Connecting Feedstock availability and Market opportunities. Case study on a Madagascar and a European Vegetable Oil Biorefinery.

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From Vegetable Oils to High Value Monomers

Castor

Safflower

Crambe

Oil Extraction

Refined Oil

Hydrolysis

Oxidative Cleavage

Conversion to Nitrile

Conversion to Nitrile

Cross Metathesis

Hydrogenation

ENERGY

Compost / fertilizer

Biogas

Gasification

N-rich Fertilizer

Activated Carbon

Meal

Straw/Hull

HIGH VALUE
Monomers
C9, C11, C12, C13
Value Chain 1: Castor – Case Study

Objective: Create value for local community with food co-products (crop-rotation) and other industrial activities, energy production, honey, silk…

- Castor
- Crushing
- Trans-Ester.
- Step 1 (Process Design)
- Step 2 (Demo)
- Step 3 (LCA)
- Step 4 (Social impact)

Soabe
- Activated carbon
- Biogas
- Syngas
- High value Monomer
Oil crops: Rotation field tests

- Madagascar

Cowpea crop rotation test  Corn crop rotation  Castor Production

- Greece

The oil crop rotation field (25.06.2012).
• **2 options identified for cake valorization in fertilizer and biogas**

  • [Castor plantation](#) → [Cake oily](#) → [Biogas](#) → [Energy](#)

  - Fertilizer → [Cake oily](#)
  - Fruits wastes → 50% Biogas, 50% Digestate

  - Additional biomass source available in Madagascar

• **Interesting potential in Madagascar for local energy supply**

  • Cake (nitrogen source) to be used with other carbon sources such as fruit wastes
  • Feasibility of oily cake use to be confirmed
Castor → PA12: Several Chemistries investigated

- **Chemistry A: Metathesis** – Base case
  - Castor
  - Crushing
  - Trans ester
  - Step 1
  - Step 2
  - Step 3a
  - Step 4
  - PA12

- **Chemistry B: Metathesis** – Best case → Less steps=Lower CAPEX
  - Castor
  - Crushing
  - Trans ester
  - Step 1
  - Step 3b
  - Step 4
  - PA12

- **Chemistry C: Hydroformylation** → High TurnOver Numbers
  - Castor
  - Crushing
  - Trans ester
  - Step 1
  - Step 2
  - Step 5
  - Step 6
  - Step 4
  - PA12

- **Chemistry D: Oxidative cleavage** → No expensive catalyst
  - Castor
  - Crushing
  - Trans ester
  - Step 7
  - Step 8
  - Step 2
  - Step 9
  - Step 4
  - PA11-PA12

🔗 Benchmark of the different options: risks, IP, LCA, costs…
Castor
Castor oil production and use

Castor oil production: 
≈600,000 T/y 
≈80% India 
+ China, Brazil 
Price ≈ 1200 €/T

Uses:
- Lubricants
- Polymers (PU, PA, PE)
- Cosmetics
Castor: Potential cultivation areas

Map based on temperature during germination, precipitation during growing period, altitude, irrigated land, monthly average temperature, germination date

Legend
- NUTS0_RG_03M_2010
- castor_may_irr_non_irr_ETRS

Datum: D_ETRS_1989

Variety improvement program recommended
Safflower – VC2
Safflower oil trade

2009: 706 $/ton
2010: 936 $/ton
2009: 1194 $/ton
2009: 1956 $/ton
2010: 2186 $/ton
2009: 1487 $/ton
2010: 1235 $/ton
2009: Nr 1
2010: Nr 3
2009: Nr 4
2010: Nr 4
2009: Nr 10
2010: nc
2009: Nr 4
2010: Nr 4
Safflower : Potential cultivation areas

Map based on temperature during germination, precipitation during growing period, altitude, irrigated land, monthly average temperature, germination date
Polyamides market

**Value / Performance**

- Commodities
  - PA 6,6
  - PA 6

- Specialties
  - PA 6,10
  - PA 6.12
  - PA 12
  - PA 10.10
  - PA 11

- VC1&2 target

- $\approx 200$KT/Y

- Growth $\approx 5\%/Y$

- US$15,000 / Metric Ton

- US Market Value\(^{(2)}\)

- US$3,000 / Metric Ton

- Performance Properties\(^{(1)}\)

**Main end-markets**

- **Transportation**
  - Fuel lines
  - Air brake systems

- **Energy**
  - Flexible pipes for deep off shore oil recovery

- **Consumer goods**
  - Sport (shoes, ski boots, etc.)
  - Cosmetics

- **Industrial coatings**
  - Powder coating
  - Adhesives (hot melt)

- **Electronics**
  - Covers for laptops and mobile devices

*Source: Cathay Industrial Biotech Ltd., IPO F1 form, July 19th 2011*
Value Chain 1 – Castor to Polyamides

Technology Analysis

Risk - SWOT – IP Score – LCA – CAPEX - Jobs
## Value Chain 1 – Six Forces Analysis

