WOOD 474

Pulp and Paper

It is widely accepted that Ts'ai Lun,
a Chinese court official, invented paper in 105 CE

Learning objectives

- Understand what society uses paper products for
  - Global trends in different markets
- Know how pulp and paper are manufactured
- Understand the structure of the BC industry
  - Its place in the world
  - Likely future trends

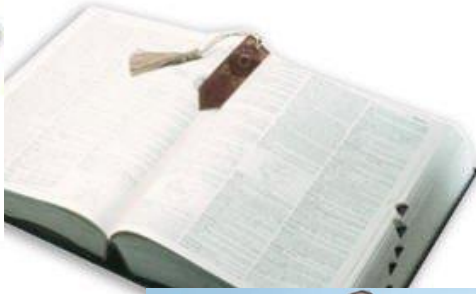
Photos: Cordyne 2013; Alibaba 2013

Major Products

- 3 major paper categories
  - Printing and writing (P&W)
  - Packaging
  - Hygiene
- Pulp products
  - Market pulp
- Fabrics
- Series of minor products

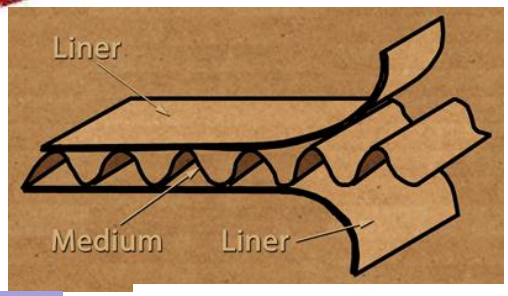
P&W papers

- newspapers
- magazines
- catalogs
- directories
- books
- commercial printing
- business forms
- stationery
- photocopying paper
- digital printing paper



Packaging Papers

- Carton board
  - E.g. cereal carton
  - Tetrapak
- Box board
- Corrugating medium
- Fluting medium
- Sack kraft paper
  - Brown bags
  - Multi-walled bags
- Wrapping paper



Hygiene papers

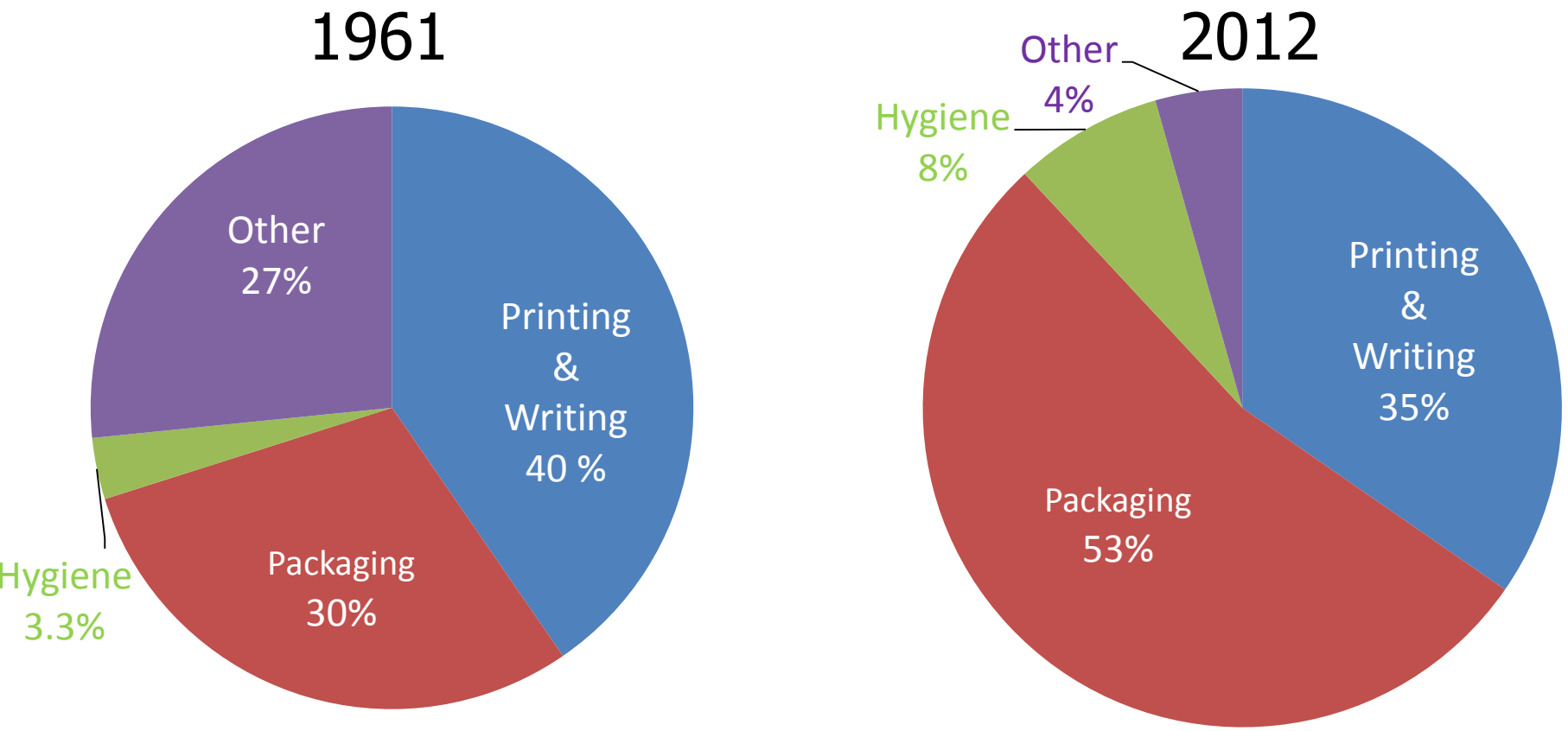
- Tissues
- Toilet paper
- Paper towels
- Diapers
- Wet wipes/baby wipes
- Liners & pads
- Industrial towels
- etc

Fabrics

- Dissolving pulps may be used to make fabrics that compete with cotton and silk
  - Rayon
  - Lyocell
  - Tencel
  - Modal
  - Galaxy

Photos: Lenzing 2013

Global production of paper by category (FAO 2013)

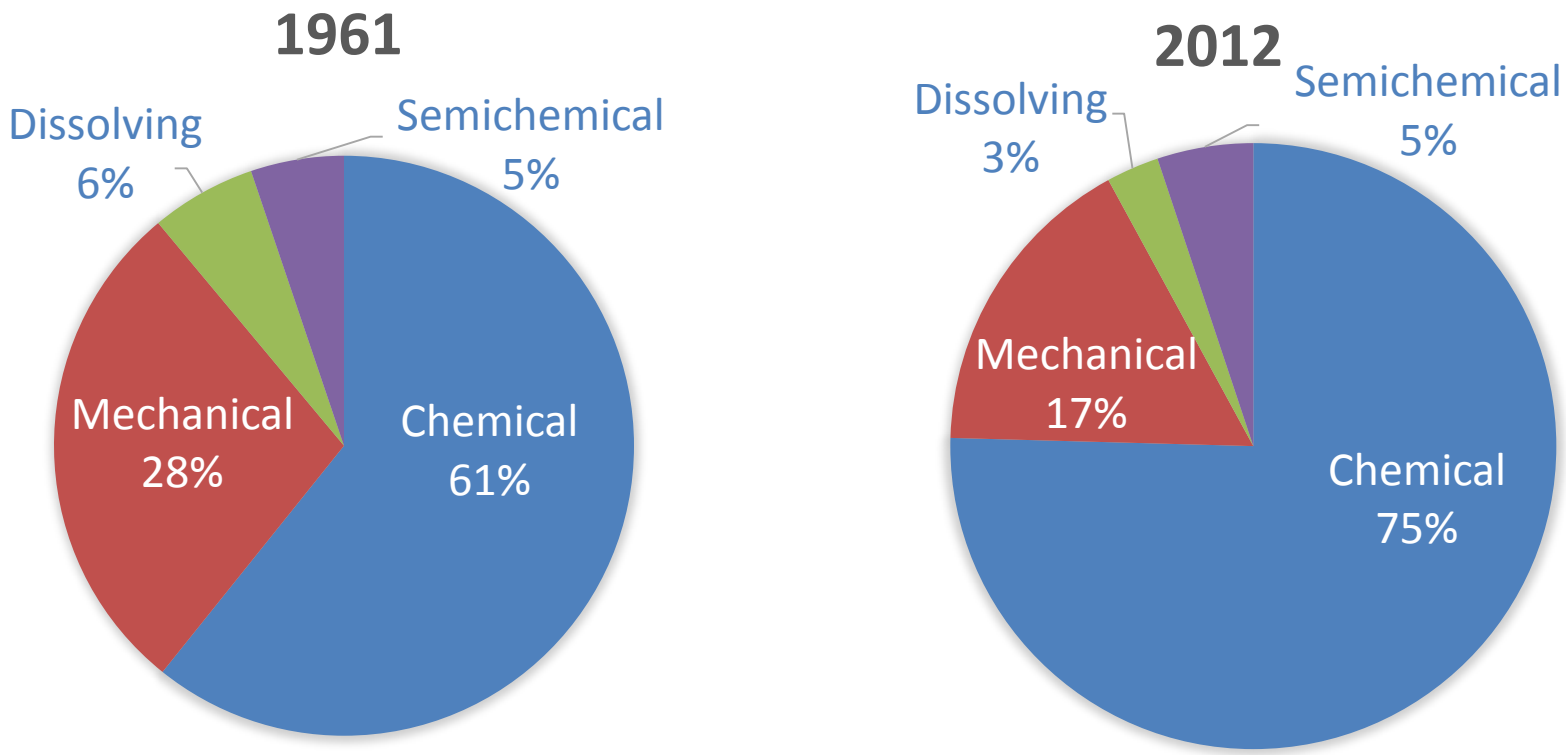


Total production (million tonnes/year):

1961: 74.2 2012: 401

Growth (1961-2012)= 5.4 fold

Global production of pulp by category (FAO 2013)

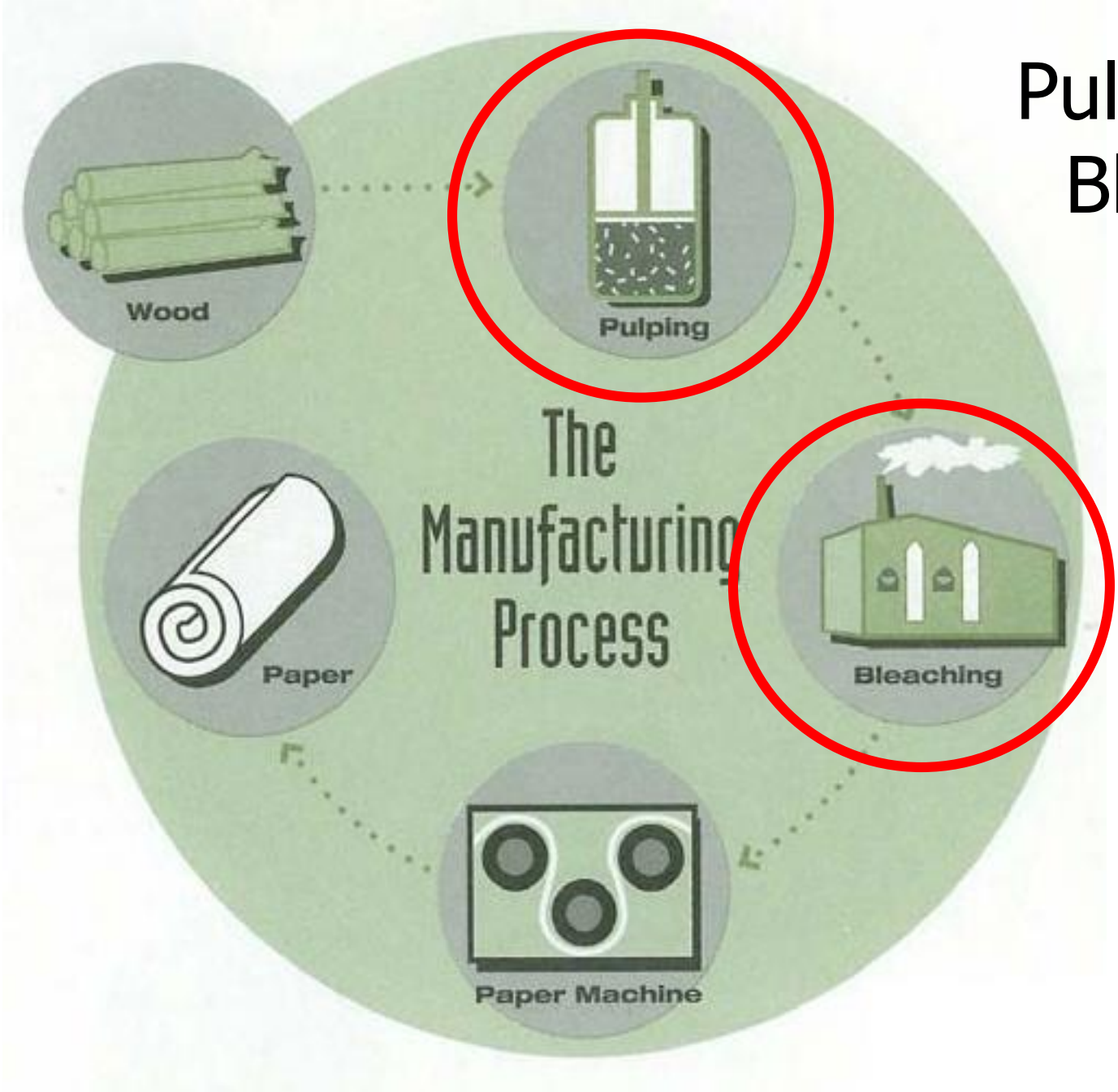


Total production (million tonnes/year):

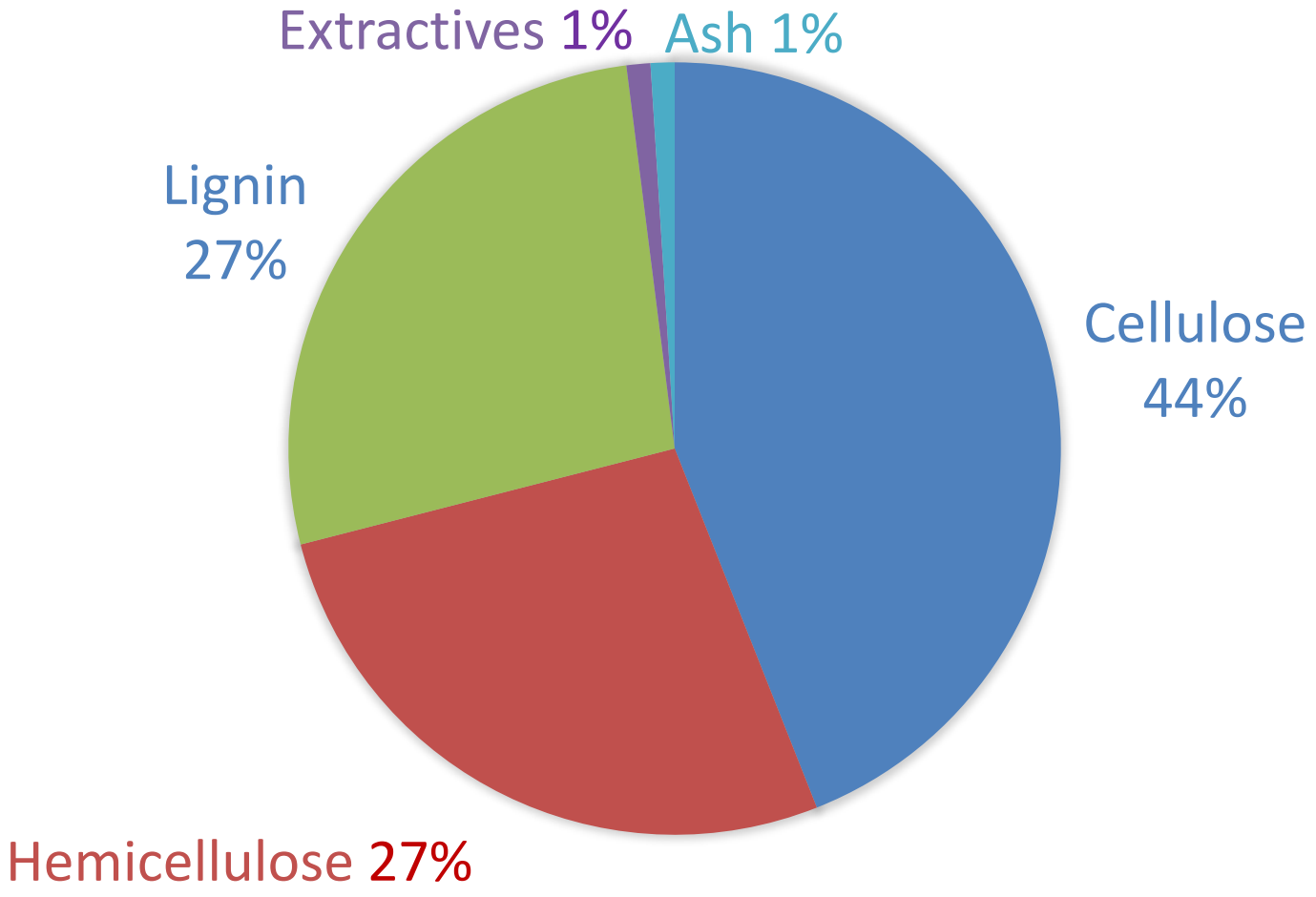
1961: 61.5 2012: 174

Growth (1961-2012)= 2.8 fold

Pulping and Bleaching

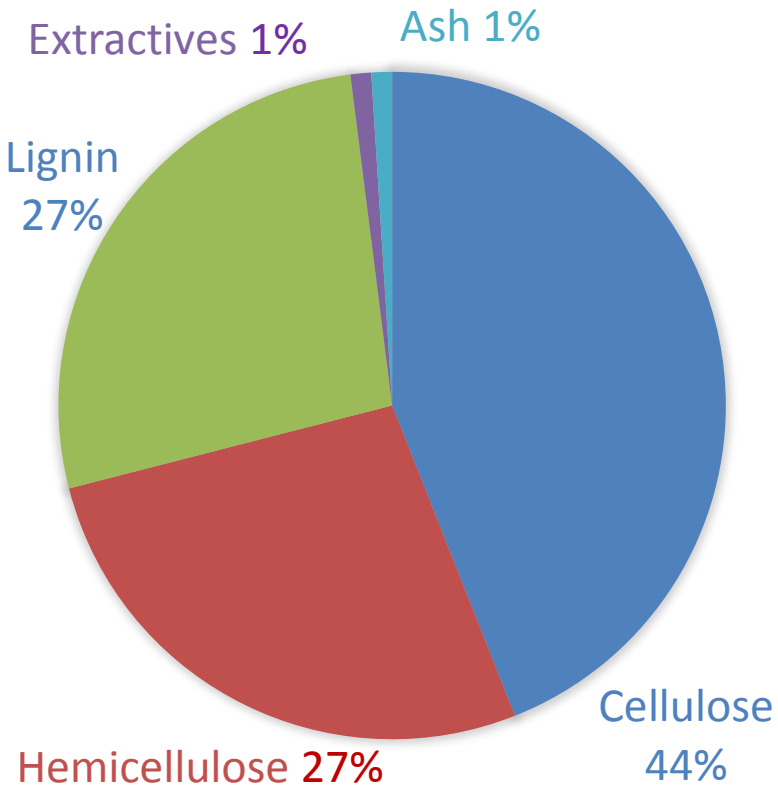


Composition of starting material - softwood



Composition of pulping input & products

starting softwood



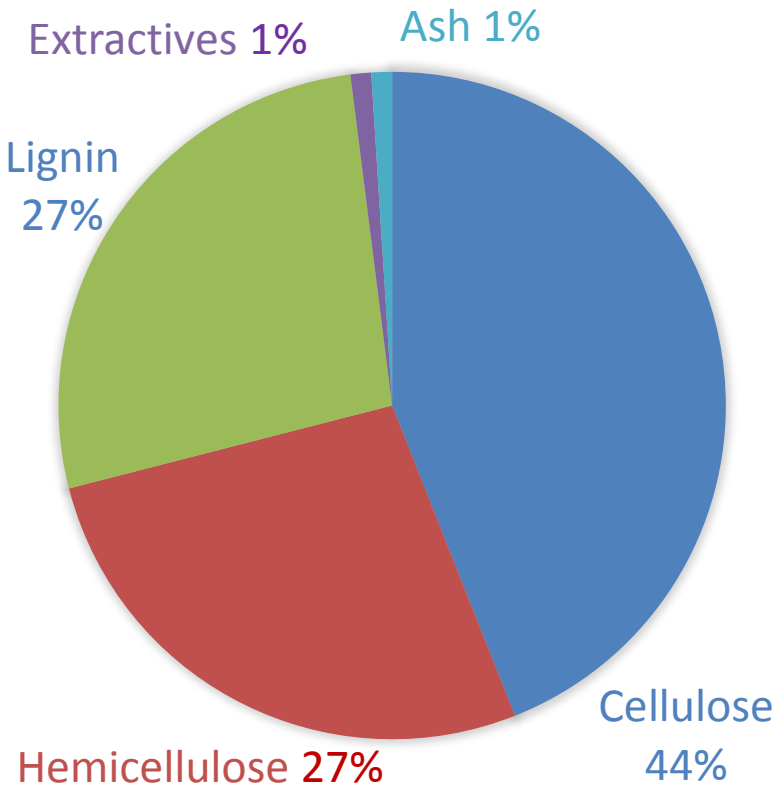
final product(s)

?

What components do we want to keep

Composition of pulping input & products

starting softwood



final product(s)

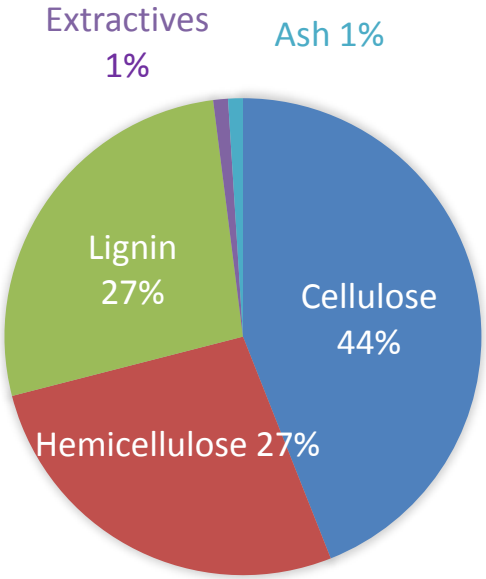
It depends on use.

Desired attributes:

- Strength
- Flexibility
- Opacity
- Whiteness
- Softness
- Absorbancy
- Low cost
- …..

