Production of Valuable Organic Acids from Anaerobic Digestion of Organic Wastes

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Disclaimer

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THIS PRESENTATION CONTAINS ESTIMATES, FORECASTS, AND PREDICTIONS OF ANTICIPATED FUTURE PERFORMANCE THAT ARE FORWARD LOOKING. NO ASSURANCE CAN BE GIVEN AS TO THEIR ACCURACY. NO INVESTMENT DECISION SHOULD BE BASED UPON THIS PRESENTATION.

May 14th, 2014
Earth Energy Renewables

Demonstrated success creating high-margin green alternatives to petroleum-derived fuels and chemicals

Feedstock flexible

State-of-the-art laboratory, pilot and 100,000 GPY Demo Plant

Fuels and Chemicals
## Company History

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>University Research</td>
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<tr>
<td>2007</td>
<td>Lab</td>
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<tr>
<td>2008</td>
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<tr>
<td>2009</td>
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<td>2011</td>
<td>DARPA</td>
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<tr>
<td>2012</td>
<td>Earth Energy Renewables LLC</td>
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</tbody>
</table>

- **1995**: University Research (Lab)
- **2007**: Lab
- **2008**: Pilot
- **2009**: Demo
- **2011**: DARPA
- **2012**: Earth Energy Renewables LLC

### Key Events:

- **Texas A&M MixAlco Process Prof. Mark Holtzapple 1995 to 2007**
- **Terrabon, Inc. Fermentation Tests Bench-scale 2 – 10 L**
- **Terrabon/Texas A&M Fermentation 4000 gal**
- **Terrabon, Inc. Demostration Scale plant 100,000 GPY Bryan, TX**
- **Terrabon Inc. Jet fuel Demo Plant under DARPA contract 2011**
- **Earth Energy acquires all assets, Demo plant & IP Nov ’12. Technical staff, engineers, scientists, operators**

**Over $70 Million Invested**
Demonstration Plant

6150 Mumford Rd., Bryan, TX

• Field Scale
• Demonstration-Scale operation of process
• Indoor & outdoor operations
• Extensive laboratory capabilities
Demonstration Plant

6150 Mumford Road
Bryan, Texas

- 100,000 gal of gasoline/year nameplate capacity
- Demonstration-scale operation of process
- 48,000 gallon fermentation tank
- Indoor & outdoor empirical testing
- Extensive laboratory capability
Feedstock Flexible = Globally Replicable

Over 30 feedstock tested

- Alfalfa
- Food wastes
- White office paper
- Paper-mill fines
- Sugarcane bagasse
- Pineapple waste
- Glycerol
- Raw Glycerin
- Corn Stover
- Rice Straw
- Cotton gin trash
- Water hyacinth
- Switchgrass
- MSW-Wet organics
- Poplar Wood
- Sugarcane molasses
- Sorghum stalks
- Municipal sewage sludge
- Cellulosic municipal solid waste
- Bio-sludge (from chemical plant WWTP)
- Chicken manure
- Cattle manure
- Sugar beet pulp
- Lipid-extracted micro-algae
- Whole micro-algae
- Pulp-mill molasses (aka wood molasses)
- Orange peels
- Oil Palm empty fruit bunch
Anaerobic digestion

Promote carboxylic acids – Acetic, propionic, butyric, etc. – From C2 to C8 – a.k.a short- and medium-chain fatty acids by inhibiting methanogenesis

Biomass

Cellulose, hemicellulose, starch, proteins, fats

Hydrolysis

Free sugars, amino acids, long-chain fatty acids, glycerol

Acidogenesis

Medium-chain fatty acids, NH₃, CO₂, H₂S

Acetogenesis

Acetic acid, CO₂, H₂

Methanogenesis

CH₄, CO₂
Typical Acid Spectrum out of our AD

**C2 – C8 Carboxylic Acids**
- C2: Acetic
- C3: Propionic
- iC4: Iso-butyric
- C4: Butyric
- iC5: Iso-valeric
- C5: Pentanoic (Valeric)
- C6: Hexanoic (Caproic)
- C7: Heptanoic (Enanthic)
- C8: Octanoic (Caprylic)

The final product acid spectrum can be controlled by modifying operating conditions. C2 and C3 can be minimized by recycling to continue elongation.
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Methane-inhibited Anaerobic digestion: Carboxylate Platform

