Case Study:
Product and Process Design Methodologies for Engineering the Forest Biorefinery
The “perfect storm” of strengthening dollar, rising energy prices, rising fibre costs, small older mills….
Some Forestry Industry Survival Strategies

- Go for Survival in Commodities, or Make the Most of Our Existing Industry
- Buy/Build Elsewhere In Emerging Markets, or Make the Most of Our Pulp and Paper Competency in Emerging Economies
- Diversify Core Business with Marketing & Technological Partners, or Make the Most of Our Existing Value Chain by Migration to New Business Paradigms
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→ The Forest Biorefinery!
Forest industry strategists are talking about “revenue diversification” and industry transformation via the forest biorefinery.

...do forestry company executives know how to go about designing and implementing biorefinery?

How should we apply process systems engineering techniques to address the biorefinery, recognizing that it is an industry transformation?
Tembec Temiscaming: Forest Biorefinery?
Bio-Ethanol

- **Capacity:**
  - 18 million liters per year
- **Second largest industrial alcohol supplier in Canada**
- **High purity (95%) alcohol produced from a renewable resource**
- **Vinegar**
- **Mouth washes**
- **Pharmaceutical products**
- **Only “true” green ethanol producer in North America.**
Forest Biorefinery Definition

One forest biorefinery definition:

- full utilization of incoming woody biomass for the production of:
  - Wood products
  - Pulp and paper products
  - Energy
  - Chemicals

Another (more practical) forest biorefinery definition:

- Maximizing the economic value from trees
- Improved business model
- Corporate transformation…

The Challenge: Mitigating Risks, Improving Existing Core Business

Pulp & Paper Sector: Stalemate situation

Opportunity: Biorefinery

Identify & Mitigate risks

Technical

Economic

Commercial

Un clásico. Dos astros.
Objective of this Presentation

To present (certain) critical issues that should be considered by forestry companies seeking to identify promising biorefinery pathways based on biorefinery design activities, consulting activities, and pulp and paper company strategic planning leading to a proposed implementation strategy and multidisciplinary design methodology employing process systems engineering, for exploring the implementation of the forest biorefinery.
Presentation Outline

- Leading companies are implementing the forest biorefinery
- Key biorefinery concepts and definitions
- Biorefinery implementation strategy for forestry companies
- Overall design methodology for the forest biorefinery
- Some interesting process systems engineering approaches that we are exploring
Leading companies are implementing the forest biorefinery

- See 3 survey papers by Thorp, March-May 2008

Key biorefinery concepts and definitions

Biorefinery implementation strategy for forestry companies

Overall design methodology for the forest biorefinery

Some interesting process systems engineering approaches that we are exploring
NSE Biofuels Oy Ltd
Demonstration planned for Varkaus Mill (2008)
At Weyerhaeuser, we believe in releasing the potential in trees to solve important problems for people and the planet. The need for imaginative, sustainable solutions to the world’s challenges has never been greater.

We currently collaborate with several research universities, national laboratories and technology-based companies in research on conversion of forest products into ethanol and other biofuels. Our latest alliance with Chevron Corporation is another step toward finding innovative uses for cellulose fiber to help meet growing energy needs. We feel cellulosic biofuels will fill an important role in diversifying the nation’s energy sources.
R&D increased from 50 to 80 MM euros (March 2007)

PORTFOLIO DEVELOPMENT – BIODIESEL

Sustainable optimisation of gain from biomass base adds value

Forest biomass
- forestry
- harvesting
- assorting on site
- drying

Logs for wood products
Fibre wood for pulp and paper
Logging residue
  Small wood
  Stumps

Plywood
  Sawn timber
Pulp and Paper

Bio-diesel
  Heat
  On-site electricity

Bio-diesel is a natural extension for a company whose core business is adding value to wood raw material - primary fibres will remain in pulp and paper production
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Identifying the Right Biorefinery Configuration is Complex...

- **Biomass**
  - White wood
  - Bark/Forest Residues
  - Agri waste
  - MSW
  - Industrial waste
  - Energy crops

- **Processing**
  - Biochemical Transformation
    - Anaerobic Digestion
    - Fermentation
  - Biomass Pre-processing Technologies
    - Steam Explosion
    - Chemical Treatment
  - Thermochemical Transformation
    - Pyrolysis
    - Gasification
    - De-Polymerization
  - Chemical & Others
    - Lignin chemistry
    - Chemical Synthesis
    - Refomation
    - Others

- **Bio Products Markets**
  - Energy
  - Biofuels (Transportation)
  - Commodity chemical (Building Block)
  - Added Value chemicals (Specialty)
  - Materials
  - Pharmaceuticals / Nutraceuticals
**Definition: Building Blocks and Derivatives...**

- **Waste**
  - Chips Biomass
  - Pulp and Paper Mill
  - P&P Products

- **Co-products or wastes?**
  - Building Block
  - Derivative

- **Main Biorefinery Products to Market**
  - $$
  - $$

- **Reducing Volumes, Flexible Throughputs...**
- **Increasing Process Complexity**

**Main Biorefinery Products to Market**

- $$ Main Biorefinery Products to Market $$
Definition: Petrochemical Value Chains and Product Replacement

Biorefinery Platform
Example: Product Replacement in Mature Supply Chain...

