Title: **Renewable chemicals into bio-based materials: from lignocellulose to PEF**

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Curriculum:
Ed graduated at Agricultural University Wageningen, the Netherlands and also defended his PhD thesis at the Agricultural University Wageningen, the Netherlands on the degradation of lignocellulose by white-rot fungi (1993). He has been research associate for 3 years at the University of British Columbia, Vancouver, Canada at the group of Jack Saddler, on the use of softwood species for biofuels application. He has been Head of the Department of Fibre and Paper Technology, Food and Biobased Research, Wageningen University & Research Centre, The Netherlands. He joint Avantium Chemicals in 2007. He is currently VP Development – responsible for Public-Private partnerships of Avantium, feedstock selection and pretreatment (Avantium's Zambezi technology) and Catalytic Biomass Conversion of carbohydrates into building blocks for polyesters such as PEF a improved replacement of PET. He is also involved in the production of aromatics from furanics via the so-called Diels-Alder chemistry and the valorization of side products of the YXY Process, cq humins and levulinates. He is co-chair of the IEA-Bioenergy Task 42 on biorefineries.

Abstract:
The vast majority of chemical building blocks are produced from fossil resources. In the future society there is a need to move to a circular, carbon neutral economy to mitigate the adverse environmental and geopolitical aspects associated with the exploitation of fossil resources. Many chemical building blocks can be produced from biomass, nowadays mainly from 1st generation based carbohydrates [1]. The use of non-edible lignocellulosic feedstocks is an equally attractive source to produce chemical intermediates and an important part of the solution addressing these global issues (Paris targets). In principal, the use of a biorefinery approach to use only part of the lignocellulosic biomass for bioenergy applications further improves both the economics as well as the sustainability of biomass use for bioenergy applications. Biomass chains have to be developed as soon as possible, and can be used for the production of electricity and heat during the construction and starting/upscaling phases [2]. Avantium's strategic objective is to deliver with it's 2nd generation Zambezi technology the best in class 2G "pure" glucose technology for (bio-)chemical & bioenergy applications for a sustainable future; in parallel delivering value generation from the implementation of this technology. All products streams should be marketed at their highest value [3].

Avantium Chemicals (www.avantium.com) is an high tech SME company known of their exploration into novel furan (YXY) chemistry, focused on efficient and low cost conversion of C6 sugars via HMF derivatives [4] into the promising chemical key intermediate FDCA.

FDCA can be used as building block for a wide range of applications including polyesters such as PEF, polyamides, resins and plasticizers [5]. PEF is a next-generation polyester that offers superior barrier and thermal properties, making it ideal material for the packaging of soft drinks, water, alcoholic beverages, fruit juices, food and non-food products. Therefore PEF is the 100% biobased alternative to PET. Currently, Avantium is working to bring 100% biobased PEF bottles to the market and intends to commercialize the YXY process in a Joint Venture called Synvina together with BASF. In the longer term brand-owners want to have the option to choose between 1st and 2nd generation feedstocks, therefore, Avantium has also developed forementioned Zambezi pretreatment technology to convert 2nd generation feedstocks in a “pure” glucose stream as well as the Mekong project to convert glucose into moneethylenglycol via hydrogenolysis. The potential of electrochemical reduction of CO2 to building blocks will also be addressed.

[1] de Jong, E., Higson, A., Walsh, P., Wellisch, M. (2012). Product developments in the bio-based chemicals arena. Biofuels, Bioproducts & Biorefining 6: 606-624.

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[3] de Jong, E., Gosselink R.J.A. (2014) Lignocellulose-based chemical products. In: “Bioenergy Research: Advances and Applications” (eds. Gupta, V.K., Kubicek, C.P., Saddler, J., Xu, F., Tuohy, M.G.) Elsevier, Amsterdam, The Netherlands. pp. 277-313. ISBN: 978-0-444-59561-4.

[4] van Putten, R-J., van der Waal, J.C., de Jong, E., Rasrendra, C.B., Heeres, H.J., de Vries, J.G. (2013) Hydroxymethylfurfural, a versatile platform chemical made from renewable resources. Chemical Reviews 113:1499-1597.

[5] de Jong, E., Dam, M.A., Sipos, L., Gruter G-J.M. (2012) Furandicarboxylic acid (FDCA), a versatile building block for a very interesting class of polyesters. ACS Symposium Series "Biobased Monomers, Polymers and Materials" (eds Smith, P.B. and Gross, R.) 1-13. DOI: 10.1021/bk-2012-1105.ch001.

Renewable Chemicals into Bio-based Materials:

from Lignocellulose to PEF

Ed de Jong

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Avantium - business units

avantium

Renewable Chemistry portfolio

- Zambezi: sugar from non-food biomass
- Mekong: 1-step conversion to bio-MEG
- Early stage research: various biomass
- Electrochemistry: various e-chem routes

YXY technology: bio-based plastics

- 100% biobased, recyclable PEF with superior properties
- Major market potential in packaging materials and fibers

Oct 2016, joint venture with BASF: Synvina

SYNVINA™
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Supported by an established business based on proven technology