Biomass

Excess Potable Water

Water

Anaerobic Digestion

Clarification

Water Management

Acidification/Extraction

Distillation

Undigested Residue

Concentrated Carboxylic Acid Salts

Carboxylic Acids

Purified Carboxylic Acids

Recycle of short-chain fatty acids for elongation

Proprietary/Patented Technology

Conventional Technology
Advantage of Earth Energy Renewables’ AD process

- Thermodynamically favored
- Non-sterile process
- Only natural cultures; no GMOs
- No extraneous enzymes
- Ultra-feedstock agnostic (cellulose, hemicellulose, proteins, fats, pectin, chitin, etc)
- High yields, theoretical > 130 gal EthOH equivalent/ton (>87 gge/ton)
Advantages of Earth Energy Renewables’ Extraction Process

- Simple, efficient and effective.
- No extraneous extractant
- Produces very pure acids without complex and expensive purification techniques
- Nitrogen, sulfur and metals content (catalyst poisons) in acids is very low.
Biomass
- Carboxylic Acid Salts
- Butyric Acid
- Valeric Acid
- Caproic Acid

Chemical Conversion
- Di-ketone Alcohols
- Secondary Alcohols
- Esters
- Fatty Esters
- Long-Chain Fatty Acids And Lipids
- Jet fuel/Diesel
- Omega-3 Fatty Acids
- Dienes
- Olefins
- Gasoline/jet Fuel/Diesel
- Primary Alcohols
- Fatty Alcohols

2nd Biological Conversion
Carboxylic Acids – Large Established Markets

- **C2 Acetic Acid**
  - Vinyl Acetate Monomer
  - Acetic Anhydride
  - Acetate Esters
  - Process Solvent for Terephthalic Acid (TPA)
  - Manufacture
  - Other

- **C3 Propionic Acid**
  - Animal Feed
  - Grain Preservative
  - Food Preservative
  - Herbicide
  - Pharmaceuticals

- **C4 Butyric Acid**
  - Cellulose Acetate
  - Butyrate Propionate
  - (CAB/CAP)
  - Flavor & Fragrance

- **C5 Valeric Acid**
  - Neopolyolesters (NPE)

- **C6 Caproic Acid**
  - Polyethylene/Propylene Glycol (PEG/PG) Esters

- **C7 Heptanoic Acid**
  - Molding Resin
  - Sheet Resin
  - Rheology Modification
  - Coatings (Automotive)

- **C8 Caprylic Acid**
  - Ester Based Synthetic Lubricants
  - Emulsifiers
  - Thickeners
  - Resin Plasticizers
  - Viscosity Control
  - Wetting Agent
  - Emollients
# Derivatives Applications and Markets

## Carboxylic acids and Carboxylic acid derivatives

<table>
<thead>
<tr>
<th>Short- and Medium-chain fatty acids</th>
<th>Carboxylic acid derivatives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acetic acid</td>
<td>Acetic esters</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>Propionate esters</td>
</tr>
<tr>
<td>n-butyric acid</td>
<td>Butyrate esters</td>
</tr>
<tr>
<td>Iso-butyric acid</td>
<td>Valerate esters</td>
</tr>
<tr>
<td>Valeric acid</td>
<td>Caprate esters</td>
</tr>
<tr>
<td>Iso-valeric acid</td>
<td>Heptanoate esters</td>
</tr>
<tr>
<td>Caproic Acid</td>
<td>Octanoate esters</td>
</tr>
<tr>
<td>Heptanoic Acid</td>
<td>(esters such as methyl and ethyl esters and polyethylene/propylene glycol esters)</td>
</tr>
<tr>
<td>Octanoic Acid</td>
<td>Ethanol</td>
</tr>
<tr>
<td>Acetone</td>
<td>n-propanol</td>
</tr>
<tr>
<td>2-Butanone</td>
<td>n-butanol</td>
</tr>
<tr>
<td>2-Pentanone</td>
<td>n-pentanol</td>
</tr>
<tr>
<td>3-Pentanone</td>
<td>n-hexanol</td>
</tr>
<tr>
<td>3-Hexanone</td>
<td>n-heptanol</td>
</tr>
<tr>
<td>4-Heptanone</td>
<td>n-octanol</td>
</tr>
<tr>
<td>4-Octanone</td>
<td>5-decanol</td>
</tr>
<tr>
<td>5-Decanoate</td>
<td>6-undecanol</td>
</tr>
<tr>
<td>6-Undecanol and higher</td>
<td>Hexylene glycol and higher</td>
</tr>
<tr>
<td>Polyols</td>
<td>Ethylene</td>
</tr>
<tr>
<td>Olefins</td>
<td>Propylene</td>
</tr>
<tr>
<td>Hydrocarbon fuels</td>
<td>Butylene</td>
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<tr>
<td></td>
<td>2-pentene</td>
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<tr>
<td></td>
<td>3-pentene</td>
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<tr>
<td></td>
<td>3-hexene</td>
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<tr>
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<td>2-hexene and higher</td>
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<tr>
<td></td>
<td>Gasoline</td>
</tr>
<tr>
<td></td>
<td>Jet fuel</td>
</tr>
<tr>
<td></td>
<td>Diesel</td>
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</tbody>
</table>

