YXY FUELS

TKI•BBE

Ed de Jong
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avantium

Avantium, an innovative renewable chemicals technology company

avantium

Founded in **2000** In Amsterdam

61 patent families

Geleen YXY pilot plant **24 / 7** operational

140 employees

18 nationalities

Intended JV with BASF the global #1 chemical company

ALPLA · The Coca-Cola Company · DANONE · SWIRE · sfpi•fpim · PMV · Aesculap · aster · Capricorn · DEHOGEDENNEN · ING · NAVITAS · SOFINNOVA

€20m Last financing round April 2016

YXY Technology · Catalysis · Renewable Chemistries

2015 Global Cleantech 100

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YXY FUELS Partners

avantium

Smurfit Kappa Roermond Papier

ECN Your energy. Our passion.

tfc BIOMASS BASED CHEMICALS

Progression-Industry "GREEN" out of the box technologies

FOOD & BIOBASED RESEARCH WAGENINGEN UR

YXY FUELS

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Use of lignocellulosic and paper residues as feedstock for the production of YXY building blocks and energy components (heat and fuels)

FDCA monomer ▶ PEF polymer

YXY Technology Platform

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Technology

Plant based Feedstock

Dehydration · Oxidation

MMF (5-methoxy methyl furfural) → FDCA

Polymerization → PEF

Dehydration → Levulinics

Hydrogenation, oxidations → Bio-fuels Chemicals Materials

Tunable process

YXY FUELS Objectives

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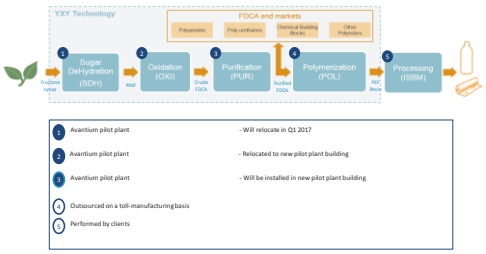
- **Proof of Process**
  Develop and validate YXY process on industrial pilot scale with 2G feedstocks
- **Integration**
  Integrated biomass fractionation by organosolv and subsequent processes for processing and upgrading of fractions
- **Proof of Products**
  Industrial scale production of cellulose, YXY building blocks and lignin for application development key industrial markets
- **Energy outlets**
  Proof that the lignin / humins side stream can be used for energy generation (heat) as well as a component of (marine) fuels

The YXY technology



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...and it looks like this

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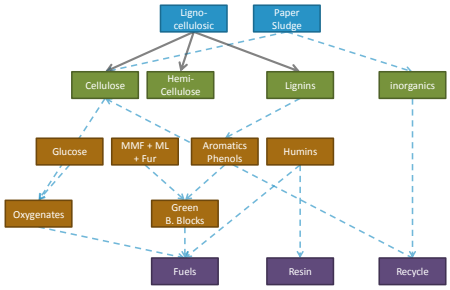
Research Lines

- WP 1 Feedstock selection, characterization and pretreatment residues
- WP 2 Pretreatment technologies: OrganoSolv & **Zambezi**
- WP 3 Separation and post-processing of product streams
- WP 4 Upgrade of **YXY building blocks**
- WP 5 Upgrade of lignin fraction
- WP 6 Evaluation of **biofuel** components
- WP 7 Analysis of integrated system and chain evaluation

YXY-FUELS Roadmap

The *Cellulosic* program



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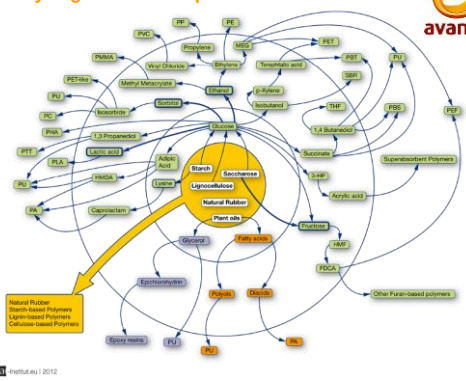
YXY-FUELS - The Cellulosic Program

- Look at the methods to convert the feed stocks, paper sludge or lignocellulosic biomass, into its main constituents: cellulose, hemi-cellulose, lignin and inorganics.
- This program line also considers processing of carbohydrate streams, cellulose in particular, into smaller sugar fragments.
- These sugars then serve as feedstock for a range of bio-based chemical processes, including Avantium's YXY process.

