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Task 42 – Biorefineries

Product Developments in the Bio-based Chemicals Arena

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Market size and potential GHG savings

Technology push or market pull?

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Introduction

Why producing Biobased Chemicals (in conjunction with Bioenergy) in a Biorefinery

- To improve the economics of bioenergy production
- To make scaling up easier (makes plant already commercial viable at smaller scales)
- Unique functionality
- Medium term CO2 storage (depending on chemical)
- Reduction of NREU usage (both because of renewable product and less fossil fuel used in production

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Current Market Size

Fossil based Chemicals:

330 million tonnes

Main molecules:

methanol, ethylene, propylene, butadiene, benzene, toluene and xylene

Biobased Chemicals & Materials

50 million tonnes

Main molecules:

Non-food starch, cellulose fibres/derivatives, tall oils, fatty acids and fermentation products

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Potential for GHG savings

Product	GHG savings (t CO_2/t of product)	Installed world capacity (million t/year)	Annual GHG savings (million tonne CO_2/year)[4]
Acetic acid	1.2	8.3	9.6
Acrylic acid	1.5	2.9	4.4
Adipic acid	3.3	2.4	7.9
Butanol	3.9	2.5	9.6
Caprolactam	5.2	3.9	20.0
Ethanol	2.7	2.6	7.1
Ethyl lactate	1.9	1.2	2.2
Ethylene	2.5	100.0	246
Lysine	3.6	0.6	2.3
Succinic acid	5.0	1.4	6.8
1,3-propanediol	2.9	-	-
PHA	2.8	57.0	160
PLA	3.3	11.1	36.5

Hermann, B.G., et. Al. 2007 *Environ. Sci. Technol*. 41, 7915-7921.

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Pull or Push ?

- Governmental – Legislative push
  - Sustainability
  - GHG/NREU usage
- Technological push
  - Biochemical / Chemical
  - Concepts versus applicability
- Market pull
  - Brand owners

What does the market think about this?

"We are working to completely eliminate the use of nonrenewable fossil fuels in our plastic bottles while maintaining quality and recyclability"

"Reducing the environmental impact of packaging: we will be developing partnerships with 2nd and 3rd generation bioplastics manufacturers"

"Using 100% renewable or recycled materials for all products and packaging"

"Reduce the carbon footprint of our operations"

"Halve the greenhouse gas impact of our products across the lifecycle by 2020"

"Leading in the development and use of packaging materials made from sustainably managed renewable resources such as bioplastics"

"Green. That's how we'd like the world to be. As an environmental leader, we do more than meet industry standards – we seek to raise them"

