CHEMSYSTEMS
PERP PROGRAM

Plastics From Trees

PERP 2011S4

Report Abstract
March 2012

Nexant

Plastics From Trees

March 2012

Eric Bober

CHEMSYSTEMS

PERP PROGRAM

Nexant

www.chemsystems.com

The ChemSystems Process Evaluation/Research Planning (PERP) program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. PERP reports are available as a subscription program or on a report by report basis.

Nexant, Inc. (www.nexant.com) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, ChemSystems has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. Nexant has its main offices in San Francisco (California), White Plains (New York), and London (UK), and satellite offices worldwide.

For further information about these reports, please contact the following:

Dr. Alexander Coker, Global Manager, PERP Program:	phone: + 44-207-950-1570, e-mail: acoker@nexant.com
Mrs. Heidi Junker Coleman, Global Support Manager, Multi-Client Programs	phone: + 1-914-609-0381, e-mail: hcoleman@nexant.com
Dr. Y. Larry Song, General Manager, Nexant China	phone: +86 21 6182 6791, e-mail: ylsong@nexant.com

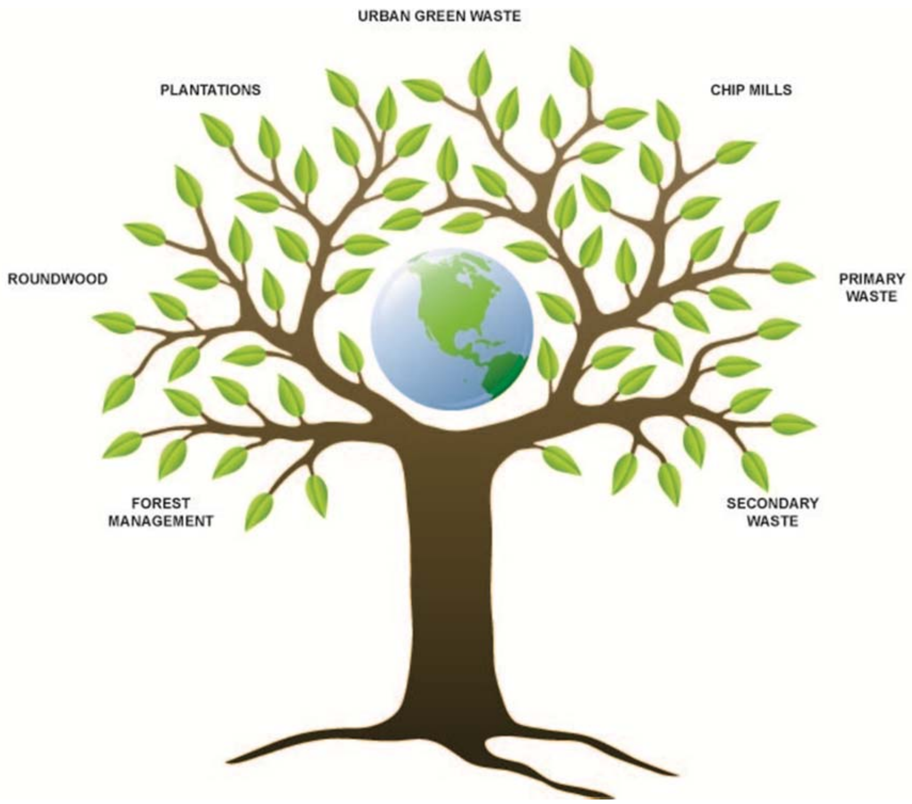
INTRODUCTION

The objective of this report is to assess the technological and economic potential of various routes to produce Plastics From Trees. Nexant seeks to illuminate the key issues surrounding a host of practical commercial questions, such as:

- Are technologies to convert tree-based feedstocks to plastics ready for prime time?
- Can plastics produced from woody feedstocks be cost-competitive with traditional petroleum-based products?
- Should plastics producers using traditional feedstocks and technologies feel threatened?

Trees are a prolific and renewable source of raw materials for a host of conversion processes. Trees have been used as raw materials for centuries (e.g., pulp and paper, building materials). The next stage in this evolution of trees and tree-based raw materials is being explored in a host of value-added products, including combined heat and power, liquid biofuels, and renewable chemicals, such as renewable plastics and intermediates.

