Avantium
Innovative Technologies for Today’s Bioeconomy

2-Gen Sugars, Renewable Technologies, Electro catalysis of CO₂
XYX™ Technology: FDCA to PEF
Novel Bio-Based Plastic
JV BASF / Avantium

Renewable Chemistries

Catalysis

Foundational Technology and Expertise
Leading Systems and Services Provider for Catalyst R&D

160 employees
>75% scientists
20+ nationalities

100+ patent families

Euronext
Amsterdam & Brussels
Ticker: AVTX

€109M Raised from IPO
15 March 2017

Founded in 2000
Amsterdam
History of Avantium: 18 Years of Innovation

Founding Avantium: Spin-off from Royal Dutch Shell

Strategic Partners

Innovative focus on chemicals

- 1st gen. Nanoflow: 16 parallel reactors gas phase
- 3rd gen. Nano-flow: 64 parallel reactors trickle flow
- Start offering of R&D systems to customers
- 1st Flowrence installed at customer
- Started with Proprietary R&D
- Proof-of-principle YXY achieved
- YXY technology pilot plant
- 1st PEF bottle made using YXY technology
- Market launch Flowrence XD

2000: Divestment of software platform for laboratory automation
2001: 1st gen. Nanoflow
2003: 3rd gen. Nano-flow
2005: Start offering of R&D systems to customers
2006: 1st Flowrence installed at customer
2008: Proof-of-principle YXY achieved
2011: Divestment of pharma services
2013: Introduction of Microfluidic chips
2014: Divestment crystallisation systems BU
2015: Initial Public Offering
2016: Liquid Light assets Acquisition
2017: Market launch Flowrence XD

Financial partners: INVEST, ALP, DFJ, SR One, eedbi, SIGNET

University partners: TUDelft, University of Twente, TU/e

Solid financial backing

Funding round 2006: NAVITAS, ING, Capricorn, Aegic
Funding round 2011: SOFINOVA, ASTER, DEHGEDEENEN
Strategic shareholders joining in 2014: Coca-Cola, Danone, JDA, BASF
Funding round 2016: Swire, Coca-Cola, Alpla, Synvina
2017: Initial Public Offering

Agreement with Mitsui to commercialise FDCA and PEF in Asia
Pilot plant consortium for bio-refinery
JV of Avantium and BASF established: Synvina
JDA signed with ALPLA
Global Trends Drive Transition Towards a Bio-Based Economy

**Demographic Change**

A growing population, leads to a growing demand for materials and resource stress.

**Climate Change**

Reduce CO₂ production and dependency on fossil resources.

**Shift in Consumer Preferences**

Brands want to become sustainability champions.
Avantium’s Renewable Chemistries
Leadership in innovative renewable technology

Commercialization enables the transition to a sustainable bioeconomy
Partnering Strategy

Strategic Choices

- Stand-alone
- Partnering
- Sell

Development Phases

- Ideation (In-House)
  - Lab-scale
  - Pilot plant
  - Reference plant
  - Industrial scale

Phases

- Phase I
  - Stand-alone
  - Pilot plant build
  - Scale technology
  - Prove process economics
  - Partner criteria/discussions

- Phase II
  - Partnering
  - Align partner intent
  - Combine core competencies
  - Decide commercial deployment
  - Structure agreements

- Phase III
  - Business Model Execution
  - Continue technology improvements
  - Monitor market conditions
  - Execute against growth strategies

Activity

- Ideation
  - Validate lab scale performance
  - Assess market position
  - Model business case (technoeconomic)

- Phase I
  - Pilot plant build
  - Scale technology
  - Prove process economics
  - Partner criteria/discussions

- Phase II
  - Align partner intent
  - Combine core competencies
  - Decide commercial deployment
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- Phase III
  - Continue technology improvements
  - Monitor market conditions
  - Execute against growth strategies

Potential Timeline

- Year 0-2
- Year 1-2
- Year 3-4
- Year 5 →
Avantium’s Renewable Chemistries Portfolio

Process stages:
- Approx. 3-6 months
- Approx. 2-3 years
- Approx. 1-2 years

- Concept stage
  - Validate and optimize process
  - Process economics to support business case

- Lab stage
  - Prove chemical process at lab scale
  - Validate business case and evaluation of partnerships

- Pilot plant stage
  - Validate technology at pilot plant scale
  - Establish collaborations to address commercial risks

