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Section 1
Background and Introduction
New technology occasionally emerges with potential for significant economic benefits and job creation

Biotechnology has transformed the U.S. agricultural sector through genetically modified seeds that:
- improve yields
- increase tolerance to damaging factors such as drought, heat, and cold
- fight pests by internally producing pesticides
- resist weeds by providing herbicide tolerance

Biotechnology is also enabling the emergence of a renewable chemicals and materials industry, with products that offer even greater potential economic benefits
- Emerging technologies enable conversion of cellulose to sugars that serve as cost effective feedstocks for chemicals and polymers, preempting the food-versus-fuel debate
- DuPont, Abengoa, and POET are among the U.S. companies currently building commercial scale cellulosic sugar manufacturing plants
- Biomass gasification coupled with conventional catalysis is another route to renewable chemicals and materials

Nexant estimates the value of the global renewable chemicals and materials market to be approximately $2.5 billion (~1.2 million metric tons) in 2012, excluding oleochemicals
Section 2
Study Objectives
Study Objectives

Objectives

The primary objectives of this white paper are to:

- Estimate the potential for U.S. bio-based chemicals and materials
- Assess the competitiveness of bio-based chemicals and materials versus traditional petrochemicals and the competitiveness of the United States compared to other countries
- Investigate whether industry development is being constrained by the reluctance to finance first of a kind commercial operations, suggesting a need for a public/private effort to de-risk these investments

It is important to note that U.S. renewable chemicals potential has been based on demonstrated technology, but the conclusions estimate the upside assuming technology improvements over the next 5 to 10 years
Section 3
Renewable Chemicals Value Chain
and Cost Competitiveness
Renewable Chemicals Value Chain

Feedstocks
- Corn
- Sugar
- Switchgrass
- Hybrid Poplar
- Corn Stover
- MSW

Conversion Technologies
- Cellulosic Hydrolysis
- Genetically Modified Fermentations
- Biomass Gasification
- Thermochemical and Catalytic Transformation

Chemicals/Plastics
- C1
- C2
- C3
- C4
- Aromatics
- Vegetable Oils
- Others

Fabrication Technologies
- Injection molding
- Blow molding
- Thermoforming

End Products
- Packaging
- Automotive
- Electronics
C2 Renewable Chemicals Cost Competitiveness

Ethylene Competitive Costs
(Cost of Production Plus 10% Return on Investment)
C3 Chemicals

Renewable Chemicals Value Chain and Cost Competitiveness

Raw Text Start

Crude Oil
  → Propylene
    └── Propylene Oxide
        └── Unsaturated Polyesters (fiberglass composites)
            × Auto Patch Compounds, Furniture Parts, Boats, Fibers
            × Foams, Coatings, Lacquers, Sports Equipment, Shoes

Polyols
  → Polyurethane
    × Auto Steering Wheels, Knobs, Auto Grills, Pipe, Film, Shirt Packages, Strapping, Rope & Twine

Polypropylene
  × Indoor/Outdoor Carpets, Matting

Isopropanol Alcohol
  → Acetone
    → Methyl Methacrylate
    × Plastics, Signs, Plexiglass, Paints, Tail-light Lenses, Lighting Panels
    × Coatings, Solvents, Cosmetics, Health Care

Oxo-Alcohols
  → Plasticizers
    × PVC Plastics
    × Rain Coats, Inflatable Toys
    × Solvents

Acrylonitrile
  × Acrylic Resins
    × Lenses, Light Fixtures, Domestics, Coatings

Polyacrylonitrile
  × Acrylic Fiber
    × Carpets, Sweaters, Draperies, Dresses, Coats

Cumene
  → Phenol
    × Phenol Resins, Nylon Fibers, Solvents

Miscellaneous
  × Coatings, Adhesives, Super Absorbent Polymers, Detergents

Acrylic Acid, Acrylates
  × Coatings, Adhesives, Super Absorbent Polymers, Detergents

