Session 1
Presentation by: Peter Tollington, *Cargill*

Title: **Big and powerful or small and beautiful ? Dilemmas in the bio-based supply chain**

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Curriculum:
Peter (Tollington) studied Chemical Engineering at Cambridge University in the UK, and started his working career with Unilever Research in Port Sunlight (UK), developing new processes for detergent production. In 1995, he transferred to Unilever's Chemicals Division, joining Unichema in the Netherlands and working on oleochemical process development. Following the acquisition of Unichema by ICI (and formation of Uniqema) in 1997, he joined the Homecare / Industrials business unit and worked in a variety of technical - commercial roles there. Croda acquired Uniqema in 2006, and Peter worked as R&D Manager for the Industrials business until 2011, when he moved to his current role in the Bio-Industrials business in Cargill. There he is responsible for the development of new products, applications and markets for refined vegetable oils and related products; this includes cross-business collaborations, combining plant-derived raw materials such as starches, sugars, proteins and lipids from around the Cargill group, to achieve novel functional and value-enhanced products for industrial markets.
In his spare time, Peter is a keen amateur musician and music arranger.

Abstract:

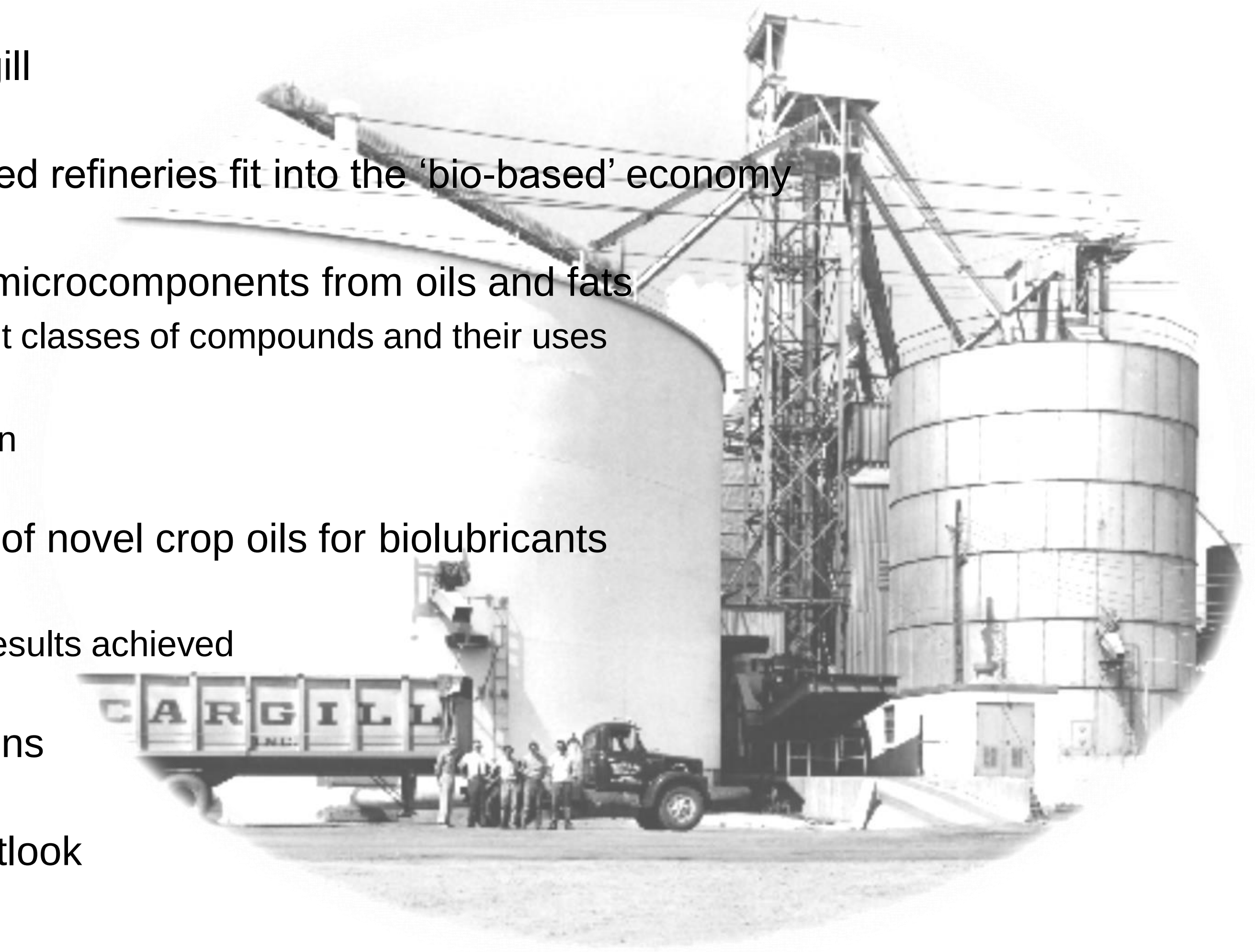
As the bio-based economy achieves a certain degree of maturity, producers of the basic plant-based building blocks seek ways to use or adapt existing refinery scale and infrastructure to advantage, in order to find a sustainable and viable position in the bio-based supply chain. There are many different strategies and themes implied by such an approach: development of new crop varieties that yield raw materials with enhanced properties for industrial use, valorisation of 'waste' (inedible) co-streams of refining, new conversion processes integrated into the refinery infrastructure to functionalise the basic products and co-streams, to name but a few. R&D challenges abound; in many cases, 'start small' is not a viable option, and new raws, products or processes must achieve the economic scale and yields appropriate for a refinery environment from the outset.
We will present two contrasting examples of the importance of R&D combined with scale efficiencies in the development of a viable, sustainable and far-reaching bio-based economy. In the first case, we consider the isolation of valuable functional microcomponents (unsaponifiable fractions) from vegetable oils, and factors influencing the economics of purification. In a second example, we look at the challenges in developing new oil crop varieties with tailored properties for industrial markets, taking as a case study a recent project in the growing bio-lubricants sector.

Big and powerful or small and beautiful ? Dilemmas in the bio-based supply chain

Peter Tollington, Cargill
BPM Symposium
June 15 2017
Wageningen

www.cargill.com

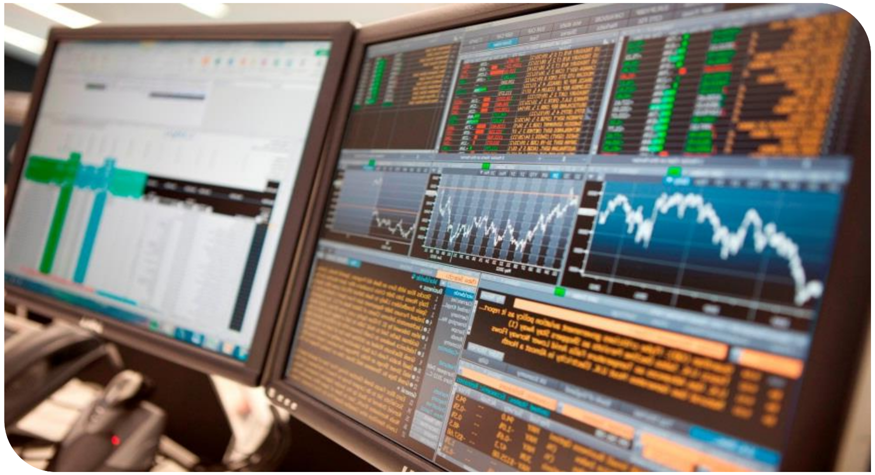
Big and powerful or small and beautiful ? Dilemmas in the bio-based supply chain.