Trees absorb carbon dioxide from the atmosphere as they grow and provide a wide range of feedstocks, as illustrated below:



Technologies to tap the chemical precursors locked within biomass feedstocks (such as from trees) have improved over time. Products and pathways explored in this report include the following:

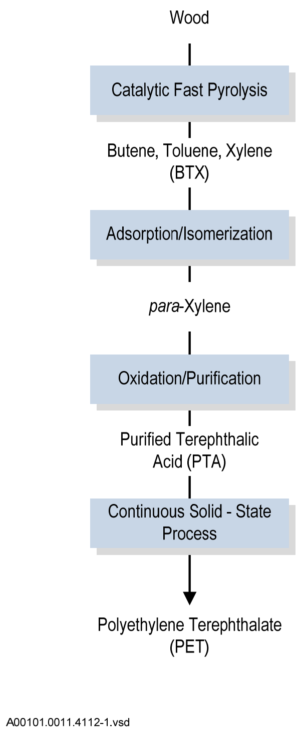
- **Catalytic Fast Pyrolysis** of wood to the key aromatic compounds, Benzene, Toluene, and Xylene (BTX), with generation of *para*-xylene from the BTX and subsequent conversion to purified terephthalic acid (PTA) and polyethylene terephthalate (**PET**).
- **Gasification** of woody biomass to syngas with subsequent synthesis of methanol, plus methanol to propylene and polymerization to **polypropylene**.
- **Enzymatic hydrolysis** of wood to ethanol, with subsequent catalytic dehydration to ethylene and production of high density polyethylene **(HDPE**).
- **Cellulosic plastics** pioneered by Eastman (i.e., "Tenite™ Cellulosics"), which find commercial application in tool handles, toothbrushes, golf putters, alternatives to urethanes, etc.

These are compared to traditional fossil-fuel-based routes.

TECHNOLOGY ANALYSIS

Catalytic Fast Pyrolysis to PET (Tree-Based PET)

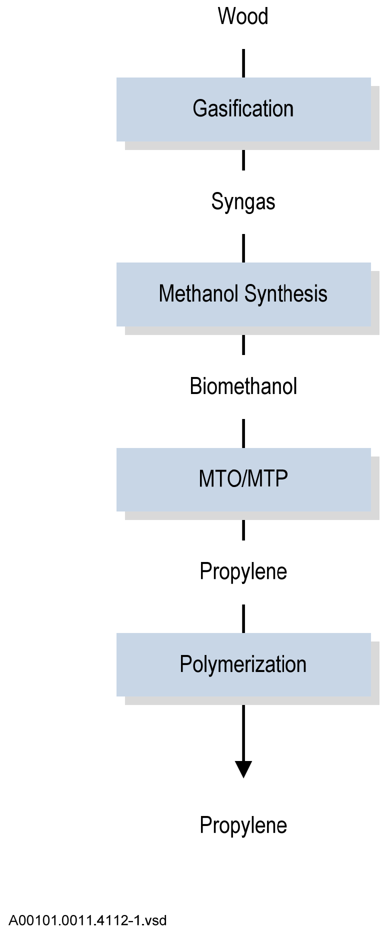
Anellotech's innovative Catalytic Fast Pyrolysis technology and subsequent processing to produce a renewable, wood-based *para*-xylene (*p*-X), from which tree-based purified terephthalic acid (PTA) is synthesized; PTA is a key ingredient (along with monoethylene glycol) used to make PET:



The tree-based process only differs from the conventional petroleum-based process in the first step, using the CFP™ process to generate the BTX from trees, instead of from petroleum-based naphtha at an oil refinery.

Gasification to Polypropylene (Tree-Based Propylene)

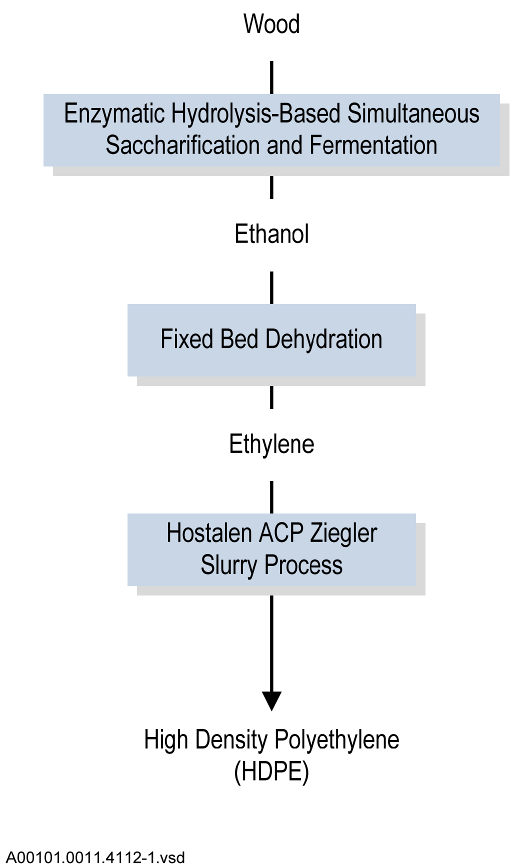
Gasification of woody feedstock generates syngas, which is subsequently converted to methanol via the well-known Methanol-to-Propylene (MTP™) process, and polymerization of the propylene to polyolefin, as shown below:



This process has multiple steps but is rather straightforward, with each of the technologies having been proven commercially.

