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EFFICIENCY

Introduction

It is usually assumed that the criterion by which technological progress should be judged is efficiency. A much quoted passage from Ellul's *Note to the Reader* prefacing the English translation of *La technique ou l'enjeu du siècle* gives it a central role.

> "In our technological society technique is the *totality of methods rationally arrived at and having absolute efficiency* (for a given stage of development) in *every* field of human activity." (Ellul's italics).

The theme of efficiency therefore runs like a thread throughout the discussion of technology. In this chapter I have brought together the discussion of many different types of efficiency measurement in order to show what they have in common and where they come into conflict.

Ellul's proposition conceals two fundamental difficulties. Firstly, there are very many distinct kinds of efficiency and the concept of a generalized "efficiency" is not very useful. The truth lies in the particulars. Secondly, efficiencies are often in conflict or contradiction with one another in such a way that to achieve one kind of efficiency we may have to sacrifice another kind; this is true not only of the efficiencies of physical processes but between the achievement of such efficiencies and the achievement of social goals. The final section of this chapter is devoted to a discussion of these contradictions.

Efficiency is the maximization of some *desired* output or effect for the least amount of input, means or effort. "Efficacy" might be a better word, as it would distinguish the more general meaning from a narrow engineering interpretation (the French word in Ellul's books, which is translated as "efficiency", is "efficacité'). Efficacy is a measure of the closeness you come to some achievable goal. In any case it is wrong to ignore the word "desired" in the above definition of efficiency because its presence reminds us that the measure of efficiency is always a value judgement. As an example: for the worker, one desirable output of work is personal fulfillment, and this will be factored into her concept of efficiency. The hard-headed industrialist may refuse to acknowledge this.

Efficiency is achieved through design[1], the process by which intelligence is substituted for matter and energy in technological systems. It might be supposed that market forces could be relied upon to bring this about, but this is only partly the case. Efficiency takes on many forms in modern industrial society and some of them are in mutual contradiction.

A process can hardly be considered efficient if it results in social distress or environmental destruction but these important factors are often left out of the efficiency calculation. In fact, we lack a language of measurement to describe them. Winner[2] tells how, in a certain situation, "Regardless of how a particular energy solution would affect the distribution of wealth and social power, the case for or against it had to be stated as a practical necessity deriving from demonstrable conditions of technical or economic efficiency." I shall devote a separate section to the imponderables which the economists call "externalities" and leave out of their calculations.

Andrew Feenberg[3], discussing Critical Theory, observes that, "The concept of efficiency ... is usually applied against a background of unexamined sociological assumptions about worker resistance to work. The point is not that these assumptions are false: they are often true, the result of unquestioned structures of ownership and control that exclude workers from any interest in the firm, resulting in difficult problems of labour discipline. But insofar as this background is ignored or suppressed, the concept of efficiency becomes ideological in its application."

Types of efficiency and their measurement

Efficiency is measured as the ratio of some quantity of output to some quantity of input. Usually, the larger the ratio, the greater the efficiency. Some measures invert the relationship to a ratio between input and output so that the smaller the ratio, the greater the efficiency (see italicized measures in the Table). The input may be labour, energy, raw material, or money (also intangibles such as knowledge and know-how). The outputs include intermediate goods, finished products, power, and cash value. The power may be thermal, chemical, electrical or mechanical. Various units of measurement are used.

Many ratios are given special names such as: labour productivity, yield, energy efficiency, EROI, mechanical efficiency (engineering efficiency), cost efficiency, economy of effort etc. A selection of commonly used measures is presented in the Table below.

SOME MEASURES OF EFFICIENCY

INPUT	OUTPUT	NAME OF MEASURE
power (electrical)	power (mechanical)	mechanical efficiency e.g. drill
power (electrical or thermal)	standard quantity of thermal energy removed per annum	*energy consumption* (inverse of performance efficiency) e.g. refrigerator (840 kW.h/a)
work supplied	heat delivered	coefficient of performance e.g. heat pump (>1.0)
power (thermal)	power (thermal)	thermal efficiency e.g. hot water boiler (85%)
power (thermal) fuel energy per unit time	power (electrical)	efficiency e.g. electric power plant (35%)
energy	energy	EROI energy return on investment e.g. oil extraction
energy	mass of finished product	*energy efficiency* e.g. steel (20 GJ/t)
fuel volume	distance travelled	*fuel economy* (inverse of efficiency) e.g. automobile (6L/100 km)

man-hours	mass of finished goods value of product	labour productivity
work	mechanical displacement	economy of effort
work and skill	number of tasks achieved in a given time	efficiency e.g. as achieved by "efficiency experts" Taylorism.
raw material	finished product	yield e.g. Steel
energy	Value of GDP	*Energy Intensity* (inverse of energy efficiency) e.g. USA (17 PJ/G$ or 17 MJ/$)
power	luminous flux	lighting efficiency e.g. fluorescent lamp (100 lm/W)
cost of investment	profit per unit time	economic efficiency (macroeconomics) e.g. rate of return (15%/a)
cost of production	cost of product	cost efficiency (microeconomics)
flue gas	purified flue gas	scrubbing efficiency e.g. SO_2 removal (99.5%)
crude oil in situ	crude oil to surface	recovery e.g. primary methods (40%)
message or information	speed, accuracy and comprehensibility of information	communication efficiency