- (Brief) Introduction to Cargill
- How large-scale plant-based refineries fit into the ‘bio-based’ economy
- Example 1 : Extraction of microcomponents from oils and fats
  - What is out there ? Different classes of compounds and their uses
  - Technical challenges
  - Economic scale of operation
- Example 2 : Development of novel crop oils for biolubricants
  - Project objectives
  - Technical challenges and results achieved
- Other successful innovations
- Conclusions and future outlook

Cargill at a glance

- Founded in 1865
- HQ in US (Minneapolis)
- Privately owned company. Majority shareholders Cargill & MacMillan families



- 150,000 employees
- 70 countries
- More than 1,000 locations
- $ 107 billion in sales + other revenues and adjusted operating earnings of $1.64 billion (2016)

Cargill is organized around four major segments

Agriculture	We buy, process and distribute grain, oilseeds and other commodities to makers of food and animal nutrition products. We also provide crop and livestock producers with products and services.	
Food	We provide food and beverage manufacturers, foodservice companies and retailers with high-quality ingredients, meat and poultry products, and health-promoting ingredients and ingredient systems.	
Financial	We provide our agricultural, food, financial and energy customers around the world with risk management and financial solutions.	
Industrial	We develop and market sustainable products made from agricultural feedstocks such as starches and vegetable oils. We also serve industrial users of energy, salt and steel products.	

Our corporate responsibility commitments are in four main areas

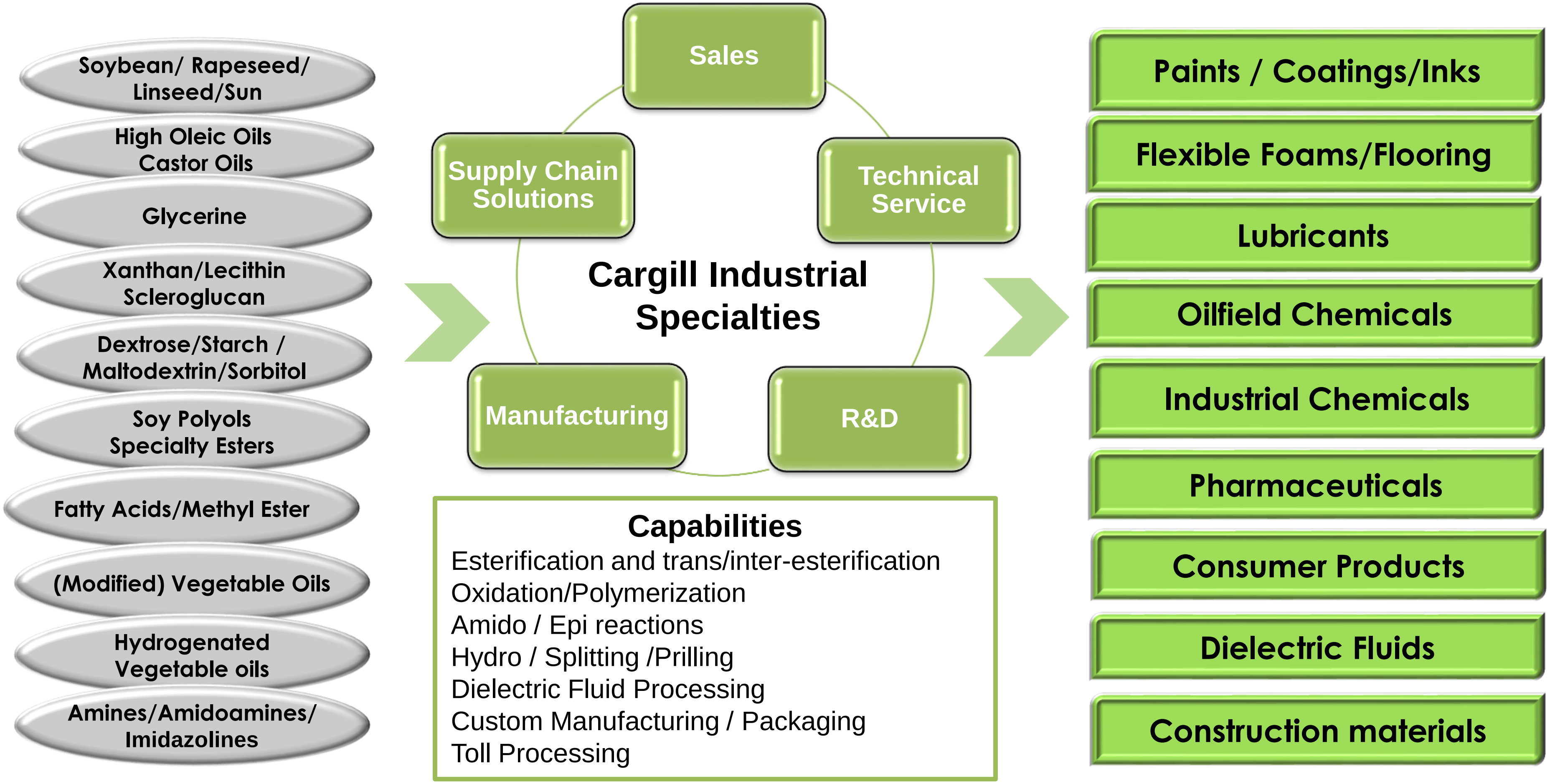
Conducting Business with Integrity

Operating Responsible Supply Chains

Enriching Our Communities

Working to Feed the World

Cargill and the bio-based economy



- Soybean/ Rapeseed/ Linseed/Sun
- High Oleic Oils Castor Oils
- Glycerine
- Xanthan/Lecithin Scleroglucan
- Dextrose/Starch / Maltodextrin/Sorbitol
- Soy Polyols Specialty Esters
- Fatty Acids/Methyl Ester
- (Modified) Vegetable Oils
- Hydrogenated Vegetable oils
- Amines/Amidoamines/ Imidazolines

Cargill Industrial Specialties

- Sales
- Technical Service
- R&D
- Manufacturing
- Supply Chain Solutions

Capabilities

Esterification and trans/inter-esterification
Oxidation/Polymerization
Amido / Epi reactions
Hydro / Splitting /Prilling
Dielectric Fluid Processing
Custom Manufacturing / Packaging
Toll Processing

- Paints / Coatings/Inks
- Flexible Foams/Flooring
- Lubricants
- Oilfield Chemicals
- Industrial Chemicals
- Pharmaceuticals
- Consumer Products
- Dielectric Fluids
- Construction materials

