5-HMF as Key Enabler in Bio-based Chemistry

4.10.2018 Dr. Stefan Krawielitzki

WELCOME TO
A NEW WORLD OF RENEWABLE CHEMICALS

Company

Established in 2009

20 Experts

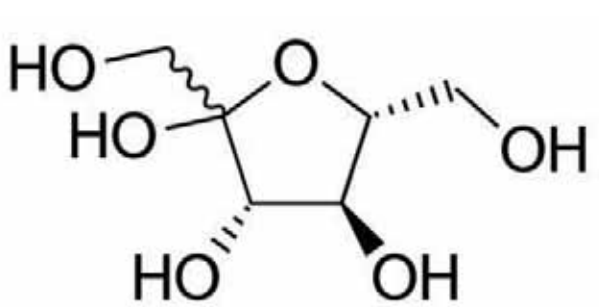
15 Patents

Based in Switzerland

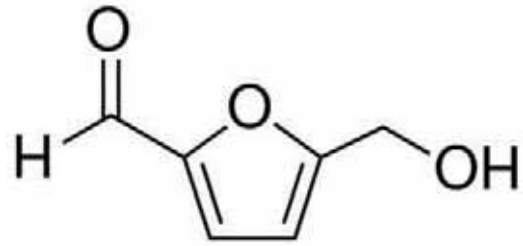
100% Privately owned

6 Nationalities

HMF – It's only sugar and water



Fructose

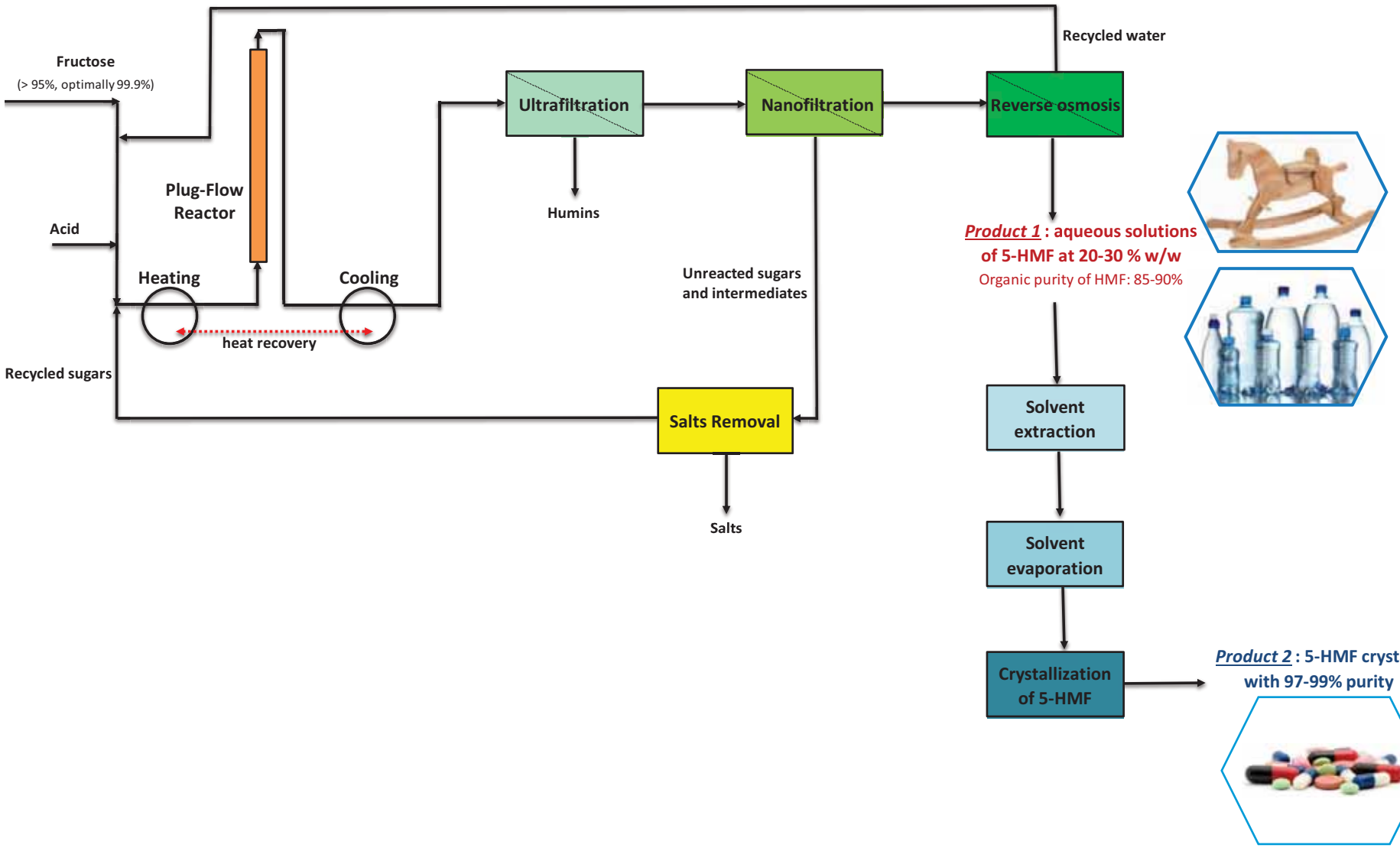


5-HMF: 5-Hydroxymethylfurfural

Aqueous solution
20-55 w%

Crystals 95-99%

AVA-Biochem`s Process



5-HMF pilot plant by AVA Biochem

Largest 5-HMF production plant world-wide

AVA Biochem, Muttenz
Industrial scale Single Plug Flow Reactor

Max. Production Capacity