Composition of pulping input & products

starting softwood



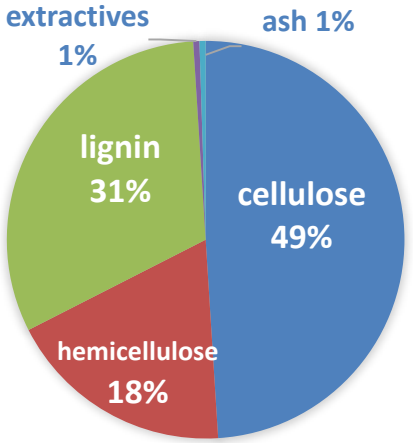
Mechanical pulping

Chemical pulping

final product

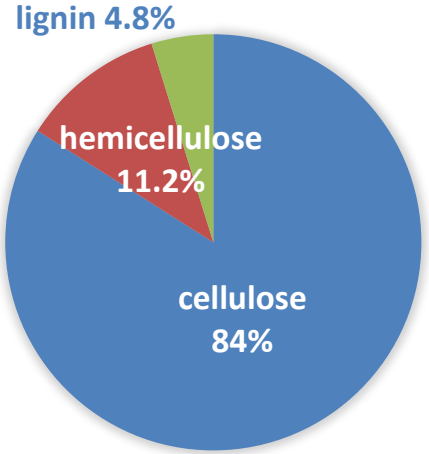
TMP

Yield: 85-90%



Unbleached kraft

Yield: 40-45%

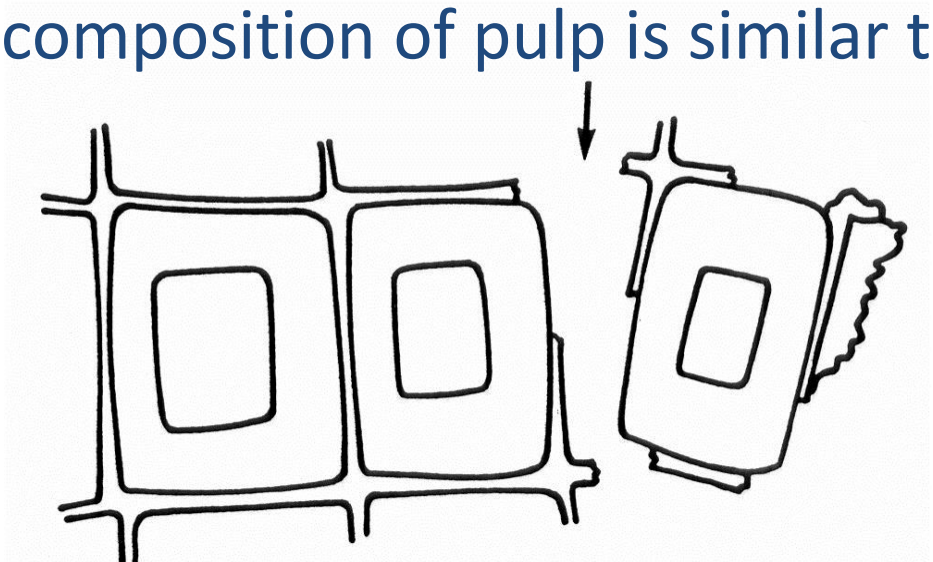


Two dominant pulping processes

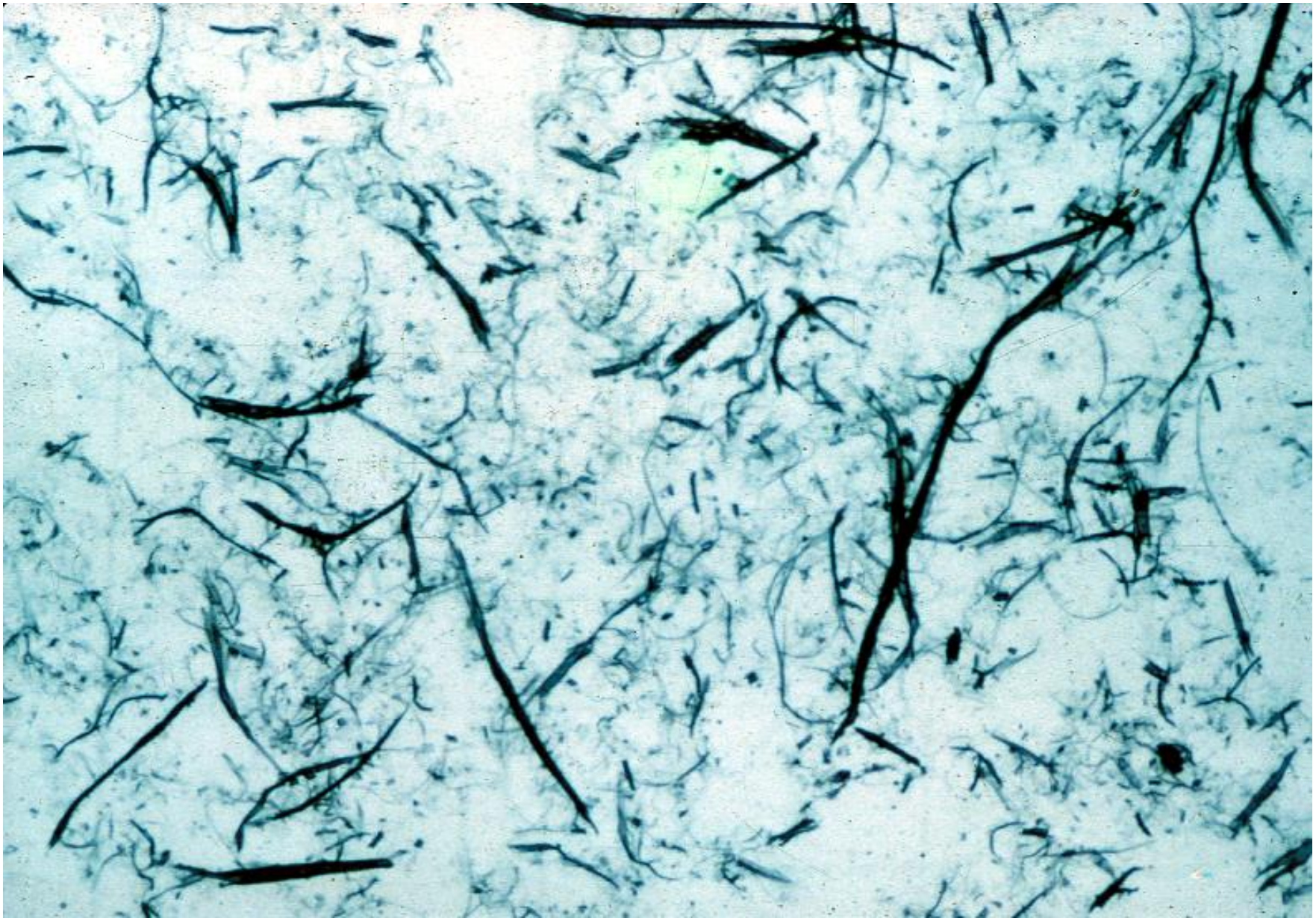
- Mechanical Pulping
  - Fibres are mechanically removed from the wood matrix
    - Lignin remains in the pulp
    - Some hemicelluose and extractives removed depending upon process
- Chemical Pulping
  - Chemicals and heat used to dissolve lignin
    - Lignin holding fibres together is dissolved
    - Much of the hemicellulose removed
    - Extractives removed

Mechanical Pulping

- Wood is physically disrupted
  - lignin is softened and mechanical action breaks the middle lamella which is more brittle than the fibre wall
  - fibre wall is left intact but substantial fibre cutting occurs
  - yield (= fibre recovery) is high : typically 85-95% w/w
  - chemical composition of pulp is similar to wood used



Mechanical Pulp

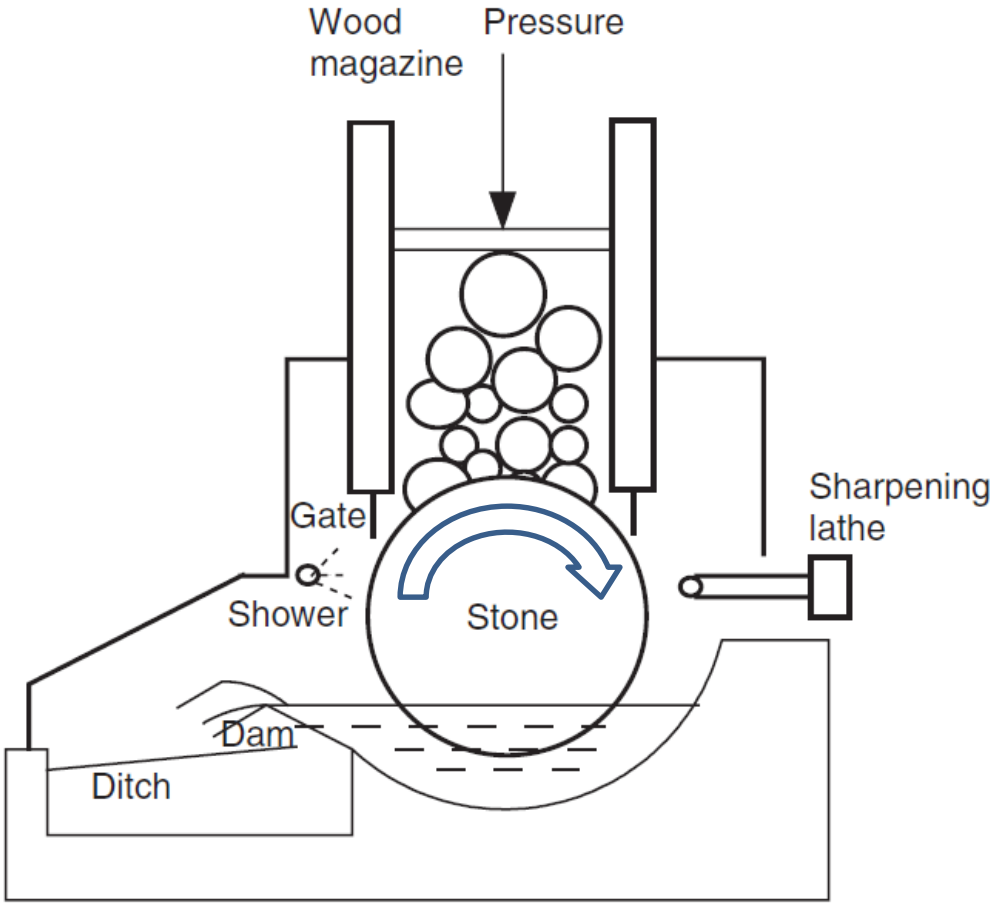


Mechanical Pulping

- Pulps cannot be brightened very much; therefore good quality material must be used
  - Chips used should be less than 2 weeks old (oxidation and biological decay darken chips after this point).
  - Low bark and dirt tolerance (color and machinery wear issues)
- Dense hardwood species not used due to short thick walled fibres and high % of vessels
- Resinous species can also present problems
- Pulp unsuitable for several uses due to lignin content which stiffens fibres
- Lignin also results in yellowing of pulp with time

Mechanical pulping technologies: Stone Groundwood (SGW)

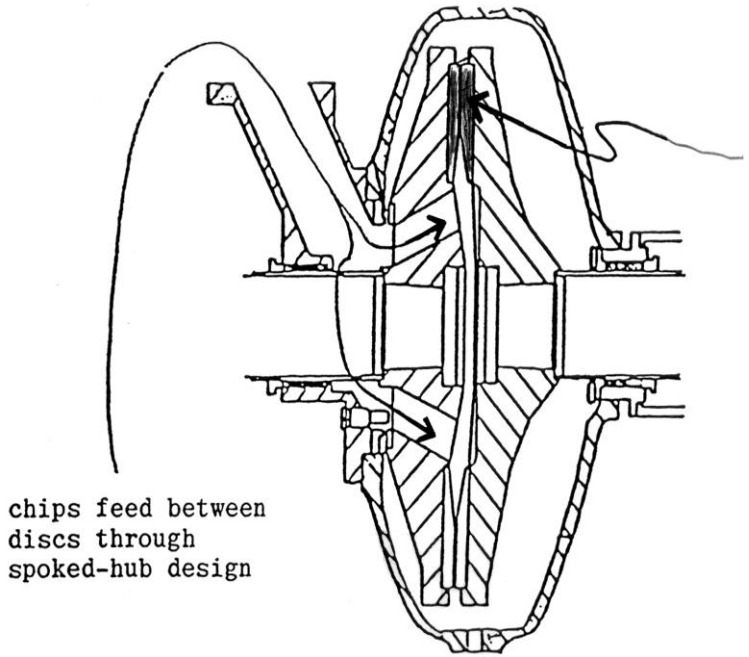
- Old technology
- Pulp produced by pressing *logs* against rotating grindstone
- Fibres are compressed, and loosened
- Friction creates heat to soften the lignin

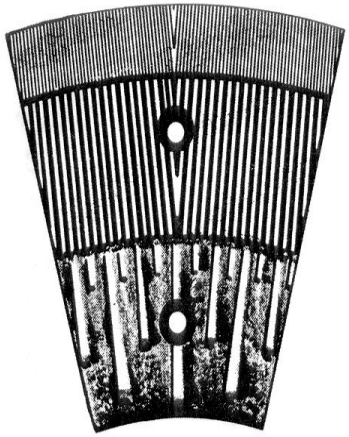


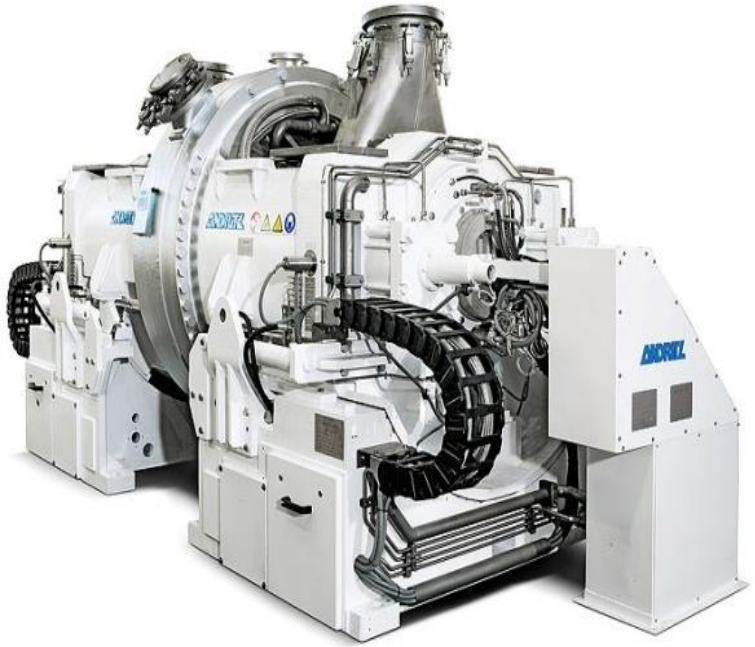
(Cameron 2003)

Mechanical pulping technologies: Refiner Mechanical Pulp (RMP)

- Wood *chips* are broken down to fibres in refiners
  - by bars on two rotating (or one rotating and one stationary) discs
  - water carries chips through refiner
- Consume large amounts of electricity







Commercial refiner

Versions of refiner mechanical (or alphabet) pulping

- Increased use of heat and chemicals improves fibre quality and decreases yield
- Various chip pretreatments may be used:
  - RMP = Refiner mechanical pulp:
    - no pretreatment
    - Yield 93-95%
  - TMP = Thermo-mechanical pulp:
    - steam pretreatment
    - 120-130 ^{o}C for 1 - 3 minutes => yield 85-90%
  - CTMP = Chemi-thermomechanical:
    - chemical and steam pretreatment
    - sodium sulphite and sodium hydroxide pre-steamer => yield 80-90%

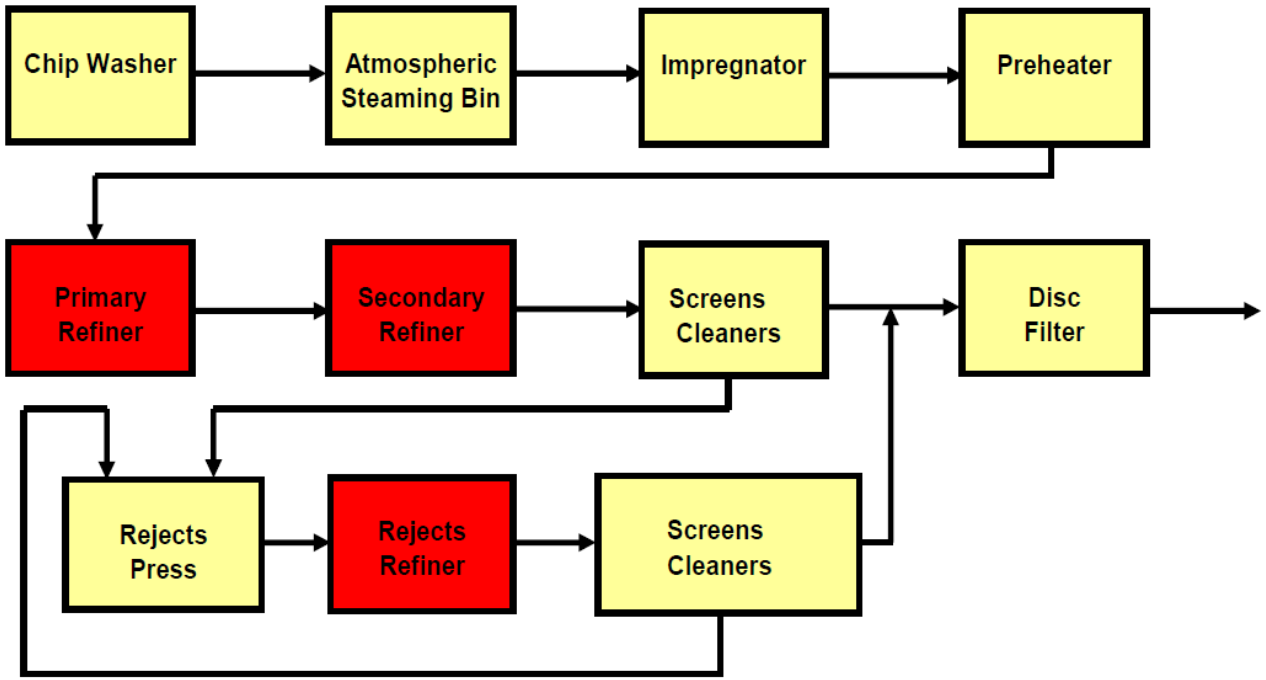
Thermomechanical Pulp (TMP)

- Pulping carried out in two refiners
- First refiner - pressurized with steam
- Second refiner is atmospheric pressure
- Heat softens the lignin makes the fibres easier to separate
- Produces longer fibres (stronger paper) and fewer shives (bundles of fibres) than SGW

Screening

- Pulping process imperfect
- Small bundles of fibres (shives) remain
- These must be removed and further refined
- Mechanical pulping is therefore followed by an elaborate screening system
  - Oversize fibres are recycled for further refining

Flow chart for a typical TMP mill



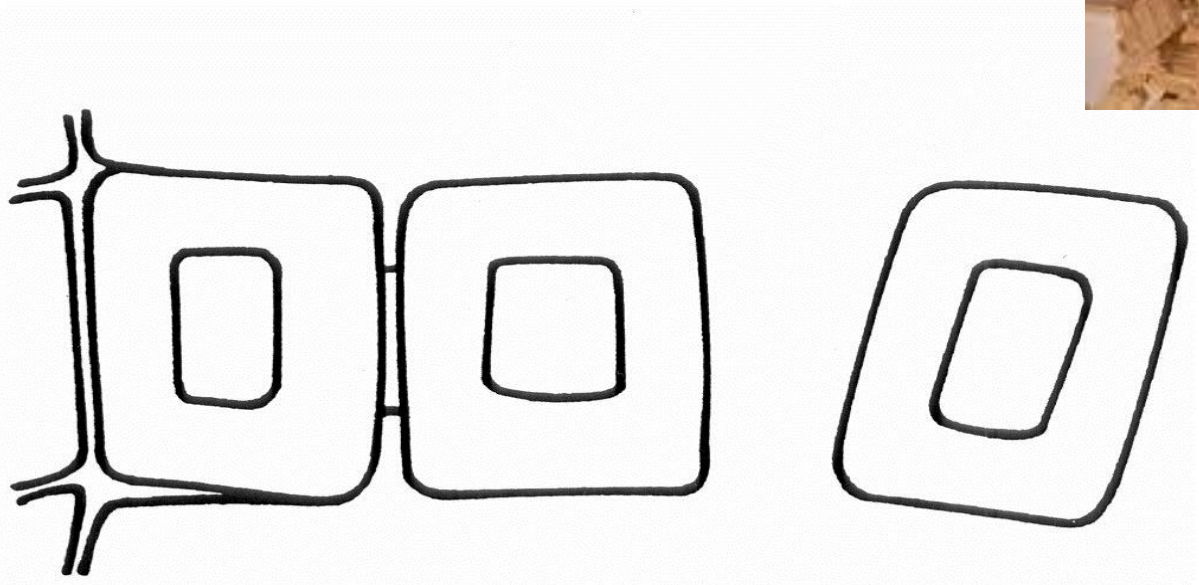
Mechanical Pulp Brightening

- May also be referred to as 'bleaching'
  - misnomer
- Consumers usually want white product
- Lignin is major source of colour
  - But to keep yield high don't want to remove lignin
- Use "brightening" chemicals that reduce colour of lignin
  - hydrogen peroxide (H_2O_2)
  - sodium dithionate ($Na_2S_2O_4$)
- Colour reduction is not permanent

Mechanical pulp mill

Chemical Pulping

- Feedstock = chips
- Chemicals are used to degrade & dissolve the lignin.
- Hemicellulose is also removed.
- Mainly secondary wall material remains



Chemical Pulp

Two Dominant Types of Chemical Pulping

- **Kraft (Sulphate)**
  - $NaOH + Na_2S$
  - First mill = 1890
  - Accounts for about 85% chemical pulp prod'n
  - Always alkaline conditions
  - High strength
  - Efficient recovery of chemicals
  - Handles a variety of species
  - Tolerates bark
  - Dominates market

- **Sulphite**
  - H_2SO_3 + bisulfite (HSO_3^-)
  - First mill = 1874
  - Accounts for about 10% global chemical pulp prod'n
  - pH range varies depending on base
  - Bright pulp & easy to bleach
  - Higher yield
  - Weaker fibre
  - Easier to refine
  - Higher environmental impact
    - Byproducts are important

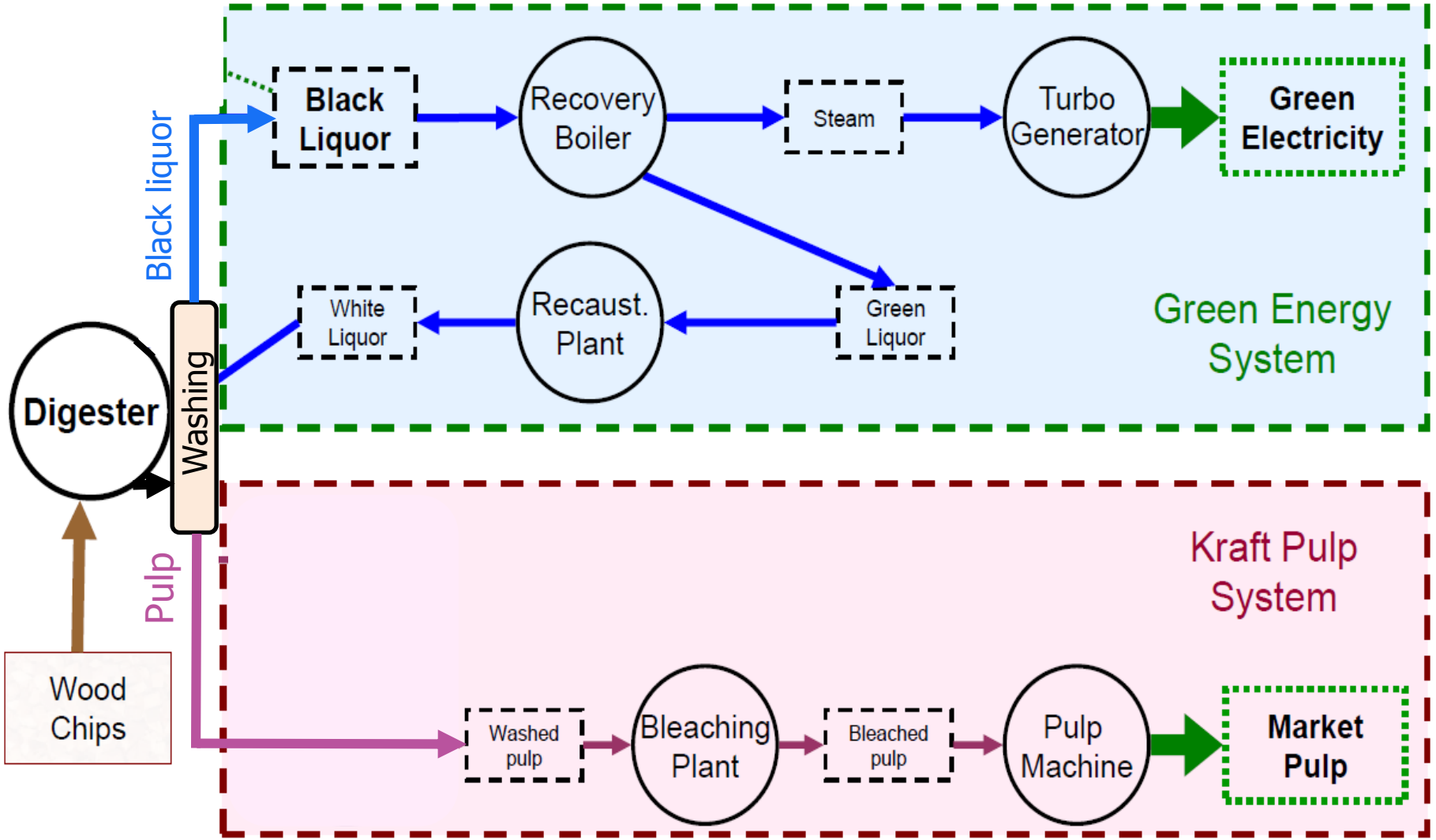
Capital intensive: new world scale kraft mill > $US 1 billion