Application examples

Crop Protection

Consumer

Paints, Inks, Coatings

Industrial Renewables

Lubricants

Transformers

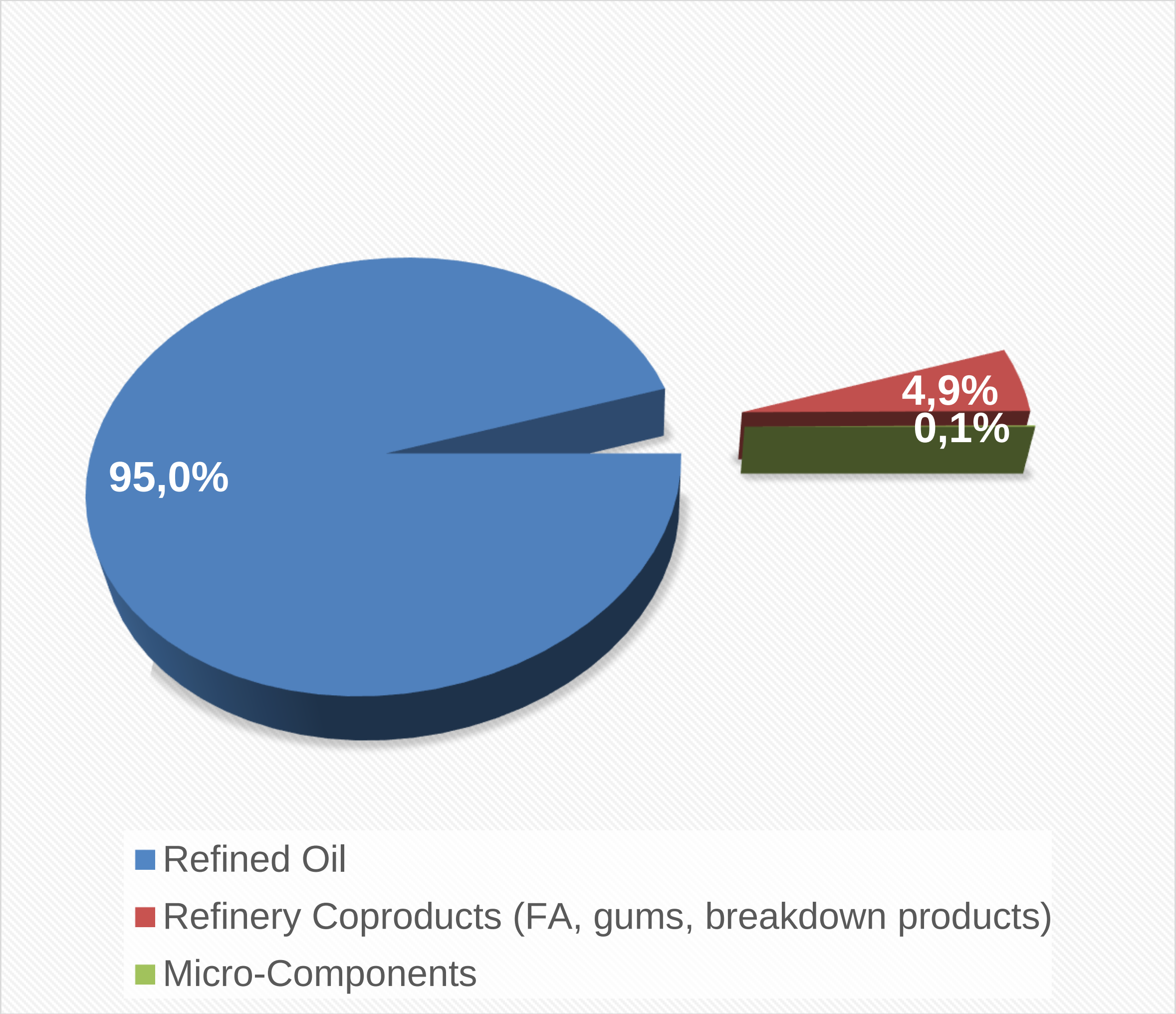
Flexible Foams

Construction

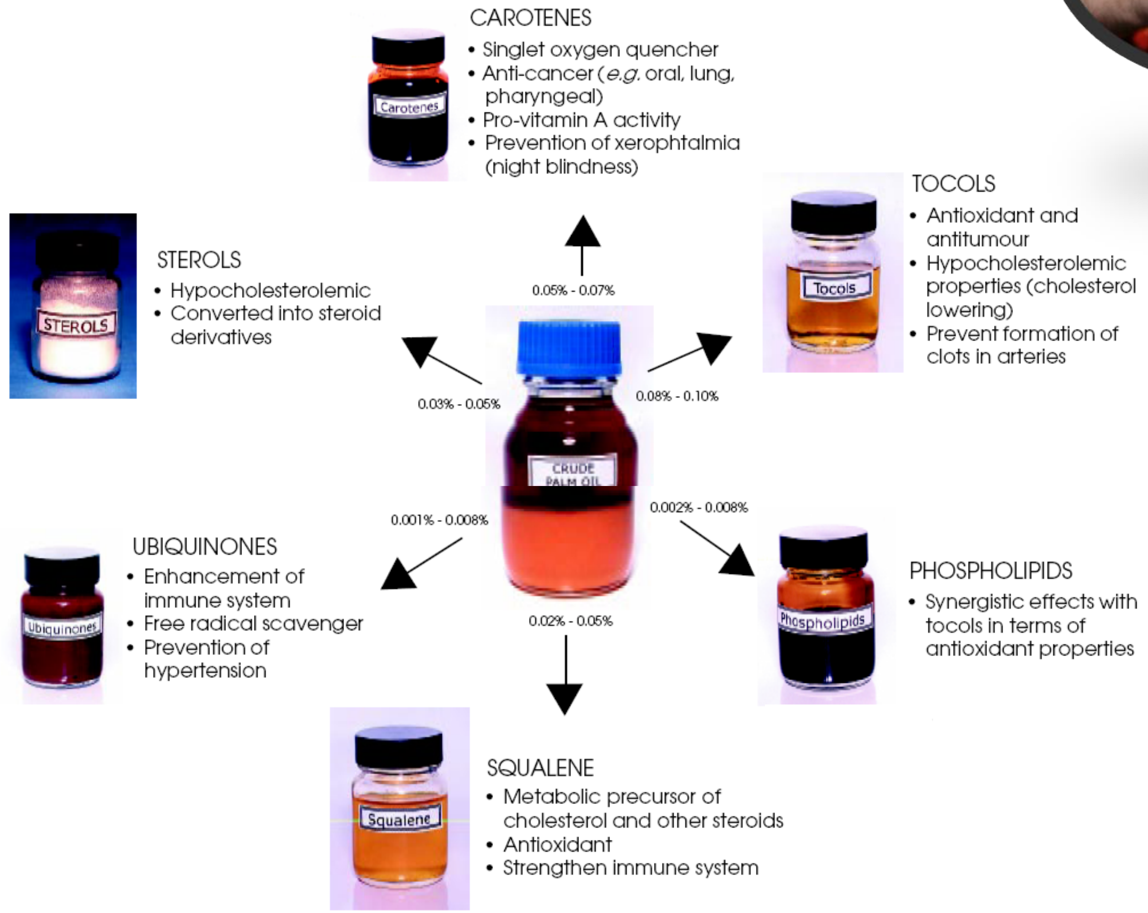
Oilfield

Microcomponents in vegetable oils

Crude vegetable oils - composition



Microcomponents in vegetable oils – palm oil



CAROTENES
- Singlet oxygen quencher
- Anti-cancer (*e.g.* oral, lung, pharyngeal)
- Pro-vitamin A activity
- Prevention of xerophtalmia (night blindness)

TOCOLS
- Antioxidant and antitumour
- Hypocholesterolemic properties (cholesterol lowering)
- Prevent formation of clots in arteries

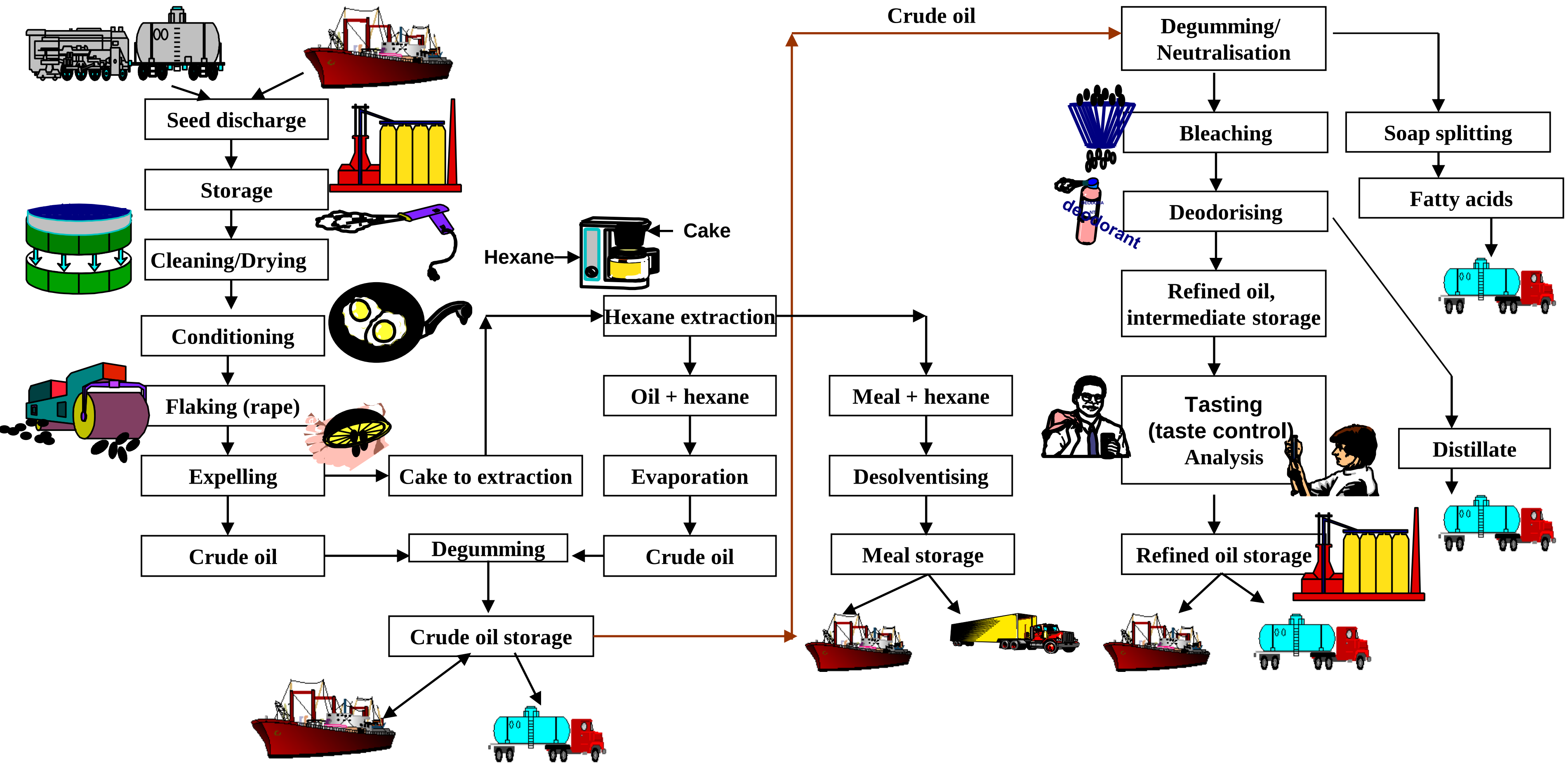
STEROLS
- Hypocholesterolemic
- Converted into steroid derivatives

