FOREST AND PAPER INDUSTRY

A mature industry that has done much to clean up its act.

http://individual.utoronto.ca/abdel_rahman/paper/fpmp.html
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.
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.


So, roughly, paper consumption is occurring according to:

\[
\frac{70 \text{ metric tons}}{\$1 \text{ million of GNP}} = 70 \text{ grams/\$}
\]

With a footprint of 1.15 kg of CO$_2$ per kg of paper produced,

\[
\frac{0.070 \text{ kg of paper}}{\$1} \times \frac{1.15 \text{ kg of CO}_2}{\text{kg of paper}} = 80.5 \text{ g of CO}_2/\$
\]
“Around 80% off all products sold in United States and the European Union are packaged in cardboard.”

“In the United States, 850 million tonnes of **paper and cardboard** are thrown away annually.

This equates to around 1.4 billion trees, a terrifyingly high number.

To put this into further perspective, the average American uses around 3.6 trees per year in **paper and cardboard**.”

… more

---

A few numbers from  
*How Bad Are Bananas? The Carbon Footprint of Everything*  
by Mike Berners-Lee, GreyStone Books, 2011

<table>
<thead>
<tr>
<th>Item</th>
<th>Carbon footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown grocery bag</td>
<td>12 g CO₂e</td>
</tr>
<tr>
<td>Fancy paper bag from department store</td>
<td>80 g CO₂e</td>
</tr>
<tr>
<td>Paperback book on recycled paper*</td>
<td>400 g CO₂e</td>
</tr>
<tr>
<td>Book on thick virgin paper**</td>
<td>2 kg CO₂e</td>
</tr>
<tr>
<td>Daily newspaper on recycled paper</td>
<td>0.3-0.8 kg CO₂e</td>
</tr>
<tr>
<td>NYT Sunday paper, recycled afterwards</td>
<td>1.5 kg CO₂e</td>
</tr>
<tr>
<td>Roll of toilet paper (recycled/new paper)***</td>
<td>450/730 g CO₂e</td>
</tr>
</tbody>
</table>

* Assuming all printed copies are sold  
** Assuming half printed copies are pulped  
*** Amounting to 75 kg/person in US
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.
The average is 17 trees per metric ton of paper.

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 15.4 trees.
1 ton of coated, lower-end virgin magazine paper (used for newsmagazines and most catalogs) uses 7.68 trees.

(Source: Cushman-Roisin & Tanaka Cremonini, Useful Numbers, Elsevier 2021)
In brief,

Tree trunks = wood
Wood = Fibers + Lignin (glue)
Pulp = Loose fibers in water
Paper = dried pulp in sheet form

The longer the fibers, the stronger the paper.
Recycling shortens the average length of fibers.
1. Forest logging

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

16 to 20 mature trees per acre

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
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

Dartmouth College does a great job balancing these several objectives in its Second Grant Land in northern New Hampshire.

---

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

(15 seconds)  (30 seconds)
The most environmentally conscious form of logging is
- with draft horses,
- especially when a snow cover is present.

2. Papermaking

![Papermaking process diagram]
From logs to chips

Some brute force is applied…

= energy consumption

Hydropower at the rescue
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 SO₂ 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

Fig. 7-1. The kraft liquor cycle.
Various bleaching technologies

<table>
<thead>
<tr>
<th>Year</th>
<th>ECF</th>
<th>TCF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>1995</td>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>2000</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>2005</td>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

- ECF bleaching substantially reduces but does not fully eliminate chlorinated organic compounds, including dioxins, from the effluent.
- TCF bleaching, by removing chlorine entirely from the process, eliminates chlorinated organic compounds in the effluent.