Kraft process

- Simplistically, cooking solubilizes lignin & hemicellulose
  - Pulp yield ~ 45%
- Cooking liquor separated from fibres and burned
  - chemicals are recovered
  - energy produced
    - recovering energy in lignin and hemicellulose
    - modern mills are net energy producers
  - closed cycle process (except for wastewater)
    - water is used the medium for conveying pulp
- Process tolerates wide species range
- High strength pulp produced
- Sulphur by-products may create odour problems

Process flow schematic for a market bleached kraft mill

(Adapted from Mercer 2011)



Market kraft pulp mill

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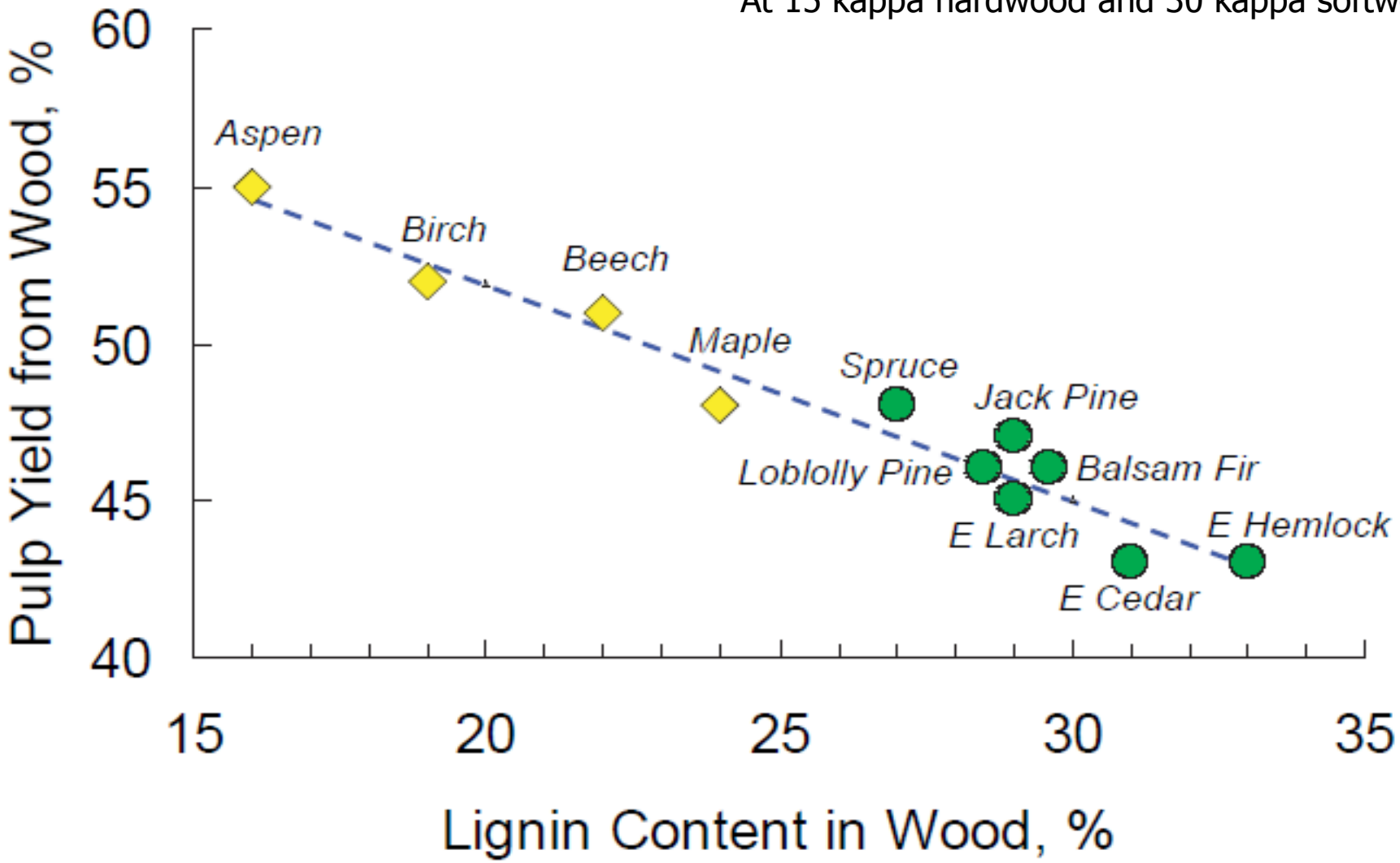
Pulping

- Purposes
  - Selectively solubilize lignin
  - Preserve cellulose
- Chips ‘cooked’ in digester
  - Batch or continuous
  - Conditions vary with wood species
- Major control parameter
  - Kappa number
    - Measure of residual lignin
- Typically
  - Temp = 160-175 ^{o}C
  - Time = varies (~ 2hrs)

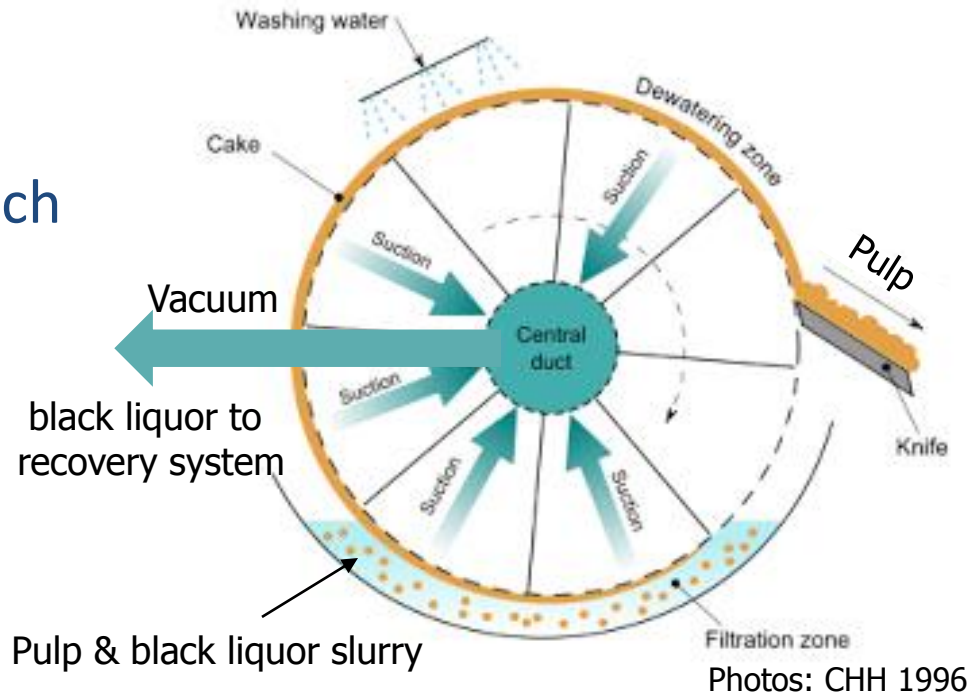
Lignin content of wood affects kraft pulp yield (MacLeod 2007)

At 15 kappa hardwood and 30 kappa softwood



Washing

- Purposes:
  - separate black liquor & pulp
    - produce pulp suitable for bleaching
    - recover dissolved solids to burn
    - minimize liquor carryover
- Black liquor contains
  - ~ 13% dissolved solids of which
    - lignin (30-45 %)
    - hemicellulose (28-36 %)
    - extractives (2-5 %)
    - Na_2O (25-40 %)



Photos: CHH 1996

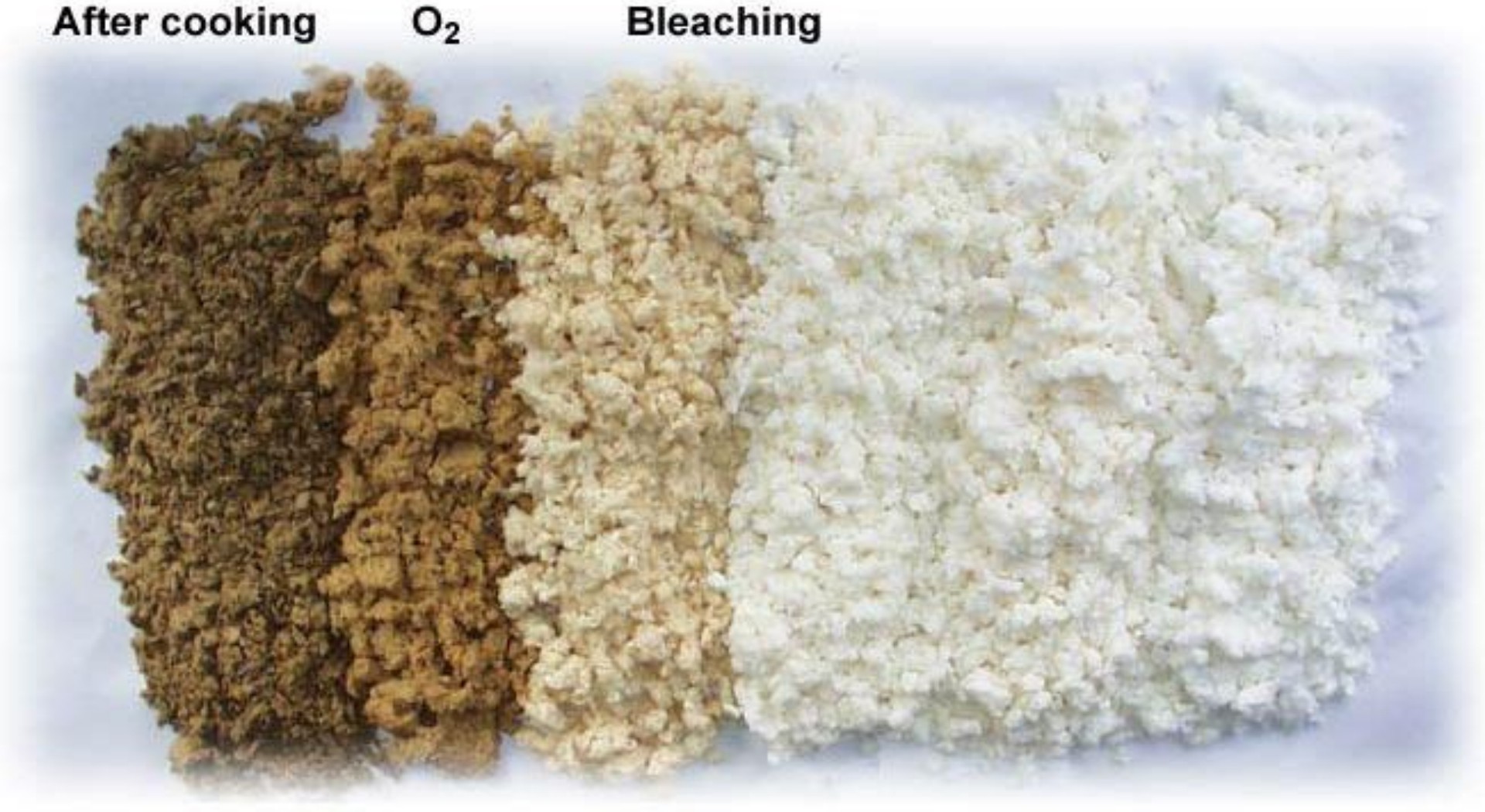
Bleaching

- Purposes
  - Improve printing contrast
  - Whiter, cleaner product (customer demand)
- Two mechanisms
  - Delignification – reduction in residual lignin (Kappa)
  - Brightening – removal of colored components

Bleach plant

Pulp bleaching

The dark colour of the pulp is mainly due to residual lignin.
This is removed gradually during bleaching.



Bleaching sequences

- Bleaching is a multi- stage process using two types of chemicals
- - one for oxidation & one for extraction
- Sequences (each letter = bleach tower)
  - old = CEHEH
  - traditional = CEDED
  - elemental chlorine free (ECF)= ODEDED
  - totally chlorine free (TCF) = OZEP

Bleaching chemicals and abbreviations

C	Chlorine	Cl_2
H	Hypochlorite	HOCl
D	Chlorine dioxide	ClO_2
O	Oxygen	O_2
Z	Ozone	O_3
P	Peroxide	H_2O_2
E	Alkaline extraction	NaOH

Chemical vs. Mechanical Pulping

	Chemical	Mechanical
Yield Fibre/Wood Input (% w/w)	- Low 40-50%	- High 85-95%
Cellulose Purity	- High - lignin dissolved	- Low - lignin remains
End Uses	- Packaging - High quality paper (e.g. book) - Dissolving pulp	- High volume paper (e.g. newsprint) - Hygiene products - Molded products
	Several products mix Chem and Mech pulps	
Raw Material Sensitivity	- Low	- High
Capital cost	-High	-Moderate

Attributes of Chemical Pulps

- Advantages
  - Relatively strong
    - Long fibres give greater tensile and tear strengths
    - Increased burst strength
  - Whiter fibre (when bleached)
    - Bleached pulp is whiter than mechanical
    - More permanent whiteness due to removal of lignin
  - Smoother surface
    - Better printing qualities when uncoated
- Disadvantages
  - Low opacity product
    - Fewer fines to fill sheet
    - Creates problems printing on both sides of thin sheet
  - Less stiff
  - Less bulk
    - Use more fibre for same mass
- Major Uses
  - Where strength and/or brightness are important
    - Packaging grades
    - High quality papers

Pulp properties: Attributes of Mechanical Pulps

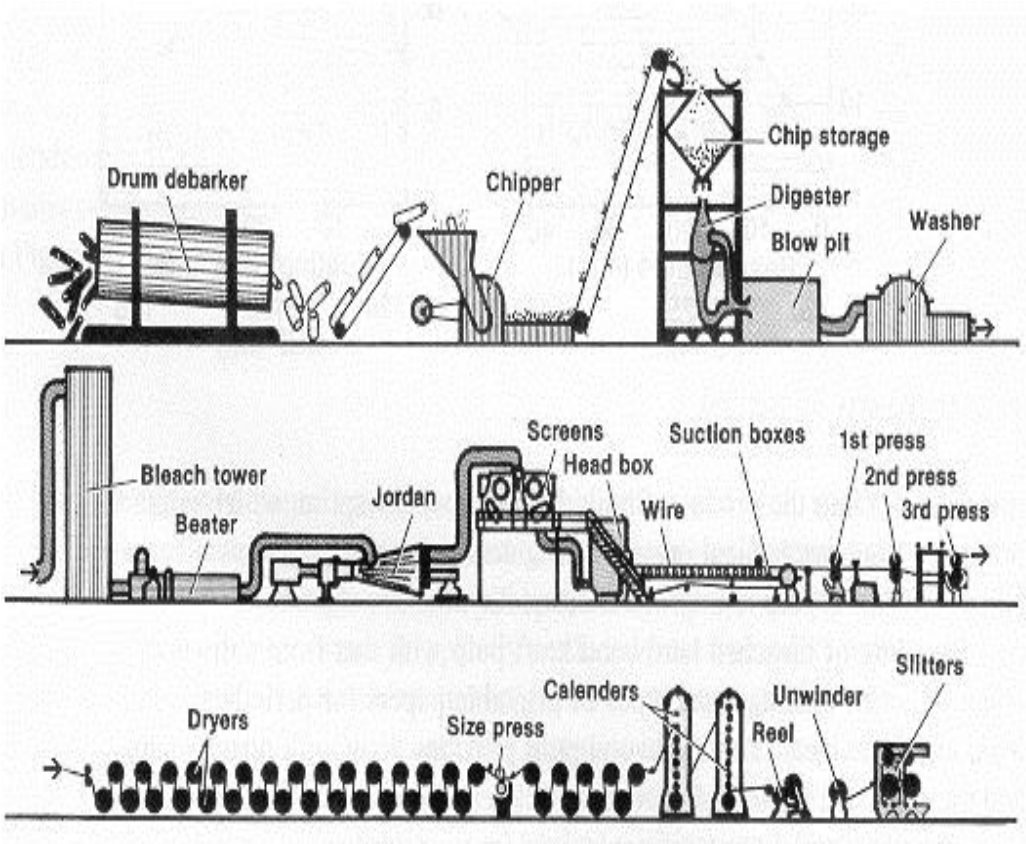
- Advantages
  - Relatively cheap
    - High yield of product (85-95%)
    - Low capital costs relative to kraft mill
  - High opacity product
    - Large amount of fines in product scatter light
    - Allows printing on both sides of thin sheet
  - High stiffness
  - Good printing surface
    - Broad fiber size distribution gives smooth surface
    - Good bulk
    - High ink absorbency

Attributes of Mechanical Pulps

- Disadvantages
  - Relatively weak
    - Short fibres (compared to chemical pulps)
  - Tendency to yellow with time
    - Most lignin remains in fibre
  - Lower brightness
  - Rougher surface
    - Poorer printing surface (unless coated)
    - Coarser surface and poorer ink absorbency
  - Relatively sensitive to chip quality
- Major end uses
  - Where bulk, low cost are imp and brightness not too important
  - primarily used in
    - newsprint, telephone directories, catalogs
    - "pulp" magazines,
    - paper towels and tissues.

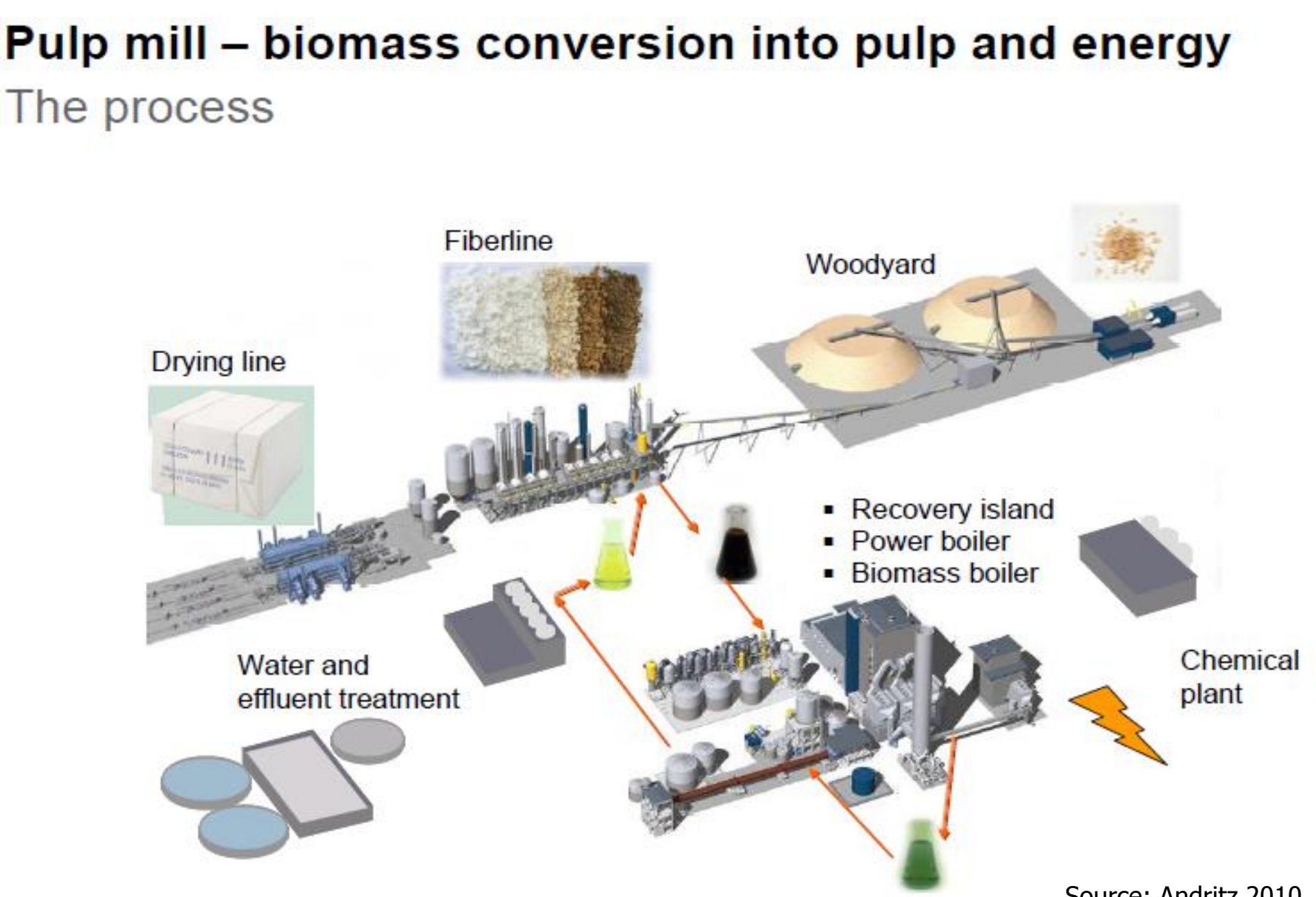
Market & *Integrated* pulp and paper mills

- Integrated pulp mill
  - Has a pulp mill(s) and a paper machine(s) on one site
  - May still sell or buy pulp on the market
- Market pulp mill
  - 'stand alone'
    - ie: no paper machine on site
  - Sells pulp 'on the market'



Integrated mill schematic

Market pulp mill schematic



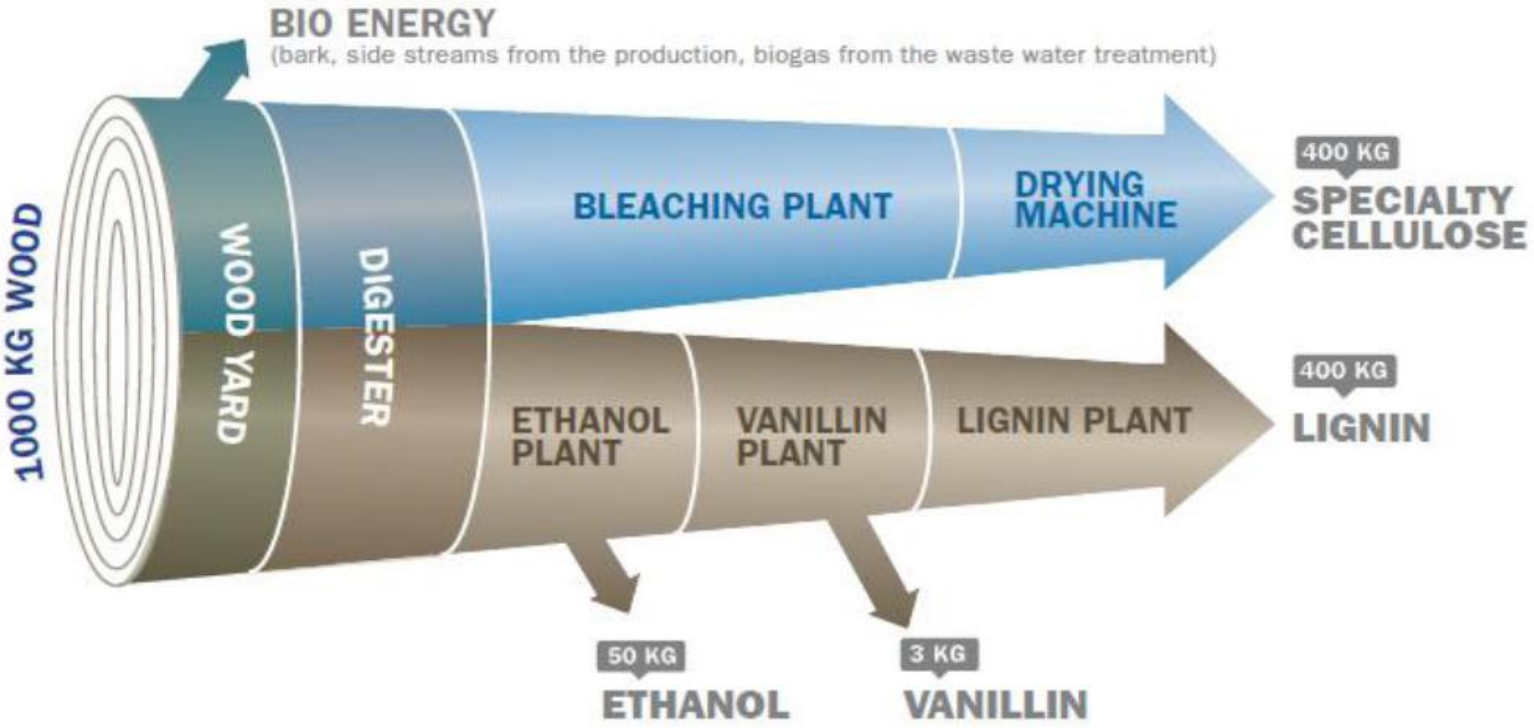
Source: Andritz 2010

Chemical pulp mill

http://w3.upm-kymmene.com/upm/internet/cms/upmmma.nsf/lupGraphics/Botnia_Fray%20Bentos%20mill_1.jpg/$file/Botnia_Fray%20Bentos%20mill_1.jpg

