Renewable Route to Acrylic Acid

Platts 2nd Annual Renewable Chemicals
BioAcrylic Acid Scaling Up – Current Experience
Objective – Develop an Industrial-Scale Process to Cost-Effectively Produce Acrylic Acid from Sugar
Dow Chemical-OPXBiO Strategic Partnership

**Faster, Lower-Risk, Shared-Cost Development and Commercialization**

- **Dow**
  - Largest US producer of petro-acrylic and derivatives
  - Demonstrated capability to develop recovery technology and applications
  - Committed bio-based strategy and investments

- **OPXBiO**
  - Unique biocatalyst development capability
  - Multiple products in development

- **BioAcrylic joint development agreement**
  - Joint funding and work to demonstrate BioAcrylic process
  - Intent to jointly commercialize

Sugar Feedstock → Microbe & 3-HP Bioprocess → BioAA Conversion Process → Commercial Plant → Channel to Market
Dow provides a diversified, industry-leading portfolio of technology-based products and solutions to customers in approximately 160 countries worldwide.

- More than 5,000 products manufactured at 188 sites in 35 countries with 2011 sales of $60B.
- 50,000 employees worldwide.
Dow Performance Monomers

- **Acrylic Acid & Acrylates**
  - GAA, BA, EA, 2 EHA, MA
  - Acrylic coatings, water treatment, detergent additives, adhesives, super absorbent polymers

- **Methacrylates**
  - MMA, GMAA
  - Acrylic sheet and resins, petroleum additives, plastic additives, electronic displays

- **Specialty Monomers**
  - Hydroxies, GMA, BMA
  - Automotive and industrial coatings, printing inks, and powder coatings

- **Vinyl Acetate Monomers**
  - VAM
  - Acrylic coatings, fibers, adhesives
Why Is This Project Important to Dow?

- Acrylic monomers are key strategic building blocks for several of Dow’s market-facing businesses
  - coatings, personal care, packaging, building and construction
- Creating differentiated, sustainable product offerings for our customers is a top Dow priority
- Dow is interested in cost-effective, renewable alternatives to conventional petroleum-based feedstocks
- This project is an opportunity to commercialize a differentiated, bio-based acrylic acid product based on a fermentable sugar feedstock
Existing $8+ Billion Growing Global Market

Customers interested in renewable alternative

Acrylic Markets %

- Diapers: 28%
- Coatings: 24%
- Adhesives: 5%
- Water Treat: 5%
- Textiles: 6%
- Detergents: 10%
- Other: 22%
Customers are asking for renewable options
• Improved sustainability / carbon footprint
• Increased consumer interest in “green” products
• Feedstock flexibility

Source: SRI Feb 2011
BioAcrylic Acid Process Technology

Fermentation

• Dextrose (corn) or sucrose (cane)
• Genetically engineered E-Coli organism optimized via OPXBIO EDGE™ Technology Platform

3-HP Recovery

• Biomass Kill & Removal
• Water Removal and Recycle

Conversion to Acrylic Acid

• 3-HP Dehydration to Acrylic Acid
• Acrylic Acid Purification

J. Repman 11/2/11
OPXBIO Strategy

Grow a Large, Global, Profitable & Highly Valued Renewable Chemicals Company

**Renewable Chemicals**
- Portfolio of direct replacement chemicals
- Penetrate multi-billion dollar existing markets

**Leading EDGE Technology**
- Rapid, development of efficient bio-processes
- Build broad product portfolio faster

**Strategic Development Partners**
- Leveraging partner capital & capabilities
- Achieve commercial faster with less investment

**Commercial Joint Ventures**
- Leveraging partner capital & capabilities
- Capture higher value for OPXBIO
OPXBIO EDGE™ Technology Platform

Efficiency Directed Genome Engineering

Massively Parallel Genetic Manipulations

Quantitative Experimental Design

Comprehensive & High Resolution Parallel Processing
**Conventional Microbial Pathway Engineering**

Create **random and unknown** genetic variants in microbe population

Test **population and select better performing microbes**

Repeat to directionally evolve optimized microbe

**EDGE Microbe Engineering**

Create **specific and known** genetic variants across entire microbial genome

Test each genetic variant and **analyze performance**

Design **comprehensive, rational strategy** and construct optimized microbe
OPXBIO EDGE™ Technology for BioAcrylic

The Technology EDGE™ for BioAcrylic
lower costs, faster time to market

1. Genetically Modify the Microbes
   Turn off and on various metabolic pathways; tag and track every change to each microbe.

2. Design & Run Quantitative Experiments
   Rapidly and simultaneously test millions of modified microbes in the lab.

3. Evaluate Microbes
   Analyze performance of all the microbes; determine how genetic changes impact performance.

4. Design Microbe
   Use data from evaluation to design microbe with specific characteristics and performance.

5. Test & Optimize Designed Microbe
   Test designed microbe in a lab and evaluate performance against goals; optimize process and microbe.

6. Produce 3HP
   High-performing microbes released to production-level fermenter. Microbes turn sucrose and dextrose into 3HP.

7. Recover 3HP
   Collect 3HP; remove any by-products.

8. Analyze & Optimize
   Measure 3HP yield and analyze the resulting by-products; optimize 3HP production by improving microbes (EDGE) or fermentation process.

9. Produce BioAcrylic
   Convert 3HP into BioAcrylic

Send microbes to production 70% faster with EDGE.
BioAcrylic Acid Downstream Process

Fermentation

3-HP Recovery

Conversion to Acrylic Acid

Development Highlights

- Screening tests completed on >10 different processing schemes
- Scale-up validation in progress (batch and continuous lab-scale units)
- Developmental samples available 4Q 2012
Key Challenges - Sugar Price Volatility

Sugar prices will strongly influence bio acrylic acid market penetration

**Challenges**

- Potential linkage to fuel prices
- Weather/seasonal impacts
- Feasibility of cellulosic sugar alternatives
Key Challenges - Impact of Shale Gas

Shale gas availability in U.S. will strongly influence long term conventional feedstock prices

Challenges

- Impact on conventional acrylic acid economics
- Regional differences

Historical U.S. Natural Gas Prices
Key Challenges – Right Sizing of Plant Investments

Challenges

• Capacity planning to meet customer demands
• Achieving economy of scale vs. overbuilding
• Feedstock selection
• Location / Integration options
– Dow and OPX are jointly developing a new industrial-scale process for production of acrylic acid from sugar
– Excellent progress made on organism development, fermentation and downstream process scale-up
– Anticipate commercialization in 2014-2016 timeframe