2006 Forum on Energy:
Immediate Solutions,
Emerging Technologies
May 15-17
Appleton, WI

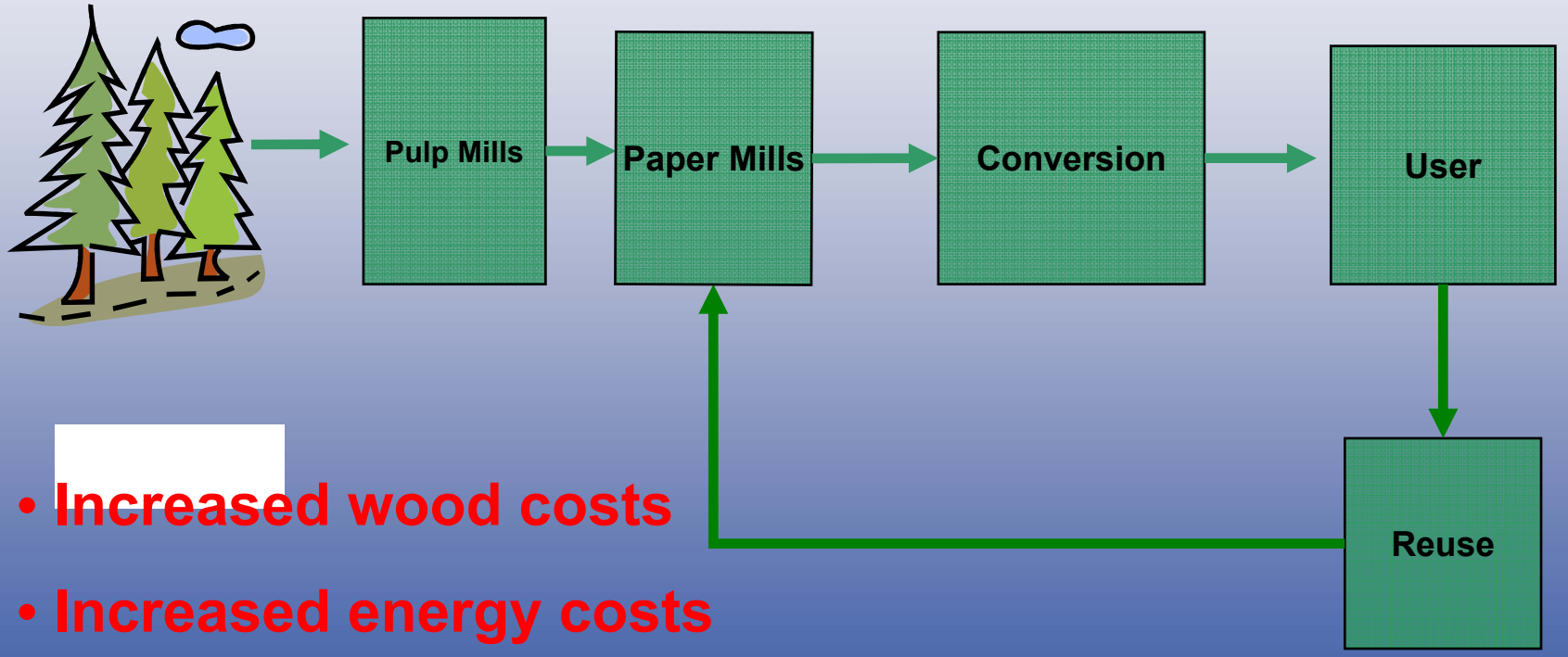
Status of the Bio-refinery Development in Scandinavia

Presented by: Dr Peter Axegård, STFI

Outline

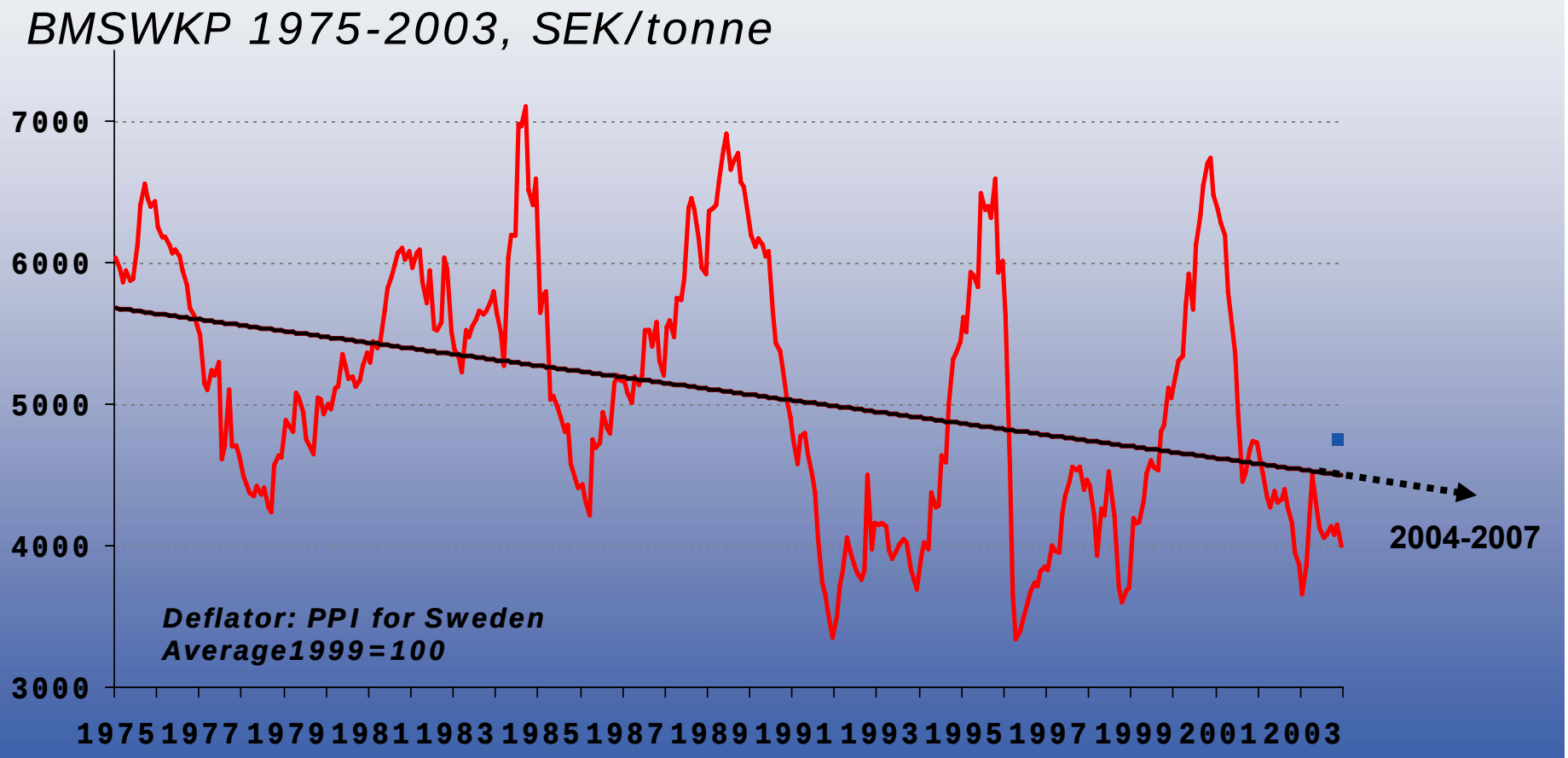
- Why a pulp mill biorefiney?
- Energy export from modern mills
- Birch bark
- Softwood knots
- Xylan from black liquor
- Glucomannan from TMP white water
- Lignin from black liquor
- Black liquor gasification
- New process for soap removal
- Conclusions

Pulp and Paper Under Pressure

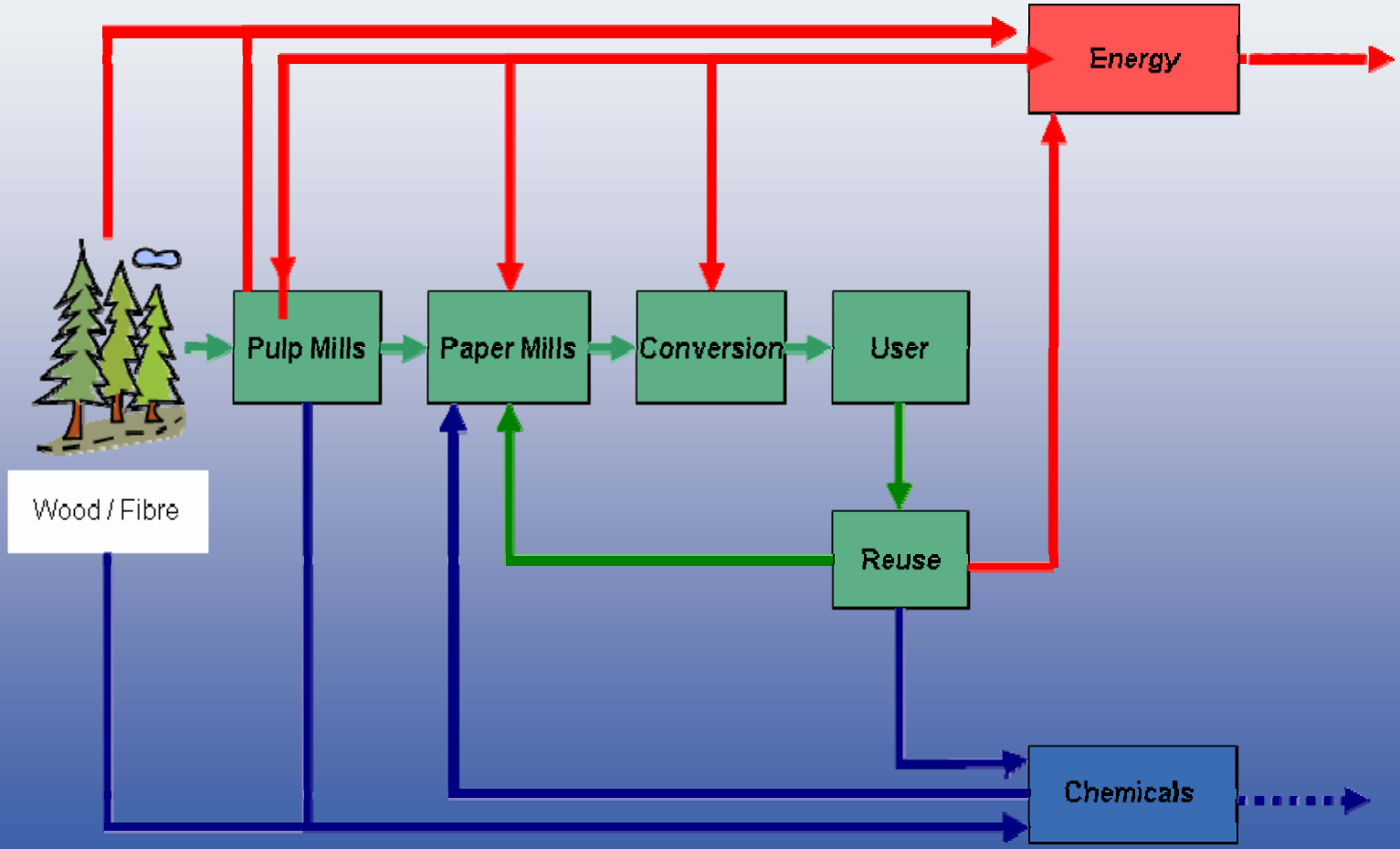


- Increased wood costs
- Increased energy costs
- Decreasing trend prices on pulp