Chips Biomass

Waste

Pulp and Paper Mill

Ethanol

Ethylene

PE

P&G Products

$\$  Main Biorefinery Products to Market  $\$$
Definition: Emerging Carbohydrate Platforms and Product Substitution
Example: Product Substitution in Emerging Supply Chain...

Chips Biomass → Pulp and Paper Mill → Lactic Acid → PLA → PLA Polymers

Waste

P&O Products

$\$$ Main Biorefinery Products to Market $\$$\$$
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Some Key Competitive Factors

Main competitive advantages for forestry companies:

- Access to biomass availability and harvesting know-how
- Existing infrastructure in close proximity to forest biomass
- Established SC for wood, pulp and paper products

Main competitive disadvantages for forestry companies:

- Lack of capital
- Lack of product development culture
- Lack of knowledge of product quality requirement, SC practices etc for new bioproducts
Some Lessons Learned from Our Case Studies Thus Far...

- Biorefinery **technology** will be critical for competitive position in the short-term, the **unique supply chain** will be critical for competitive position in the longer-term.
- In order to be competitive in the longer term: **product design**, before process design.
- Meet profitability targets for varying market conditions by designing for **manufacturing flexibility**.
- The key to success in the forest biorefinery will be through implementing “**knowledge-based manufacturing**” in conjunction with flexible manufacturing and advanced supply chain management.
Strategic Approach for Implementing the Biorefinery

Implementation: compete with all capital spending

Phase I
Lower Operating Costs:
- Replace fossil fuels at mill (natural gas, Bunker C), and/or
- Produce “building block” chemicals
- Lower risk technologies

Compete internally for capital

Phase II
Increase Revenues:
- Manufacture of derivatives
- Market development for new products
- Higher process complexity and technology risk
- Partners essential

Select the most sustainable product platform and partner(s)

Phase III
Improve Margins:
- Knowledge-based manufacturing and production flexibility
- Business flow transformation
- Product development culture
- Off-shoring, Outsourcing, etc...

Company culture transformation
SCM key to success

Strategic Vision: Phase III must determine Phase I
Strategic Approach for Implementing the Biorefinery

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Margins improvement is the goal

Strategic Vision: Phase III must determine Phase I
Phase I: Lower Operating Costs

- Generate more free cash flow (EBITDA), in competition with all other capital spending proposals
- The mill operation remains manufacturing-centric, i.e. produces a commodity and seeks to be a low-cost producer
- Seek to reduce biorefinery costs by identifying synergies with the existing mill:
  - Utilization of existing infrastructure to offset equivalent greenfield biorefinery capital cost
  - Exploitation of green credits
- Possible partnership with technology provider

Phase I Lower Operating Costs:
- Replace fossil fuels at mill (natural gas, Bunker C), and/or
- Produce “building block” chemical
- Minimum risk technologies
Is Cellulosic Ethanol the Right Product?

Bank of America Ethanol Forecast
(gallons in billions)

- Corn-Based Ethanol
- Cellulosic Ethanol

Alternative Energy report by Enc. K. Brown
Source: Renewable Fuels Association, National Biofuels Board, Bank of America Securities LLC estimates

Source: NREL - 2006
Ethanol Price Volatility: An Important Risk

Price volatility due to:
- Impact of crude oil and natural gas prices
- Changing balance between supply and demand
- Diverse feedstock types and their relative competitiveness
- Energy legislation – tax credits and incentives

In 4 months: Ethanol prices dropped by half…

How can companies stabilize margins in the context of volatility and uncertainty?

Source: Gulf Ethanol Corp
Biochemical Ethanol Technology

Building on Past Successes

State of Technology Estimates

- ≈4.2$/gal
- ≈2.2$/gal
- ≈0.6$/gal

Source: NREL - 2006
Should Biochemical Ethanol be Implemented Today?

Building on Past Successes

How can margins be stabilized?

July 2007 Scenario @ 3 $/gal

November 2007 Scenario @ 1.5 $/gal

Integrated large-scale BC/TC processing

Source: NREL - 2006
Implementing the forest biorefinery is about mitigating risk…

…and clearly ethanol represents a great opportunity, but also presents risks.

These can be mitigated as part of a forest biorefinery product design strategy, e.g.:

- What derivatives can be made from ethanol?
- What opportunities are there with by-product lignin?
- What manufacturing flexibility between products is required, including perhaps producing ethanol from cellulose?