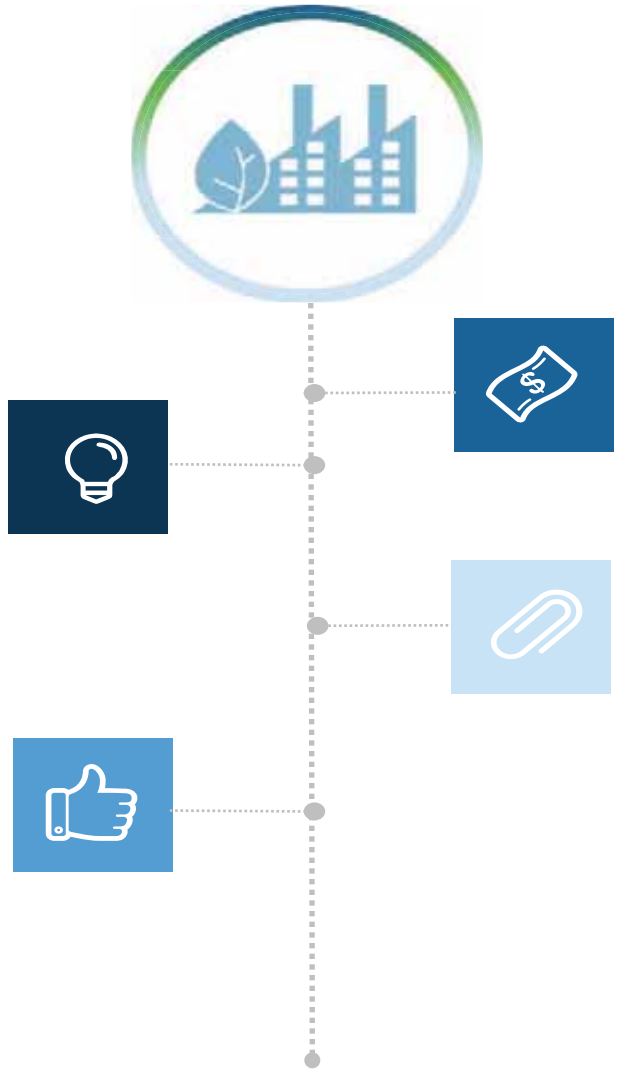
- 5-HMF in water: 50kg/h (dry weight)
- 5-HMF crystalline: 10 t/a (dry weight)

Start of Operation 2014

Customer Base

- Blue Chip Chemical Enterprises
- Pharmaceutical Companies
- Food additive Producers
- Universities and R&D Institutes

Best in Class Process / Technology



HTP

AVALON Industries developed, patented and piloted a breakthrough **Hydro Thermal Processing** technology (HTP) for large scale production of 5-HMF

LONG-TERM

The most efficient, **robust**, environmentally friendly and **scalable** process offering the best economic **yield** for the 5-HMF production and thus securing **long-term competitiveness**

