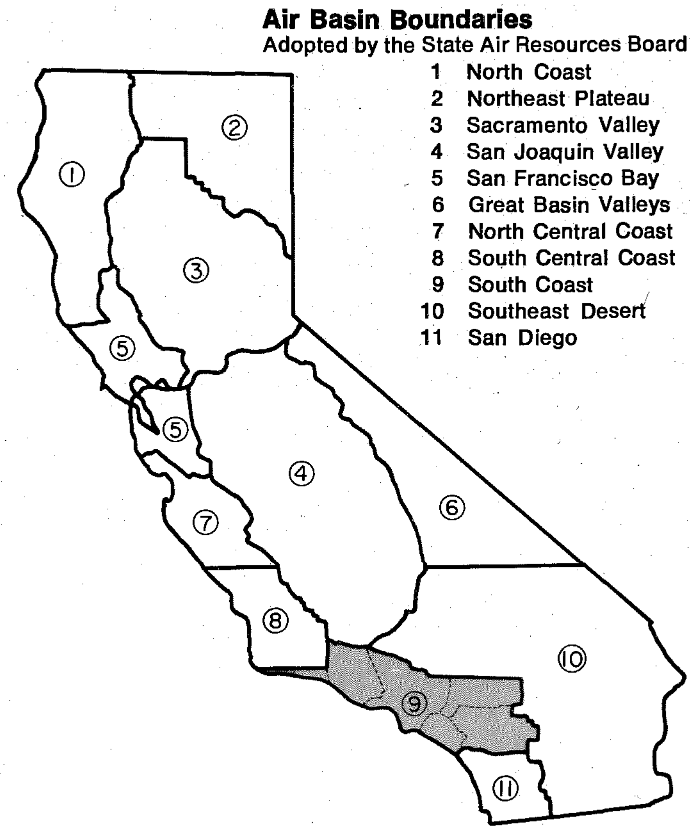
Energy and the Environment in Southern California

By E. J. List

Who's right about our highly publicized energy problems? The conservationists who shout about possible environmental crises caused by energy use, or the energy marketers who complain about energy crises aggravated by excessive environmental concern? Both are in some measure correct.

There *is* an energy crisis caused by such factors as dwindling domestic petroleum and gas supplies, cartel formation by oil-rich countries, increased tanker rates resulting from the Suez Canal closure, reduction in the depletion allowance, increased costs of mining coal, pressures on well drillers not to spill, and increased demands for low-sulfur fuels because of clean air requirements.

At the same time, the environmentalists are also correct. In some areas we are indeed reaching the capacity of the air and water to receive the heat and wastes we wish to dissipate. One region of the nation that is faced with severe environmental problems as a consequence of energy use is the South Coast Air Basin of California.

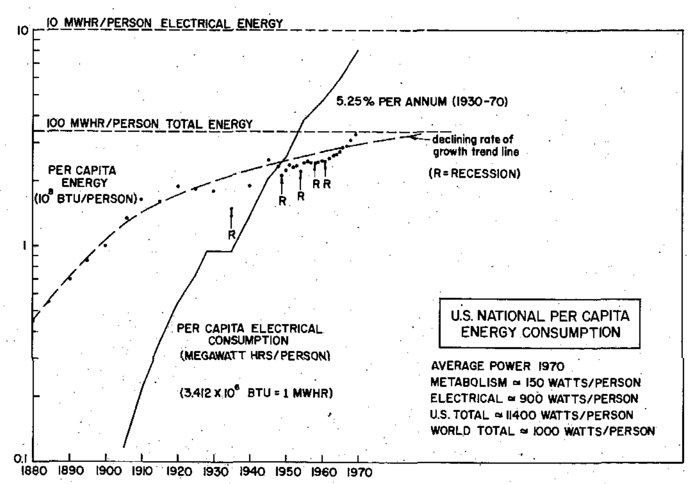


Energy Use

Nationally, our per capita energy use (right) has shown an almost continuous increase for the last 100 years, and, although the long-term trend appears to indicate a reduction in the growth rate, the high level of economic activity of the last ten years has meant a rather sharp departure from that trend. Growth in electrical energy consumption per capita shows little interruption in trend over the last 30 years. We assume that we can anticipate at least a 4 percent growth rate in per capita energy consumption over the next 10 to 20 years.

In 1969 the South Coast Air Basin accounted for almost one half of California's population, on less than 6 percent of the land area, and its residents operated more than 50 percent of the state's automobiles. The energy-use statistics for this group are given in the table at the top of the following page.