**ECF = Elemental Chlorine Free**
(Use of ClO2 instead of Cl2)

**TCF = Total Chlorine Free**
(Incl. ozone)

**The ECF vs TCF debate:**

<table>
<thead>
<tr>
<th>Arguments pro-ECF or against TCF</th>
<th>Arguments pro-TCF or against ECF</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECHNOLOGY</td>
<td></td>
</tr>
<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 → corrosion → leaks</td>
</tr>
<tr>
<td>- Efficiency of H2O2 is not great</td>
<td></td>
</tr>
<tr>
<td>ENVIRONMENT</td>
<td></td>
</tr>
<tr>
<td>- ECF is good enough*</td>
<td>- TCF = only guarantee against release of Cl compounds</td>
</tr>
<tr>
<td>- Anti-Cl position is like a religion</td>
<td>- Easier to filtrate effluents</td>
</tr>
<tr>
<td>- Stronger fibers</td>
<td>- Theoretical possibility of producing dioxin from ECF</td>
</tr>
<tr>
<td>→ fewer trees &amp; more recycling</td>
<td></td>
</tr>
<tr>
<td>- ECF generates no dioxin in practice</td>
<td></td>
</tr>
<tr>
<td>MARKET</td>
<td></td>
</tr>
<tr>
<td>- Weaker paper from TCF</td>
<td>- Strong European demand for TCF paper</td>
</tr>
<tr>
<td>- Low demand for TCF in USA</td>
<td></td>
</tr>
<tr>
<td>- European demand may not last</td>
<td></td>
</tr>
<tr>
<td>ECONOMICS</td>
<td></td>
</tr>
<tr>
<td>- Too costly to retrofit an existing plant from ECF to TCF</td>
<td>- Not more expensive to go TCF when building a new facility</td>
</tr>
<tr>
<td>- Higher production costs with TCF incl. cutting more trees</td>
<td></td>
</tr>
</tbody>
</table>

* with primary and secondary treatment of wastewater
A technical solution for an ECF mill with closed water system

3. Recycling
First off: Is it better to recycle than to incinerate or landfill?

- Recycling → re-use of fibers but energy spent in transportation and remanufacture fibers get shorter, weaker paper, not for all applications.

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

- Landfilling → Least effort but methane emissions during decomposition

In general, landfill is the least preferable option, 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.

Table 4: Environmental releases under a recycling scenario for newsprint compared with an incineration scenario

<table>
<thead>
<tr>
<th>Study</th>
<th>Total energy</th>
<th>Fossil energy</th>
<th>Net CO₂ equivalents</th>
<th>SO₂</th>
<th>NO₃</th>
<th>BOD</th>
<th>COD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BMMA 1995</td>
<td>H</td>
<td>n/a</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>BAT</td>
<td>L</td>
<td>n/a</td>
<td>H</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Kärna et al. 1992</td>
<td>n/a</td>
<td>n/a</td>
<td>H</td>
<td>H</td>
<td>L</td>
<td>n/a</td>
<td>S</td>
</tr>
<tr>
<td>EDF 1995</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>H</td>
<td>L</td>
</tr>
<tr>
<td>Johnson 1993 a)</td>
<td>L</td>
<td>n/a</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Johnson 1993 b)</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Skanis 1993</td>
<td>L</td>
<td>L</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>IFEU 1993 a)</td>
<td>L</td>
<td>L</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>IFEU 1993 b)</td>
<td>L</td>
<td>L</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

L, H, S: Lower, higher or same emissions under the recycling scenario as compared with an incineration scenario. See IED Substudy no. 14 for details of the scenarios compared and key assumptions of the studies.

L = Lower emissions during recycling than during incineration
S = Same emissions during recycling as during incineration
H = Higher emissions during recycling than during incineration
Recycled versus virgin paper:

Recycling white office paper requires 44% less energy, generates 50% less wastewater, and produces 38% less carbon emissions than virgin paper. This is because most of the impacts in papermaking are in the delignification of wood into pulp. Recycling only needs de-inking before pulping (fibers in 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.

Every ton of paper recycled saves more than 3.3 cubic yards (~3 m³) of landfill space.
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. Offices 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. But they are now a vanishing breed.

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

A previous and now solved issue

Those handy Post-It®
Recycling of paper or cardboard when no de-inking does needs to be done

Total paper recovery in the U.S. exceeded 51 million tons in 2012.
Nearly three times more paper is recycled than is sent to landfills.
By weight, more paper is recovered for recycling from municipal solid waste streams than glass, plastic, steel and aluminum combined.

Source: https://sites.psu.edu/congxuncibblog/2014/03/20/paper-recycling/
Industrial Ecology applied to the forest and paper industry

A discharge free 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.

[Link: http://showcase.netfins.net/web/creativecomposites/FAQs.html]
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 could 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.