Forest biorefinery

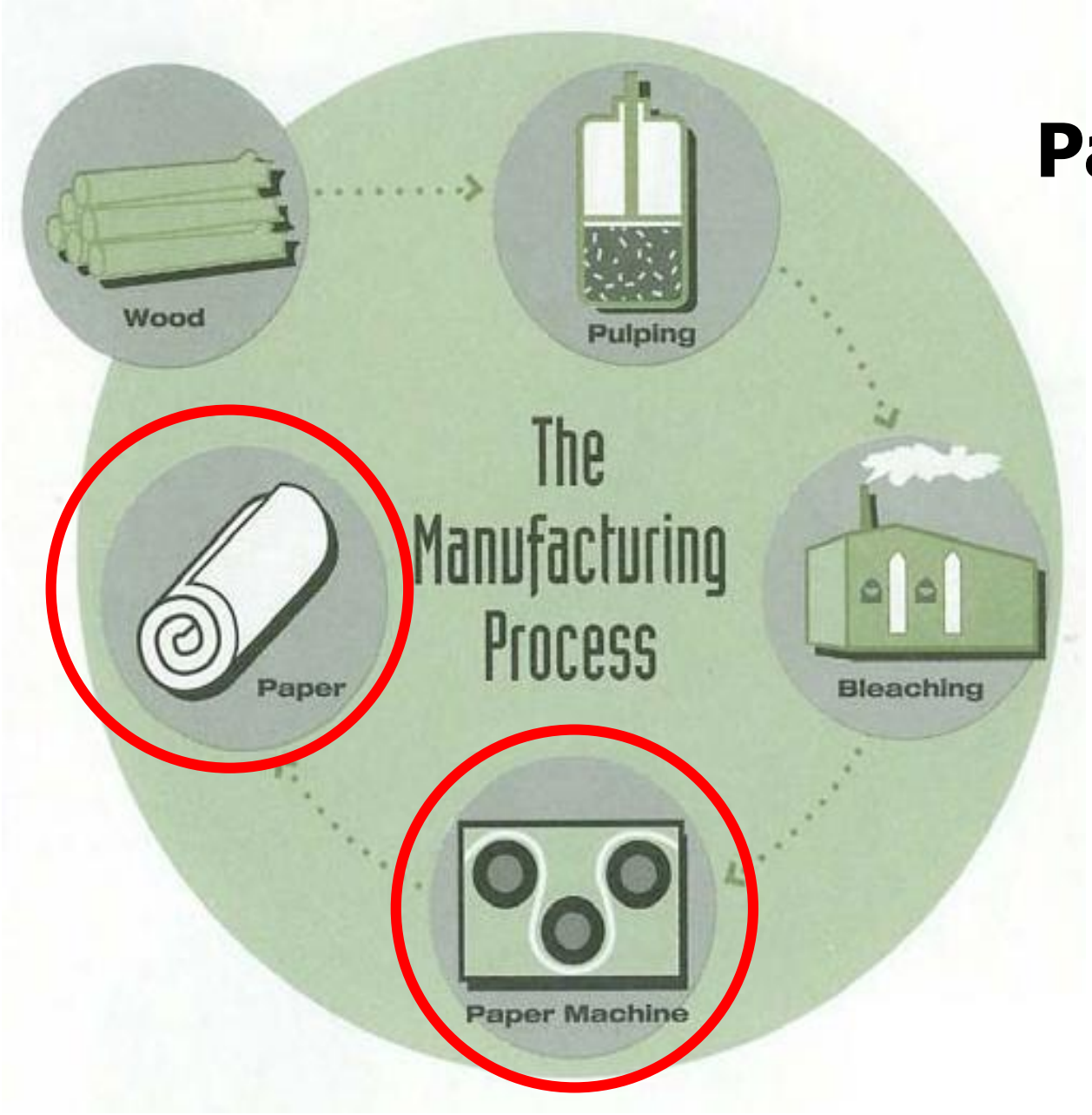
(Frolander & Rodsrud 2011)



Example: Borregaard: a Swedish biorefinery

- Based on the sulfite process
- Leading supplier of specialty cellulose
- Global leader in lignin performance chemicals (50%+ of market)
- Only producer of vanillin from lignocellulosics
- World's most advanced operating biorefinery

Papermaking



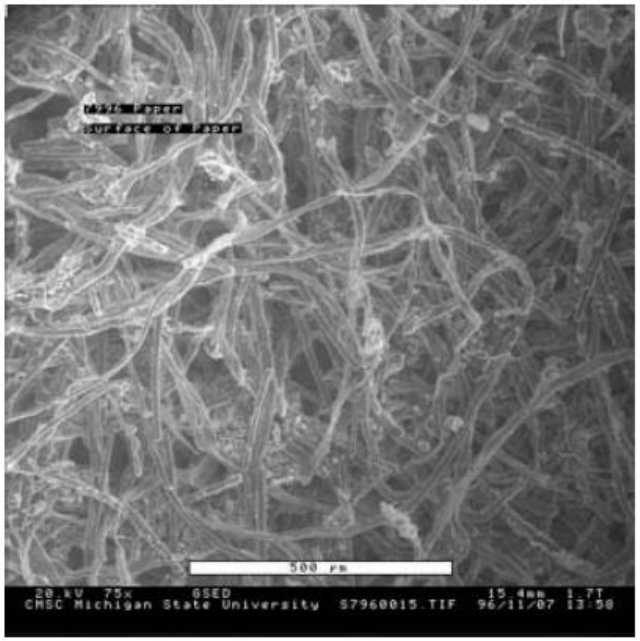
Papermaking Technology

Pulping

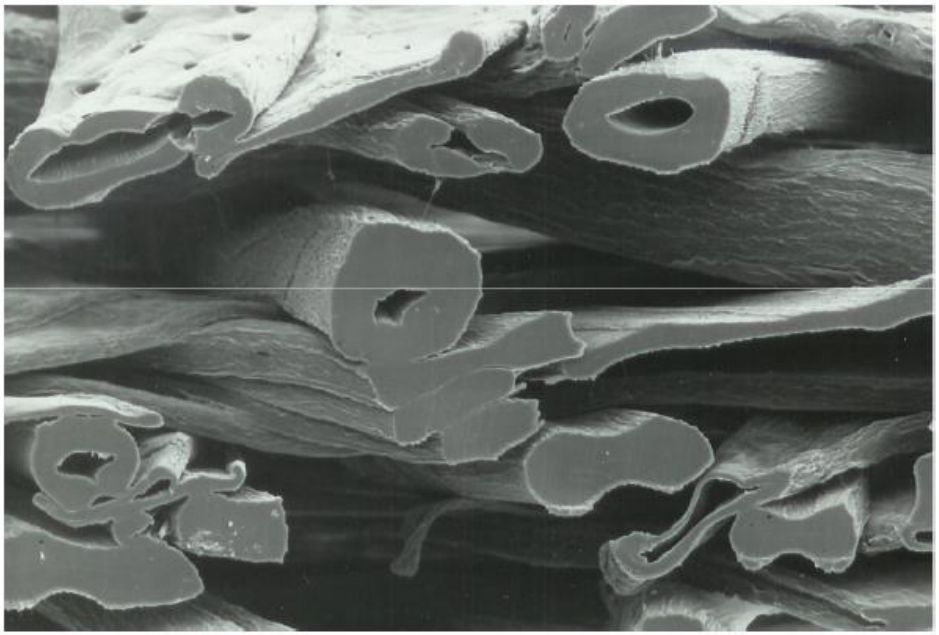
- Liberation of fibres from wood matrix

Papermaking

- Formation and bonding of fibres into sheets

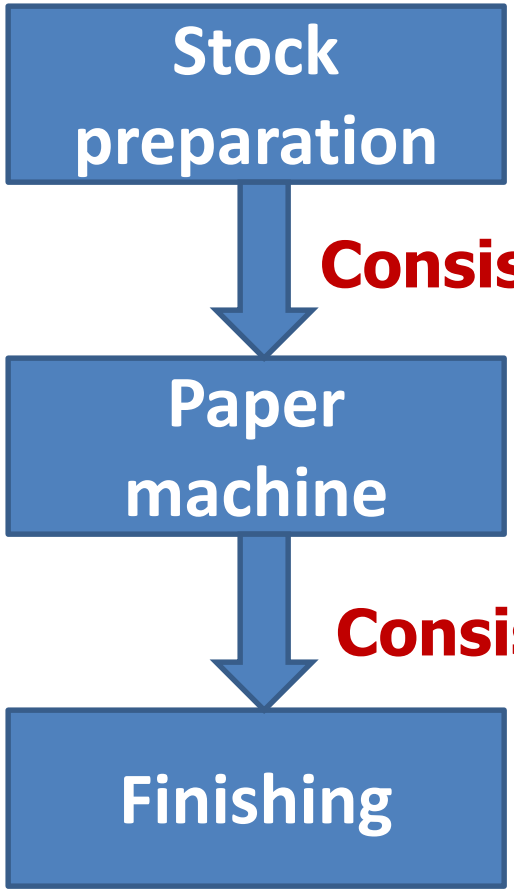


Surface



Section through paper sheet

Papermaking unit operations



- Re-pulping
- Beating/refining
- Additives & Blending
- Cleaning and screening

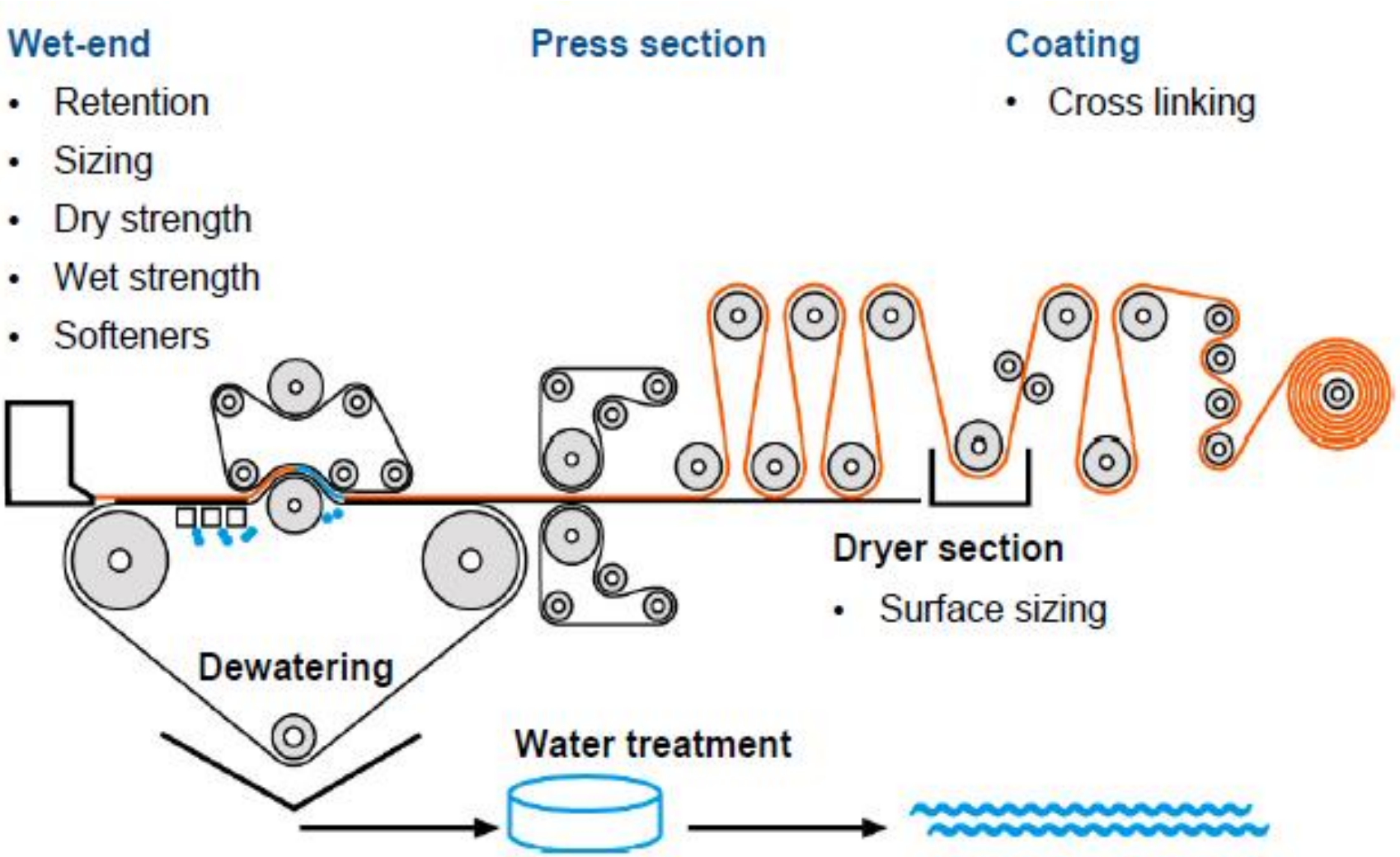
Consistency = ~0.7% w/w

- Forming **Consistency = ~18% w/w**
- Pressing **Consistency = ~45% w/w**
- Drying

Consistency = ~93% w/w

- Coating (some grades)
- Calendaring
- Reeling
- Winding

Paper machine schematic

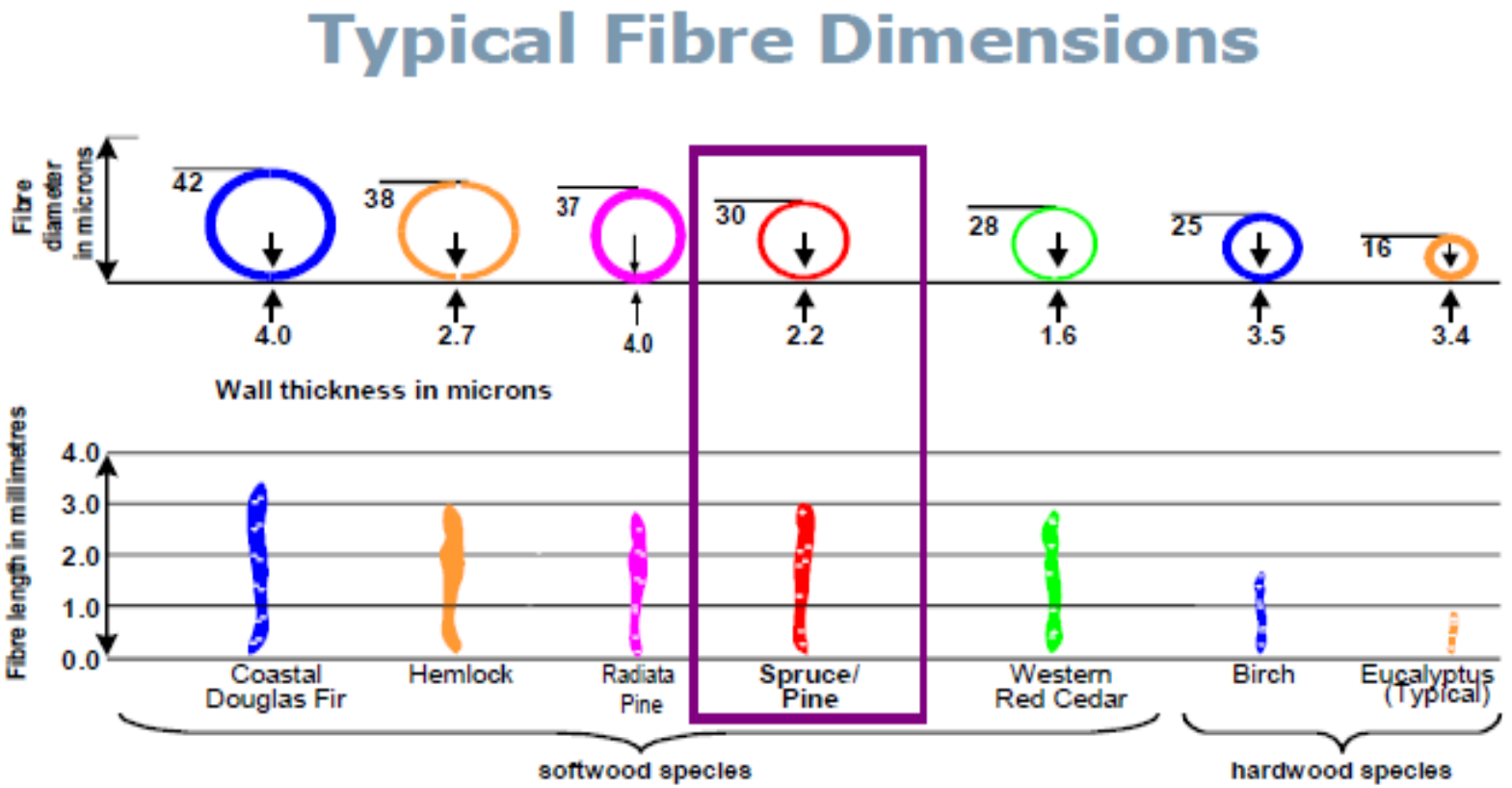


Modern Paper Machine

(Domtar 2012)

Fibre quality (Source Canfor 2010)

Not all pulps are the same: Northern spruce and pine fibre grown in the central interior of British Columbia is recognized as one of the strongest in the world due to the long, slender, thin-walled fibres. This provides for a better printing surface, better softness and better strength, which in turn commands a premium return.



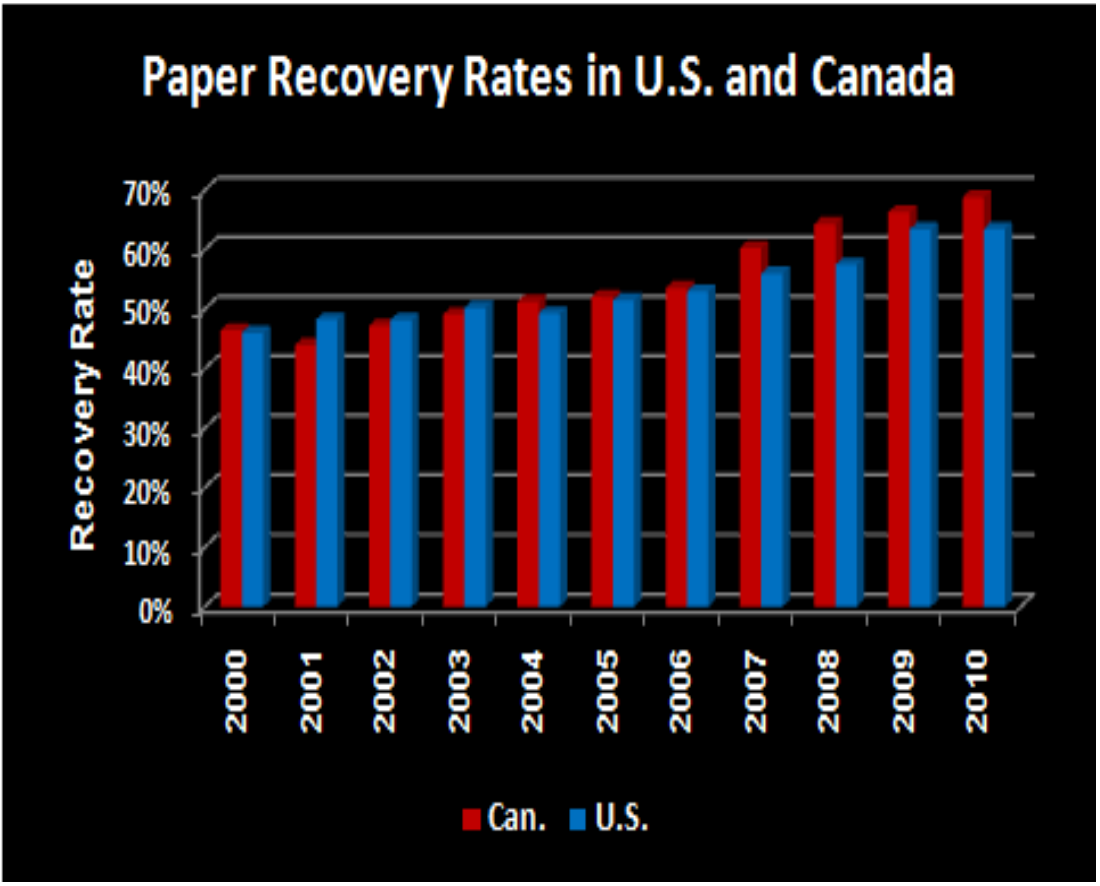
Paper grades and typical pulp types

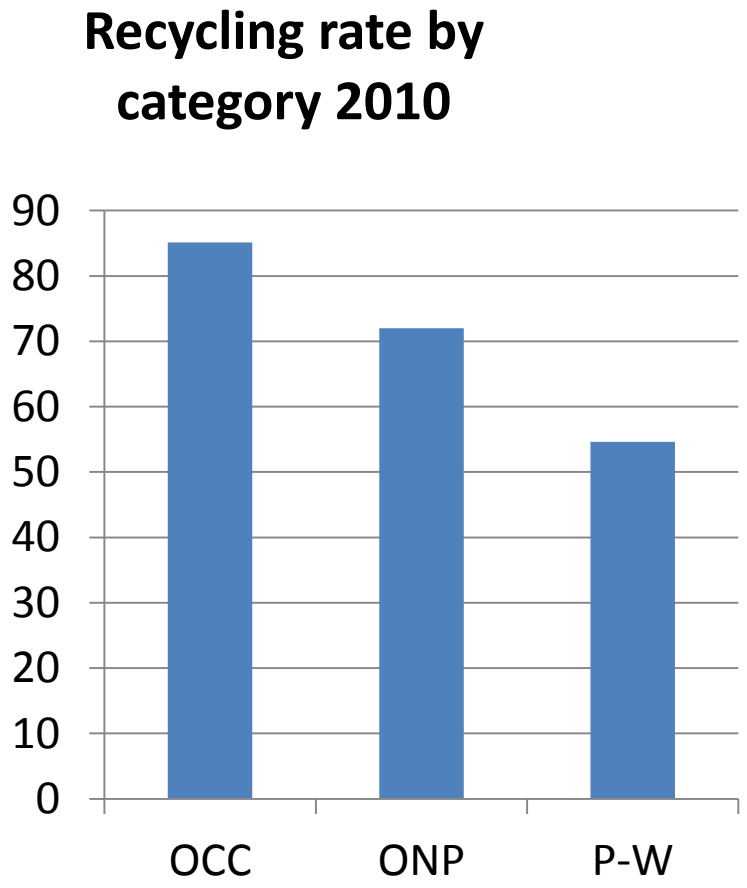
Grade	Pulp type	Important properties
Linerboard	Softwood kraft, recycled	Strength, printability
Corrugating medium	Hardwood kraft, recycled	Stiffness, ability to hold shape
Grocery bags	Softwood kraft	Strength
Paperboard	Recycled, softwood kraft	Bulk, stiffness
Printing & Writing	Softwood kraft, hardwood kraft, sulphite	Printability, whiteness, optical properties, ink retention
Newsprint	Mechanical pulps	Printability, cheapness, optical properties, short life
Tissue	Sulphite, recycled	Absorbency, strength, softness
Paper towels	Recycled	Wet strength, absorbency

Recycling

- **In the USA in 2011**
  - 44 million tons of paper and paperboard were recovered
  - equivalent to 360 pounds for each person living in the US
  - a recycling rate of over 50 percent
  - about 88 percent of newspaper and 72 percent of corrugated cardboard were recovered
  - recycled fibre accounted for 37 percent of the fiber used to make new paper products

North American paper recycling rates (AF&PA 2013 , P&PPC 2013)





Value to the US economy = $US 8.9 billion (2010)

Recycling - Problems

- De-inking,
- Removal of contaminants such as adhesives, plastics, waxes,
- Mixing of recycled fibres of different quality
- Reduction in fiber length and strength limits the number of times can be recycled.
  - P&W recycled 7 to 12 times
  - Newsprint 3 to 4 times

