# Pulping and Papermaking

# Introduction and overview

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## Course introduction - Biography

- Instructors
  - Professor James Olson, Mechanical Engineering UBC
    - Mechanical pulping and pulp processing
    - James.olson@ubc.ca, 604.822-5705
- Textbook – no textbook
  - Notes available at Website www.mech.ubc.ca/~mech450/
  - Written notes and presentations on site
  - Email you the password and username
- Grading: 2 midterms
  - Mechanical pulping and pulp processing (40%)
  - Chemical pulping and papermaking (40%)
  - Novel bio-materials video project (20%)
  - No final exam
  - Assignments unmarked

# Course outline

- **Introduction**
- **Natural resource**
- **Mechanical pulping**
- **Low Consistency refining**
- **Suspension rheology**
- **Screening**
- **Cleaning**
- **Chemical pulping**
- **Bleaching**
- **Papermaking**
- **ApproachFlow**
- **Forming**
- **Pressing**
- **Paper products**

- Class Cancellations
  - No Classes Week of Feb 4.

# What is paper?

**"A thin flat *surface* usually made of wood fibres."**

- ***Surface for communicating*** **text and images**
  - ***e.g. magazines, newspapers, books, brochures, ...***
- ***Surface to enclose, protect and carry***
  - ***e.g. corrugated boxes, bags, shoe boxes, paper cups, ...***
- ***Surface to cover, absorb or stop fluids***
  - ***e.g. hygiene grades, Kleenex, toilet paper, paper towel, medical tissues, ...***

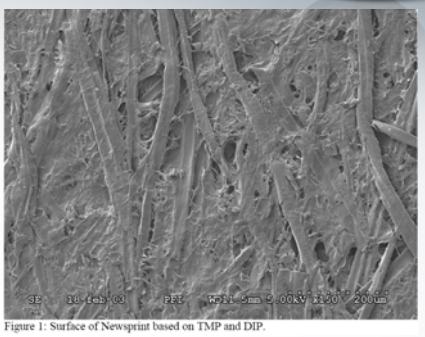


Figure 1: Surface of Newsprint based on TMP and DIP.

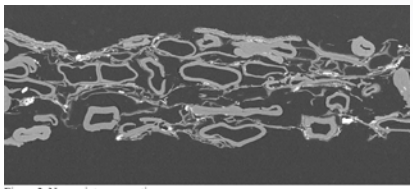


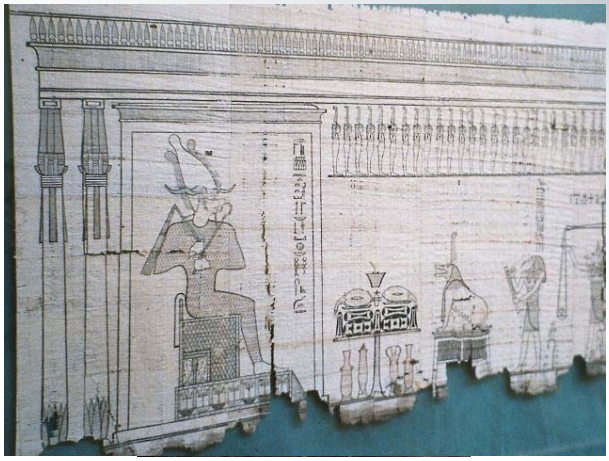
Figure 2: Newsprint cross section

## What inventions have fundamentally changed our lives ?

- Early 14th century no one here would know how to read!
- The Printing Press
  - Johann Gutenberg, Mainz, 1439
    - (MSN Encarta ranks it 3rd after the clock and the toilet)
- What did he print?
- New found literacy
  - Fed the renaissance
  - Created the scientific revolution

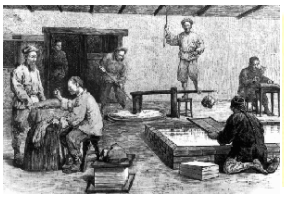
## History of paper

- 3000BC Egypt made from papyrus



# History of paper

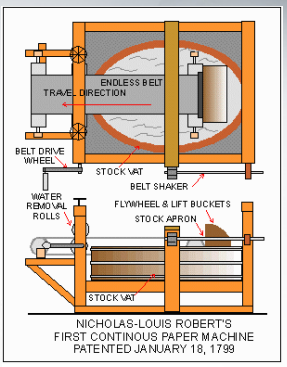
- 105 AD – Cai Lun (China) first to make cotton paper
- Bamboo paper was produced in the Tang Dynasty (608 – 907 AD)
- Korea in 300 AD
- Printing in 11th century



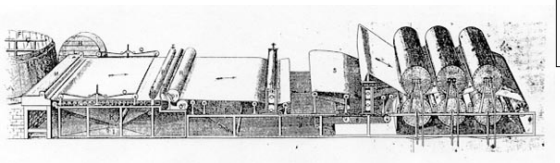
Early paper money 600AD

# History of paper

- First modern paper machine
- 1799 Patent issued to Nicholas-Louis Robert for first continuous paper making machine (France)
- 1803 Patents issued to Fourdrinier brothers for improved continuous paper machine

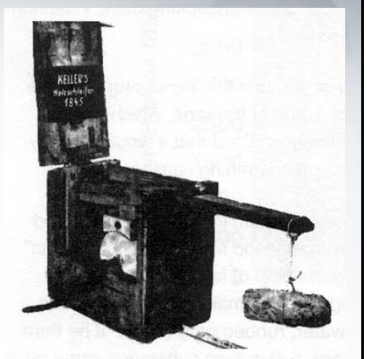



NICHOLAS-LOUIS ROBERT'S FIRST CONTINOUS PAPER MACHINE PATENTED JANUARY 18, 1799



# History of paper

- Pre-mid 1800's paper was made from what?
- 1841, Friedrick Keller "inventor" of the mechanical pulping process for wood
- 1848 Johan Voith in Heidenheim made first commercial grinder.
- 1867 Full plant powered by steam Paper made with 70% wood
  - Worlds fair Paris
- 1868 Tampella (Finnish company) started making grinders.