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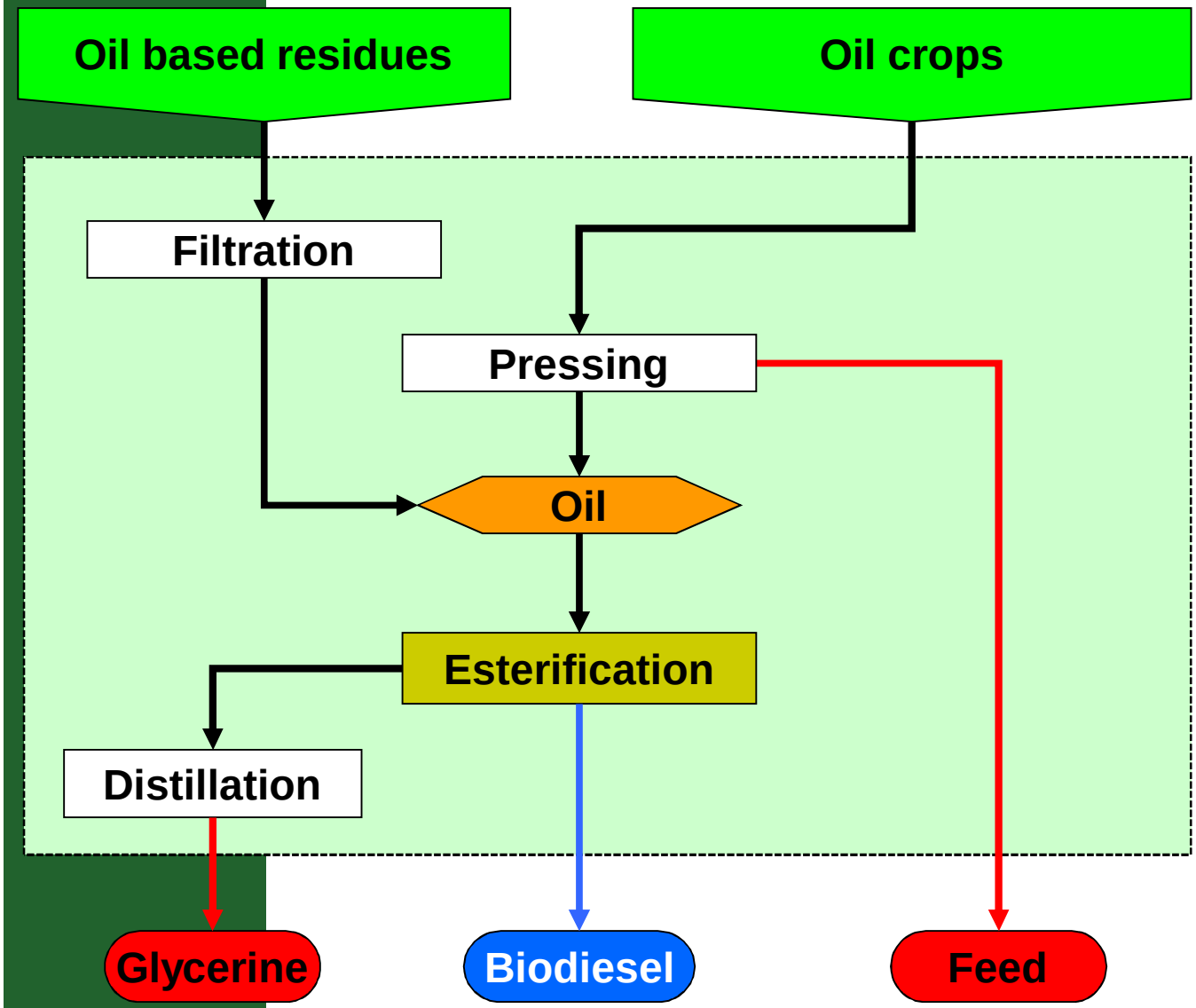
What value chains are used ?