UBIQUINONES
- Enhancement of immune system
- Free radical scavenger
- Prevention of hypertension

PHOSPHOLIPIDS
- Synergistic effects with tocols in terms of antioxidant properties

SQUALENE
- Metabolic precursor of cholesterol and other steroids
- Antioxidant
- Strengthen immune system

Vegetable oil refining - schematic



CRUSHING

Seed discharge

Storage

Cleaning/Drying

Conditioning

Flaking (rape)

Expelling

Crude oil

Cake to extraction

Hexane

Cake

Hexane extraction

Oil + hexane

Evaporation

Crude oil

Degumming

Crude oil storage

Meal + hexane

Desolventising

Meal storage

Crude oil

REFINERY

Degumming/ Neutralisation

Bleaching

Deodorising

Refined oil, intermediate storage

Tasting (taste control) Analysis

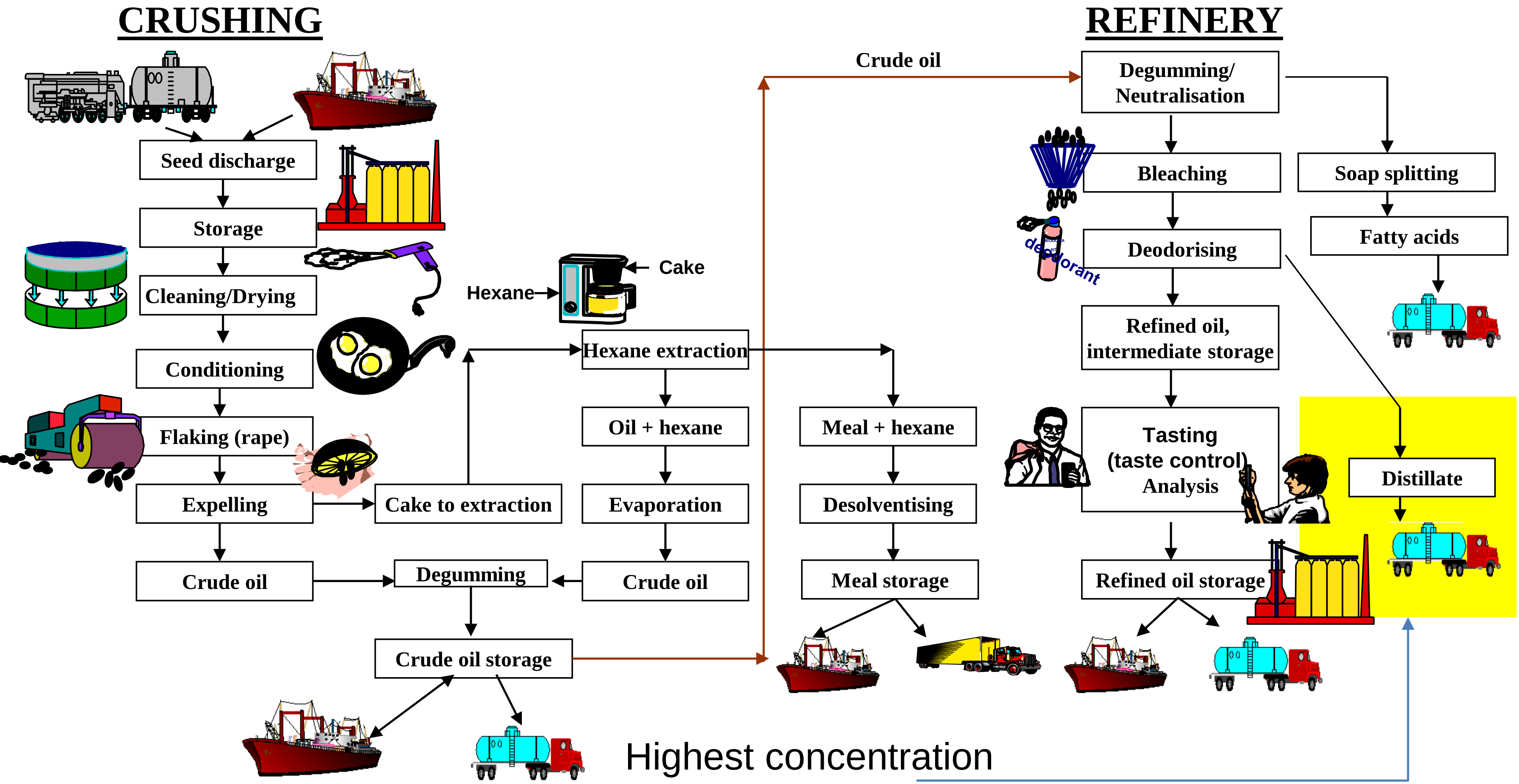
Refined oil storage

Soap splitting

Fatty acids

Distillate

Vegetable oil refining - schematic



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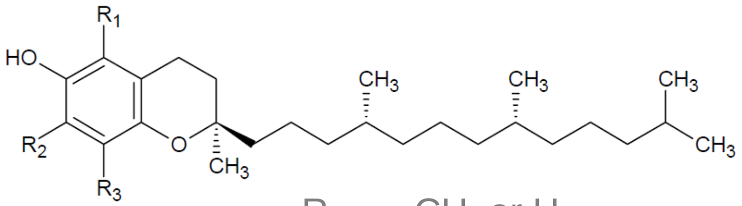
Distillate

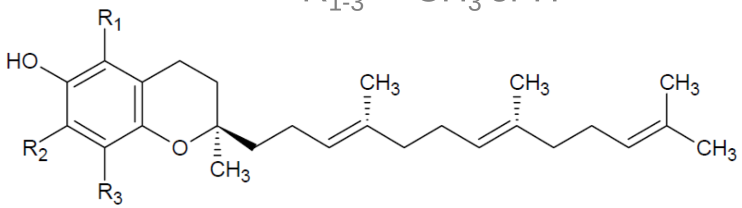
Highest concentration of microcomponents

Vitamin E - chemistry and functions



Tocopherols (TP)

$R_{1-3} = CH_3$ or H



Tocotrienols (T3)

Vitamin E is the collective term for a family of chemical substances that are structurally related to α-Tocopherol