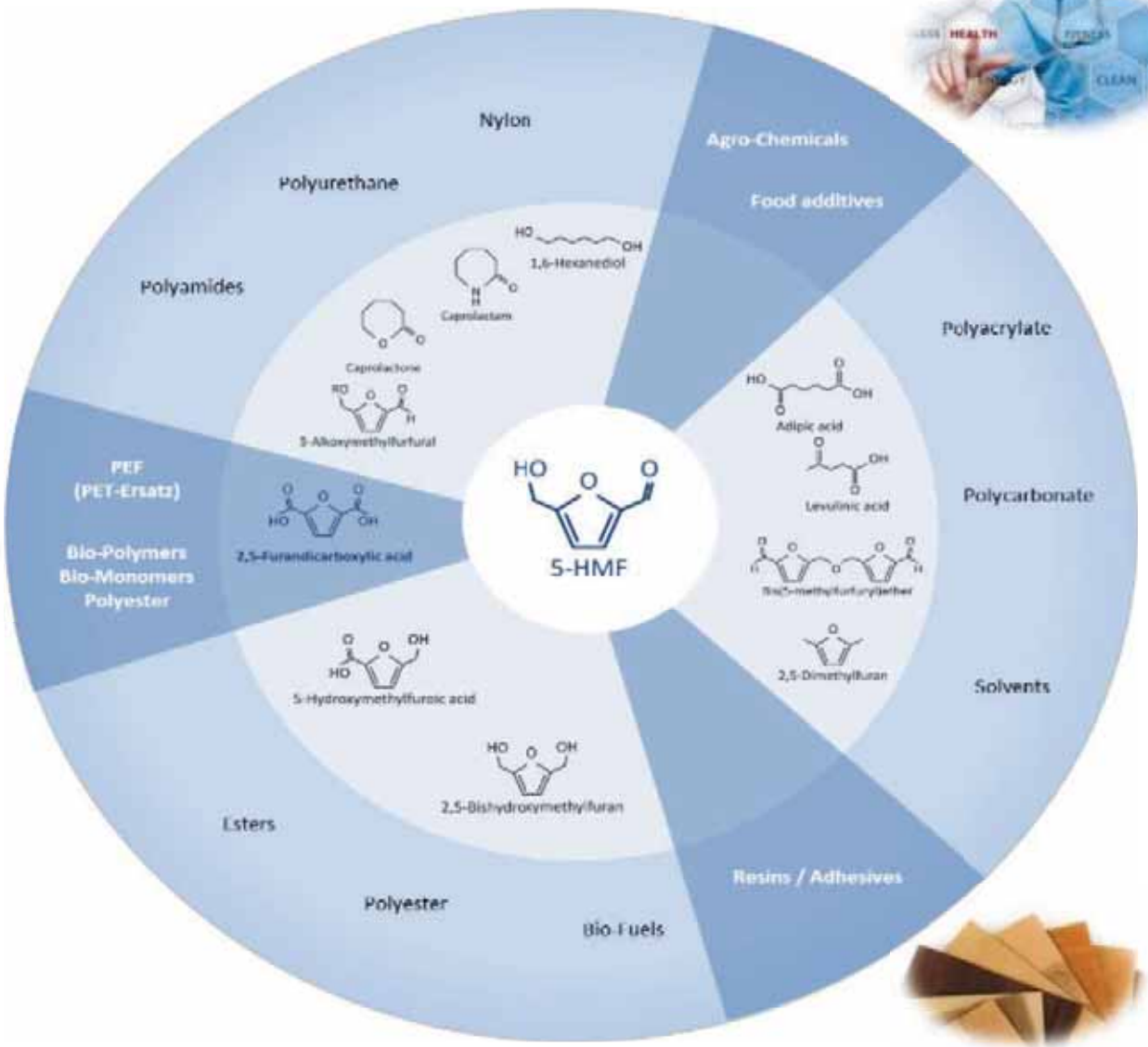
COST COMPETITIVE

HTP is a cost competitive, **water-based** 5-HMF production technology

HIGHLY FLEXIBLE SOLUTION

AVALON Industries' **water based** HTP technology supports the main FDCA oxidation routes (biological, enzymatic and electro chemical) through a proprietary **solvent-switch** process all chemical oxidation processes are also being supported. This makes AVALON's HTP process **highly flexible** and a real drop-in solution

Market Focus



Aqueous solutions of 5-HMF at 20-50 % w/w for:

- Formaldehyde replacement
- Polymer industry

5-HMF crystals for:

- Fine chemical industry
- Health & Wellness

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Market Focus

Blockbuster markets for 5-HMF-based applications

PEF polymer for packaging and other applications

- Bottles
- Fibers
- Films
- Tires

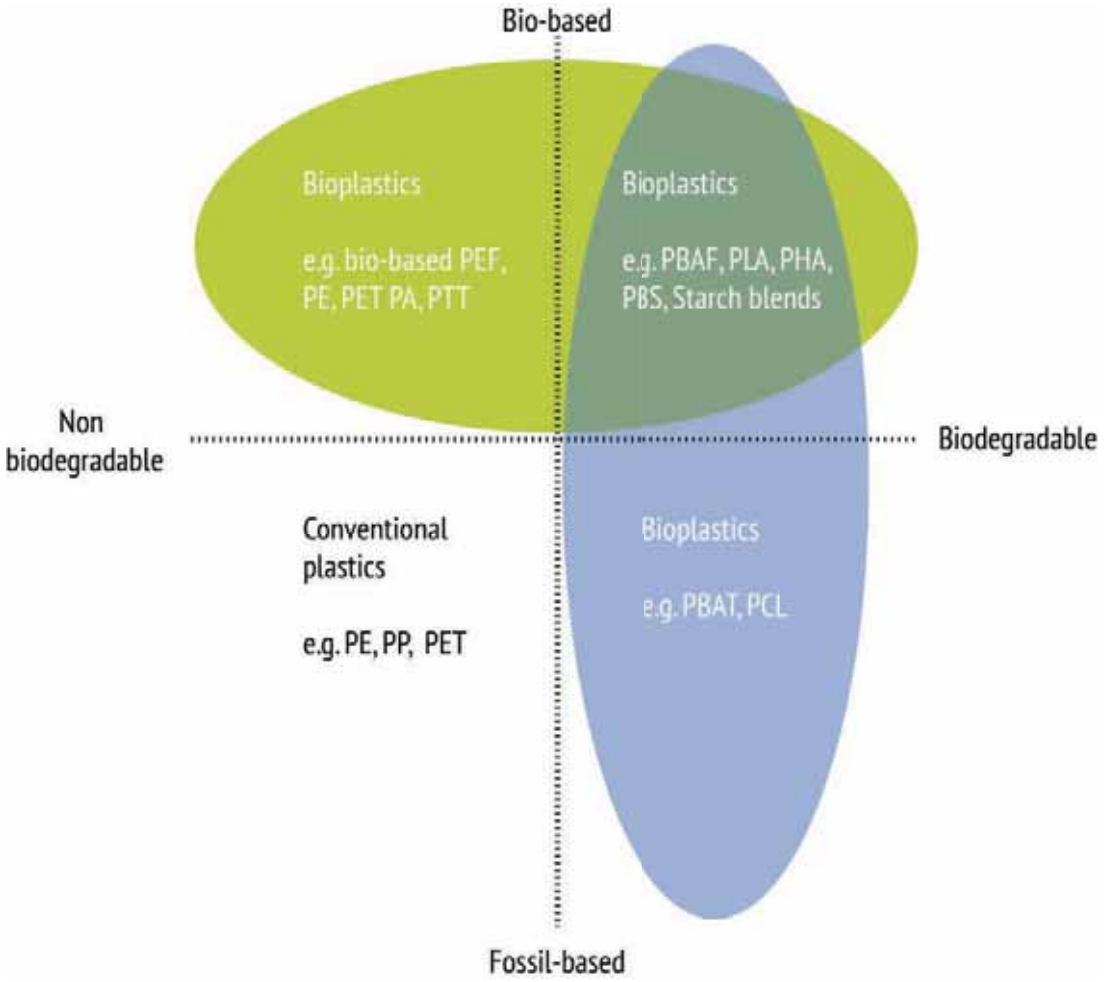
Formaldehyde replacement in composite materials

