The miraculous inventiveness of Man shall not be dedicated to his death, but consecrated to his life.

Propaganda from the
Man and Atom Society
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In This Number

THIS first number, of what we hope will become an ongoing series, is necessarily a trifle thin. A considerable part of the material is shared with the **Man and Atom Briefing Book**. We eagerly solicit your contributions — letters of comment, pieces of writing which might suit, illustrations suitable for line or halftone reproduction, extracts of text or image from some source which has crossed your path. (As will be seen throughout, graphics are an especially urgent need.) We mean to be forthright in our viewpoint, but not necessarily bombastic, and certainly not mean–spirited.

Our intent is, first, to articulate our positions to our friends, and to those who might be friends; and, as much as we can, to bring the *story* and the *spirit* as well as the plain facts before the public, recognizing always that those facts (although well recited in many places) are not common knowledge to the man in the street. Indeed — and here is the point upon which attempts at communication, no matter how well–meant, often stumble — he is often not prepared to receive them, not only because they rest on a basis of other facts with which he is not conversant, but even more because he does not have the world–picture into which they fit.

We must take the more care to keep our facts factual, and to be always as honest and forthright as we can, precisely because there are so many merchants of world–pictures who do not scruple over the truth of what they say, or even its accordance with their own views, so long as it draws attention and gains agreement.

> In the early years of this century there seemed no way ahead for the human species, no way to the stars, nothing but a disaster of fantastic dimensions, followed by what at best might be the village life of immediate post–mediæval times. Nuclear energy changed this apparently hopeless situation within a couple of momentous decades. By 1940, the way to the stars was there for the taking.

The Atom in the World Energy Picture

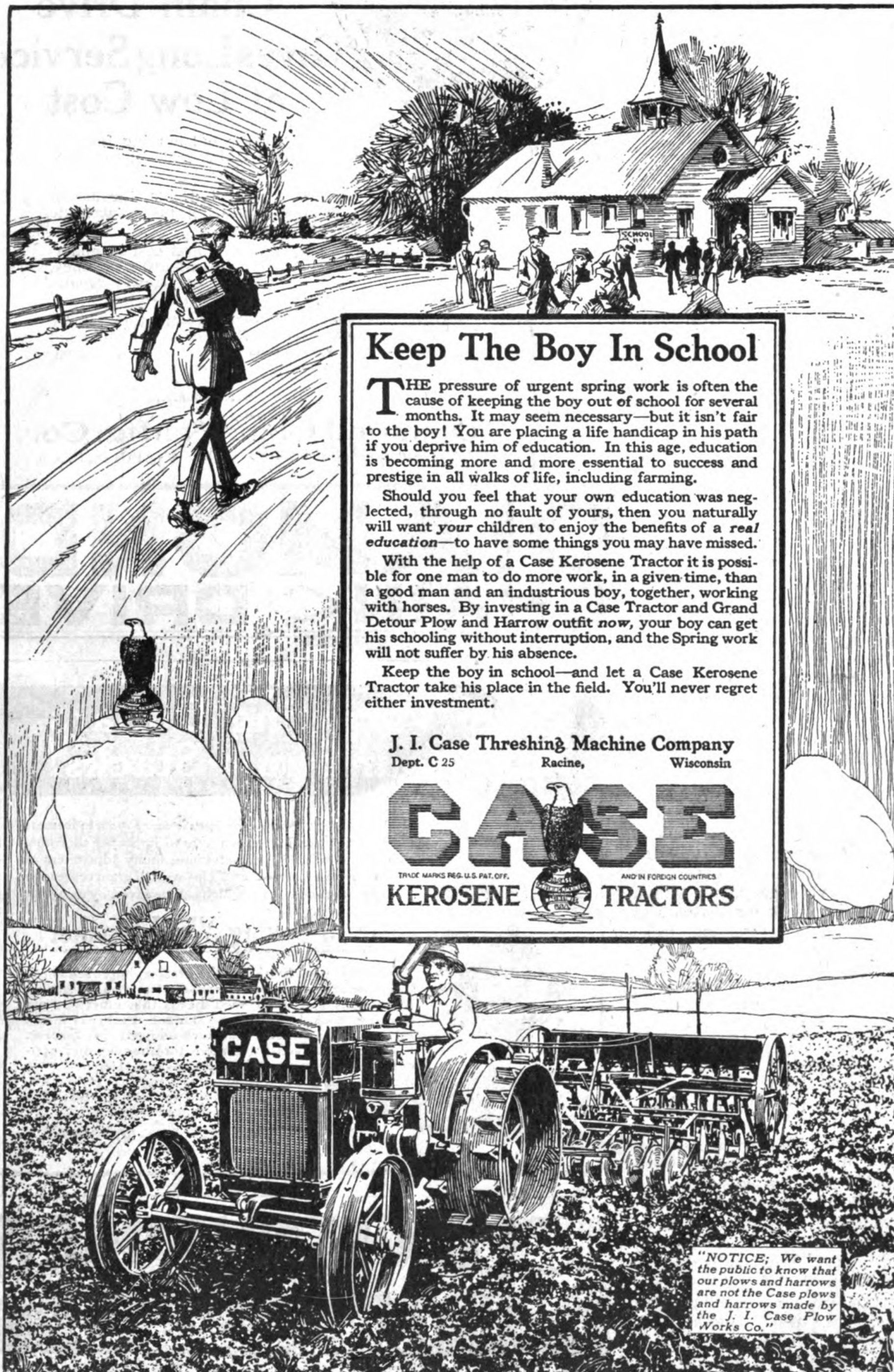
ENERGY undergirds our modern world. Energy is what makes possible the unprecedented agricultural and industrial productivity, without which *eight thousand million* humans could scarcely live on this globe at all — much less could any substantial number of us enjoy leisure and culture. Indeed, we all rely for our daily bread on the fixation of nitrogen by the energy–intensive Haber–Bosch process.