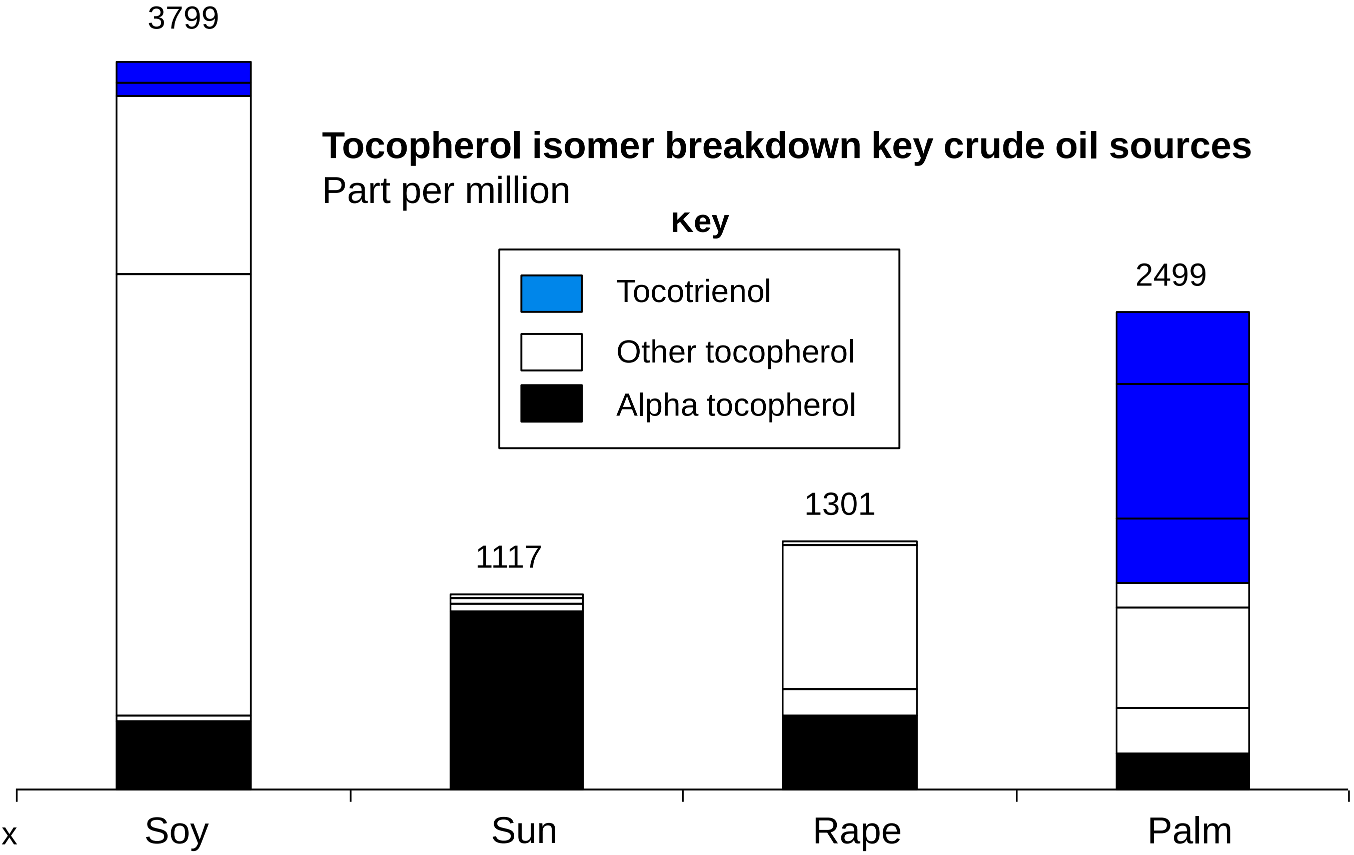
Vitamin E occurs naturally in 8 different forms;

- 4 Tocopherols (TP) (α, β, γ, δ)
- 4 Tocotrienols (T3) (α, β, γ, δ)

Vitamin E

- Functions as an antioxidant, preventing oxidation of e.g. PUFAs
- Is an essential nutrient for the development of the animal fœtus
- Reduces the risks of certain cancers
- Slows down cell aging

Key natural sources of Vitamin E



Source: Codex

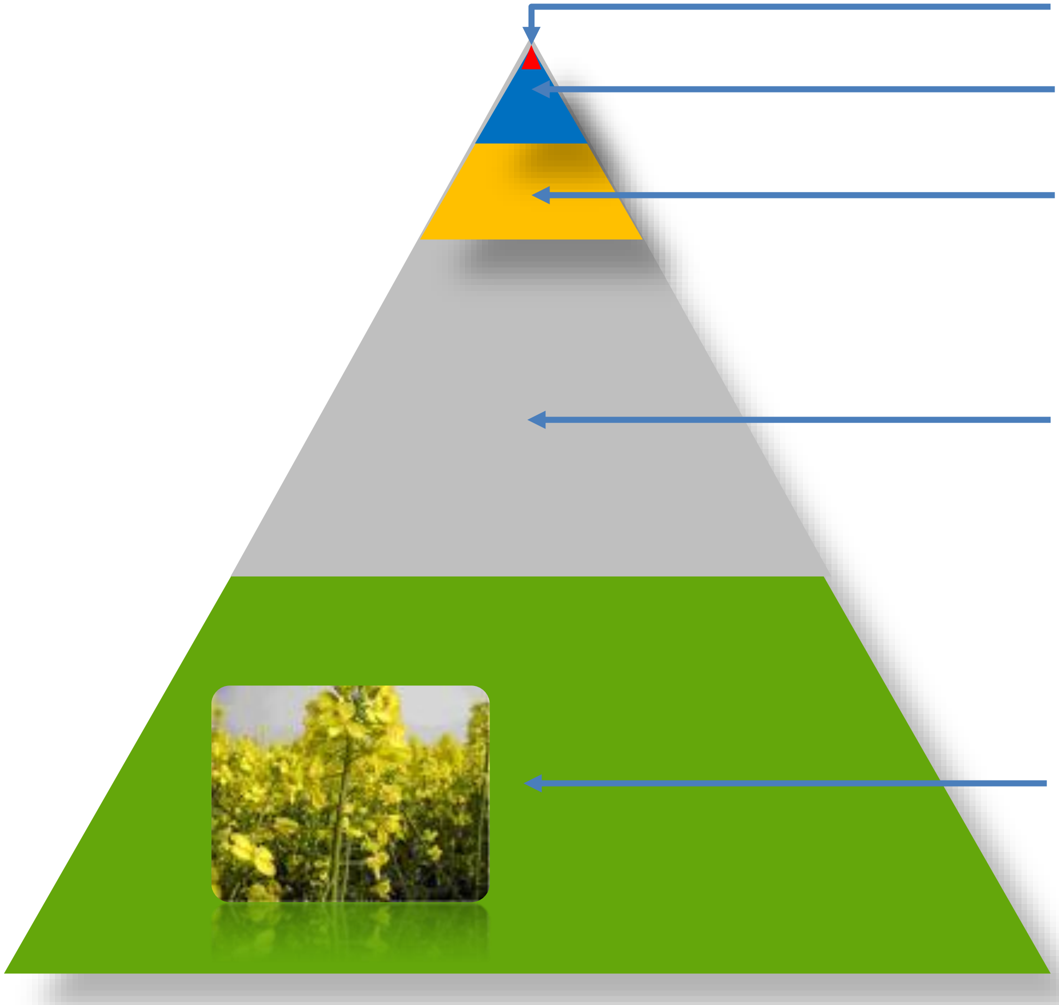
Note: Represents maximum available quantities in crude oil

Soy has the largest mix of natural tocopherols and represents approximately 70% of today's natural Vitamin E supply; Palm is rich in Tocotrienol

Concentrating microcomponents in the refining process

Compounds (%)	Soap stock	Acid oil	Deodorizer distillates	
			Phys	Chem
Water	32-67	<1-3	-	-
FFA	10-28	39-75	80-90	30-60
Acylglycerols	12-13	18-30	5-20	10-60
Phospholipids	5-9	-	-	-
Unsaponifiable matter	<1	<1-4	5-10	10-50
Micro-components •Tocopherols •Tocotrienols •Sterols •Squalenes •Pigments •Others				