The first thing to note is that the total annual energy release within the South Coast Air Basin was 557 billion kilowatt-hours. Natural gas is the major contributing factor (over 50 percent), but gasoline also accounts for a substantial portion (26.8 percent) of that energy release. Since 96 percent of our energy is derived from fossil fuel sources, we can expect the supply problems to cause a substantial increase in energy costs over the current approximate $200 per person per year. This, of course, does not include the cost of food energy.



ANNUAL ENERGY RELEASE IN SOUTH COAST AIR BASIN

SOUTH COAST AIR BASIN — 1969

AREA: 9,200 square miles (5.87% of California)
POPULATION: 9,761,000 (49.4% of California)
MOTOR VEHICLES: 5,047,000 (50.2% of California)

	ENERGY		Billions kwh	% Basin
FOSSIL FUELS				
Gasoline	4,050	million gallons	149	26.8
Diesel	320	million gallons	13	2.3
Aviation*	40	million gallons	1	0.2
Jet*	128	million gallons	5	0.9
LPG	51	million gallons	1	0.2
Residual Oil**	20,720	thousand barrels	38	6.8
Refinery Gas	100,140	million cu. ft.	47	8.5
Natural Gas	910,240	million cu. ft.	280	50.3
ELECTRICITY				
Fossil Fuel *(included above)*	47,871	million kwh		
Imports	7,863	million kwh	8	1.5
Hydro	450	million kwh		
FOOD				
Metabolism†	9,761,000	people	14	2.5
TOTAL ENERGY RELEASE			557	100.0

*Includes only that burned below 3500 feet altitude.
**There is some argument about the accuracy of this figure.
†3200 Calories/day/person.

It is also interesting to compare the basin's total energy release with the incident solar energy (sunlight) represented by 5.0 billion kwh per square mile per year. In 1969 the 9,200-square-mile basin released energy representing about 1.2 percent of the incident solar energy. However, the energy release is by no means uniform over the entire basin, since 70 percent of the population lives in the unforested parts of Los Angeles County—an area of 2,300 square miles. The total energy released for this area is 425 billion kwh, representing 3.7 percent of the incident solar energy on an annual basis.

It is difficult to assess the effect of such energy releases on the basin's climate because so many factors are involved. Any estimate of a temperature increase depends, among other things, on the wind speed, inversion-layer height, temperature gradient between the coast and mountains, and the time rate of heat release. However, Lester Lees, professor of environmental engineering and aeronautics at Caltech and director of the Environmental Quality Laboratory, has developed a rough mixing-layer model of the basin in an attempt to get some indication of the temperature effect. Using his model and a conservative annual growth rate of 4 percent in energy consumption, we can estimate that by 1990 the increase in temperature could be as high as 5 degrees Fahrenheit. This is not surprising in view of the fact that such a growth rate could lead to energy releases by that date on the order of 8 percent of the incident solar radiation for the populated part of Los Angeles County.

Air Pollution From Energy Sources

The two primary sources of air pollution are combustion of fuels and non-combustion processes such as solvent evaporation and chemical processing. We will confine our discussion here to the combustion of fuels.

The total amount of pollutant of any kind, e.g., oxides of nitrogen, arising from combustion can easily be calculated if we know the emission factor for each type of fuel. To compare fuels in various uses we have compiled tables of emission factors in terms of grams of pollutant emitted in the combustion of the amount of fuel releasing the heat equivalent of 1 kilowatt-hour (3412 BTU). (This unit may seem an unusual way of measuring the energy of some fuels like gasoline—one gallon equals 37 khw—but it does put all fuels on a common basis.) The table below is such an emission factor matrix for oxides of nitrogen derived from published emission factors and fuel energy values. Since differences exist between continuous and intermittent operation and different conditions of loading, we have therefore given a minimum and maximum emission factor, representing the range of published values.

