The challenge of Guayule
An alternative source of natural rubber
A model of bio-refinery

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“Equally important are the considerations now being given to alternatives of NR... consuming countries have come to firmly accept the imperative need of a sole cis-polyisoprenic rubber. They are circumspect on the capacity of NR producing countries to meet projected requirements. The USA and Mexico are reviewing.. technical viability of deriving cis-polyisoprene from other rubberbearing plants, such as Guayule...

. the world requires a substantially larger supply of cis-polyisoprene. Unless this is forthcoming from the most advanced and techno-economically attractive industry, i.e. Hevea, the world must look for alternatives. In other words, the natural rubber industry is moving into an exciting and challenging era....”

In the grapes of wrath (1939) chapter 9, John Steinbeck wrote
“…remember in the war we planted mustard ? remember a fella wanted us to put in that rubber bush they call guayule ?get rich he said.....”
WHY ALTERNATIVES SOURCES OF NR?

- **HEVEA**, only commercial source of NR (93% world prod. in Asia)

- Growing demand from emerging countries (China, India,..).
  
  5.0 M. Tons in 1990  ➔  17.0 M.T. in 2025

- Price NR & SR linked with volatile price of oil (80-150 $/ barrel)

- Replacement of rubber plantations by palm oil plantations

**NR Consumption** (source SNCP & IRSG)

**NR Production** (source SNCP & IRSG)
NR prices have rocketed upward (4,800€/T. Feb. 2011)

Threat Microcyclus ulei (SALB), South America but risk to spray in Asia/Africa exists. When? How? Climatic changes?

Proteins Hevea cause IgE-latex allergy. Guayule hypoallergenic.

Rubber tapping manual, laborious, Guayule can be mechanized
HOW TO GUARANTY NR SUPPLY

- New plantations & replanting
  8.3 M. ha in production, 11.4 M. ha with young planting.

- Improve SALB  Hevea clonal resistance (IRRDB)

- Develop new alternatives sources
  - GUAYULE
  - Khazakstan or Russian DANDELION

- Implement European or International projects
  - EU-PEARLS (2008-2012),
  - EAGLES (2011),
  - G-VALUE (2013)
WHAT IS GUAYULE?

✓ A bush, native from Mexico/Chihuahua desert

*Asteraceae/Compositae* (*Parthenium argentatum* Gray)
in the wild, age up to 40 years, commercial up to 10 - 12 years
MAIN STEPS OF DEVELOPMENT

1906-1912: 55,000 T. of GR, < 1000 T. than hevea at same period

WWII: Emergency Rubber Project, 8,000 ha, end of the war stopped with new access to hevea plantations in Asia and synthetic rubber development
✓ 1970s: Oil embargo. R&D in California, Arizona, Australia, Africa. Firestone project in Texas (Fort Stockton).

✓ 1980s: Pilot plant in Saltillo, Mexico. Native Latex commercialization Act (1978) , Firestone plant, Sacaton - Arizona. CIRAD in Morocco & West Africa, Australia, etc...
2000s: YULEX, Guayule hypoallergenic latex (K. Cornish)

2008: EU-PEARLS project, G. Fields in France (Montpellier), Spain (Cartagena/Murcia). End 2012 with prototypes + fields in EU

2012: Bridgestone Project on sustainable source of NR, Yulex new factory in Chandler, AZ. Cooper Tire with Yulex

2013: Bridgestone interest for high value uses of Co-Product. New EU projects. Yulex with VERSALIS and PIRELLI in Italy. PANARIDUS-USA releases GR samples project in India.
AGRONOMY OF GUAYULE

✓ Commercial conditions: soils well-drained, 12 years, -9°Cmin, 380-640 mm. Needs of irrigation, nursery plants, density planting 30,000 to 55,000 plants/ha.

