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ABSTRACT

This is the student guide in a set of five computer-oriented environmental/energy education units. Contents are organized into the following parts or lessons: (1) introduction to power and energy; (2) energy consumption and supply; (3) energy conservation and distribution; (4) energy flow and the question of transportation; and (5) computer models and energy. Exercises are given with each part and students can solve these problems with a calculator or may use a computer. (MB)

COMPUTER TECHNOLOGY PROGRAM
ENVIRONMENTAL EDUCATION UNITS

A Computer Oriented Problem Solving Unit

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CCCCC    OOO    N   N  SSSSS  U   U  M   M  EEEEE
C   C   O   O   NN  N  S      U   U  MM MM  E
C   C   O   O   N N N  S      U   U  M M M  E
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C   C   O   O   N  NN      S  U   U  M   M  E
CCCCC    OOO    N   N  SSSSS   UUU   M   M  EEEEE
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STUDENT GUIDE

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Prospective users of this manual are urged to first run the sample simulation program provided in order to determine any needed or desirable adjustments prior to use.

September 1975

TABLE OF CONTENTS

APPROACHING THE ENERGY CRISIS

The many headed monster of Greek mythology called the Hydra had the unpleasant characteristic of growing back two heads for each one cut off. The list of crises which have plagued us in the past decade seems to behave somewhat in the same fashion. As soon as we begin to cope with one crisis, two new problems appear. We have seen in rapid succession the problems of air pollution, water pollution, noise pollution, monetary crises, mineral shortages, food shortages, commodity shortages, etc. Now, a new and more disturbing crisis which is implicitly involved in all the problems above has exploded onto the contemporary scene--the energy crisis.

This most recent unpleasantness is particularly alarming for several reasons. First, it seemed to develop very rapidly springing from political and economic events over which we had little if any direct control. The crisis touched us all in a more personal sense than have the earlier problems listed above. The average American, still deep in a love affair with the automobile, experienced great trauma when fuel for the object of his affection either was not available, or had to be purchased at a much higher price. Our sensitivities were jarred when, in the midst of the energy crisis, oil companies reported record profits. There seemed to be more than a little justification for the suspicion that the petroleum shortage was engineered, and that in the process, the public had been "had."

A year or so ago, we were exhorted to find new ways to use electricity so that we could all have more of the "good life." Now we are bombarded from the media with hints about how we can do our part to conserve energy and help solve the crisis which is implied to be the public's fault in the first place.

Great gobs of information about the energy crisis have been disseminated through the media. Much of it is either misleading, incorrect, or both. The new drive toward "self sufficiency in ten years" sounds like an admirable energy goal for the United States, but is there more in the concept than meets the eye? Exploitation of vast coal reserves seems like a good idea, but should this be at the expense of air pollution standards which were so difficult to win? Is there really an energy crisis, or were the long lines at the gasoline pumps a short term perturbation, and now its back to "business as usual?" Possibly we shouldn't be too concerned with the energy crisis in any case, because with our technical ability we can engineer a "fix" to the problem.

The taxpayer is caught in the middle between concepts he doesn't understand and prescribed solutions which may or may not produce the desired results. Most dangerous is the assumption that, being ignorant of the true issues, the best thing for the average citizen to do is not to worry. "They" will see to the problem and tell us what is best to do. Of course, "they" often have no valid expertise at all but are merely in a position of political or economic power which lends a degree of credibility to their comments.

Understanding of the issues and concepts involved in the energy crisis does not guarantee good solutions, but it does help avoid making serious blunders or errors. The educated citizen is at least in a better position to objectively evaluate the "crisis activity" around him. In this unit we will explore some of the fundamental ideas pertaining to the energy crisis, using the computer as a tool. When you have completed this manual, you should have some feeling for the real dimensions of the problem, and hopefully you will have an understanding of some of the viable possibilities for its solution.

MEASURES OF POWER AND ENERGY

Measuring Power

The best way to approach the energy crisis initially is with the concept of power since this is generally much more familiar than energy. We all have a fundamental appreciation for the concept of power. The difference between the capabilities of a 300 horsepower engine and a 1 horsepower engine is well understood and unequivocal. This is interesting since most of us haven't the vaguest notion of how much power a horse can deliver! However, through experience, we have a very clear picture of what can be done with a 1 horsepower gasoline engine on a pump or lawn mower. To provide a frame of reference, consider these typical activities and rough estimates of the power involved:

Lawn Mower	1 Hp
Automobile	200 Hp
Jet (Boeing 707)	30,000 Hp

Thus, measured in Hp, a lawn mower is "small" and a jet is "big."

To explore the concept of power a bit deeper, consider the following example. Suppose that, if we mow grass for 1 hour with a 1 Hp mower, we use 1 pint of gasoline. It follows that if we mowed for 2 hours, the engine would consume 2 pints of gasoline. The engine on the mower is thus a device which converts the energy of the gasoline into useful work (cutting grass) at the rate of 1 pint of gasoline per hour. Power, then, is the rate at which energy (in some form) is converted to useful work.

$$\text{Power} = \frac{\text{Energy (E) converted to useful work}}{\text{Time (t) required for conversion}}$$

or

$$P = \frac{E}{t} \quad (1)$$

To further illustrate the concept, suppose we calculate the "power" of a human. The human body is an engine (among other things) which converts energy from nutritional sources into the work required to maintain the operation of the body and to perform useful external work (stacking bales of hay, painting houses, etc.). The average nutritional requirement of a human is 2400 large calories of food (energy) per day. Therefore E 2400 Kcal (Kcal is an abbreviation for 1000 ordinary calories which is equal to the large calorie) and t 24 hours. The computed power rating is

$$P \quad \frac{2400\ \text{Kcal}}{24\ \text{hr}} \quad 100\ \text{Kcal/hr}$$

This number has little impact since the unit of power used (Kcal/hr) is not generally familiar to us. We can convert to Hp by multiplying by 0.001559 giving a human power rating of 0.1559 Hp. This number is only an average power consumption figure, and probably shouldn't be taken too seriously. A man can deliver more power than this but only for short periods of time. The rating of 0.1559 Hp, however, does illustrate the power advantage man enjoys through the use of energy conversion devices (automobiles, jets, machines, etc.).

Another common unit of power is the kilowatt, abbreviated kw. The kw is 1000 watts, the watt being reasonably familiar since we have all purchased light bulbs whose power rating is given in watts. But, what is the relationship between a kw and a Hp? Let's look at an example. An electric griddle typically has a power rating of about 1.5 kw. The griddle converts electrical energy into heat which is then used to cook food. To make the power rating more meaningful, we can convert from kw to Hp by multiplying by 1.3410. The electric griddle, rated at 1.5 kw, thus has a horsepower rating of 2.012 Hp. This is a very good illustration of the way we often silently consume huge amounts of energy. The contrast between eggs sputtering on the griddle, and two lawn mowers working outside the kitchen window is dramatic, yet the two activities are consuming energy at roughly the same rate!

A third unit of power which is commonly used is the British Thermal Unit abbreviated BTU. A medium sized air conditioner which would cool two large rooms has a rating of 13,000 BTU's. That is, the air conditioner can remove heat at the rate of 13,000 BTU/hr. As before, this unit of power is difficult to appreciate. We can convert to Hp by multiplying by 0.0003929. Thus, 13,000 BTU/hr is equivalent to 5.11 Hp. The contrast between silent, cool air and a 5 Hp engine consuming gasoline and making noise is again dramatic.

A summary of the various horsepower ratings discussed thus far provides the basis for a very revealing comparison. Arranged in decreasing order we have

Jet	30,000 Hp
Car	200 Hp
Air Conditioner	5 Hp
Lawn Mower	1 Hp
Human	0.16 Hp

Now we can express jets in terms of cars or lawn mowers to get the relative power ratings. These comparisons are given in Table 1. The numbers are rounded off and are not precise calculations. The intent is to provide a meaningful basis to gauge energy demands of various activities. It is important, for example, to realize that when driving a car we are consuming energy at a rate equivalent to the nutritional requirements of 1200 humans. We should understand that a jet consumes energy at a rate equal to 200,000 people, or 6000 air conditioners. If the general trend of the numbers in Table 1 is kept in mind, off-handed comments or projections about energy consumption will begin to be viewed in a significant new light.

	JET	CAR	AIR CONDITIONER	LAWN MOWER	HUMAN
JET	1	150	6,000	30,000	200,000
CAR		1	40	200	1,200
AIR CONDITIONER			1	5	30
LAWN MOWER				1	6
HUMAN					1

Table 1. Comparisons of Hp Ratings.

Measuring Energy

Now, let's turn the treatment around and look at energy rather than power.