Pulp and Paper market trends and impacts on BC Industry

- Trees are local
- Pulp is global
- Paper is regional
  - *Hylander 2009*

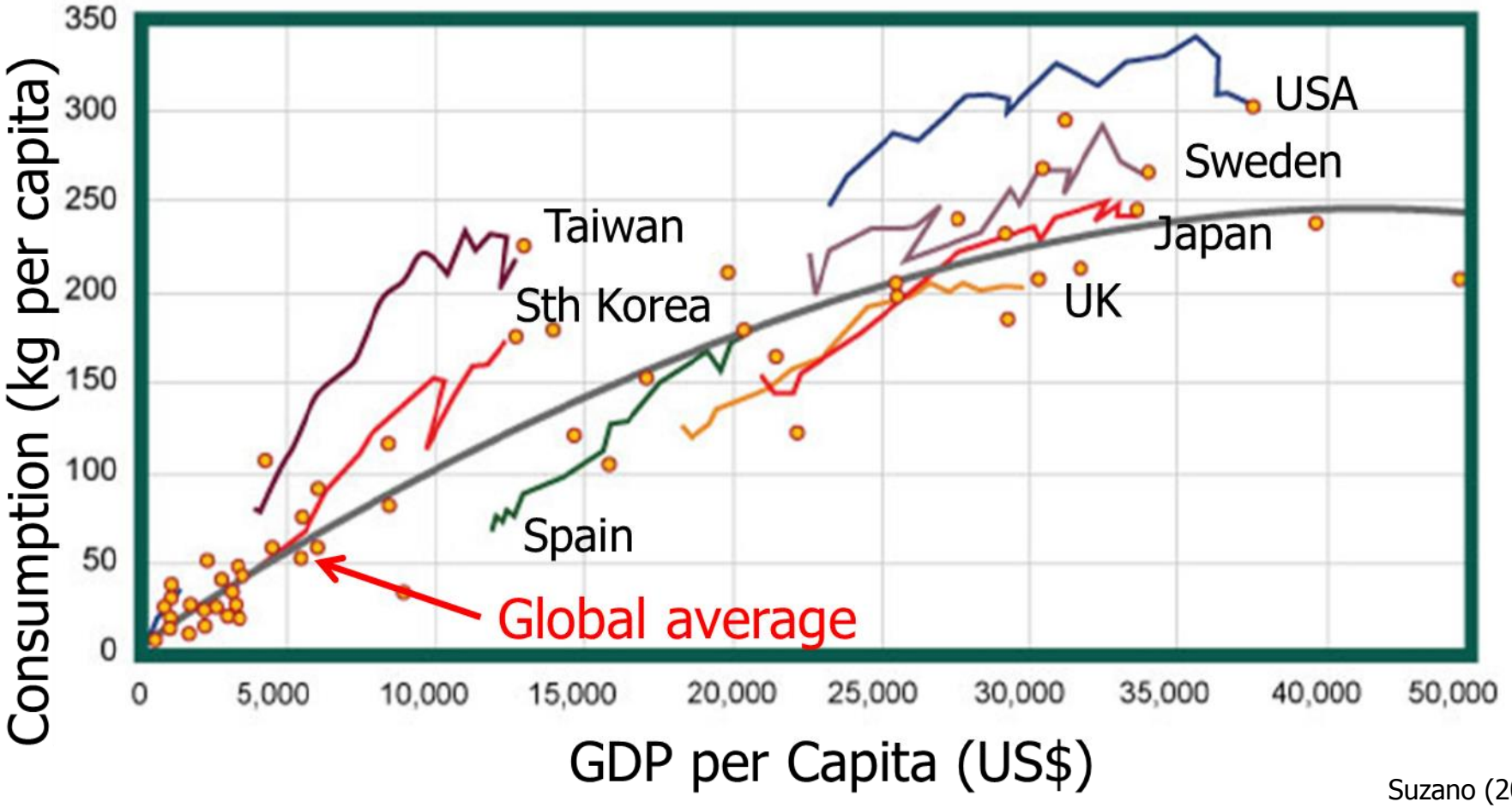
Maribuni 2012

Major trends

1. Changing consumption/person
   - decreasing in developed world
   - increasing in developing world
2. Changing fibre supply
   - southern hemisphere plantation hardwoods replacing northern softwoods
   - recycled fibre replacing virgin fibre
3. Pulpwood regimes being located for optimal growth rates
   - ‘trees are local’
4. Market pulp connects the forest with the paper machine
   - ‘pulp is global’
5. Paper being manufactured close to market
   - ‘paper is regional’

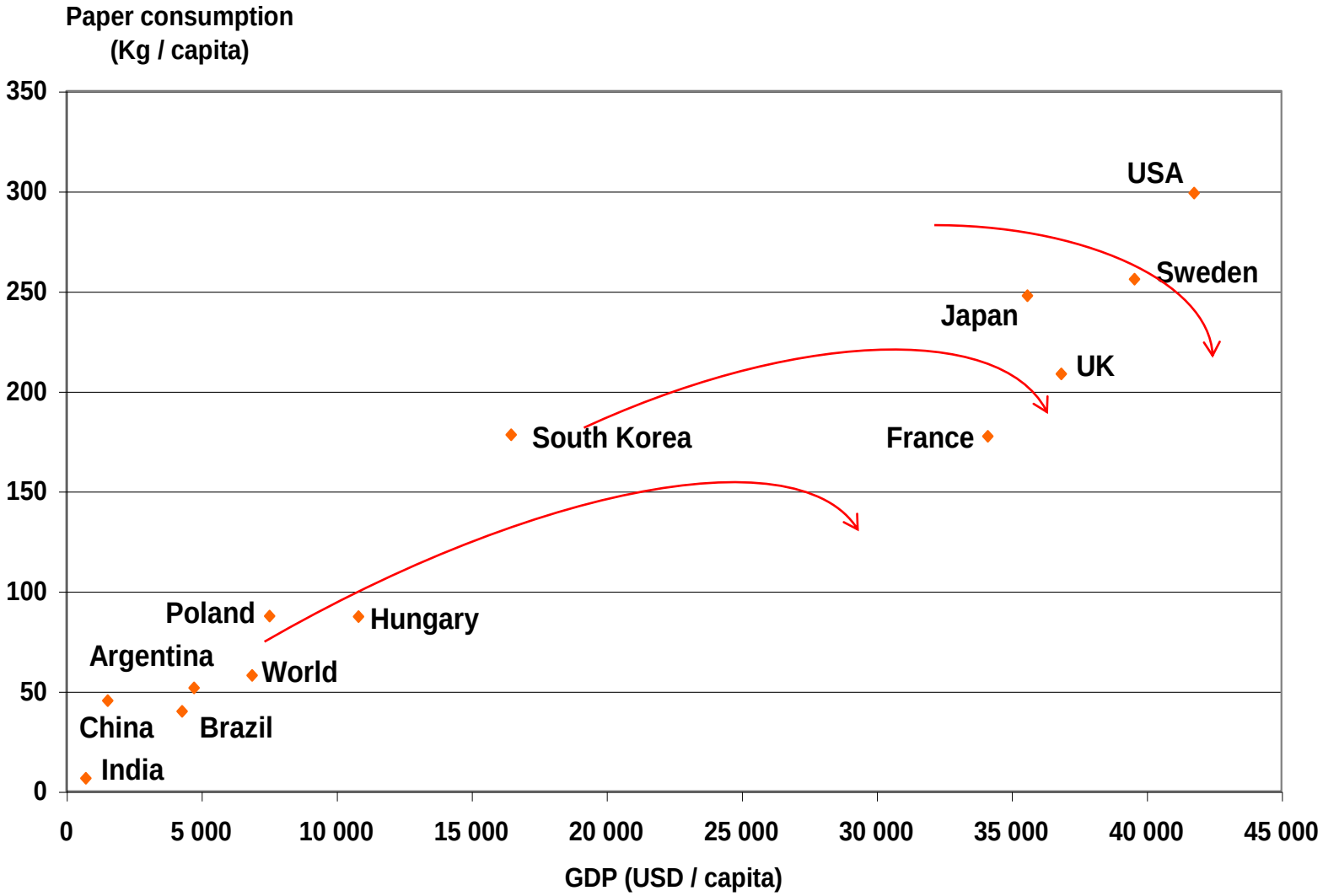
Trend 1: Changing Paper Consumption

- Historically paper consumption has been correlated with GDP



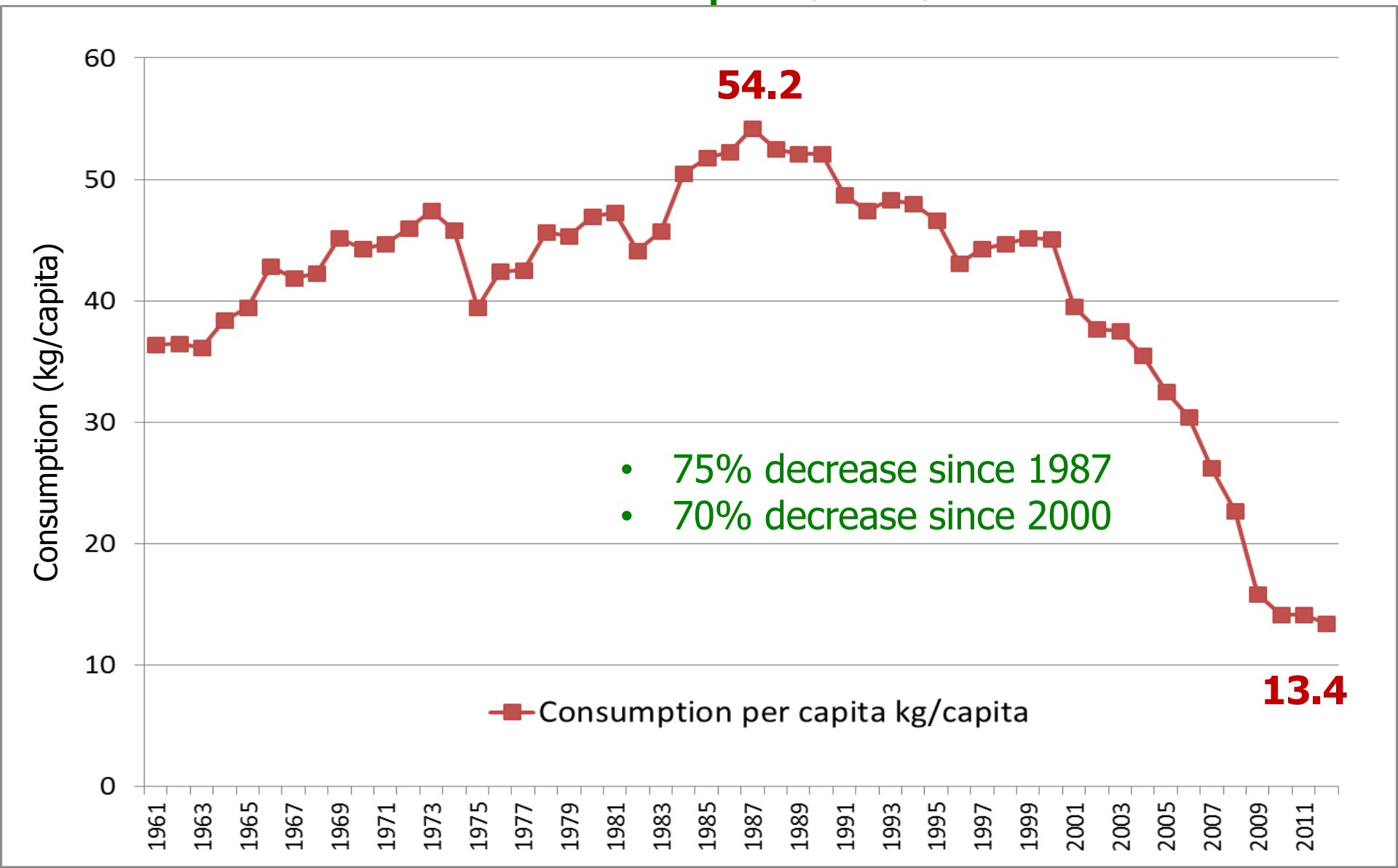
Suzano (2011)

Slope is decreasing as developed world reduces consumption

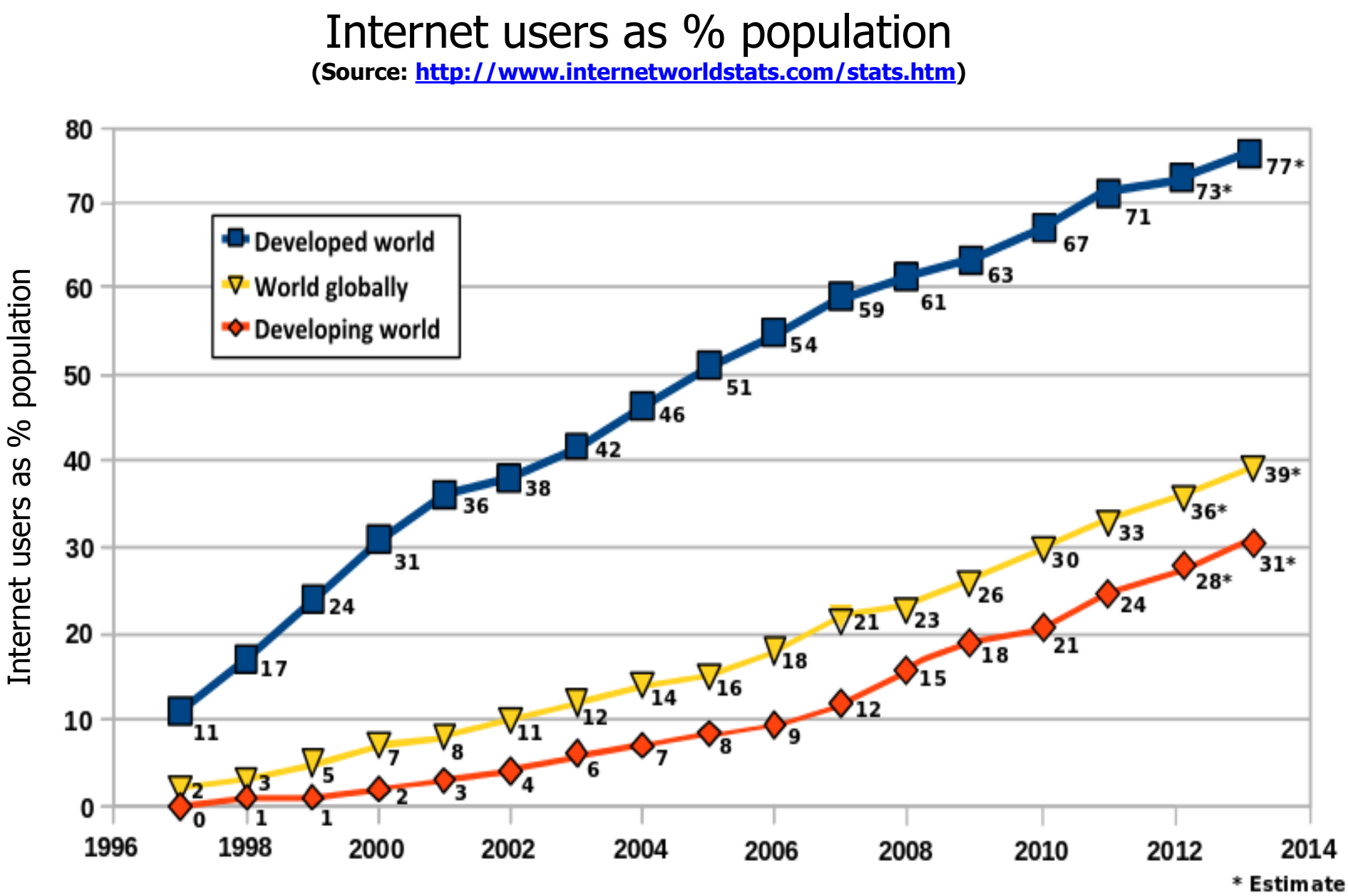


Source: RISI, UN

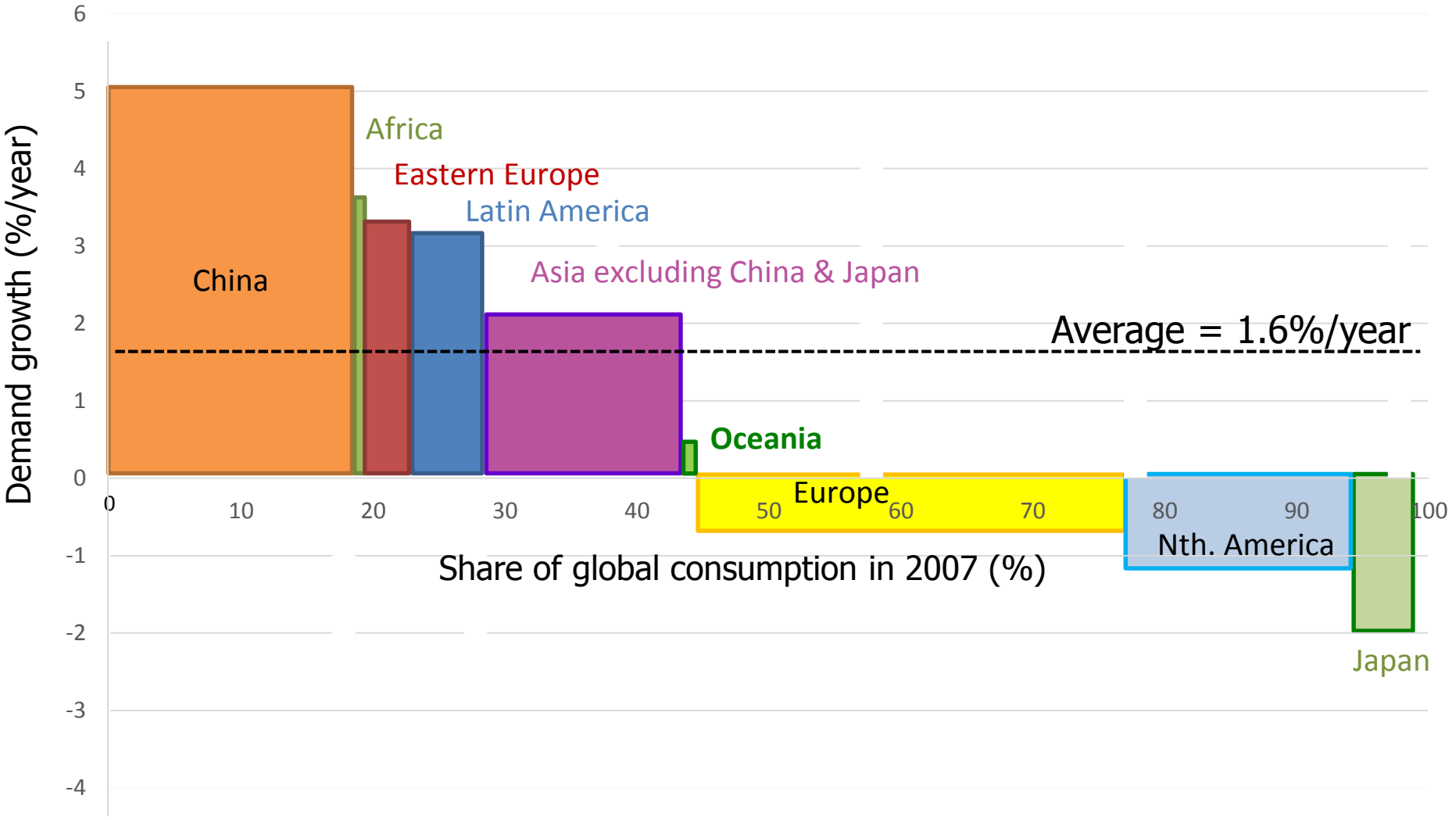
Annual newsprint consumption in USA as an example (FAO 2013)



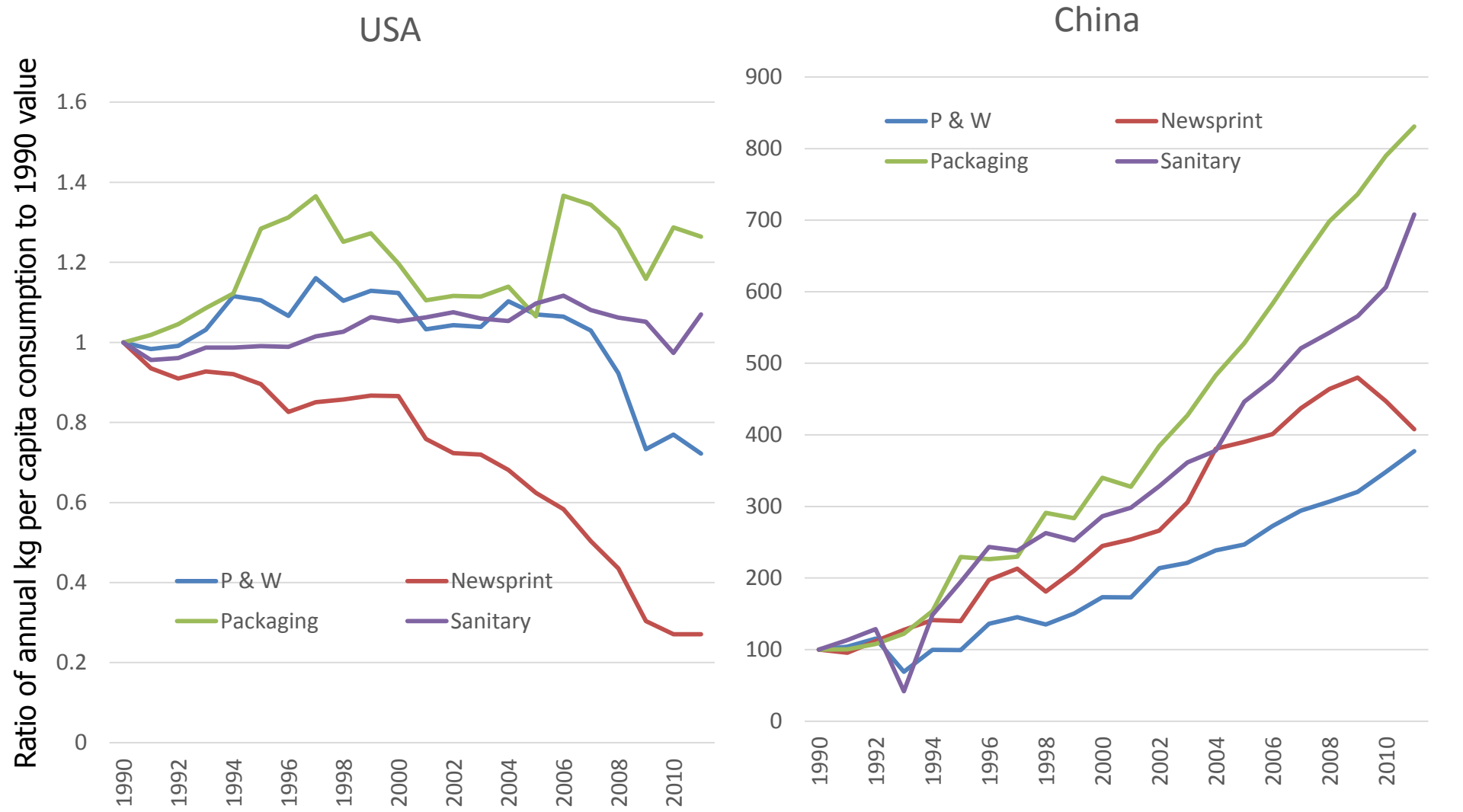
Why has paper consumption decreased?