More biomass ≈ more rubber

✓ Guayule: apomitic, Tetraploids most common form and bigger plants more productive. Best USDA lines: AZ2, AZ1, AZ3, CAL 6, 11591, N565, 593 (EPR)

Rubber content 6–12% (dry weight biomass)

81% of rubber in branches, 1% in leaves, 18% in roots

Yield 0.5-1.0 kg/ha/an (harvested every 1-2 years).
By combining the maps (temperature and rainfall), GIS generates a potential land suitability map for guayule, showing six potential yield categories, where optimal conditions exist.
Two sites were selected for EU-PEARLS field trials:

• France, Montpellier
  Agropolis research station

• Spain, Cartagena
  El Molinar farm
HISTOLOGY HEVEA vs GUAYULE
GUAYULE EXTRACTION

HARVEST

LATEX
- YULEX
- USDA
- CIRAD

SOLVENT
- DRY RUBBER & RESINS

SC FLUID
- RESINS & Low Mw

USDA, YULEX
- Laboratory level
  - High Mw ?

SALTILO / CIQA
- TEXAS A&M
- FIRESTONE/SACATON
  (1980s)
- PANARIDUS (2012)

COMMERCIAL (500 T./Y)

PILOT

RESEARCH LEVEL
<table>
<thead>
<tr>
<th></th>
<th>HEVEA LATEX</th>
<th>COMMERCIAL GUAYULE LATEX*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid content (%)</td>
<td>61.4</td>
<td>55.6</td>
</tr>
<tr>
<td>Viscosity (Cp)</td>
<td>48</td>
<td>53</td>
</tr>
<tr>
<td>pH</td>
<td>9.6</td>
<td>10.9</td>
</tr>
<tr>
<td>Average size (µm)</td>
<td>1.0</td>
<td>1.2</td>
</tr>
</tbody>
</table>
GUAYULE and HEVEA gloves mechanical properties are similar after slight formulation and process adaptations.

<table>
<thead>
<tr>
<th></th>
<th>HEVEA latex</th>
<th>COMMERCIAL GUAYULE latex</th>
<th>EU-PEARLS GUAYULE light phase latex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulcanising dispersion ratio</td>
<td>27</td>
<td>54</td>
<td>54</td>
</tr>
<tr>
<td>Stress at break (Mpa)</td>
<td>17</td>
<td>7.0</td>
<td>13.3</td>
</tr>
<tr>
<td>Strain at break (%)</td>
<td>810</td>
<td>860</td>
<td>808</td>
</tr>
</tbody>
</table>
GUAYULE LATEX NO-ALLERGY

Allergy Type I (anaphylactic choc)  Allergy Type IV (irritation, cross allergy)

- ASTM (D6499-00) = ELISA test
- FITKit® (test immuno-enzymatic 4 major allergens)
MICROSTRUCTURE CHARACTERISATION

✓ NMR \textsubscript{C13}, FTIR : GR, TKSR and HR , all PI cis 1,4

✓ SEC-MALS analysis shows molar mass (Mw, Mn) varies with age of plants, storage conditions, type of extraction process, method of measurement, aging. Ratio of gyration ($R_g=f(M_w)$), more branching for GR than HR and TKSR raw rubber

FTIR

resins

PI

SEC-MALS

Source F. Bonfils, CIRAD-IATE.
### GR TSR SPECIFICATIONS

<table>
<thead>
<tr>
<th>PROPERTIES</th>
<th>GR 1</th>
<th>GR 2</th>
<th>HR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Plasticity P₀ , ISO 2007</td>
<td>13</td>
<td>31 - 33</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Plasticity retention indice PRI (ISO 2930)</td>
<td>15.4</td>
<td>6.5 - 15.2</td>
<td>&gt;40</td>
</tr>
<tr>
<td>Mooney Viscosity ML (1+4) 100°C ISO 289-1</td>
<td>25</td>
<td>52 -53</td>
<td>60-80</td>
</tr>
<tr>
<td>Dirt content % ISO 249</td>
<td>-</td>
<td>0.016</td>
<td>&lt;0.20</td>
</tr>
<tr>
<td>Acetone extract ISO 1407</td>
<td>12.4</td>
<td>12 -14</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Ash content % ISO 247</td>
<td>-</td>
<td>0.19- 1.25</td>
<td>&lt;1.00</td>
</tr>
<tr>
<td>Total nitrogen ISO 13878</td>
<td>-</td>
<td>0.21</td>
<td>&lt;0.60</td>
</tr>
</tbody>
</table>
GUAYULE BIO-REFINERY
## GUAYULE BIO-PRODUCTS