Energy Converted = Power x Conversion Time

or,

$$E = Pt \tag{2}$$

If we drive a car with a rating of 200 Hp for 5 hours, the energy consumed is 1000 Hp hr. We note that Hp hr is not one of the measures of energy we are most familiar with. However, if we cook on a 1.5 kw griddle for two hours, we consume 3 kw hr of energy. This unit of energy is more familiar since it is the way we are billed for electricity in our homes. Usually we pay a few cents for each kw hr of electrical energy consumed.

Recall that the nutritional requirement for a human is 2400 Kcal per day. In two days a human would consume 4800 Kcal or 4,800,000 calories of energy. An air conditioner with a rating of 10,000 BTU per hr operating for 5 hours will process 50,000 BTU's of heat energy.

Other useful energy units can be derived from those we have been discussing. For example, a pound of coal has a realizable energy content of about 13,100 BTU. Thus, 26,200 BTU of energy can equivalently be expressed as 2 pounds of coal. A barrel of oil has an energy content of about 5,510,000 BTU. Thus, 10,000,000 BTU's and 1.815 barrels of oil describe the same realizable quantity of energy.

Often, "equivalent energy units" can allow us to convey much more meaning than do the rigorous scientific units. Five kw hrs may or may not say much to us; however, the equivalent unit--42.99 human hrs--has much more meaning. We can readily see that the 5 kw hrs of energy means enough energy to sustain 1 human for about 43 hours, or 43 humans for 1 hour. Likewise 10,000 barrels of oil is simply a lot of oil to most of us. Its equivalent--721.5 jet hours, or 108,200 car hours--is something we can identify with.

Energy and Power Conversion

All we have discussed thus far, and a great deal more, is summarized in Table 2. This table gives the conversion factors necessary to convert from one energy measure to another, or from one power rating to another. If we are interested in energy conversion, the information at the left and top of the table is used to locate the proper conversion factor. If power ratings are to be converted the information at the right and bottom of the table is used. The "E notation" familiar to BASIC language users has been used in the table. In this notation 5.200E-8 5.200×10^{-8}, 7.635E7 7.635×10^{7} and so on.

To illustrate the use of Table 2, suppose we convert the nutritional energy consumed by a town of 10,000 people in one year to an equivalent number of barrels of oil. Human hrs = 10,000 x 365 x 24 = 8.760E7. From the table we see that to get barrels of oil, we must multiply human hours by 7.206E-5. Therefore, barrels of oil = 8.760E7 x 7.206E-5 = 6312. If we further desire to convert this quantity to jet hours the table indicates we must multiply by 7.215E-2. Jet hours = 6312 x 7.215E-2 = 455. Thus, 10,000 people for a year = 6312 barrels of oil = 455 jet hours.

ENERGY

MULTIPLY → BY, TO GET ↓	BTU	Hp hr	Kw hr	Kcal	Gal gas	Tons coal	Barrels oil	Human hr	Cubic ft Nat Gas	Jet hr	Car hr	
BTU	1	2545	3413	3.969	1.260 E5	2.620 E7	5.510 E6	396.9	1050	7.635 E7	5.090 E5	BTU/hr
Hp-hr	3.929 E-4	1	1.341	1.559 E-3	49.50	10290	2165	.1560	.1126	30000	200	Hp
Kw hr	2.930 E-4	.7457	1	1.163 E-3	36.92	7677	1614	.1163	.3077	22370	149.1	Kw
Kcal	.2520	641.3	860.0	1	31740	6.601 E6	1.389 E6	100	264.5	1.932 E7	1.282 E5	Kcal/hr
Gal gas	7.937 E-6	2.020 E-2	2.709 E-2	3.151 E-5	1	208.0	43.73	3.151 E-3	8.335 E-3	606.0	4.040	Gal gas hr
Tons coal	3.817 E-8	9.718 E-5	1.303 E-4	1.515 E-7	4.808 E-3	1	.2102	1.515 E-5	4.007 E-5	2.914	1.942 E-2	Tons coal/hr
Barrel oil	1.817 E-7	4.619 E-4	6.194 E-4	7.204 E-7	2.287 E-2	4.757	1	7.206 E-5	1.906 E-4	13.86	9.241 E-2	Bar. oil/hr
Human hr	2.520 E-3	6.410	8.598	.0100	317.4	66007	13880	1	2.645	1.924 E-5	1282	Human
Cubic ft Nat. Gas	9.524 E-4	2.454	3.250	3.781 E-3	120.0	24960	5247	.3780	1	72730	484.6	Cubic ft Nat. Gas/hr
Jet hr	1.310 E-8	3.333 E-5	4.470 E-5	5.200 E-8	1.650 E-3	.3432	7.215 E-2	5.198 E-6	1.375 E-5	1	6.667 E-3	Jet
Car hr	1.965 E-6	5.000 E-3	6.707 E-3	7.800 E-6	.2475	51.50	10.82	7.800 E-4	2.064 E-3	150.0	1	Car
	BTU hr	Hp	Kw	Kcal hr	Gal gas hr	Tons coal/hr	Barrels oil/hr	Human	Cubic ft Nat Gas hr	Jet	Car	↑ TO GET, BY ↖, ← MULTIPLY

POWER

Table 2. Energy-Power Conversion Factors[1]

---

1. Assumptions: 1 gal gasoline = 1.26E5 BTU, 1 lb. coal = 1.31E4 BTU
1 cu ft natural gas = 1.050E3 BTU, 1 barrel oil = 5.51E6 BTU,
1 car = 200 Hp, 1 jet = 30,000 Hp, 1 human = .156 Hp

We can convert power measures by the same process except we use the information on the bottom and right of the table. To illustrate, one jet is equivalent to how many BTU's per hour? From the table we see that to get BTU's per hour we must multiply the number of jets by 7.635E7. Therefore, 1 jet = 76,350,000 BTU per hour. We note in passing that this is equivalent to many many air conditioners.

We can use the conversion factors in Table 2 to acquire a "feeling" for a wide range of phenomena bearing on energy and power. If you have access to a pocket calculator or know how to use a slide rule, the exercises can be done quite easily without resorting to the computer. For those who prefer to use the computer, a simple program is given in Figure 1.

```
100  REM CONV PROG
110  PRINT
120  PRINT
130  PRINT "QUANTITY TO BE CONVERTED";
140  INPUT X
150  PRINT "CONVERSION FACTOR";
160  INPUT F
170  PRINT "CONVERTED QUANTITY = ";F*X
180  GOTO 110
190  END
```

Fig. 1. Conversion program.

EXERCISES

1. A frankfurter contains about 150 Kcal of food energy.

   a. How many BTU's is this?
   b. How many human hours?
   c. Suppose we eat and convert to energy 2 frankfurters per hour. What is the power rating in Hp?

2. A quarter pound block of TNT has an energy content of 410 Kcal. A quarter pound block of butter has an energy content of 812 Kcal.

   a. Assume it takes 24 hours for the quarter pound of butter to be converted to energy. Compute the power rating in kw and Hp.

   b. Assume it takes 0.0001 seconds (or 2.778E-8 hr.) for the quarter pound of TNT to be converted to energy. Compute the power rating in kw and Hp.

   c. The energy content ratio of TNT to butter is about 1 to 2. During the time energy is being converted, what is the power ratio of TNT to butter?

3. The 1970 population of California was about 20,000,000 people.

   a. How many jets will consume energy at the same rate as the nutritional requirements of the population of California?

   b. What is the nutritional power rating of the population of California in barrels of oil per hour?

   c. What is the nutritional power rating in horsepower?

4. The overall energy consumption per capita in the United States is about 20,500 BTU per hour, while the same figure in Japan is about 3400 BTU per hour.

   a. What is the equivalent horsepower rating for a United States family of five?

   b. What is the equivalent horsepower rating for a Japanese family of five?

5. One of the largest electrical generation facilities in the world is operated by the TVA at Paradise, Kentucky. The plant has a capacity of 1,150,000 kw. What is this power rating in:

   a. Tons of coal per day?

   b. Barrels of oil per day?

   c. Jets?

   d. Cars

   e. The actual consumption of coal is 10,570 tons of coal per day (enough to fill 210 railroad cars). How do you explain the difference between this number and the answer obtained in a.? What is the overall conversion efficiency of the plant, if

$$\% \text{ efficiency} = \frac{\text{Energy Consumed}}{\text{Actual Consumption}} \times 100$$

6. The 1971 automobile registration in the United States was 92,700,000.

   a. On the average 92,700,000 cars operating intermittently is equivalent to how many cars operating continuously? (Make a reasonable estimate.)

b. How many barrels of oil per hour are implied by the answer to part a?

c. Assuming a conversion efficiency of 50% from coal to electricity, how much coal (tons per hour) would be required if we powered the cars by electricity in the answer to part a, and generated the electricity from coal?