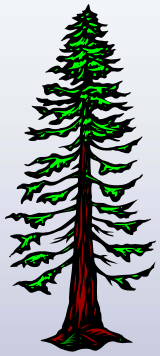
Steady Drop in Market Pulp Prices…



The Pulp Mill Biorefinery



The Pulp Mill Biorefinery



Chips

Bark & forest residues

Pulp mill

Spent liquor

Specialty Cellulose

Pulp

Paper

Extractives

Glucose

Hemicelluloses

Lignin

- *Fibre additives*
- *Barriers*
- *Hydrogels*
- *Food additive*

- *Phenols*
- *Carbon fibre*
- *Porous carbon*
- *Binders*

Solid fuel from bark and forest residues

Solid fuel

Industrial Wood Based Chemicals

Wood tar	1500´s ---
Potash	1672 - 1800´s
Turpentine	1910´s -
Tall Oil	1913 -
Ethanol, sulfite	1921 –
CMC	1944 –
Lignosulfonates	1940-ies
Sulfite lignin	1965 -
Furfural	1968 –
Acetic acid	1968 -
Xylitol	1974 -
Protein	1974- 1991
Sitosterol, sitostanol	1980 –
Lignans	1998 -

The Pulp Mill Biorefinery

Example 1

Energy efficient modern kraft pulp mills

Södra Cell -
Pulp Producer and Supplier of Energy

Power
0.4 TWh

District heating
0.4 TWh

Biouel
1.8 TWh

Modern Kraft Pulp Mills are Very Energy Efficient

Model Mill Case	Sold Fuel GJ/ADt	Sold power kWh/ADt	”Fossil CO_2 kg/ADt
Reference Mill ECF-bleaching	3.1	540	-260
Swedish average year 2000	-0.6	-140	+320

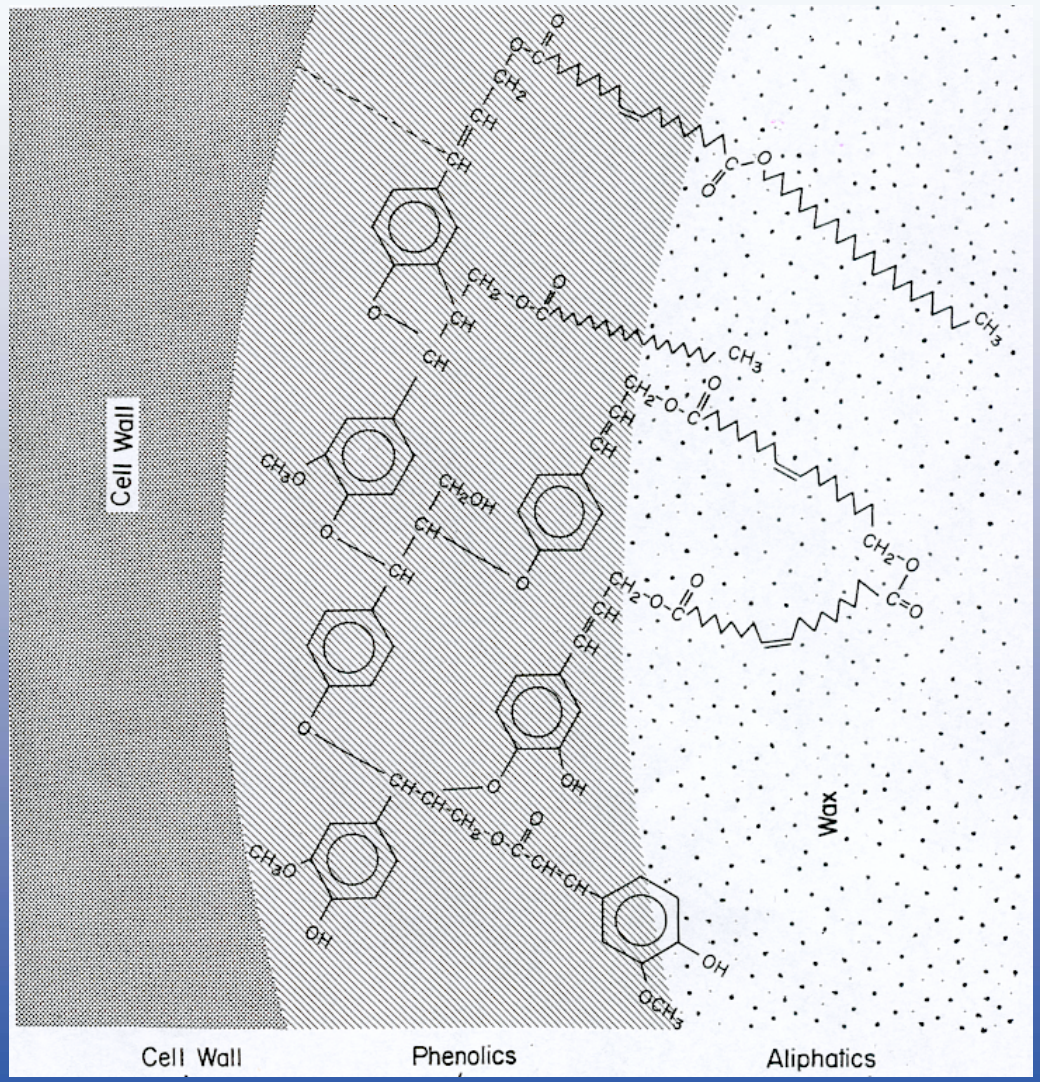
The Pulp Mill Biorefinery

Example 2

Fatty acids from birch bark

STFI, VTT

Bark Suberin



SUBERIN

Major Monomers

$CH_3(CH_2)_mCOOH$

$CH_3(CH_2)_mCH_2OH$

$CH_2(CH_2)_nCOOH$
|
OH

$HOOC(CH_2)_nCOOH$

Phenolics

$(m = 18-30;\ n = 14-20)$

[Rowe J W (Ed.), Natural Products of Woody Plants I, Heidelberg, Germany1989]

Fatty Acids in Birch Bark

C_{16}-Family	C_{18}-Family
$CH_3-(CH_2)_{14}-COOH$	$CH_3-(CH_2)_7-CH=CH-(CH_2)_7-COOH$
$CH_2(OH)-(CH_2)_{14}-COOH$	$CH_2(OH)-(CH_2)_7-CH=CH-(CH_2)_7-COOH$
$CH_2(OH)-(CH_2)_x-CH(OH)-(CH_2)_y-COOH$	$CH_2(OH)-(CH_2)_7-CH-O-CH-(CH_2)_7-COOH$
	$CH_2(OH)-(CH_2)_7-CH(OH)-CH(OH)-(CH_2)_7-COOH$

The Pulp Mill Biorefinery

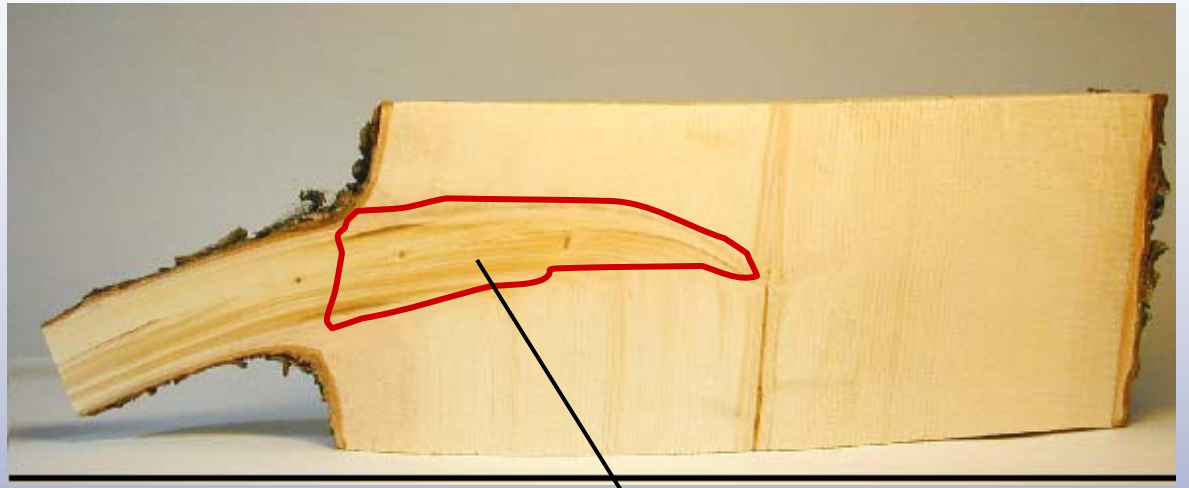
Example 3

Lignans from softwood knots

Åbo Akademi

Spruce
Picea abies

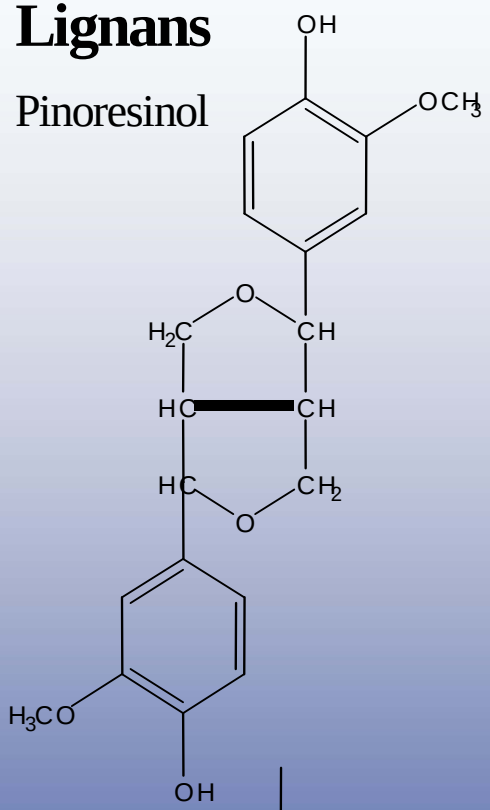
As it happened in 1998 - - -

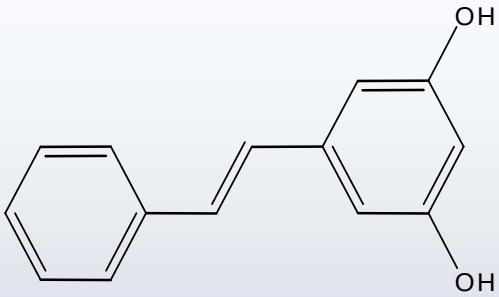


10% lignans !