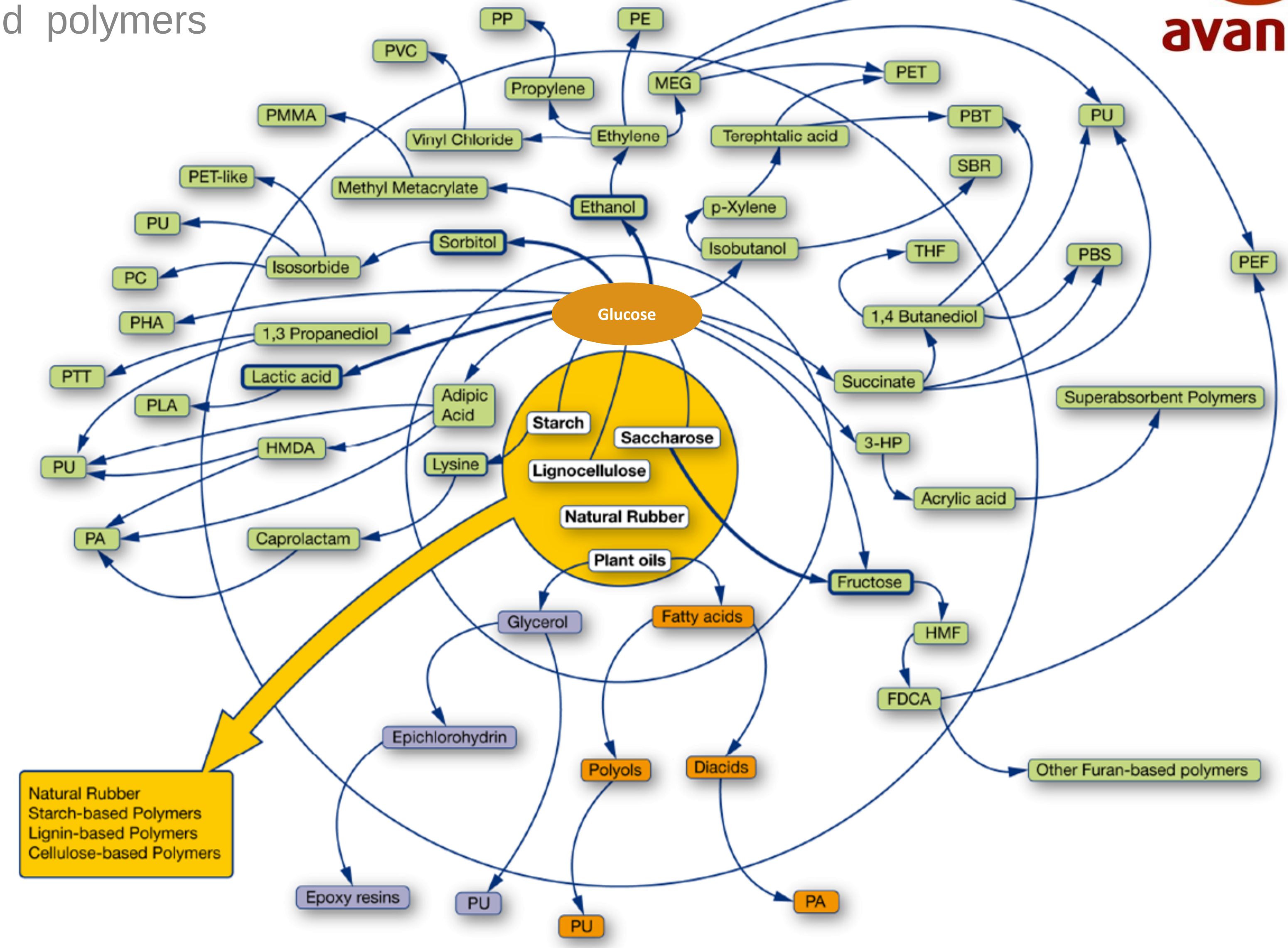
Catalysis R&D business

- Leading service and systems provider for blue chip clients in chemical and energy industry

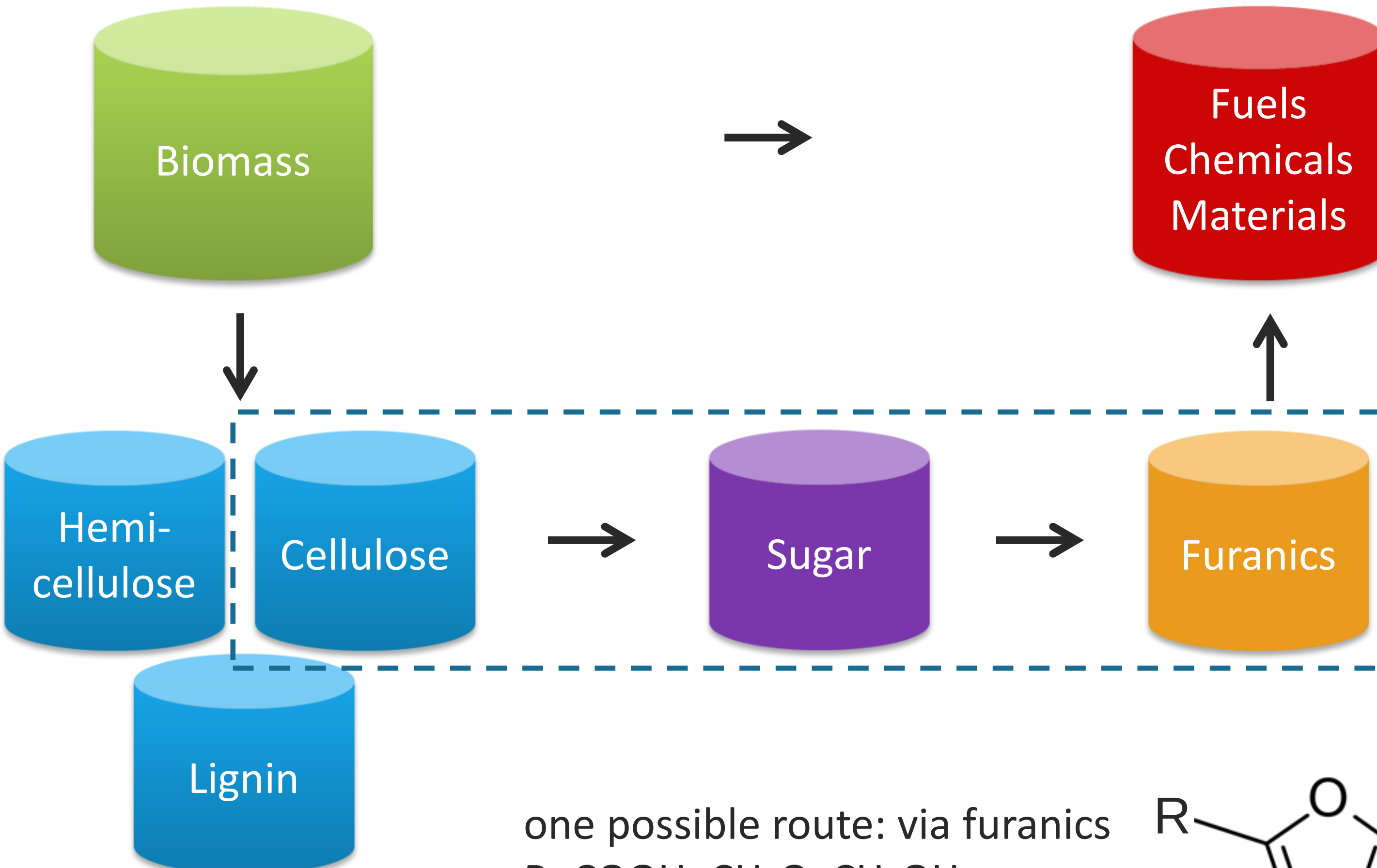
Shell | bp | ExxonMobil | Dow | Sinopec | sasol | Mitsubishi | sabic | ifp | Celanese | SCG | AkzoNobel | siluria | Chevron