The efficiencies in the above table may be grouped in various ways. I have chosen the headings: resource-use efficiency; power generation efficiency; labour productivity; energy use in production facilities; end-use efficiency; economic efficiency; environmental, social and imponderable efficiencies. End-use efficiencies could readily be subdivided and other categories such as transportation and research could be added, but the chosen categories are enough to give the reader a broad overview. End-use efficiency seems to be the field in which improvements would yield the greatest energy savings.

Resource-use efficiency

The efficient use of materials and resources has a dual benefit. In the form of **yield** from an industrial process it tends to increase profit and in the form of **recovery** from a natural resource it also increases the life expectancy of the deposit. Yield is a measure of the amount of finished product from a given amount of raw materials. For example, in 1994 Dofasco Inc. improved its material efficiency i.e. yield of finished steel product, by 3%.[4] Some people group efficiency in the use of materials with energy efficiency on the grounds that, given enough energy, any material can be recovered from waste. In practice there is a limit to this "substitution of factors" set by the entropy law (the second law of thermodynamics) and the law of diminishing returns.

In the development of natural resources we may wish to focus efficiency studies on a material balance (measuring inputs and outputs of energy and materials): How efficiently do you produce a reservoir of oil in terms of ultimate recovery per unit volume of oil in place.? The most common measure is a simple percentage. It varies according to recovery method: with primary recovery the oil flows under its own energy into the bore-hole; with secondary recovery the flow may be improved by injecting water into the substrate (water flood) or by gas pressurization of the capping beds. In tertiary recovery, steam, chemicals or other exotic techniques may be employed to increase resource extraction efficiency. Few recovery methods are more than 50% efficient.

Energy return on investment

A measure of efficiency peculiar to the energy industry calculates the energy output for each unit of energy input. The result is the EROI. If the desired output were simply energy, regardless of quality, it would be foolish to put more energy into extracting the fuel than one got out of the final product. Since it is highly unlikely that such a project would be viable in the marketplace, we find projects approaching a unity or negative EROI mainly in Government-subsidized undertakings. This subject is discussed in rather more detail in the Chapter on Energy Supply and Demand.

Efficiency of power generation

There is no doubt that a considerable reduction in total use can be achieved by increasing efficiency in the production of energy as well as in the more promising end-use

Type of plant	Efficiency (percent)[5]
Conventional steam turbine. Gas fired	36
ditto . Coal fired	34
Combined cycle (steam and gas). Gas	47
ditto Coal (with gasification)	42
Pressurized fluidized bed combustion. Coal combined cycle	42
Steam injected gas turbine. Gas	40
ditto Coal	36
Intercooled steam injected gas turbine. Gas	42
Advanced fluid cells (design concept)	45-55?

applications which I shall discuss below. In principle, the forces of the marketplace should result in a maximization of efficiency in power generation. In practice these forces are strongly distorted by government intervention and monopoly situations.

The table above shows the range of efficiencies attainable in electrical power plants of various design. It shows that there is some room for improvement but also that possible improvement is limited (theoretical limits are set by the Second Law of Thermodynamics). This table shows us that thermal power plants lose between half and three quarters of their energy during the process of conversion to electricity. They lose still more during transmission to the end user. That is why it is important to use energy of an appropriate quality. From a resource-use viewpoint it does not make sense to convert heat to electricity in order to heat something! However, convenience may be valued more than efficiency in some cases.

Second-Law Efficiency[6]

The measurement of power generation efficiency is not as simple as it seems. The expression "first law efficiency" refers to the ratio of (heat) energy supplied to (electrical) energy delivered. It is contrasted with "second law efficiency" which is calculated by making a comparison between the performance of the actual power plant and the efficiency which would be achieved by an ideal heat engine under the same operating conditions. The reference is to the First and Second Laws of Thermodynamics. Marchetti[7] refers to Second-Law Efficiency as "Thermodynamic efficiency". The concept of Second-Law Efficiency is rather technical and so has been relegated to an Appendix. It is applicable to all efficiency calculations but is only of importance to those involving heat.