Lignans

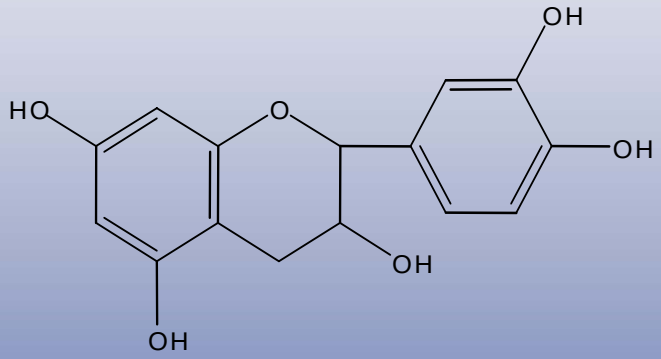
Pinoresinol





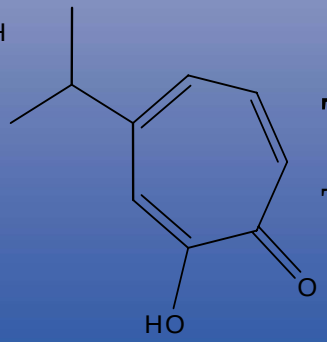
Stilbenes

Pinosylvin



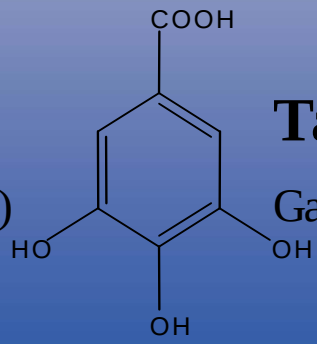
Flavanoids

Catechin



Tropolones

Thujaplicin (corrosive)



Tannins (garvämnen)

Gallic acid

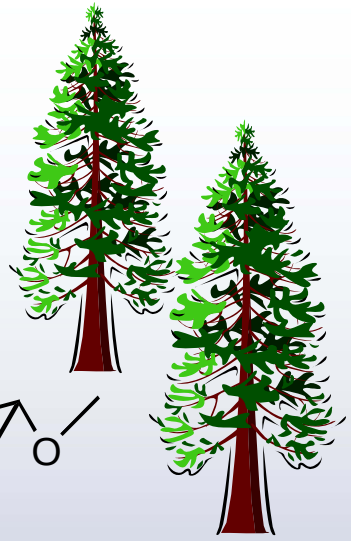
The Pulp Mill Biorefinery

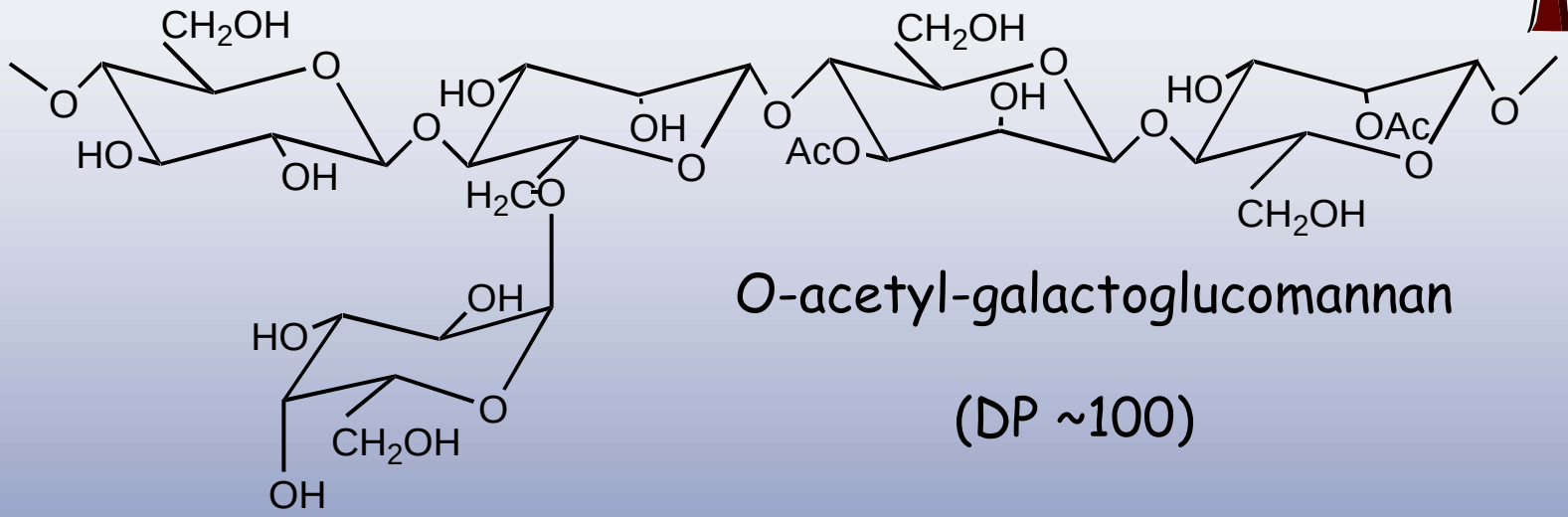
Example 4

Xylan from black liquor

STFI

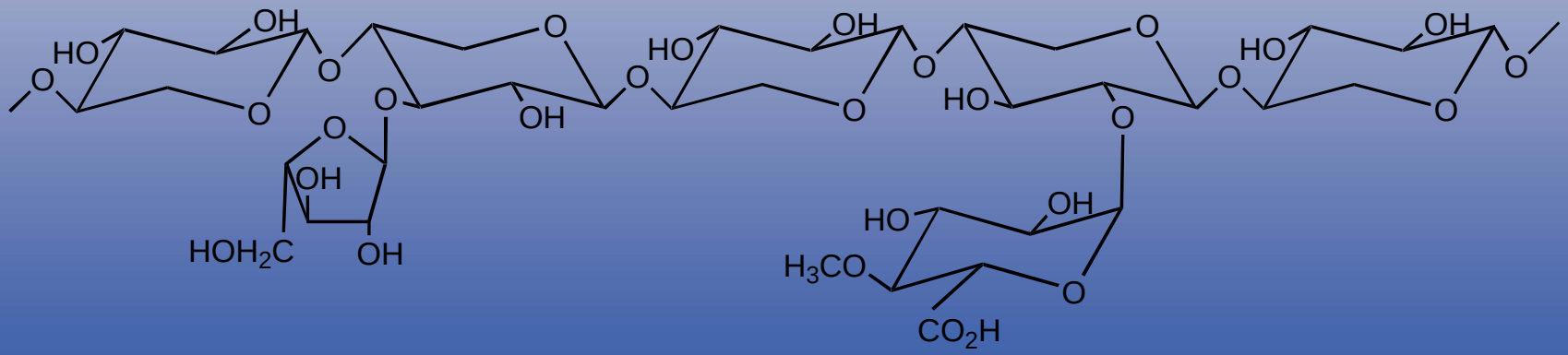
Hemicelluloses in Softwood





O-acetyl-galactoglucomannan

(DP ~100)



Arabino-4-O-methylglucuronoxylan (DP ~100)

Kraft Pulping - Hemicelluloses

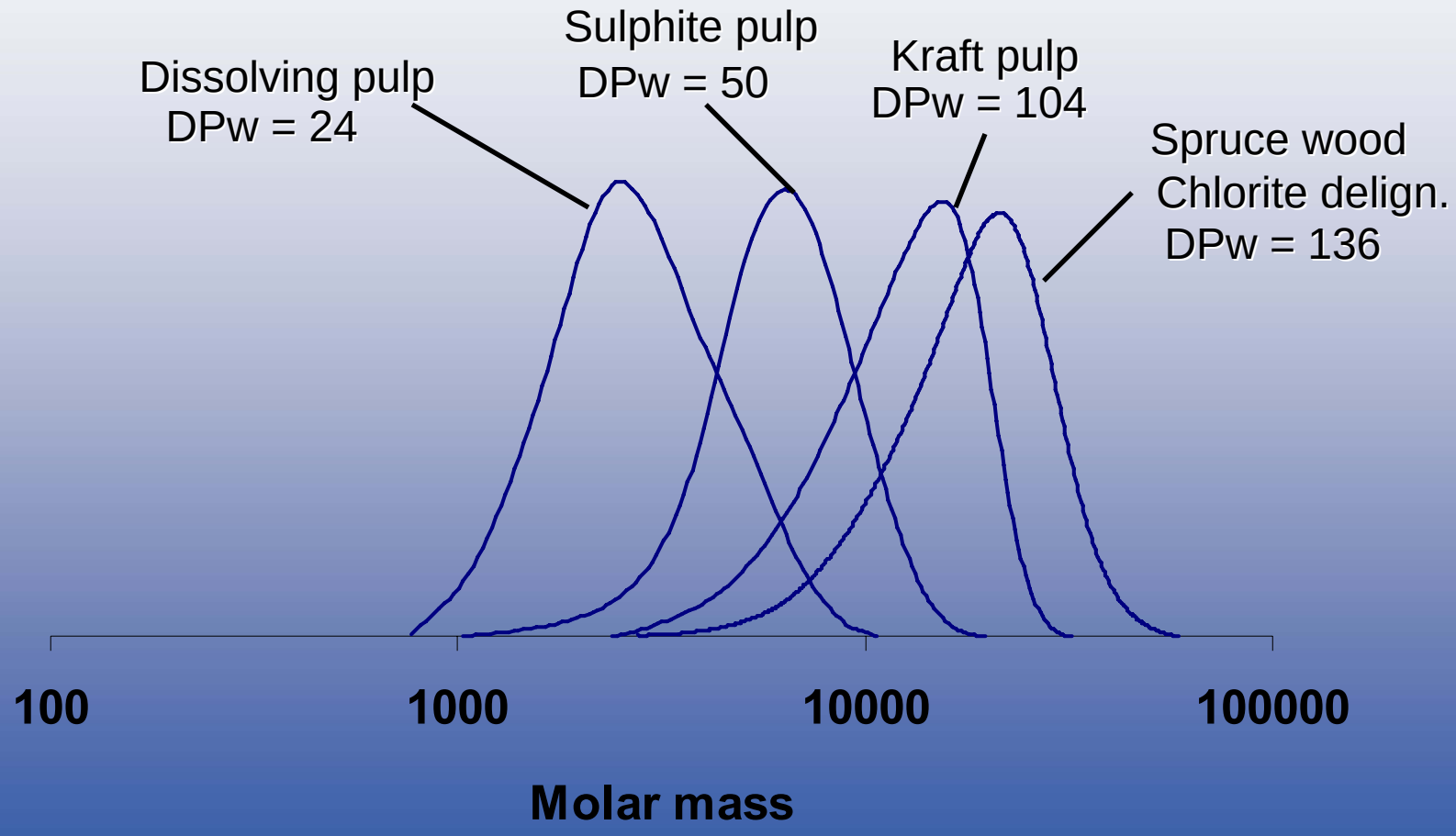
O-acetyl-galactoglucomannan

~ 130 kg /tonne wood is degraded into sugar acids and to other low molar mass sugars found in the cooking liquor