Glucose

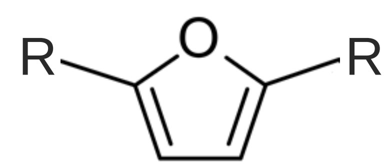
Glucose is a central building block for many bio-based chemicals and polymers



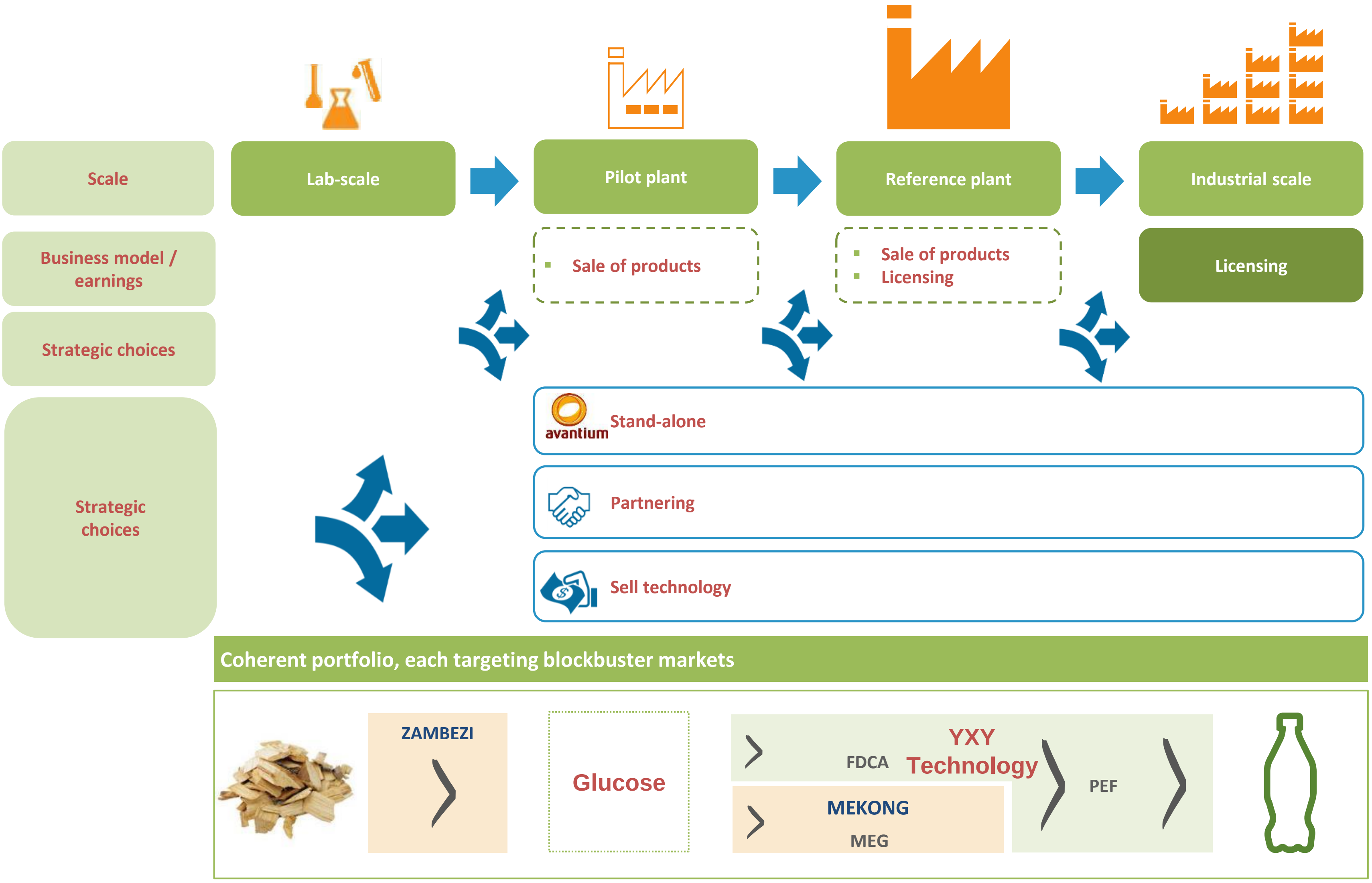
A lignocellulosic Biorefinery



one possible route: via furanics
R=COOH, CH_2O, CH_2OH



Strategic Options to Deploy Renewable Chemistries Projects



ZAMBEZI LignoCellulose pretreatment Biorefinery

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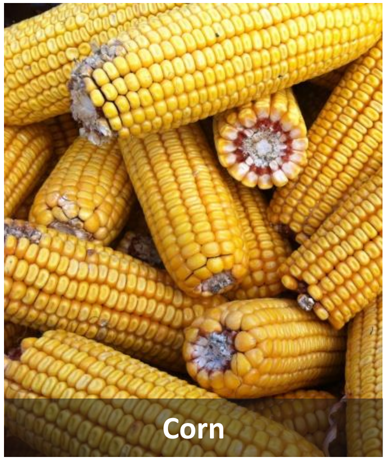
