fuel economy and reduced emissions. Since the automobile manufacturers do not necessarily subscribe to these goals, their solution to the emissions problem may not be the best one. Before abandoning the Clean Air Act, however, we should pursue paths the manufacturers apparently have chosen to ignore, such as reduction of weight, elimination of unnecessary accessories, and improvement of the fuel metering (*3*) or the combustion process (*4*), or of the engine itself (*5*). We should also take more of our short trips by bicycle or shanks' mare, since "... half the consumption of gasoline in autos occurs on trips of 3 miles and less" (*6*).

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References and Notes

1. R. E. Train, *Sci. Pub. Aff.* **29**, 43 (November 1973).
2. *Profile of Air Pollution Control in Los Angeles County* (Air Pollution Control District, County of Los Angeles, Los Angeles, Calif., 1971).
3. Various modified carburetors have been made, for example by W. Z. Kendig. See P. Michaels, Glendale [Calif.] *Ledger*, 29 and 30 December 1973, p. 1, sect. 1.
4. Several methods have been suggested; air injection by A. C. Nixon, *Science* **182**, 967 (1973); water injection in the Los Angeles *Times*, 16 February 1974, p. 1, part 2; and the use of alcohol (methanol) as fuel by T. B. Reed and R. M. Lerner, *Science* **182**, 1299 (1973). The Aerospace Corporation, El Segundo, Calif., also is pursuing the last method, which reduces carbon monoxide and lead emissions, allows higher compression ratios, and permits replacement of up to 10 percent of the gasoline with methanol (see *Ind. Res.*, February 1974, p. 42).
5. Honda's new engine, for example; reported, among other places, in *Bus. Week*, 24 February 1973, p. 70.
6. See P. H. Abelson, *Science* **182**, 339 (1973).

Naumann writes that thermal efficiency in automotive engines is incompatible with necessary reductions in nitrogen oxide (NO_x) emissions and concludes that we cannot build efficient engines that can meet pollution standards in urban areas. However, there are already in production automobile engines of high efficiency whose emissions of NO_x are low enough to be compatible with good air quality (*1*) and which have obvious potential for further reduction of NO_x emissions.

Two diesel-powered passenger cars tested by the Environmental Protection Agency (EPA) have shown emissions of hydrocarbons (HC) and carbon monoxide (CO) less than one-half the maximum limits specified by the Clean Air Act of 1970 (*2*) for 1976, with emissions of NO_x less than 1.5 grams per mile (*3*). A slightly modified version of one of the tested cars showed HC and CO emissions of less than one-third the 1976 limits. These cars were not equipped with any auxiliary devices for reduction of emissions. They showed fuel economy in miles per gallon that averaged more than 60 percent higher than the average of 1973 model gasoline-powered cars tested by EPA in the same weight classes (*4*).

The tested cars were not competitive with gasoline-powered cars in acceleration, quietness, or weight of power plant, but these are the kinds of problems that yield to engineering development, and almost no effort has been directed toward the development of a light-duty, lightweight diesel engine for exclusive use in passenger cars (*5*). An adequately powered car with such an engine would operate at a lower average load factor than the underpowered cars tested, and it must be assumed that it would have lower NO_x emissions and somewhat lower economy, because both efficiency and NO_x increase as load factor increases.

The diesel engine is the only alternative to the gasoline engine that is entirely compatible with existing vehicles, transmission components, and production facilities, so a gradual and orderly changeover to diesel-engine production could be accomplished without problems. A study (*6*) of the oil industry's potential for increased production of automotive diesel fuel indicates that the balancing of outputs of gasoline and distillate fuels would not present problems until the passenger-car consumption of diesel fuels was approximately the same as the consumption of gasoline. This would be when the proportion of diesel-powered cars was about 60 percent of the total, which would take at least 7 years even if we were to change over to 100 percent diesel production tomorrow morning. This would leave plenty of time for the development of new fuels, additives, and processes, so that it is hard to predict what the ultimate optimum mix of diesel- and gasoline-powered passenger cars would be.