O-acetyl-4-*O*-methylglucuronoxylan

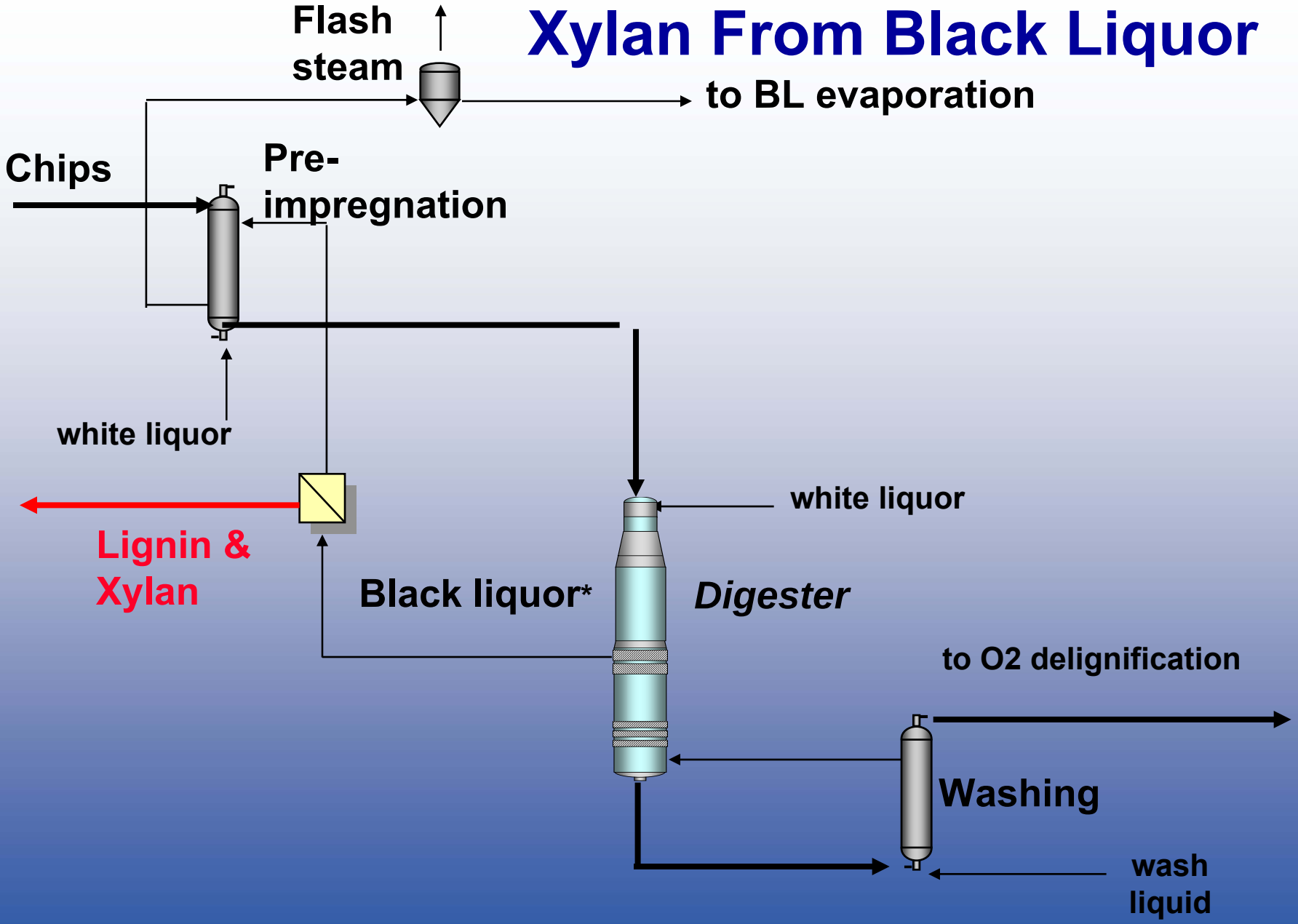
~ 150 kg /tonne wood is dissolved in the cooking liquor, most of it in polymeric form

Degree of Polymerization for SW Xylan



(A. Jacobs and O. Dahlman. Biomacromolecules, 2001)

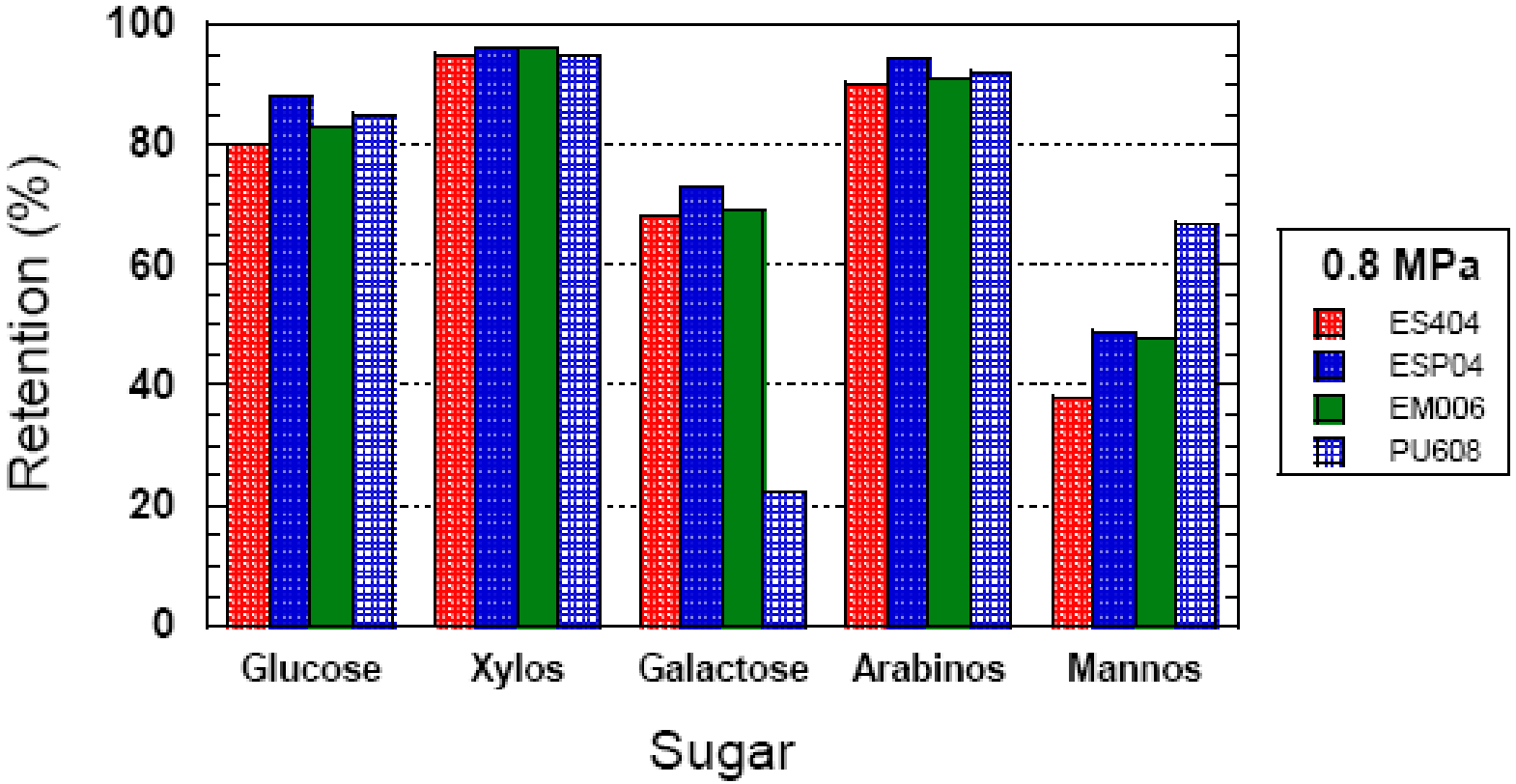
Xylan From Black Liquor



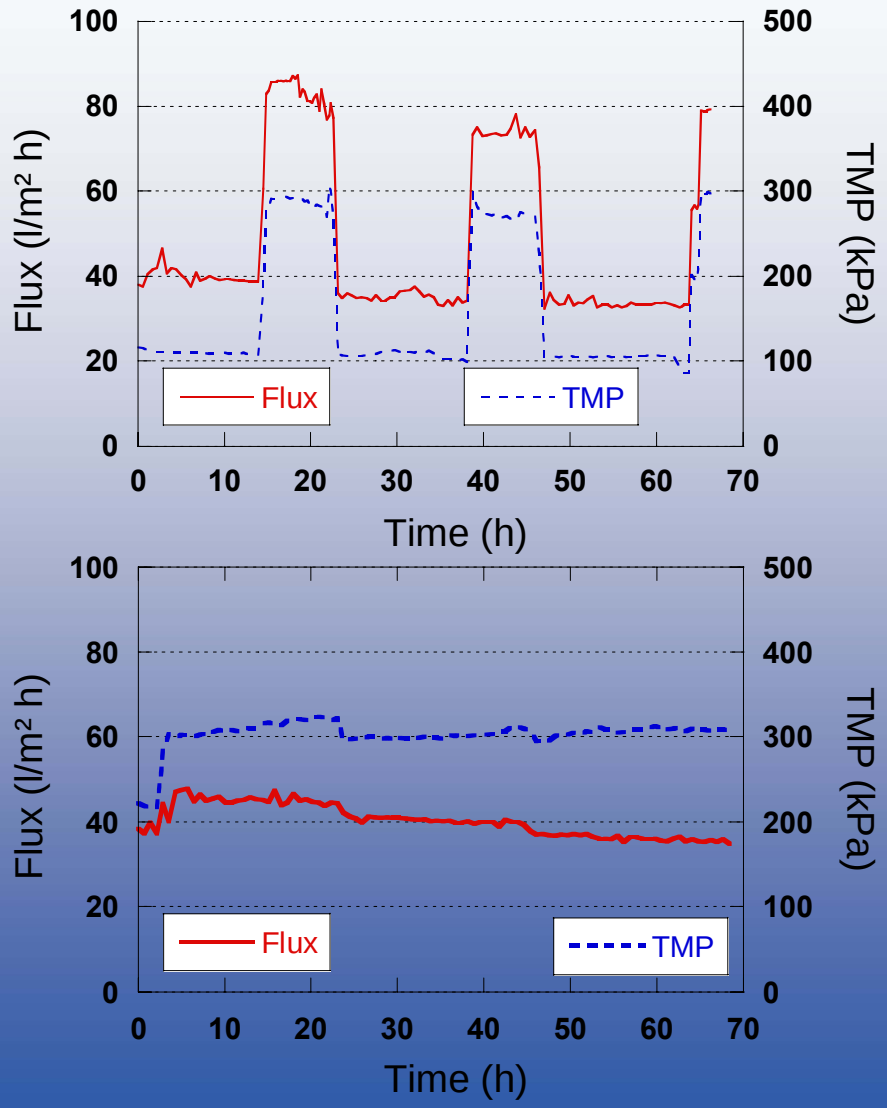
Mill Trial With Ceramic Membrane 2005

High Retention of SW Hemicelluloses

- cut-off 4 - 8 kDaltons

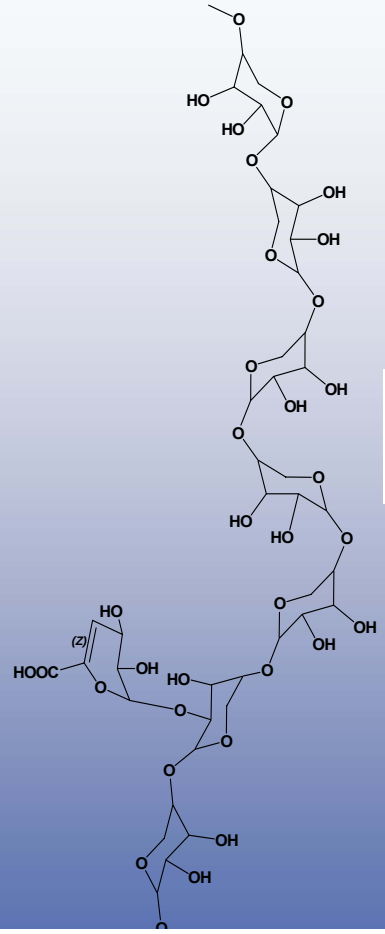


Fouling in Mill Pilot – No Problem!!