Concentration pyramid for tocopherols –rapeseed



Tocopherols (100% basis) : 30 mt/a

Unsaponifiables : 90 mt/a

Deodoriser distillates : 300 mt/a

Crude vegetable oil: 200,000 mt/a

Oilseed: 500,000 mt/a

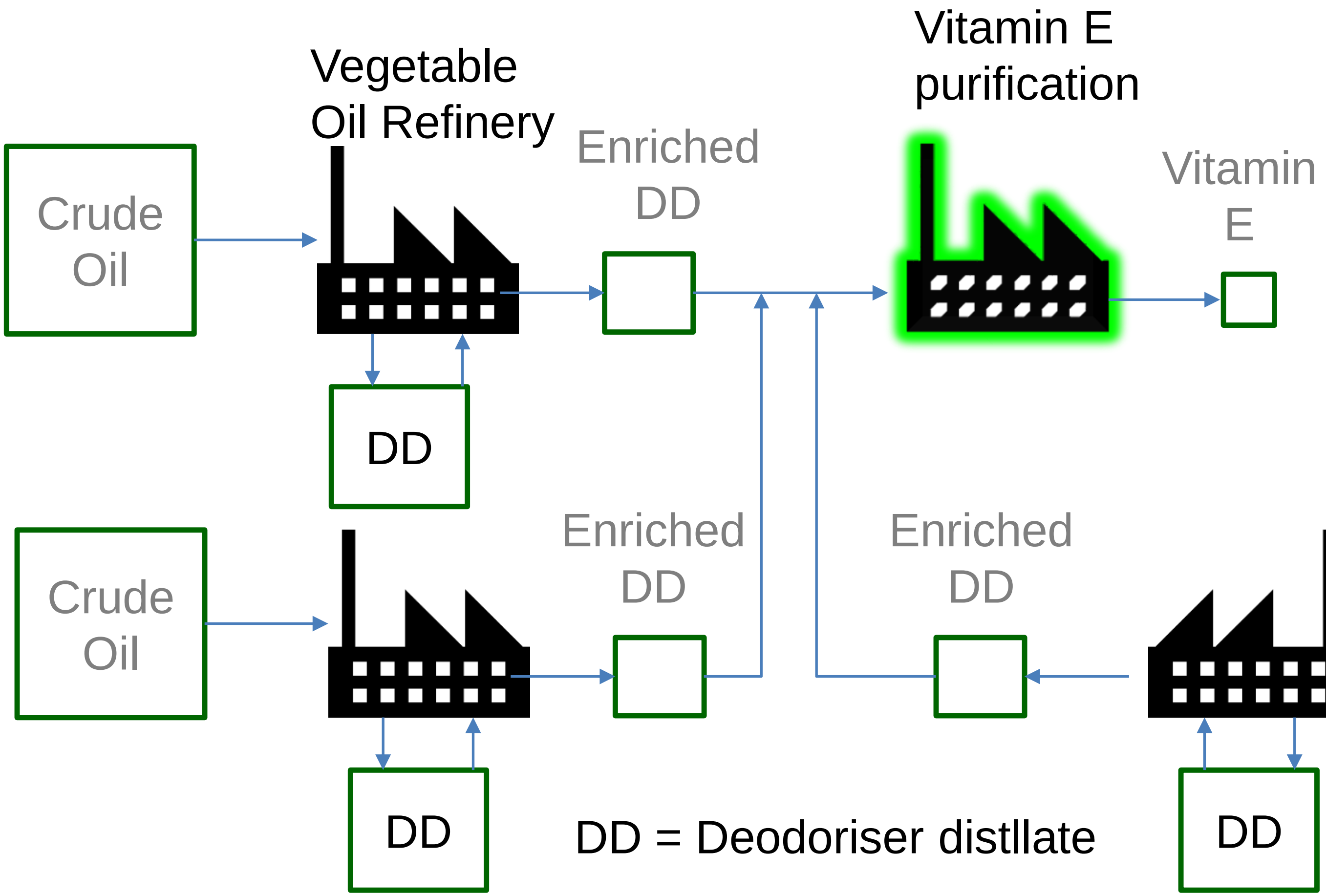
Basis : actual refinery values

Purification of Vitamin E

R&D CHALLENGES

- Initial extraction of tocopherol from oil into DD stream, and at economic concentration
- Complex and capital-intensive multi-stage purification process involving physical and chemical separation steps
- Different products and derivatives according to application ie. mixed tocopherols, alpha tocopherols, tocopherol acetates, pure D-enantiomer, conversion of β, γ,δ into α etc.
- Complex analytics
- Stringent regulatory environment reflecting end-markets (food, pharma, animal feed, cosmetics)
- Significant low-value co-stream production and management

Supply chain strategy for Vitamin E purification



DD = Deodoriser distllate

"Hybrid" model – enriched deodoriser distillates shipped from multiple refineries for final purification at one location

How can R&D impact the economics of Vitamin E production?

- **Process R&D** is key to competitive advantage and efficient supply chain models :
  - Initial extraction and concentration of the desired components
  - Minimum overall number of process steps
  - Efficient and high-yield purification/separation steps
  - Robust processes able to deal with variations in feedstock origin and concentration
  - ‘Feed-forward’ analytical capabilities
  - Strategies for valorisation of co-product streams

Cargill approach

RETRO-FITTING OF PROPRIETARY PROCESS ENGINEERING FOR EXTRACTION AND PRE-CONCENTRATION

- Characterisation of microcomponents in distillate streams
  - Develop relevant analytical techniques
  - Measure physical properties of pure components and mixtures
- Computer-aided modelling and prediction
- Small-scale experimental validation
- Scale-up
- Patent protection (for proprietary processes)
- Full process design and costing
- Installation and commissioning

Typical concentration factors of 3x to 5x
(@ no net losses) achieved with this approach

Conclusions - microcomponents

BIG IS POWERFUL, SMALL IS BEAUTIFUL

- Economic refining scale (or ability to source sufficient quantity of concentrated distillate streams) is a pre-requisite for exploitation of microcomponents
- Process R&D critical to success in achieving viable conversion processes : purification costs are strongly dependent on input concentration in feed
- There are almost NO true ‘waste’ streams in vegetable oil refining, and some microcomponent streams (depending on purity) command prices of many multiples of the crude oil value, thus positively contributing to refinery economics

High-oleic oils for Biolubricants

Sponsored by:
BBSRC (UK) through the Renewable Materials LINK programme (LK0843) and HGCA (RD-2007-3356)
Lead Partner : Prof. Ian Bancroft, York University/John Innes Centre (UK)
Phase I : 1st April 2008 – 31st March 2014

Bio-lubricants 1: Reducing the carbon footprint of the lubricants industry by the substitution of mineral oil with rapeseed oil

Partners
Cargill, Fuchs, HGCA, JIC, KWS,
Monsanto, Saaten Union, Velcourt

Aims

- Mutation of specific genes (FAD2 orthologues) to reduce overall PUFA content
- Confirmation of physical properties of modified oil
- Supply oilseed rape lines for the breeding of cultivars
- Catalyse formation of a supply chain

bbsrc
biotechnology and biological sciences research council

LINK
COLLABORATIVE RESEARCH

VELCOURT

JOHN INNES CENTRE

HGCA

SAATEN UNION
ZÜCHTUNG IST ZUKUNFT

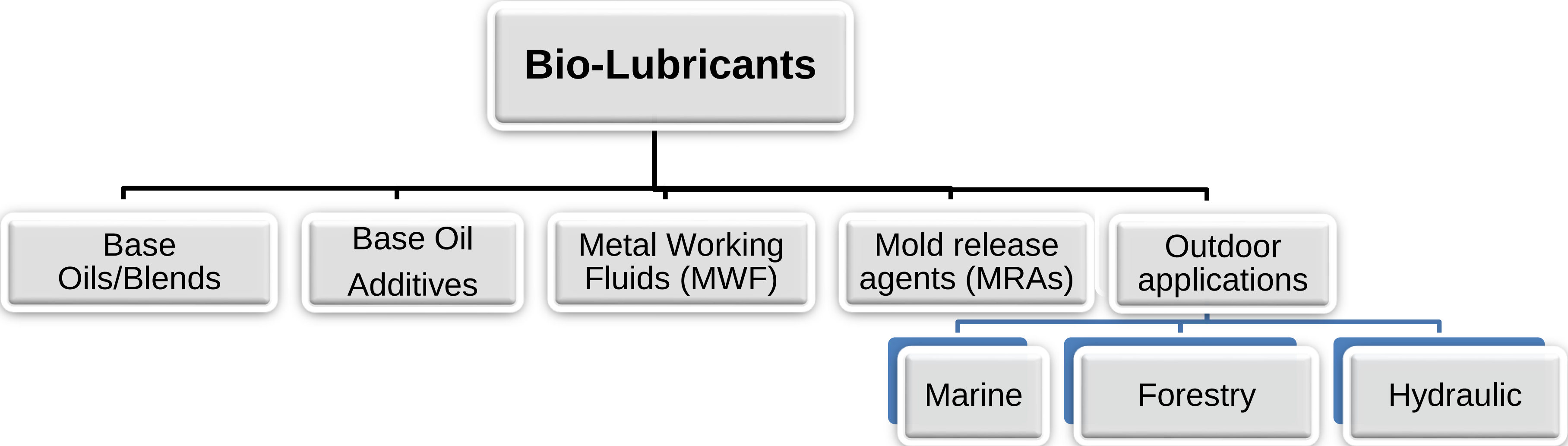
KWS

Cargill

FUCHS

MONSANTO

Biobased Lubricants:
Use of vegetable oils and derivatives



Bio-Lubricants

Base Oils/Blends

Base Oil Additives

Metal Working Fluids (MWF)