Why is glucose so important



Which actors are active in the field

First and second generation biomass

For bio-based chemical & fuel production

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

Now

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

Future

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2G Sugar Technologies Evaluated by Avantium

Technology	Example Companies	Advantages	Disadvantages	Application Area
Pre-treatment + enzymatic hydrolysis	M&G Chemtex /Beta Renewables Sweetwater Comet ...	+ High yield + Mild conditions	- Mixed products - Enzyme cost	- Biofuels
Dilute acid / high temperature		+ Cheap process	- Low yield - Poor selectivity (Inhibitors)	- Biofuels
Organosolv + enzymatic hydrolysis	ECN Lignol CIMV	+ High grade lignin + High grade cellulose fibre	- High solvent recycle costs - Enzyme cost	- Biofuels - Biochemical
Hot Compressed Water	Renmatix	+ Low cost reagents	- Low yield - High pressure/temp	- Biofuels - Biochemical
Concentrated acid / low	Avantium Stora Enso	+ High yield + High	- Acid / sugar separation	- Biofuels - Biochemicals

Avantium selected technology

Bergius Concentrated HCl hydrolysis technology

1916	Bergius began development of industrial process of saccharification
1933	Mannheim-Rheinau plant completed (single step hydrolysis) 6-8 kt/a mixed sugars
1939	Regensburg plant completed (destroyed 1945) 20 kt/a sugars
1948-59	Modified- Rheinau process (with sugar fractionation) 12 kt/a glucose
1953-55	Japan pilot plant
1957–87	Russia pilot plants (10 m3 scale hydrolysis reactors)
1980's	Dow USA: Pilot Plant - HCl recovery by solvent extraction
2007	HCl CleanTech (Israel) → → Stora Enso (2014) (HCl recovery via amine complexation)
2013-2016	Avantium studied all available know-how on Bergius process and developed proprietary improvements leading to glucose production competitive to 1G glucose

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ZAMBEZI Process

- Features
  - Concentrated acid, low temperature, two-stage, high selectivity
  - Near quantitative conversion of cellulose to glucose
  - Fractionation: glucose, C5/C6 sugars, extractives and lignin
  - Feedstock flexibility: forestry residues (wood), wastepaper, corn stover and bagasse
- Technical Breakthroughs
  - Acid sugar separation
  - Materials of construction
  - Lignin deacidification

IP filed

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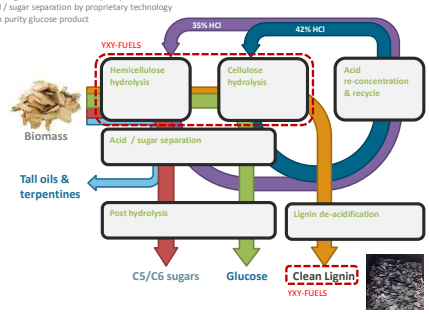
ZAMBEZI Process

Process outline

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



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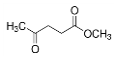
Methyl levulinate

- Side product of YXY process



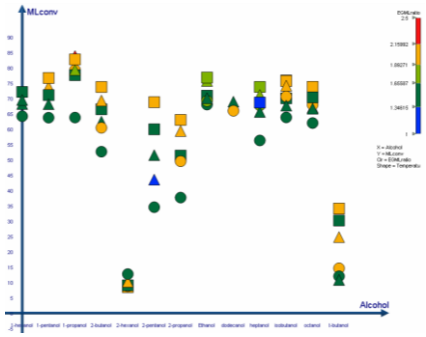
- Interesting compound for fuel and solvent applications
- Positive effects for solvents
  - √ Ketone
  - √ Ester
- Cannot be used in consumer paints
  - X Boiling point < 250 °C
  - X Hydrolysis leads to formation of methanol (Toxic)
- Transesterification with a biobased alcohol
  - Higher boiling point
  - Biobased solvent

Transesterification of ML with different alcohols

- ethanol
- 1-Propanol
- 2-Propanol
- 2-butanol
- t-butanol
- iso-butanol
- 1-pentanol
- 2-pentanol
- 1-hexanol
- 2-hexanol
- 1-heptanol
- 1-octanol
- 1-dodecanol

- Quick catalytic screening (QCS)
  - Effect of chain length
  - Effect of position of OH
  - 36 reactions

Transesterification of ML with different alcohols



Color alcohol:ML ratio
0.05 mol% $Ti(BuO)_4$

Shape temperature
Circle 160 °C
Triangle 180 °C
Square 200 °C

Transesterification of ML with different alcohols Conclusions

- Transesterification with different alcohols
  - Fast transesterification with primary alcohols
  - Secondary alcohols are limited by chain length
  - Tertiary alcohols show slow transesterification,
  - Strong effect of temperature points at kinetic limitation → steric hindrance

General Conclusions

- YXY Fuels project is on track
- Lignocellululosic feedstocks have high potential
- Side products can be used for many applications