TABLE 1.3 U.S. Trade Balance in 1989 (billions of dollars)

Sector	*Import*	*Export*	*Balance*
Chemicals	20	36	+16
Machinery	206	148	−58
Other manufactured goods	139	60	−79
Fuels and petroleum products	53	9	−44

was involved in the manufacture of ethical drugs and pharmaceuticals. This group was closely followed by those workers involved in the manufacture of plastics and synthetic materials. To back up this immensely important part of the economy, the chemical industry (chemicals and allied products) employed about 75,000 scientists and engineers, which is about 10 percent of the total number of scientist and engineers employed by industry in the United States. On an average, the larger chemical companies (top 15 companies in chemical sales) invested approximately 4 percent of their gross sales in research and development activities to support growth and to maintain their market share.

CHARACTERISTICS OF THE CHEMICAL INDUSTRY

Investment Trends

The chemical industry tends to be a high-investment business. Capital spending by the chemical and allied products industry in the United States has been a sizable percentage of the total spent for all manufacturing. Amounts spent in this industry and in certain facets of it are detailed in Table 1.4. The amount spent for all chemical process industries has been, of course, even larger; it totaled $68.9 billion in 1990, for example, a 5.3 percent increase over the amount spent in 1989. For perspective, annual expenditures for new plant and equipment in the United States for the chemical and allied products industry in recent years have averaged about 2.5 times

TABLE 1.4 New Capital Spending in the U.S. Chemical and Allied Products Industry and Comparison with That Spent a Decade Earlier[1]

	Billions of Dollars	
	1986	*1976*
Total chemical and allied products	7.9	7.1
Selected Segments		
Agricultural chemicals	0.52	1.05
Industrial inorganic chemicals	0.81	0.81
Industrial organic chemicals	1.84	2.69
Plastic materials, synthetic resins, and thermoplastic elastomers	1.90	1.37
Soap, detergents, perfumes, cosmetics, and other toilet products	0.74	0.29
Miscellaneous chemicals	0.51	0.32

the amount spent for iron and steel and about half of that invested in the petroleum industry. For the past decade a significant part of these capital investments have been made in pollution control and projects related to the environment.

Much of the capital investment in the chemical industry is spent for facilities used to produce major chemicals (Table 1.4) in truly enormous quantities. The volume produced is reflected in the size of plants being built to achieve the required economies of scale. That such economies are achieved is seen in the more modest increases in the chemical producers' price indices relative to the inflation levels in the general economy. (Economy of scale refers to the relative cost of building a larger plant; a rule of thumb is that the relative cost of building a smaller or a larger plant is the ratio of the productivities of the two plants being considered, raised to the 0.6 power. In other words, the unit cost of producing a chemical markedly decreases as the size of the plant producing it is increased, provided that the plant can be operated near capacity.)

Today, a typical, base petrochemicals plant will consume the equivalent of 30,000 barrels per day of naphtha to produce about one billion pounds of ethylene a year, plus 2.5

Estimates from a recent study by the U.S. Center for Drug Development at Tufts University[2] place the cost of research and development for a new chemical entity at $231 million in 1987 dollars, and the time required to bring a product to market at 12 years. Only five of 4000 compounds screened in preclinical testing survive to human testing, and only 20 percent of these obtain FDA approval.

Although the drug industry involves the application of scientific research and technology to combating disease, it is at the same time a highly successful commercial endeavor. Table 25.3 lists the 25 top-selling branded drugs worldwide, divided into categories and with 1990 estimates of sales figures.

The drug discovery and development process is not only increasingly more costly and more time consuming; its fundamental nature is changing.

In the process that had been standard in the past, the initial "screening" involved evaluation of novel substances prepared by synthetic organic chemists and designed to have the potential for biological activity. These tests, usually in intact animals, were

TABLE 25.3 Top-Selling Branded Drugs Worldwide, with 1990 Estimates of Sales Figures

