POLLUTION AND A BETTER ENVIRONMENT

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Introduction

In many ways, the performance of our economy has been impressive in this decade. The sixties have seen the United States emerge from a period of relatively slow economic growth and soul-searching about its inability to keep up with the growth rates of the Western European countries. The economy's annual increase in Gross National Product of about four percent per year has become one of the highest in the developed world, and man-hour productivity growth of about six percent per year is well above the post-war trend. Productivity gain has been particularly impressive in the manufacturing and agricultural sectors, and prices of goods have been falling relative to services, thus making food, energy, and material goods more and more copiously available to the population. These developments would seem to be good reasons for euphoria and in many ways they certainly are.

There is a dark lining on this silver cloud, however. The vast increase in manufacturing activity and output and the rapidly rising conversion of fossil fuels to energy has imposed an ever-increasing burden of waste residuals on the environment. In fact, the total weight of residuals discharged to the environment tends to rise *pari passu* with the increase in manufacturing activity and energy conversion unless there are gains in the technical efficiency of converting inputs to useful outputs or the recycle of used goods is increased.

Throughout most of our history, the discharge of residuals to air, water, and the land was of concern only in particular and unusual instances, if at all. Granted some of these instances were spectacular, such as the smoke in Pittsburgh early in this century. But overall, we were endowed with immense space and vast flows of water which could dilute and assimilate residuals with little damage to the natural environment. This was fortunate because the air and water are "common property" resources with respect to which the private market, on which we have relied so heavily to allocate resources to their most valuable uses, cannot function. In recent years, the naturally available assimilative

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capacity of the natural environment has been rapidly used up and it is becoming more difficult to protect one environmental medium, such as water, without damaging another, such as air. In the past, when pollution control efforts were undertaken, it was often assumed that if a liquid or gaseous waste stream was treated, or solid wastes were burned or hauled off the premises, the pollution problem was solved. In recent years we have gradually come to appreciate that air, water, and solid waste problems are closely interdependent and their analysis and control is best viewed as a systems problem relating to the whole process of residuals generation and control.

The Overall Residuals Problem

To clarify and illustrate these points, it is useful to view the residuals problem initially as a materials balance problem for the entire economy. A highly simplified schematic of how the goods and residuals production process works is shown in Chart I. The inputs to the system are fuels, foods, and raw materials which are partly converted into final goods and partly become waste residuals. Except for increases in inventory, final goods also ultimately enter the waste stream. Thus, goods which are "consumed" really only render certain services. Their material substance remains in existence and must either be reused or discharged to the ambient environment.

In an economy which is closed (no imports or exports) and where there is no net accumulation of stocks (plant, equipment, inventories, consumer durables, or residential buildings), the amount of residuals which is inserted into the natural environment must be approximately equal to the weight of basic fuels, food, and raw materials entering the processing and production system, plus oxygen taken from the atmosphere. This result, while obvious upon reflection, leads to the, at first rather surprising, corollary that residuals disposal — in terms of sheer tonnage — is an even larger operation than basic materials production.

In an open (regional or national) economy it would be necessary to add flows representing imports and exports. Similarly, in an economy undergoing stock or capital accumulation the production of residuals in any given year would be less by that amount than the basic inputs. In the entire United States, economy accumulation accounts for about ten to fifteen percent of basic annual inputs,[1] and there is some net importation of raw and partially processed materials amounting to four or five percent of domestic production. Table 1 shows estimates of the weight of raw material produced in the United States in several recent years, plus net imports of raw and partially processed materials.

[1] Mostly in the form of construction materials.