Researchers have pointed out that if some of the power output is taken as heat, the combined energy of the heat and electrical power produced will exceed the total energy produced when all the power is taken in the form of electricity. The principles have been widely adopted in the technologies known as Co-generation ("combined heat and power") and "cascading".

Co-generation

One of the most common methods of increasing overall efficiency is by co-generation or what the Europeans call CHP, combined heat and power. (Fig. 188) This is a set-up in which electricity is generated and the waste heat that results from condensing the steam in the turbines is used to heat a factory or to carry out some thermal process such as cooking tomatoes. A problem is that there is seldom any demand for low temperature heat in the neighbourhood of thermal power stations. As a result, some "first law" efficiency has to be sacrificed so that the waste heat is delivered at a higher temperature than the best engineering design would permit.

A paradox we find here is that the technological change introduced to achieve conservation at the same time produces **more complexity** and thus more centralized control. Planning for maximized used of co-generation is beyond the capacity of small groups and entails the bringing together of at least two industries. This may prove politically difficult. Where ideal conditions for co-generation exist, e.g. in the pulp and paper industry, most provincial power companies have refused to cooperate. "With big megaprojects to pay for, they're far more interested in protecting their provincial monopolies and keeping power-hungry forest companies as captive customers."[8]

Cascading

Co-generation is a form of efficient energy use called "cascading" because the "waste" energy from one stage in a process becomes the input energy for another stage requiring a lower quality of energy. Another example, from the steel industry this time, is Dofasco's use of the by-product gases from its coke generation process to make steam for use in the plant. (Fig. 414 from Dofasco)

These examples show that the quality of energy is as important as the quantity and it follows that energy budgeting based solely on joules is inappropriate; some utility function has to be included in any energy audit.

Aggregating all sources of energy, we find a conversion efficiency from primary to final use of about 70%, i.e. with about 30% of the primary energy being lost to unavailable heat during conversion and transmission. The difference between these numbers and those in the table is due to the fact that much primary energy is used directly in the form of heat, without the costly conversion to electricity that is needed for high quality applications.

Labour Productivity

In national statistics, productivity generally refers to labour productivity. This is the value of goods produced per unit of labour (usually the man-hour based on the average number of hours worked during the year). Crudely, this might be considered a measure of combined technical and organizational efficiency in the use of labour. A variation, favoured by "efficiency experts" of the Taylorist school, is the number of tasks accomplished in a given time by an operator.

Increases in labour productivity over time that are not accounted for by increases in input factors have usually been attributed to technology but increasingly it is realized that intangible human factors play a most important role.

X-Efficiency

The economist Harvey Leibenstein showed the importance of organizational efficiency in achieving high productivity in the work place. Just as Robert Solow had identified a "technology" residual from his studies of changing productivity over time, Liebenstein demonstrated a residual X-factor to account for differences between firms.[9] Sources of internal inefficiency are both individual and organizational, though the two are linked by motivational procedures.[10]

Taylorism

Frederick Winslow Taylor (1856-1915) was one of the founders of time and motion study which aims to put all aspects of work on a scientific basis. In France Henri Fayol (1841-1925) is likewise remembered[11]. Both had been anticipated by Leonardo da Vinci who in the 16th. C. had studied the movements of workers building a cathedral.[12] Taylor was followed by Frank B. Gilbreth whose particular contribution was to break down a movement into its individual steps, eliminating those which served no useful purpose. Those who adopted the methods of Taylor and the Gilbreths (husband and wife) became known as "efficiency experts" - to-day they would be called management consultants. Taylorism, together with Fordism, was adopted with enthusiasm by Lenin and Stalin in the industrialization of the Soviet Union. (See also "End-use efficiency")

Energy use in production.

Energy use in the production of goods and services can be measured either as Energy Intensity or Energy Efficiency. Both are inverse measures i.e. energy use per unit output, but they have different conditions of use and purposes.[13]

Energy Intensity

The energy intensity of a process at the disaggregate level or of an entire national economy at the aggregate level can be expressed as the amount of energy per unit product, expressed in physical or monetary terms. At the aggregate level only monetary terms are practical. The common measure for an economy is in some multiple of joules per dollar of Gross Domestic Product (GDP). A caution is needed before interpreting the numbers: aggregate energy intensity is directly related to the degree of industrialization as well as being inversely related to energy efficiency in specific applications.

Energy intensity is informative in the comparison of different industrial processes for the same product e.g. mechanical pulping of wood has a far higher energy intensity than chemical pulping which is more capital intensive.

