Frontiers in Bioaromatics: Characterization, Refining, and Applications

Breakout Session, July 20th,

Jeff Moore
Chief Operating Officer
Virent
Virent Overview

*Leading catalytic route to replace crude oil with ‘drop-in’ bio-based chemicals and fuels*

- Founded in 2002 and headquartered in Madison, Wisconsin
- BioForming® Technology: Continuous process, catalytic technology, scalable
- Industry leaders as partners and investors
  - Shell: Active 8 year partnership in biofuels with royalty income to Virent when commercialized
  - Coca-Cola: Active 4 year partnership for Bio-PX
- Extensive Intellectual Property (IP) portfolio
  - 119 patents issued
  - 146 patent pending applications

Partners & Investors

Infrastructure
Virent Competitive Advantages
Low cost bio-based route to aromatics

- Virent process with external $H_2$

- Higher yields of aromatic chemicals and fuels v. fermentation
- Competitive economics at commercial scale
- Feedstock flexibility: Converts water-soluble oxygenates to drop-in products
BTX Demonstration Production

BioForming Process
- Aromatics output: ~35k – 40k L/yr (25-30T/yr)
- Commercial scale catalyst
- Products
  - Aromatic Chemicals
  - Jet Fuel (Synthetic Aromatic Kerosene)
  - Gasoline

BTX Separation
- Isomerization and transalkylation
- Capability to now produce benzene, toluene and mixed xylene streams

Crystallization Capacity to Produce Bio PX
- Purification of mixed xylenes to 99.7+% para-xylene
- >500 kg/month bio PX production
BTX Demonstration Production

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<tr>
<th>Carbon Number vs. Product</th>
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<td>Aromatic chemicals (BZ+PX)</td>
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<td>Aromatic Jet Fuel</td>
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<td>Diesel blendstock</td>
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Virent capable of making multiple products from Bioreformate stream
Bio-PET Supply Chain

*Drop-in to existing supply chain*

- **Biomass** → **Ethanol** → **Ethylene** → **Ethylene oxide** → **Ethylene glycol**
- **Natural Gas** → **Ethane** → **NGL**
- **Crude Oil** → **Naphtha**
- **Reformer** → **Cracker**
  - **Ethylene** → **Ethylene oxide** → **Ethylene glycol**
  - **Pygas** → **BTX** → **PX** → **PTA**

PTA = purified terephthalic acid; produced from PX and raw material for PET

**Biomass** → **Reformate** → **BTX** → **PX** → **BioFormPX™**

PET = polyethylene terephthalate, used in packaging and fibers applications

Virent’s Drop-in Bio-benzene
Strong Foundation for Derivatives

Virent Technology

Specialty Chemicals & Pharma

End-Use Markets:
- Surfactants
- Personal Care
- Consumer Goods
- Packaging
- Construction
- Textiles
- Furniture
- Automotive

CH₃CH₂OH → C=CH₂

CH₃CH₂OH → CH₃CH =CH₂

CH₃CH₂OH → CH₃C=CH₂

CH₃CH₂OH → CH₃C=CCH₃

CH₃CH₂OH → CH₃C=CH₂

End-Use Markets:
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- Automotive
Virent Products Provide Significant Reduction in Carbon Footprint

Example LCA: Small Commercial Plant Using Ethanol as Feedstock

LCA analysis conducted by Virent and third party LCA consultant.
Providing the Foundation for a Renewable Future

**Fuels**
- Renewable backyard torch fuel
- Renewable white gas

**Paraxylene**
- Polyester – fleece & performance clothing
- Non-woven polyester matting – sleeping bag

**Aromatic Solvents**
- Solvents for coatings
- Carrier – Insect repellant treatment for clothing (permethrin)

**Toluene**
- DEET – insect repellant
- Urethanes – sleeping pad

**Benzene**
- Nylon – sleeping bag, tent
- Phenol – polycarbonate – flashlight lens & sunglasses
- Styrene – SBR – boot soles
- Styrene –for ABS – camera body
- Building block – sun screen ingredients

Find the early adopters to build case for scaling
Historical Commodity Pricing
Indexed Monthly Pricing

Data Sources: U.S. Energy Information Administration and USDA
Building Your Commercial Case

- **Power of external partners**
  - Long journey from raw material to end product – Supply chain support required!
  - Small companies need big strategics to advance process – knowledge, dollars and capability
  - Advantage if burden of go forward plan shared across multiple parties

- **Research and development focused on key commercial metrics**

- **The challenge of early premium pricing**
  - Appetite for volume at high premium challenged
  - Accounting approach on early volumes would be useful
  - Find the early adopters with a reason to build sustainability story

- **The interest is there, but action takes time – Be patient**