What are the primary environmental issues concerning the forest and paper industry?

1. Sustainability of forest resources: trees + habitats + species + water

2. Clean paper making: transportation to and from paper mill energy consumption water usage bleaching and other chemicals

3. Paper consumption: Can it be reduced?

4. Recycling of used paper and cardboard energy, chemicals recycling vs. incineration

5. Alternatives to wood for paper? Alternatives to paper itself?
Paper is a commodity:
  low design, near impossibility of changing the product itself
  huge amounts → huge impact nonetheless

Paper accounts for 2.5% of industrial production
  2.0% of world trade

Paper consumption is related to population
  and to wealth
So, we consume more paper than others. Why?

Hint: Paper consumption is highly correlated with wealth.

Source: Earth Trends, 2005 data
For a wide range of countries

GDP and Paper Consumption per Capita in Selected Countries, 2005

Zoom on the less wealthy countries (bottom left of previous plot)

GDP and Paper Consumption per Capita in Low and Middle Income Countries, 2005
Look at historical data:
GNP is about the only factor affecting paper consumption.

Think of making useful by-products along the way.

http://www.agenda2020.org/Tech/Biorefinery/iFPB_research.htm
1. Forest logging

A tree = 25% branches and bark
75% trunk wood → logs

Wood log = 27% lignin (glue)
73% fiber (what goes into paper)

Every tree requires
130 gallons (490 L) of water for growth
50 gallons (189 L) of water for processing into paper

The production of 1 metric ton of paper requires
17 trees (in average)
24 trees for white office paper, 12 trees for newsprint
25 m³ of water
10,061 kWh of electricity
680 gallons (2.57 m³) of oil
1 ton of uncoated virgin (non-recycled) printing and office paper uses 24 trees
1 ton of 100% virgin (non-recycled) newsprint uses 12 trees

A “pallet” of copier paper (20-lb. sheet weight) contains 40 cartons and weighs 1 ton.

Therefore,

1 carton (10 reams) of 100% virgin copier paper uses 0.6 trees.
1 tree makes 16.67 reams of copy paper or 8,333 sheets.
1 ream (500 sheets) uses 6% of a tree.
1 ton of coated, higher-end virgin magazine paper (as used for high-end magazines) uses a little more than 15 trees (15.36)
1 ton of coated, lower-end virgin magazine paper (used for newsmagazines and most catalogs) uses nearly 8 trees (7.68)

(Source: http://www.conservatree.com/learn/EnviroIssues/TreeStats.shtml)

---

**Basic rule:**

Trees cut + trees lost to forest fires and diseases < trees reaching maturity (on annual basis)

**But …**

- Mind soil erosion
- Mind habitats
- Mind aesthetics

In other words, cut in an environmentally conscious way.

- Balance the various forest resources:
  - Lumber and firewood
  - Paper
  - Recreation
The Sustainable Forestry Initiative® (SFI) Program

On October 14, 1994, members of the American Forest & Paper Association agreed to adhere to a set of forestry principles that would meet the needs of the present without compromising the ability of future generations to meet their own needs. These principles call for a land stewardship ethic which integrates the reforestation, nurturing, and harvesting of trees for useful products with the conservation of soil, air and water resources, wildlife and fish habitat, and forest aesthetics.

Check out SFI’s Forest Art Television Advertisements

![Image](http://www.rurdev.usda.gov/rts/pub/jan00/trees.htm)


The most environmentally conscious form of logging is with draft horses, especially when a snow cover is present.
From logs to chips

Some brute force is applied...

= energy consumption

From chips to pulp

Here, the process is chemical

The purpose of this step is to remove the lignin (= glue) that holds the wood fibers together. The product is loose fiber in water, called pulp.

Fig. 6-3. A representative pressurized acid system for absorbing $SO_2$ gases. The flash vapors are absorbed in stages, first by the high pressure tank (accumulator); and as the digester is depressurized, by the low pressure tank.
Pulping

From used chemicals to new chemicals

COOKING & WASHING

BLACK LIQUOR
- Alkali Lignin
- Metabolism Solts
- Sulphonation Products

WHITE LIQUOR
NaOH
Na₂S

GREEN LIQUOR
Na₂CO₃
Na₂S

EVAPORATION & BURNING
Water
Heat
New or Reused Chemicals

CAUSTICIZING
CaCO₃
CaO

Fig. 7-1. The kraft liquor cycle.