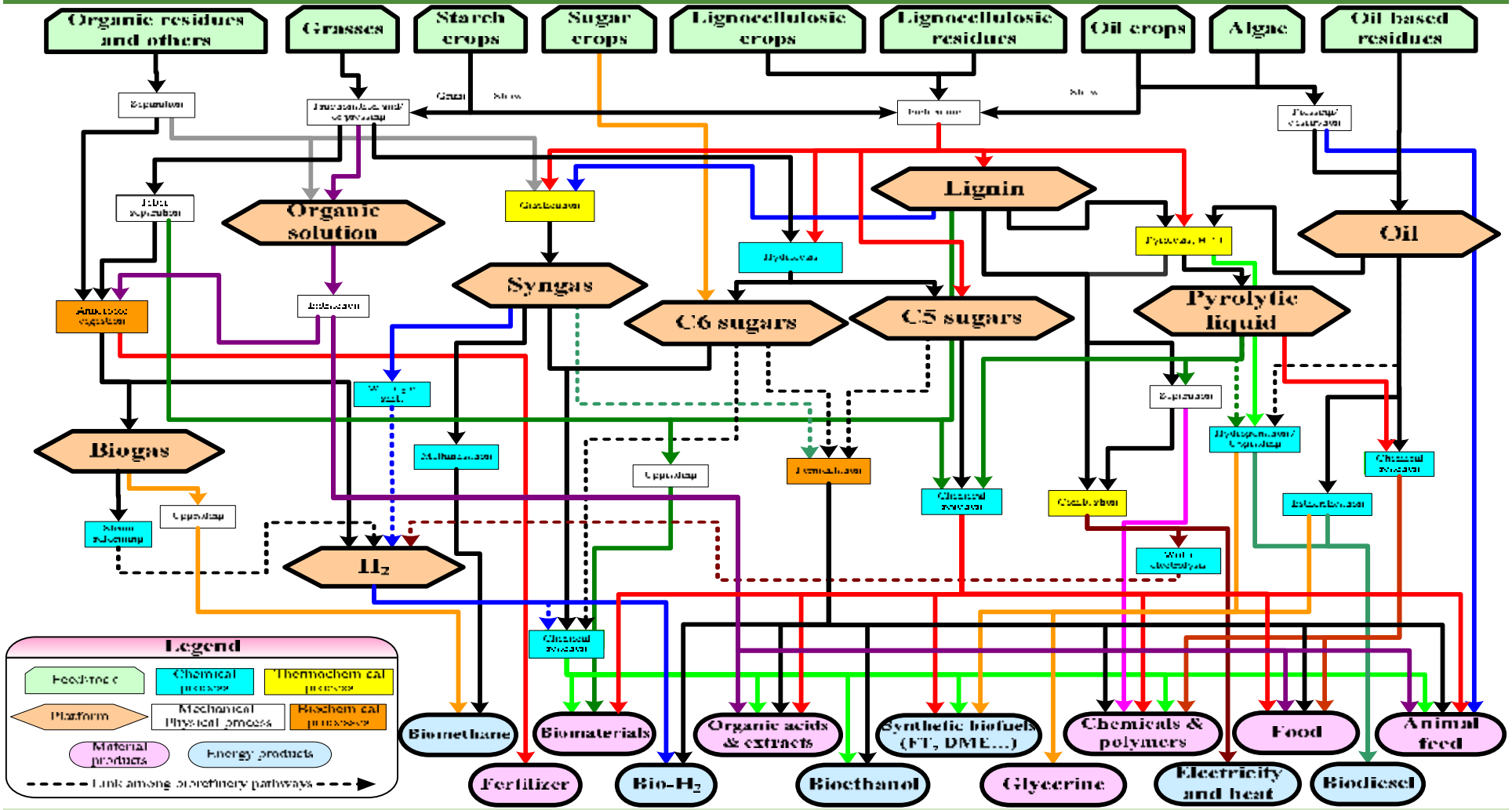
Feedstocks

Platforms

Processes

Products

Overview of Biorefinery Classification system



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Platforms

Syngas Platform
Biogas Platform
C6 sugar platform*
C6/C5 sugar platform
Plant-based Oil Platform*
Algae Oil Platform
Organic Solutions Platform
Lignin Platform
Pyrolysis Oil Platform

* Currently the dominant platforms for biobased chemicals

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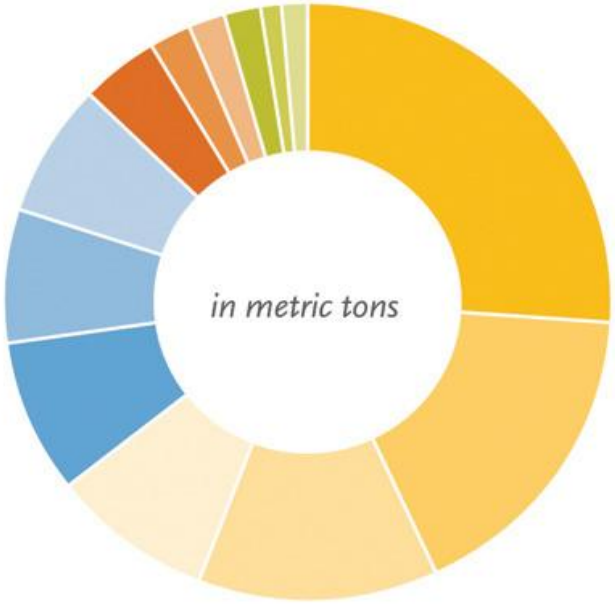
Biopolymer production capacity

Biopolymers production capacity 2015 (by type)



Bio-PE	450.000	26 %
Bio-PET	290.000	17 %
PLA	216.000	13 %
PHA	147.100	9 %
Biodegradable Polyesters	143.500	8 %
Biodegradable Starch Blends	124.800	7 %
Bio-PVC	120.000	7 %
Bio-PA	75.000	5 %
Regenerated Cellulose[1]	36.000	2 %
PLA-Blends	35.000	2 %
Bio-PP	30.000	2 %
Bio-PC	20.000	1 %
Others	22.300	1 %
Total	**1.709.700**	100 %

[1] *only hydrated cellulose foils*

Plastics Europe anticipated biopolymer production capacity (tonnes) by 2015

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Biobased Chemicals Table:

- Gives an overview of the biobased chemicals status in two categories
  - High growth potential
  - In the pipeline (Demonstration or pilot facility running)
- Organized from C1 (methanol, formic acid etc) to Cn (all molecules with more than 6 C atoms)
- Exhaustive list but certainly not complete
- Field is very dynamic at the moment so probably already some new changes / additions needed