Mold release agents (MRAs)

Outdoor applications

Marine

Forestry

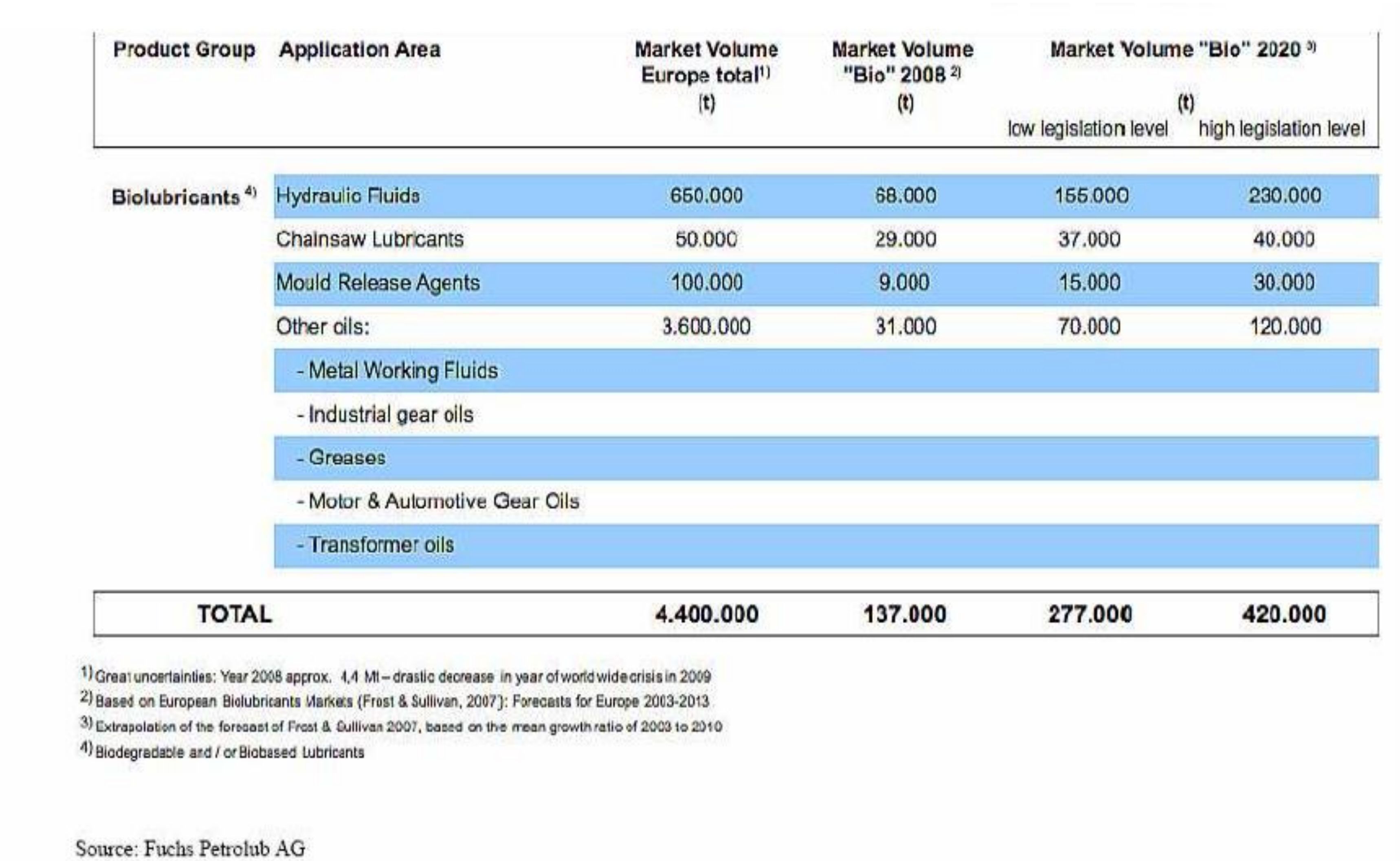
Hydraulic

Key requirements

- High bio-based content
- Ready biodegradability
- Good thermal and oxidative stability
- Good low-temperature fluidity
- High viscosity index
- Low human, environmental and aquatic toxicity
- Adequate purity (for production of derivatives)

See eg - A Review on the Science and Technology of Natural and Synthetic Biolubricants
Carlton J. Reeves • Arpith Siddaiah• Pradeep L. Menezes
J Bio Tribo Corros (2017) 3:11 DOI 10.1007/s40735-016-0069-5

Growth of biolubes - forecast



Product Group	Application Area	Market Volume Europe total[1] (t)	Market Volume "Bio" 2008 [2] (t)	Market Volume "Bio" 2020 [3] (t) low legislation level	high legislation level
Biolubricants [4]	Hydraulic Fluids	650.000	68.000	155.000	230.000
	Chainsaw Lubricants	50.000	29.000	37.000	40.000
	Mould Release Agents	100.000	9.000	15.000	30.000
	Other oils:	3.600.000	31.000	70.000	120.000
	- Metal Working Fluids				
	- Industrial gear oils				
	- Greases				
	- Motor & Automotive Gear Oils				
	- Transformer oils				
TOTAL		**4.400.000**	**137.000**	**277.000**	**420.000**

[1] Great uncertainties: Year 2008 approx. 4,4 Mt – drastic decrease in year of world wide crisis in 2009

[2] Based on European Biolubricants Markets (Frost & Sullivan, 2007): Forecasts for Europe 2003-2013

[3] Extrapolation of the forecast of Frost & Sullivan 2007, based on the mean growth ratio of 2003 to 2010

[4] Biodegradable and / or Biobased Lubricants

Source: Fuchs Petrolub AG

R&D strategy for enhancing selectivity to monounsaturated FA

PUFAs

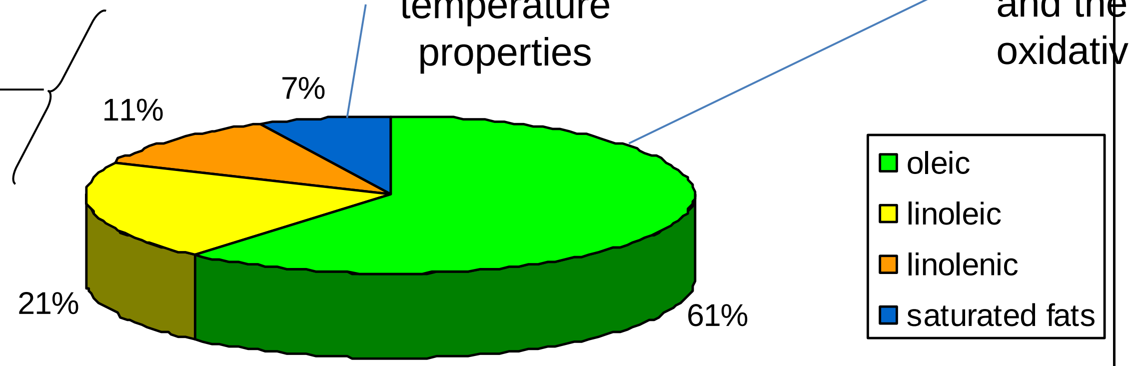
Determines thermal and oxidative stability

SAFAs

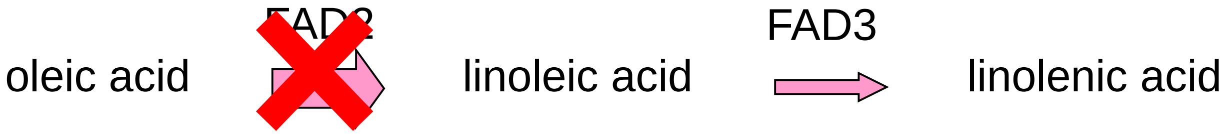
Determines low-temperature properties

Mono-unsaturate

Determines fluidity and thermal / oxidative stability



Low-erucic rapeseed oil FA profile



Agronomical aggravation!