- Commercial stage

New projects:
- Volta
- Mekong
- Zambezi
- YXY/Synvina
ZAMBEZI
Second Generation Biorefinery
Branding Zambezi as DAWN Technology

(http://www.avantium.com/the-future-of-biorefining/)
Creating a Bio-Based Economy
From Renewable Feedstock to Biopolymers for a Growing Market

Biomass as Renewable Feedstock

- Second generation (2G) biomass (non-food)
  - Wood
  - Corn stover
  - Waste paper

- First generation (1G) biomass (food)
  - Corn
  - Sugar cane
  - Sugar beet

Production of Bio-Based Materials by Polymerization of Monomers

- Glucaric Acid
- Adipic Acid
- HMDA
- 1,3 Propanediol
- Sorbitol
- Isoridine
- 1,4 Butanediol
- Succinate
- Teraphtalic acid
- MEG
- HMF
- FDCA
- MMF
- Ethanol
- Methyl Metacrylate
- Ethylene
- Vinyl Chloride
- Propylene
- Isobutanol
- Acrylic Acid
- Lactic acid

- PHA
- PA
- PU
- PC
- PET-like
- PTT
- PBS
- PBT
- PET
- PEF
- Furanbased Pol.
- PMMA
- PE
- PVC
- PP
- SBR
- Superabsorbent Pol.
- PLA

... In a Growing Bio-Based Materials Market

- Bioplastics market
  - 8% expected CAGR 2016-2021
  - 6.1 M tonnes

Most important applications of bioplastics

- 40% packaging
- 22% consumer goods
- 14% transport and automotive
- 13% building and construction

1. Nova Institute 2015
Market Potential for Glucose
Bio vs fossil market size – Growth potential

Bio-Market Sales
$ 65 bn

Related Fossil & Bio Sales
$400 bn

Ethanol
MEG
Ethylene

From the Sugar Platform to Biofuels and Biochemicals
Final report for the European Commission Directorate-General Energy
N° ENER/C2/423-2012/SI2.673791
April 2015

From Opportunities for the Fermentation Based Chemical Industry; Analysis of Market Potential and Competitiveness in North West Europe – Deloitte 2014
First and second generation biomass (glucose)

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

Now
- Corn
- Sugar cane
- Sugar beet

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

Future
- Wood
- Corn stover
- Recycled paper
Why Woody Biomass?

- **Reasons:**
  - **Economic:**
    - Economically available feedstock
    - Efficient and mature logistics
  - **Technological:**
    - Tests at lab scale have been done on the basis of wood chips
    - Does not require other pre-processing step
    - Retains structural integrity after process (does not crumble or slump)
  - **Sustainable:**
    - Good ecological footprint

- **We continue to evaluate other alternative feedstock options**
## 2G Sugar Technologies Evaluated by Avantium

**Key technology identified:** fit-for-purpose in biobased chemicals

<table>
<thead>
<tr>
<th>Technology</th>
<th>Example Companies</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Application Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-treatment + enzymatic hydrolysis</td>
<td>M&amp;G Chemtex /Beta Renewables Sweetwater Comet</td>
<td>+ High yield</td>
<td>- Mixed products</td>
<td>Biofuel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ Mild conditions</td>
<td>- enzyme cost</td>
<td></td>
</tr>
<tr>
<td>Dilute acid / high temperature</td>
<td></td>
<td>+ Cheap process</td>
<td>- Low yield</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Impure product</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Dilute product</td>
<td></td>
</tr>
<tr>
<td>Organosolv + enzymatic hydrolysis</td>
<td>Lignol CIMV</td>
<td>+ High grade lignin</td>
<td>- High solvent &amp; enzyme costs</td>
<td>Biofuel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Dilute product</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot Compressed Water</td>
<td>Renmatix</td>
<td>+ Low cost reagents</td>
<td>- Low yield</td>
<td>Biofuel</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- High pressure/temp</td>
<td></td>
</tr>
<tr>
<td>Concentrated acid / low temperature hydrolysis</td>
<td>Avantium Virdia (Stora Enso) Green Sugar</td>
<td>+ High stream yield</td>
<td>- Acid / sugar separation</td>
<td>Biofuel</td>
</tr>
<tr>
<td></td>
<td></td>
<td>+ High purity</td>
<td>- Corrosion</td>
<td>Biochemical</td>
</tr>
</tbody>
</table>

Avantium selected technology
Bergius 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)