Various bleaching technologies

Estimates of 1994 Bleached Kraft Pulp Production

Traditional ECF
Enhanced ECF
Traditional pulping and bleaching 43% using chlorine (Cl₂)

Ozone ECF
TOF

ECF = Elemental Chlorine Free
( use of ClO₂ instead of Cl₂)
TCF = Total Chlorine Free

Total Production = 37.1 million metric tons
ECF = Elemental Chlorine Free (substitution of Cl₂ by chloride dioxide ClO₂)
TCF = Total Chlorine Free (no Cl in whatever form, use of O₃ and H₂O₂ instead)

The ECF vs TCF debate:

<table>
<thead>
<tr>
<th>PRO-ECF</th>
<th>PRO-TCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>- ClO₂ gives better bleaching</td>
<td>- TCF technology exists</td>
</tr>
<tr>
<td>- ECF fibers are stronger</td>
<td>- Easier to start/stop facility</td>
</tr>
<tr>
<td>- Water loop can be closed</td>
<td>- Cl builds in closed loops</td>
</tr>
<tr>
<td>- Efficiency of H₂O₂ is not great</td>
<td>(\rightarrow) corrosion (\rightarrow) leaks</td>
</tr>
</tbody>
</table>

**ENVIRONMENT**
- ECF is good enough*
  - Anti-Cl position is like a religion
  - Stronger fibers
  \(\rightarrow\) fewer trees & more recycling
  - ECF generates no dioxin in practice
- TCF = only guarantee against release of Cl compounds
  - Easier to filtrate effluents
  - Theoretical possibility of producing dioxin from ECF

**MARKET**
- Weaker paper from TCF
- Low demand for TCF in USA
- European demand may not last
- Strong European demand for TCF paper

**ECONOMICS**
- Too costly to retrofit an existing plant from ECF to TCF
- Higher production costs with TCF incl. cutting more trees
- Not more expensive to go TCF when building a new facility

* with primary and secondary treatment of wastewater

---

**A technical solution for an ECF mill with closed water system**

---

---

---
First off: Is it better to recycle than to incinerate or landfill?

- **Recycling** → re-use of fibers but energy spent in transportation and remanufacture

- **Incineration** → Getting energy without much transportation
  Energy produced displaces fossil-fuel energy
  but cascading not as good as recycling, in principle
  Also: air emissions!

- **Landfilling** → Least effort but methane emissions during decomposition

In general, landfill is least preferable, and there are conflicting opinions regarding incineration versus recycling.

In most cases, recycling results in lower total energy cost but with a greater fraction coming from fossil fuel.
Recycled versus virgin paper:

Producing recycled paper involves between 28–70% less energy consumption than virgin paper and uses less water. This is because most of the energy used in papermaking is the pulping needed to turn wood into paper.

Recycled paper produces fewer polluting emissions to air (95% of air pollution) and water.

Recycled paper is not usually re-bleached and where it is, oxygen rather than chlorine is usually used. This reduces the amount of chlorinated compounds which are released into the environment as a by-product of the chlorine bleaching processes.
An additional reason to recycle paper:
There is a lot of it in your garbage, and it adds to landfill volume.
Basic issues faced in paper/cardboard recycling:

- Collection & Sorting
- Transportation to sorting/recycling center
- Recycling process itself: de-inking, loss in fiber strength, hazardous chemicals
- Marketing of recycled paper
Challenges in collection and sorting:

- Impossibility to capture all forms of paper used by consumers
  - Hygienic paper, waxed paper are not recyclable
  - Harder to collect from individuals than from companies

- What is captured ought to be sorted in grade categories
  - P&W = printing and writing (white office paper)
  - OCC = old corrugated cardboard
  - ONP = old newspapers
  - Mixed paper

- White office paper has the highest grade for recycling but is relatively hard to collect. More diffuse. Office hang on to documents. Often mixed with magazines, which has the lowest grade (glossy, colors).

- Old newspapers are also relatively easy to capture because people pile them up at home.

- Collection of corrugated cardboard boxes is relatively easy in back of retail stores such as Walmart.

When de-inking does not need to be done
If de-inking is involved:

(http://www.biomatnet.org/secure/Fair/S502.htm)

Those handy Post-It ®

ISSUE FOCUS: PAPERMAKING

Esterase-type Enzymes Offer Recycled Mills
An Alternative Approach to Stickies Control

http://www.biomatnet.org/secure/Fair/S502.htm
Progress is being made with recovery of paper for recycling.