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Class</th>
<th>Chemicals</th>
<th>Tested applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatile</td>
<td>Terpenes</td>
<td>α, β Pinene, Camphene, α and β Phellandrene, Sabinene, β Myrcene</td>
<td>Essential oil, Tall oil</td>
</tr>
<tr>
<td></td>
<td>3-5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-volatile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water soluble</td>
<td>Short acid, ester Polyphenols</td>
<td>Bornyl acetate, Cinnamic acid Tannins, flavonoids Polysaccharides</td>
<td>Cockroach attractant</td>
</tr>
<tr>
<td>Water insoluble</td>
<td>Hydrocarbons</td>
<td>α &amp; β Ocumene, Limonene</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fatty acid TG 20-25%</td>
<td>Linoleic (65%), Linolenic, Palmitic, Oleic</td>
<td>Termite control, Nematod control, Weed control, Antimicriobiol, Fungistatic, Adhesives (UF substitutes), Strippable coatings, New to be discovered</td>
</tr>
<tr>
<td></td>
<td>Wax (leaves)</td>
<td>Carnauba</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sesquiterpenes</td>
<td>Guayulines A,B, Partheniol</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Triterpenes</td>
<td>Argentatine A,B,C,D,E,F,G,H</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alkaloid</td>
<td>Guayulamine A,B</td>
<td></td>
</tr>
</tbody>
</table>

Accumulated balances of hevea and guayule cultivation

Source: Nisrin SFEI IAMM/CIRAD 2011-2012 with « Olympe » software (for publication)

1 ha farm of guayule for 10 years
Dry biomass branches = 10 T./ha/year
Dry rubber C. 8% (800 kg/ha/Y)
Planting density 50,000 plants/ha

Field Prod. Costs = 1.500-2.000€ /ha
Sale dry biomass = 3.000€ /ha/year

Hevea/Guayule Faster return

Guayule 8% no fertilisation
Guayule 8% + fertilisation
Guayule 5%
Option 1: only Latex (centrifugation)
• With current technology, it is possible to extract 60% of the total rubber as latex.
➢ The valorisation of sole guayule latex would be possible only through a niche market with very high added value.

Option 2: only crude rubber + resin (solvent extraction)
• With current technology, it is possible to extract 90% of rubber + 95% of the resin.
✓ (Prices recorded in 2011).

Option 3: Latex as step 1, followed by crude rubber + resin as step 2.
• It is possible to extract 25% of latex + 65% of crude rubber + 95% of resin.

Threshold selling price (€ /kg) to reach profitability

<table>
<thead>
<tr>
<th>Option</th>
<th>Latex</th>
<th>Crude rubber</th>
<th>Resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Latex only</td>
<td>8.0-9.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Solvent only</td>
<td></td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>3. Latex, then solvent</td>
<td>5.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
</tbody>
</table>
CONCLUSION

- Guayule (GR) not a threat to Hevea
  
  If Hevea NR capacity not available, alternative raw materials will develop.

- Commercial production for GR (5000 T. in 2025 ?)
  
  - Price of NR (> 3.0 $US /kg),
  - High rubber Yield /ha (≈1 ton/ha target),
  - Lower costs of production, efficiency of processing
  - New cultivars, genetic improvement,
  - Valorisation of bioproducts and bio-refining
Commercial production for GR depends on:

- Rubber prod. & demand (China, India).
- More commercial plants of GR needed with higher capacity, new areas for planting
- Tyres and industrial rubber companies, national and international organizations to be involved on alternatives sources of NR.
- New cultivars with higher yield (> 1T./Ha/Y)
- More economics & feasibility studies

CIRAD (UR BiowooEB) opened to development on guayule with IRRDB research institutes.
Growing American Rubber: Strategic Plants and the Politics of National Security
(Mark R. FINLAY, Rutgers University Press, 2009)

French translation by D. Michelin & CIRAD, Editions QUAE, March 2013
PAPER PRESENTED IN MEMORY OF

J.B SERIER
IRCA/CIRAD Researcher

&

Dr AFS BUDIMAN

During his PhD at the Institute of Polymer Sciences, Dr AFS Budiman worked on the study of fundamental parameters of guayule desination 1981-1984
“Catch the Alternative Natural Rubber ball”

THANK YOU