- Fiber boards
- Laminated wood panels
- Tires

Fine Chemistry applications Health & Wellness

- Pharmaceuticals
- Dietetic Additives
- Food and Drink Ingredient

Hydrothermal processing (HTP) technology: Biobased vs. Biodegradable



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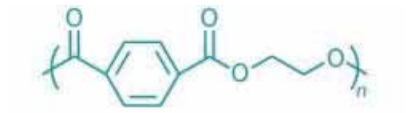
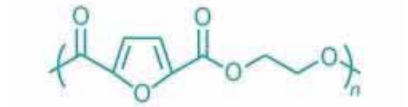
COMPARISON OF THE PATHWAYS PET vs. PEF



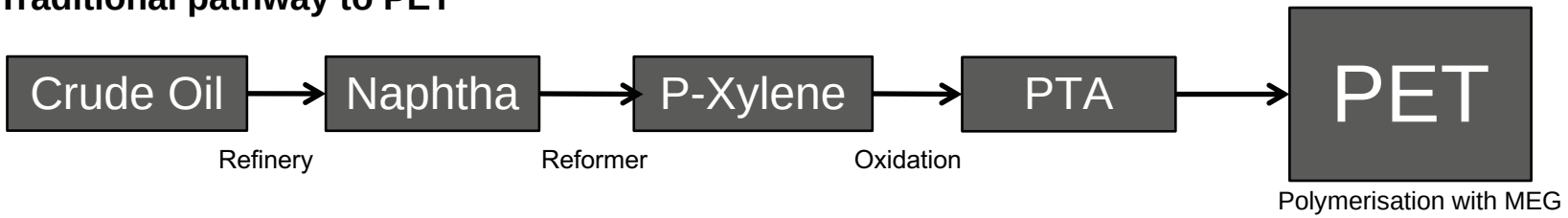
Polyethylene terephthalate (PET)



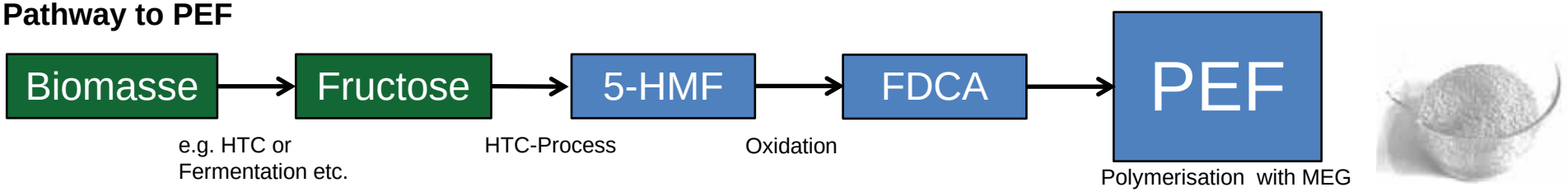
Polyethylene furanoate (PEF)

PET and PEF differ slightly, but importantly, in their chemical structures. The diagrams of the molecular structures (left) show that the “ends” of PET and PEF are identical (both are linear polyesters of aromatic di-carboxylic acids with ethylene glycol). It is a recognized goal to use PEF as a “drop-in” substitute in equipment used today for PET. PEF’s furan ring structure leads, amongst other things, to its having much better gas barrier properties than PET. This is highly valued in the packaging and other industries.

Traditional pathway to PET



Pathway to PEF



PTA = purified terephthalic acid

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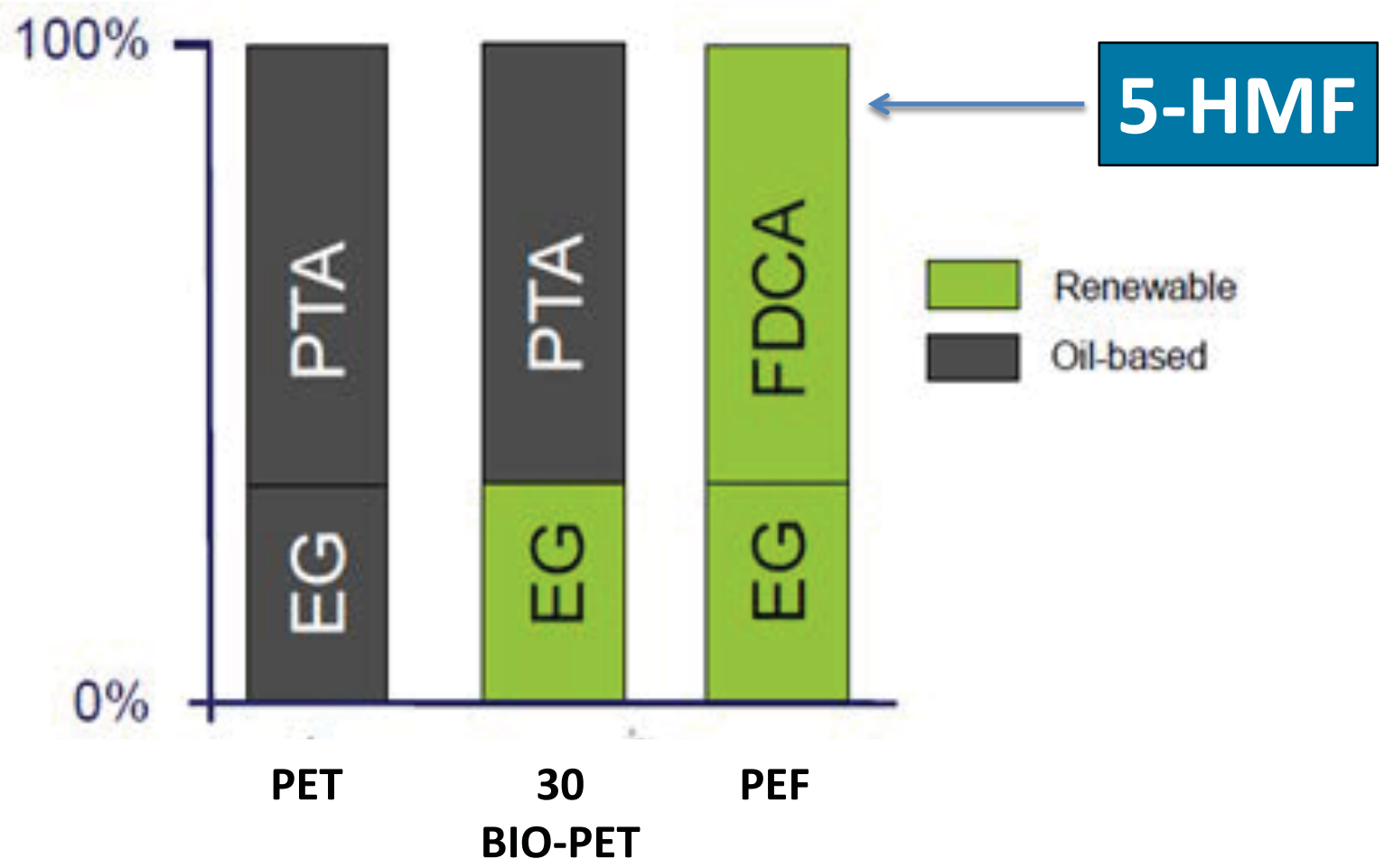
Hydrothermal processing (HTP) technology:
PEF: 100% Biobased