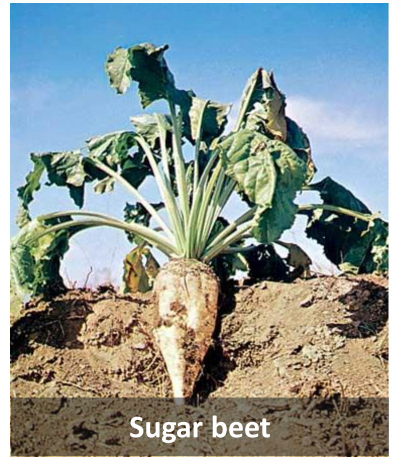
Sugar from 1G & 2G Biomass

First generation (1G) – Sugar cane, corn, sugar beet, wheat

Now

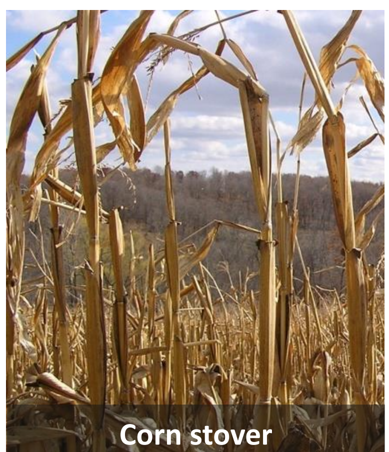




- Well established technology
- Delivers high quality sucrose & dextrose

Second generation (2G) - Wood, agricultural waste, waste paper, energy crops

Future

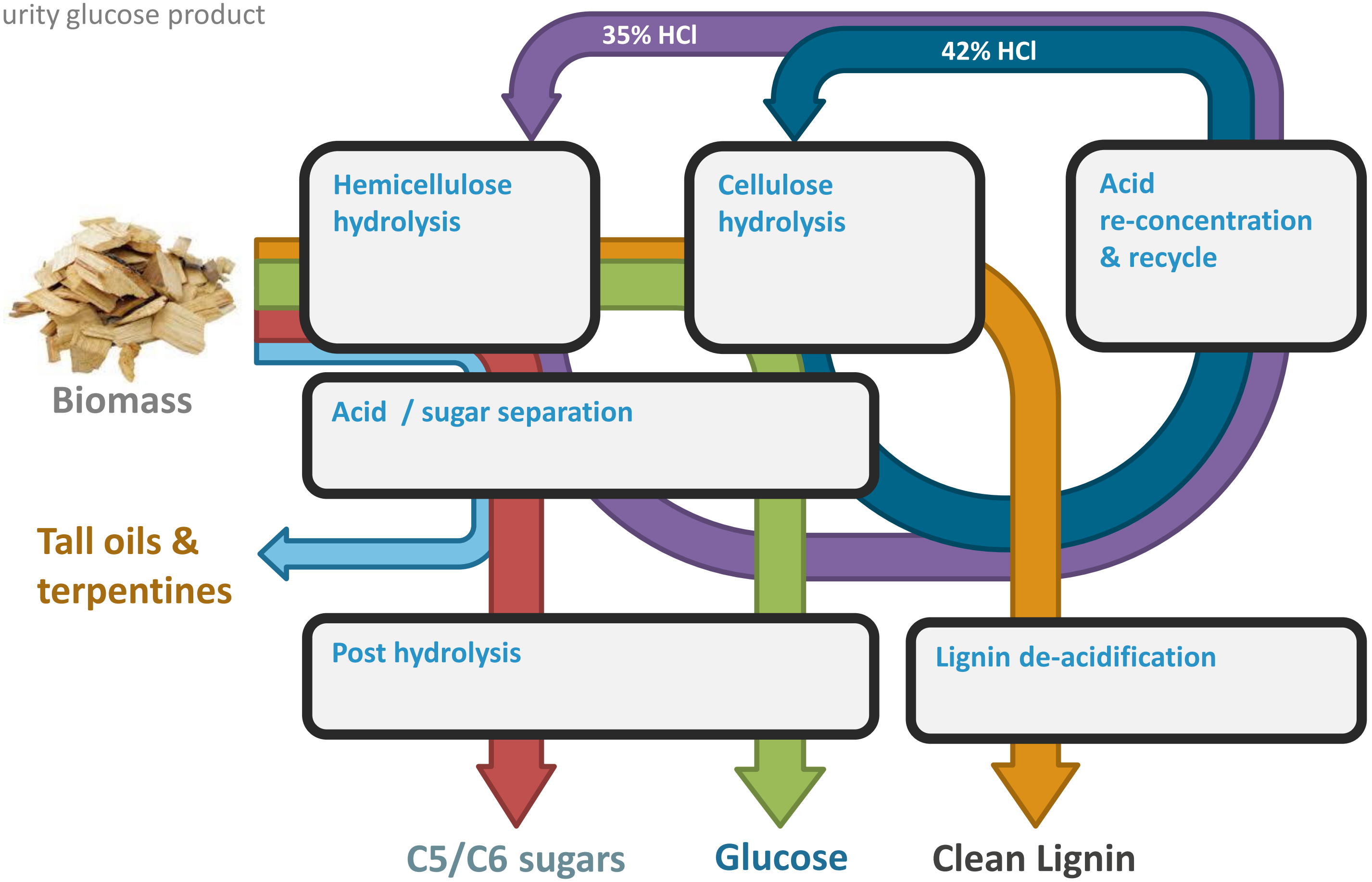


- Technologies still in development
- A challenge to deliver high quality dextrose