Growth in market wood pulp demand: forecast to 2025 (Poyry 2013)

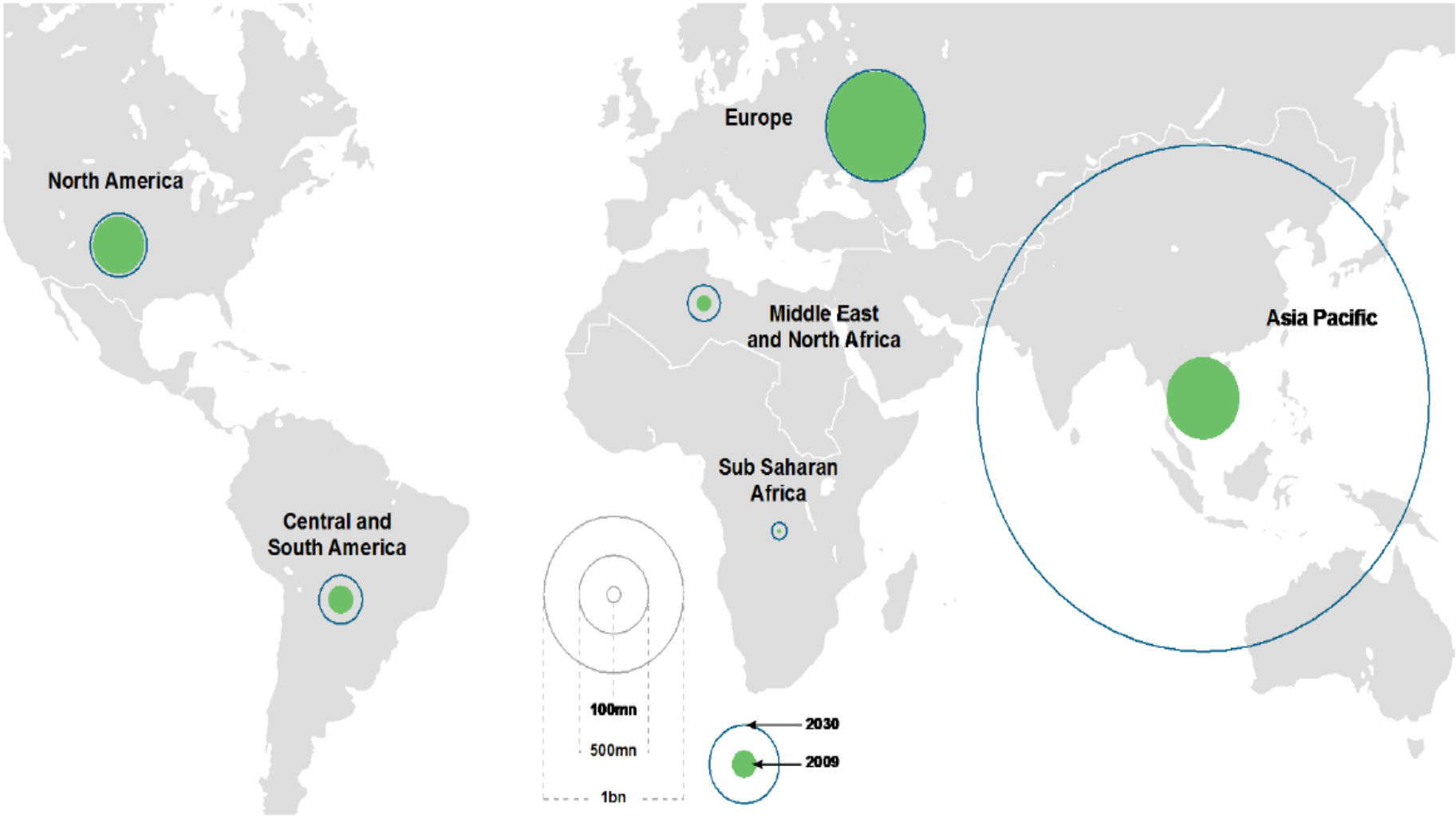


Comparison of per capita consumption by grade in USA and China -Indexed to 1990 value for each grade



Global growth in the middle class: 2009 & forecast for 2030

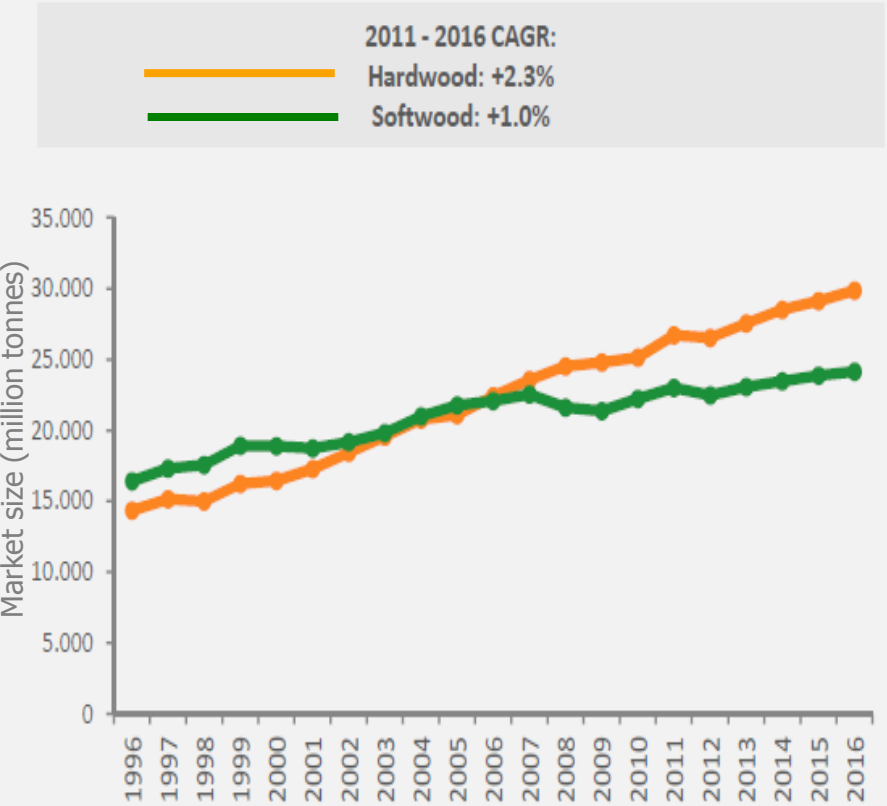
(McKinsey 2010, World Economic Forum 2010)



Trend 2: Changing fibre supply

- southern hemisphere plantation hardwoods replacing northern softwoods
  - See global market pulp demand curve below (Fibria 2013)

Hardwood (BHKP) vs. Softwood (BSKP)

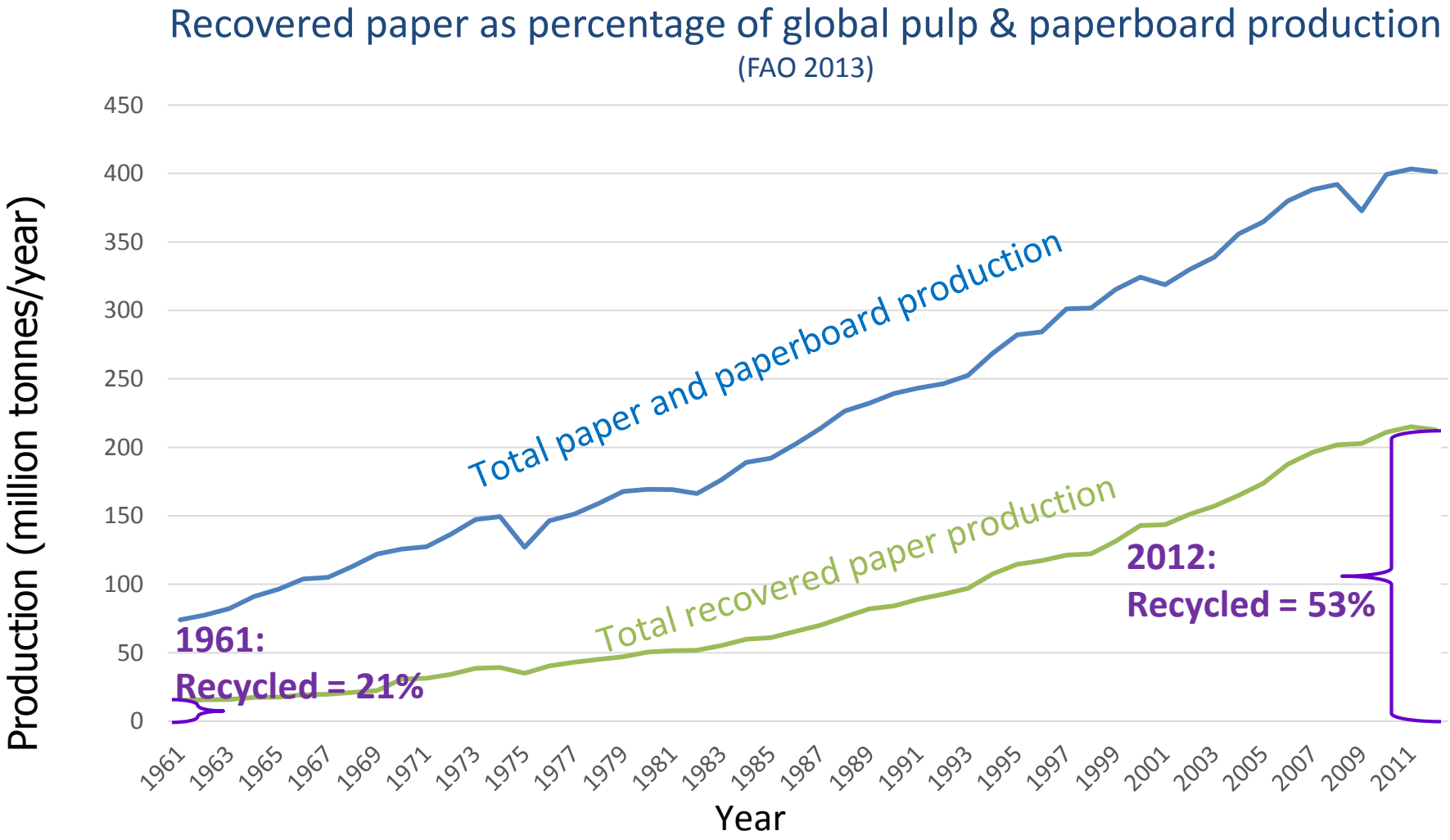


Demand growth rate

000 ton	1996	2006	2016	Growth 1996-2006	Growth 2007-2016
Hardwood	14.3	22.4	29.9	56%	27%
Eucalyptus	5.4	11.1	21.4	106%	67%
Softwood	16.4	22.0	24.1	35%	7%
Market Pulp	30.8	44.4	54.0		

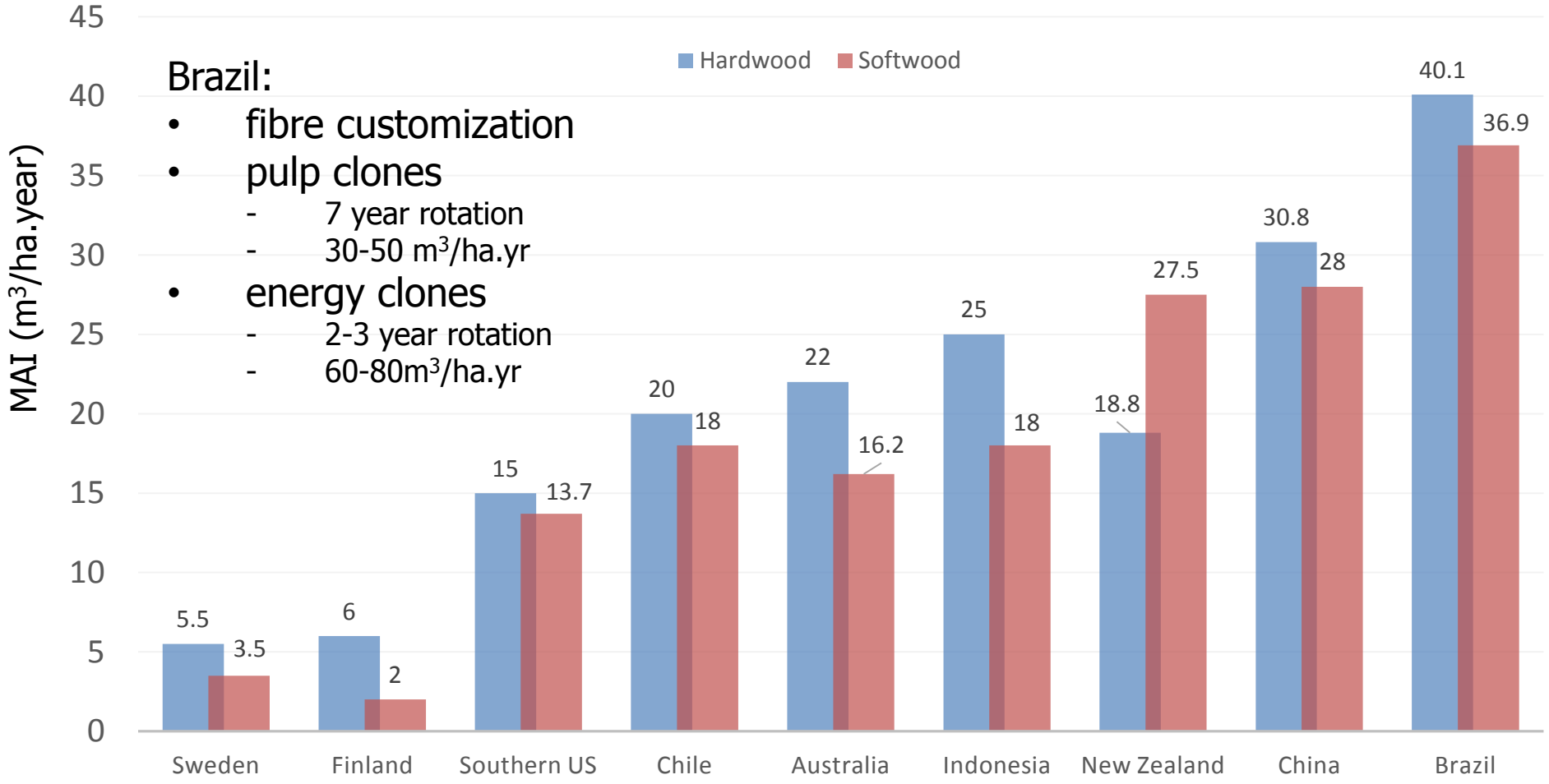
Trend 2: Changing fibre supply

2.2 recycled fibre replacing virgin fibre

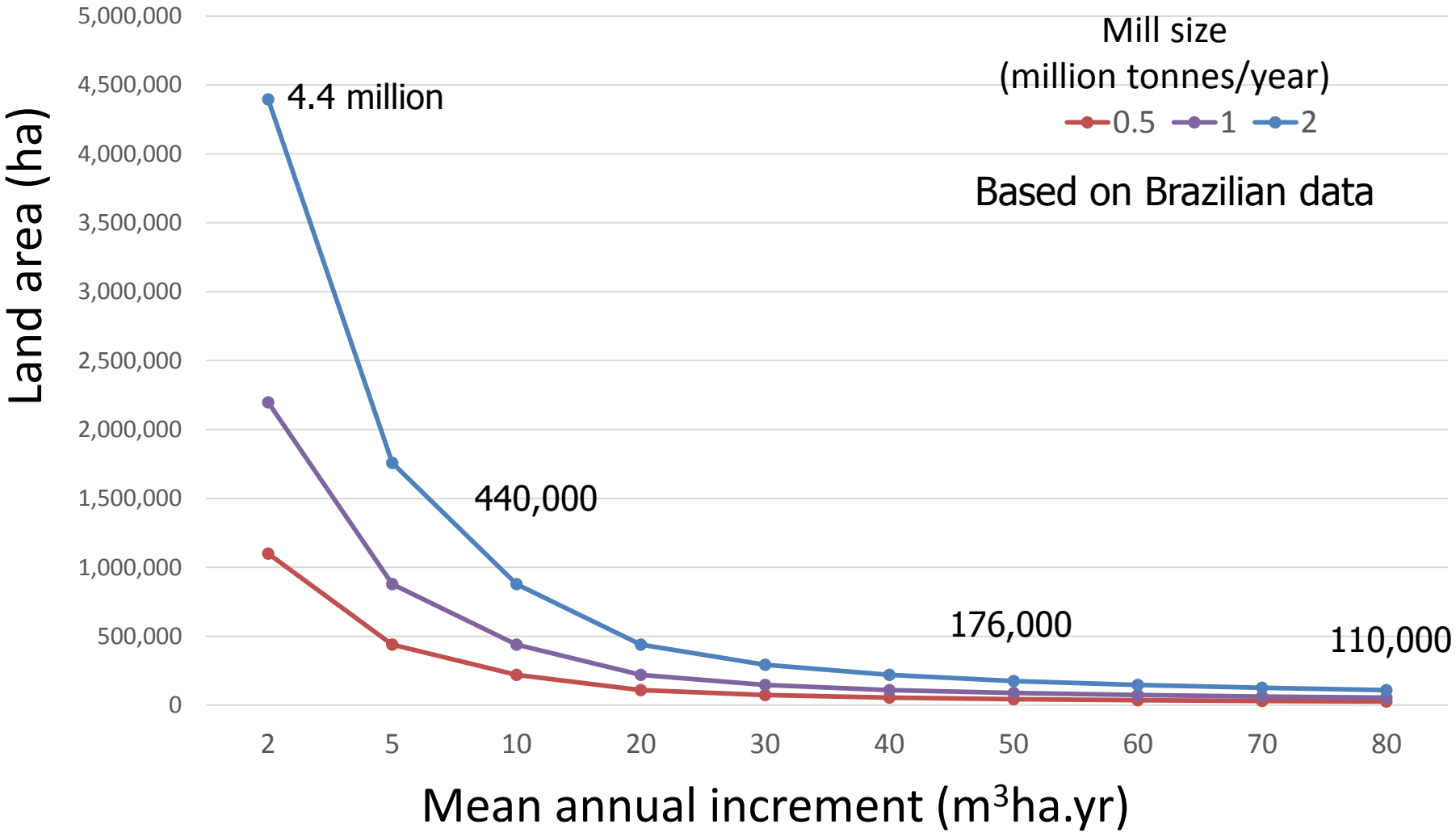


Trend 3: Pulpwood regimes located for optimal growth rates

- ‘trees are local’ (data Bracelpa 2013)

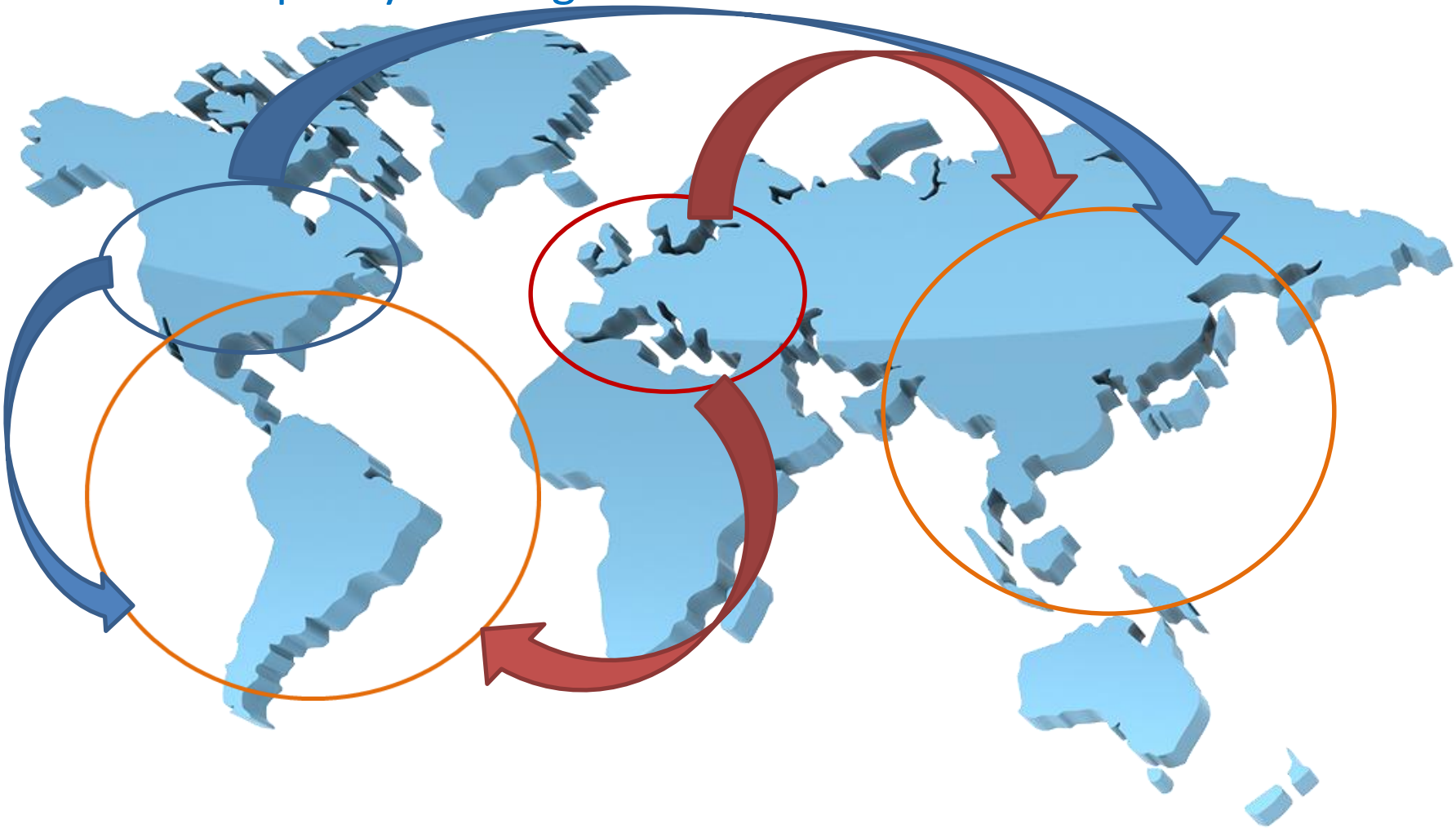


Effect of MAI on land area required for a market kraft mill

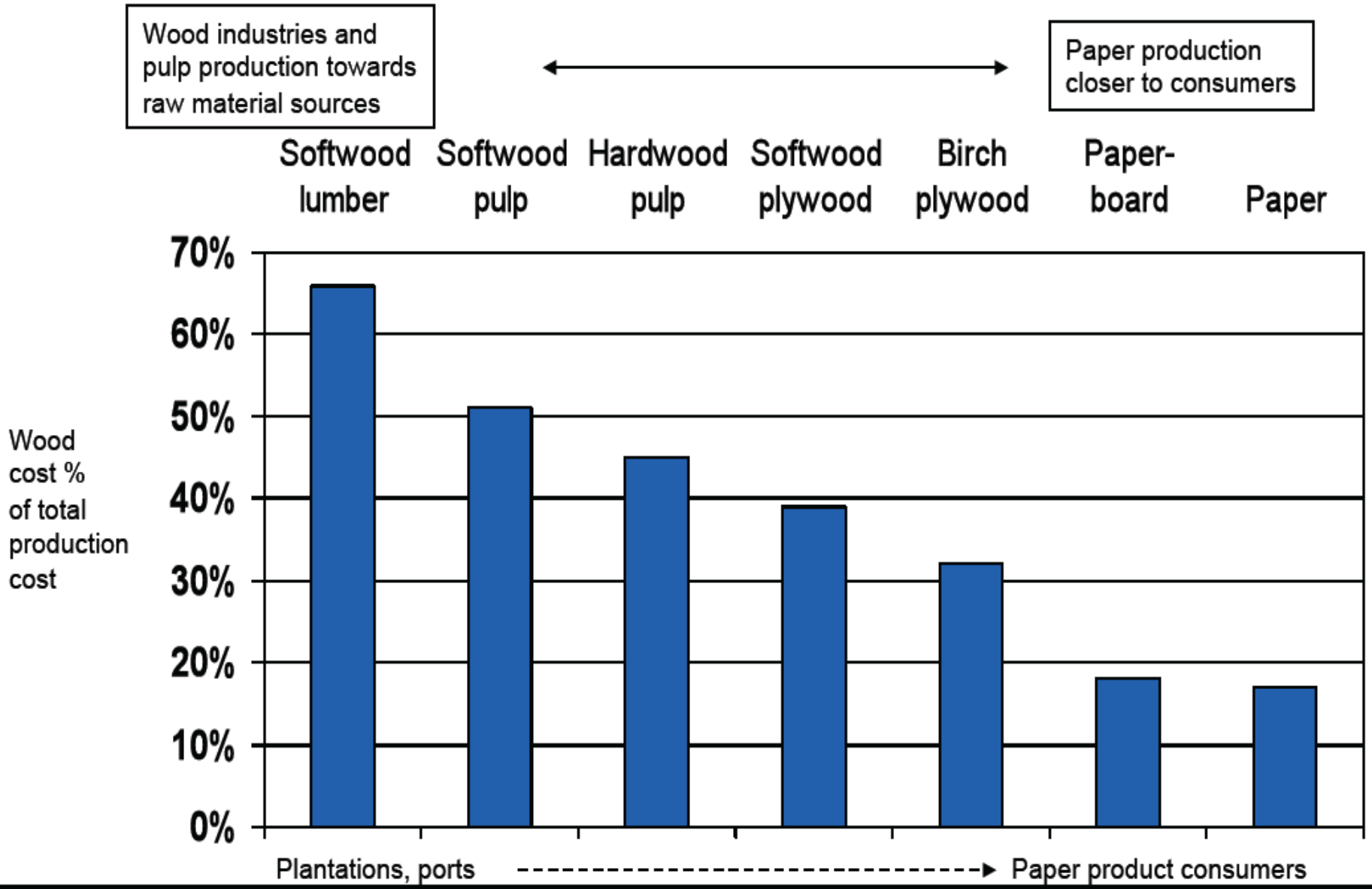


Trend 4: New market pulp mills being built close to the forest

- Pulp mills in EU and North America closing
- New capacity is being built in South America and Asia