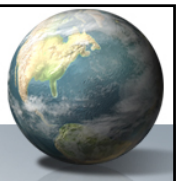



# Modern Papermachine

# Paper - In the works!

Our forest

# Forests - Overview

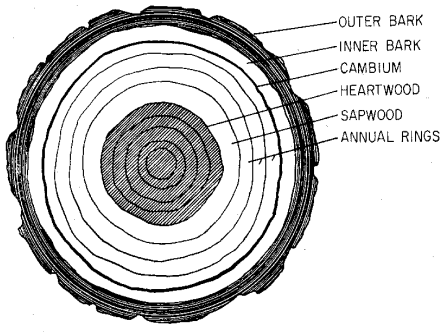


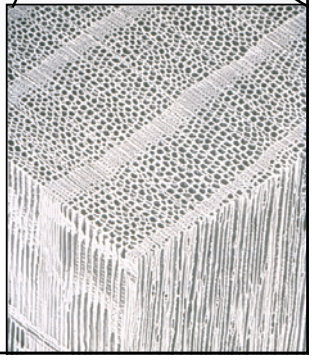
- 27% of land mass is forested
- Annual world harvest is 3.5 B m^3
  - 50% fuel
  - 33% wood
  - 16% pulp and paper
- 6%  of annual harvest is plantation but is 23% of Pulp and Paper
- Canada has 10% of worlds harvest
- Support 1.6% population increase requires forest the size of BC

# Types of Trees

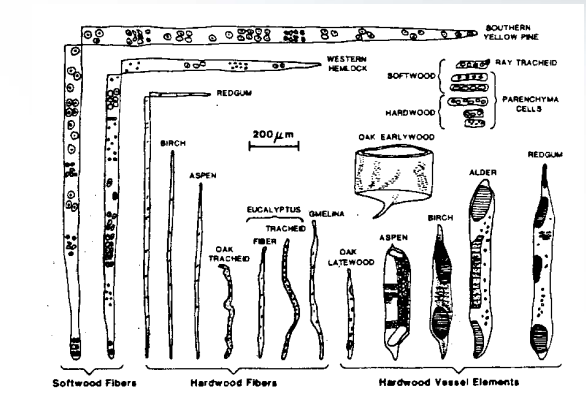
- Gymnosperms (Naked seed)
  - Conifers
  - Softwoods
- Angiosperms (Vessel – seed)
  - Deciduous
  - Hardwoods
- Name some species?

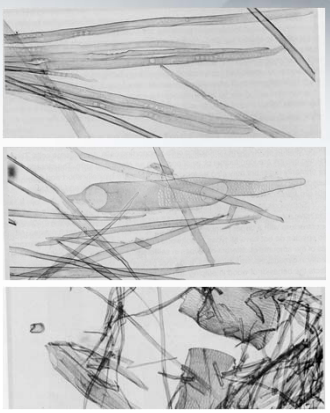
# Tree cross-section



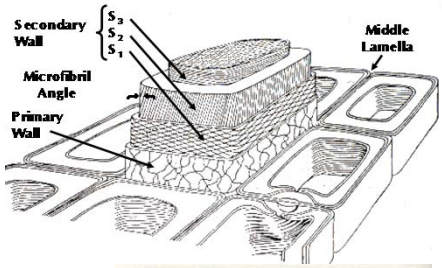



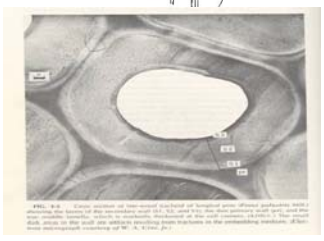
# Different types of cells



# Cell Structure

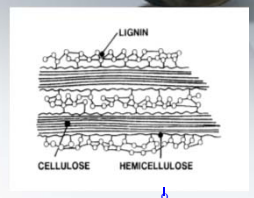


- **Primary Wall**
- **Secondary Wall:**
  - **S1 Layer:**
  - **S2 Layer**
  - **S3 Layer**
- **Middle Lamella**:

# Chemical structure

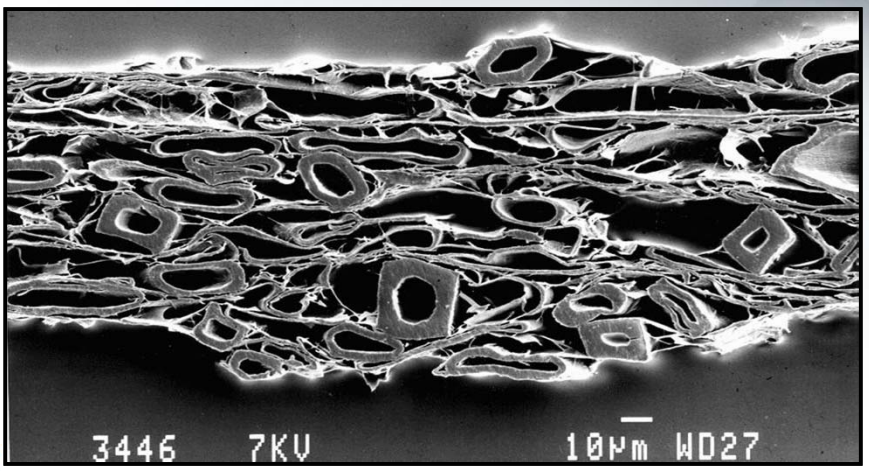
- Cellulose
  - Glucose monomers
  - Primary wall 6000 units
  - Secondary 16000 units
- Hemi-cellulose
  - Poly-sacharides
  - Branched polymers
  - Eg, xylose, arabinose
- Micro-fibrils
  - Crystals of cellulose
  - 20 nm ~ 2000 cellulose molecules







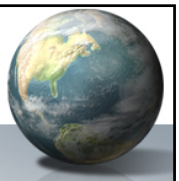
# SEM of paper cross section



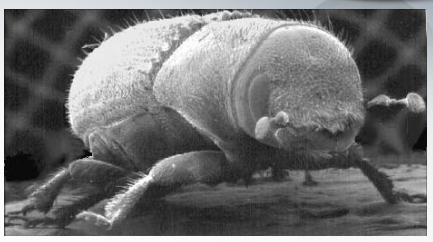
# Paper – In the works!