2013-2015 Avantium studies all available know-how on Bergius process and developed proprietary improvements leading to glucose production competitive to 1G glucose
Zambezi Process in a Nutshell

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

Technical Breakthroughs
- Acid sugar separation
- Material construction
- Lignin deacidification

Intellectual Property captured through patent filings
Market potential for C5/6 Sugars

Properties of Mixed sugar stream
- Feedstock dependent
  - Hardwood/softwood/grasses
- C6: Mannose/glucose/galactose
- C5: Xylose/arabinose

- Biofuels: bio-ethanol
- Bio-Jet Fuels
- Biogas
- Lactic Acid

Market potential for Lignin

- **Base case:**
  - Use lignin for energy production (steam)

- **Potential higher value applications such as activated carbon or asphalt**
  - Asphalt
  - Activated Carbon
    - E.g. for water purification
    - Global activated carbon market was 1.37 MMtpa in 2013 and grow 2.96 MMtpa by 2020 (CAGR of 11.7%)
  - ‘Bergius Lignin’ has been proven in activated carbon applications

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Zambezi Project Partners & Location
Pilot Plant Opening 10 July 2018
Flagship Plant: Zambezi Wood Biorefinery

- Can be implemented in the Netherlands!
- Strong partnership established
- Available locations for Demonstration plant, flagship plant and commercial plant
- Logistics Rail/ Road/ Port
- Availability & knowledge of concentrated HCl
- Woodchips/residues availability
- Utilities (Steam, Electricity, waste water)
- Site Services/Engineering
- Availability of personnel
- Lignin (co-)firing possibilities
- Global licensing (also for other feedstocks)
Delfzijl Technology Deployment Strategy

**Stage 1: Build Pilot Plant**
- Pre-PDP
- Flagship PDP
- Flagship FEED

**Stage 2: Flagship Commercial scale design and EPC**
- Flagship launch

**Stage 3: Expansion Commercial scale design and EPC**
- Expand to Full Capacity

**Phase I**
Flagship Consortium Agreement Level

**Phase II**
Ownership Vehicle & Operational Level for Flagship

**Phase III**
Full Commercial Scale Operation

**Collaborations & JDA’s**

**Business Cases for Global Deployment**
- Licence multiple plants in multiple locations
Opportunity by Localized Economics

Avantium is engaged globally to evaluate the economics of local scenarios.
Examples Business Cases
Case by case number crunch

Plant OPEX (500kpta Feedstock Input Scale)
Partnering Universe

Feedstock
- Pulp & paper
- Forestry
- Agricultural

Conversion
- Chemical
- Engineering
- Site / Services

Off-takers
- 2G Glucose
- Mixed Sugars
- Lignin (specialty or energy)
- Tall oils
Zambezi Summary

- Zambezi:
  - Avantium transformed the economics of the Bergius process

- Market:
  - Today polymer market ~300mpta increasing 1.2Bn tpa by 2050 (4x increase)
  - Growth in renewable fuels and materials will demand a 2G solution
  - Currently no commercially viable high purity 2G glucose available today for chemical applications

- Technology:
  - Feedstock flexible
  - Innovation in:
    - Acid sugar separation
    - Material construction
    - Lignin deacidification
  - Lab demonstration in Hydro 2 unit
  - Pilot Plant opening in July 2018

- Application:
  - Successfully made FDCA from Zambezi 2G glucose and polymerized to PEF
  - Multiple collaborations on qualification on feedstock and product stream qualification

- Commercialization:
  - Identified partnership to support Reference Plant business case in Delfzijl (Netherlands)
  - Actively evaluating multiple business cases in multiple locations around the world
Mekong Mono-Ethylene Glycol Project
Production Routes for MEG

Prime Raw Material

<table>
<thead>
<tr>
<th>Fossil based</th>
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<tbody>
<tr>
<td>Crude Oil/Naphtha/Gas/Fuel Oil</td>
</tr>
<tr>
<td>Natural Gas</td>
</tr>
<tr>
<td>Shale Gas</td>
</tr>
<tr>
<td>Coal</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Biomass based</th>
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</thead>
<tbody>
<tr>
<td>Sugar Cane</td>
</tr>
<tr>
<td>Maize/Corn</td>
</tr>
<tr>
<td>1G and 2G C6 carbohydrates</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Biomimetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
</tr>
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</table>