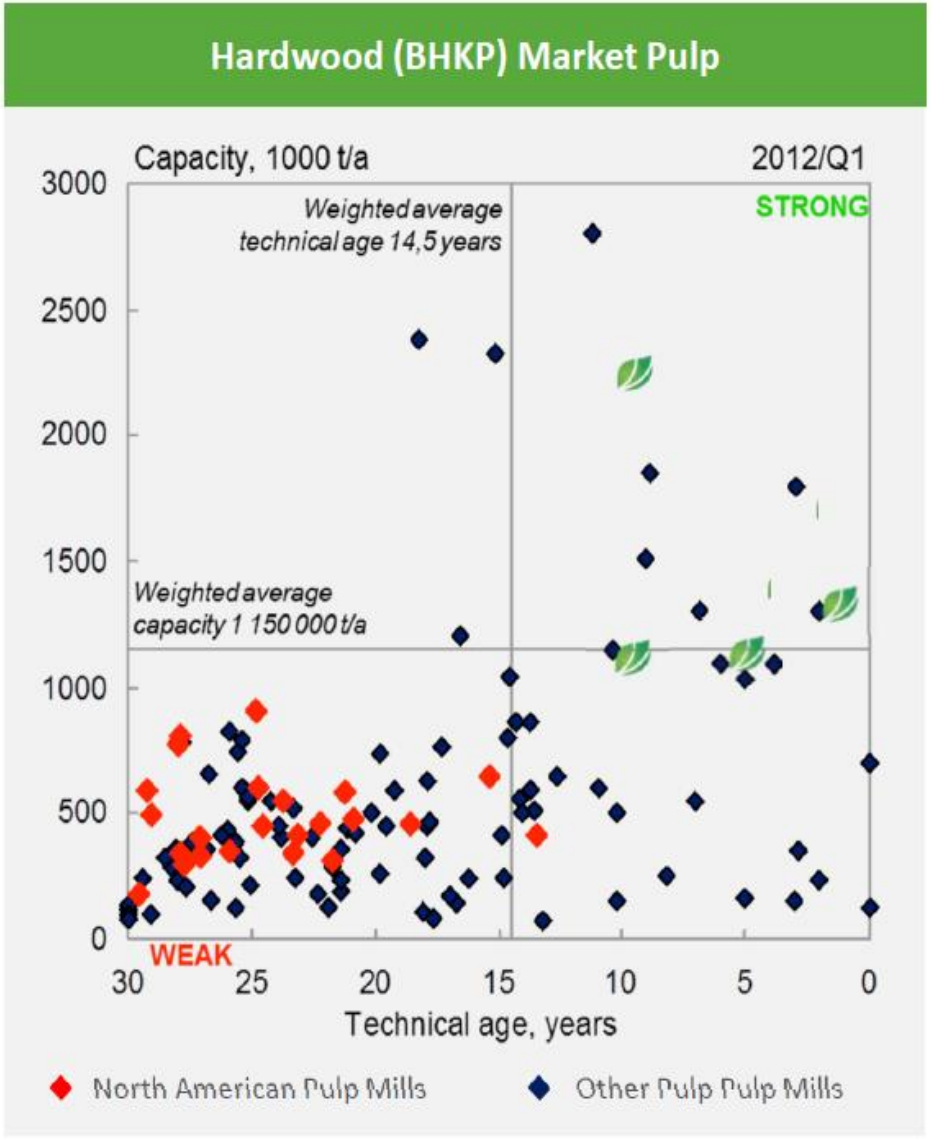


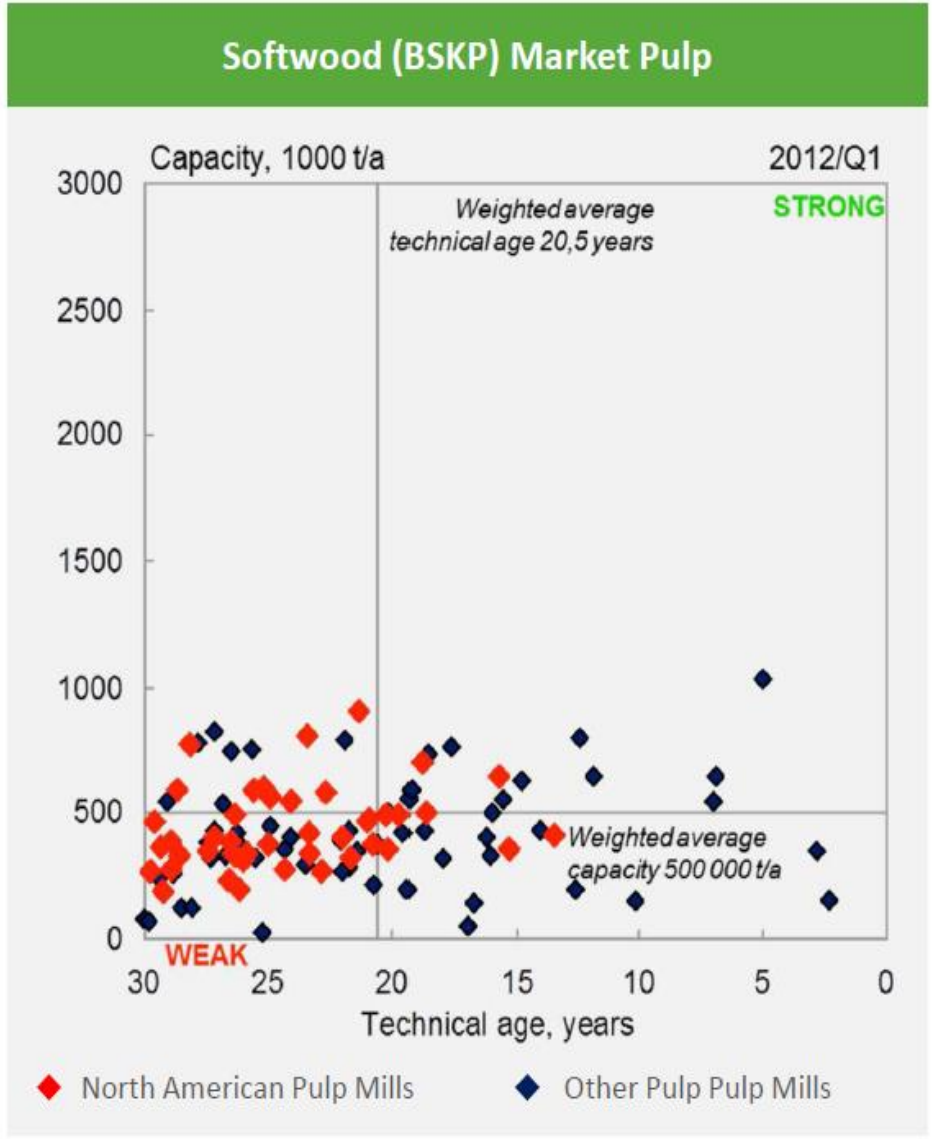
Wood costs as proportion of total costs have strategic impact on location of manufacturing



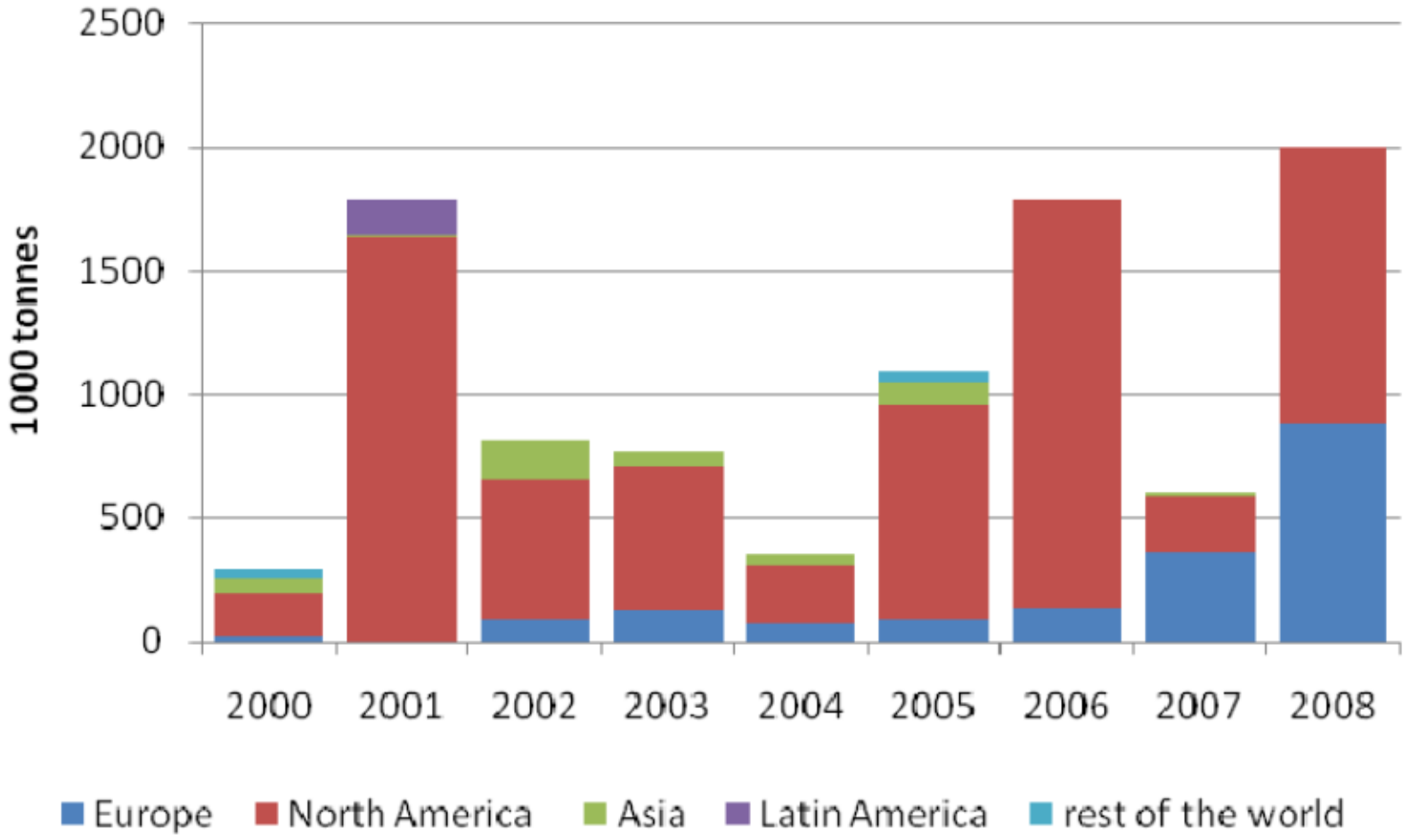
Scale and age of pulp mills

(Fibria 2013)



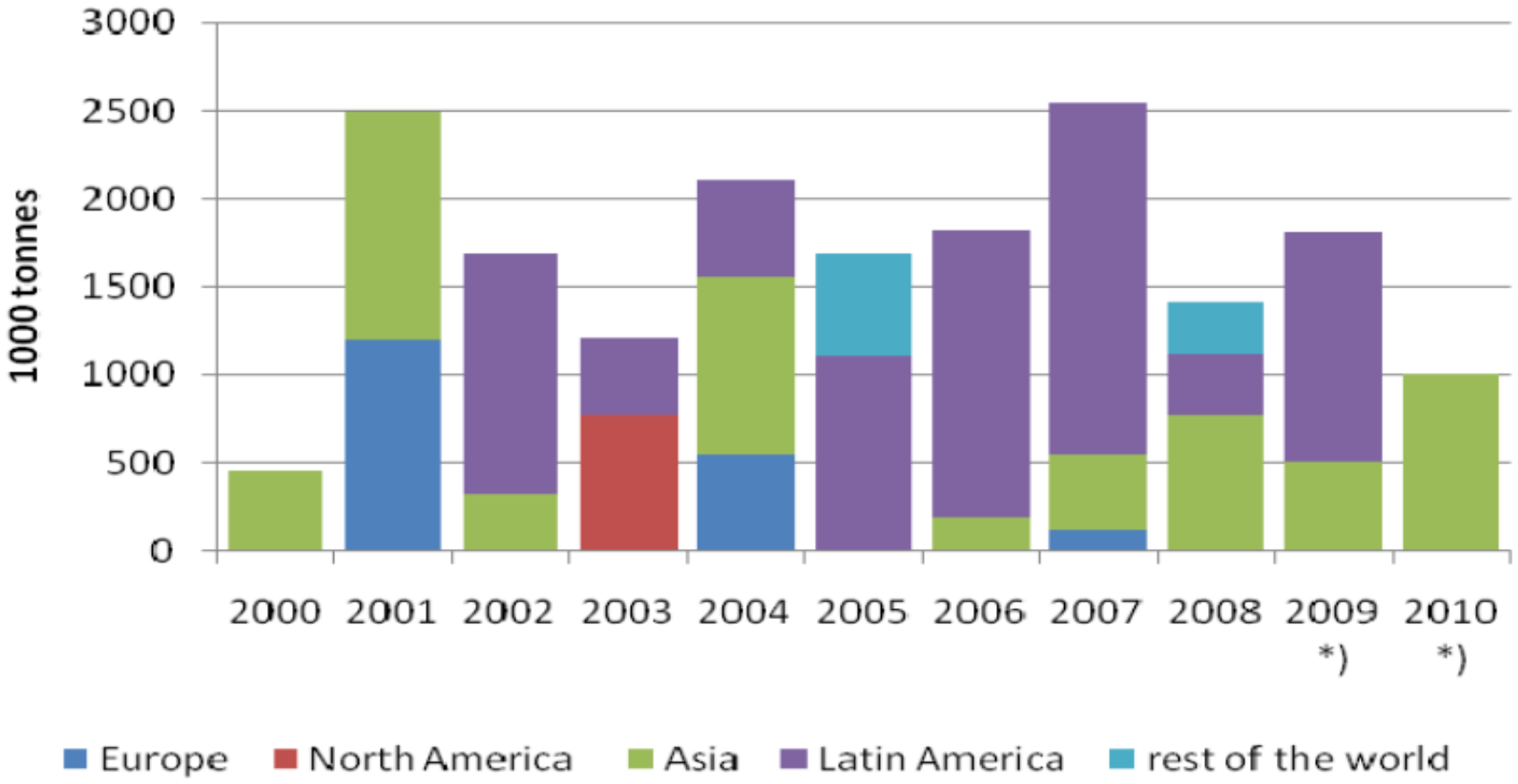


Chemical pulp mills shut down globally since 2000



Total 9.5 million tons

New global chemical pulp mills since 2000



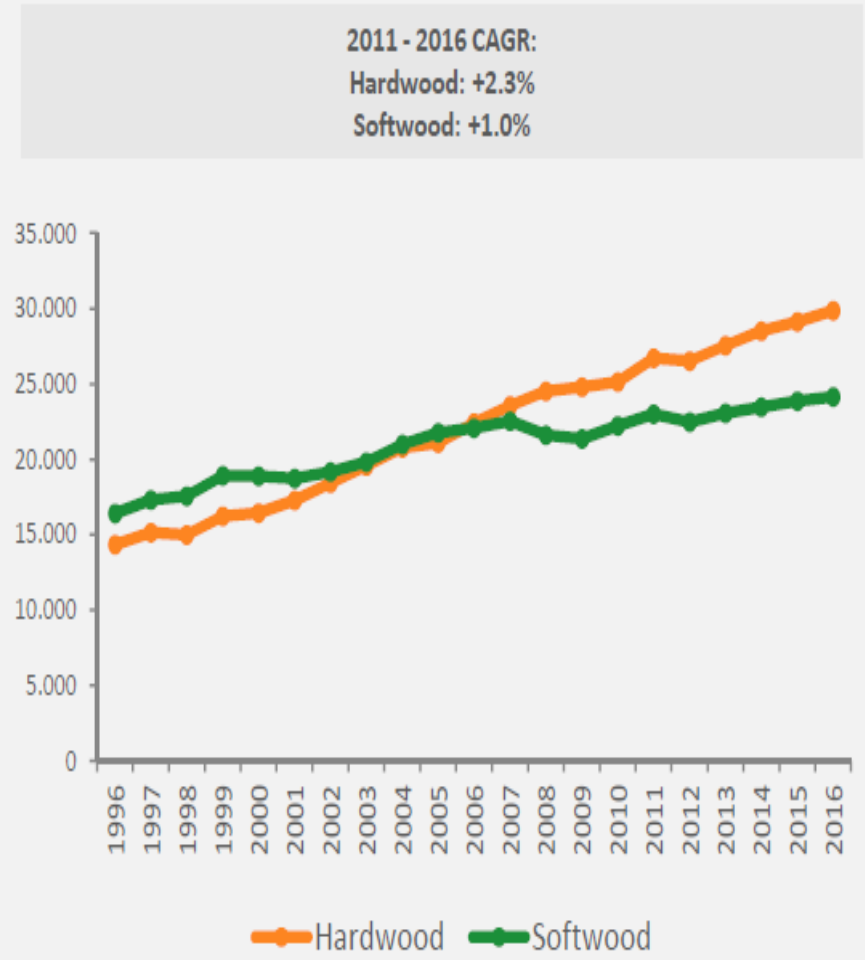
Total 18 million tons

*) 2009-2010 includes decided projects, delays may occur.

Global market pulp demand

(Fibria 2013)

Hardwood (BHKP) vs. Softwood (BSKP) (000 ton)



Demand growth rate

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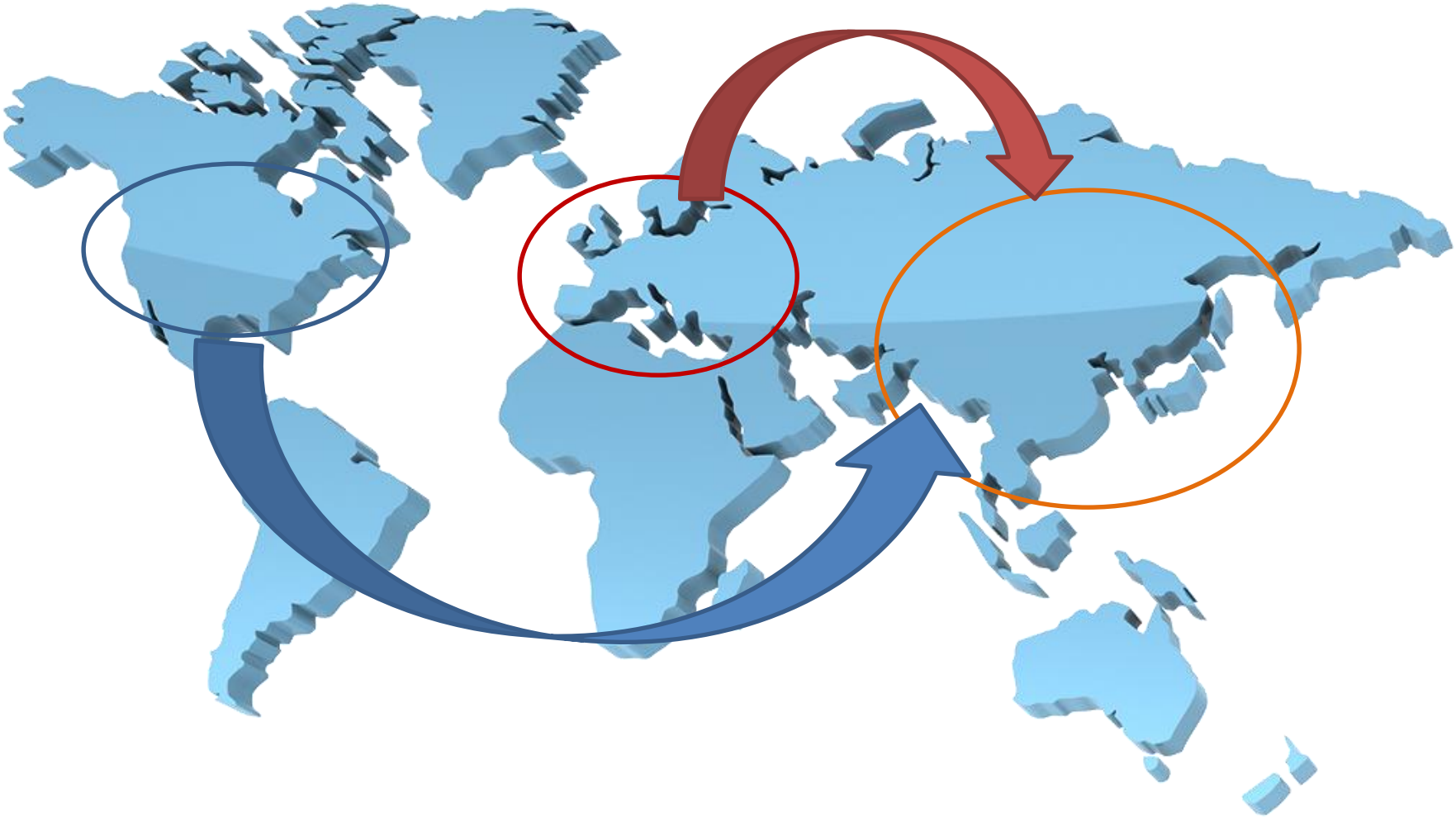
Market Pulp	30.8	44.4	54.0		

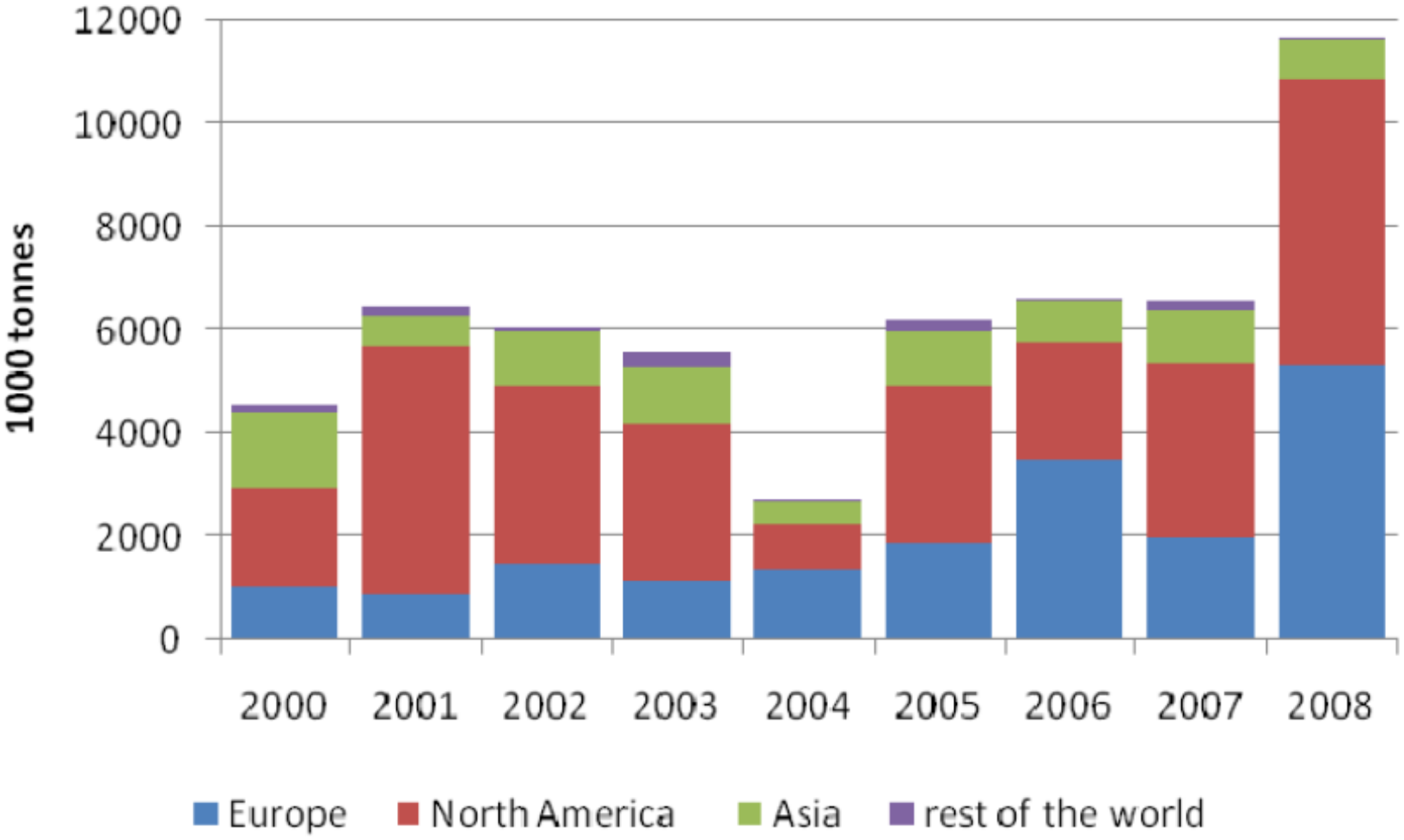
Trend 5: Paper is being manufactured close to market