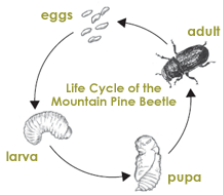
The Pine Beatle in BC

# Introduction



- Pine Beetle
  - Attacks Lodge pole pines first
  - Can also attach Jack, Ponderosa, Western white, etc.
- Burrows under the tree bark and reproduces
  - Winter eggs mature into pupae
  - Fly off to new trees in the spring





## The Attack – Beatles burrow into the tree's cambium layer

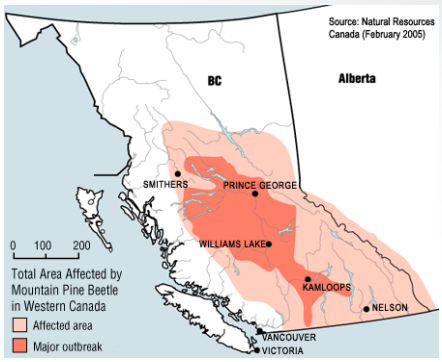
## The Attack! – The tree defends itself by pitching them out

## The Attack! – Chemical warfare. Blue stain fungus counters the pitch

## The tree dies! Turns red in first years

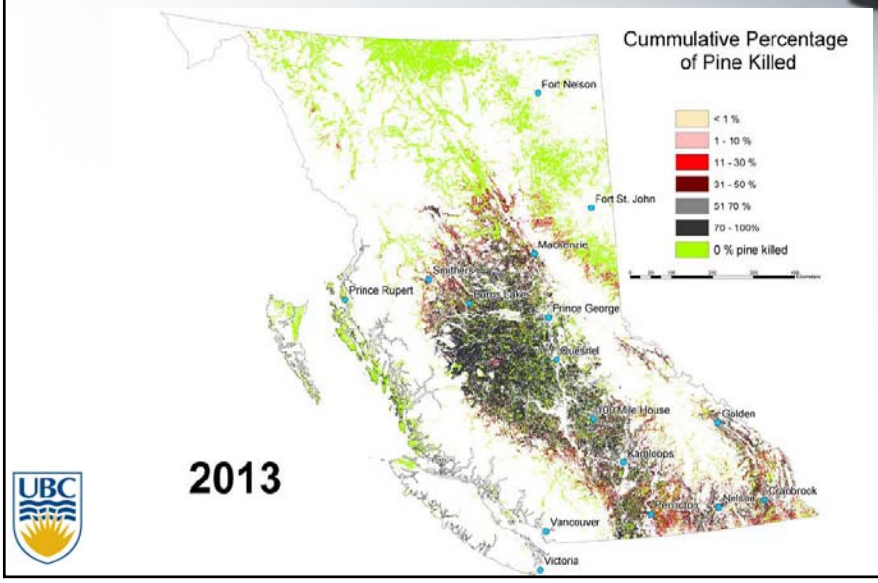
## Tree turns grey in subsequent years

## How big is this problem?



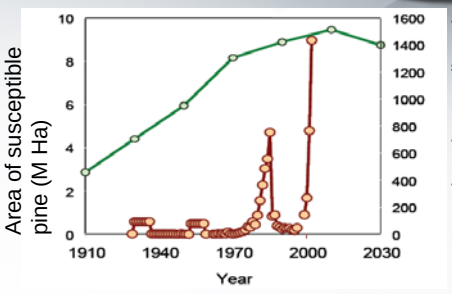

- 2005 area of infection
- 80% of BC pine is affected

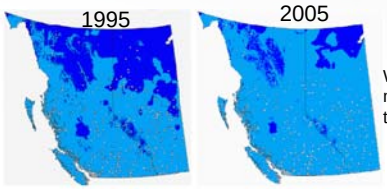
## When will it end?




## How did it get so bad?

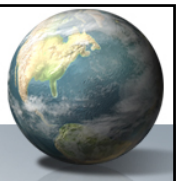
- Climate change?
  - Hot dry summers and mild winters
- Plenty of food due to 40 years of fire suppression
- Lack of early management
- Inaccessible hot spots



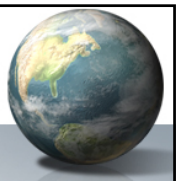

Winter minimum temp (<-40C)

## What problems are we facing?



- Fire hazards
  - Communities, recreation, other species at risk
- Lost value
  - Forestry is 40% of our GDP in this province
  - Blue stain
    - Darkens the chips used in paper
    - Colors the wood / lumber
  - Grey trees are dry and crack
    - Cant be sawn into lumber
    - Difficult to pulp into paper

## What can we do about it?



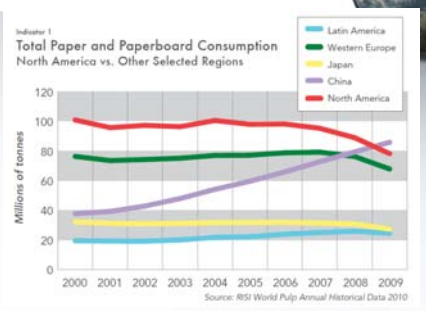
- 50% increased wood harvest for 10 years,
  - More pine in fibre mix
  - Cheaper wood but lower quality
  - Build new sawmills to process wood into lumber
- Research into how to best utilize this resource
- Extensive replanting of mixed species forests

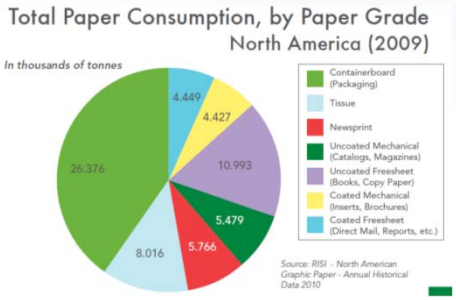
# Paper - in the works!

The Industry in Canada / BC

# World paper production

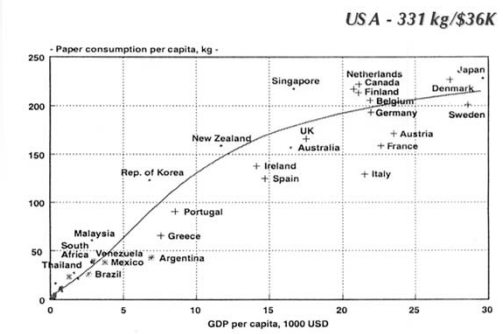
- Globally increasing demand for paper
- Decrease in printing and writing but increase in tissue / packaging



# Consumption per capita

- Consumption closely tied to standard of living
  - Why?