The diesel and gasoline engines are like Jack Sprat and his wife in their appetites for octane numbers—the gasoline engines can tolerate no low octanes and the diesels can tolerate no high octanes. It is safe to predict, then, that whatever the optimum mix of diesel- and gasoline-powered cars, there should be available enough high-octane clear stock to satisfy the needs of the gasoline-powered cars. This would permit the complete elimination of lead from motor fuels without decreasing the yield of motor fuels from crude oil, and without large investments in additional refining facilities (*7*). If we had 60 percent of our passenger cars powered with diesel engines, we would accomplish a 20 percent saving in our consumption of motor fuel and an even greater saving in our consumption of crude oil, an objective worthy of some effort.

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References and Notes

1. Air Pollution Control Office, Environmental Protection Agency, *Air Quality Criteria for Nitrogen Oxides* (Government Printing Office, Washington, D.C., 1971). Measurement methods of ambient NO_x and transfer coefficients for the computation of emission standards are complex and not yet firmly established. Standards for NO_x are presently being reviewed, and 1.5 grams per mile has been set as an interim standard. Levels of NO_x and oxidants (HC and CO) are to some degree complementary in their effects on air quality, from which it is concluded that, with substantial reductions of oxidant emissions below the original limits, some increase in NO_x can be tolerated.
2. The Clean Air Act of 1970 specifies maximum emission limits of 3.4 grams of CO per mile, 0.41 gram of HC per mile, and 0.4 gram of NO_x per mile, effective 1976 (now 1977).
3. *Exhaust Emissions from Three Diesel-Powered Passenger Cars* (Report 73-19 AW, Emission Control Technology Division, Office of Air and Water Programs, Environmental Protection Agency, Ann Arbor, Mich., 1973).
4. In the 3500-pound inertia-weight class, the fuel consumption was 23.6 miles per gallon for the Mercedes-Benz 220 diesel (the average for gasoline-powered cars tested was 14.0); in the 3000-pound class, the fuel consumption of the Opel Rekord diesel was 23.8 (the average of gasoline-powered cars was 16.2). For a Mercedes diesel with added dampers on the fuel lines, the fuel consumption was 24.6 miles per gallon.
5. In separate unpublished presentations in 1972 to the Advisory Committee for Advanced Automotive Power Systems, Council on Environmental Quality, W. B. Schwab, vice president of engineering for the Cummins Engine Co., and Rex Robinson, director of research for the Caterpillar Tractor Co., two leading independent producers of diesel engines, stated that it is feasible to produce a passenger-car diesel engine that weighs between 4 and 5 pounds per horsepower.
6. "Potential increased production of automotive diesel fuels" (Study Contract 70-68, Refinery Process Division, M. W. Kellogg Co., Houston, Tex., prepared for the Office of Air and Water Programs, Environmental Protection Agency, Washington, D.C., 1972).
7. Panel on Automotive Fuels and Air Pollution, U.S. Department of Commerce, *Automotive Fuels and Air Pollution* (Government Printing Office, Washington, D.C., 1971), pp. 19–22.

Blended Fuels

Gaylord B. Castor (Letters, 22 Feb., p. 698) comments on the use of ethyl alcohol as a substitute for gasoline. Many methods for the use of lower-carbon alcohols as fuels in internal combustion engines have been suggested in the patent and the scientific literature. The letter from William H. Smyers (22 Feb., p. 698) attests to the actual combination of various percentages of alcohol with gasoline for use as fuel in European countries in the early 1930's.

However, use of a fuel composed of a mixture of water-miscible alcohols and gasoline has some drawbacks. If alcohols were added in percentages that would make their blending with gasoline practical, the absorption of moisture by the blend would not only affect the octane number of the mixed fuel, but would have a corrosive effect on the pistons and cylinder walls of modern automobile engines, particularly under the high heat of compression prevalent in such engines.

On the other hand, *n*-butyl alcohol and other higher carbon alcohols that are immiscible with water would be too expensive to use for blending unless new methods of fermentation could be applied to the large-scale manufacture of these alcohols.