<table>
<thead>
<tr>
<th>Year</th>
<th>Supply (600 tons)</th>
<th>Recovered (600 tons)</th>
<th>Recovery Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>31,538</td>
<td>35,460</td>
<td>38.70%</td>
</tr>
<tr>
<td>1994</td>
<td>96,170</td>
<td>39,691</td>
<td>44.60%</td>
</tr>
<tr>
<td>1995</td>
<td>55,971</td>
<td>42,109</td>
<td>74.00%</td>
</tr>
<tr>
<td>1996</td>
<td>45,529</td>
<td>41,075</td>
<td>45.00%</td>
</tr>
<tr>
<td>1997</td>
<td>40,957</td>
<td>42,088</td>
<td>44.00%</td>
</tr>
<tr>
<td>1998</td>
<td>101,163</td>
<td>45,076</td>
<td>45.00%</td>
</tr>
<tr>
<td>1999</td>
<td>105,310</td>
<td>49,618</td>
<td>44.00%</td>
</tr>
<tr>
<td>2000</td>
<td>102,810</td>
<td>47,311</td>
<td>46.00%</td>
</tr>
<tr>
<td>2001</td>
<td>97,565</td>
<td>45,665</td>
<td>46.00%</td>
</tr>
<tr>
<td>2002</td>
<td>89,849</td>
<td>47,646</td>
<td>48.00%</td>
</tr>
<tr>
<td>2003</td>
<td>88,016</td>
<td>45,256</td>
<td>50.30%</td>
</tr>
<tr>
<td>2004</td>
<td>101,082</td>
<td>50,287</td>
<td>49.90%</td>
</tr>
<tr>
<td>2005</td>
<td>99,013</td>
<td>61,272</td>
<td>61.5%</td>
</tr>
<tr>
<td>2006</td>
<td>103,665</td>
<td>63,314</td>
<td>59.0%</td>
</tr>
<tr>
<td>2007</td>
<td>96,751</td>
<td>52,727</td>
<td>54.1%</td>
</tr>
</tbody>
</table>

For reference:
- The American Forest & Paper Association had set a recycling target of 55% for 2012. We take satisfaction in noting that this target was reached and exceeded in 2007!
- The recycling rate in Europe was 56.3% in 2006.

The theoretical maximum recycling rate for paper is 81% rather than 100% on account of paper that cannot be recycled, such as archives and libraries, and papers used in construction materials. (eubusiness.com)

Same data displayed graphically

Total U.S. paper recovery reached a record high 64.3 million tons this year, up 6% relative to 1990 and 1.9% over 2006. The 64.3 million tons works out to 396 pounds for each person living in the U.S.

Footnote:
1. "Supply" includes consumption of all paper, corrugated and paperboard, including construction paper and board.
2. "Recovery Rate" is the ratio of total paper, corrugated and paperboard recovered to supply.

Source: http://stats.paperrecycles.org/
Corrugated cardboard boxes:

Generated waste: 29.7 million tons or 12.6% per weight in municipal solid waste (MSW) equivalent to 204.2 lbs. per person
33 million tons total in 2004

Recycled: 21.2 million tons (71.3%) in 2005 (up from about 50% in 1990)

Recycled content in new boxes: Generally less than 40%

Incinerated or landfilled: 8.5 million tons (5.2%).

(Waste Age, January 2006, page 54)

Industrial Ecology applied to the forest and paper industry

A dischargefree pulp and paper mill in an ecologically balanced cycle
Paper alternatives:

The only requirement: Paper must be made from a fibrous material.

Fibers can be found in biomass other than wood. For example:

KENAF - Kenaf is a plant originating from Africa and is a member of the hibiscus family, currently being tested as an alternative to cutting trees. It can grow up to 12-14 feet in as little as 4 to 5 months. U.S. Department of Agriculture studies show that kenaf yields of 6 to 10 tons of dry fiber per acre per year are generally 3 to 5 times greater than the yield for Southern pine trees. Because kenaf is grown for the fibrous stalk, and not the fruit or flower of the plant, insecticides are not required.

HEMP - Industrial hemp is illegal in the United States, although it contains far less THC than marijuana. Hemp can produce 10 tons per acre in 4 months and can be grown in a variety of climates. The plant resists diseases and shades out weeds so the use of chemicals is not required during cultivation. Additionally, hemp paper can be recycled 7 times versus 3 times for wood pulp paper. It can also serve as an alternative for edible oil, automotive oil, cooking and heating fuel, fabric, medicine and construction beams.

COTTON - Cotton is the world’s most widely used natural textile fiber, grown in over 70 countries and meeting nearly half of our clothing needs. About 35% percent of the cotton plant is used for fiber. The rest—seeds and gin trash—go into the food chain, either as industrially processed cooking oil or animal feed. Unfortunately conventional cotton farming is extremely chemical-intensive. According to the California-based Sustainable Cotton Project, in the United States, nearly a third of a pound of chemical fertilizers and pesticides is required to produce the pound of fiber that goes into a T-shirt.
OTHER - Many of the fibers left from plants we already grow for food go to waste after harvest, including rice, wheat, sugar cane and coffee.