This table shows that an uncontrolled automobile operating on gasoline has by far the largest emission factor. By comparison, the emissions from the same automobile engine are much lower when operated on propane (LPG) or natural gas. It can therefore be seen that a conversion of automobiles to LPG or natural gas would have an enormous effect on the air pollution problem. One solution to the problem of what to do with the displaced gasoline would be to burn it in power plants, where the oxides of nitrogen would certainly be no larger than that for residual oil. Another significant gain from

GRAMS OF OXIDES OF NITROGEN FROM ONE KWH OF FUEL

FUEL	HEAT		TRANSPORT		ELECTRICITY	
	low	high	low	high	low	high
Gasoline			1.40	2.41		
Diesel			1.34	2.48		
Ref. Make Gas	0.22	0.22				
Aviation Gas			1.82	2.00		
Jet Fuel			0.18	0.51		
Residual Oil	0.74	0.83			0.37	1.23
Natural Gas	0.164*	0.33	0.22	0.46	0.28	2.47†
LPG			0.20	0.43		

*A kitchen range actually has the lowest emission factor (0.086 gms/kwh), but accounts for only about 5% of the gas consumed.
†Exceptionally high figure from one particular power plant.

burning the gasoline in power plants would be to eliminate the emission of unburned hydrocarbons from automobiles as well as the evaporative transfer losses, both of which are a significant part of the air pollution. We are simply using the wrong fuels for the wrong purposes from a pollution control point of view.

We can use the emission matrices such as those shown in the previous table for another purpose. Since we already have the fuel totals used to compile the first table on page 15, we can use the same emission factors to compute the range of air pollution emissions in the South Coast Air Basin as in the table below. The oxides of nitrogen are derived mostly from the combustion of gasoline and natural gas. The emission levels given in this table, when scaled to the ratio of energy consumption, agree reasonably well with the combustion levels calculated by the Los Angeles APCD. The spread in the results reflects the range of the reported emission factors, and it is worthwhile to note that the difference between using the highest and lowest published emission factors is not a fantastically wide margin in the computed emissions. It seems reasonably safe to assume that the actual pollution levels lie between the given levels. From this fact it is apparent that an *order of magnitude reduction* in emission factors will be necessary to attain a substantial reduction in total emissions in the air basin.

ANNUAL AVERAGE COMBUSTION EMISSIONS
FOR THE SOUTH COAST AIR BASIN — 1969 (IN TONS/DAY)

EMISSION	LOW ESTIMATE	HIGH ESTIMATE
Organics	2,310	3,180
Nitrogen Oxides	1,260	2,250
Carbon Monoxide	12,360	15,420
Particulates	150	220
Sulfur Oxides	200	480

In view of the interest we all have in removing air pollution it is important that we calculate the residual pollution we can expect when the emission factors are reduced to a technologically and economically feasible minimum. Let us assume that *all* the natural gas and oil is burned at the low emission levels of a kitchen range, and that *all* vehicles have emission levels equivalent to those from the exhaust of a 1976 automobile. Furthermore, assume that this is accomplished by 1975 (a highly unlikely assumption) and that in the interim, energy from combustion has risen at 4 percent each year. The following table gives the results of such a calculation, and a comparison with the previous table shows that significant gains in air quality should be apparent. Just precisely what ambient air quality such emission figures represent is not easy to determine. However, John Trijonis, a Caltech graduate student in environmental engineering science, has developed an emission-level/air-quality model in an attempt to solve this problem. His model predicts that, even at the minimum emission levels resulting from the almost utopian assumptions above, the federal ambient air quality standards for ozone would be exceeded approximately 10-15 days per year. The disturbing fact is that the number of days could only increase from this level unless *all* energy consumption growth is absorbed by some non-polluting energy source. This raises the question of just what strategies one can use to attain clean air.

PREDICTED MINIMUM POSSIBLE COMBUSTION EMISSIONS
FOR THE SOUTH COAST AIR BASIN FOR 1975 (IN TONS/DAY)

FUEL	ORGANICS	NITROGEN OXIDES	CARBON MONOXIDE	PARTICULATES	SULFUR OXIDES
Gasoline	106	93	1,090	81	54
Diesel	9	8	16	7	27
Aviation	31	9	152	1	1
Jet Fuel	43	4	8	3	4
Residual Oil	4	24	—	21	120
Refinery Gas	1	15	—	3	9
Natural Gas	6	90	—	14	—
1969	2,310	1,260	12,360	150	200
1975 TOTAL	200	243	1,266	130	215

(See preceding table, low estimate.)

Compiled from federal and state statistics and data provided by numerous energy companies in the basin.
Data from U.S. Statistical Abstract.

The amount of any pollutant X from combustion sources is given by:

$$\text{Amount of X} = (\text{Energy from source a}) \times (\text{Emission factor for a}) + (\text{Energy from source b}) \times (\text{Emission factor for b}) + \ldots \times \ldots$$

Thus, to reduce the amount of X we have three options:

(A) Reduce the emission factors.
(B) Reallocate energy consumption to those energy sources with the lowest emission factors.
(C) Reduce the amounts of energy consumed.