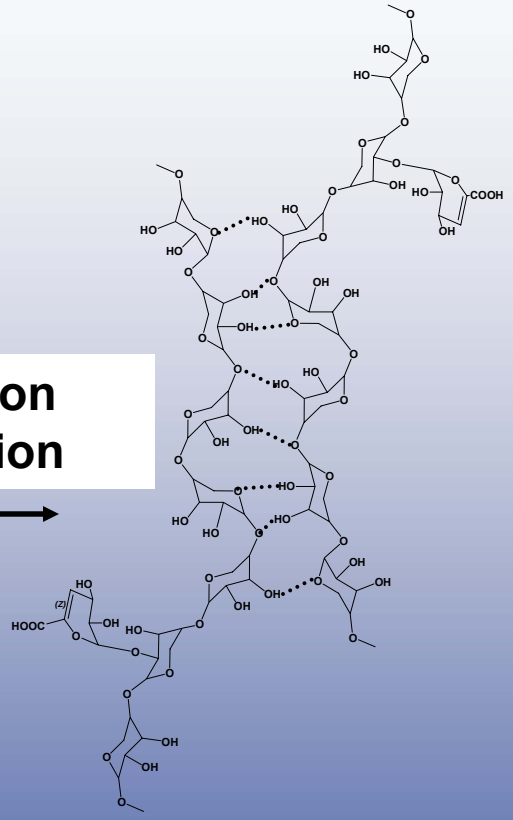
5 kDalton
145 °C

Xylan Sorbs Onto Fibers

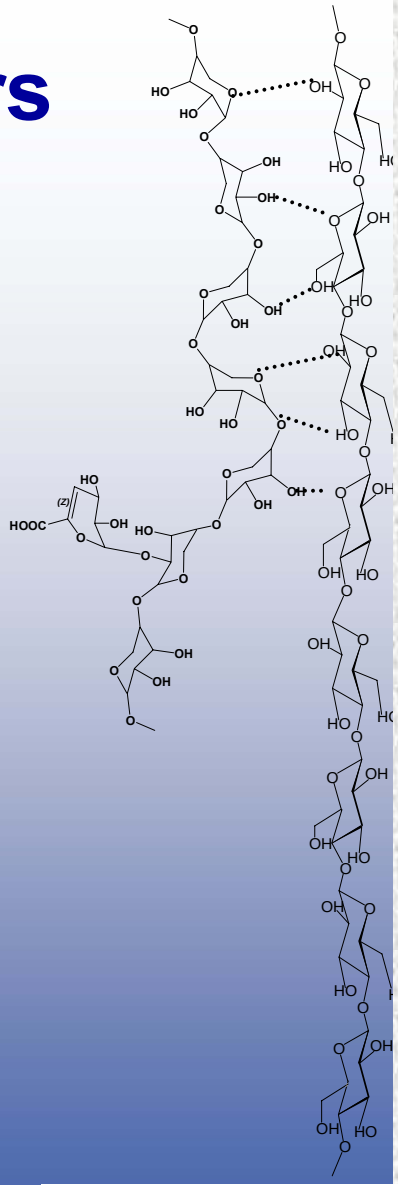


Debranching of xylan in the cooking liquor

Aggregation and sorption



Aggregation of xylan polymers



Sorption of xylan onto fibre surface

The Pulp Mill Biorefinery

Example 5

Glucomannan from TMP white water

STFI, Åbo Akademi

Glucomannan From TMP White Water

Interesting barrier properties!

The Pulp Mill Biorefinery

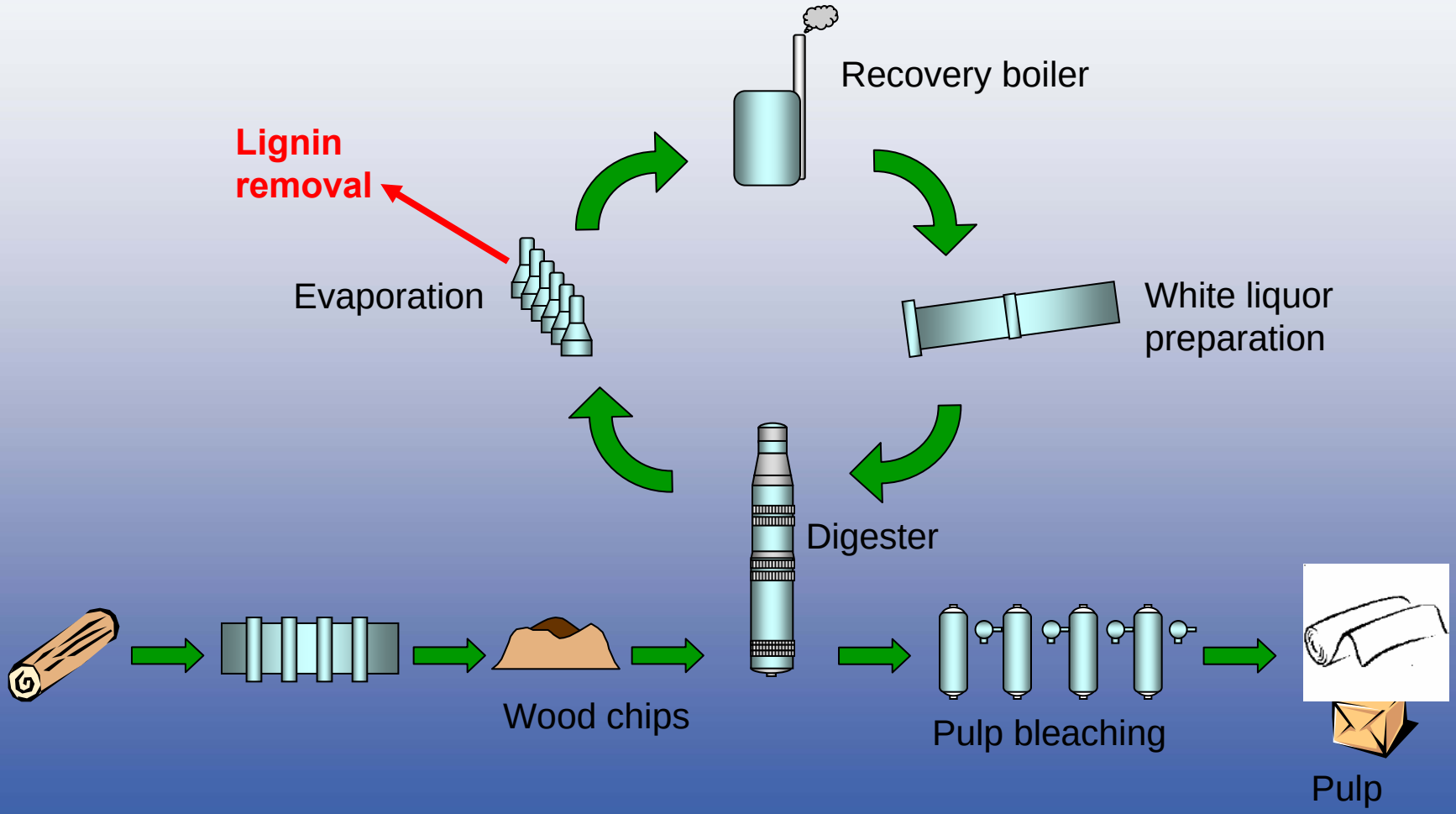
Example 6

Lignin from black liquor

FRAM2-program

STFI, Chalmers, LTH, Sydkraft, ÅF, Fortum, Södra, StoraEnso, Weyerhaeuser…….

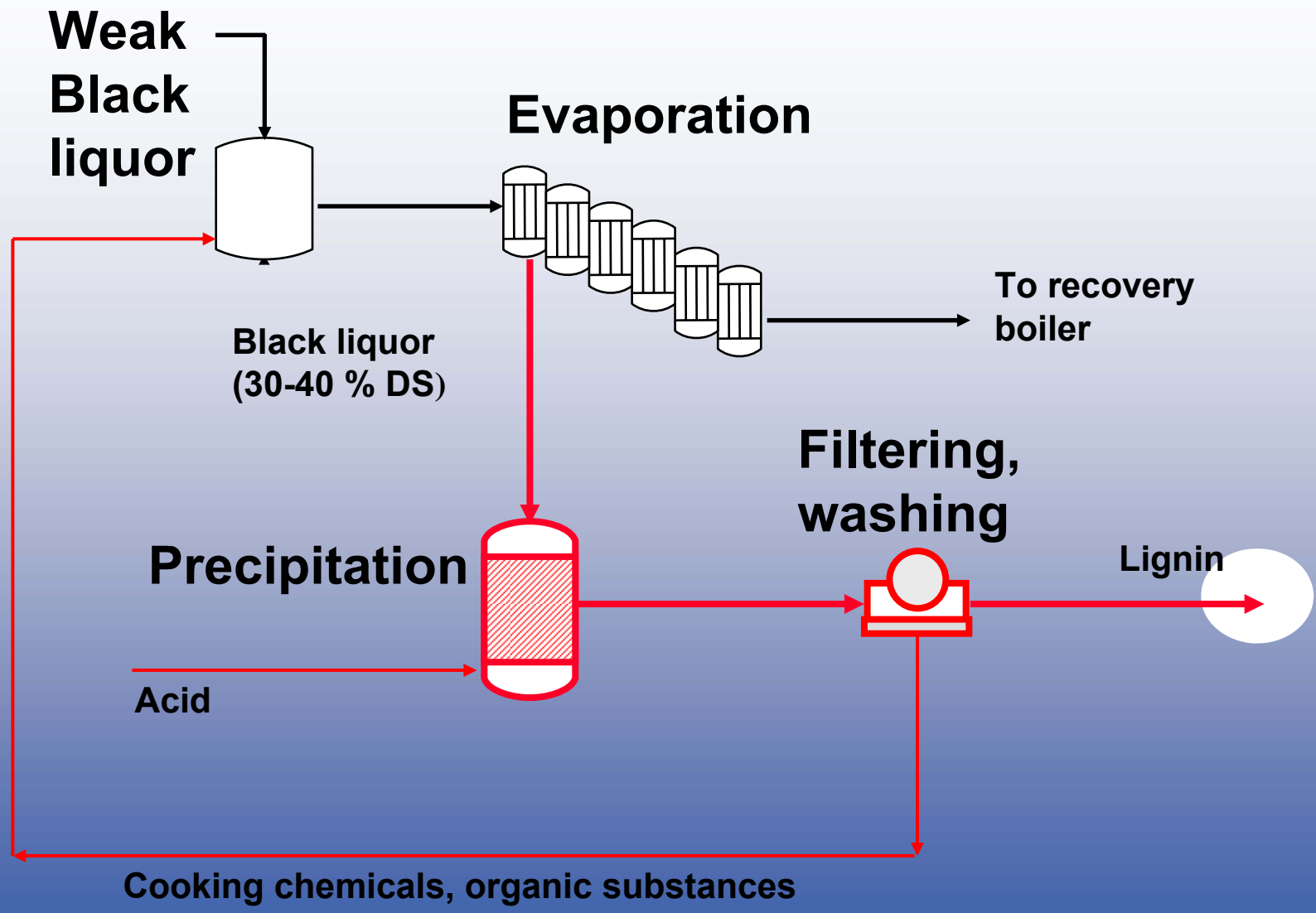
Lignin Removal



Removal of Lignin – Industrial Value

- Removal of lignin is a low capital-cost alternative to de-bottleneck the recovery boiler
- Lignin can replace mineral oil in the lime kiln or outside the pulp mill or be a chemical feed-stock for “green chemicals