The Energy/GDP ratio has been used to compare progress in energy technologies over a period of time within a given country or between countries. The statistics are hard to interpret because the statistics lump together many variables. The published data plotted on Figure 185 are interesting and, at first sight, encouraging. "The US E/GNP ratio declined 42% 1929-1984, about half of this since 1973."[14]. Since the early 70s there has been a decline in the energy intensity of all the AICs. However, most of the big savings in such industries as the manufacture of ammonia took place in the first half of the century.[15] Lighting is another area in which most improvements had already been made by mid-century (See below). Other factors may give a false appearance of efficiency gains since that time. First, over the period of declining energy intensity in the USA there has been a switch from lower quality to higher quality fuels[16]. Second, there has been a switch from heavy industry to services or, in general terms, from energy intensive to information intensive industry. It is perhaps significant that the ratio has gone **up** in the LICs which have received many of the displaced smokestack industries. Needless to say the problem of prices and exchange rates makes comparison between countries very unreliable.

Energy efficiency

Energy Efficiency is measured as the energy consumed in producing a given quantity of finished product. To be meaningful, measures of energy efficiency must be at a very disaggregate level (e.g. individual firm) or at least across facilities having the same composition of inputs and outputs. The measure can be used for "horizontal" comparisons across firms or for "vertical" time series in a single firm. As an example of the latter the energy consumption per tonne of shipped steel at Dofasco over a five-year period was[17]:

1990 22.9 GJ
1991 23.3 GJ
1992 22.7 GJ
1993 21.8 GJ
1994 19.6 GJ

These data provide a measure of continuing technical progress.

End-use efficiency

Fig. 407 shows, more or less to scale, the energy losses from a coal mine to a power drill in the hands of a householder.

The final step in the consumption of energy is not readily amenable to data gathering and so is often left out of statistics. The problem is that operating conditions are not optimized. Who knows how efficiently you *use* your fridge, freezer and kitchen oven or what the efficiency of your drill and your soldering iron are? Paradoxically, that may be the point at which *the greatest savings can be effected;* and yet to achieve them, we would have to make cultural or behavioural changes rather than technical ones. The subject deserves much fuller treatment than it gets here. Suffice it to say that the energy efficiency of many end-use appliances (power tools, fridges, washing machines, furnaces etc.) is inexcusably low. The competitive pressure of the market place favours "cheap" goods; and various forms of energy subsidy reinforce the poor design choices that are made.

The greatest immediate potential saving in energy use, particularly for a country like Canada, is in electricity. And in electrical use the biggest opportunities occur in lights, motor systems and refrigeration of food. In warmer countries the refrigeration of rooms is a major savings target.

Everyone should, by now, be familiar with the energy savings achievable through the use of fluorescent lighting. Compact fluorescent lamps, for instance, consume 75 to 85% less electrical power than do incandescent ones. We are misled by the manufacturers of lamps who sell us power consumed (measured in watts) when what we want to buy is light emitted or luminous flux (measured in lumens). (Fig. 415).

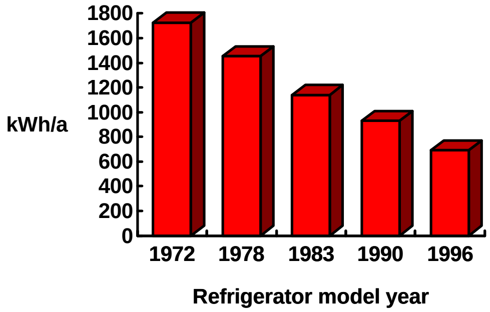
Older fluorescent systems in offices and factories could be retrofitted to save large quantities of energy. A four-tube office light with two ballasts consumes 175 W and emits 7 000 lm. An efficient two tube system with reflectors and one ballast and giving the same light consumes only 90 W (78 lm/W).[18] The latest (1996) specifications offer tubes with electronic ballasts emitting 95 lm/W[19]

The EnerGuide label helps one select appliances, especially refrigerators, that are efficient users of electrical power. Some EnerGuide labels shows the expected energy consumption in kWh/a. For example 840 kWh/a represents an average power consumption of

$$840 \times 1000 \times Wh \div (360 \times 24)\, h = 96W$$

More recent labels show that figure converted to an expected annual expenditure. It is unfortunate that the actual power consumption is not given but manufacturers are always reluctant to place technical performance data in the hands of consumers.

The steady increase in efficiency of average domestic refrigerators over time (largely the result of Government standard regulation in the USA) is shown in the following graph (fig. 409)[20]



Savings in the energy used by domestic appliances can result as much from the efficiency of their use as from changes in the physical technology. Switching off lights, using illumination levels appropriate to the task, organizing the refrigerator, freezer and laundry in an intelligent way, are all steps that can be taken prior to capital investment in technically advanced appliances.

