surement at a level of technological sophistication quite beyond the present level and beyond that proposed for routine monitoring. Access to somebody's monitoring system, or to a few years of ship time, will not suffice to obtain the kind of information the scientist needs about the oceanic velocity field. Some carefully designed measurement programs are going to be needed—on a scale larger than an oceanographic institution can manage but smaller than the space program. To be useful scientifically, these programs will have to give first priority to questions of hydrodynamics. To date there is little indication that they will do so.

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Man's Oxygen Reserves

Claims that this important resource is in danger of serious depletion are not at all valid.

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In almost all grocery lists of man's environmental problems is found an item regarding oxygen supply. Fortunately for mankind, the supply is not vanishing as some have predicted. There are hundreds of other ways that we will hazard the future of our descendants before we make a small dent in our oxygen supply. A few basic facts will make clear why this is the case.

First of all, each square meter of earth surface is covered by 60,000 moles of oxygen gas (*1*). Plants living in both the ocean and on land produce annually about 8 moles of oxygen per square meter of earth surface (*2*). Animals and bacteria destroy virtually all of the products of this photosynthetic activity; hence they devour an amount of oxygen nearly identical to that generated by plants. If we use the rate at which organic carbon enters the sediments of the ocean as a measure of the amount of the photosynthetic product preserved each year we find that it is about 3×10^{-3} mole of carbon per square meter per year (*3*). Thus animals and bacteria are destroying all but 4 parts in 10,000 of the oxygen generated each year. The net annual oxygen production corresponds to about 1 part in 15 million of the oxygen present in the atmosphere. In all likelihood even this small amount of oxygen is being destroyed through the oxidation of the reduced carbon, iron, and sulfur being exposed each year to weathering processes. Thus, in its natural state the oxygen content of our atmosphere is exceedingly well buffered and virtually immune to change on a short time scale (that is, 100 to 1000 years).

Man has recovered altogether about 10^{16} moles of fossil carbon from the earth's sedimentary rocks (*4*). The fuels bearing this carbon have been combusted as a source of energy. The carbon dioxide produced as a by-product of this enterprise is equal in amount to 18 percent of the carbon dioxide contained in our atmosphere (*5*). Roughly 2 moles of atmospheric oxygen was required to liberate each mole of this carbon dioxide from its fossil fuel source. By so doing we have used up only 7 out of every 10,000 oxygen molecules available to us (*6*). If we continue to burn chemical fuels at our currently accelerating rate (5 percent per year), then by the year 2000 we shall have consumed only about 0.2 percent of the available oxygen (20 molecules in every 10,000) (*7*). If we were to burn all known fossil fuel reserves we would use less than 3 percent of the available oxygen. Clearly a general depletion of the atmospheric oxygen supply via the consumption of fossil fuels is not possible in the foreseeable future.

Even in a large urban center oxygen depletion is a second-order problem. For examples, auto exhausts contain about one molecule of carbon monoxide for each ten molecules of carbon dioxide (*8*). Continuous exposure to carbon monoxide contents of 100 parts per million creates serious physiological problems (*9*). If automobiles account for 50 percent of the total oxygen demand in an urban area, carbon monoxide would reach the critical level before the oxygen content of the air had dropped by 2 percent (*10*).

There has been considerable reference to man's alteration of photosynthetic rates and the resulting change in the oxygen content of the atmosphere. From the above it should be clear that the oxygen supply is immune to such changes. The extreme case makes this

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point. What would happen if all photosynthetic activity were to cease and animals and bacteria were to destroy the organic debris in existing living tissue and in the humus stored in soils and the sea? There is roughly 200 moles of carbon per square meter of earth surface available in this form (*11*). Complete oxidation would require only a fraction of 1 percent of atmospheric oxygen. Although changes in the rate of primary photosynthesis are certainly critical to man's food resources, they have no bearing on his oxygen supply.

The situation with regard to our natural waters is quite different. There is no doubt that the high oxygen demand of organic and inorganic material added to our lakes and streams has, in many cases, reduced the standing level of oxygen in these waters below that required by fish and other aerobic organisms. Although the oxygen content of the atmosphere is immutable, the finite invasion rates of this gas into natural waters often cannot meet the high demands generated by man's pollutants. A disproportionate amount of the photosynthetic product is being dumped into these very limited reservoirs.

Were man to dump all his sewage into the deep sea would he endanger the oxygen supply of this vast reservoir? If spread over the entire earth, this reservoir would have a mean depth of about 2500 meters. The oxygen content of this water averages about 2.5 cm^3 at standard temperature and pressure per liter (0.1 $mole/m^3$) (*12*). Hence, for each square meter of earth surface, we have available in the deep sea about 250 moles of oxygen gas. Since the oxygen content of the waters in the deep sea is renewed with a time constant of about 1000 years on a time scale of decades, this reservoir can be considered static (*13*). To gain a feeling for the magnitude of this oxygen reservoir, let us first consider how long the reservoir would last if the entire terrestrial photosynthetic product were dumped each year into the deep sea. The annual oxygen demand of this material would be about 5 $mole/m^2$ of earth surface (*2*). Thus our supply of deep-sea oxygen would last 50 years. If we limit the input to the waste products of 1 billion people, each contributing 100 kilograms of dry organic waste per year, this consumption would use only 0.01 mole of oxygen per square meter of earth surface (*14*). At this rate of usage, the oxygen supply in the deep sea would last 25,000 years.