7. In 1971 the United States produced 22.5 trillion (22.5E12) cubic feet of natural gas. Averaging the production out over 365 days, what is the natural gas production power rating:

   a. In kw?

   b. In jets?

   c. In power plants (1,000,000 kw per plant)?

9/10

PART II. ENERGY CONSUMPTION AND SUPPLY

EXPONENTIAL GROWTH

At the heart of the energy crisis are exponentially growing energy demands while the supplies of energy tend to remain fixed. The whole notion of exponential growth is not well understood in general, because we ordinarily tend to think in terms of linear growth. Since the contrast between linear and exponential growth has such fundamental importance, we must make certain that the characteristics are clearly understood.

Linear growth is characterized by a fixed amount added in each time interval. To illustrate, suppose we agree to work for 1 cent the first day, 3 cents the second, 5 cents the third day, and so on. The daily pay is growing linearly at the rate of 2 cents per day. (The term "linear" refers to straight line growth.)

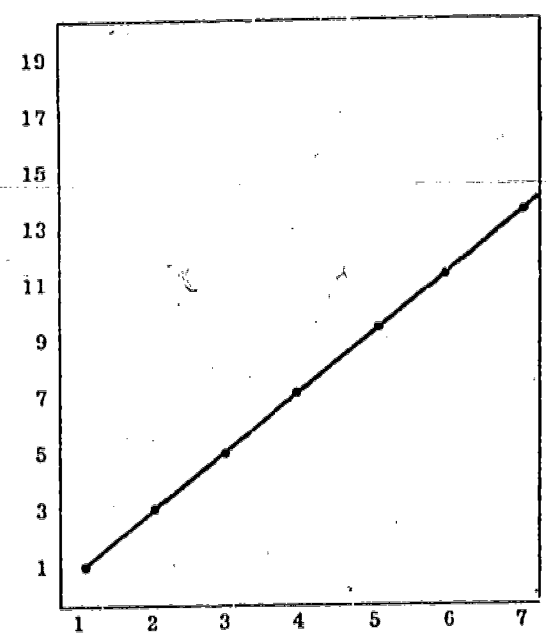

Fig. 2. Linear growth is in a straight line.

Exponential growth, on the other hand, is quite different. Here instead of adding a fixed amount, a fixed percentage of the amount at the beginning of each time period is added during that time period. If we return to the example of receiving 1 cent pay the first day, but now set the growth at 100% each day, we would receive 1 cent the first day, 2 cents the second, 4 cents the third day, and so on. In this particular case when the growth in each time interval is 100%, there is a doubling each time interval.

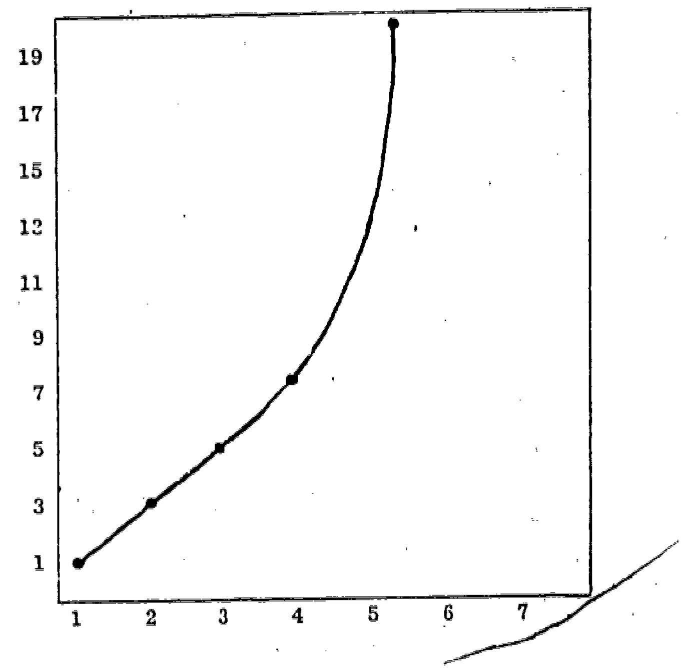

Fig. 3. Exponential growth double in each time interval.

The comparison between the two types of growth is shown in the list in Fig. 4.

Day	Linear Growth	Exponential Growth
1	1	1
2	3	2
3	5	4
4	7	8
5	9	16
6	11	32
7	13	64
8	15	128
9	17	256
10	19	512

Fig. 4. Exponential versus linear growth.

Now it is clear why the old fable about working for 1 cent the first day, 2 cents the second, 4 cents the third and so forth is so startling. As seen in Figure 2 the wages the 10th day would be $5.12. If we project forward the worker receives $5,242.88 on the 20th day, and $5,368,709.12 on the 30th day. Such are the astonishing and somewhat terrifying characteristics of exponential growth.

It is also clear that no quantity can grow exponentially for too long without absurd conclusions. If a doubling process is allowed to proceed for 333 time periods, the quantity will have grown to a googol (10^{100} or 1 followed by 100 zeros) a number so large there is question whether any physical meaning can be assigned to it. Thus, we can be very certain that if bacteria are doubling, for example, that the process will be interrupted long before 333 doubling times have passed. A simple program which will permit us to investigate exponential growth is given in Figure 5.

```
1ØØ  REM GRO
11Ø  PRINT
12Ø  PRINT "INITIAL AMOUNT";
13Ø  INPUT A
14Ø  PRINT "PER CENT GROWTH PER TIME INTERVAL;
15Ø  INPUT P
16Ø  PRINT "HOW MANY INTERVALS";
17Ø  INPUT N
18Ø  PRINT
19Ø  PRINT
2ØØ  PRINT "INTERVAL", "AMOUNT"
21Ø  PRINT
22Ø  FOR I = 1 TO N
23Ø  PRINT I,A
24Ø  LET A=A+P*A/100
25Ø  NEXT I
26Ø  END
```

Fig. 5. Program for exponential growth.

The Simple Rule of Seventy Two

In the exercises concerning resources and consumption at the end of this section we will examine the characteristics of exponential growth in detail. However, there is a very simple rule which can give quick information about the subject. If the growth in percent in each time period is divided into 72, the result is the number of time periods to double the quantity growing.

If we are lucky enough to find a steady 12% investment and invest $1000, leaving the interest to add to the principal, the investment will grow to $2000 in 72/12 or 6 years. If bacteria increase by 2% each hour, the number of bacteria will double in 72/2 or 36 hours. The rule of 72 is not precise, but it does give very rapid and reasonably correct insight into exponential growth.

RESOURCES AND CONSUMPTION

Oil Reserves and Consumption

There is a bewildering, and often contradictory, set of data purporting to describe the world oil reserves and consumption rates. Upper estimates of the Earth's original store of oil range from 1000 to 2000 billion barrels.[1] Of course, the original amount present isn't what concerns us the most at the present time. What we need to know is: how much oil is presently available for exploitation on some reasonable economic basis, what is the present consumption rate, and how is the consumption rate changing?

The U.S. Bureau of Mines estimates the known global reserves at 455 billion barrels. The global consumption rate is about 15 billion barrels per year, and is growing at an average rate of 3.9 percent per year.[2] Putting aside for the moment the staggering political and distribution problems involved in equitable consumption of the world's oil reserves, and assuming that there is no additional growth in consumption rates, we have a 31 year supply of oil remaining. Of course, even this alarmingly small number of years must be very optimistic because it is almost certain that consumption rates will grow, if not in the developed countries, then certainly in the underdeveloped countries.

A program which will enable us to investigate depletion of resources with assumed growth in consumption rates is given in Fig. 6. We will use this program to consider other depletable energy resources in turn. Without making any calculations beyond those presented above, however, we can already conclude that there must be fundamental and far reaching changes in the United States in the next three decades. It is particularly important to consider the United States since with only 6% of the world population, we account for approximately 33% of the total energy consumption.[3] First, there is bound to be a shift away from oil to other energy resources. This will cause economic shock waves in those parts of our economy primarily concerned with consumption of oil (the automobile and power production industries). Second, the oil will not simply run out on a given day. As the oil reserves become more difficult to locate and work, the price of oil must inevitably rise. There is only one way gasoline prices can go, and that is up! To fail to recognize these simple facts is to deal in the most dangerous type of fantasy.

```
100  REM RES DEPL
110  PRINT
120  PRINT "TOTAL RESOURCE (ARBITRARY UNITS)";
130  INPUT T
140  PRINT "ANNUAL CONSUMPTION (SAME UNITS)";
150  INPUT A
160  PRINT "ANNUAL GROWTH IN CONSUMPTION (PERCENT)";
170  INPUT R
180  LET N=1
190  LET T=T-A
200  IF T<0 THEN 240
210  LET A =(1+R/100)*A
220  LET N=N+1
230  GOTO 190
240  PRINT
250  PRINT "RESOURCE DEPLETED IN 'N' YEARS"
260  END
```

Fig. 6. Program for resource depletion.