# Recyclable

- One of the most recycled materials
- Very high recover rates.

# Canadian export

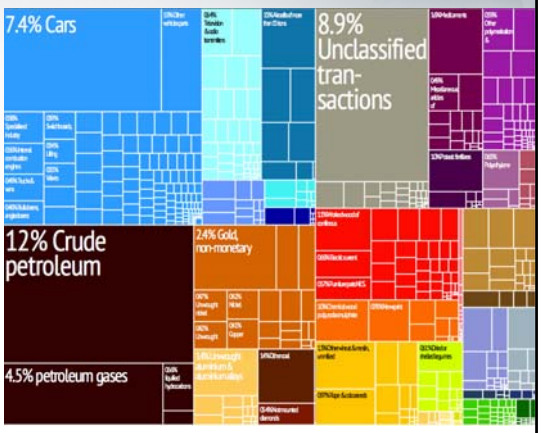
- What is largest exported product?

Table 3. Forest facts

| Commodities | World production ranking 2010* | Domestic exports 2010 | Destination | | |
|---|---|---|---|---|---|
| Total forest pro ducts | – | $26 B (100%) | U.S. | $16.8 B | 64.7% |
| | | | China | $3.0 B | 11.5% |
| | | | E.U. | $1.4 B | 5.3% |
| Softwood lumber | Second (13.6%) | $4.8 B (18.5%) | U.S. | $2.9 B | 60.7% |
| | | | Japan | $0.7 B | 14.8% |
| | | | China | $0.68 B | 14.0% |
| Newsprint | First (13.8%) | $2.8 B (10.8%) | U.S. | $1.4 B | 52.1% |
| | | | E.U. | $0.3 B | 10.5% |
| | | | Brazil | $0.2 B | 7.9% |
| Wood pulp | Second (11.0%) | $7.0 B (26.9%) | U.S. | $2.9 B | 40.9% |
| | | | China | $2.0 B | 28.6% |
| | | | E.U. | $0.5 B | 7.1% |
| Other | – | $11.4 B (43.8%) | U.S. | $9.5 B | 84.3% |
| | | | E.U. | $0.5 B | 4.5% |
| | | | China | $0.3 B | 2.7% |

E.U. – European Union (27 countries)
U.S. – United States
* United Nations Food and Agriculture Organization data for 2010.

Export industries in Canada




http://en.wikipedia.org/wiki/Economy_of_Canada

# Where is pulp / paper made in BC?


- BC's papermills are concentrated in the Southwest and North of the province
- These mills are usually the biggest source of work in these communities and directly employ 17,000 people
- They are fed largely by unused fibre from solid wood processing and collectively account for $4,280,000 in revenues and 20% of BC's manufacturing economy
- With indirect jobs total BC employment is about 50,000 people

## BC and Canada Forest Sector Revenues (CFS statistics):

| | BC 2010 | Canada 2010 | BC Share 2010 |
|---|---|---|---|
| | $ million | $ million | % |
| **Revenue from goods manufactured (dollars)** | **14697** | **53795** | **27%** |
| **Forestry and logging industry** | **3295** | **7766** | **42%** |
| **Pulp and paper product manufacturing industry** | **4757** | **25771** | **18%** |
| Converted paper product manufacturing | 280 | 7937 | 4% |
| Pulp, paper and paperboard mills | 4477 | 17833 | 25% |
| **Wood product manufacturing industry** | **6644** | **20257** | **33%** |
| Other wood product manufacturing | 1100 | 6327 | 17% |
| Sawmills and wood preservation | 4450 | 9628 | 46% |
| Veneer, plywood and engineered wood product manufacturing | 1093 | 4301 | 25% |

## BC Product Breakdown by Export $ 2011 (CFS statistics)

| | $ million |
|---|---|
| **Domestic exports** | **9,835** |
| **Primary wood products** | **888** |
| Logs and bolts | 567 |
| Pulpwood | 23 |
| Wood chips | 39 |
| Other primary wood products (includes Christmas trees) | 259 |
| **Pulp and paper products** | **4 278** |
| Converted paper | 12 |
| Newsprint | 189 |
| Other paper and paperboard | 741 |
| Other paper products | 64 |
| Recovered paper | 72 |
| Wood pulp | 3,199 |
| **Wood-fabricated materials** | **4,669** |
| Lumber | 3,809 |
| Oriented strandboard | 294 |
| Particleboard | 3 |
| Plywood | 78 |
| Shingles and Shakes | 133 |
| Veneer | 103 |
| Other wood-fabricated materials (includes non | |

# Paper - In the Works!

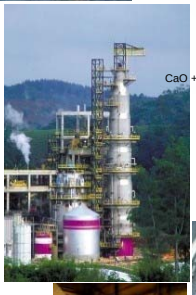
Pulp and paper technology-
How do we make paper?

## Pulping technology

- Two methods for converting wood to papermaking fibres
- Chemical (Kraft) Pulping
  - Uses chemical to dissolve lignin from wood to produce nearly pure cellulose fibres
  - 1 ton of tree ~ 0.5 ton of paper
  - Strong, smooth, expensive
- Mechanical Pulping
  - Use grinders / refiners to separate fibres mechanically
  - 1 ton of tree → ~ 1 ton of paper
  - Low cost, opaque, weaker

# Modern kraft pulp mill

# Modern kraft pulp mill



2000 t / d
Lignin / Cellulose / Hemicellulose
Complex metabolites (Sterols/ fats/ etc)