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5-HMF based PEF: Superior Properties

Bio-based	• 100%
Strength	• 60% higher modulus • Less material per application
Superior heat resistance	• 12° C higher glass transition temperature
Better Barrier Properties	• CO_2 10x • Oxygen 10x • Moisture 2x
Recyclability	• 100%

Illustrative Example

Beer bottle
330ml

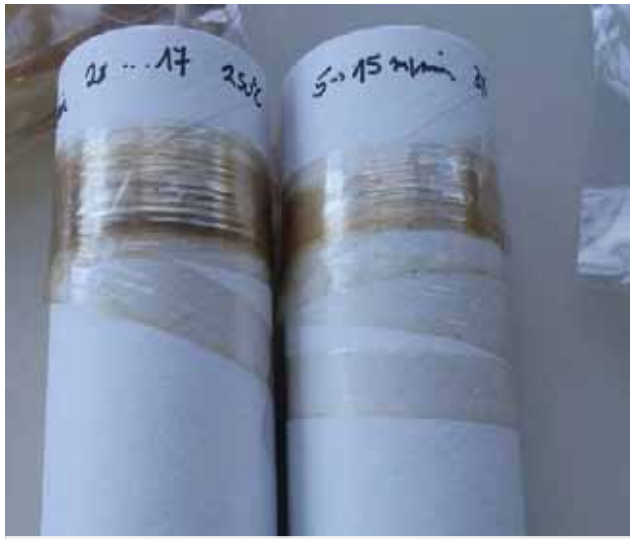
- **Weight 30 grams**
- **Must be spiked with additives**
- **Additional layers to reach required barrier properties**

PET

PEF

- **Weight 20 grams**
- **Less need for additives**
- **3 times better barrier properties than PET bottle**

5-HMF based PEF : 1st films and yarns



Mechanical analysis films

Material	Draw ratio	Extruder T	Tenacity (N/tex)	Modulus (GPa)
PEF 231017	2x	240 °C	0,06	2,4
	3x	240 °C	0,07	2,5
	2x	250 °C	0,06	2,5
	3x	250 °C	0,05	2,1
PEF 190218	2x	250 °C	0,06	2,6
	3x	250 °C	0,10	2,8
PET RT20	2x	275 °C	0,04	1,4
	2x	275 °C	0,04	1,6

- **Bio-based**
- **Strength**
- **Thermal properties**
- **Better barrier properties**
- **Recyclability**

Examples of 5-HMF Chemicals & Polymers

OTHER IMPORTANT PATHWAYS FROM 5-HMF TO POLYMERS CONTAINING A FURAN RING

Pathways from 5-HMF to Polymers containing a Furan Ring		
Furandicarboxylic Acid	FDCA	Polyesters PEF (Polyethylenefuranoate) PBF (Polybutylenefuranoate) Polycarbonates PBAF (replacing PBAT)
2,5-Bis(hydroxymethyl)furan	DHMF	Polyesters / Polyurethanes
5-Hydroxmethyl-furan-2-carboxylic Acid	HFCA	Polyesters
2,5-Bishydroxymethyltetrahydrofurane		Polyesters / Polyurethanes
2,5-Bis(aminomethyl)furan		Polyurethanes

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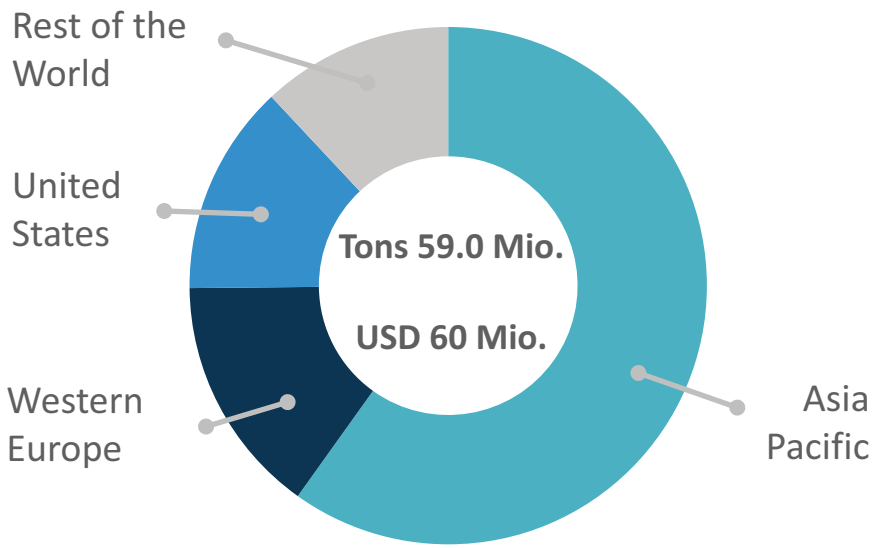
Formaldehyde substitution with 5-HMF