<table>
<thead>
<tr>
<th>Category</th>
<th>Relative Power</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bargaining power of <em>Suppliers</em> (of Biomass)</td>
<td>Medium</td>
<td>Castor is mostly grown in India (80% of world production). Current producers are now well organize and control the production volume and price. There is an opportunity to create some competition, in generating a new value chain.</td>
</tr>
<tr>
<td>Bargaining Power of <em>Customers</em> (of chemicals &amp; fuels)</td>
<td>Medium</td>
<td>Long chain Polyamide market, is growing. The customers are mostly looking for technical properties, such as in application where polyamides can replace metals. They can chose between fossil based and bio-based materials, but will prefer highest technical properties, which is currently delivered by bio-based materials.</td>
</tr>
<tr>
<td>Threat of <em>New Competitors</em></td>
<td>Low</td>
<td>Castor oil can be produced in Brazil, China and several other places, but needs expertise. Long chain polyamides are highly technical products, and current processes are capital intensive. Products have to be certified by the customer in a long process.</td>
</tr>
<tr>
<td>Threat of <em>Substitute Products</em> or services</td>
<td>Medium</td>
<td>Currently there are no possible substitute for castor oil, although there are some research on GMO crops, producing ricinoleic acid. Polyamide could be substituted by other products with higher properties, but this would take a very long time. There are more threats of substitution by other polyamides.</td>
</tr>
<tr>
<td>Competitive <em>Rivalry</em></td>
<td>High</td>
<td>Polyamide production is a well established and capital intensive process. Existing technology is well established as large scale plants, but it is difficult to replicate the existing processes at small scale.</td>
</tr>
<tr>
<td><strong>Stakeholders:</strong> Government / Public</td>
<td>High</td>
<td>Public is favoring renewable products. Government can positively favor renewable products (Bio-Preferred) and Biofuels, through subsidies, Non Governmental Organization should see positively the potential of economic development for African countries proposed by the Value Chain 1</td>
</tr>
</tbody>
</table>
IP score – Competition benchmark

Diagnostic report on risk and potential factors

**IPscore®**

- Benchmark A
- Benchmark B
- Alternative route Combining VC1 & VC2
- Chemistry D
- Chemistry C
- Chemistry B

J.L. Couturier – Arkema – February 12, 2014
IP score – Metathesis catalysts

Diagnostic report on risk and potential factors

- Low risk, low opportunity
- Low risk, high opportunity
- High risk, low opportunity
- High risk, high opportunity

- Umicore
- Catalyst producer A
- Catalyst Producer B
LCA: Castor → PA12

Chemistry A - base case

Chemistry B – Best case
TRL evaluation: Castor → PA12

- Castor – Crushing – Transesterification – Step 1
- Castor (Madagascar)
- DEMO
- Step 1 (improved) – Step 2 - Step 3a/3b – Step 4 - Step 9
- Step 3c  ➔  Alternative scenario in progress
Production costs: Castor → PA12
From base case (chemistry A) to best case (chemistry B)

20% saving achieved from base case to best case
Step 1 critical step for cost reduction

21% cost reduction
Capital Cost Impact

What do we get for 150 M€ CAPEX?

Plant assumed to be built in France, overnight in 2011. Data based on plants announced in literature. Extrapolation factors assumed to be 0.65 for Chemical plants and 0.85 for Fermentation processes.
Jobs creation

Analysis of Biobased projects announced and completed
Public support is not related to number of jobs created.
Conclusion – VC1&2 summary

Market Need, Opportunity & Impact

Market demand and growth for renewable high performance polyamides

Main end markets: automotive, energy, consumer goods, lubricants, cosmetics…

Opportunity to reduce CO₂ emissions in transportation with metal substitution by lightweight polyamides
(100 kg weight saving → -0.35 L fuel/100km → -9 g CO₂/km)

Business Model & Commercial applications

Castor seeds & oil (Soabe), meal & fertilizers (Soabe, BKW), crambe & safflower oil, electricity/heat (BKW), activated carbon (CECA), catalyst (Umicore), PA (Arkema)

Seeds (Madagascar, Europe) → Oil (crushing unit, Europe) → PA (customers – Europe)

Interest Group: fuel company (road fuel)

Technology

Castor → Seeds → Oil → Transesterification → → Polymerization → PA12
Safflower/Crambe → Seeds → Oil → → Polymerization → PAs

Meal/Hull → fertilizer, activated carbon, energy (biogas)

Energy ↔ biogas (electricity, heat), fatty esters (road fuel), jatropha oil (crushing)

Technology Development Level (TRL)

8 new technologies at TRL=6 or more (pilot) at the end of the project

Castor (Madagascar), Crambe (Poland), Safflower (Greece) thermal cleavage, metathesis, oxidative cleavage, hydrogenation, fatty esters (biodiesel)
Castor based PA12 sample
Thanks to Myrsini Christou (CRES), Charles Themistocle (Soabe) Wei Zhao (PDC), Arnaud Dauriat (Quantis), Angelino Doppiu (Umicore) Markus Brandhorst, Jean-Luc Dubois (Arkema) All the Value Chain contributors…

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Thanks for your attention…