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
1	Methanol	BioMCN, Chemrec	Formic acid	Maine BioProducts
	Methane Syn gas	Many BioMCN, Chemrec		
2	Ethylene	Braskem, DOW/Mitsui, Songyuan Ji'an Biochemical	Ethyl acetate	Zeachem
	Ethanol	Many	Glycolic acid	Metabolix Explorer
	Ethyleneglycol	India Glycols Ltd, Greencol Taiwan	Acetic acid	Wacker
3	Lactic acid	Purac, NatureWorks, Galactic, Henan Jindan, BBCA	Acrylic acid	Cargill, Perstorp, OPXBio, DOW
	Glycerol	Many	Propylene	Braskem
	Epichlorohydrin	Solvay, DOW	3-Hydroxypropionic acid	Cargill
	1,3-Propanediol	DuPont/Tate&Lyle	n-Propanol	Braskem
	Ethyl lactate	Vertec BioSolvents	Isopropanol	Genomatica
	Propylene Glycol (1,2-Propanediol)	ADM		

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
4	n-Butanol	Cathay Industrial Biotech, Cobalt/Rhodia	1,4-Butanediol	Genomatica/M&G
	iso-Butanol	Butamax, Gevo	Methyl methacrylate	Lucite
	Succinic acid	BioAmber, DSM/Roquette, Myriant, BASF/Purac		
5	Furfural	Many	Itaconic acid	a.o. Qingdao Kehai Biochemistry Co, Itaconix
	Xylitol	a.o. Danisco/Lenzing, Xylitol Canada	Isoprene/Farnesene	Goodyear/ Genencor, GlycosBio, Amyris
	Glutamic acid	a.o. Global Biotech, Meihua, Fufeng, Juhua	Levulinic acid	Maine BioProducts, Avantium, Segetis, Circa Group

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Biobased Chemicals

Cn	Products with strong growth potential		Bio-Based Chemicals in the pipeline	
	Chemical	Company	Chemical	Company
6	Sorbitol	a.o. Roquette, ADM	Adipic acid	Verdezyne, Rennovia, BioAmber, Genomatica
	Lysine	a.o. Global Biotech, Evonik/RusBiotech, BBCA, Draths, Ajinomoto	FDCA	Avantium
	Isosorbide	Roquette	Glucaric acid	Rivertop renewables
	Citric acid	a.o. Cargill, DSM, BBCA, Ensign, TTCA, RZBC	Caprolactam	DSM
n	PHA	Telles, Meridian plastics (103)	*Para*-Xylene	Gevo, Draths*, UOP, Annellotech, Virent
	Dicarboxylic acids	Cathay Biotech, Evonik		
	Fatty Acid derivatives	Croda, Elevance		

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Product Commercialization

Key criteria

Market assessment

Market fundamentals (local, regional, global)
Feedstock availability and price
Product profitability
Competitive nature of market
Need for partnerships
Downstream development opportunities

Technology assessment

Commercial experience
Necessary capital investment
Process complexity
Access to technology
Environmental considerations

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Drop-in versus New Functionality

Bio-based chemicals	Reference petrochemicals
Ethyl lactate	Ethyl acetate
Ethylene	Ethylene
Adipic acid	Adipic acid
Acetic acid	Acetic acid
n-Butanol	n-Butanol
PTT	PTT & Nylon 6
PHA	HDPE
PLA	PET and PS
FDCA	Terephthalic acid
Succinic acid	Maleic anhydride

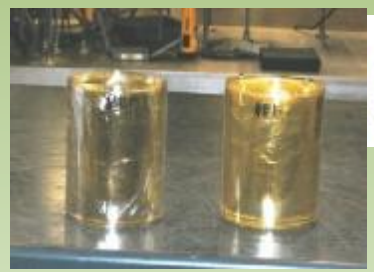
Drop-in versus Unique functionality

	Drop-in	Unique molecule
Market acceptance	↑↑	↓↓
Speed of introduction	↑↑	↓↓
Fit with existing infrastructure	↑↑ ↔	↔ ↓
Oil/Feedstock price sensitivity	↑↑↑	↑
Sustainability	↑ ↔ ↓	↑↑↑ ↔
Unique market space	↓↓↓↓	↑↑↑↑
Scalability	↑↑↑	↑ ↔ ↓
Legislation (e.a. REACH)	↑↑↑	↑↑↑↓↓↓

Example: FDCA versus PTA

Bottles

Fibers



Film

NatureWorks

Compared to oil-based products…

- Can YXY compete on price?
- Can YXY compete on performance?
- Can YXY deliver a significantly better environmental footprint?