The lion's share of this vital principle, which lights and heats our homes, turns the wheels of our factories, lightens the burdens of toil in the fields and the workshops to a degree unintelligible to men of past ages — which raises and keeps us above the level of the beasts — comes from burning coal, oil, and fossil gas. *And we know that cannot long continue.* These leavings of ancient life are hardly unlimited in extent, and the heavier the draw we make on them, the more work (energy again!) we must put forth to obtain them.

What presses us even harder, however, is the waste. The residues of burning these fuels arise in such unmanageable quantities that we have little choice but to discharge them into our environment. Of course such a torrent of effluvia changes our surroundings, and shifts the balance of Nature. From all we can tell, those shifts are not in a direction that benefits us. And so, to sustain ourselves in a world grown more hostile, we require *more energy.* That may be for keeping us cool in our homes, or for obtaining fresh water when the rains fail, or for building dikes against violent seas — but so long as it comes from those same fuels, the coils only tighten.

For three quarters of a century after Jevons published **The Coal Question**, the only answer seemed to be the radiant energy of sunlight, and its transformations, the potential energy of water, the kinetic energy of wind, and the chemical energy of green plants. These resources, although vast in extent and continually renewed, are spread very thinly over the surface of the Earth, and also very unevenly in both space and time. The press of the period is full of elaborate schemes — for damming the Straits of Gibraltar and allowing the level of the

The demand for energy arises out of a need for energy. The need for energy of groups of people, of a nation, is born out of a desire to live in a just and prosperous society. The demand for energy thus reflects, directly and indirectly, the political aspirations of the people.


Keep The Boy In School
THE pressure of urgent spring work is often the cause of keeping the boy out of school for several months. It may seem necessary—but it isn't fair to the boy! You are placing a life handicap in his path if you deprive him of education. In this age, education is becoming more and more essential to success and prestige in all walks of life, including farming.
Should you feel that your own education was neglected, through no fault of yours, then you naturally will want *your* children to enjoy the benefits of a *real education*—to have some things you may have missed.
With the help of a Case Kerosene Tractor it is possible for one man to do more work, in a given time, than a good man and an industrious boy, together, working with horses. By investing in a Case Tractor and Grand Detour Plow and Harrow outfit *now*, your boy can get his schooling without interruption, and the Spring work will not suffer by his absence.
Keep the boy in school—and let a Case Kerosene Tractor take his place in the field. You'll never regret either investment.
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"NOTICE; We want the public to know that our plows and harrows are not the Case plows and harrows made by the J. I. Case Plow Works Co."