Zambezi Process

Process outline

Improved Bergius-Rheinau process
Two stage, concentrated HCl hydrolysis
Acid / sugar separation by proprietary evaporation technology
High purity glucose product



Opportunity and Impact of Zambezi

- Demand for sugars will increase
  - Arable land will come under increasing pressure
    - Demand for 1G products (grain, starch, sugars) will increase
    - More 1G milling will need to come on-line (primarily for food and feed)
  - Demand for 2G glucose to support bio-fuels will increase
  - Volume of plastics, especially bio-based, will increase
    - Demand for high purity 2G glucose will increase

- 2G Advantages:
  - free-up more 1G sources for food
  - reduce pressure on arable land
  - reduce volatility due to reduced seasonal effects

- We believe Zambezi, more than any other 2G technology, addresses the feedstock demands for the growing bio-based chemicals industry

Expected to enter commercial stage after 2020

Zambezi

H2 2016	2017	2018	2019	2020
Pilot plant design	Pilot plant construction	Application development & validation	Application development & validation	
Investment decision Pilot Plant			Basic engineering	Detailed engineering
▪ Feedstock partnerships ▪ Start construction pilot plant	▪ Start up pilot plant	▪ Partnerships	▪ Site selection ▪ Partner selection	▪ Start construction commercial plant

AkzoNobel
staatsbosbeheer
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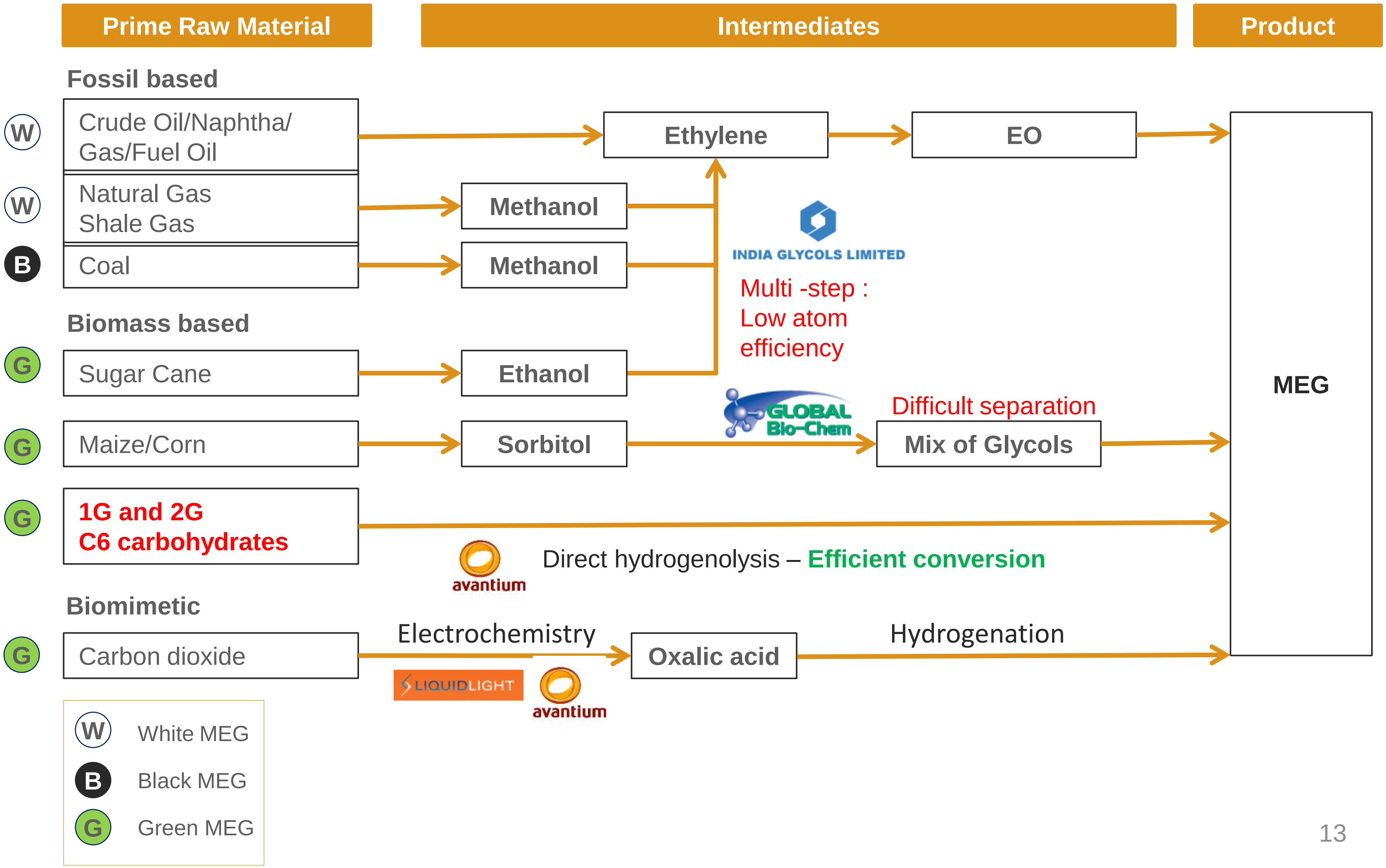
CHEMPORT EUROPE
RWE