Coal Reserves and Consumption

The world situation with regard to coal is certainly much brighter than the oil picture. The known global reserves of coal are estimated to be 5000 billion tons. The annual total consumption is about 2 billion tons per year, and the consumption rate is growing at 4.1% per year.[4]

If world consumption went on at the present rate, there would be a 2500 year supply which looks very good indeed. However, the oil will certainly be exhausted soon, and we realistically should replace consumption of oil with coal. The present world consumption of oil is 15 billion barrels of oil per year, which is equivalent to 3.2 billion tons of coal per year. Thus, the total consumption of coal and oil is equivalent to 5.2 billion tons of coal per year, giving a 480 year supply at present rates. Even with reasonable growth in consumption rates, it would appear that there is still plenty of coal.

The true situation is not quite this simple. First, the mining of coal itself can be very destructive to the environment. Underground mining does little to the land but is expensive compared to other methods. The mining method preferred by coal companies is strip mining where the coal deposits are laid bare and scooped out with mammoth machines. This is the process that has laid waste to large areas in Appalachia. Powerful forces are presently being brought on Congress to pass legislation requiring strip miners to restore the land they dig up to the same condition it was in when they found it. However, this will add to the price of strip mined coal, and may well foreclose the possibility of massive strip mining of huge coal deposits in Montana and Wyoming.

Another problem is that combustion of coal, most of it with high sulfur content, produces unacceptable levels of air pollution. We will have gained little if we solve the oil crisis by turning to coal, and in the process convert the atmosphere into an open air cesspool! The technology is available to convert coal to synthetic oil or natural gas. Synthetic oil was produced from coal in Germany in World War II. Massive projects are underway in the United States now to develop an economically sound coal gasification process. However, coal gasification is still in the experimental or pilot plant stage and is many years away from a significant contribution to the nation's energy needs. For the next decade, it seems likely that we will continue to use oil reserves, buying time to develop the technology to take advantage of our coal resources without creating an ecological disaster.

Natural Gas Reserves and Consumption

Of all the fossil fuels, natural gas is in the shortest supply and the greatest demand. Natural gas provides the cleanest source of energy, and is used in many different manufacturing processes. The world situation with regard to natural gas, however, closely parallels that of oil. This is not accidental since there is an almost constant ratio of natural gas reserves to oil reserves. Historically, about 6000 cubic feet of natural gas are discovered for each barrel of oil.

The world reserves of natural gas are estimated to be 1140 trillion (1140E12) cubic feet. The world wide consumption is 30 trillion cubic feet per year and is increasing at an average annual rate of 4.7%.[5] If consumption remains at the present level, there is a 38 year supply left.

The United States is in a particularly unfortunate position in that federal regulation of natural gas prices has encouraged residential and industrial usage at a time when the gas prices should realistically be much higher. Thus, an artifically low price, and delay in development of new natural gas fields has produced a serious shortage in the United States. It is interesting to note that one of the first trade agreements with Russia calls for importing large quantities of liquified natural gas.

Other Energy Reserves

Much has been said recently about nuclear, geothermal, solar, tidal, and other new sources of energy. In the long run some of these new power sources may be very promising. At the present time, however, nuclear power plants are still not providing a significant part of the total energy input into our economy. In point of fact, our economy is almost completely dependent upon oil, natural gas, and coal, and probably will continue to be so for the next decade. This is required by the lead time needed to design, construct, and begin operation of new nuclear power plants. Other new sources of power will require even longer lead times. Like it or not, we are inescapably bound to the economics and politics of fossil fuel for the near future.

EXERCISES

1. Use the program in Fig. 5 to verify the "rule of seventy two." Look at growth rates of 1, 2, 3, ..., 20%. For what growth rates is the rule most applicable?

2. In an exponentially doubling process, the size at any stage is 1 more than the sum of all the preceding stages (check this out in Fig. 4.) After about 10 doubling periods, the sum of all the sizes is essentially double the last one. Use this fact to investigate how much wheat is involved in the Indian fable about 1 grain of wheat on the first square of a chess board, 2 grains on the second, 4 grains on the third square, and so on for the entire 64 squares on the board. How many grains of wheat are on the board? (Extra credit: Assume a grain of wheat is 0.25 inches long and 0.02 inches in diameter. How big a bin would be required to hold the wheat?)

3. Use the program in Fig. 6 to investigate the time to depletion of the fossil fuels discussed in this chapter.

   a. Begin with the estimated reserves, annual consumption, and growth rates given in the discussion.

   b. Find out what is the effect of changing the size of the reserves.

   c. What is the effect of changing the growth in consumption?

   d. Suppose we cut down on consumption (a negative percentage in growth of consumption)? What effect does this have on times to depletion?

4. Possibly the nations of the world could stretch out the oil reserves by cutting back on the growth in consumption by a fixed amount each year as indicated below.

Year	Growth in Consumption
1	4%
2	3%
3	2%
4	1%
5	0%
6	-1%
7	-2%

etc.

The growth in consumption is decremented by a constant amount each year. Modify the program in Fig. 6 to take this into account by adding these lines:

```
175  PRINT "DECREMENT";
176  INPUT D
215  LET R=R-D
```

Try different decrements and see what the effect is on the lifetime of the oil reserves.

Optional for Programmers

5. Let D be the depletion of a resource in percent, and N be the number of doubling periods in consumption of the resource to exhaustion. The relation between N and D is

$$N = \frac{2 - 0.434294\text{Ln}(D)}{0.301205}$$

a. Write a BASIC program to generate a table giving N for D equal to 100, 10, 1, 0.1, ..., 0.00000001%.

b. Suppose we have used 10% of the world's oil, and that the growth in consumption is 4% per year. What is the doubling period in years? How many years until depletion of the oil resources?

c. Suppose we have used only 0.1% of the oil supply in the world. What does this do to the answers to b.?

PART III. ENERGY CONVERSION AND DISTRIBUTION

ENERGY CONVERSION

Energy resources in their natural form are usually not available or useful to us as consumers. A barrel of crude oil in a well in Kuwait is of no value when we attempt to prepare a meal on an electric range in California. Similarly, water impounded in a dam above a hydroelectric plant in Washington provides no direct assistance to a commuter traveling to work in Chicago. Energy must be transformed into forms which are easy to distribute and convenient to use. An important difficulty in the complex of energy-related problems is that the processes of converting and distributing energy are not very efficient.

When examining the effectiveness of an energy conversion process, the energy losses at each stage are considered. Table 3 gives a number of conversion processes and their corresponding efficiencies. The ratings were taken from a number of sources and should be considered only as typical. They are sufficiently accurate, however, to provide insight into the overall efficiency of energy consumption patterns.

By efficiency, we mean the fraction of energy that survives the process. For example, Table 3 indicates that a diesel engine has a conversion efficiency of 0.38. If 1000 BTU's of diesel fuel are consumed by the engine, only 380 BTU's (equivalent) are delivered in the form of mechanical energy. The balance of 620 BTU's is lost in the form of heat which may not be recovered. If more than one stage is involved, the corresponding efficiencies must be multiplied together. If the diesel engine is coupled to an electric generator which is used to power an incandescent lighting system, the overall efficiency is

$$0.38 \times 0.98 \times 0.05 = 0.019$$

In this example, for every 1000 units of energy that enter the conversion process, only 19 emerge as light, with 981 units lost and no longer available. This example makes it painfully clear that this type of illumination is incredibly wasteful.