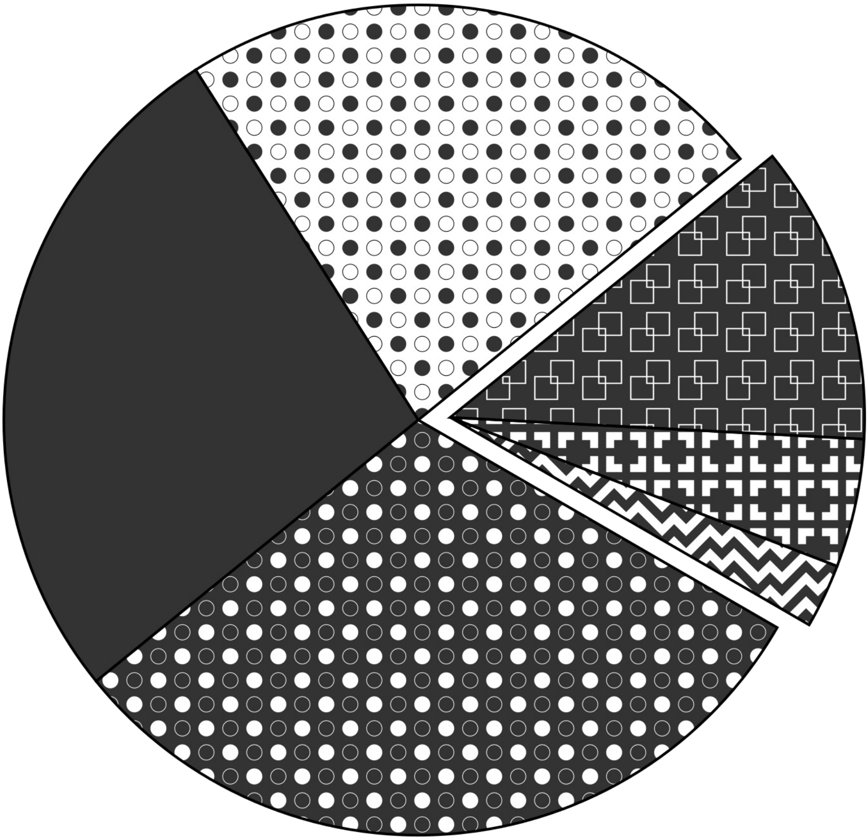
Mediterranean Sea to drop for fifty years, so as to use the Atlantic as a reservoir of hydraulic power; or for a vast circumpolar ring of electrical transmission lines, with branches dipping down to lower latitudes, to collect sunpower at one hour by the clock and deliver it to another. Always looming in the background is the specter of conflict over lands most suitable for such projects. If the Twentieth Century was one of wars over oil, previous centuries, time out of mind, were typified by wars over croplands and forests.

All of this changed forever in 1939, when Halban and Kowarski measured the multiplication of neutrons in uranium oxide powder suspended in heavy water. A self–propagating nuclear reaction implied that the energy locked up in atoms, a million times greater than that in the chemical bonds between them, could be released. At least one person recognized that change immediately: Frédéric Joliot, head of the laboratory (and Marie Curie's son–in–law), rushed across town to the offices of the Union Minière du Haut–Katanga, the world's leading producer of uranium in those days, to negotiate an agreement for cooperation in the peaceful uses of the energy liberated in nuclear fission. Curious to say, both the French and Belgian Governments accepted the agreement, although neither party had any formal authority to bind them. In the end, however, the achievement of the fission chain reaction would come more than two years later, in secret and on another continent, while both countries were occupied by a hostile power.

It appears to be extremely wasteful to convert mass into heat energy by using the chemical or burning process. Last year we converted approximately 10 000 million tonnes of fossil fuels into useless ash and toxic fumes in order to produce heat with an intrinsic efficiency of one part in a thousand million. This is the more worrying when one realises that these fossil fuels are in many cases valuable raw materials for the chemical industries of the future.