One hesitates to advocate a thorough-going Taylorism in the house, although it seems that Taylor's disciples Frank B. Gilbreth Jr. and his wife Ernestine Gilbreth Carey practised it (their book "Cheaper by the Dozen" made into a movie). The Fourth International Congress for the Scientific Organization of Work (1929) received a report from The Electrical Association for Women:

> The report from Holland by Mesdames E.J. van Waveren-Resink and Muller-Lulofs suggested that there should be an international centre for the training of efficiency experts. A correspondence course on the standardization of household tasks, the choice and operation of labour-saving devices, the rationalization of space and house building, the application of business principles to the management of household finances.
>
> An intensive study of work in the home laundry was given by Mrs. Christine Frederick , a pioneer in the field of applying the scientific principles of motion-study to household tasks.
>
> Frau Silberkuhl-Schulte of Berlin explained how the children were taught economy of effort by means of attaching string to different pieces of furniture so as to arrange that equipment in the most step saving way.[21]

One is inclined to cry "Enough, already, Frau Silberkuhl-Schulte!"

About half the world's oil is consumed by a fleet of 500 million road vehicles, with the number increasing at about 5%/a. This gives rise to a major pollution problem as well as the future fuel supply problem that is part of our problematique. However, it would be inadvisable to concentrate all our efforts on vehicle technology. Computerized traffic management and a heavy switch to telecommuting and video conferencing might make a great deal of current automobile use unnecessary. Nevertheless, achieving efficiency in the residual fleet would still be desirable. In recent years, improvements in fuel efficiency of about 50% have been achieved by the use of light weight materials and improved chassis design. For the major manufacturers, future opportunities are seen to lie in engine design.[22]

The use of new materials in engines and the achievement of continuous high load operation through computer controlled smoothly variable devices are promising lines of research. Both electrical vehicles and hydrogen powered vehicles have their protagonists for environmental reasons but neither fuel has a higher power density (power yielded per unit of mass) than gasoline although the sodium/nickel chloride battery has a fourfold increase in energy density compared to lead batteries. In all future decisions there will be a necessary trade-off between mechanical efficiency, fossil fuel conservation, pollution standards, and the comfort and convenience of the users.

The Rocky Mountain Institute, operated by Hunter and Amory Lovins, have offered a basic redesign of the family car[23]

> An ultra light family car weighing less than 450 kg can still be very safe if it uses shock absorbing materials ...Each wheel could be driven (and braked) by a small "switched reluctance" electric motor, fed in turn by a highly efficient engine sized for the average load; a small battery bank, capacitor or electric flywheel, recharged also by braking energy, would provide surges of power for hill-climbing and acceleration. This approach eliminates the transmission, drive shaft, differential, and axles; perhaps even the brakes and steering gear. We can probably later replace the engine, and batteries too, with a "monolithic solid-oxide" fuel cell; a couple of 15-cm cubes that would burn methane or, ideally, hydrogen, producing 10 kW each. ...The heuristic value of this example is ..to show the conservatism of the dozen-odd prototypes that have already been tested at [fuel economies of better than 2.3 L/100 km].

Economic efficiency

Peter Nicholson, Senior Vice-President of the Bank of Nova Scotia said in January 1992:

> "The world has entered an era where the *objective of economic efficiency* -[my italics]- and the set of political values and institutions associated with competition -- will hold sway virtually everywhere. Globalization and competitiveness...refer to a fundamental shift in the character of the economic relationships between individuals and between societies.[24]

An enterprise exists - in the eyes of most economists - to maximize profit for its owners. Using this criterion, we judge the most efficient firms by the bottom line. This attitude is clearly expressed in the report of Ford Foundation's Nuclear Energy Policy Study Group[25] who decided that "energy should be considered an economic variable, rather than something requiring special analysis".

Economic efficiency can be measured at the macro level or at the micro level where it is usually referred to as cost efficiency. Efficient firms hammer away at cost efficiency because it is something fairly easily measured. Their mistake is to imagine that it can be treated in isolation from matters such as the quality of product or the quality of working life.

Increasingly, efficiency has to be judged not merely in terms the manufacturability of products but also of disassembly so that economies can be calculated on total product cycle.

Environmental efficiency

All people of good will wish to preserve the land, air and water of the Earth as far as it is compatible with their other objectives (e.g. of getting rich). Therefore voluntary or negotiated standards have been adopted in many industries to achieve the reduction of effluents and the recycling of materials. These are susceptible of measurement and the degree to which the objectives are achieved may be considered one measure of the efficiency of the technology employed. A case of particular concern to Albertans is the efficiency with which harmful gases are removed from the flues of gas-processing plants. Successive improvements over the years now result in a removal of over 99% of sulphur dioxide from these gases, with the recovery of the sulphur contributing to the favourable economics of the process. The extraction efficiency corresponding to the greatest economic efficiency depends, of course, on the current market price of sulphur.