	Anti-ulcer Agents		*$B*
1	Ranitidine (Glaxo/Sankyo)	H-2 antagonist	2.78
6	Cimetidine (SmithKline Beecham)	—	1.10
22	Famotidine (Merck & Co.)	—	0.50
	Antihypertensives		
2	Nifedipine (Bayer/Takeda & Pfizer)	Ca antagonist	1.95
3	Captopril (Bristol-Myers Squibb)	ACE inhibitor	1.50
4	Enalapril (Merck & Co.)	—	1.48
5	Atenolol (ICI)	Beta blocker	1.13
13	Diltiazem (Marion-Merrell Dow)	Ca antagonist	0.75
	Nonsteroidal Anti-inflammatory Agents		
7	Diclofenac Na (CIBA-GEIGY)		1.04
16	Naproxen (Syntex)		0.69
18	Piroxicam (Pfizer)		0.64
	Antibiotics		
8	Cefaclor (Eli Lilly)	Oral cephalosporin	0.84
9	Ciprofloxacin (Bayer)	Quinolone antibiotic	0.80
14	Clavulanate K (SmithKline Beecham)	Combination antibiotic	0.71
17	Ceftriaxone (Hoffmann-La Roche)	—	0.67
23	Cefotaxime Na (Hoechst-Roussel)	Antibiotic	0.49
24	Amoxicillin (SmithKline Beecham)	Antibacterial	0.44
	Miscellaneous		
10	Albuterol (Glaxo)	Bronchodilator	0.78
11	Fluoxetine (Eli Lilly)	Antidepressant	0.77
12	Lovastatin (Merck & Co.)	Hypolipemic	0.75
15	Acyclovir (Wellcome)	Antiviral	0.70
19	Iopamidol (Schering AG)	Contrast medium	0.60
20	Iohexol (Sterling/Daiichi/Schering AG/Nycomed)	—	0.55
21	Terfenadine (Marion-Merrell Dow)	Anti-allergy	0.52
25	Alprazolam (UpJohn)	Anxiolytic	0.44

*Barclays de Zoete Wedd, "Pharmaceutical Industry Perspectives."[3]

application would be to use these types of enzymes for removal of lignin pollutants from waste effluents. Biotechnology should lead to safer and cleaner methods for pulping and bleaching.

Recycling

Worldwide, approximately 32 percent of wastepaper (73 million tons) is recycled. However, the rate of recycling varies considerably between countries, as shown in Fig. 7.16. The United States is a major exporter of wastepaper—over 4 million metric tons in 1990. The majority of the wastepaper exported goes to "fiber-poor" countries that have much less virgin fiber than does the United States and therefore recycle much greater quantities of paper.[5]

A variety of problems are associated with paper recycling, such as collection, distribution, and wild cyclic swings in the market. However, with landfill sites now at a premium and paper representing about 40 percent of municipal solid waste, it makes good sense in the long run to promote paper recycling, which reduces landfill needs and the consumption of virgin timber. The U.S. paper industry has set the goal of a 40 percent wastepaper collection rate by the year 1995. This means that large volumes of wastepaper will be available for reuse in the future.

There are a wide range of different grades of wastepaper available, depending on the source and the extent of separation. As the name implies, wastepaper designated as "direct pulp substitutes" is utilized with little treatment before reslushing in a hydrapulper. The direct pulp substitutes are the highest grade of wastepaper.

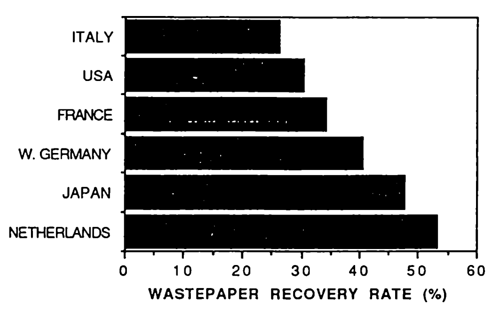

Fig. 7.16. Comparison of paper recycling in selected countries.

The majority of recycled paper (about 75%) is used with no attempt to remove inks, dyes, or pigments from the paper. The resultant pulp is of rather poor color and quality, and is used primarily as filler stock in paperboard. The bulk grades are the largest-volume wastepaper source.