Before implementing ethanol production facilities, know what product portfolio your company will ultimately produce…
Process-Centric and Product-Centric Design

“Towards a Product-Centered Chemical Industry - Rethinking the Role of R&D and its Interaction with Marketing and Business Strategy” FOCAPD (2004), and AIChE webcast (2004 – see link in background materials)

Chemical Engineering is moving from being process-centric to product-centric

Product centered: market trends → product specifications → components and subsystems → chemicals and materials → manufacturing systems design

George Stephanopoulos, MIT
Start With Phase II: Define your Product Portfolio

- Product Design first, Process Design second
  - Increase revenues by producing new “green” organic chemicals

- Determine promising product portfolios for your company using a market perspective
  - Which are technically feasible?
  - Secure the best partners for securing the value chain…
  - Examine the implied company transformation
Product Portfolio Identification

What products could we manufacture? e.g. NREL 2004

What products should we manufacture? e.g. Penner 2006

The most appropriate choice for your company

Innovation

Technology Push

Process-centric design

Market Pull

Product-centric design

Substitution

Replacement

Adaptation

Novel product
Phase III = Enterprise Transformation

- **Supply Chain Restructuring**, e.g., simplifying supply chains, negotiating just-in-time relationships, developing collaborative information systems

- **Outsourcing & Offshoring**, e.g., contracting out manufacturing, information technology support; employing low-wage, high-skill labor from other countries

- **Process Standardization**, e.g., enterprise-wide standardization of processes for product and process development, R&D, finance, personnel, etc.

- **Process Reengineering**, e.g., identification, design, and deployment of value-driven processes; identification and elimination of no value creating activities

- **Web-Enabled Processes**, e.g., online, self-support systems for customer relationship management, inventory management, etc.

- **Market-driven culture** to be established through a phased transformation
Argentina knock out rivals Brazil

Argentina beat Brazil 3-0 to set up an Olympic final against Nigeria in the men’s football competition.

Aguero celebrates scoring against Brazil in Beijing

Overall design methodology for the forest biorefinery

Some interesting process systems engineering approaches that we are exploring
Overall Biorefinery Design Framework

Product Design

- Promising Biorefinery Products
- Technology Strategy

Process Simulation

- LCA
- Advanced Thermal Pinch Analysis
- Large Block Analysis of Processes

Set of Preferred Biorefinery Configurations

MCDM

Preliminary Engineering

Process Design

- Supply Chain Management
- Reconciled Process and Economic Data
Coupling the Problem Context with the Design Approach

- The forestry executives we work with understand the story to this point in the presentation, but don’t understand PSE tool strengths and limitations.

- How can we apply PSE tools to create competitive advantage during the implementation of the sustainable biorefinery…?

- This is a great case study in product and process design – there is a race for forestry companies to identify novel and sustainable strategies, and secure quality partners as well as market strategies.

- What strategies best meet industry’s profitability requirements, and at the same time are sustainable?
Leading companies are implementing the forest biorefinery

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Product Design:
Which Biorefinery Sequence?

Individual Product Analysis
- Which replacement/substitution products should be considered?
  - Promising technologies
  - Product growth
  - Potential for competitive advantage with green product
  - Competitive manufacturing costs/existing value chain

Product family analysis:
- Creating added value along the value chain
- What are the competitive factors associated with the aggregated product family?

Product Portfolio:
- What potential new supply chain opportunities are there?
- Will a unique SC result, that can’t be achieved by others?

Partnership Selection:
- Who are the promising partners for the candidate product families?
- Do their corporate visions align with yours, i.e. implementing the biorefinery in partnership?

Risks?
Overall Product/Process Opportunities Methodology

**Partnership Screening**
*Opportunistic Identification*

**Market-based Assessment and Product Triage**
*Refined List of Opportunities*

**Potential Product Families**
*Preliminary Process Definitions*

- **Product 1**
- **Product 2**
- **Product 3**
- **Product 4**
- **Product 5**

- Market-based Criteria
- Process-based Criteria
- Techno-Economic Criteria

**Triage Analysis**

**Process Synthesis**

**Product Families**
Techno-Economic Analysis: Some Key Questions

- What are the available feedstocks, and emerging processes available to manufacture the set of targeted products? Other “show-stoppers”?
- Is there a competitive opportunity through partnership with innovation companies?
- How will biorefinery implementation enhance the competitive position of the core business of pulp and paper products?
- How can the capital cost of the biorefinery be reduced through existing mill infrastructure?
Data Processing and Data Reconciliation

Data Processing

Objectives
- Cleansed data
- Near steady-state detection
- Process trends

Process-Driven Cost Modeling
- Bottom-up approach to linking costs with process data
- ABC-like methodology for tracking resources consumption in mill

Process Data Reconciliation

Objectives
- Further improved data quality by making it consistent with an underlying process model

Operation regime distribution

Probability of occurrence %

Production cost $
Activity-Based Cost (ABC) Accounting

Mill wide data reconciliation

Process-Driven Cost Modelling

Technology Strategy

Process Analysis

<table>
<thead>
<tr>
<th>INPUTS</th>
<th>VALUE</th>
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<tr>
<td>Raw material</td>
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Value from this Preliminary Analysis?