Lignin Removal –Precipitation/washing

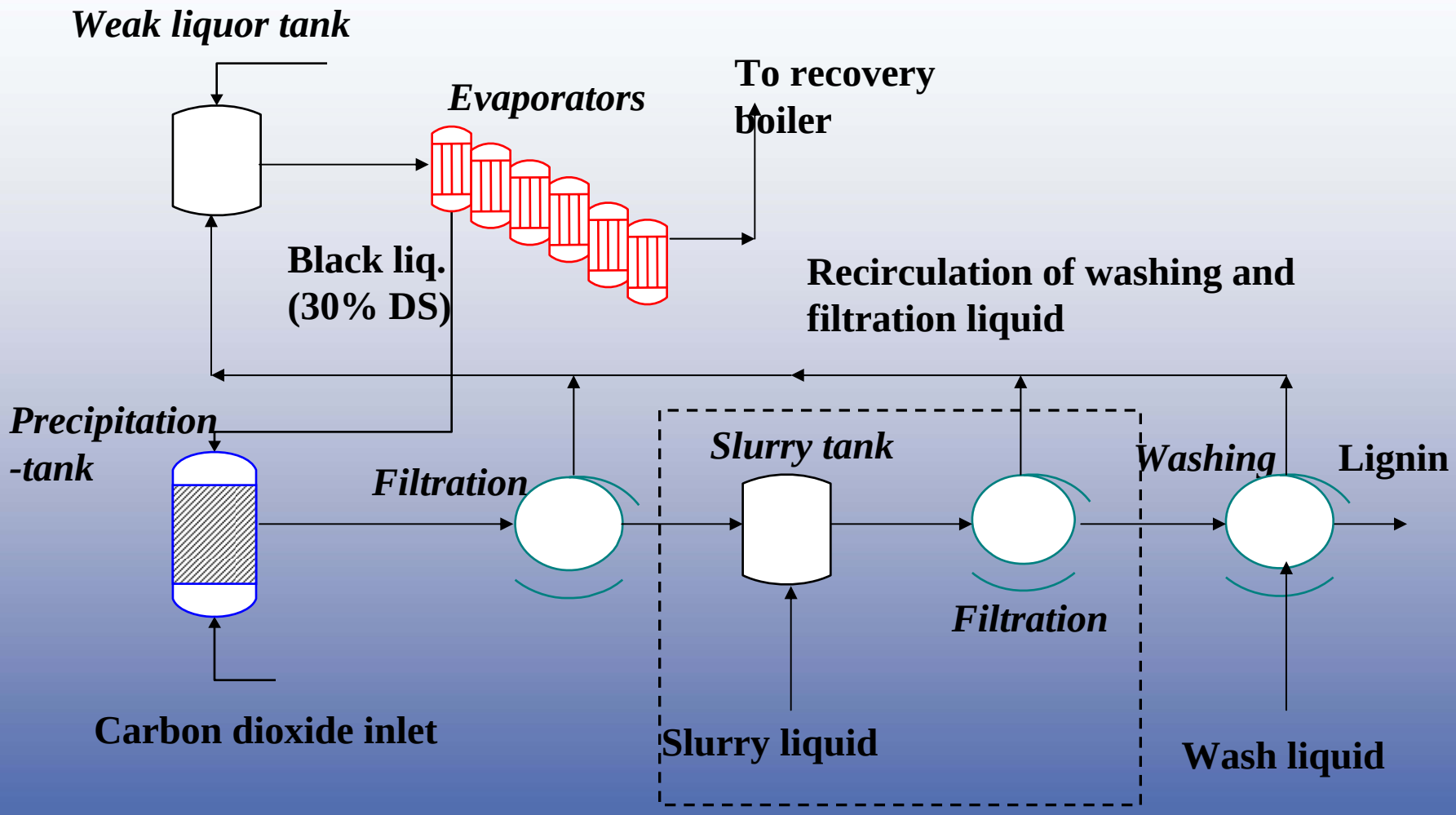


Mobile Equipment for Lignin Removal

Precipitation vessel

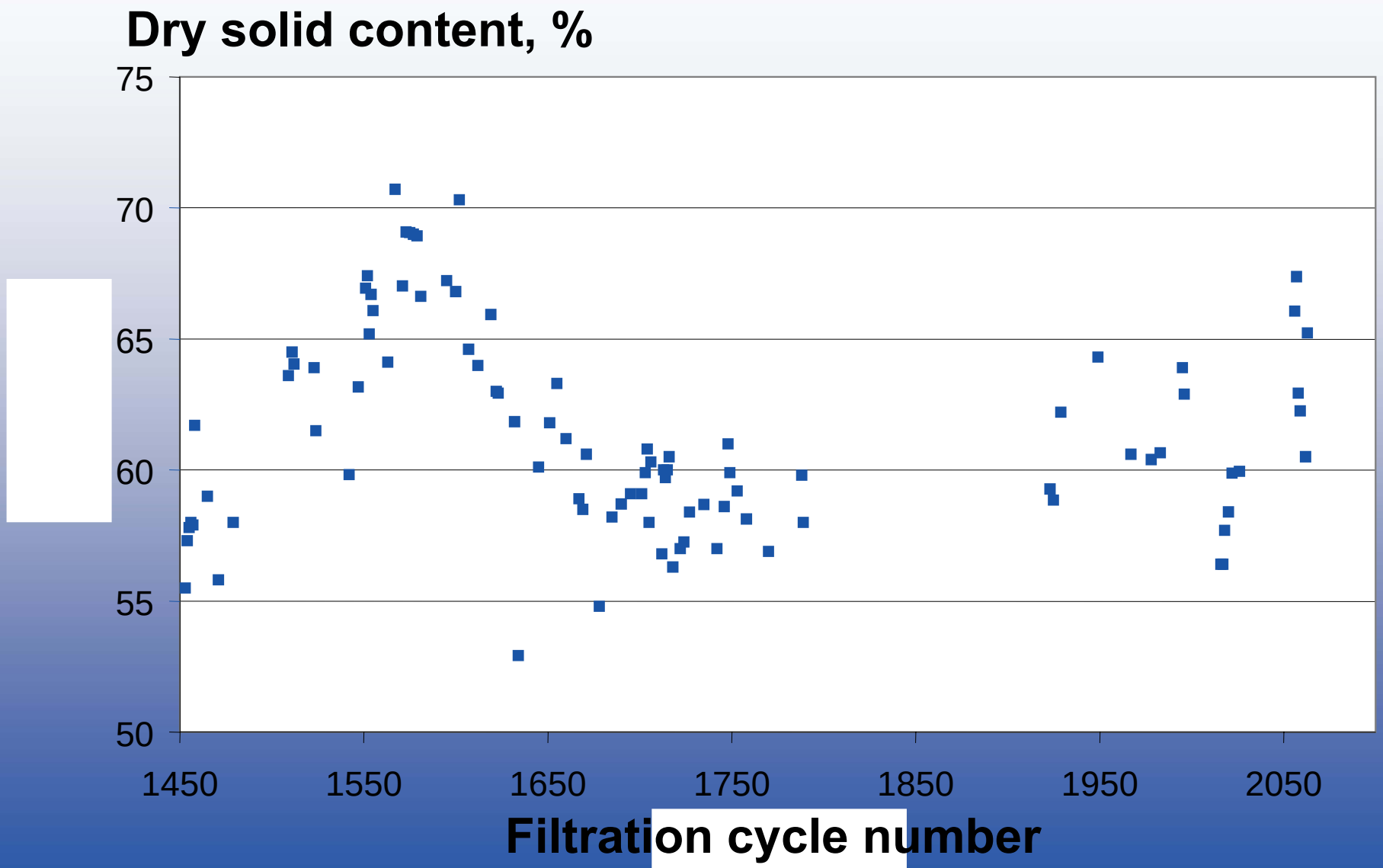
0.1 m^2 filter press

New Process for Lignin Removal

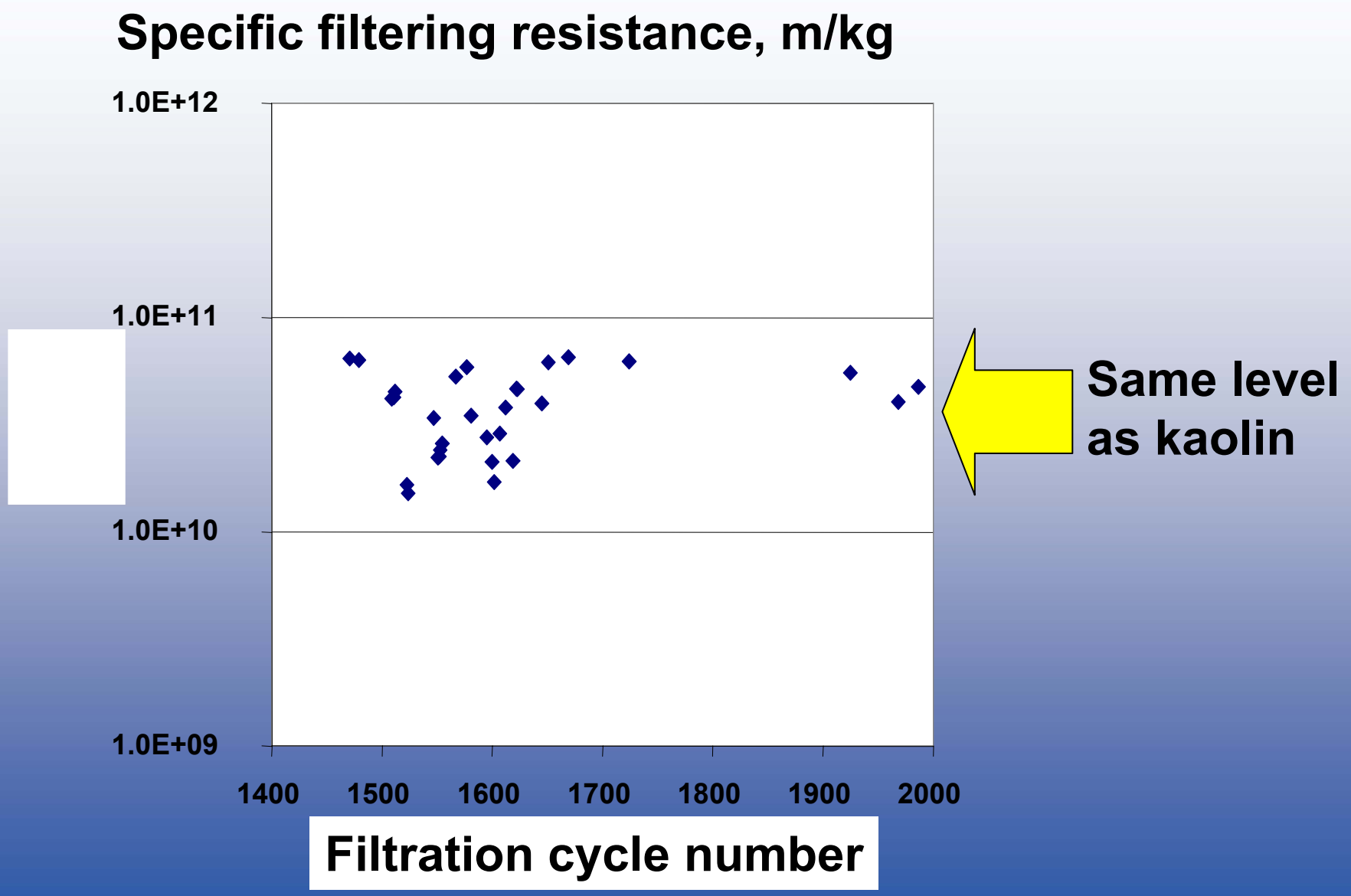


Mill Pilot 2004 – 10 Tonnes Produced

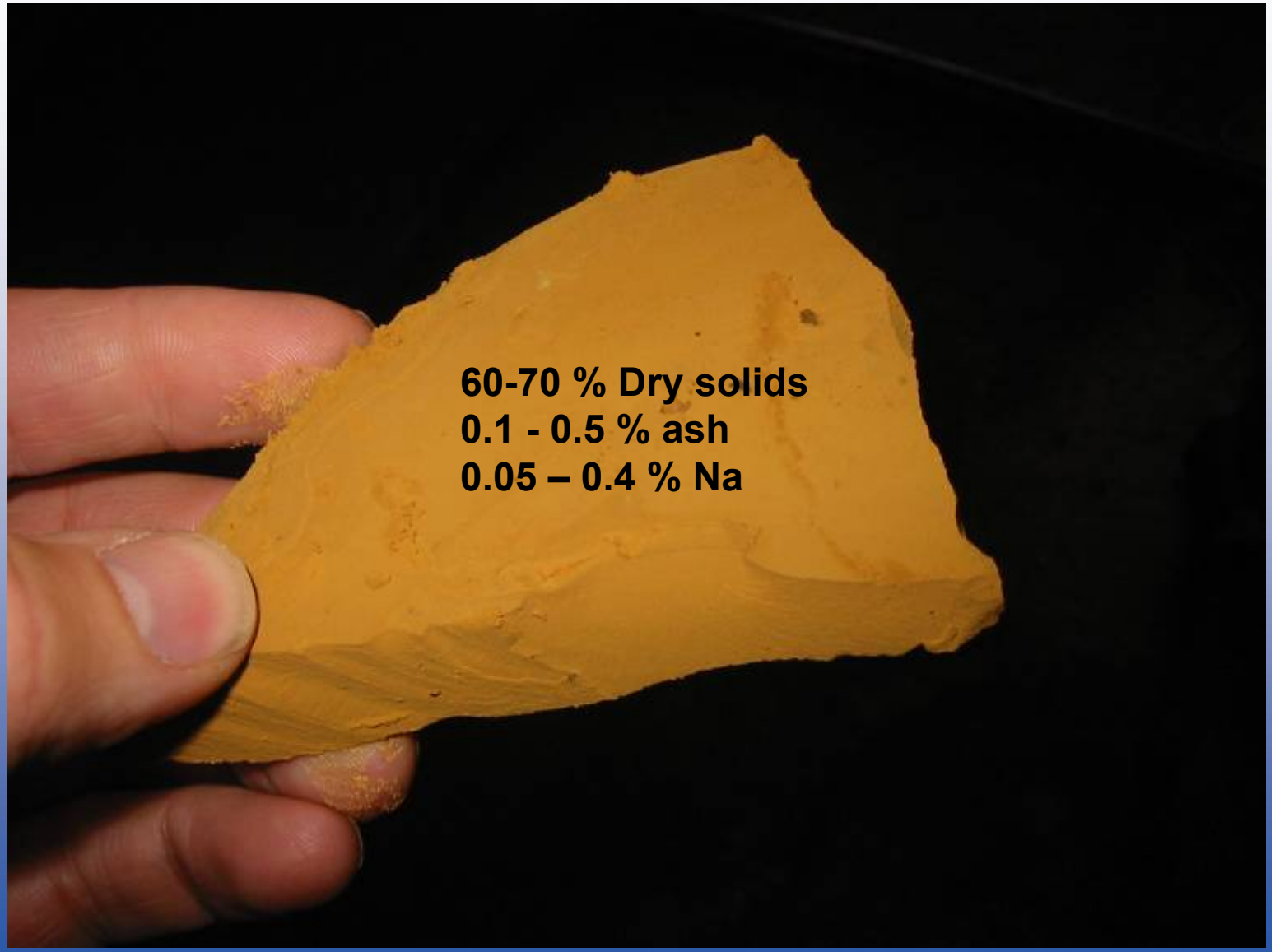
Mill Pilot Trials



Mill Pilot Trials



Lignin from Mill Pilot



Possible Lignin Applications

- Solid fuel for lime kilns
- Carbon fiber for composites
- Porous carbon structures

- Chemicals
  - Fenols
  - Binder
  - Dispersant
  - Sequestering

Lignin Pellets 700 kg/m^3

Lignin Removal - Mill Pre-study

A recovery boiler limited kraft pulp mill

Annual capacity of 250.000 t

Capacity increased 25 % to 320.000 tpy

This corresponds to 50.000 tonnes of lignin per year