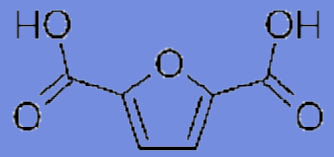
Compete on price

PTA

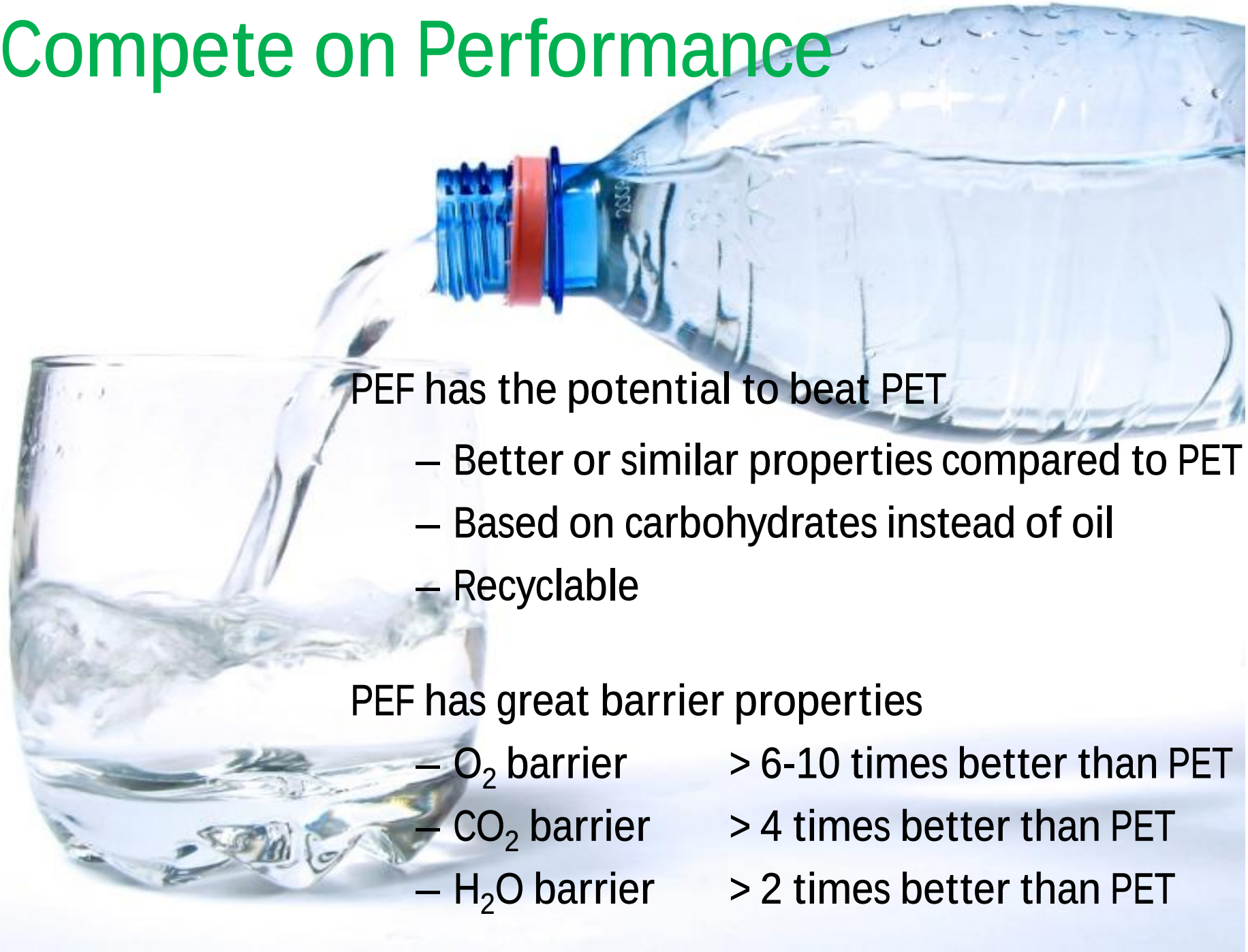
- **Oil-based**
- **Building block for PET**
- **50 million ton per year**
- **Price drivers:**
  - **Ø Oil price**
  - **Ø Supply/demand**

FDCA

- Bio-based
- Building block for PEF
- Potential market > 100 million ton
- Price drivers:
  - Ø Carbohydrate price
  - Ø Economy of scale