Another problem would be the raising of the flash point of the vapor of the mixtures; this would tend to adversely affect the propulsive properties of the exploding gases in the engines. New engines might have to be designed to cope with the changes resulting from the use of blended fuels.

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In response to Castor's letter regarding the possibility of a "cheap, rapid method of hydrolyzing cellulose," we offer the following information.

Any number of methods have been proposed for *direct* or *indirect* utilization of cellulose wastes to produce food, energy, or chemical feedstocks. An indirect method, enzymatic conversion, using the cellulase complex of enzymes to hydrolyze cellulose to soluble sugars has been pioneered at Natick Laboratories (*1*). Glucose produced from waste cellulose can be used to grow yeast, or other single cell protein, to produce fuels, solvents, chemicals, antibiotics, and enzymes by microbial conversion and chemicals and raw materials by chemical conversion. Enzymatic hydrolysis, unlike acid hydrolysis, is selective. Only the cellulose is solubilized, and the crude sugar syrups produced are reasonably free of extraneous substances, reversion compounds, and so forth, and reasonably constant in composition when derived from various sources of waste.

The process as presently conceived consists of three operations. The enzyme is produced in a submerged fermentation with the crude culture filtrate being used as the enzyme solution. Waste cellulose is shredded and milled and, in the third operation, is mixed with the culture filtrate in an enzyme reactor. The cellulose remains as a solid substrate and glucose syrups are withdrawn through a filter. Mutants of the fungus *Trichoderma viride* are used in the fermentation process to produce large quantities of the cellulase enzyme. These strains have been freely distributed to other investigators and are now being used in several other laboratories for saccharification studies.

We hope through continued effort to further develop this cheap rapid method of hydrolyzing cellulose so that some day many of the ideas put forth by Castor will become reality.

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The Dirigible

In the search for long-term energy, pollution, and transportation solutions, the dirigible, revived and modernized, deserves consideration. The advantages of a large buoyant aircraft are many. Being lighter than air, it is borne aloft by the lifting surge of its helium, using propulsive power only to move and maneuver. The airship's energy needs are accordingly low, so low that it lends itself more immediately and practicably to nuclear propulsion than does any other type of aircraft.

The large airship is environmentally attractive: it employs "clean" propulsion techniques. It can also be exceptionally quiet. To take off, it floats skyward. To land, it settles to the ground. Runways are not needed. Only a flat clearing which—ecologists please note—can be an open field. In some cases, using thrust vector control, the craft should be able to hover and winch shipments up and down without landing, an ability with immense implications for the future of air cargo transportation.

A commercial version with a volume of 750,000 cubic meters (four times the volume of the *Hindenburg*) could fly a payload of 270,000 kilograms nonstop at 160 to 200 kilometers per hour between North and South America. Southbound, it might carry automobiles on transporter racks beneath the hull from assembly plants to foreign points. Returning, it could penetrate undeveloped Latin American interiors to airlift out agricultural products, timber, or other resources.

Stable and vibration-free, the dirigible could perform uniquely and usefully as an airborne scientific work platform, its size enabling antennas, data processing facilities, and other equipment to be carried with few constraints imposed by weight or geometry. As a flying oceanographic research ship, it could markedly reduce transit times, overfly and reach ice-blocked regions, and serve as a long-range and long-endurance "mother" to aircraft, environmental buoys, sensor-equipped RPV's (remotely piloted vehicles), survey launches, and research submersibles, all of which it could carry, launch, and recover, employing techniques developed by airships in the 1920's and 1930's.

Modern technology has not been applied to the development of a rigid airship, the type best suited to achieve the performance potential of large dirigibles, for about 35 years. By using materials and engineering techniques as sophisticated as those that went into Saturn 5, Skylab, and the jumbo jets, we should be able to make airships safe and practical. But a survey of aerospace firms has shown that few are inclined to pursue the dirigible concept in any way, a preference to adhere to established product lines being the reason usually given.

The dirigible has much to offer. Since the aerospace firms are apparently not interested, is there some other segment of the American scientific and technological community, not so committed to existing programs, that is willing to take up the challenge?

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