Early experimental lines highlighted several issues such as low vigour and reduced cold tolerance :

Experimental line
Ixworth, UK
2013

Healthy LE rapeseed

Fatty acid profiles of experimental lines

	18:1	18:2	18:3	18:3/18:2	SAFA total	MUFA total	PUFA total
TAP	60,41	21,72	7,71	0,35	8,11	61,96	29,49
CAB	74,34	8,89	7,33	0,82	6,94	76,24	16,28
V141	82,00	5,86	2,86	0,49	6,70	84,01	8,76
M0830	86,42	1,80	2,83	1,57	6,17	88,51	4,63
M0814	85,50	2,06	3,33	1,62	6,19	87,49	5,43
M0814	85,30	2,35	3,66	1,56	6,31	87,08	6,01
K0472	84,69	2,31	3,63	1,57	6,31	86,83	5,98
S0092	84,22	2,41	3,66	1,52	6,44	86,51	6,11
K0472	84,04	2,34	3,56	1,52	7,18	86,05	5,90
K0692	84,03	2,52	4,18	1,66	6,43	86,20	6,70
M2444	83,98	2,46	4,41	1,79	6,32	85,90	6,94
M0643	83,89	2,44	3,52	1,44	6,90	86,31	6,01
S0619	83,28	2,86	4,88	1,71	6,09	85,37	7,78
K0047	83,25	2,25	4,11	1,83	6,84	85,70	6,39
S0619	82,55	3,04	5,16	1,70	6,39	84,65	8,24
S0619	82,21	3,27	5,12	1,57	6,55	84,35	8,43
S0619	82,11	3,25	5,44	1,67	6,34	84,24	8,73
M2234	82,08	3,23	5,30	1,64	6,60	84,06	8,58
S0032	81,98	3,34	5,44	1,63	6,14	84,07	8,84
S0619	81,96	2,95	5,36	1,82	6,63	84,10	8,36

- Increased oleic
- Decreased PUFA
- Slight decrease in SAFA
- Increased 18:3/18:2 ratio
- Greater proportion of linolenic

Comparison of Fatty Acid Compositions

		Biolubes HORO 13/14 crop	Biolubes HORO 12/13 crop	Cargill HO Sun Oil	Cargill LE Rape Oil
GC Fatty acids					
C16:0	% w/w	3,1	3,2	3,7	4,5
C18:0	% w/w	1,4	1,3	3,0	1,7
C18:1	% w/w	86,2	81,2	82,7	61,8
C18:2	% w/w	2,0	6,1	8,5	19,0
C18:3	% w/w	3,8	5,8	0,2	9,4
C20-22	% w/w	3,5	1,3	1,5	2,6
OTHERS	% w/w		1,1	0,4	1,0

Oil physical properties

Property	Unit	Biolubes HORO 13/14 crop	Cargill HO Sun Oil	Cargill LE Rape Oil	Mineral Hydraulic Oil (Fuchs)
KV @ 100°C	mm^2/s	8,4	8,4		6,6
KV @ 40°C	mm^2/s	39	41		46
KV @ 0°C	mm^2/s	263	237		ND
Viscosity Index	NU	170	186		101
Flash point	°C	262	270		210
OSI, 120 °C	hours	11,3	10,9	4,0	
Pourpoint	°C	-30	-11	-9	-27

Results and impact of project

- Mutation breeding supported by knowledge of target genes can be used to successfully develop defined genotypes of oilseed rape with inactivation of complete gene families.

- Oilseed rape genotypes are available that produce oil with much lower content of thermally unstable polyunsaturated fatty acids.

- The physical properties of extremely low polyunsaturate rapeseed oil are excellent, and offers the prospect of a high-oleic oil crop for N Europe.

- The project is likely to lead to the development of new markets for rapeseed oil: extremely low polyunsaturate type suitable for high temperature food and industrial uses.

Key learnings from the biolubes project

- It is technically and economically feasible to use modern crop breeding (non GM) technologies to develop base oil crop profiles *exclusively* for industrial and non-food purposes
    - Though food industry participation remains highly beneficial w.r.t. risk management, economics and speed-to-market
- Conflicting requirements of the ideal agronomic profile and the desired profile for industrial use remain, and must be optimised (eg cold tolerance)
- Concentration of specific fatty acids has broader relevance/benefits in other industrial applications:
    - Lower purification costs and/or higher yields of desired products (reduced side reactions)
    - Reduced dependence on co-stream economics

Bio-based success stories

Owens Corning

- Home Depot asked for new all-natural, formaldehyde-free insulation
  - OC, the industry leader, also insists upon superior performance and cost parity
- Engagement to implementation in 14 months
- Results: ”EcoTouch” brand created and launched in Jan 2011, 100% conversion by Summer 2011, increased safety for plants and employees - no more fires

Large utility in Western US

- Replaces 20,000 distribution transformers/year
- Sought to reduce failure rate by 1/6 and prolong asset life by at least 2 years
- Results: Achieved 17%/year reduction in transformer replacements, $9M NPV estimated savings over 30 years, increased fire safety and improved environmental footprint

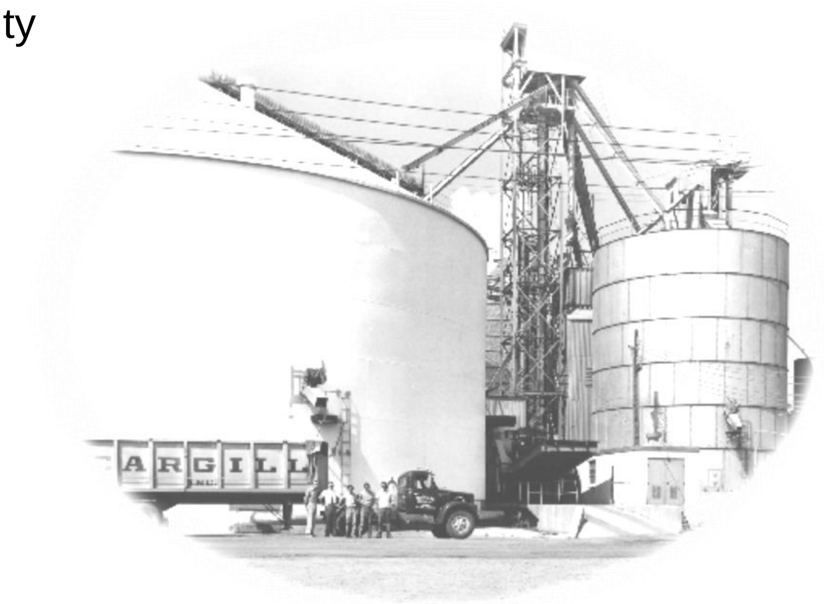
Big and powerful or small and beautiful ?
Concluding comments

- The two examples given today illustrate the importance of scale in supporting the development of the bio-based economy

  - To achieve ‘critical mass’ for purification of high–value microcomponents
  - To exploit existing refinery infrastructure for processing of new raws
  - To achieve ‘pay-back’ for high upfront investments eg in crop research

- R&D is critical to long-term and sustainable profitability
  - Proprietary process technology
  - Unique crop oils with added value functionality
  - Combinations of different classes of plant-derived raws
  - Integrated biorefinery concepts
  - (Bio)catalytic transformations of biomass

- The Bio-Future is bright !



Thank You !