It is interesting to note that primitive man in his use of fire to heat his cave was applying Einstein's mass–energy equivalence. This is perhaps the most outstanding example of the practical application of a physical principle predating its theoretical explanation. We have been applying the principle ever since with only marginal improvements in overall efficiency, since the upper limit of about $1/10^9$ is in fact fundamental for chemical processes.

World Primary Energy Supply (2019)
606 exajoules
equivalent to 20 700 million tonnes of coal



Oil.................................... 31% − 187 EJ / 6380 Mtce
1 tce (tonne coal equivalent) = 29·3 GJ

Coal................................. 27% — 162 EJ / 5530 Mtce
Includes lignite, oil shale, and peat

Fossil Gas....................... 23% — 141 EJ / 4810 Mtce
Total Fossils : 81% — 490 EJ / 16 700 Mtce

Other.............................. 12% — 70 EJ / 2390 Mtce
Includes biofuels, waste, and non-hydro renewables

Fission............................ 5% — 30 EJ / 1020 Mtce

Hydroelectricity......... 2·5% — 15 EJ / 512 Mtce

When Experimental Breeder Reactor Number One generated electricity in December of 1951, it proved two things. The first was that the energy of the controlled fission chain reaction could be usefully transformed. This had not really been in doubt, but it had not been demonstrated up to that time, because previous reactors had operated at a temperature too low for producing steam — since Newcomen's "Engine for Raising Water by Means of Fire" circa 1700, the accepted mode of obtaining mechanical work from heat. The second requires some explanation.

As it comes from the Earth, the element uranium, atomic number 92, consists almost entirely of a type of atom having 146 neutrons in its nucleus, and known for that reason as "uranium–238" (^{238}U for short). Fission cannot propagate in these atoms, because the likelihood that one will break up when it encounters a free neutron is too small. Most often, the neutron simply caroms off. One atom in every 140 is uranium–235 (with 143 neutrons), and this impurity is the only substance found in nature that can sustain a fission chain reaction. Uranium, although more plentiful in the crust of the Earth than silver, is certainly neither common nor cheap, and the one–hundred–fortieth part of it so much the less, even before we consider the difficulty of separating the two types of atoms.