Clear roadmap from lab to commercialization

MEKONG
Bio-MEG

Production Routes for MEG

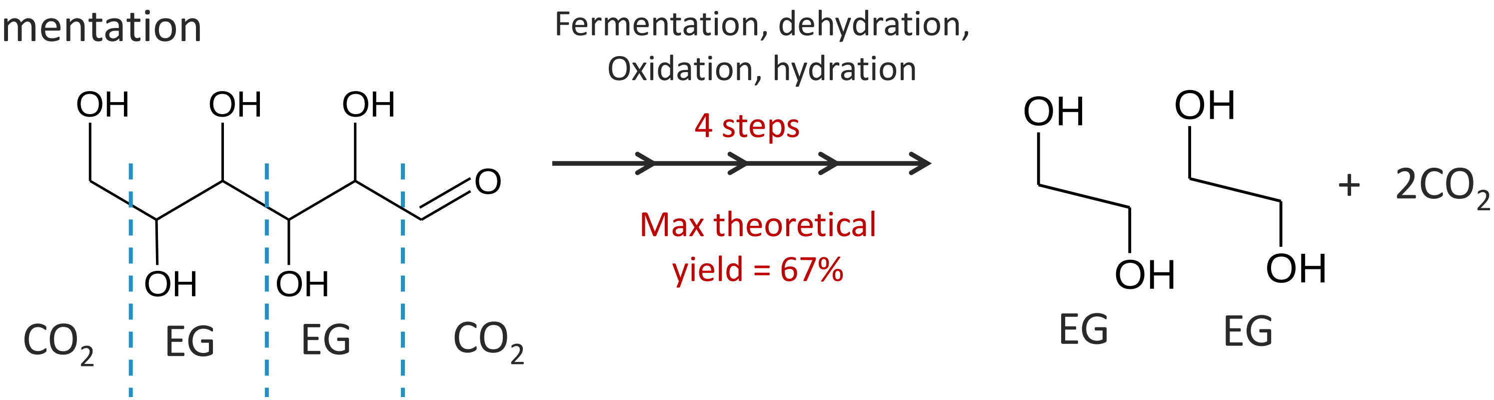


MEKONG: Superior Carbon Efficiency

Superior economics

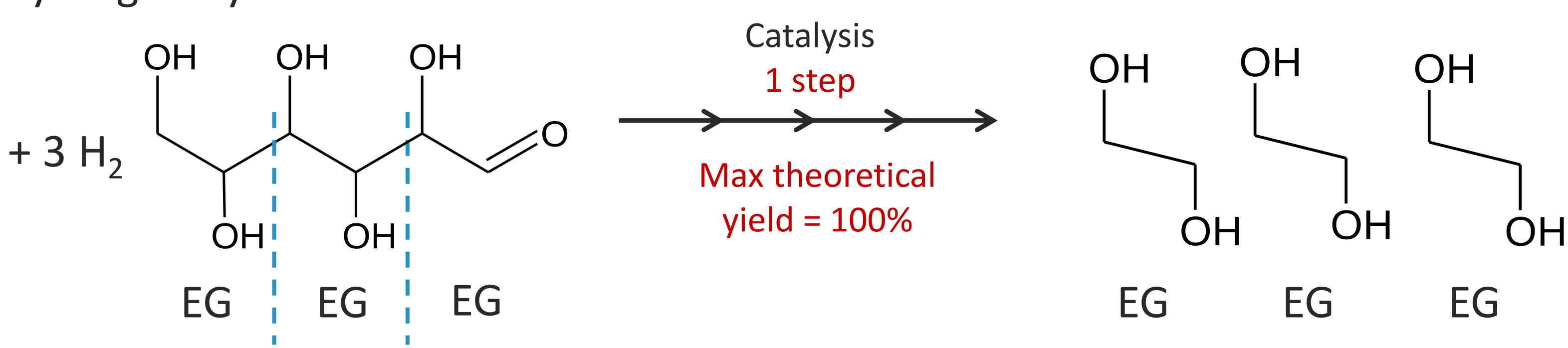
Current Commercial Production of Bio-based MEG