In conclusion it can be stated with some confidence that the molecular oxygen supply in the atmosphere and in the broad expanse of open ocean are not threatened by man's activities in the foreseeable future. Molecular oxygen is one resource that is virtually unlimited. If man's existence is to be threatened by pollution of the environment he will succumb to some other fate long before his oxygen supply is seriously depleted. We are faced with so many real environmental crises that there is no need to increase the public concern by bringing out bogeymen. Hopefully the popular press will bury the bogeyman it created.

References and Notes

1. The weight of the gas above each square meter of earth surface is about 10^7 g. Of this, 20 percent is O_2. As the molecular weight of O_2 is 32, this corresponds to 6×10^4 moles of O_2 above each square meter.
2. Rates of plant productivity for the ocean have been estimated by studies on ^{14}C uptake. The ocean-wide average is about 6 $mole/m^2$ [see J. D. H. Strickland, in *Chemical Oceanography*, J. P. Riley and G. Skirrow, Eds. (Academic Press, New York, 1965), pp. 478–595]. That for the land is less accurately known but is thought to be about 12 $mole/m^2$ per year [G. E. Hutchinson, in *The Earth as a Planet*, G. P. Kuiper, Ed. (University of Chicago Press, Chicago, 1954), pp. 371–433].
3. Since the final resting place for all detritus formed on the earth's surface is the ocean floor, any organic material which survives oxidation must reach this sink. The average rate of sediment accumulation in the sea is about 1 cm per thousand years [T.-L. Ku, W. S. Broecker, N. Opdyke, *Earth Planet. Sci. Lett.* **4**, 1 (1968)]. Since the dry density of such material averages 0.8 g/cm^3, this corresponds to an accumulation of detritus of 8 g/m^2 per year. The mean for the organic carbon content of this detritus is about 0.5 percent [G. Arrhenius, in *Report of the Swedish Deep-Sea Expedition* No. 5, Goteburg (1952)]. Since the molecular weight of carbon is 12, 3×10^{-3} mole of organic carbon accumulate on each square meter of sea floor each year. About 1.2 moles of oxygen is left behind in the atmosphere for each mole of organic carbon stored in the sediment. Thus the net production of oxygen must be about 3×10^{-3} mole per square meter of *earth* surface each year.
4. R. Revelle and R. Fairbridge, *Geol. Soc. Amer. Mem.* **67**, 239 (1957).
5. Prior to man's use of fossil fuels, the air contained 3×10^{-4} mole of carbon dioxide per mole of air. Since the area of the earth is 5×10^{14} m^2 and since the amount of total gas above each square meter is 3×10^5 mole, the natural carbon dioxide burden of the atmosphere was 5×10^{16} moles.
6. Man-made carbon dioxide amounts to about 20 moles per square meter of earth surface. About 2 moles of oxygen is required to produce each mole of carbon dioxide. Thus of the available 60,000 moles of oxygen above each square meter, only 40 have been consumed.
7. The assumption is made that 4 percent of our total fossil fuel reserves have been consumed.
8. Committee on Chemistry and Public Affairs, American Chemical Society, "Cleaning our environment—the chemical basis for action" (a report by the subcommittee on environmental improvement, 1969), pp. 23–92.
9. H. E. Stokinger and D. L. Coffin, in *Air Pollution*, A. C. Stern, Ed. (Academic Press, New York, 1968), vol. 1, chap. 13.
10. For each 20 moles of carbon dioxide produced in the city about 40 moles of oxygen would disappear and 1 mole of carbon monoxide would appear. The carbon monoxide content of clean air is less than 1 ppm, and the oxygen content is 200,000 ppm. Thus when the carbon monoxide content reaches 100 ppm the oxygen content will have dropped only 4000 ppm (that is, 3 percent).
11. The amount of humus in the sea is about 3×10^{-4} g of organic carbon per liter. Since for each square meter of sea surface there are 4×10^6 liters of sea water, this corresponds to 100 moles of organic carbon per square meter of sea surface. The average terrestrial soil is about 10 cm thick and contains 5 percent of organic carbon (dry weight). Taking the dry density to be 1 g/cm^3 this yields 5000 g (400 moles) of organic carbon per square meter of land surface.
12. H. U. Sverdrup, M. W. Johnson, R. H. Fleming, *The Oceans, Their Physics, Chemistry and General Biology* (Prentice-Hall, Englewood Cliffs, N.J., 1942).
13. W. S. Broecker, in *The Sea*, M. N. Hill, Ed. (Interscience, New York, 1963), vol. 2, pp. 88–108.
14. The carbon content of 100 kg of dry organic matter is about 4000 moles. If the amount of oxygen required to oxidize this material is 1.2 moles per mole of organic carbon, then 5000 moles of oxygen would be required per year by each person. Since the area of the earth is 5×10^{14} m^2, each of the billion people has 5×10^5 m^2. Hence, per square meter, the oxygen demand would be only 1×10^{-2} mole per year.
15. Lamont-Doherty Geological Observatory Contribution No. 1539.