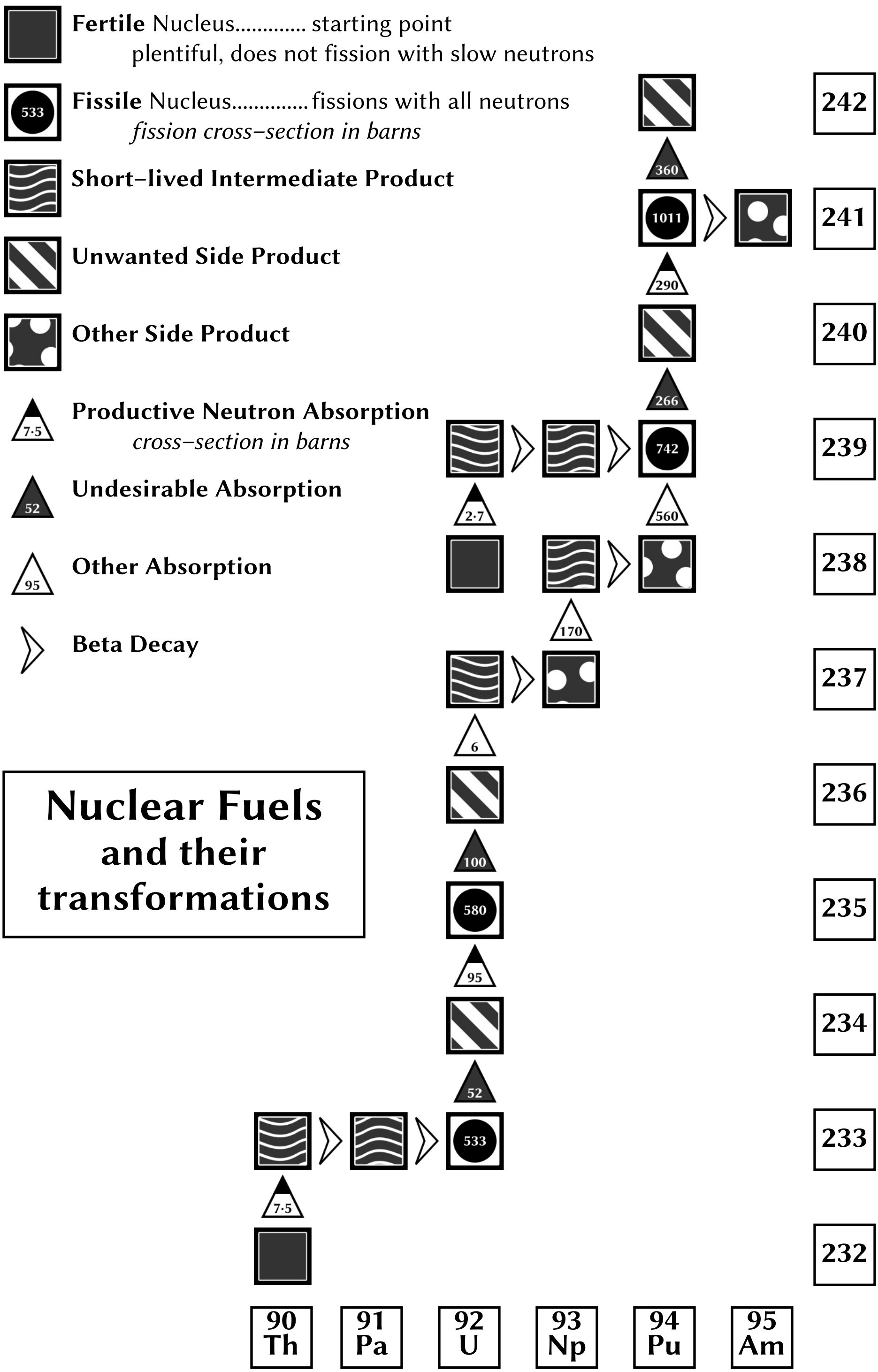
Because the affinity of ^{235}U for slow neutrons greatly exceeds that of ^{238}U, by skillful engineering, a chain reaction can be supported in natural uranium. Some of the neutrons released in fission are then absorbed in ^{238}U, and give rise to a new element, plutonium, atomic number 94. This substance in turn can sustain a chain reaction, and the general effect is to extend the life of the fuel charge, by counterbalancing the depletion of ^{235}U and the build–up of neutron–absorbing fission products. In the end, a trifle over 1% of the uranium can be "burned up". As the fissioning of one gram of heavy atoms yields up approximately one megawatt–day of heat, each kilogram of uranium can now do the work of about thirty tonnes of good coal.

The International System of units of measurement employs prefixes to represent multiplication by powers of ten. When reading the graphs and tables in this publication, it is important to know:

kilo–	k–	10^3 (1000)	tera–	T–	10^{12}
mega–	M–	10^6	peta–	P–	10^{15}
giga–	G–	10^9	exa–	E–	10^{18}

The *joule* is the unit of energy, and the *watt* of power: 1 W = 1 J/s
Electricity is metered by the *kilowatt–hour* of 3·6 MJ (1 GJ = 278 kWh)