Figures in Table 3 indicate that water turbines are highly efficient, as are electric generators. It seems clear that the most efficient way to utilize hydropower is in hydroelectric plants. The overall efficiency of the generation of electricity by hydroelectric plants is:

$$0.83 \times 0.98 = 0.81$$

Device	Efficiency	Converts	To
Diesel Engine	0.38	Fossil Fuel (diesel oil)	Mechanical Energy
Gasoline Engine	0.25	Fossil Fuel (gasoline)	Mechanical Energy
Water Turbine	0.83	Energy of falling water	Mechanical Energy
Steam Turbine	0.47	Steam	Mechanical Energy
Electric Motor	0.63	Electricity	Mechanical Energy
Human	0.24	Food Energy	Mechanical Energy
Steam Boiler	0.88	Fossil Fuel (any type)	Steam
Nuclear Reactor	0.65	Nuclear Fuel (uranium	Steam
Gas Furnace	0.85	Fossil Fuel (natural gas)	Heat
Oil Furnace	0.65	Fossil Fuel (heating oil)	Heat
Gas Range	0.65	Fossil Fuel (natural gas)	Heat
Electric Range	0.90	Electricity	Heat
Thermocouple	0.07	Heat	Electricity
Generator	0.98	Mechanical Energy	Electricity
Solar Cell	0.10	Light	Electricity
Fuel Cell	0.60	Elemental Fuels (H_2 and O_2	Electricity
Incandescent Light	0.05	Electricity	Light
Florescent Light	0.20	Electricity	Light
Electrolysis Cell	0.98	Electricity	Elemental Fuels (H_2 and O_2)

Table 3. Energy Conversion Efficiencies

24

An additional advantage of this process is that hydroelectric plants are clean and nonpolluting. Unfortunately, the amount of developed hydroelectric power available in 1970 to the United States was only about 4.2% of the total energy consumption. Geography and weather place absolute upper limits on the hydroelectric power that is theoretically available. This becomes very clear if we compare the hydroelectric potential to the annual per capita consumption of power in the United States which is about 10 kw. The entire hydroelectric potential in the United States is 0.8 kw per capita which is about 8% of our current energy consumption. At the other extreme, Norway has a hydroelectric potential of 13 kw per capita.[6] Obviously hydroelectric power cannot provide long range solutions to the energy problems facing the United States.

If one were to step into an electric generating plant in the United States, the odds are overwhelming that it will be a steam generating plant fired by fossil fuel. The conversion is by steam boiler, to steam turbine, to generator with an overall efficiency of

$$0.88 \times 0.47 \times 0.98 = 0.41$$

It is most important to note that if 1000 energy units are converted to electricity by this process, 590 units will be lost as a heat load to the environment. Any time electric applications are considered, we must remember this basic fact. If, as some recommend, we move to nuclear electric plants, the overall efficiency

$$0.65 \times 0.47 \times 0.98 = 0.30$$

goes down and the heat load on the environment is increased. In addition, nuclear plants pose difficult safety and disposal problems; their radioactive fuels and wastes, while not explosive, are extremely toxic.

ENERGY DISTRIBUTION

Just as important as the conversion of energy in providing consumers with usable energy is its distribution. Certain types of energy, such as mechanical energy, steam and heat, can only be distributed in a very limited sense. For example, it is practicable to distribute steam within a plant, or even possibly within a town; however, it is not possible to distribute steam economically over larger areas.

The network of high voltage transmission lines which crisscross the United States bears mute testimony to the ease with which electricity can be distributed. Indeed, this distribution system extends into individual rooms within our homes. If society desires, the generating plants can be located far from the area served with consequent decrease in air pollution for the consumer.

The vast majority of our energy needs are provided by fossil fuels. Oil can be distributed easily over land through pipelines. The cheapest mode of transportation of oil known is by sea. The super tankers shuttling from the mideast to world markets transport incredible quantities of crude oil very economically. Like oil, natural gas can be moved easily in pipe lines; and it can also be moved in refrigerated tankers which hold liquified natural gas for ocean transport. Coal can be moved economically in any bulk transport facility (trains, ships, barges, etc.). Coal can also be pulverized, mixed with water to make a slurry, and then pumped through pipelines as any other fluid.

In summary, fossil fuels can be transmitted and distributed easily using existing techniques. When fuels are converted to electricity, the energy can be distributed very easily over transmission lines. This fact (among others) has encouraged the rapid growth in demand for electricity.

NEW ENERGY CONVERSIONS

As the price of fossil fuels goes up, as it inevitably must, serious consideration must be given to new sources of energy. These include:

a. Nuclear reactors

b. Breeder reactors

c. Solar energy

d. Wind energy

e. Tidal energy

f. Geothermal energy

g. Fusion reactors

Each of these has certain advantages and each has problems which must be considered and dealt with.

Nuclear reactors are already on the scene. Every year new plants come on-line and new construction permits are filed. Nuclear fuel (Uranium 235) is fissioned, or split, with the resultant release of energy used to generate steam which through turbines powers electric generators. As already discussed, the process is not particularly economical having an overall efficiency of about 30%. Two serious problems mar the desirability of nuclear power. The first is that there are limited supplies of uranium to fuel the reactors. It would only be a question of time until the price of nuclear generated electric power would start the inevitable climb due to scarcity of uranium. The second problem is more serious--that of absolute containment of the radioactive residues from the reactors. Much has been written, and many solutions have been proposed, but no foolproof method has been demonstrated to date. This hazard of radioactive contamination is responsible for most of the protests against nuclear power that have been filed by environmental groups.

Breeder reactors offer a solution to the potential uranium shortage problem mentioned above. During the fission process, neutrons which are released in abundance can be used to convert a non fissionable form of uranium (U238) to a fissionable form of plutonium (Pu239). In effect, while generating power the breeder reactor generates new fuel which can be used to generate more power. The problem of radioactive residue, however, remains. The technology for the breeder reactor is not well developed. It seems likely that significant power generated by breeder reactors is at least a decade away.

Solar energy has been referred to as the "giant beyond reach." Whether this is true or not remains to be seen. It was solar energy, converted to biomass by photosynthesis laid down over millions of years that is responsible for the fossil fuels we are depleting in a few decades in modern times. A little data shows why solar energy is potentially so attractive. At the latitude of the United States, about 0.15 watt per square inch of power is received at ground level from the sun. From here on, it is strictly a question of efficiency of conversion. Solar cells have proven efficiencies of at least 10%. At this efficiency 1 kw of electric power would require a square solar cell 22 feet on a side. Higher efficiencies would cut down the size of the necessary converters. At the present time, a great deal of research is taking place looking for cheap, efficient ways to convert solar power to electricity or heat. At 50% efficiency, the 1970 power requirements of the United States could be furnished (when the sun is shining!) with a square conversion facility 85 miles on each side.

Since the solar energy is available only during hours of sunshine, this source of energy is feasible only if a storage mechanism can be found to permit the steady distribution of power. One very attractive solution has been proposed. Electricity generated during hours of sunshine would be used in electrolytic cells to convert water to hydrogen and oxygen. These gasses could be distributed using natural gas distribution facilities and consumed as fuels. Or, the gasses could be recombined in fuel cells which generate electricity with water as a byproduct. The electricity generated with fuel cells is completely nonpolluting. A 42 million dollar project is under way at Pratt & Whitney to develop a 26,000 kw fuel cell. Nine power companies hope to begin delivering fuel cell produced electricity by 1978. Each of the 26,000 kw fuel cells will produce sufficient electricity for a city of 20,000, will be located on less than half an acre, and will be about 18 feet high.

Wind energy has been used since early in the 18th century to provide power. In modern times, technology has ignored this free source of energy. Considerable power is available. One source indicates the average wind power in the Oklahoma City area is about 18.5 watts per square foot of area perpendicular to the wind direction.[7] In 1941, an experimental wind turbine was constructed in Vermont which developed up to 1400 kw of power. At that time studies indicated that an economically optimum wind turbine would stand about 165 feet high, with a diameter of about 225 feet, and could deliver up to 2000 kw.[8] Since that time new techniques, and especially new materials may have made wind power much more feasible. The federal government has a five year program which will study and build prototype wind power plants. By mid-1975 a 100 kw wind operated plant capable of heating, cooling, and lighting six homes will be in operation in Ohio. As in solar energy, if the electricity produced from the intermittent wind is used to produce oxygen and hydrogen, constant distribution of energy can be achieved. Once again, no pollution results from harnassing this energy source.

The tides furnish another free source of energy. The total tidal power has been estimated at 3 billion kw. As the tides flow, water can be impounded and subsequently directed through turbines. Only one full scale tidal electric plant is in operation. Built on the channel coast of France, and started up in 1966, it had an initial power output of 240,000 kw.[9] The average power consumed per capita in the United States is 10 kw. Thus the total power consumption in the U.S. at the present time is about 2 billion kw, or about the same as the total estimated tidal power. It is clear that if world power requirements keep growing, tidal power can be only part of the total solution.

There are two potential sources of geothermal power. The first derives steam from underground volcanic activity near the surface of the earth. At several locations in the world, power is being produced commercially from this source. The total capacity has been estimated to be 0.3 billion kw. A second source which potentially is far larger is the heat conduction in the earth's rock crust. This has been estimated to have a total capacity of 32 billion kw, or roughly 16 times the 1970 U.S. power rating.[10] There are great unsolved technical problems in the economical recovery of geothermal power in significant quantitites. As the price of fossil fuel increases, geothermal power will certainly receive more attention.