$CaCO_3$ +heat = CaO + $CO_3$

Wood

Lime Kiln

Digester

Cellulose / fibres

Pulp

Washing

White Liquor

NaOH + $Na_2S$

Lime Mud

Lime

Weak Black Liquor

Causticizing Plant

Evaporators

$CaO + Na_2CO_3 + H20 = 2NaOH + CaCO_3$ +heat

Green Liquor

Water

Heavy Black Liquor

Recovery Boiler

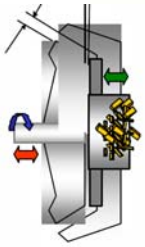
Smelt

Lignin + Na + S

$Na_2S + Na_2CO_3$

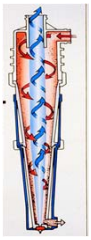
Combined heat and electrical power (55 MW)
660 kWh/t of pulp + Hog Fuel boiler

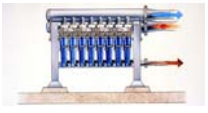
# Modern mechanical pulp mill



- Fibres separated mechanically
- 30 MW motor
- How big is that?
  - 42,000 HP
  - In BC, 78 Motors that consume 11% of all the electricity produced! (5,500 GWh/y)

# Recycling






*A ton of paper made from recycled fibers conserves:*

**7,000 gallons of water**

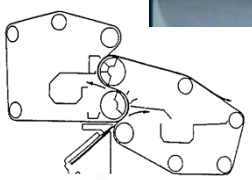
**17-31 trees**

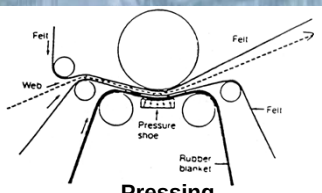
**4,000 KWh of electricity**

**60 pounds of air pollutants**

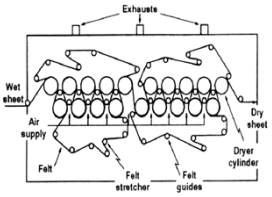
# Modern papermacine

- 10 m wide
- 100 m long
- 1000 m/min.
- $400,000,000






Pressing Section




Drying Section

Forming Section

# BC paper shipped to the world!


# A close up look at paper
# Newsprint

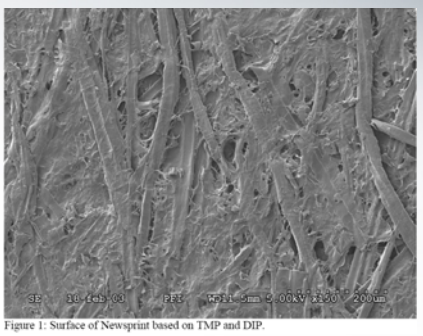


Figure 1: Surface of Newsprint based on TMP and DIP.

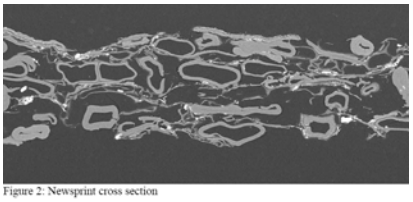
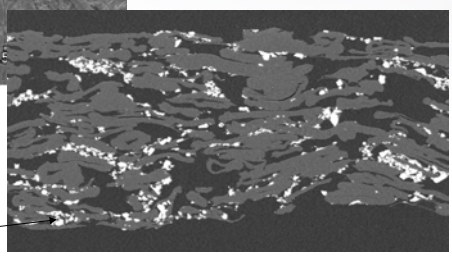


Figure 2: Newsprint cross section

# A close up look at paper
# Copy paper

Figure 3: Surface of copy paper.



Mineral
fillers (clay)

## A close up look at paper
## Supercalendered magazine

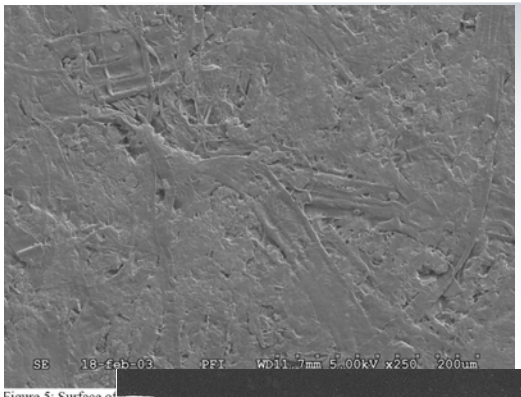
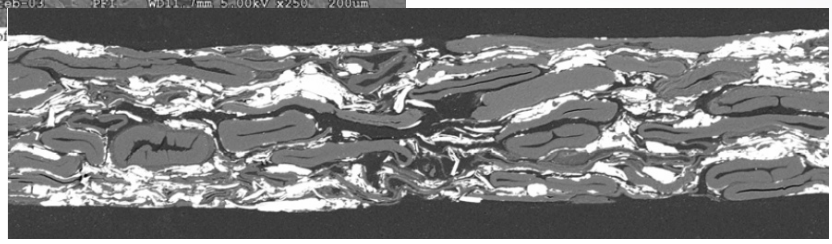



Figure 5: Surface of



## A close up look at paper
## Coated magazine paper

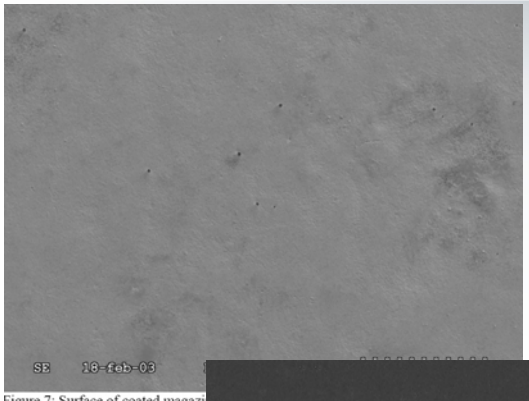
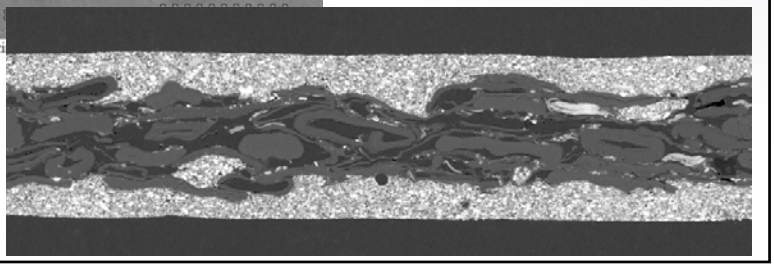