In the production of paper, environmental efficiency is measured by the volume of toxic wastes discharged into the river on which the plant is located. The latest processes are, in fact, wholly contained.

In most applications no standard of environmental efficiency has been established and measurement equipment is not installed. Traditionally, these matters were considered as "externalities" by the industries giving rise to the pollution and no concern of theirs. In the developed countries, this attitude has been changed by public pressure during the last few decades.

One measure of great importance is the carbon intensity (analagous to energy intensity) - the mass of carbon produced per unit of production. Carbon is liberated in the form of its dioxide, one of the radiatively active gases (RAGS) in the atmosphere that retain the heat on the earth's surface. An excessive thermal blanket ("greenhouse effect") would cause, and very likely is causing, the average temperature of the Earth's surface to rise with vast and largely unpredictable consequences. At any given time the effect of the RAGS is modified by the presence of particulates and the intensity of the solar flux.

The carbon intensity of a process depends largely on the primary source of energy used. Wood has a hydrogen/carbon ratio of about 0.1, coal of 1, oil of 2, and natural gas of 4. Hydroelectric, nuclear, solar and wind sources of power have zero carbon emmissions. The carbon intensity of an economy depends chiefly on the mix of energy sources supplied.

The reduction in carbon intensity of the world's national economies has been steadily progressing.[26] through a switch to higher quality fuels. However, this does not necessarily mean that less carbon is being discharged to the atmosphere.

Social Efficiency

The problem of social efficiency should surely be our central concern although it is so hard to measure that we may term it "imponderable". What is all this technology for, if not to improve people's quality of life, in terms of their own cultural values? When we replace the craft skills of a local village culture with a petroleum and coal economy, or even with solar panels and other high technology devices, we achieve higher efficiencies. Do we automatically come closer to our goal of social betterment? Many people think not.

Harold Innis wrote: "The effective government of large areas depends to a very important extent on the efficiency of communications. The conquest of Egypt by Rome gave access to supplies of papyrus, which became the basis of a large administrative empire."[27]

If our aim is to achieve global communication of the greatest amount of so-called knowledge at the greatest speed, then we have to look forward to a more efficient system based on a thousand interactive TV channels -- efficient, that is, in terms of data transfer ("bandwidth") and of economic profit. Would it be a more efficient system socially than the one it replaces and renders obsolete based on the printed word? There are doubters even here.

Another aspect of social efficiency concerns the production process itself. If people are not properly administered, are denied the opportunity to contribute ideas, are given useless tasks or macjobs, or are inadequately trained so that they perform below their potential[28] then both social efficiency and economic efficiency suffer.

If the ultimate purpose of technics is the betterment of the human condition, we are entitled to judge any process by the degree to which it meets that end. From a certain ethical viewpoint, social efficiency would be judged by the achievement of social equity (i.e. "fairness", not necessarily equality). But since there are many measures of social welfare, a socially efficient system would be one that maximizes social welfare by some agreed measure.

Contradictions in efficiency

Now, even as I explained the different types of efficiency, it must have become clear to the reader that they are not always mutually compatible. In fact it might be true to say that there are always incompatibilities in the ends of technique when these ends are dissected into their component parts. Amongst the contradictions that I have identified, it appears that it is the search for economic efficiency that most frequently comes into conflict with other desired ends. Perhaps it is time for us to challenge the assumption that in every case of conflict, economics has the right to win? Perhaps it is the economic system that is at fault?

Economic vs. resource efficiency

There is no doubt in the minds of business leaders that economic efficiency should dominate all other considerations. That was clearly expressed by Peter Nicholson in the remarks quoted earlier. Unfortunately firms and nations usually look **only** at economic efficiency measured as return on investment (ROI). This is a **rate** --in other words a time dependent function -- and is often in sharp conflict with the material efficiency. As an example, the faster the oil is extracted from an underground reservoir the higher the ROI but the lower the extraction efficiency.

On the other hand, engineering efficiencies usually go hand in hand with sustainability. Equipment can be designed for durability, ease of recycling, frugal use of material and so forth. We can design equipment which is extremely energy efficient and this should prolong the availability of fossil fuels. But if we wish to be truly independent of non-renewable sources of energy we have to accept lower levels of engineering efficiency; for example in photovoltaic cells where the maximum theoretical efficiency is around thirty percent of incident solar radiation. There is, moreover, a remarkable "efficiency paradox" known as "the rebound effect" by economists.[29] "Improved energy or material efficiency may enable firms to raise wages, increase dividends or lower prices, which may lead to increased consumption by workers, shareholders or customers respectively. Continuing growth will eventually overwhelm gains from efficiency unless the savings are captured by governments in increased taxation for investment in essential natural resource rehabilitation."