Acrylic Resins
  × ABS Resins
    × Phones, Auto Parts, Bathubs

Modacrylic Fiber
  × Coatings, Synthetic Furs

Miscellaneous

A02175 USDA Renewable Chem
C3 Renewable Chemicals

Green Routes to Propylene

- Corn (Sugar Fermentation) → Ethanol Dehydration → Dimerization → Metathesis → Propylene (Case 1)
- Biomass (Gasification) → Butanol Dehydration → Metathesis → Propylene (Case 2a & 2b)
- Corn (Sugar Fermentation) → Propanol Dehydration → Metathesis → Propylene (Case 3)
- Vegetable Oil (NExBTL® or Ecofining™) → Propane Dehydrogenation → Propylene (Case 4)
- Vegetable Oil (Fluid Catalytic Cracking (FCC) Unit) → Recovery → Propylene (Case 5)
- Biomass (Gasification) → Methanol Synthesis → Methanol to Propylene → Propylene (Case 6)

- Commercial
- Early Stage Commercial
- Developmental
C3 Renewable Chemicals Cost Competitiveness

Comparison of Bio-Propylene with PDH
(COP plus 10% ROI, $ per mt)
C4 Chemicals

Crude Oil -> C4

- Butadiene
  - Styrene-Butadiene Rubber -> Tires, Footwear
  - Polybutadiene Rubber -> Tires, Golf Balls
  - Styrene-Butadiene Latex
  - ABS Resins -> Automotive Parts, Spas, Appliances, Electronics
  - Chloroprene Rubber
  - Nitrile Rubber
  - Miscellaneous

- Isobutylene
  - Synthetic Rubber
    - Additives
    - Miscellaneous

- Butylene Oxide
  - Unsaturated Polyesters
    - Foams, Insulation

- Maleic Anhydride
  - Unsaturated Polyesters
  - Alkyd Resins

Miscellaneous
- Tires, Golf Balls
- Carpet Backing, Adhesives
- Gaskets, Seals, Hoses
- Shoe Soles, Kitchen Mats, Hoses, Gaskets

Synthetic Rubber
- Auto Tires, Plastic Compounds

Miscellaneous
- Tires, Footwear
- Automotive Parts, Spas, Appliances, Electronics
- Silicone Rubber
- Gaskets, Seals, Hoses
- Shoe Soles, Kitchen Mats, Hoses, Gaskets
C4 Renewable Chemicals under Development
Renewable Adipic Acid Versus Conventional Technology

- Stand-Alone Adpic Acid Plant
- Plant Integrated Upstream with Benzene

Dollars per Ton

<table>
<thead>
<tr>
<th></th>
<th>Net Raw Materials</th>
<th>Net Utilities</th>
<th>Fixed Costs</th>
<th>Depreciation</th>
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<tr>
<td>Boric Acid</td>
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<tr>
<td>Rennovia 20 kta</td>
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<tr>
<td>Rennovia 135 kta</td>
<td></td>
<td></td>
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<tr>
<td>Boric Acid</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

00101.0013.4103_Figs_8.xlsx
Aromatics: Xylenes

- Xylene
  - o-Xylene
    - Phthalic Anhydride
    - Plasticizer D.O.P.
    - Plastic Products
  - m-Xylene
    - Alkyd Resins
    - Auto Parts, Coatings, Furniture
    - Solvents and Miscellaneous
    - Polyester Polyol
    - Urethanes
    - Foams, Insulation
  - p-Xylene
    - Isophthalic Acid
    - Alkyd Resins
    - TV Parts
    - Dyes
    - Adhesives
    - Sovlents
    - Polyester Fibers for Apparel, PET Resins for Bottles, Tapes and Film
    - Unsaturated Polyesters, Fiberglass Structures for Industry, Infrastructure, Sports, Vehicles, Boats
  - Terephthalic Acid / Dimethyl Terephthalate
    - Polyamide Resins
    - Polyester Polyol
    - Urethanes
    - Foams, Insulation
    - Auto Parts, Coatings, Furniture
    - Unsaturated Polyesters, Fiberglass Structures for Industry, Infrastructure, Sports, Vehicles, Boats
    - Polyester Fibers for Apparel, PET Resins for Bottles, Tapes and Film
Aromatic Renewable Chemicals Cost Competitiveness: *para*-Xylene