Intermediates

<table>
<thead>
<tr>
<th>Ethylene</th>
</tr>
</thead>
</table>

| EO |

Product

| MEG |

White MEG

Black MEG

Green MEG

Multi-step: Low atom efficiency

Difficult separation

Efficient conversion

Direct hydrogenolysis

Hydrogenation

Electrochemistry

Oxalic acid

Carbon dioxide

White MEG

Black MEG

Green MEG
MEKONG: Superior Carbon Efficiency

Superior economics

Current Commercial Production of Bio-based MEG

Fermentation

\[
\begin{align*}
\text{OH} & \quad \text{OH} & \quad \text{OH} & \quad \text{OH} \\
\text{CO}_2 & \quad \text{EG} & \quad \text{EG} & \quad \text{CO}_2
\end{align*}
\]

Fermentation, dehydration, Oxidation, hydration

\[
\text{OH} \quad \text{OH} \quad + \quad 2\text{CO}_2
\]

Max theoretical yield = 67%

Avantium MEKONG Process

Hydrogenolysis

\[
\begin{align*}
\text{OH} & \quad \text{OH} & \quad \text{OH} & \quad \text{OH} \\
\text{EG} & \quad \text{EG} & \quad \text{EG}
\end{align*}
\]

+ 3 \text{H}_2

Catalysis

\[
\begin{align*}
\text{OH} & \quad \text{OH} & \quad \text{OH} & \quad \text{OH} \\
\text{EG} & \quad \text{EG} & \quad \text{EG}
\end{align*}
\]

Max theoretical yield = 100%
MEKONG: Process / Technology Assessment

Process outline

1G or 2G Carbohydrates

CAT. recycle

Reactor 1

Water removal

Distillation

MEG

Hydrogen

Light Ends Recovery

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

<table>
<thead>
<tr>
<th></th>
<th>Monomers</th>
<th>Ex-Reactor PEF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MEG</td>
<td>Mn</td>
</tr>
<tr>
<td>1</td>
<td>Bio-MEG</td>
<td>16100</td>
</tr>
<tr>
<td>2</td>
<td>Petro-MEG</td>
<td>16100</td>
</tr>
<tr>
<td>3</td>
<td>Mekong-MEG</td>
<td>16100</td>
</tr>
</tbody>
</table>
Using Bio-MEG
Trend: Shifting from Petroleum to Plant-based

Yesterday
100% Petroleum

i.e. General PET

Today
70% Petroleum, 30% Plants

e.g. Plant Bottle™

Tomorrow
100% Plants

e.g. PEF
Opportunity
Bullish bio-MEG market projections & green premium

Bio-MEG Demand Projection (2014-2020)

<table>
<thead>
<tr>
<th>Year</th>
<th>America</th>
<th>Europe</th>
<th>Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>400</td>
<td>800</td>
<td>3000</td>
</tr>
<tr>
<td>2016</td>
<td>800</td>
<td>3000</td>
<td>3000</td>
</tr>
</tbody>
</table>

Projected Bio-MEG Growth

CAGR=39%

Source: NOVA Institute

<table>
<thead>
<tr>
<th>MEG</th>
<th>Prices of conventional and Bio-MEG (USD/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>America</td>
</tr>
<tr>
<td>Conventional/Petro-MEG</td>
<td>948</td>
</tr>
<tr>
<td>Price Premiums on Bio-MEG</td>
<td>25-30%</td>
</tr>
<tr>
<td>Price offered by India Glycols and Greencol Taiwan for Bio-MEG</td>
<td>1200</td>
</tr>
</tbody>
</table>

Source: MEGlobal; MEGlobal; Platts; Orbichem; Greenchemicals Blog; Bioplastics News; Mouldpulp DataStream; ; MG Chemicals; Indalca; Polymerinnovation; HKGem Primary Research; Evalueserve Analysis
Market Growth Assessment Bio-MEG

- Significant cancellations in planned capacity expansion limiting expected growth
- Bio-MEG price premium over petro-MEG is the likely barrier to support capacity investments
- Significant volume opportunity for price competitive Bio-MEG
- Mekong: competitive with Petro-MEG
Mekong Summary

- Current commercial bio-MEG
  - is made from an inefficient processes
  - making it expensive and
  - hampering the widespread use

- Avantium has developed
  - a 1-step conversion
  - high atom efficiency process
  - competitive with petro-MEG
  - there is no need for a “green premium”

- Projections for the Bio-MEG to reach 3 MMtpa in the next years
  - the wider petro-MEG market being some 10x this figure

- Strong opportunity for Mekong
Thank you for your attention.

Questions??

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