- Paper machine capacity is being relocated to Asia, especially China



Global paper machines shut down

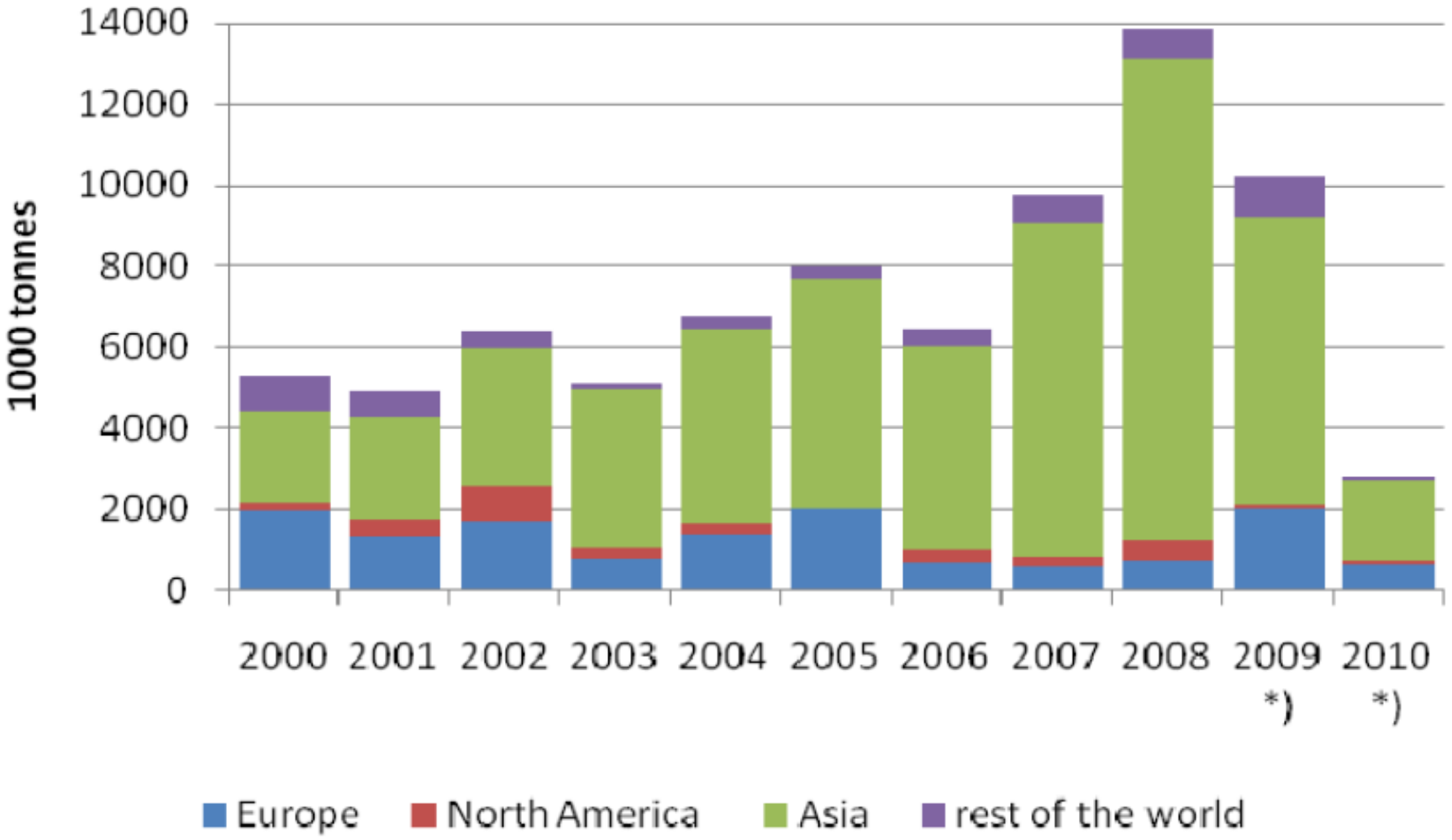
(all grades)



Total 56 million tons, 1,436 machines.

New global paper machines since 2000

(all grades)



Total 79 million tons, 822 machines.

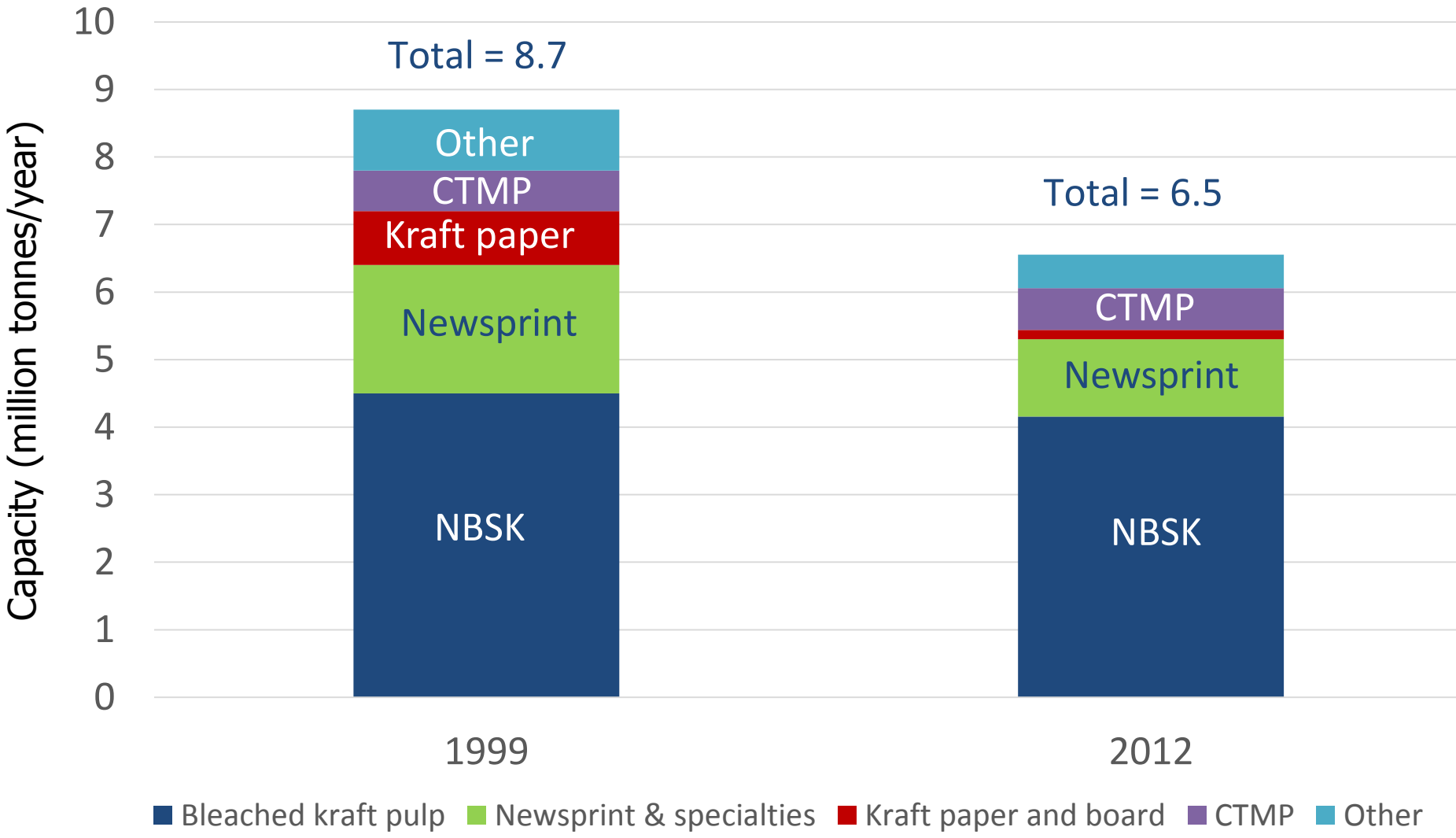
*) 2009-2010 includes decided projects, delays are possible.

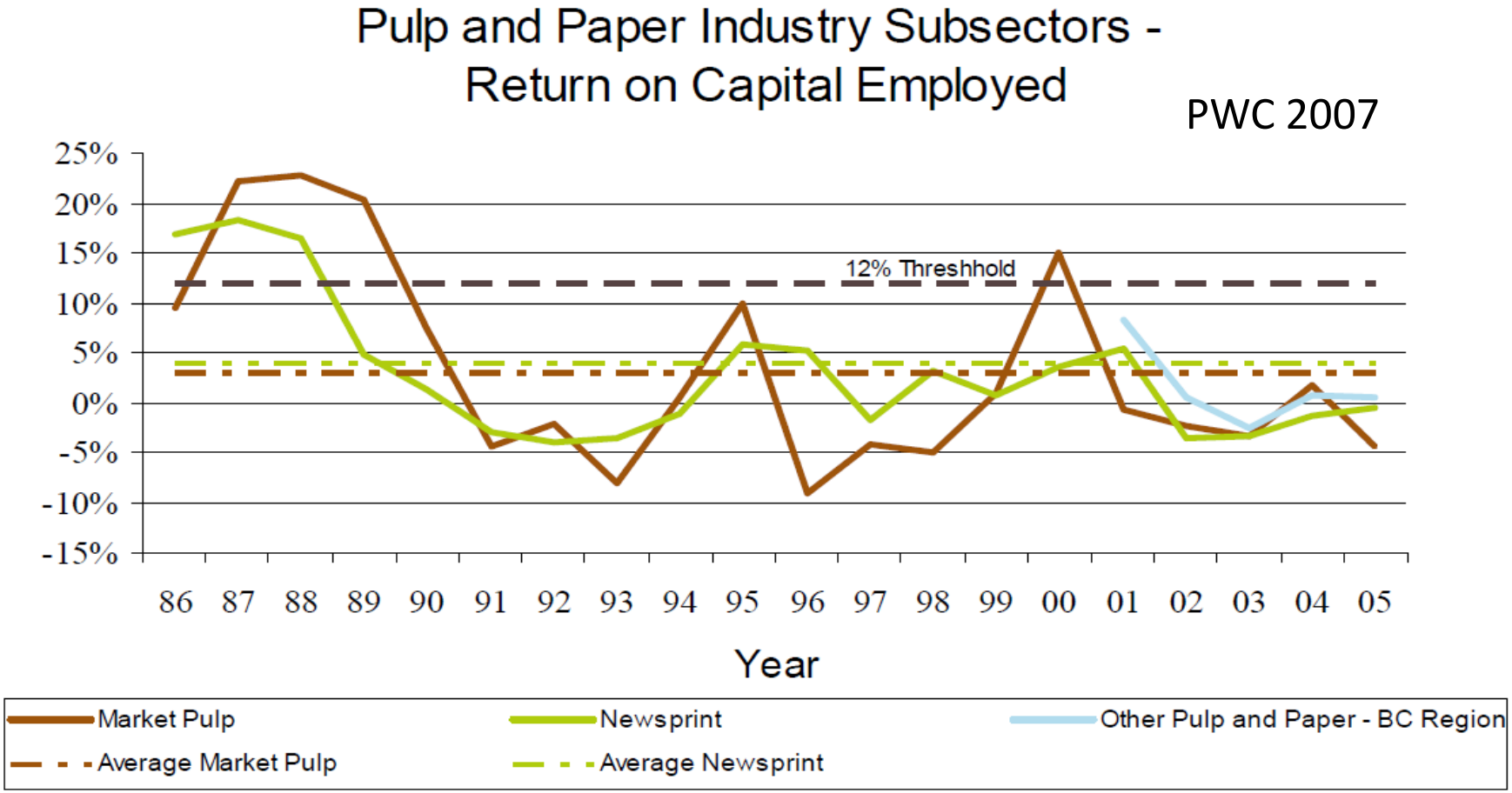
BC pulp & paper industry

- *Major companies*
  - *Canfor = 4 mills*
  - *Catalyst =3 mills*
  - *Paper Excellence = 3 mills*
  - *West Fraser = 2 mills*

Installed Capacity of BC's Pulp Mills

(Company reports, BC MoF 2000, 2013)





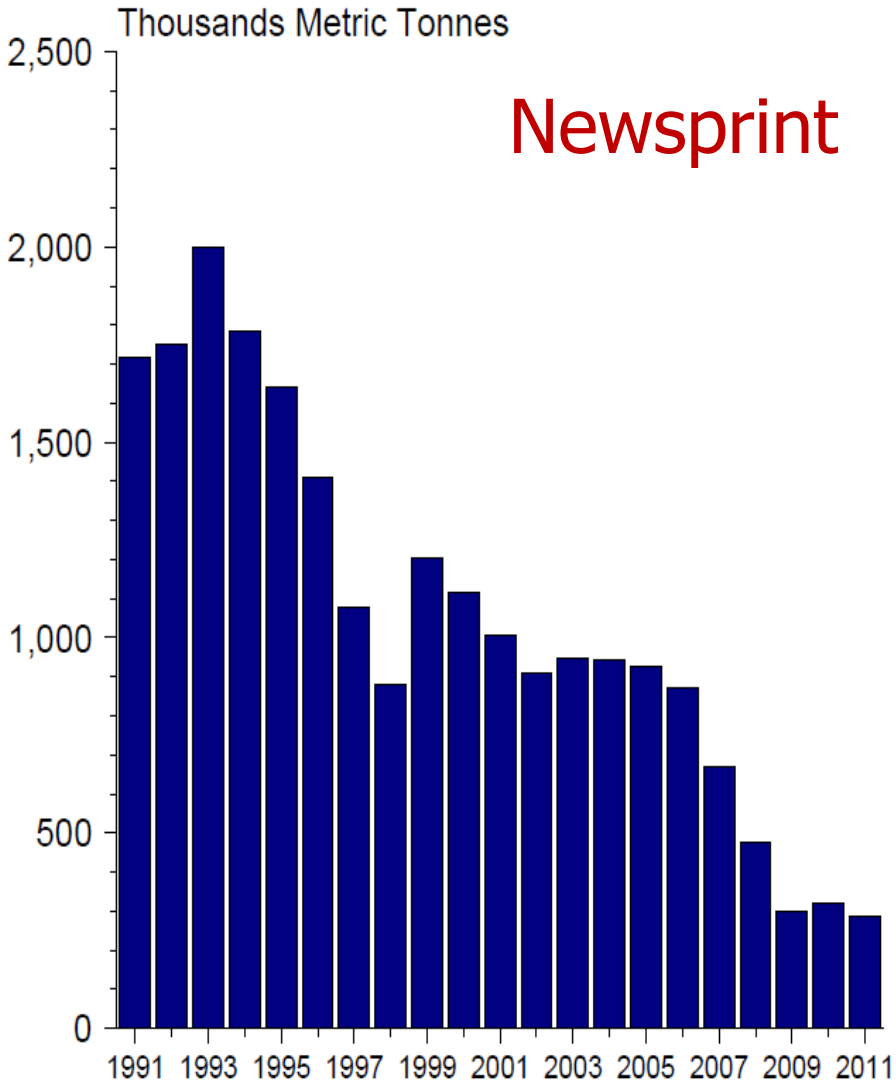
Average ROCE from 1986 – 2005

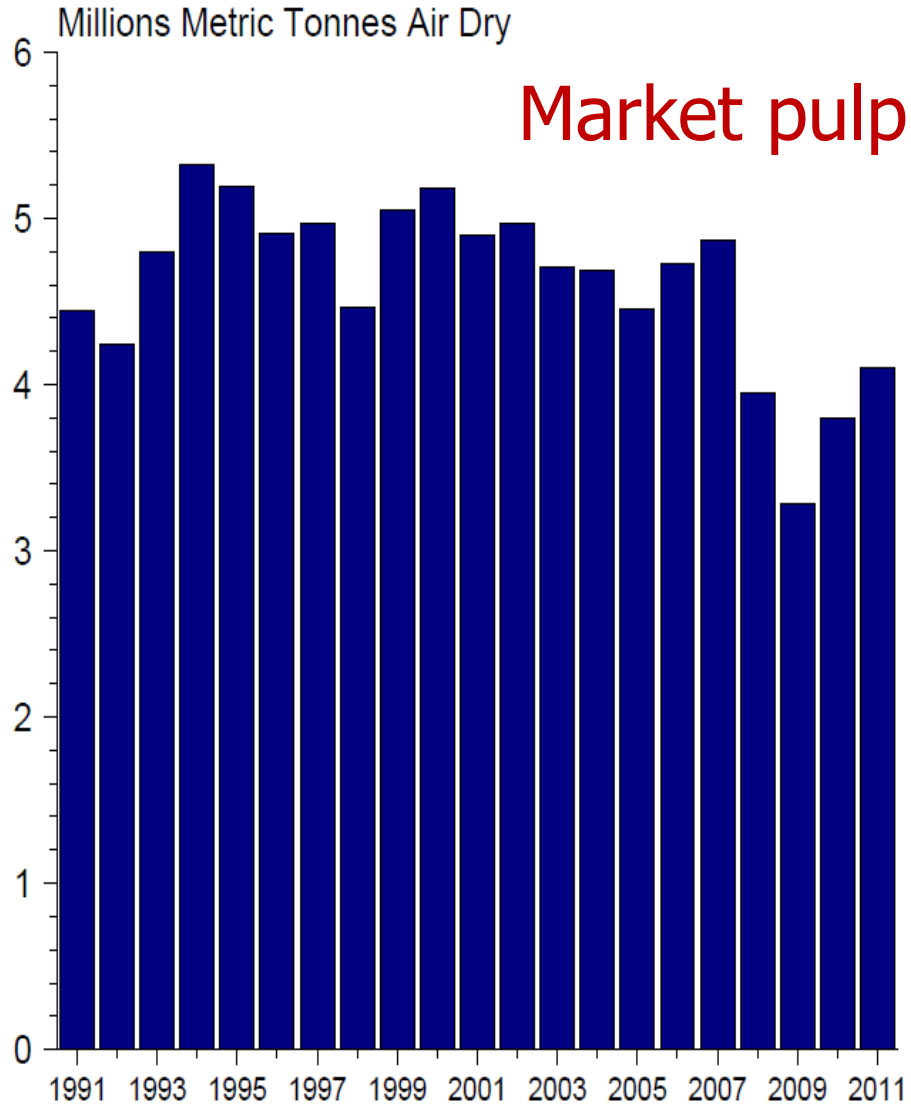
- Coastal market pulp 2.8%
- Interior market pulp 7.1%
- Newsprint/groundwood papers 4.2%

Top Canadian forest sector companies performance (PWC 2010- 2013)

	Sales (US $ millions)				Net Income (US $ millions)			
Company	2011	2010	2009	2008	2011	2010	2009	2008
Domtar	5,612	5,850	5,465	6,394	592	603	310	(573)
Resolute (Abitibi-Bowater)	4,756	4,746	4,366	6,394	41	2,614	(1,553)	(2,234)
Cascades	3,625	3,843	3,416	6,771	99	17	53	(52)
West Fraser	2,762	2,801	2,070	3,792	58	161	(300)	(129)
Canfor	2,421	2,359	1,868	3,010	12	68	(62)	(326)
Tembec	1,743	1,822	1,573	2,243	47	50	(193)	(142)
Catalyst	1,080	1,193	1,059	1,746	(974)	(385)	(4)	(208)
Mercer		1,195	865	1,060		114	(86	(107)

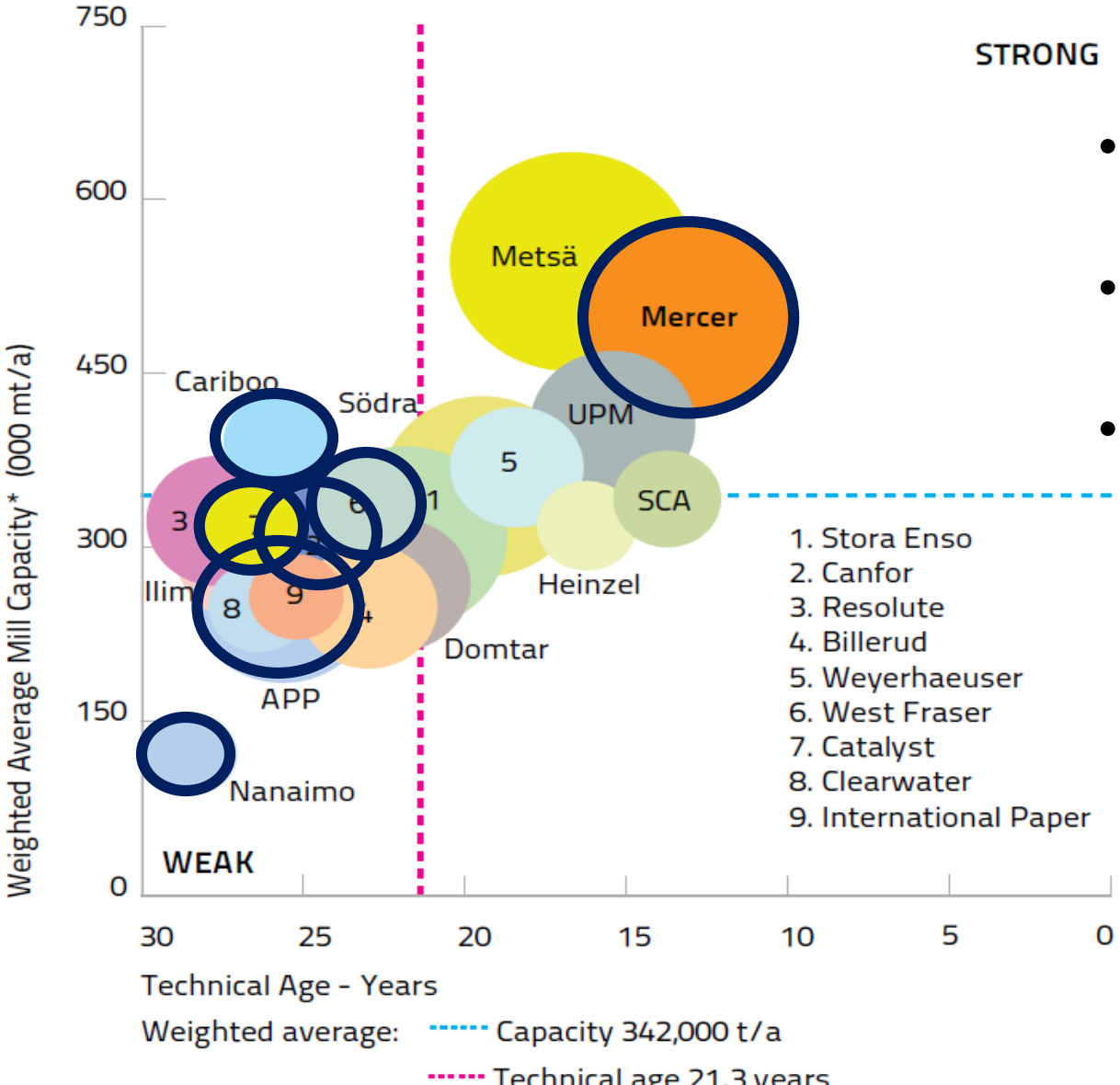
A tale of two products: BC`s pulp and paper exports (Stats Can 2011)





Strategic positioning of BC's kraft mills

(Mercer 2013)



- Comparison with NBSK mills
- Bubble size reflects capacity
- BC mills tend to be old and small-medium sized

Take home messages

- Paper markets changing quite rapidly
  - Developing world growing
  - Developed world shrinking
  - Packaging and hygiene grades growing fastest
- Structure of supply chain changing
  - Trees are local
  - Pulp is global
  - Paper is regional
- BC industry challenging future
  - Poor long term financial performance
    - Affecting reinvestment
  - Newsprint = poor market
  - NBSK market = better
    - Under pressure from hardwood pulps & large modern southern mills