- **The investment is reduced 140 MSEK (18 MUSD)**
- If lignin replaces mineral oil the **annual revenue is 40 MSEK (5 MUSD)**.

The Pulp Mill Biorefinery

Example 7

Gasification of black liquor

Swedish BLG Program

STFI, ETC, Chalmers, Umeå Univ., ETC, Luleå Technical Univ., Corrosion Institute

Swedish BLG Program

0. Synthesis and coordination

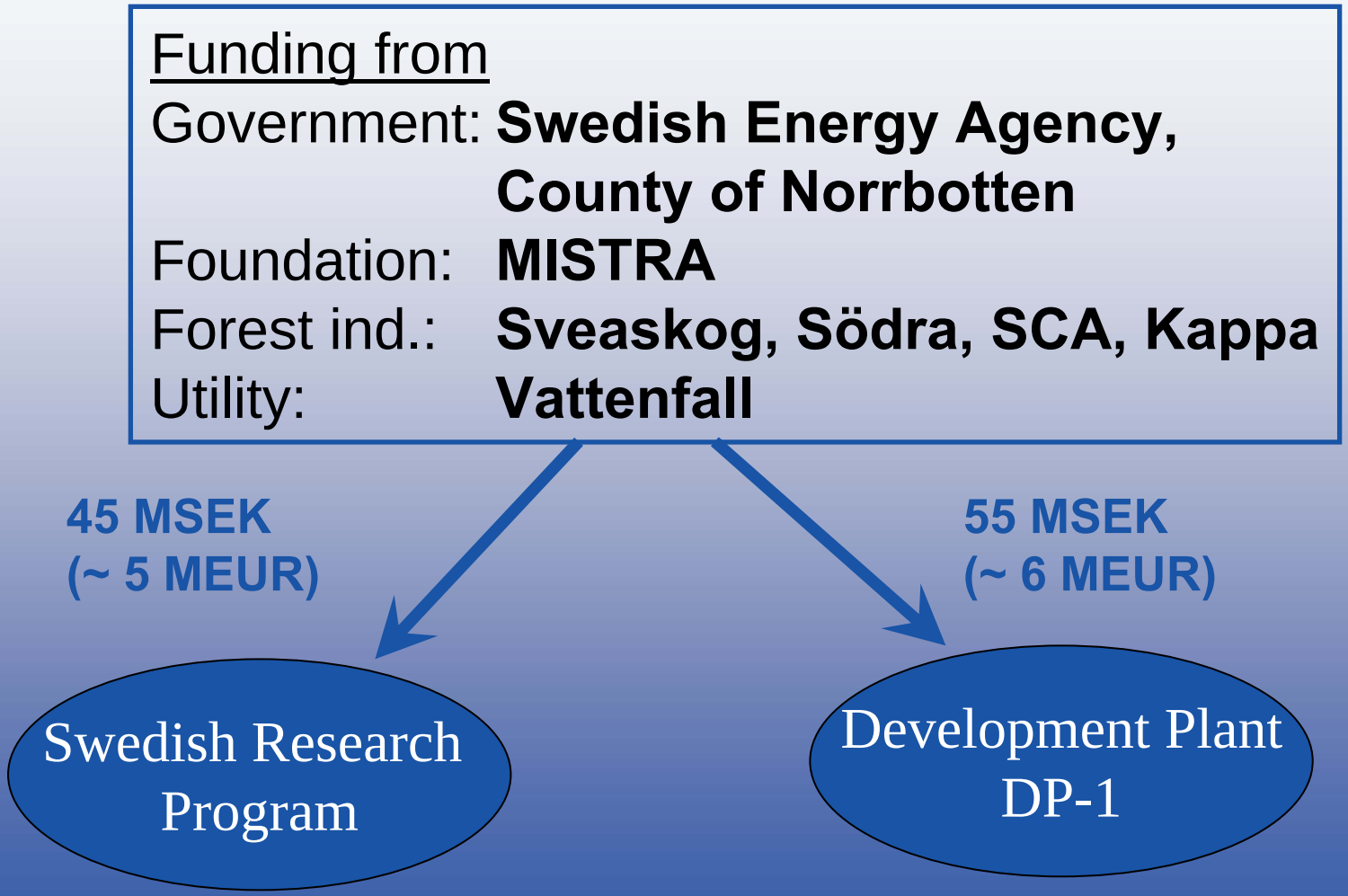
Gasifier projects

1. CFD modelling of gasification reactor (ETC)
2. CFD modelling of quench cooler and condenser (Luleå Technical Univ.)
3. Smelt formation (Umeå Univ.)
4. Gasification kinetics (Chalmers)

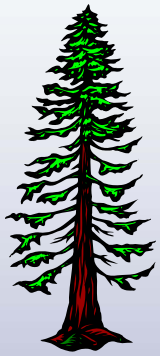
Mill-oriented projects

5. Autocausticising with borates (ETC)
6. Pulping with new liquors (STFI-Packforsk)
7. Kidneys, NPEs (STFI-Packforsk)
8. Construction materials hot green liquor (Corrosion Institute)