*para*-Xylene Competitive Costs, 1Q2014

- Anellotech
- Gevo
- Micromidas
- Virent
- Petro

pX price
Oleochemical Market Structure

RAW MATERIALS
- FATS/OILS
  - TALL OIL
  - TALLOW
  - COCONUT OIL
  - PALM OIL
  - PALM KERNEL OIL
  - OTHERS

BASIC OLEOCHEMICALS
- FATTY ACID
- FATTY NITRILES
- FATTY ACID METHYL ESTERS
- FATTY ALCOHOLS
- GLYCEROL

SELECTED DERIVATIVE OLEOCHEMICALS
- ESTERS
- DIMER ACIDS
- SLATS
- OZONOLYSIS PRODUCTS
- INGREDIENTS IN MANY FORMULATIONS
- FATTY NITROGEN COMPOUND (E.G., AMINES)
- FATTY ALKANOLAMIDES
- FATTY ALCOHOL SULFATES AND ETHOXY SULFATES
- ALKYD RESINS EMULSIFIERS
Section 4
The Impact of Shale Gas and Shale Oil
Development of shale resources has decoupled the price of natural gas (and ethane a key ethylene feedstock) from oil (and naphtha, another key petrochemical feedstock of all primary petrochemicals)

Greatest impact is on ethylene cost competitiveness since ethane is expensive to ship (use LNG tankers)

There is also a major direct impact on U.S. propylene, butylenes and aromatics supply as ethane cracking does not produce these coproducts while naphtha cracking does

While shale gas also produces substantial other gas liquids like propane and butane and will transform the U.S. from a traditional importer of these gas liquids to a major exporter, there is less decoupling of U.S. propane/butane prices from global prices due to the relative ease of shipping LPGs

The impact of shale oil on the aromatics business is still to be determined:

- Shale oils are generally lighter than many of today’s imported crude oils
- U.S. refineries, which been negatively affected by ethanol blending, will be reconfigured to optimize product mixes.
- Some feel it will benefit aromatics production, others that it will limit aromatics production potential
Section 5
U.S. Cost Competitiveness Versus Other Regions
The U.S. is cost competitive against primary regional competitors

Bio-feedstock availability and cost:

- The estimated cost plus return on investment for cellulosic sugars in the United States is comparable to that for conventional corn sugars.
- The United States is at a cost disadvantage versus Brazil and Southeast Asia with regard to the cost of biomass (roughly $40 per metric ton disadvantage). However, this cost disadvantage is offset by the superior distribution infrastructure in the United States versus Brazil and Southeast Asia.

Accessible market:

- United States has a $275 billion petrochemical market.
- Brazilian petrochemical industry is estimated to be $75 billion, of which $15 to $20 billion is imported(1). The fact that Brazil is such a large importer is illustrative of its underlying competitiveness.
- Southeast Asian petrochemical business is smaller than Brazil’s.

Technology:

- The U.S. is the unquestionable leader in renewable chemical technology. This technology advantage is ours to exploit or to allow it to be used in other countries offering greater incentives.

(1) Derived from Potential de Diversificacao da Industrial Quimica Brasileira, BNDES, June 2013.
Section 6
U.S. Renewable Chemicals Potential
### U.S. Renewable Chemicals Market Potential

**U.S. Renewable Chemicals/Materials Market Potential**

*(Thousand metric tons)*

<table>
<thead>
<tr>
<th></th>
<th>2012</th>
<th>2017</th>
<th>2022</th>
<th>Growth to 2022</th>
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<tr>
<td><strong>C₂</strong></td>
<td>0</td>
<td>0</td>
<td>1,000</td>
<td>1,000</td>
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<tr>
<td><strong>C₃</strong></td>
<td>40</td>
<td>100</td>
<td>300</td>
<td>260</td>
</tr>
<tr>
<td><strong>C₄</strong></td>
<td>100</td>
<td>150</td>
<td>400</td>
<td>300</td>
</tr>
<tr>
<td><strong>Aromatics</strong></td>
<td>&lt;10</td>
<td>100</td>
<td>500</td>
<td>495</td>
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<tr>
<td><strong>Specialty Oils</strong></td>
<td>20</td>
<td>400</td>
<td>1,000</td>
<td>980</td>
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<tr>
<td><strong>Total</strong></td>
<td>165</td>
<td>750</td>
<td>3,200</td>
<td>3,035</td>
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## U.S. Renewable Chemicals Market Potential