Fermentation



Avantium MEKONG Process

Hydrogenolysis



MEKONG: Process / Technology Assessment

Application Testing: Polyester polymerization

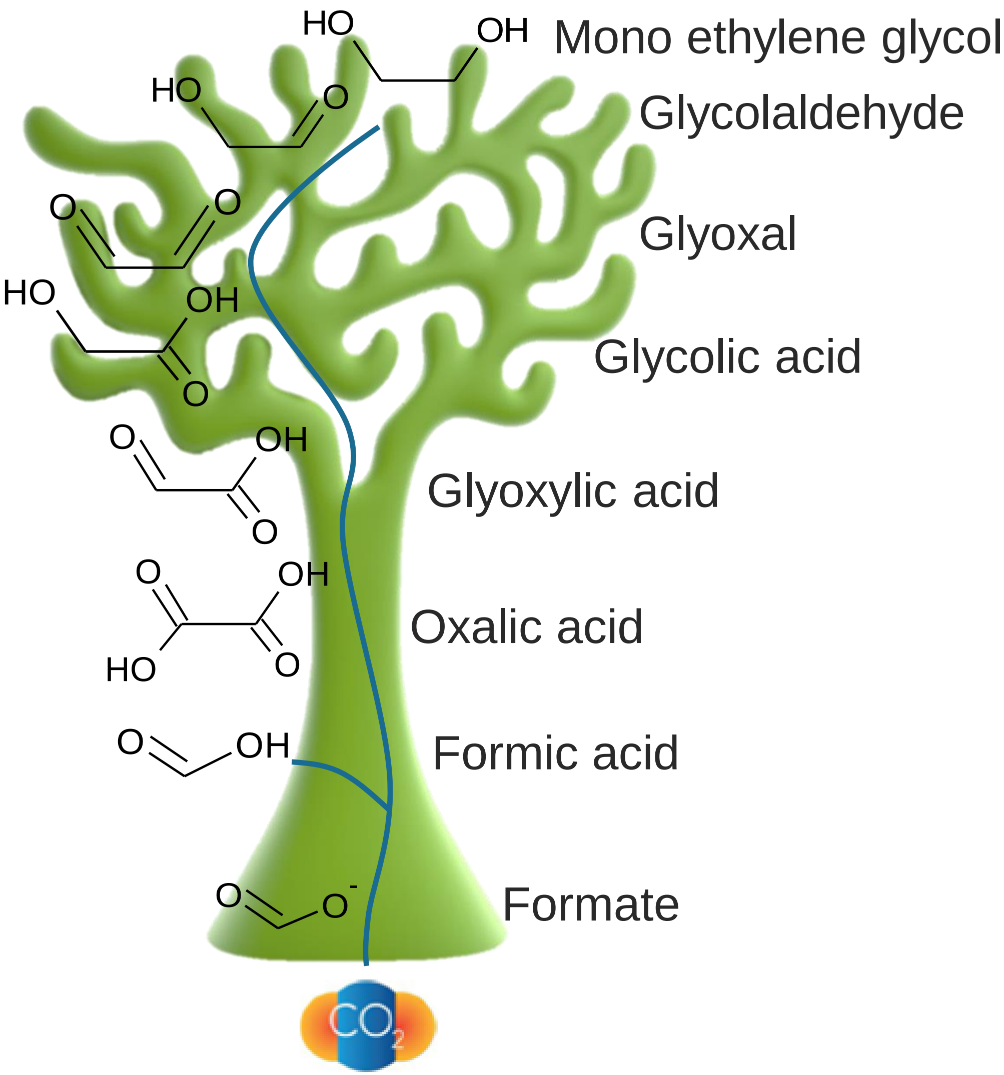
- Polymerization trial with distilled-only EG
- Mn/Mw similar to Petro- and Bio-MEG
- Color very similar

	Monomers	Ex-Reactor PEF		
	MEG	Mn	Mw	UV-Abs
1	Bio-MEG	16100	33200	0.005
2	Petro-MEG	16100	33100	0.006
3	**Mekong-MEG**	**16100**	**34400**	**0.007**

VOLTA

Electrochemical CO_2 Reduction

Electrochemistry: challenges & opportunities



- Replacing existing processes is not easy:
  - H_2 / O_2 for reduction / oxidation is often more economical
  - Margins on bulk processes are low: everything needs to be optimized
- Combination of skills required to design new electrochemical process:
  - Organic chemistry, Electrochemistry, Catalysis, Electrochemical engineering, Process design, Process Economics
- Opportunities: regimes that are not accessible to conventional catalysis or chemistries:
  - Target specific molecules / new feedstocks
  - Where number of process steps can be reduced
  - Where the amount of waste can be diminished

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Building the PEF Value Chain

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1	**Manufacturing Strategy of FDCA and PEF**
2	Commercial Opportunities for PEF films

SYNVINA: Joint Venture of two strong parents

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BASF
We create chemistry

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Building first commercial scale production plant
Reference plant of up to 50,000 tons FDCA capacity
PEFerence BBI Flagship project

Commercial launch of FDCA and PEF
Joint market development with key customers to go to market

Building licensing package for Synvina's technology and enabling industrial scale roll-out

Synvina Application Areas

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YXY technology

Fructose › FDCA › PEF

Applications of FDCA

FDCA
- Polyesters (incl. PEF)
- Polyamides
- Polyurethanes
- Other polymers
- Chemical building blocks

Applications of PEF

PEF
- Bottle
- Film
- Fiber

Synvina Pilot Plant

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- Synvina Pilot Plant Objectives
  - Process development
  - Engineering baseline for reference plant
  - Production of FDCA and PEF for evaluation of market applications with customer

- The pilot plant is in operation from 2011, and runs continuously 24hrs per day, 365 days per year

- New pilot plant building opened in 2016

Commercial Scale Up

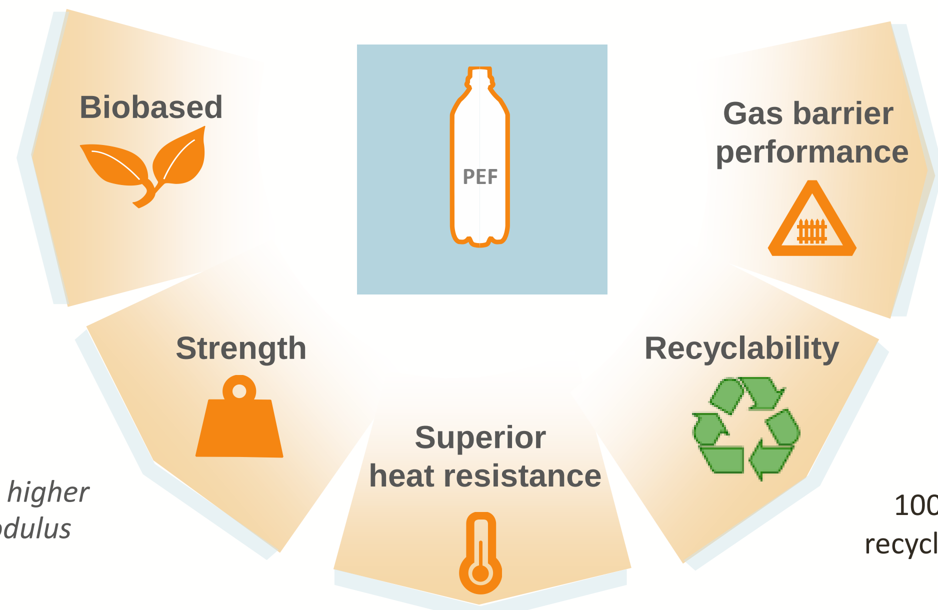
Lab-scale	Pilot Plant scale	Commercial scale	Industrial scale
Amsterdam	**Geleen**	**Antwerp**	**Licensee Site (tbd)**
Kg's	Tons	Up to 50kt	Industrial Scale
Innovative research	Technology development	Commercial launch of FDCA & PEF	Roll-out of FDCA & PEF at larger scale
←	Synvina	→	Licensing

