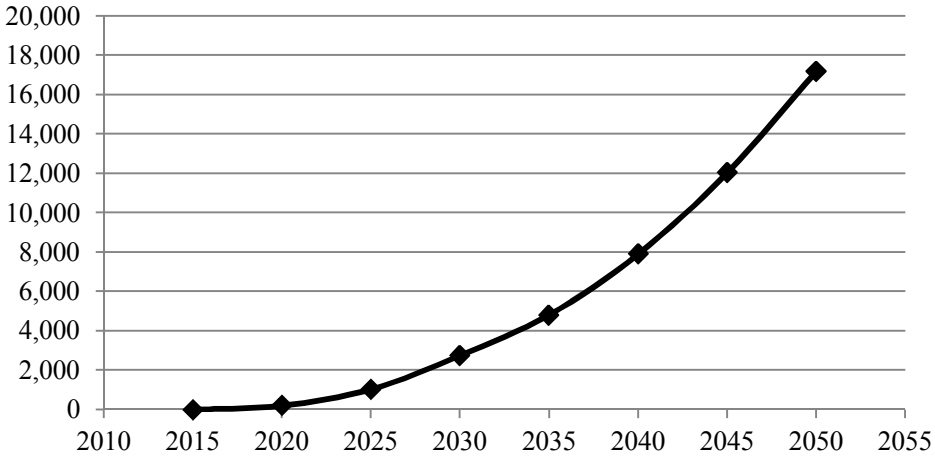
The Future

- **After 2045 Hydrothermal Processing could continue to grow with more feedstocks, possibly reaching 25% of US oil supply**
- **Huge potential outside USA—same feedstocks**

% of US Oil Supply



US HTP Systems at 100 t/d



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What Is Needed--Financial

- **Many systems will be structured similarly to investor-owned Power Producer Agreements (PPAs)**
  - Used today for wind and solar
  - Will significantly expand number of projects and capital
- **Some projects will be owned by feedstock owner**
- **Projects can be profitable today with time to recover investment (TTR) between three and five years**
  - Requires several factors to be aligned—tax structure, waste cost, fuel price, incentives, regulatory, etc.
  - Need to make these factors easier and more standard

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What Is Needed--Technical

- Continue to reduce cost, time to manufacture, and simplify design
- At least three successful installations are needed to provide demonstrations and proof to users and investors; then growth will accelerate
- Refiners need to learn to handle the bio-crude and optimize processes where needed
- Optimize feedstock preparation for various feedstocks

What Is Needed--Government

- **Hydrothermal processing can involve DOE, USDA, EPA, IRS, WERF (for wastewater utilities)**
- **Treatment of hydrothermal processing needs to be understood and standardized (like wind and solar)**
  - RINs, Carbon Credits, eligible feedstocks, etc.
  - Investment Tax Credits and other tax treatments
  - Rural Energy financing eligibility
  - Dairy and other livestock programs
  - State regulations and incentives (e.g. California)
  - Air and Water standards for hydrothermal systems
  - Gas and electricity feed-in tariffs and procedures

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Conclusion

- **Wet wastes are available immediately—no additional time or investment to grow energy crops**
- **Hydrothermal processing is the best and sometimes the only viable technology for some wet wastes**
- **By starting now, we can make a real contribution to fuel supply quickly, with very large future growth**
- **Key requirement is to get several systems into commercial operation as soon as possible**

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