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<thead>
<tr>
<th>Renewable Chemical</th>
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<th>2022</th>
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<tr>
<td>C₃</td>
<td>660</td>
<td>1,980</td>
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<tr>
<td>C₄</td>
<td>825</td>
<td>2,200</td>
</tr>
<tr>
<td>Aromatics</td>
<td>150</td>
<td>750</td>
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<tr>
<td>Specialty Oils</td>
<td>1,770</td>
<td>4,420</td>
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<tr>
<td>Others</td>
<td>95</td>
<td>190</td>
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<tr>
<td><strong>Total</strong></td>
<td>3,500</td>
<td>19,400</td>
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### U.S. Renewable Chemicals Market Potential

<table>
<thead>
<tr>
<th></th>
<th>2017 Fixed Investment (MM$)</th>
<th>2017 Value Added (MM$/yr)</th>
<th>2022 Fixed Investment (MM$)</th>
<th>2022 Value Added (MM$/yr)</th>
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<tr>
<td>C₂</td>
<td>0</td>
<td>0</td>
<td>250(1)</td>
<td>660</td>
</tr>
<tr>
<td>C₃</td>
<td>565</td>
<td>210</td>
<td>1,420</td>
<td>630</td>
</tr>
<tr>
<td>C₄</td>
<td>1,130</td>
<td>200</td>
<td>2,040</td>
<td>530</td>
</tr>
<tr>
<td>Aromatics</td>
<td>490</td>
<td>125</td>
<td>1,840</td>
<td>625</td>
</tr>
<tr>
<td>Specialty Oils</td>
<td>200</td>
<td>240</td>
<td>455</td>
<td>600</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>2,385</strong></td>
<td><strong>775</strong></td>
<td><strong>6,005</strong></td>
<td><strong>3,045</strong></td>
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</table>

(1) This assumes retrofit of existing ethanol plants for the production of ethylene.
Section 7
Environmental Benefits
Environmental Benefits of Renewable Chemicals

Primary benefits:

- Reducing carbon dioxide and other “greenhouse gas” emissions related to climate change
- Reducing other pollutant emissions associated with supply, processing, and use of petroleum, natural gas, coal, and petrochemicals
- And, if biodegradable products are produced:
  - Reduced risks to animals of plastics litter hazards
  - Reduced risks of non-biodegradable detergent, paint, solvent, and other chemical emissions harming the ecosystem

There are three types of bio-renewable products:

- Chemicals or polymers that are completely identical to the incumbent petrochemically-based products (i.e., drop-ins), which are generally not biodegradable
- Biodegradable, but also “synthetic” substitutions that are compositionally different from the petrochemical versions, such as PLA or PHA polymers, or viscose rayon fibers
- Materials that are completely biologically-derived and are naturally biodegradable, such as wood flour fillers or natural fiber re-enforcements in plastics, etc.
Section 8
Obstacles to Development and De-risking
Obstacles to Renewable Chemicals Development in the U.S. and Derisking

The greatest obstacle to development of the renewable chemicals and materials industry is obtaining capital for commercialization of first-of-a-kind technologies.

Beyond outright loans, Nexant sees three potential approaches for risk mitigation to facilitate development of renewable chemicals in the United States:

- **Investment tax credits** – can be applied to the entire sector or selected broad segments
- **Loan guarantees** – requires “picking winners” from among the many contending companies in a segment
- **Production credits** – would make much broader judgments on the segments of the renewable chemicals industry most likely to succeed and provide production credits for those products, with time limit provisions, to assist in the introduction of the best of the technologies. The time limits would ensure that once the processes are commercialized and are economically viable, the production credits would expire
Section 9
Conclusions
Renewable Chemicals Represent A Substantial Opportunity for U.S. Agriculture and Industry

The base case market size and value added presented above are based on current technology.

Technology advances in the sector have been dramatic and an upside potential model has been developed, using historical technology advances in agricultural biotechnology, with similar technology enablers.

The model results suggest the potential could be six times the levels in this report:

- Market size: Almost 20 million metric tons per year in 10 to 15 years
- Over 100 thousand jobs created
- 18 billion dollars in annual value added created