Economic vs. ecological efficiency

An obvious example of conflict is between economic and ecological efficiency. The more toxins can be dumped in the public domain and not processed in the plant, the better the bottom line. (This is not to say that responsible firms will always maximize economic efficiency under these circumstances). As another example, consider a gain in the mechanical (energetic) efficiency of a production process. This may result in the production of same amount of goods for less energy, material or environmental impact (the eco-centrist path) or it can result in the production of more goods, and hence inevitably a greater environmental impact, for the same amount of energy that we used before (the techno-centrist path). To the extent that we are stuck in the technic frame of mind we shall probably choose the path of greater production. It is, after all, what we are being urged to do all the time by our political leaders.

If China could be persuaded to switch from coal to gas this would reduce the carbon intensity of its power generation and thereby increase ecological efficiency. But the cost in terms of economic efficiency might well be prohibitive.

Economic vs. energy efficiency

That there may be a conflict between economic and energy efficiencies is made clear in the following passage from a report of the Canadian Energy Research Institute:

> "Economic efficiency is achieved when a given output is produced at the least possible cost, taking into account the costs of all inputs to the production process. Production decisions are made on the basis of economic efficiency, not energy efficiency. Producers attempt to minimize their total costs of production, not the costs of a particular input. This implies that there may often be a conflict between energy efficiency and economic efficiency. Depending on the relative proces of energy and other inputs, it may be economic to use more energy relative to other inputs in order to minimize the total cost of production."[30]

Economic vs. social efficiency

The conflict between economic and social efficiencies is well described by Arthur Okun in the following passage:[31].

> "In this chapter I will examine the ways in which American society promotes equality (and pays some cost in terms of efficiency) by establishing social and political rights that are distributed equally and universally and that are intended to be kept out of the marketplace. Those rights affect the functioning of the economy and, at the same time, their operation is affected by the market. They lie basically in the territory of the political scientist, which is rarely invaded by the economist. But at times the economist cannot afford to ignore them. The interrelationships between market institutions and inequality are clarified when set against the background of the entire social structure, including the areas where equality is given high priority."

Ralf Dahrendorf[32] also discussed the conflict between the respective concerns of efficiency and equity. He showed that a major task of social arrangements is to recognize the conflicts of interest and then to seek a fair response to them, yielding more just distributions of individual freedom.

Economic vs. engineering efficiency

There are also conflicts between the efficiencies ("optimalities") sought by engineers and economists[33] "...[E]ngineers and finance people had very different notions of optimality, one based on technical criteria (resource efficiency, design elegance), the other on bucks (profitability--in the US, expressed in quarterly reports). As each group insisted on the possibility of only one true optimum, the knowledge claims were less quantitatively than qualitatively different. One found truth in the objectivity of science, the other on the revealed practical sagacity of the market." The case of technically obsolete capital equipment provides an illustration of the conflict between engineering efficiency and economic efficiency. Should a manufacturer scrap equipment which is still capable of producing excellent quality goods but has been outpaced in productivity by a newer design? The engineer will want the most efficient plant, the capitalist may find it prudent to get more life out of the old plant or impossible to raise the capital for replacement.

Another consideration is the conflict between different economic interests. Efficiency in the **manufacture** of a lamp may mean more profit for the manufacturer or a cheaper lamp for the consumer. Efficiency in the **operation** of a lamp may mean less profit for the maker and a benefit to the consumer.

Changing attitudes

Attitudes toward the balance between competing efficiencies have changed greatly over the years. The conflict between economics on the one hand and both engineering and social efficiency on the other was recognized as early as 1919 by Thorstein Veblen. But it is safe to say that the importance of ecological efficiency was not generally recognized until 1951 when Rachel Carson published *The Sea Around Us*. Up until that time, reformers set their sights on the maximization of production through engineering efficiency, confident that this was the precondition for social equity. Traditional believers in the theory of the Free Market Economy on the other hand put their faith in economic efficiency, confident that, by the operation of thousands of entrepreneurs motivated by this goal, the best results for society would be reached "as if guided by an unseen hand". The trend in the 1990s toward deregulation is an expression of that belief.