In the United States alone, an estimated 150 million tons of straw goes underutilized each year. Much of this waste is burned, only aggravating air pollution. Instead, these remainders can easily and economically be turned into paper.

Scrap material such as the leftovers from the manufacturing of denim jeans, or old money can also create tough and beautiful paper products.

Source: http://www.lucidskies.com/paper.html

Rice paper manufacturing

From perspective of priorities:

Avoidance is Top Priority.

Hence, efforts should be made to go paperless wherever and whenever we can:

- Perform banking and other service transactions by internet
- Communicate by email instead of regular mail
- Marketing on screen instead of brochures, magazines and packages
- Get used to reading on screen
- Get news from sources other than conventional newspapers
- Archive on CDs, not books and reports
  Electronic libraries
- etc.
Substitution as avoidance: The issue of "paper vs. plastic"

Paper bag vs. plastic bag at grocery store
Paper cup vs. polystyrene cup

In each case, the life-cycle analysis shows that the non-paper choice is the better choice.

Paper bag vs. plastic bag → http://techactive.mtu.edu/meec/module14/title.htm

Paper cup vs. styrofoam™ cup → Study by Martin B. Hocking (1991)
"Relative merits of polystyrene foam cup and paper in hot drink cups: Implications for packaging"

---

### Table—Raw material, utility, and environmental summary for hot drink containers.

<table>
<thead>
<tr>
<th>Item</th>
<th>Paper cup*</th>
<th>Polystyrene cup*</th>
</tr>
</thead>
<tbody>
<tr>
<td>For cup:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw materials:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood and bark</td>
<td>25 to 27 g</td>
<td>0 g</td>
</tr>
<tr>
<td>Petroleum fractions</td>
<td>1.5 to 2.5 g</td>
<td>2.4 g</td>
</tr>
<tr>
<td>Other chemicals</td>
<td>1.1 to 1.7 g</td>
<td>0.97 to 0.12 g</td>
</tr>
<tr>
<td>Finished weight</td>
<td>10.1 g</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Per metric ton of material:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steam</td>
<td>9000 to 13,000 kg</td>
<td>5,500 to 7,000 kg</td>
</tr>
<tr>
<td>Cooling water</td>
<td>190 kWh</td>
<td>260 to 300 kWh</td>
</tr>
<tr>
<td>Water effluent</td>
<td>30 m³</td>
<td>1.3 to 1.6 m³</td>
</tr>
<tr>
<td>Volume</td>
<td>50 to 190 m³</td>
<td>1 to 4 m³</td>
</tr>
<tr>
<td>Suspended solids</td>
<td>4 to 16 kg</td>
<td>0.4 to 0.6 kg</td>
</tr>
<tr>
<td>BOD</td>
<td>2 to 20 kg</td>
<td>0.2 kg</td>
</tr>
<tr>
<td>Organochlorines</td>
<td>2 to 4 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>Ashed solids</td>
<td>40 to 85 kg</td>
<td>10 to 20 kg</td>
</tr>
<tr>
<td>Air emissions:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.2 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>0.2 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>Reduced sulfides</td>
<td>1 to 2 kg</td>
<td>0 kg</td>
</tr>
<tr>
<td>Phenolates</td>
<td>1 to 3 kg</td>
<td>0.3 to 0.5 kg</td>
</tr>
<tr>
<td>Chloroform compounds</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Pentanes</td>
<td>0 kg</td>
<td>35 to 50 kg</td>
</tr>
<tr>
<td>Sulfur dioxide</td>
<td>~16 kg</td>
<td>3 to 4 kg</td>
</tr>
<tr>
<td>Recycled potential:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>For primary years</td>
<td>Possible, washing can destroy.</td>
<td>Every, negligible water uptake.</td>
</tr>
<tr>
<td>After use</td>
<td>Possible, Hot melt adhesive or coating difficulties.</td>
<td>Good, Rare reuse in other applications.</td>
</tr>
<tr>
<td>Ultimate disposal:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proper incineration</td>
<td>Clean</td>
<td>Clean</td>
</tr>
<tr>
<td>Heat recovery</td>
<td>20 MJ/kg</td>
<td>40 MJ/kg</td>
</tr>
<tr>
<td>Mass to benefit</td>
<td>10.1 g</td>
<td>1.5 g</td>
</tr>
<tr>
<td>Resting modifiable</td>
<td>Yes, BOD to leachate, non-bio to air.</td>
<td>No, Essentially inert.</td>
</tr>
</tbody>
</table>

(Martin B. Hocking, 1991)
Energy per use of each reusable cup (black lines) declines as it is used more times. The energy per use of each disposable cup (green lines) is a constant equal to the manufacturing energy, since it is used only once and is never washed. The numbers in the labels are the manufacturing energies for the different cups.