Swedish BLG Program



The Thermal Pulp Mill Biorefinery



Chips

Bark & forest residues

Pulp mill

Spent liquor

Biomass and black liquor gasification

Cellulose

- *Particles*
- *Fibres*
- *Films*
- *Sponges*

Pulp

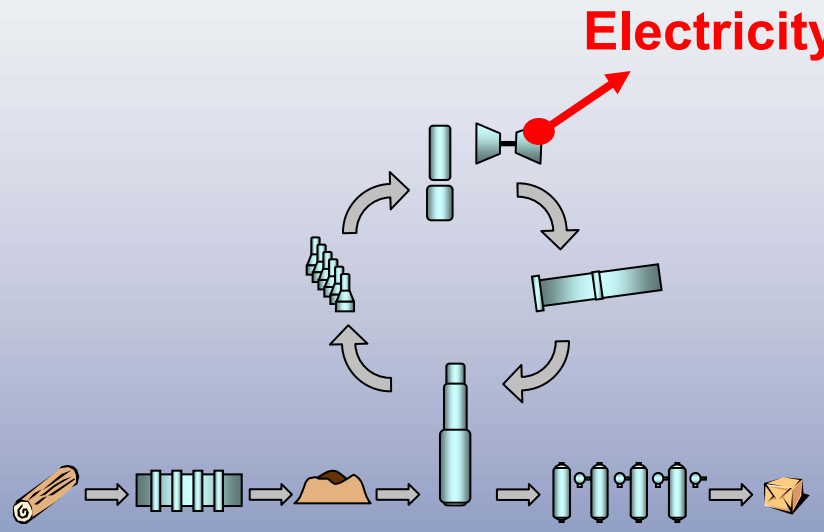
Paper

Electric power

Methanol/DME

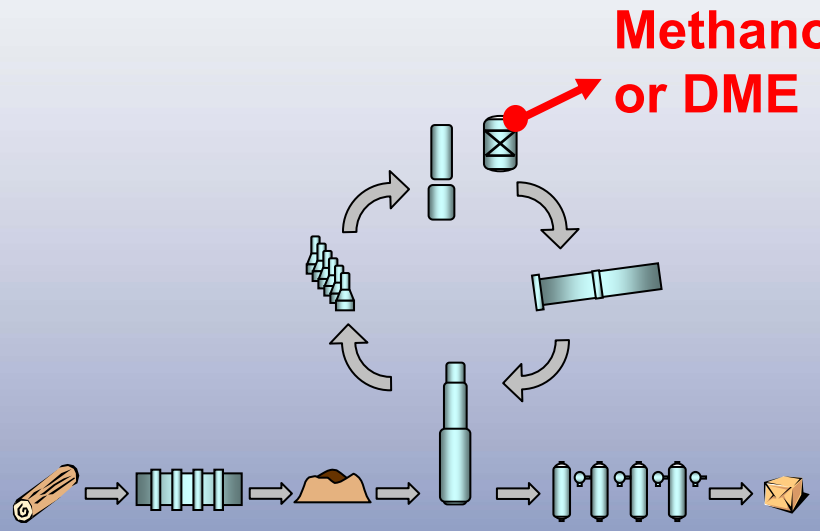
Higher hydro-carbons

Black Liquor Gasification Combi Cycle



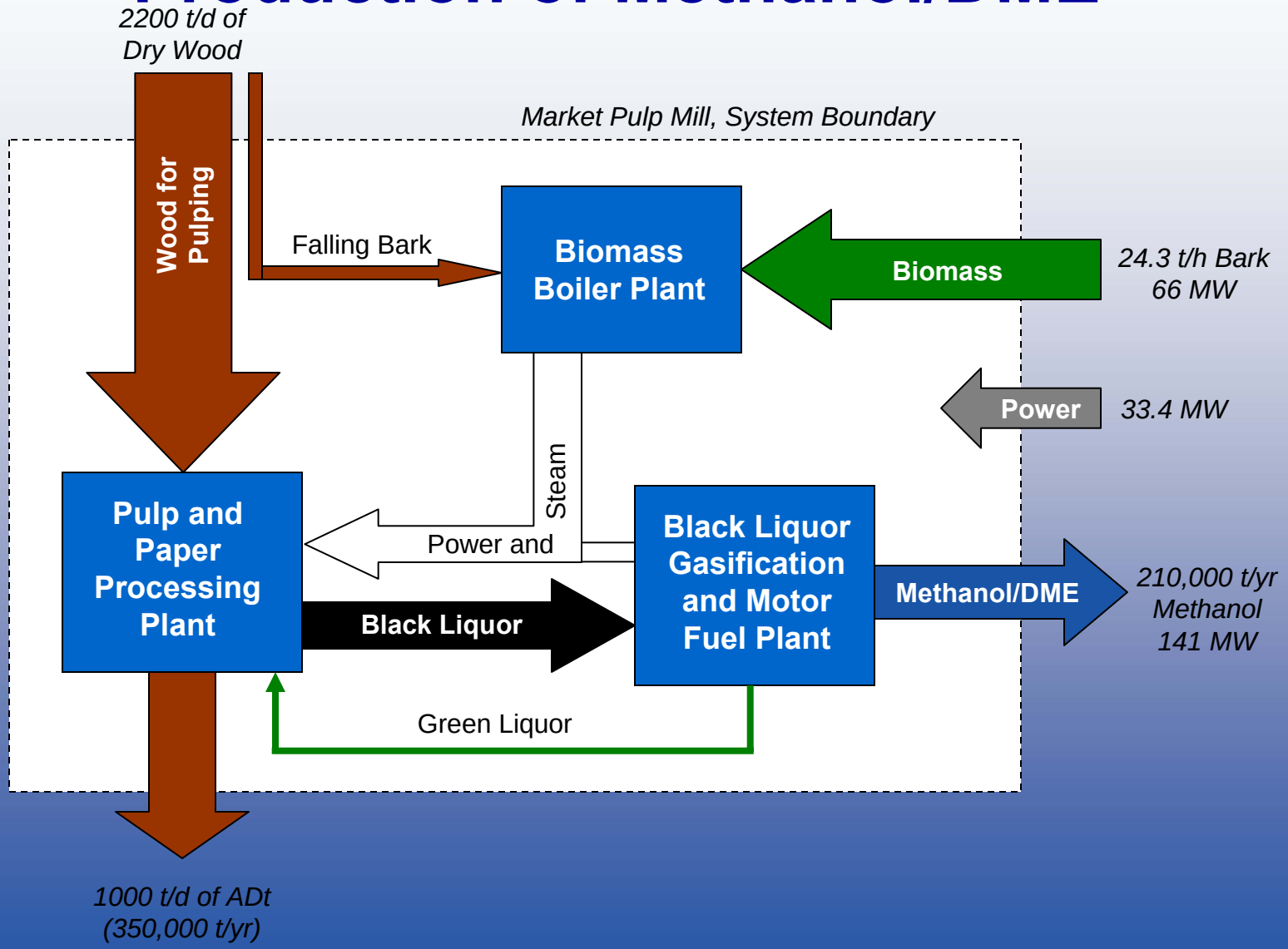
Over 1000 kWh ptp

Black Liquor Gasification Motor Fuel



300 – 600 kg methanol/DME ptp

Black Liquor Gasification Production of Methanol/DME



The Pulp Mill Biorefinery

Example 8

New process for removal of soap from black liquor

Kiram, Aga Linde

New Process for Soap Removal
Kappa Kraftliner Mill, Piteå, Swden

First step of a wood extractives refinery

- In operation spring 2006
- Capacity 25.000 tons of raw extractives (tall soap) per year
- Decreased use of sulfuric acid
- Final products
  - Resins for binders formulations
  - Fatty acid ester (biodiesel)
  - β - sitosterol

Södra Cell – Future Plans
Pulp producer and energy supplier

Electricty

Lignin

Heat

Motor fuel

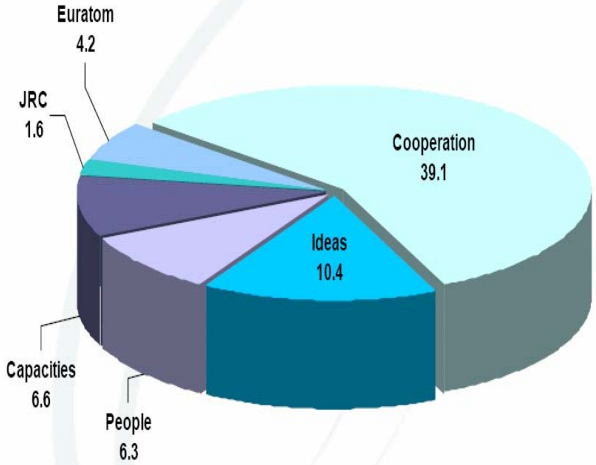
Biofuel

EUROPEAN INITIATIVES PROMOTING "THE BIOREFINERY"

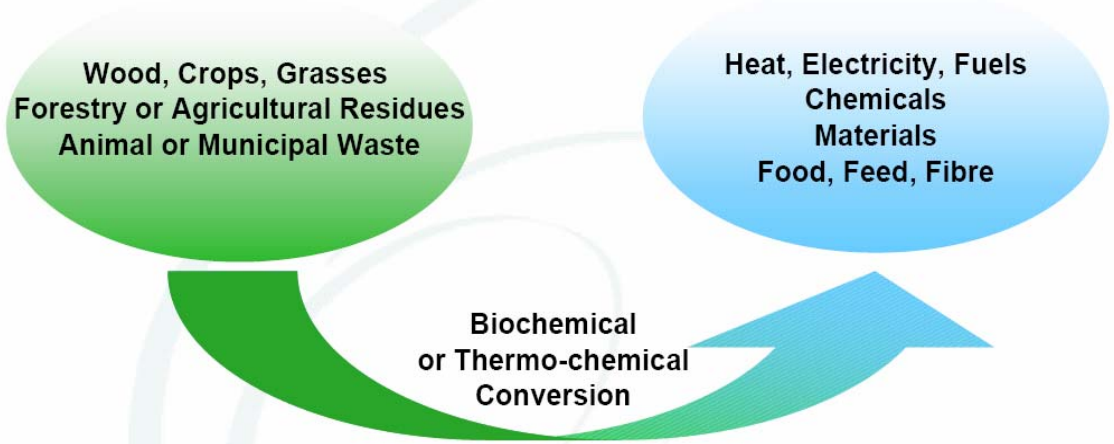
Forest-Based Sector
Technology Platform

Seventh Framework Programme

Commission proposal for 2007-2013 (Billion €)



Bio-refineries

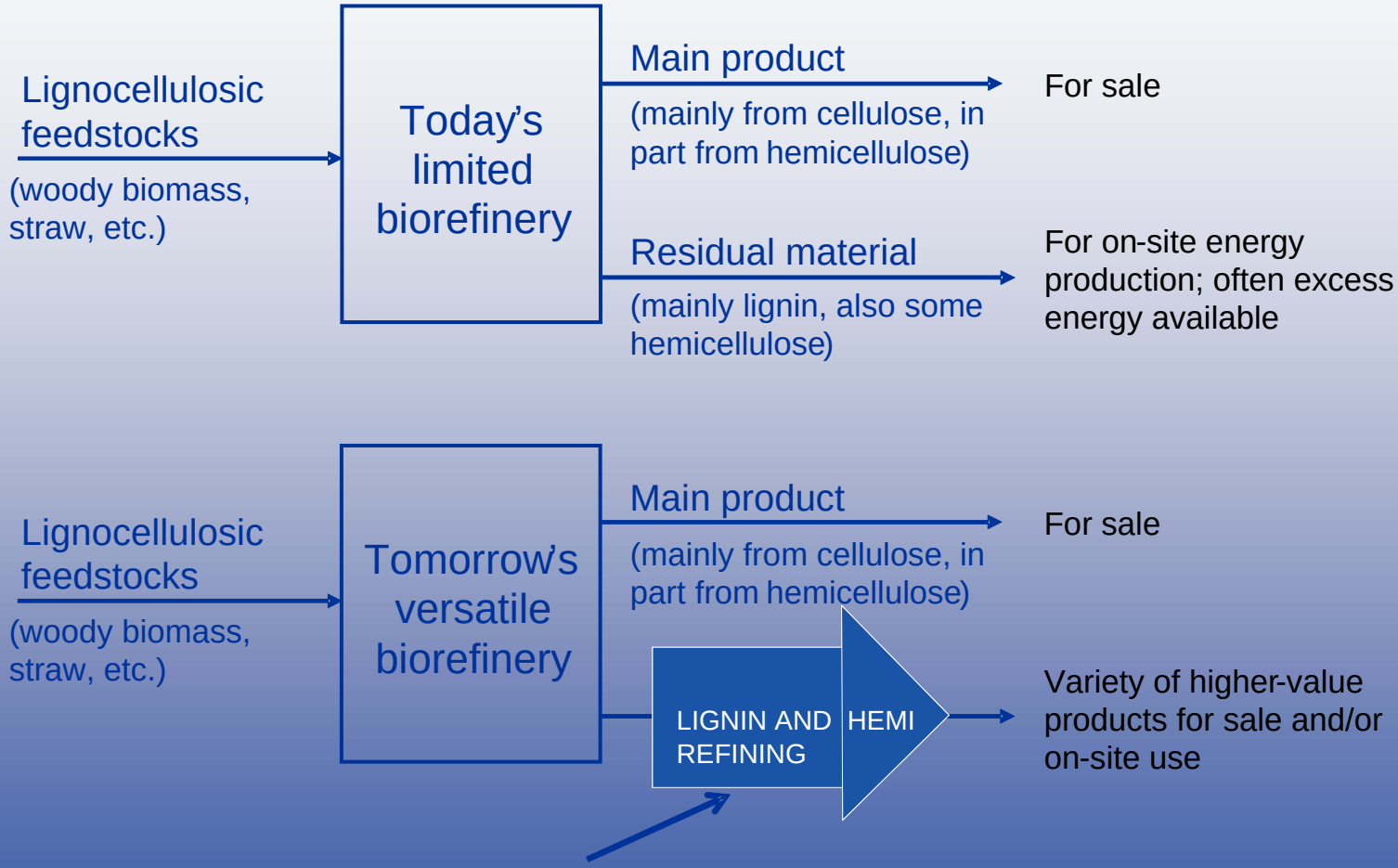


will be supported in two FP7 Thematic Priorities:

Food, agriculture and bio-technology and Energy

Is the Future Pulp Mill a Biorefinery?

Wood Biorefienry Vision



The Future Pulp Mill is A Wood Biorefinery