Conclusion

One thing that becomes quite apparent from a consideration of these contradictions is that the concept of efficiency is ambiguous. Ellul's concept of "absolute efficiency" has no precise meaning. What it really refers to is a general economising principle, a principle of parsimony which characterises the technic frame of mind and also, strangely enough, the aesthetic outlook.[34]

Efficiency can mean reducing our demands on nature for materials and energy and must therefore be a major element in any Conserver Society. But it is also the axial principle of the technic paradigm and can invade areas of our lives to which it is entirely inappropriate -- even inimical. An instructive example of different conceptions of efficiency is provided by the case of Francis Galton (1822-1911) who sat for his portrait twice and recorded the number of brush strokes used by the artist. Writing in *Nature*, he observed, "It made me wonder whether the painters had mastered the art of getting the maximum result from their labour."[35] Some would say that, even in its appropriate sphere, that of the production system, efficiency must always give way to the understanding that relations of production, transportation and exchange are relations between human beings.[36]

Review Questions

1. Describe a situation in which the most efficient solution in the eyes of one party conflicts with the most efficient solution in the eyes of another party. Does this invalidate Ellul's characterization of "technique"?
2. Why is end-use efficiency the most difficult to quantify?

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[1]Victor Papanek (1973) in *Design for the real world*, defines the design process as "the planning and patterning of any act toward a desired, foreseeable end".
[2]Winner, Langdon (1986) *The Whale and the Reactor*, p.53.
[3]Feenberg, Andrew (1991) *Critical theory of technology*. New York, Oxford: Oxford University Press, p.69
[4]Dofasco Environment Report 1994.
[5]Data from William Fulkerson et al. "Energy from fossil fuels" *Scientific American* (Sept.1990) 129-135.
[6]Goldemberg et al. 103 et seq.
[7]Marchetti, Cesare (1979) Energy Systems - the Broader Context. Technological Forecasting and Social Change, v.14, 191-203.
[8]"How to save the pulp and paper industry" Financial Times of Canada, Apr. 23, 1993.
[9]Leibenstein, Harvey (1976). *Beyond Economic Man: A New Foundation for Microeconomics*. Cambridge and London: Harvard University Press.
[10]Leibenstein, Harvey (1987). *Inside the firm: the inefficiencies of hierarchy*. Cambridge Mass.: Harvard.
[11]Donald Scott (1970) *The Psychology of Work*. London: Duckworth, p.46.
[12]May Smith, *An Introduction to Social Psychology* (ref. not checked)
[13]McLachlan, Michele & Itani, Imad (1991). *International comparison: interpreting the Energy/GDP ratio*. Calgary: Canadian Energy Research Institute.
[14] Cleveland, Costanza, Hall and Kaufmann (1984) p.893
[15]Goldemberg et al. Fig. 2.29
[16] Cleveland, Costanza, Hall and Kaufmann (1984)
[17]Scaled from figure on p. 8 of Dofasco Environment Report 1994.
[18]Notes on the legal requirements of the Energy Efficiency Act reported in "Homes, offices, see the light and it's going to cost them." by Susan Bourette, G&M 8 Feb 1996.
[19]Hetherington Industries Inc. (www.hetherington.com).
[20]Data compiled by Association of Home Appliance Manufacturers and Lawrence Berkeley Laboratory (Scientific American, Sept. 1990, p74.
[21]Adapted from "Sources for the Study of science, technology and everyday life 1870-1950: A primary reader." Gerrylynn K. Roberts, editor. The Open University, 1988, p.28.
[22]Deborah L. Bleviss and Peter Walzer. Scientific American, Sept. 1990, 103-109.
[23]RMI Newsletter (Summer 1991).
[24]G&M Jan 29, 1992 "Nowhere to hide".
[25](Winner, 1986, p.53).
[26]Marchetti, Cesare (1985). Nuclear Plants and Nuclear Riches. Nuclear Science and Engineering, v.90, 521-526. See also: Jesse H. Ausubel "Can technology spare the Earth." American Scientist v.94, 1996.
[27]Harold Innis. *Empire and Communications* p.5.
[28]Gordon Rattray Taylor (Rethink, 1972, 162) quotes figures from Sen. Philip Hart of Michigan showing that millions of dollars are spent annually on auto repairs which are improperly done, not necessary or not done at all.
[29]William E. Rees "More Jobs, Less Damage". Alternatives, v.21, no.4 (Oct/Nov 1995) p.24-30.
[30]McLachlan, Michele & Itani, Imad (1991). *International comparison: interpreting the Energy/GDP ratio*. Calgary: Canadian Energy Research Institute.(p.7).

[31]Arthur Okun. "Equality and efficiency: the big tradeoff". Godkin lectures. Brookings Institute,1975. Reported by Robert M. Solow, writing in the NYR 24 Mar 1994 p.63.
[32]*The Modern Social Conflict*
[33]frost@csc.albany.edu (Bob Frost)
[34]Wylie Sypher (1968). *Literature and Technology*. New York: Random House.
[35]Review by Tim Radford in Manchester Guardian Weekly, 25 Feb. 1996.
[36]Fr. Lavigne in Vittachi p.126