Formaldehyde

- Used in the production of resins & adhesives for wood composites, panels, tires, etc.
- Most commercially important aldehyde:
  Urea-, phenol-, and melamine-formaldehyde resins (UF, PF, and MF resins) account for 70% of world demand for formaldehyde in 2015

World Consumption of Formaldehyde - 2020



Growth Forecast (CAGR) **4.7%**

Reclassification of Formaldehyde

The reclassification of Formaldehyde is driving the demand for a alternative, non-toxic solution in Europe, North-America and Asia

5-HMF as a bio-based, non-toxic alternative to formaldehyde has the potential to quickly enter the global adhesive market and obtain an important market share for the three main resin applications:

- Urea-HMF resins
- Phenol-HMF resins
- Lignin-HMF resins

Biggest players in the resin and adhesives market	3M, Henkel, Illinois Tool Work, Huntsman, Avery, Sika, Dow and BASF

Main reasons 5-HMF will replace formaldehyde

100% **Bio-based**

- Not carcinogenic
- Not mutagenic
- Meets new regulations

Non-Toxic

- Will avoid additional investment cost in existing production
- Easy to substitute
- Existing markets

Drop-In

- Equivalent performance
- Comparable cost

Performance

Reclassification of formaldehyde

- Compulsion to manufacture low formaldehyde emission products
- Classified as ‘carcinogenic to humans’ by IARC

Current formaldehyde emission

- Standard defined by the E1 class (EN13986)
- Limited formaldehyde concentration in emission chamber tests of 0.1 ppm according to EN 717-1

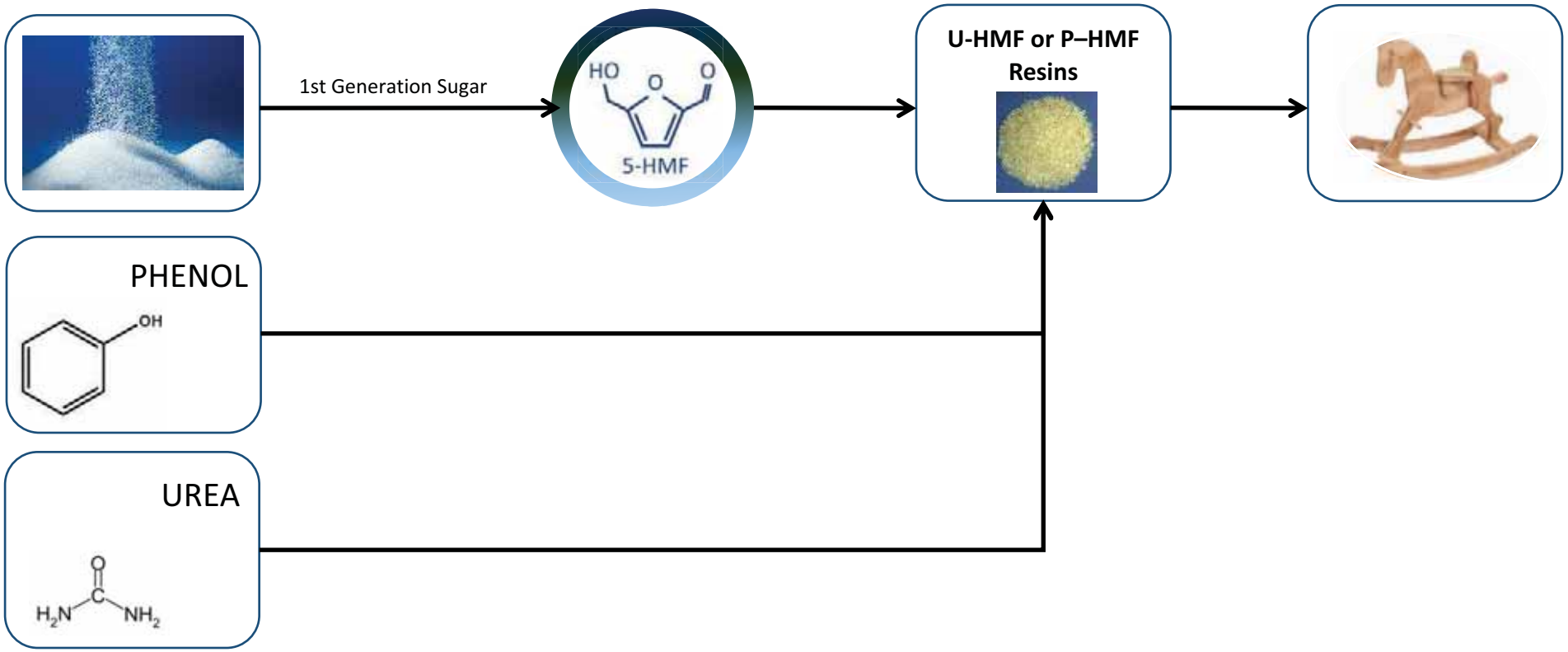
Major industrial consumers

- Such as IKEA
- Such as tannery industry
- Require ‘E0.5’ regulation
- Approximately half of the E1 class

IARC: International Agency for Research on Cancer (part of WHO)