Compete on Performance



PEF has the potential to beat PET

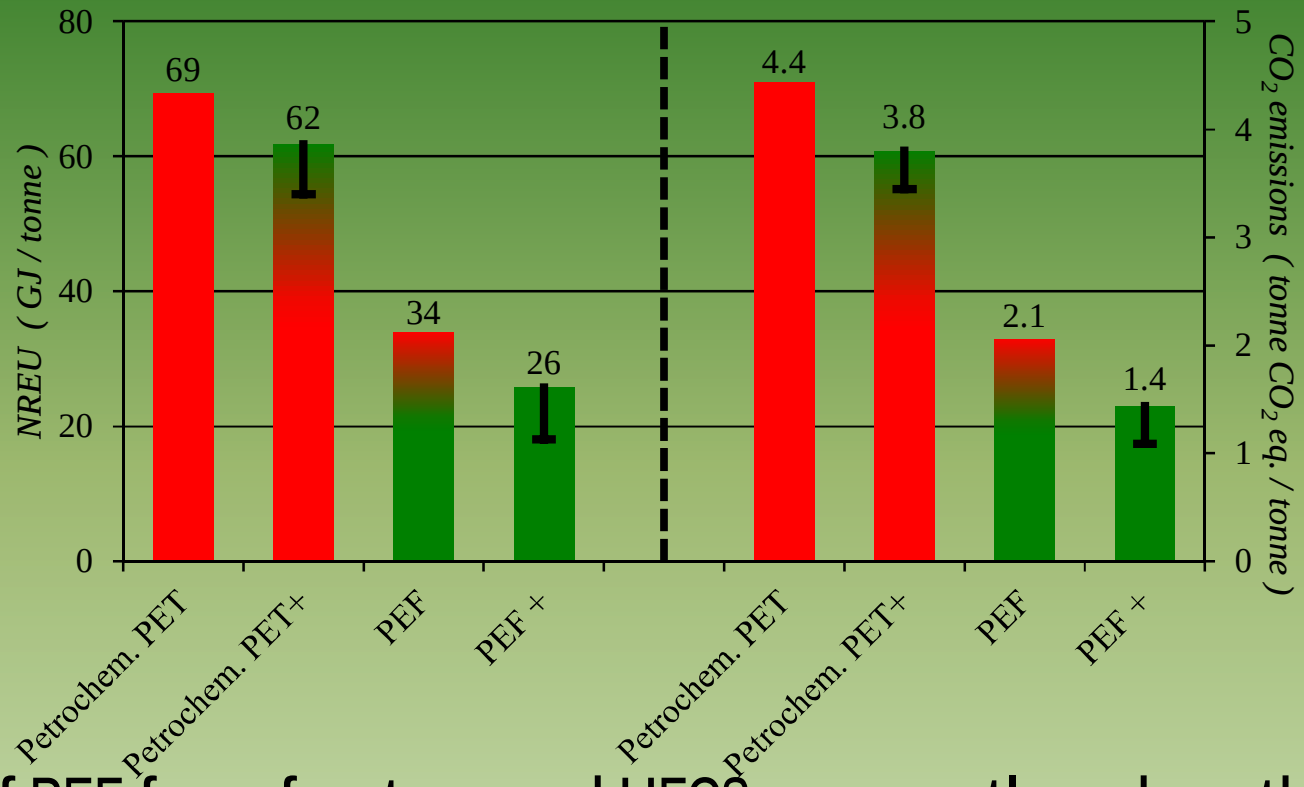
- Better or similar properties compared to PET
- Based on carbohydrates instead of oil
- Recyclable

PEF has great barrier properties

- O_2 barrier > 6-10 times better than PET
- CO_2 barrier > 4 times better than PET
- H_2O barrier > 2 times better than PET

Sustainability collaboration with Copernicus Institute

(Utrecht University; Eerhart, Patel & Faaij)



The production of PEF from fructose and HFCS can greatly reduce the NREU and GHG emissions by:

- ≈ 53% compared to its petrochemical counterpart PET
- ≈ 63% when using maize based ethylene glycol
- ≈ 75% when using sugarcane based ethylene glycol

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Conclusions

- Strong Market Pull Biobased Chemicals
- Production is currently expanding rapidly
- In several cases products are market competitive without subsidies
- No winner between drop-in versus new functionality

Dissemination

- Hard copy of report will be printed in February 2012
- Pdf version available on IEA Bioenergy Task 42 website (http://www.iea-bioenergy.task42-biorefineries.com/)
- Summary paper in Biofuels, Bioproducts & Biorefining

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