Figure 7: Surface of coated magazi



## A close up look at paper
## Sack paper

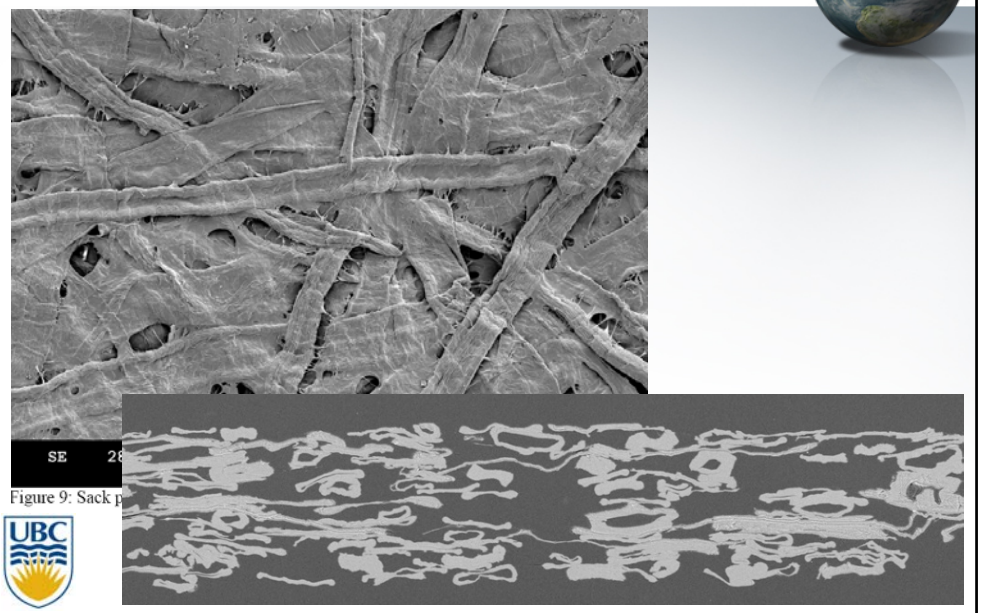



Figure 9: Sack p

## A close up look at paper
## Coated board

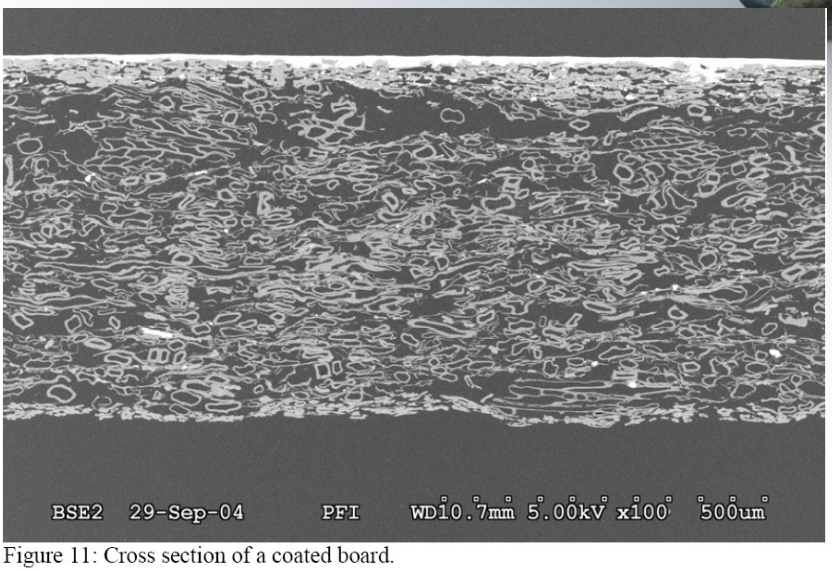



Figure 11: Cross section of a coated board.

# A close up look at paper
# Liner for orange juice container

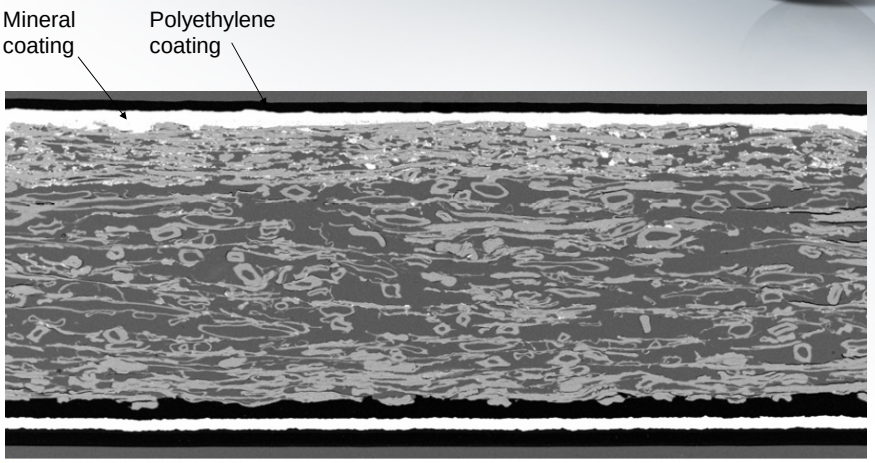



Figure 13: Liquid board for orange juice.

# A close up look at paper
# Corrugated board

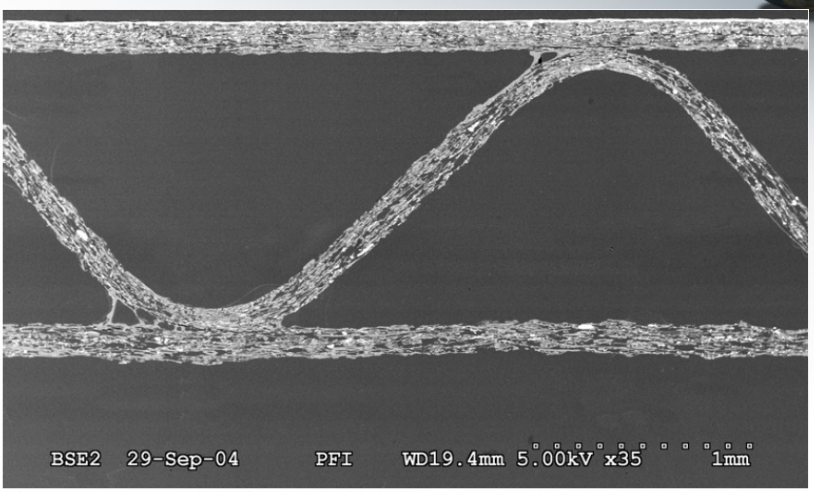



Figure 15: Cross section of corrugated board.