## Key applications

- **Paints and adhesives**
- **Lubricants**
- **Surfactants**
- **Plasticizers**
- **Animal feed**
- **Thickeners**
- **Flavors and fragrances**
- **Polymer Stabilizers**
- **Fungicides**
- **Corrosion inhibitors**

- **Detergents**
- **Cleaners**
- **Printing and inks**
- **Paint & Coatings**
- **Pharmaceuticals**
- **Lubricants**
- **Plasticizers**
- **Surfactants**
- **Fuels Additives**
- **Cosmetics and Personal Care**

- **Solvents**
- **Pharmaceuticals**
- **Cosmetics**
- **Resins**
- **Pesticides**
- **Lubricants**
- **Softening agents**
- **Anti-freeze**

## End Markets

- **Consumer and Retail**
- **Cosmetics**
- **Industrial Goods**
- **Agriculture**
- **Packaging**

## Market Size

<table>
<thead>
<tr>
<th>$8 Billion</th>
<th>$500 Billion</th>
<th>$2.3 Trillion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automotive Industrial Goods Construction &amp; Real State Consumer &amp; Retail Pharmaceuticals Cosmetics Print Media</td>
<td>Automotive Agriculture Industrial Goods Construction &amp; Real State Consumer &amp; Retail Pharmaceuticals Cosmetics Print Media</td>
<td>Automotive Construction &amp; Real State Pharmaceuticals Consumer &amp; Retail Agriculture Textile Packaging Industrial Goods Consumer &amp; Retail Refiners/DOD Transportation</td>
</tr>
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</table>
Common Scale-up Strategy

Not profitable until large biofuel facility is built

Not profitable, with high burn-rate

Biofuels Demonstration Plant

5 - 30 tons/day Feed

Pilot Plant

2 kg/day Feed

~500 ton/day Feed

Biofuel Commercial Plant

Plant Feed Capacity on a dry basis
Exceptional at Each Stage of Engineering Scale-up

Except for pilot plant, all cases have a positive return with < 5 year payback

$10 - $30/gal
- C3 Propionic
- C4 Butyric
- C5 Valeric
- C6 Caproic

$6 - $15/gal
- Propionate
- Butyrate
- Valerate
- Caproate

$4 - $9/gal
- Propanol
- Butanol
- Pentanol
- Hexanol

$4.50/gal
* With RINs

CAPEX

1000 ton/day Feed

$10 - $30/gal

8 tons/day Feed

30 tons/day Feed

50 ton/day Feed

90 ton/day Feed

280 ton/day Feed

1000 ton/day Feed

Plant Feed Capacity on a dry basis
Summary of Improvements

**Improvements for acid production**
- Elongation of short-chain fatty acids to medium-chain fatty acids
- Direct conversion of carboxylic salts to acids
- Liquid/Liquid Extraction of acids

**Results**
- Elimination of solids handling/Improves throughput
- Mechanical reliability
- Reduction of de-watering
- Lower CAPEX
- High-purity product
Technical Milestones

• Begin operation of pilot plant to generate kg quantities of product to send out to potential off-takers (within 2 months)
• Engineering of 8 dry ton/day facility (Q4 2014)
• Construction of 8 dry ton/day facility (Q2 2015)