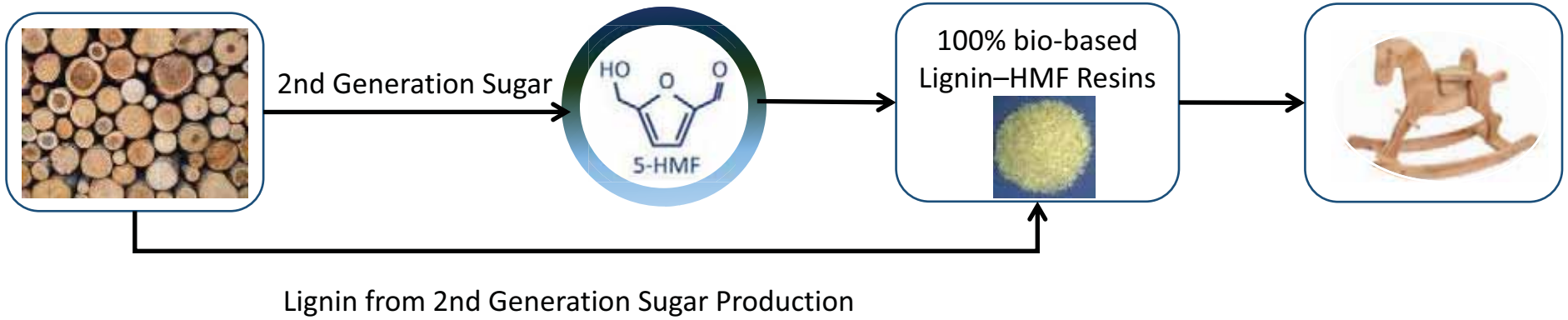
5-HMF: Formaldehyde replacement

The formaldehyde replacement approach

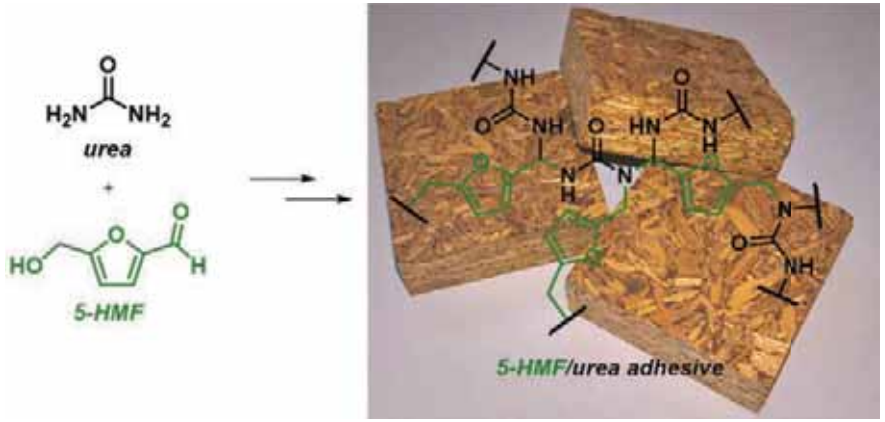


5-HMF: Formaldehyde replacement

The 360° circular approach



Case study: replacement of formaldehyde in UF-resins



- Proof of concept for adhesive formulation/synthetic protocol have been established
- Scope and limitations of press-parameters (time & temperature profile) are still under evaluation
- Target density of particle boards: 650-700 kg/m^3
- Adhesive loading: ≤10% with respect to dry wood
- Mechanical evaluation according to NF EN 319
- 0.3-0.55; 18-26 s/mm
- Solid content between 50 to 75%
- Emission testing results:
  - exceptionally low VOC emission profile (ISO 16000-6): relevant VOCs well below **20 µg/m³**
  - formaldehyde emission (ISO 16000-3): **7.5 µg/m³** (day 3) and **7.1 µg/m³** (day 28)

→ "natural formaldehyde wood emission"

Examples of 5-HMF Chemicals & Polymers

FORMALDEHYDE REPLACEMENT IN DUROPLASTICS, THERMOPLASTICS AND ELASTOMERS

5-HMF's reactivity and its functional groups make it an interesting candidate for the replacement of formaldehyde in e.g. UF or PF resins for the furniture or tire industry.

Replacement of Formaldehyde in Duroplastics, Thermoplastics and Elastomers	
5-HMF + Phenol	Phenoplasts
5-HMF + Urea 5-HMF + Thiourea 5-HMF + Melamin 5-HMF + Cyanamide 5-HMF + Polyamines	Aminoplasts
5-HMF + Polyisocyanates	Polyurethanes
5-HMF + Butanone p-Toluenesulfonamide	Thermoresistant Resins

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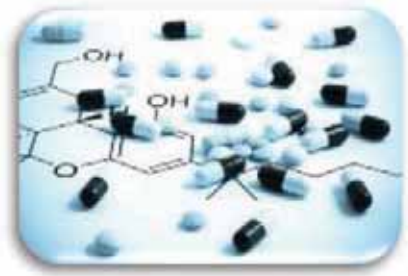
Pharma, functional food and dietary products



Novel pharmaceuticals represent a growing and interesting future market for 5-HMF as a promising active pharmaceutical ingredient (API).