Chart I.---Materials Flow

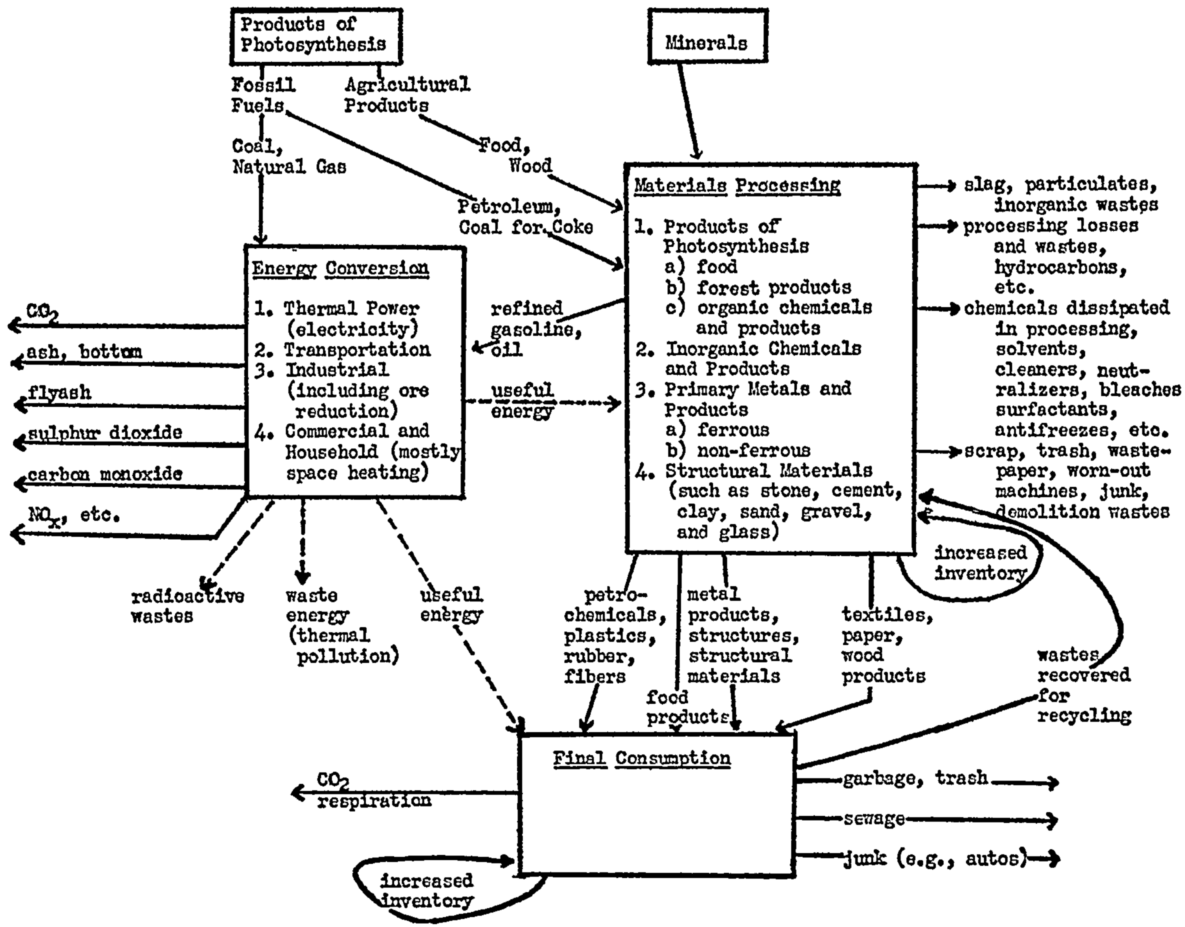

Table 1

Weight of Basic Materials Production in the United States plus Net Imports, 1963

(10^6 tons)

	1963		1964		1965	
Agricultural (incl. Fishery and Wildlife and Forest Products)						
Food: Crops (excl. livestock feed)	125		128		130	
Food: Livestock	100		103		102	
Other Products	5		6		6	
Fishery	3		3		3	
Forestry Products (85% dry wt. basis)						
Sawlogs	53		55		56	
Pulpwood	107		116		120	
Other	41		41		42	
Total		434		452		459
Mineral Fuels		1,337		1,399		1,448
Other Minerals						
Iron and ferroalloys	204		237		245	
Other metals	161		171		191	
Construction materials	1,579		1,668		1,763	
Other non-metals	125		133		149	
Total		2,069		2,209		2,348
Grand Total		3,840		4,060		4,255
Total "active" materials[2]		2,261		2,392		2,492

Of the "active" inputs,[3] perhaps three-quarters of the overall weight is eventually discharged to the atmosphere as carbon (combined with atmospheric oxygen in the form of CO or CO_2) and hydrogen (combined with atmospheric oxygen as H_2O) under current conditions. This results from combustion of fossil fuels and from animal respiration. Discharge of carbon dioxide can be considered harmless in the short run. There are large "sinks" (in the form of vegetation and large water bodies, mainly the oceans) which re-absorb this gas although there is evidence of

[2] Excluding minerals used for structural purposes, ballasts, fillers, etc. Compiled and inferred from official statistics.

[3] Excluding stone, sand, gravel and other minerals used for structural purposes, ballast, fillers, insulation, etc. We also disregard gangue and mine tailings in this tally.

net accumulation of CO_2 in the atmosphere. Some experts believe that the latter is likely to show a large relative increase — as much as fifty percent — by the end of the century possibly giving rise to significant — and probably, on balance, adverse — weather changes.[4] Thus continued combustion of fossil fuels at a high rate could produce externalities affecting the entire world. The effects associated with most residuals will normally be more confined — usually limited to regional air and water sheds.

The remaining residuals are either gases (like carbon monoxide, nitrogen dioxide, and sulfur dioxide — all potentially harmful even in the short run), or dry solids (like rubbish and scrap) and wet solids (like garbage, sewage, and industrial wastes suspended or dissolved in water). In a sense, the solids are the irreducible limiting form of waste. By the application of appropriate equipment and energy, all undesirable substances can in principle be removed from water and air streams[5] — but what is left must obviously be solid. Looking at the matter in this way clearly reveals a primary interdependence between the various waste streams which, as previously noted, casts into doubt the traditional classification of air, water, and land pollution as individual categories for planning and control policy.