Almost all air pollution abatement strategies follow plan A; certainly this has been the policy of the State of California Air Resources Board and the Los Angeles APCD. But, given energy consumption growth, air quality gains can only be made if the emission factors decrease at a faster rate than the energy multipliers are growing. However, there is a point when either the cost of reducing the factors becomes prohibitive or we reach the limit of our technological capability to reduce them.

We have every reason to believe that this point has already been reached both with respect to power plant boilers and automobiles powered by the internal combustion engine. It does not seem technologically possible to use air as the oxidant in a high-temperature combustion process without producing *some* oxides of nitrogen. We therefore conclude that the minimum emissions calculated in the previous table are related to the best air quality that Los Angeles can expect without implementation of plan B or C. What is more important, unless growth is absorbed by a non-polluting energy source, this minimum would only be transient, and the air quality would proceed to deteriorate again.

The essential point, which must be reiterated, is that our consumption of fossil fuels has now become so large in the South Coast Air Basin that our ability to reduce emission factors has been overwhelmed. To get clean air the emission factor has to be very small indeed when the numbers multiplying these emission factors are so large, viz., 150 billion kwh for gasoline and 280 billion kwh for natural gas. And this is quite apart from the fact that energy consumption keeps growing to compound the problem.

We therefore can conclude that plan A is only an interim strategy whose effectiveness is solely dependent on a steady succession of technological breakthroughs. Then why are all the pollution control agencies using it? The principal reason seems to be that order-of-magnitude reductions in emission factors were technologically and economically possible in the past and therefore, by extrapolation, should be available in the future! The other two possible methods of control—reallocation of energy sources and discontinued growth—require major social and economic changes that our political system seems unprepared to face at this time.

If we really want cleaner air, we must find ways either to reallocate energy supplies or to decrease the demand for energy. And we have already seen that flattening the growth curve alone will not clean the air if the existing fossil fuel combustion levels are maintained.

No society, to our knowledge, has voluntarily constrained its per capita consumption of energy in peacetime. At this stage of social development it does not seem likely that our society will accept such growth controls. This leaves us with plan B—the reallocation of energy sources to those energies with the lowest emission factors.

The minimum emission factors for fossil fuels appear to be nearly the same so that reallocation of energy sources would be a short-term strategy which can be exploited only until these lowest emission factors are attained; furthermore, it is only a one-time gain. Consequently, what is required is an energy source that has practically zero air pollution emissions, and fortunately two such sources exist.

Solar energy has always been available, but development of a technology to harvest it appears to be some time away. The other near-zero emission source is nuclear power, and luckily it is in an appropriate stage of development to come into widespread use. It is also apparent that an inadvertent outcome of the strategy to reduce emission factors has been to hasten the acceptance of nuclear power. Tightening emission controls on fossil fuel plants (as well as the fuel supply problems) are raising their costs to the point where nuclear power plants are becoming the most economic for a utility to purchase. Unfortunately, it is not easy to see what the outcome of the same policy will be in the automobile business. Will it be a shift to mass transportation systems powered by electricity produced by nuclear power?

Conclusions

An examination of energy use in the South Coast Air Basin has shown that:

1. While thermal pollution is not significant at the moment, if current rates of growth are maintained there is every possibility of modest temperature increases within the basin in the next 20 years.

2. Energy use of fossil fuels has attained such levels within the basin that the residual air pollution there will remain at a significant level, even when virtually all emissions from combustion processes have been reduced to apparent feasible minimums.

3. The current policies of air pollution control agencies that require the continual reduction of emission factors has almost attained the limit of its usefulness in large energy consuming areas.

4. The only other policies open for air pollution control are either the reallocation of energy demands to those energy sources with zero emission factors, or the curtailment of the use of fossil fuels as an energy source.

5. In the largest urban areas, such as Los Angeles, a simple policy of no growth still leaves the area with significant air pollution unless energy demand is reallocated to zero emission sources.

6. The only energy source with near-zero emission factor and able to accommodate the possible demand for energy at this time is nuclear generated electric power.

7. The only way a city such as Los Angeles will ever attain air satisfying federally promulgated ambient air quality standards is to replace fossil fuel combustion by nuclear power or solar energy sources.

8. Society must find new ways of encouraging the development and use of non-polluting energy sources.

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