If there is an ultimate source of energy it is controlled fusion. The energy is derived from the fusion, or joining together, or deuterium--one of the forms of hydrogen. This is the same source of energy utilized in a hydrogen bomb, except the energy release is controlled. The most plentiful source of hydrogen is water. For every 5000 atoms of ordinary hydrogen in water a single atom of deuterium is present. To give some idea of the energy involved, the deuterium in 1 gallon of water has an energy equivalent of about 6 barrels of crude oil. If enough deuterium were withdrawn from the oceans to reduce the initial concentration by 1%, the energy that potentially could be produced through controlled fusion would be about 500,000 times the energy of the world's total initial supply of fossil fuels.[11]

Controlled fusion is the uncertain certainty. It is certain that controlled fusion will be available. It is uncertain just when it will be a reality. The consequences of free energy in unlimited quantities are mind boggling! However, this is what is implied by controlled fusion. It is clear why most of the industrial nations of the world have large controlled fusion research projects under way.

EXERCISES

1. Examine the efficiencies in Table 3 and make recommendations about how and in what form energy should be supplied to meet the needs of a home assuming that the goal is to conserve energy. State clearly any assumptions you make.

2. The following are estimates of household appliances and their power consumptions:

	Power Rating (kw)	Kw Hours Per Month
Air Conditioner	1.325	438
Electric Range	12	100
Refrigerator	0.295	98
Clothes Dryer	4.35	80
Window Fan	.200	58
Color TV	.315	38

All the appliances except the last two could be powered by natural gas if desired. Comment on the energy consumption patterns implied by the appliance ratings. What changes in habits or energy sources would you recommend?

3. The table below shows the energy resources in Russia and in the United States.[12]

Total Resources	Russia	United States
Oil (billions of barrels)	400	100
Gas (trillions of cubic feet)	3,000	1,000
Coal (billions of tons)	4,000	1,500
Hydroelectric (billions of watts)	240	160
Uranium (tons)	1,000,000	660,000

What are the political and economic implications of the information in the table?

4. A scheme that has been seriously proposed is to release perhaps 10 billion kw hours of energy underground with thermonuclear bombs. Assume that half this thermal energy could be captured and used to generate electricity. Comment on the feasibility and, or, desireability of this proposal from any point of view you desire.

5. What would be the implications of large quantities of pollution free electricity. What changes do you feel would take place in our economy?

6. Suppose natural gas furnaces were replaced in homes with electric furnaces where the electricity is generated in a natural gas fired plant. Has there been a gain or loss in efficiency?

7. The direct costs of air pollution to the consumer from all sources has been roughly estimated by the Public Health Service at about $60 per person per year. Power production from fossil fuels accounts for about one-third of this. Suppose massive exploitation of coal resources were to take place. What would happen to the costs of air pollution? What if instead, the economy shifted to nuclear power? What about other types of possible pollution?

8. Municipal solid waste has an energy content of about 5000 BTU per pound. Comment on the feasibility of this as a source of fuel to generate electricity. You may have to look up other information and make assumptions.

PART IV. ENERGY FLOW AND THE QUESTION OF TRANSPORTATION

ENERGY DISTRIBUTION

We are now ready to look in detail at energy consumption in the United States. Specifically we are interested in answers to the following questions:

a. How much of our energy comes from each source?

b. How is this energy consumed by the economy?

c. What is the overall efficiency of the main consumption patterns?

The basis for the answers to these questions is given in Table 4. The numbers are percentages of gross consumption of energy in the United States in 1970 which was 64,600 trillion BTU's per year. This gross consumption for our society is equivalent to:

a. 2.1 billion kw

b. 1.34 million barrels of oil per hour

c. 281,000 tons of coal per hour

d. 5,620 railroad cars of coal per hour

Lumped into a single figure, it is difficult to appreciate this quantity of energy flow. Perhaps the most dramatic impression is that of the consumption of about 6,000 railroad cars of coal each hour to fuel our economy.

To read Table 4, begin in the upper left corner with sources. We note that an insignificant amount (0.3%) of our energy came from nuclear sources. The alarming statistics are in imports of 11.9% of our energy in the form of petroleum and natural gas. Remember that these numbers are the 1970 rates, and are "pre oil crisis." Certainly the imports are higher now! Of the total input of energy, 26.4% is used to generate electricity, and 73.6% is consumed in end uses directly.

Following the table down, we see that almost one fifth of our energy (18.3%) is lost in electricity generation. The 8% of the total which survives in the form of electricity is split in consumption between household and commercial and industrial. Note, however, that household and commercial accounts for only 4.5% of the total. Thus, if all electricity were to be cut off to homes, the savings in electricity would not be as much as might be popularly believed.

Energy Source	Domestic Production	Import	Export	Gross Consumption	Generate Electricity	End Use Consumption
Nuclear	0.3			0.3	0.3	
Hydropower	1.2			4.2	4.2	
Natural Gas	36.2	1.4		37.6	6.2	31.4
Petroleum	26.5	10.5		37.0	3.6	33.4
Coal	23.8		2.9	20.9	12.1	8.8
				100.0%	26.4%	73.6%

	Total	Waste Energy	Electricity	End Use
Generate Electricity	26.4	18.3	8.0	
End Use Consumption	73.6			73.6
	100.0%		8.0%	73.6%

	Total	Household & Commercial	Transportation	Industrial
Electricity	8.0	4.5		3.6
End Use Consumption	73.6	20.0	25.2	28.5
	81.6%	24.5%	25.2%	32.1%

	Total	Waste Energy	Work
Household & Commercial	24.5	5.0	19.5
Transportation	25.2	18.9	6.3
Industrial	32.1	7.2	24.9
	81.8%	31.1%	50.7%
Energy Lost Generating Electricity		18.3	
		49.4%	50.7%

Table 4. Energy Flow through U.S. Economy in 1970
(Numbers are percentage of gross consumption)[11]

No electricity is shown being consumed in transportation. Of course, there are electrically powered transportation systems, but their consumption of energy is less than 0.1% of the gross consumption.

We can easily compute the efficiency of the three catagories of consumption. In each case

$$\text{Efficiency} = \frac{\text{Work}}{\text{Waste Energy}} \times 100$$

Using this relationship, the efficiencies are:

Category	Percentage
Household and Commercial	80
Transportation	25
Industrial	78

One thing is abundantly clear. If we want to save energy, one of the best places to start is with transportation. Since the automobile accounts for the majority of air pollution it is doubly important to find more efficient and less polluting forms of mass transportation.

The two numbers at the bottom of Table 4 are most revealing. Of all the energy that goes into our economy, 50.7% is converted into useful work. Thus, the overall efficiency of our society as an energy conversion and consumption mechanism is about 50%. The other side of the proposition is that 50% of the energy consumed will wind up as a heat load on the environment. Sooner or later, increasing energy consumption (even if new sources of energy can be found) will lead to severe environmental problems because of this overall conversion efficiency. There is precious little hope that the overall efficiency of any industrial economy can be raised significantly above the 50% level.

TRANSPORTATION EFFICIENCIES

As we have seen, transportation activities are among the most wasteful of energy. Consequently, we will look in detail at the process of energy consumption by transportation. To measure the efficiency of transportation, we must consider more than simply the energy input. The whole purpose of transportation (we shall assume) is to move people from one point to another. A car will consume roughly the same amount of energy whether there is a single occupant or two. However, from the point of view of passenger efficiency a car carrying two passengers has twice the efficiency of a car carrying only one. We shall define passenger efficiency as follows:

$$\text{Passenger Efficiency (PE)} = \frac{\text{Number of Passengers} \times \text{Distance Traveled In Miles}}{\text{Gallons of Fuel Required}}$$

Transportation Mode	Number of Passengers	Passenger Efficiencies
Ocean Liner	1600	5
Automobile (urban use)	1	7
	2	14
	3	21
U.S. Supersonic Jet	150	10
	75	5
747 Jet	210	25
	100	12
	50	6
Private Plane	3	34
	2	23
	1	11
Motorcycle (5 Hp)	1	105
Commuter Train (2 level)	1200	120
	600	60
	100	10
Highway Bus	22	140
	10	64

Table 5. Transportation Efficiencies.[14]

We will assume that all fuels have roughly the same energy content per gallon be it diesel fuel, jet fuel, or gasoline.

The largest component of transportation is the automobile. If the average mileage obtained is 14 miles per gallon and the car carries 2 passengers, the PE is

PE = 2 passengers x 14 miles per gallon
= 28 passenger miles per gallon.

If 4 passengers are in the automobile, the passenger efficiency jumps to 56. These numbers convey no particular meaning except in a general sense. Table 5 gives passenger efficiencies for various transportation methods. The range of efficiencies is from 5 to 140. We conclude that a PE of 10 is "bad" while one of 140 is "good." Wherever possible we should arrange transportation modes having efficiencies of over 100.

It is clear that maximum passenger loads are necessary to achieve maximum passenger efficiency. A 747 jet transport with 210 passengers has PE = 25, while if the load is only 50 passengers the PE drops to 6. The author has been on transcontinental flights in a 747 with only 26 other passengers. This ridiculous situations springs from complex roots. It is doubtful whether our economy can afford the luxury of such wasteful practices in the future.