# A close up look at paper
# Toilet paper

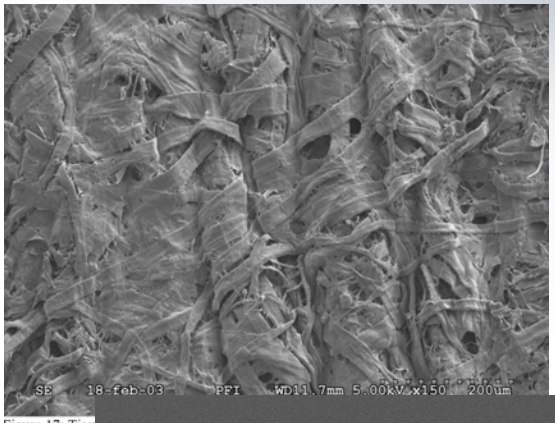
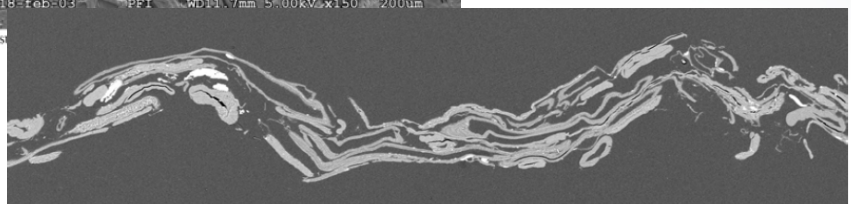



Figure 17: Tiss

Embossing pattern



# A close up look at paper
# Grease proof paper

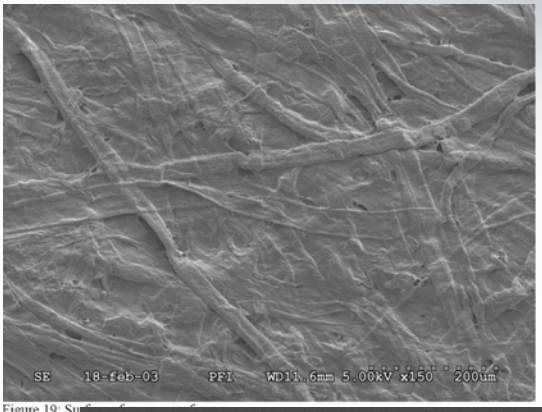
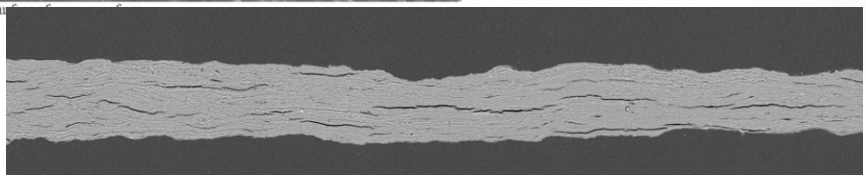



Figure 19: Su



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*The Future Pulp, Paper Forest Industry:*

*The future forest bio-economy will be based on integrated production of energy, fuel, chemicals, materials*

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## Forest bio-economy


- **The bio-economy is transforming our world and our vision of the forest**
  - Forests provide truly renewable, sustainable, recyclable, climate neutral energy, fuel, chemicals and materials
  - FPAC Bio-pathways analysis shows near future bio-economy is estimated to be $200 Billion by 2015*


- **Next generation industry is integration of**
  - Bio-energy / bio-fuel production
  - High value bio-chemicals and nutraceuticals
  - Advanced materials and composites
  - New fibre based products and building materials

Source: *FPAC – Bio Pathways

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## Current bio-energy in BC

- More than 800 MW of biomass electricity installed (mostly P&P cogeneration)
- Growing pellet industry with 2 Mt/y
- Several new ORC electricity generation installations
- 4 Nexterra gasification systems have been built
- 17 Million t/y forest biomass available for energy in BC with additional 11Mt/y for next 15 years
  - 30% of current fossil energy


http://www.energyplan.gov.bc.ca/bioenergy/PDF/BioEnergy_Plan_005_0130_web0000.pdf
http://www.biocap.ca/images/pdfs/BC%20Bioenergy%20Primer.pdf
http://www.bioenergypartnership.ca/resource_inventory.html

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## Product integration is key

- Forest based energy, fuel, chemicals, advanced materials are not economic as a stand alone industry
- Integration of advanced bio-products with existing industry is the near term key to success
- Pulp and paper companies will be the early adopters of forest bio-economy technologies
- Pre-existing, capital intensive systems:
  - Biomass collection and handling
  - Thermo-chemical conversion
  - Environmental (air and water)
- 'Bolt-on' technology for bio-energy, fuel, chemical and materials production is economic today

# Petroleum Pathways

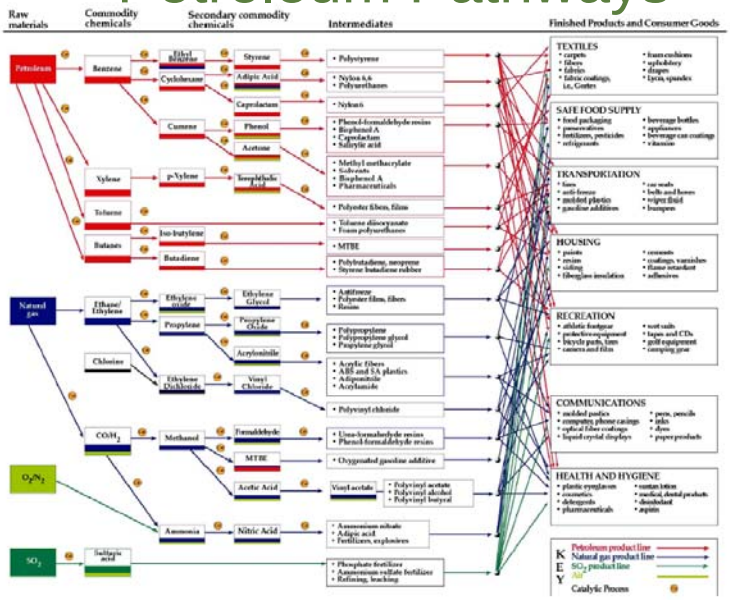



Figure 2 – An Example of a Flow-Chart for Products from Petroleum-based Feedstocks