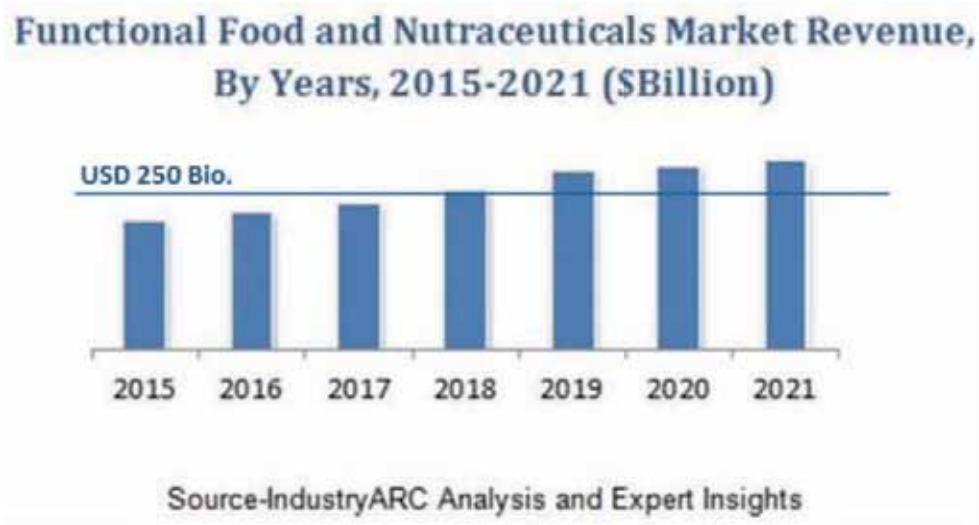
Functional Food and Dietetic Additives are fast growing markets with lower barriers to entry compared to pharmaceuticals and therefore much faster go to market possibilities.

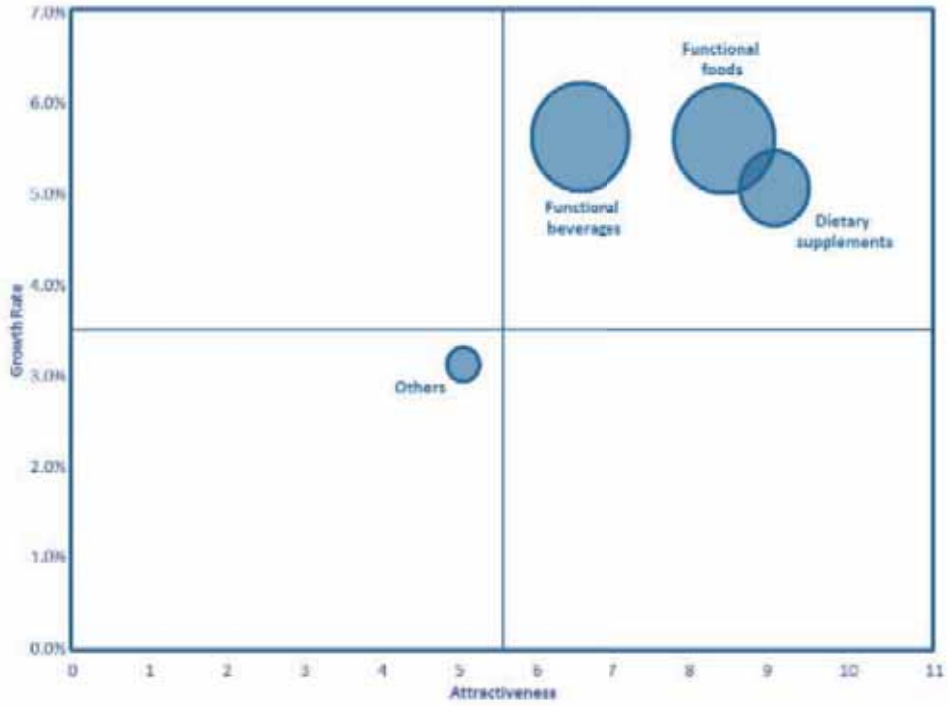
The success of the **food and drink ingredients** industry can best be seen by the triumph of the Energy Drink segment. 5-HMF is a promising ingredient for the next generation Energy Drink.

Functional foods – a large and growing market

Estimated Market 2018 **USD 250 billion**

Growth Forecast (CAGR) **5.5%**





Benefits of 5-HMF as an active ingredient

Oxidative stress

Oxidative stress is thought to be involved in a large number of disease including Parkinson and Alzheimer. 5-HMF can help to reduce oxidative stress in the body.

Capturing toxic ammonia

By capturing toxic ammonia, 5-HMF can improve the symptoms of insufficient oxygen supply e.g. at high altitude or protect molecular oxygen from attack by radicals and therefore improve overall oxygen utilisation

Minimization of Reactive Oxygen Species

The minimization of ROS by 5-HMF can prevent damage to DNA or the de-activation of specific enzymes in the human body.

Improving physical performance

By increasing haemoglobin affinity for oxygen and capturing excess ROS, RONS, RNS, 5-HMF can improve physical performance.

EU projects

EnzOx2 - New enzymatic oxidation/oxyfunctionalization technologies for added value bio-based products
ID: 720297
Start date: 2016-11-01, **End date:** 2019-10-31
Programme: H2020-EU.3.2.6.

GRACE - Growing advanced industrial crops on marginal lands for biorefineries
ID: 745012
Start date: 2017-06-01, **End date:** 2022-05-31
Programme: H2020-EU.3.2.6.

MYPACK - Best markets for the exploitation of innovative sustainable food packaging solutions
ID: 774265
Start date: 2017-11-01, **End date:** 2021-04-30
Programme: H2020-EU.3.2.2.3.

CARBAFIN - Carbohydrate-based fine chemicals: Development of a glycosylation platform cell factory and optimization of downstream processing for the sustainable production of glycosides.
ID: 761030
Start date: 2018-01-01, **End date:** 2021-12-31
Programme: H2020-EU.2.1.4.

PERFORM
ID: 820723
Start date: 2019-02-01, **End date:** 2023-12-31
Programme: H2020-NMBP-SPIRE-2018

Thank you for your attention!

Contact Details:

Dr. Stefan Krawielitzki

Expert for Organic Chemistry

+41 41 727 09 75

s.krawielitzki@ava-biochem.com

AVA Biochem AG

Bahnhofstrasse 17

6300 Zug

www.ava-biochem.com