Agenda

1 Introduction to FDCA and PEF

2 **Examples of Commercial Opportunities for PEF packaging**

PEF performance benefits



100% biobased

Oxygen 10x
CO2 10x
Water 3~4x

60% higher modulus

100% recyclable

12°C higher glass transition

Recycling

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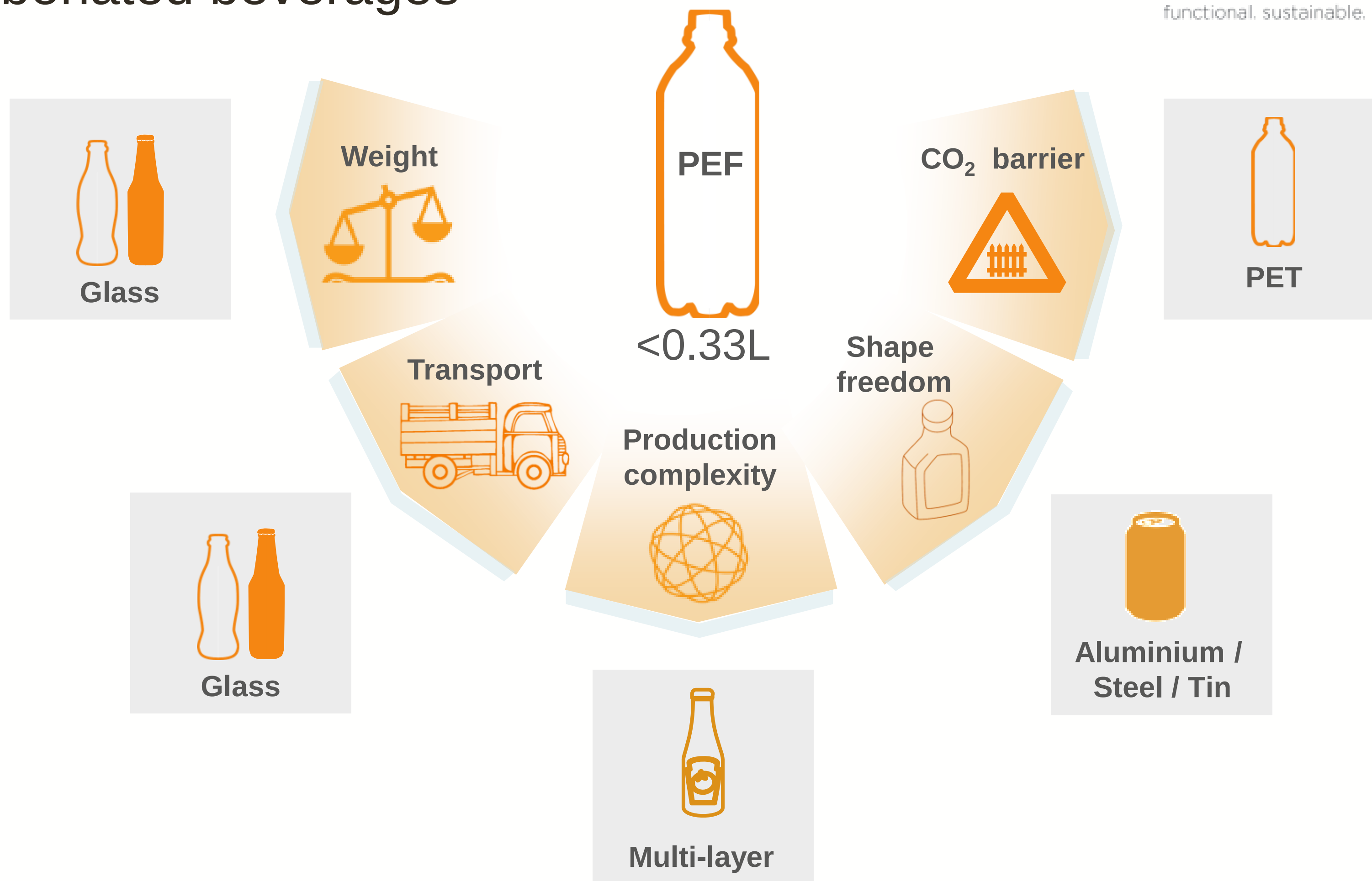
- Optimize end-of-life solutions for PEF polymer

- PEF to PEF recycling is similar to PET recycling
  - Mechanical recycling
  - Chemical recycling

- Transition period: PEF in the rPET stream
  - **Sorting:** PEF can be separated from PET by IR sorting
  - **Effect of PEF in rPET stream:**
    - Impact on rPET processes and end products assessed with recycling industry organizations
    - PEF significantly less impact on rPET than Nylon or PLA

Performance benefits of small PEF bottles for carbonated beverages



Small size PEF bottles for carbonated beverages
Customer demand for smaller servings

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In collaboration with ALPLA

8 oz (237 mL)

Compared to same bottle in PET:

- 2x Top Load
- Up to 6x CO_2 shelf life
- Improved creep resistance

Opportunities:

- Longer supply chains enable new sales channels
- Optimized production cycles
- Shape freedom enables Brand differentiation (vs. cans)

Thank you for your attention.

Questions??

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