10

## Bio-based Pathways – BioRefinery

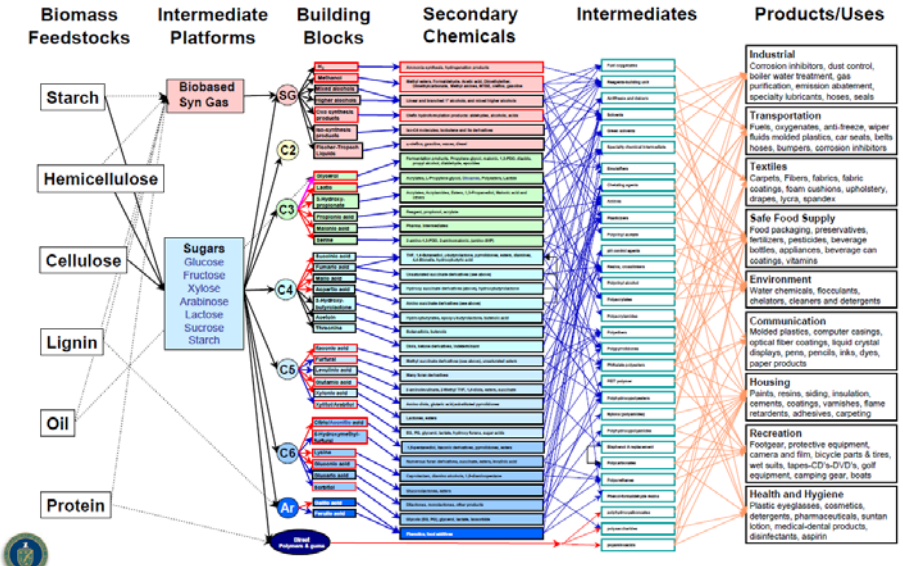
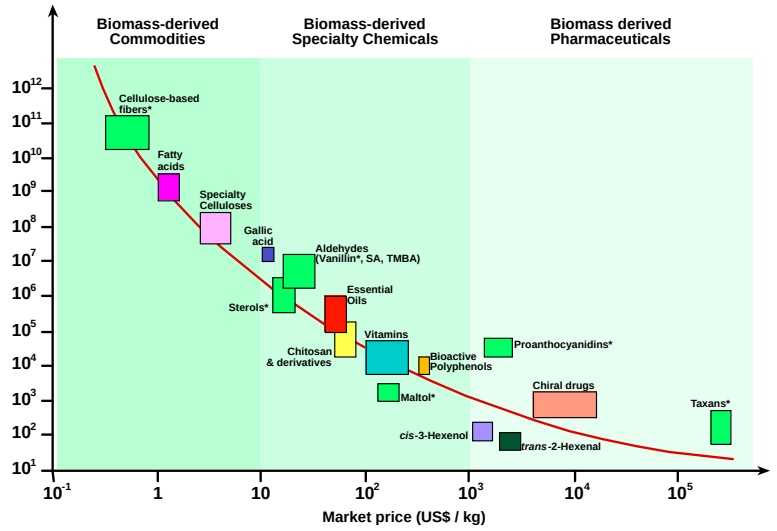



Figure 3 – Analogous Model of a Biobased Product Flow-chart for Biomass Feedstocks

BC Working Group on Innovation - Sept 18, 2012

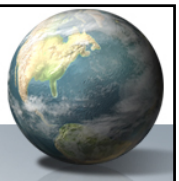
# Diverse Biomass Derived Product Options

**Market size / price for co-products derived from biomass**




Source: "Thermochemical Strategies for Biofuels, Green Chemicals, Polymeric Biomaterials and Biofuels", Esteban Chornet, November 2005.

# Future bio-products



- All consumer products, including fuels, chemicals, materials, plastics, etc. can be made from forest bio-mass!
- We will learn about the exciting new bio-products through student projects / presentations
- Project
  - Work in a group of 2-3 people
  - Choose a new bio-product that can be made from forest materials (example, carbon fibre car parts …)
  - Develop a short video presentation that covers (5-7 minutes):
    - The process of going from tree to bio-product
    - The properties of the material
    - The estimated environmental impact (benefit).
    - An economic review
    - Marks awarded for interesting / artistic / entertainment value.
  - We will review all projects during class and videos will be graded by your classmates.
  - Due (March 22nd)

It carries your thoughts, your dreams and your coffee.

Few things in life are as versatile, practical and reliable as paper. It's no wonder we can't live a day without using paper products.

**It's renewable:** Paper is not only recyclable, it is also made from a renewable and natural resource — trees. Trees not only serve as the primary source for paper, but they also provide wildlife habitat and other environmental benefits.

**It's versatile:** From the thinnest tissue, to the most absorbent diaper, to the toughest corrugated box, there are almost as many different kinds of paper as there are uses for it.

**It's comforting:** From facial tissue and paper towels, to the morning newspaper, to the carton that holds your orange juice and the paperboard packaging that holds your breakfast cereal, most of us begin each day enjoying the comforts of paper products.

**It's educational:** From kindergarten drawings to high school textbooks, paper carries the concepts our children learn and the lessons our teachers teach.

**It's dependable:** At work, office papers help us communicate. Even in this digital age, and despite talk about the "paperless office," office papers are essential for copiers, laser printers, brochures, notepads and other uses. And since digital documents can be deleted, there's nothing like having a back-up on paper.

**It's memorable:** Paper records our first footprints in this world and every milestone along the way. It captures our joys and sorrows, our past and present, our thoughts and ideas.

**Paper:** Renewable and versatile, comforting and educational, dependable and memorable, paper is the everyday wonder.

# Thank You !