Large block analysis of biorefinery technologies

- OPERATIONS-DRIVEN COST MODELLING
  - CAPITAL SPENDING EVALUATION
  - DECISION MAKING INFORMATION
    - Order-of-magnitude capital and operating costs for several biorefinery options
    - Risks and uncertainties identified for further consideration

- Wood
- Coal
- Chips_VPP
- Woody_biomass
- Corn
- River_Water
- WaterTreatment
- Chemicals
- Gasification
- GTL
- CornEtOH
- FT_Liquid
- EIOH
- Purified_waste_Water
Energy Planning: Some Key Questions

- What is the most practical **thermal pinch analysis** methodology for exploring the biorefinery?
- Retrofit context
- Simultaneous water use and energy use reduction
- Do we need to be as **energy efficient** as possible, in order to have the best energy profile for the biorefinery?
Energy Planning for the Biorefinery

Market $\rightarrow$ product $\rightarrow$ process $\rightarrow$

Mass and energy balances for the targeted biorefinery processes
Energy Planning for the Biorefinery
The Biorefinery Supply Chain will be Significantly More Complex.
The Unique Biorefinery Supply Chain

Existing Pulp & Paper Supply Chain


Design of Biorefinery Supply Chain

For competitive reasons, the FBR SC should be unique to the company implementing it.
Biorefinery Supply Chain: Key Issues

⚠️ **Product Strategy**
- Product versus product family versus product portfolio…
- What are the SC synergies for different product scenarios?

⚠️ **Supply Chain Design**
- What are the opportunities for improved SC design for different biorefinery product opportunities?
- What are the impact of strategic SC design on tactical/operational planning?

⚠️ **Supply Chain Planning**
- How can we best manage the complexity of this new SC?
- How can manufacturing flexibility be best exploited at the SC level so as to mitigate against price volatility?
For a given product portfolio:

- Fixed number of SC design configurations based on system analysis
- Explore the margins-based SC management strategy: this implies a significant transformation…
- Explore the impact of key factors on profit – especially price scenarios based on possible market conditions
- Designing for manufacturing flexibility…
Managing the Biorefinery SC: Manufacturing Flexibility

Expand the JV in order to have better flexibility?
What is the environmental performance of the **cradle-to-grave product chain** for the new biorefinery products?

How does this environmental performance compare with the **traditional product chain**?

What methodology should we use to make this comparison at the **product portfolio** level?

How should **trade-offs** be considered between different environmental criteria?
Biorefinery Environmental Impact: Life Cycle Thinking

LIFE CYCLE ASSESSMENT

Goal and scope definition
Life cycle inventory
Life cycle impact assessment
Interpretation

IMPLICATIONS OF METHODOLOGICAL CHOICES FOR PROCESS DECISION-MAKING

• Operational level: Continuous environmental improvement and environmental management systems
• Tactical level: Retrofit process design
• Strategic level: Forest biorefinery (FBR)

OTHER TOOLS

Boundaries
Allocation
Indicators
Normalization
Weighting
Biorefinery Decision-Making: MCDM for Evaluating Sustainability...

Multi-Criteria Decision Making

The sustainable biorefinery: final decision due to the use of multiple criteria instead of classical ROI-based criteria

Supply chain-level analysis

Life Cycle Assessment

Supply chain analysis

Additional insight into design alternatives due to system expansion

Operations-Driven Cost Model

Mass & energy balances

ABC modeling

Basic process alternatives identification based on product analysis; Process risk analysis

Product Strategy; Retrofit process alternatives
Risk mitigation associated with the implementation of the biorefinery can be achieved through careful strategic planning, and by employing systematic product and process design methodologies:

- Starting with **market-based product portfolio design**
- **Partner selection and partnership model** are critical in determining the company’s unique biorefinery supply chain
- **Enterprise transformation** is implicated - SC design and management must be examined, incorporating issues of manufacturing flexibility...

The **industrial context** is critical to the PSE approach we use – the industrial context is complex, subtle, and changes with time...

**Exciting point:** this business-driven biorefinery strategy is generally consistent with Dr. Siirola’s analysis using the perspective of sustainability...
Case Study:
Product and Process System Design
Methodologies for Engineering the Forest Biorefinery

Thank you!

Cristina Kirchner, President of Argentina, with Luiz Inacio Lula da Silva, President of Brazil.