Deinked grades of wastepaper require special techniques and equipment to remove inks, coatings, adhesives, and so on. The deinking process is complicated and time-consuming; depending on the quality of deinked pulp required, the process may involve a number of combinations of washing, flotation, dispersion, screening, and use of cyclone cleaners. The newer noncontact inks present special removal problems, as do wet-strength agents, adhesives, and the so-called stickies. Stickies are made from hot-melt adhesives (vinyl acetate polymers and copolymers), pressure-sensitive adhesives (styrene-butadiene), and lattices (natural and synthetic rubber). Tackifiers and waxes also are usually included in these adhesive formulations. A variety of additives are used to help remove stickies and other contaminants from wastepaper, including solvents, nonionic and cationic surfactants, zirconium compounds (to reduce tackiness), and talc. Of course, all of the additional steps and additives add to the expense of recycling. There is also the problem of waste disposal from the deinking process, which must be properly handled. Table 7.7 shows the projected consumption of wastepaper according to paper grade for 1995.[22]

Stock Preparation

Stock preparation in a paper mill includes all intermediate operations between preparation of the pulp and the final papermaking process. It can be subdivided into (1) preparation of the "furnish" and (2) "beating" or "refining." Furnish is the name for the water slurry of of the product depends mainly upon the adhesive and not upon fiber felting as in the case of fiberboards, although the size and shape of the particles influence strength properties. They may be fine slivers, coarse slivers, planar shavings, shreds, or flakes, and they are divided into two main groups: (1) hammer-mill-produced particles (slivers and splinters from solid wood residues, feather-like wisps to block-shaped pieces from planar shavings) and (2) cutter-type particles, sometimes termed "engineered" particles (flakes and shreds). The various steps in particleboard manufacture are illustrated in Fig. 7.21.

Hammer-milled particles usually vary appreciably in size. Dry raw material produces greater amounts of fines than green wood. Cutting machines (either cylinder-type or rotating-disc-type) give more uniform particles, with the length dimension in the direction of the grain of the wood. The thickness, size, and shape of particles influence the strength of the board. Boards made from sawdust have the lowest strength properties, hammer-milled particles give boards of intermediate strength, and solid wood, cut to flakes, gives boards of highest strength. The latter often are referred to as waferboards.

In another relatively new type of particleboard, the manufacturers align long strands of wood at the surface for increased strength in the direction of panel length. This oriented-strand board (OSB) and waferboard replaced a great deal of plywood sheathing in the early 1980s.

Particleboards may be made in a wide range of densities. Low-density or insulating types are a comparatively recent development in Central Europe, whereas the high-density-hardboard types are a U.S. development. Most particleboard production is in the middle-density range.

Particleboards most commonly are used as core stock for veneer in furniture and in doors, as interior panels for walls and ceilings, as subflooring, as sheathing and siding, and as components in interior millwork. The dense types are used in the same way as fiberboard hardboard, described above. Both dense particleboards and hardboards, after receiving a surface coating, may be printed with decorative designs.

Particleboard production has increased rapidly, both in the United States and worldwide, in recent years. Until recently the most significant limitation on the market for particleboard was the availability of inexpensive plywood. Now plywood is no longer inexpensive relative to particleboard, and the cost factor would seem to favor continued growth of the particleboard industry. However, the advent of waferboard and oriented-strand board has slowed this growth. These new entrants into the structural-panel market were first manufactured on a large scale in Canada, and much of the Canadian output was initially exported to the United States. Within the last decade, however, U.S. production capacity has increased from 9.8 million to 241 million square meters, and there is no indication that this rapid rate of growth will slow in the near future. It appears that waferboard and OSB and several new variants will become the major growth markets among

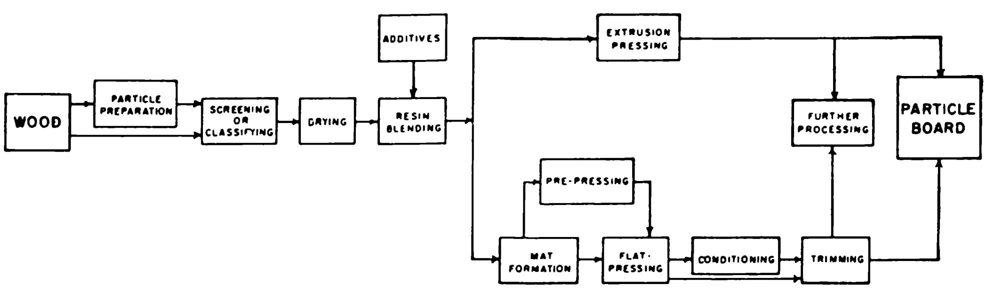

Fig. 7.21. Schematic outline for particleboard manufacture. (*From "Fiberboard and Particleboard," Food and Agricultural Organization of the United Nations, Rome, 1958.*)