But solid residuals, or for that matter those that remain in a liquid or gaseous state, do not necessarily have to be discharged to the environment. In many instances, it is possible to recycle them back into the productive system. The materials balance view underlines the fact that the total materials throughput necessary to maintain a given level of production and consumption decreases as the technical efficiency of utilization (i.e., recycle of materials) increases. Similarly, the useful lifetime of goods is closely related to the net throughput of the system. The longer cars, buildings, machinery, and other durables last, the fewer new materials are required to compensate for depreciation or sustain a given rate of capital accumulation.

Finally, the more efficient energy conversion processes can be made (in the strict energy conversion or Carnot cycle sense), the fewer waste products there will be for the environment to receive, for a given total energy production. Perfect utilization of carbonaceous fossil fuels would leave only water and carbon dioxide as residuals, while nuclear energy conversion need leave no chemical residuals at all (although thermal pollution and radiation hazards cannot be dismissed).

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[4] *See* Conservation Foundation, Implications of Rising Carbon Dioxide Content of the Atmosphere (1963). There is strong evidence already that discharge of residuals has already affected the climate of individual cities. See Lowry, *The Climate of Cities*, Scientific American, August 1967.

[5] Except CO_2 which may be harmful in the long run, as noted.

Table 2 presents estimates of the amounts of emissions to the atmosphere by type and source. The estimates are based on a materials balance calculation. The roles of transportation — mostly automobiles — and utilities power in the overall emissions picture are striking.

Table 2
Summary of Residuals from Energy Conversion, 1965
(x 10^6 tons)

	Carbon Monoxide CO	Hydro-Carbons NC	Sulfur Dioxide SO_2	Oxides of Nitrogen NO_x	Particulates
Utility Power	1.0	neg	13.6	3.7	2.4
Industry and Household	5	neg	8.4	7.0	7.0
Transportation	135	27	0.4	5.7	0.2
Total	141.0	27	22.4	16.4	9.6

Source: Based on calculations in Robert U. Ayres and Allen V. Kneese, "Environmental Pollution," paper prepared at the request of the Joint Economic Committee of the Congress of the United States.

The residuals problem from the household sector demonstrates the major interdependencies among liquid, solid and gaseous residuals streams. For the average individual there is about one half pound of residuals from food, and three and one half pounds of residuals from other durable[6] and non-durable goods per day. Of this total of approximately four pounds per person per day, about three pounds is combustible. If this seventy-five percent is burned, there will be a large amount of pollutant material introduced into the air; if it is not burned, then water and land disposal systems must be used and the pollutants concentrated in water or land fill. Consider, for example, the disposal of table scraps. They can be incinerated by the housewife, or she can grind them in a garbage disposal and flush them into the sewer, or she can give them to the garbage collector in solid form. This, however, is just the first point of possible alternatives. The sewer water can be treated, the ground scraps extracted and either burned or deposited in land fill. Likewise the solid matter collected can either be burned or buried. Thus in the household as in other sectors, liquid, solid and gaseous waste streams can be traded off for one another to a far-reaching extent.

[6] Not including automobiles.

Given the population, industrial production, and transport services in an economy (a regional rather than a national economy would normally be the relevant one), it is possible to visualize combinations of social policy which could lead to quite different relative burdens placed on the various residuals-receiving environmental media; or, given the possibilities for recycle and less residual-generating production processes, the overall burden to be placed upon the environment as a whole. To take one extreme, a region which went in heavily for electric space heating and wet scrubbing of stack gases (from steam plants and industries) which ground up its garbage and delivered it to the sewers and then discharged the raw sewage to watercourses, would protect its air resources to an unusual extent. But this would come at the sacrifice of placing a heavy residuals load upon water resources. On the other hand, a region which treated municipal and industrial waste water streams to a high level but relied heavily on the incineration of sludges and solid wastes, would protect its water and land resources but at the expense of discharging waste residuals predominantly to the air. Finally, a region which practiced high-level recovery and recycle of waste materials and fostered low-residual production processes to a far-reaching extent in each of the economic sectors might discharge very little residual waste to any of the environmental media.

In the transportation sector — which is the greatest single source of gaseous residuals and also a very significant source of solid wastes — a variety of residuals and cost tradeoffs are also possible. For example, powering automobiles electrically and supplying energy for them from conventional steam plants would tend to greatly reduce carbon monoxide and hydrocarbon emissions to the atmosphere but at the same time would increase shifts from the air to the water and to the land environment. Research progress is being made on the question of the appropriate regions for analysis and control; on providing more accurate and detailed forecasts of economic development and the residuals associated with it; on mathematically modelling the meteorological and hydrological systems which, given a rate of emissions, determine the concentrations of foreign substances and their probabilities and duration; and finally, on the measurement of damages caused by these substances in the environment.

All these tools must be brought together to plan more rational and effective environmental management strategies in our regions. But a reasonably careful review of the level of work in these areas suggests it is not nearly commensurate with the urgency of the problems we confront in creating a better environment.