Note that the highest passenger efficiency is for a highway bus. This suggests a very effective and reasonably rapid "fix" for mass transportation problems. Get people out of cars and into buses. A rapid transit system based on buses certainly doesn't have the glamour of a computer operated, electrified system (such as the Bay Area Rapid Transit system (BART) presently finishing completion in the San Francisco area) but probably could be put into operation sooner and cheaper. The economics of rapid transit is a cloudy issue at the present time in all our cities. However, rising prices and increasing scarcity of energy supplies requires a move towards buses and trains and away from private automobiles.

We can extract additional information from Table 5. The fuel consumption is determined by those entries with dotted lines. Suppose a 747 jet flies 210 passengers coast to coast (3000 miles) with a passenger efficiency of 25. Thus

$$PE = 25 = \frac{210 \times 3000}{\text{Gal Fuel}}$$

Or

$$\text{Gal Fuel} = \frac{210 \times 3000}{25} = 25{,}200$$

A bus can transport 22 passengers 3000 miles with a passenger efficiency of 140. The bus will therefore consume

$$\frac{22 \times 3000}{140} = 470 \text{ gallons.}$$

Ten buses could transport the same number of passengers as the 747 above. However the buses would consume 4700 gallons of fuel while the jet would consume 25,200! Of course, the jet completes the trip in about 6 hours while the buses would require at least 75 hours. To cut the transit time by 1/12 requires 5 times as much fuel.

Another characteristic which is important is the carrying capacity of a mode of transportation. To illustrate let us compare the carrying capacity of a lane of traffic and a railroad track. For the lane of traffic, if we assume an average speed of 40 mph and 4 car lengths between cars, about 2000 cars will pass a point in an hour. If each car carries 1.5 passengers on the average, the carrying capacity of each lane of traffic is about 3000 passengers per hour. On the other hand, if we assume a commuter train can carry 1200 passengers, and we can safely run a train every 5 minutes or 12 trains per hour, the carrying capacity of a railroad track is about 15,000 passengers per hour. Thus, a railroad track has about 5 times the carrying capacity of a lane of traffic under the assumptions we have made.

The factors of passenger efficiency, transportation time, and carrying capacity all bear on the design of a rapid transit system. Complex problems rarely have simple solutions and rapid transit is no exception. It is reasonable to assume that significant changes in patterns of mass transportation will require at least a decade, and probably longer. Energy pressures will surely force the move to more efficient modes of transportation.

<u>EXERCISES</u>

1. The program in Appendix A is designed to investigate the energy flow described in Table 4. Recall that the figures in Table 4 express percentage of gross energy consumption in the United States in 1970 (64.5E15 BTU). In the program you will be asked to input the overall efficiencies. Next, assume an annual percentage decrease in waste for each of the catagories. The output is the increase in efficiency due to cutting out waste. Do an open investigation with this program to see how much we might be able to increase our consumption of energy without increasing the supply if reasonable savings can be achieved. Make any assumptions you need.

2. The 1960 gross consumption of energy in the U.S. was 43.1E15 BTU. The 1970 value was 64.6E15 BTU.

   a. What was the annual growth in percent?

   b. What is the doubling time in years? (Hint: Use Rule of Seventy-Two)

   c. If the trend continues unchanged, what will the energy consumption be in 1980 and 1990?

3. The information below describes in detail the residential consumption of energy.[15]

	Consumption (Trillions of BTU)		Annual Rate of Growth
	1960	1968	
Space Heating	4848	6675	4.1%
Water Heating	1159	1736	5.2
Cooking	556	637	1.7
Clothes Drying	93	208	10.6
Refrigeration	369	692	8.2
Air Conditioning	134	427	15.6
Other	809	1241	5.5

a. Based on the data, where is there greatest opportunity for energy savings?

b. Compare the rate of growth of space heating with the annual growth in gross energy consumption in 2a. What information does this reveal?

c. Formulate a strategy to save energy in residential use. Be sure to state your assumptions.

4. The information below describes in detail the commercial consumption of energy.[16]

	Consumption (Trillions of BTU)		Annual Rate of Growth
	1960	1968	
Space Heating	3111	4182	3.8%
Water Heating	544	653	2.3
Cooking	98	139	4.5
Refrigeration	534	670	2.9
Air Conditioning	576	1113	8.6
Feed Stock	734	984	3.7
Other	145	1025	28.0

Compare the annual growth figures with the overall increase in gross comsumption from 2a. What can you conclude? What do you suppose "other" means? Any suggestions for saving energy?

5. The information below describes consumption of energy in transportation.[17]

	Consumption (Trillions of BTU)		Annual Rate of Growth
	1960	1968	
Fuel	10873	15038	4.1%
Raw Materials	141	146	0.4

Compare this data with all the information you have gained. What seems to be implied by the data?

6. The supersonic jet transport (SST) has an uncertain world future. The main advantage is Mach 2.7 (2000 mph) travel.

   a. Use the information in Table 5 to compute the fuel consumption in gallons per mile for a SST.

   b. The airline distance from New York to London is 3500 miles. A SST could easily be scheduled for two round trips per day. What would the daily fuel requirement be for a SST on such a flight schedule? The yearly requirement?

   c. Comment on the feasibility and desireability of a SST fleet (say 100 aircraft) both with regard to energy demands and as a mode of transportation.

7. One of the newest transportation systems in the U.S. is BART (Bay Area Rapid Transit). This is a modern, electrified, computer controlled system. The BART trains are 6 cars long, each of which can carry 72 passengers. During peak periods, trains are scheduled every 90 seconds.

   a. What is the carrying capacity of BART in passengers per hour?

   b. Compare the carrying capacity of BART to that of a highway, to a railroad.

   c. Based on your answer to Part b, what do you feel is the best answer to rapid transit? Explain.

8. The transportation requirements of our economy are varied. Typical trips might include--trip to store: 5 blocks; trip to work: 5 miles; commute to work: 50 miles; occasional long trip: 2000 miles. Using the information in Table 5, design the components of an overall transportation system which would conserve the maximum amount of energy and would fit in reasonably well with the habits and demands of our society.

9. Let us assume that a man can deliver 0.1 Hp for an hour, and in this time could ride a bike 15 miles. Use the information in Table 2 to calculate the passenger efficiency for a bicycle. Compare to the passenger efficiencies in Table 5. Be prepared for a shock.

A NATIONAL MODEL

The computer provides a very powerful and interesting way to look at energy consumption. We will construct a national power model which will take two fundamental factors into account. First, the average yearly growth rate of the population can be determined from data readily available. Also important is the fact that the average power consumption per capita has been increasing.

If the census information of the United States is examined from 1790 to 1970 we find a mean annual growth of 2.2%. The maximum average growth over any decade was 3.1%. The minimum average growth over any decade was 0.7% which took place in 1930-1940. Granted these are crude numbers, but they are certainly in the range of reason. If we assume a 1790 national population of 4 million and a net annual growth of 2.2%, the population in 1970 would be 201 million. The census value in 1970 was 203.8 million. Much of the detailed variation in the net growth caused by immigration, depression, war, etc., is concealed by the simple comparison. However, we can be reasonably sure that when all factors are averaged, the population is growing at 2.2% per year.

While the population has been growing, the power consumption per capita has also been increasing steadily. Averaged over the period 1850 to 1970, the annual increase in per capita power consumption is about 1.2%.[18] A fundamental law of modern countries seems to be "the more power a society consumes, the more it wants to consume!"

With these facts in hand, we can proceed to a simple model which will enable us to project forward into the future. Let us define the following factors:

N = U.S. population (millions)

R_1 = Net annual growth of population (%)

P = Per capita power consumption (kw)

R_2 = Net annual growth in P (%)

P_{tot} = Total power consumption of economy (billions of kw)

The model is quite simple.

$$N_{new} = N_{old} + \frac{R_1}{100} \times N_{old}$$

$$P_{new} = P_{old} + \frac{R_2}{100} \times P_{old}$$

$$P_{tot} = \frac{P_{new} \times N_{new}}{1000} \qquad (3)$$

The third equation in (3) contains a factor 1000 in the denominator since we must multiply by 1 million to convert the population entry, and divide by 1 billion to convert to billions of kw. Hence, 1 million divided by 1 billion = 1/1000. A BASIC program to describe the national power consumption model is shown in Fig. 5. The program contains its own instructions and will be used in the exercises at the end of this section.

```
100 REM A NAT'L POWR
110 PRINT "CURRENT POPULATION IN MILLIONS";
120 INPUT N
130 PRINT "ANNUAL GROWTH OF POPULATION (%)";
140 INPUT R1
150 PRINT "PER CAPITA POWER CONSUMPTION (KW)";
160 INPUT P
170 PRINT "NET ANNUAL GROWTH IN PER"
180 PRINT "CAPITA POWER CONSUMPTION (%)";
190 INPUT R2
200 PRINT "HOW MANY YEARS IN PROJECTION";
210 INPUT L
220 PRINT "PRESENT YEAR IS";
230 INPUT T
240 PRINT
250 PRINT "YEAR","POPULATION","PER CAPITA","TOTAL POWER"
260 PRINT " ","(MILLIONS)","POWER","(BILLIONS OF"
270 PRINT " "," ","(KW)","KW)"
280 PRINT
290 FOR I=1 TO L
300 LET P1=P*N/1000
310 PRINT T,N,P,P1
320 LET N=N+R1*N/100
330 LET P=P+R2*P/100
340 LET T=T+1
350 NEXT I
360 END
```

Fig. 7. A national power model.