Enzymatic Hydrolysis in SSF to HDPE (Tree-Based HDPE)

The simultaneous saccharification and fermentation (SSF) of wood chips to ethanol using enzymatic hydrolysis to generate sugars from wood chip feedstock is followed by the dehydration of ethanol to ethylene, which is subsequently polymerized to HDPE.



The pathway assessed here begins with technologies that have been long studied to extract sugars from cellulosic feedstock. The subsequent processes to ferment those sugars to ethanol, from which ethylene and HDPE are derived, are in practice commercially around the world.

Cellulosic Plastics

Eastman Chemical Company was established as an independent supplier of chemicals for their photographic processes. They established two major platforms – organic chemicals and acetyls. Leveraging their knowledge of acetyl chemistry, Eastman began making compounded cellulose acetate, literally "Plastics From Trees," in 1929; soon thereafter, this was sold under the Tenite™ cellulosics trade name[i].

Tenite™ cellulosics comprise a family of products grouped in three major categories, as shown below. Early applications of Tenite™ included several iconic consumer products, such as the first football helmets, early TVs, radios, and telephones, Duncan yo-yo's, and others.

- Tenite™ Acetates
- Tenite™ Butyrates
- Tenite™ Propionates

1. uspto.gov

The process to make Tenite™ starts with softwood trees, which are pulped. This pulp is used to make a cellulose ester which is then mixed with plasticizers and other additives to produce plastic pellets, which are converted into plastic products.

ECONOMIC ANALYSIS

Cost of production estimates have been derived for trees to plastics routes and compared to their traditional, fossil-fuel-based competitors:

- BTX from wood chips via Catalytic Fast Pyrolysis
- *para*-Xylene from tree-based BTX
- Purified Terephthalic Acid (PTA) from tree-based *para*-xylene
- PET bottle chip resin from tree-based PTA
- Syngas from wood chips via gasification
- Methanol from tree-based syngas
- Polymer grade propylene from tree-based methanol via Lurgi's Methanol-to-Propylene
- Polypropylene from tree-based propylene
- Ethanol from wood chips via enzymatic hydrolysis in simultaneous saccharification and fermentation
- Ethylene from tree-based ethanol
- HDPE bimodal/multimodal film from tree-based ethylene

(A cost of production estimate for Eastman's proprietary Tenite™ process is not shown, although the process is described and yields are discussed.)

The tree-based production costs are compared to primary current fossil-fuel-based routes to identify which renewable pathways are competitive today. Cost of production estimates for the following fossil-based routes have been developed:

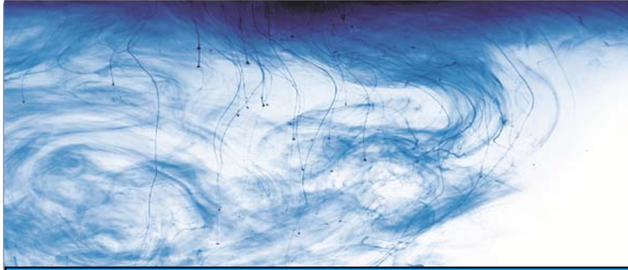
- *para*-Xylene from naphtha hydrotreating, reforming, adsorption/EB isomerization, TDP, TA
- PET bottle resin in a continuous solid state process
- Polymer grade propylene from deep catalytic cracking
- Ethylene from steam cracking of light naphtha (moderate severity)
- HDPE bimodal/multimodal film from steam cracked light naphtha

All cost tables given in this report include a breakdown of the cost of production in terms of raw materials, utilities direct and allocated fixed costs, by unit consumption and per metric ton and annually, as well as contribution of depreciation to arrive at a cost estimate (a simple nominal return on capital is also included).

COMMERCIAL OVERVIEW

There is a large and attractive potential to displace petroleum-based plastics such as PET, polypropylene, and polyethylene in existing markets, with bio-based plastics made from wood biomass feedstocks. Many finished products made from these plastics find their way into consumer product packaging, where marketing and environmental consciousness are important drivers of market share and financial performance. Well-known consumer product companies currently using bioplastic include some of the biggest names in consumer products, such as AT & T, Coca-Cola, Danone, Ford, Heinz, Johnson & Johnson, Mazda, Nestle, PepsiCo, Procter & Gamble, Shiseido, Stonyfield Farms, and Toyota.

- Demand for these end-use plastics are given and discussed.
- Ultimately, it is the potential for penetration into these traditional plastics markets with equivalent, tree-based substitutes that have been explored in this PERP report from Nexant.



Nexant, Inc.

San Francisco
London
Tokyo
Bangkok
Bahrain
New York
Washington
Houston
Phoenix
Madison
Boulder
Dusseldorf
Beijing
Shanghai
Paris

www.chemsystems.com