AN ECOLOGICAL MODEL AND PROGRAM

At the other end of the energy scale from the gross national energy consumption model is the model describing a small system of plants and its interaction with sunlight, nutrients, and water to produce biomass. Nevertheless, since our very existance is predicated on the well-being of such small biological systems, it might be well in closing to look carefully at such systems.

One of the simplest approaches to a biological system we might consider is as follows. Let I be the input of energy into the system each day from the sun. N_1 will be the amount of biomass present, and N_2 the quantity of minerals and CO_2 available to form biomass. We will assume that the biomass is formed at a rate jointly proportional to the amount of minerals and CO_2 present (N_2), the amount of sunlight per day (I), and the amount of biomass (N_1). The proportionality constant is k_2.

The biomass undergoes respiration which releases minerals and CO_2 at a rate proportional to the amount of biomass present (N_2). The constant of proportionality is k_1. Therefore, the model describing this closed system is as follows.

$$(N_2)_{new} = (N_2)_{old} + k_1 (N_1)_{old} - k_2 I (N_1)_{old} (N_2)_{old}$$

$$(N_1)_{new} = (N_1)_{old} + k_2 I (N_1)_{old} (N_2)_{old} - k_1 (N_1)_{old} \qquad (4)$$

We note that some biomass (N_1) must be present for new material to be grown. Also, I is zero during hours of darkness since photosynthesis occurs only during daylight hours. The program in Fig. 8 describes the model.

```
100  REM AN ECO MODEL
110  PRINT "ENERGY INPUT FROM SUN (KCAL/DAY)";
120  INPUT I
130  PRINT "INITIAL BIOMASS (KG)";
140  INPUT N1
150  PRINT "GROWTH CONSTANT";
160  INPUT K2
170  PRINT "MINERALS & CO2 (KG)";
180  INPUT N2
190  PRINT "RESPIRATION CONSTANT";
200  INPUT K1
210  PRINT "HOW MANY DAYS";
220  INPUT L
230  PRINT
240  PRINT
250  PRINT "DAY","HOUR","BIOMASS","NUTRIENTS"
255  PRINT " "," "," (KG)"
260  PRINT
270  FOR D=1 TO L
280  FOR H=1 TO 24
290  LET I 1 = 0
300  PRINT D,H,N1,N2
310  IF INT(H/12+.5) <> 1 THEN 330
320  LET I 1 = I
330  LET M2=N2+K1*N1-K2*I1*N2
340  LET M1=N1+K2*I1*N2-K1*N1
350  LET N2=M2
360  LET N1=M1
370  NEXT H
380  NEXT D
390  END
```

Fig. 8. An ecological energy model.

Certain assumptions have been made in the model. First, we are concerned with a square meter system containing 50 kilograms of biomass and 500 kilograms of nutrients. (A kilogram is equal to 2.2 pounds). The solar input into the square meter is 50 Kcal per day. For these assumptions a reasonable value for the growth constant is 4E-7, with a corresponding value for the respiration constant of 6E-5.

EXERCISES

1. Suppose our national population keeps growing at a net rate of 2.2% per year, and the demand for power per capita keeps growing at an annual rate of 1.2%. Using the program in Fig. 7, determine what the power consumption of our economy will be in 1980, 1990 and 2000?

   a. Recall that in 1970 our population was 204 million, and the per capita power consumption was 10 kw. Express the results for the year 2000 in terms of the 1970 power consumption, and discuss the influence of the figures for the year 2000.

2. Perhaps we could manage a steady decrease in the new growth in population of 0.1% each year with the demand for power increasing as in 1 above. Modify the program in Fig. 7 to take this into account by adding this line:

```
342 LET R1=R1-0.1
```

   Then compute the predictions called for in Exercise 1.

3. Repeat Exercise 2 except additionally cut down the rate of increase in power consumption by 0.06% each year by inserting the line:

```
344 LET R2=R2-0.06
```

Optional for Programmers

4. Use the program in Fig. 7 modified as necessary to investigate power consumption under any set of assumptions you desire. Look ahead for the next 4 or 5 decades, and try to find a scheme which will save power and which has some chance of being implemented.

---

5. Run the program in Fig. 8 with the parameter values suggested in the last paragraph of the text. What is the net production of biomass per square meter per day?

6. What happens to the production of biomass if we move the system to a more northerly latitude which cuts down the amount of energy available from the sun by, say, 25 Kcal/day?

7. Rerunning the program in Fig. 8, see if you can adjust the respiration factor to form a balanced system. A balanced system is one with the same amount of biomass at the end of each day. If the amount of biomass is changed from the balanced value, does the system move away from or back toward the balanced values?

8. Look up typical values of food production per acre and compare to predictions in Exercise 5. Remember that the model predicts total biomass production, and the food yield is only a small part of this. Assume a growing season of 4 months. One acre equals 4047 square meters.

REFERENCES

1. Committee on Resources and Man, National Academy of Sciences, National Research Council, Resources and Man, W.H. Freeman and Company, San Francisco, 1969.

2. U.S. Bureau of Mines, Mineral Facts and Problems, Government Printing Office, Washington, D.C., 1970.

3. A Scientific American Book, Energy and Power, W.H. Freeman and Company, San Francisco, 1971, p.8.

4. U.S. Bureau of Mines, op. cit.

5. Ibid.

6. Rocks, Lawrence and Runyon, Richard P. The Energy Crisis. Crown Publishers, New York, 1972.

7. A Scientific American Book, op. cit., p.103.

8. Thirring, Hans. Energy for Man, Indiana University Press, Bloomington, 1958, p.280.

9. A Scientific American Book, op. cit., p.37

10. Ibid., p.33

11. Ibid., p.40

12. Rocks, Lawrence and Runyon, Richard P., op. cit., p.137

13. Adapted from: A Scientific American Book, op. cit., p.86.

14. Adapted from: Priest, J. Problems of Our Physical Environment, Addison Wesley, Reading, Massachusetts, 1973, p.287.

15. Berg, Charles A. "A Technical Basis for Energy Conservation," Technology Review, Feb. 1974, p.14., Vol. 76, No. 4.

16. Ibid.

17. Ibid.

18. A Scientific American Book, op. cit., p.6.

45/46

APPENDIX A

APPENDIX A

A Program to Examine Efficiencies

```
100  REM PROGRAM TO EXAMINE OVERALL
110  REM EFFICIENCIES OF ECONOMY
120  PRINT "INPUT PRESENT EFFICIENCIES (%)"
130  PRINT "   HOUSEHOLD & COMMERCIAL";
140  INPUT E1
150  LET E1=E1/100
160  PRINT "   TRANSPORTATION";
170  INPUT E2
180  LET E2=E2/100
190  PRINT "   INDUSTRIAL";
200  INPUT E3
210  LET E3=E3/100
220  PRINT
230  PRINT "INPUT ANNUAL DECREASE IN WASTE(%)"
240  PRINT "   HOUSEHOLD & COMMERCIAL";
250  INPUT X
260  LET X=X/100
270  PRINT "   TRANSPORTATION";
280  INPUT Y
290  LET Y=Y/100
300  PRINT "   INDUSTRIAL";
310  INPUT Z
320  LET Z=Z/100
330  PRINT "HOW MANY YEARS";
340  INPUT N
350  PRINT
360  PRINT
370  PRINT "YEAR"," ","EFFICIENCY"
380  PRINT " ","HOUSEHOLD &","TRANSPORTA-","INDUSTRIAL"
390  PRINT " ","COMMERCIAL","TION"
400  PRINT
410  FOR I=1 TO N
420  PRINT I,E1*100,E2*100,E3*100
430  LET E1=E1+X*(1-E1)
440  LET E2=E2+Y*(1-E2)
450  LET E3=E3+Z*(1-E3)
460  NEXT I
470  END
```