Nuclear Fuels and their transformations

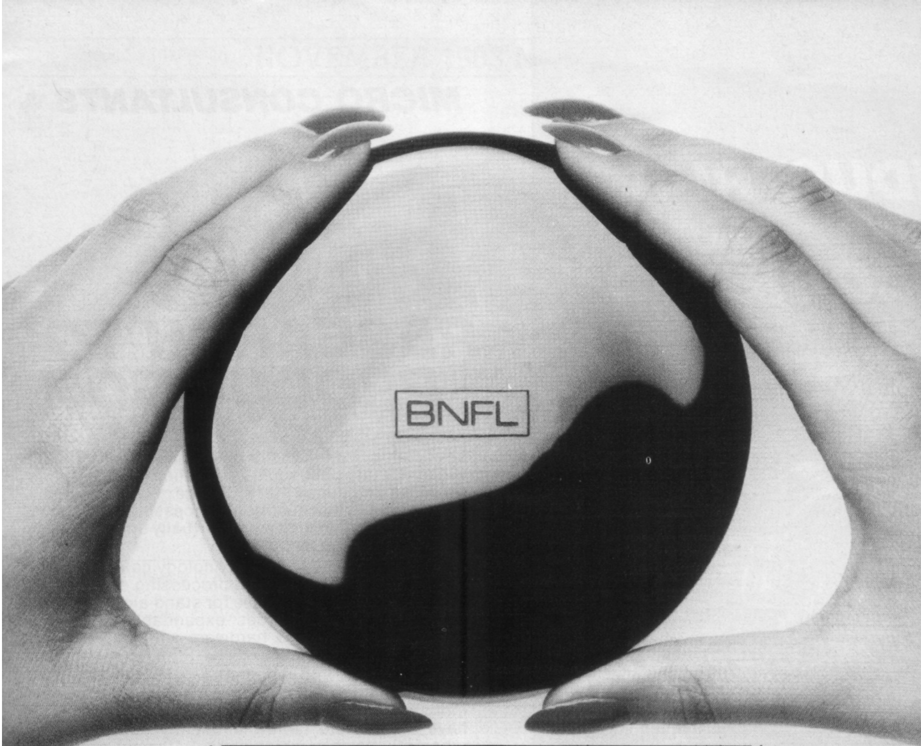


What EBR–I showed is that, in a power–generating reactor fueled partly with separated ^{235}U and worked by *fast* neutrons, the neutron balance can be adjusted so that ^{238}U is transformed into plutonium faster than the ^{235}U is consumed. A few years later, EBR–I achieved the same result using plutonium fuel. With this "fuel breeding", the loop was closed: all the energy bound up in uranium, and not merely the more accessible part in ^{235}U, could be applied to human needs.

What does closing the nuclear fuel cycle mean? First, it multiplies the energy obtainable from uranium ores. It is generally agreed that five to ten million tonnes of the element can be mined, and while three hundred thousand million equivalent tonnes of coal may sound colossal, it is not even a hundred times the consumption of 1955. In that case, fission could make a modest contribution to world energy needs for a few generations, but no more. A hundred times that, however, is more than all the fossil fuels we can ever expect to dig out. Furthermore, thorium, atomic number 90, can be put to work. This element is more common in the crust of the Earth than uranium, and occurs together with the industrially–important rare–earth metals. When used in place of ^{238}U, it forms uranium–233, which behaves very much like ^{235}U, avoiding the loss of neutrons to producing unwanted trans–plutonium elements.

This by itself would secure the global energy supply for the foreseeable future. But the second great consequence of increasing by a hundredfold the energy obtainable from a mass of fuel is to increase the price that can be paid for that fuel. Traces of uranium and thorium are ubiquitous on Earth, in minerals from granite to coal — estimates are that the nuclear fuel that could be scavenged from ash heaps at coal–fired power stations would yield up more energy than burning the coal did. And at about ten times the current price of mined uranium, it should be possible to extract uranium from the oceans, a reservoir of something like 4000 million tonnes, constantly refilled by erosion from the land. We dare call this, by any terrestrial standard, an inexhaustible resource.

> It is unfortunately true that those who have a responsibility for guaranteeing future power supplies start off with a built–in disadvantage, because at all times they must submit their statements to the tests of truth, and of what constitutes responsible behaviour. This is clearly not true of much of the nuclear opposition.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Energy Conservation is not a moral virtue

There is a widespread belief, expressed in the slogan "Negawatts Not Megawatts", that real needs for energy are considerably less than present consumption, which arises from wasteful economic systems. Granted that, in the wealthier countries, demand could be reduced by a change of living habits, such changes are not necessarily quick or easy. People will not give up their cars until they can do their daily errands some other way, and cities are not rebuilt overnight. Moreover, it is hardly obvious that uses such as maintaining a comfortable temperature in one's dwelling year–round are really as wasteful as some would make out.

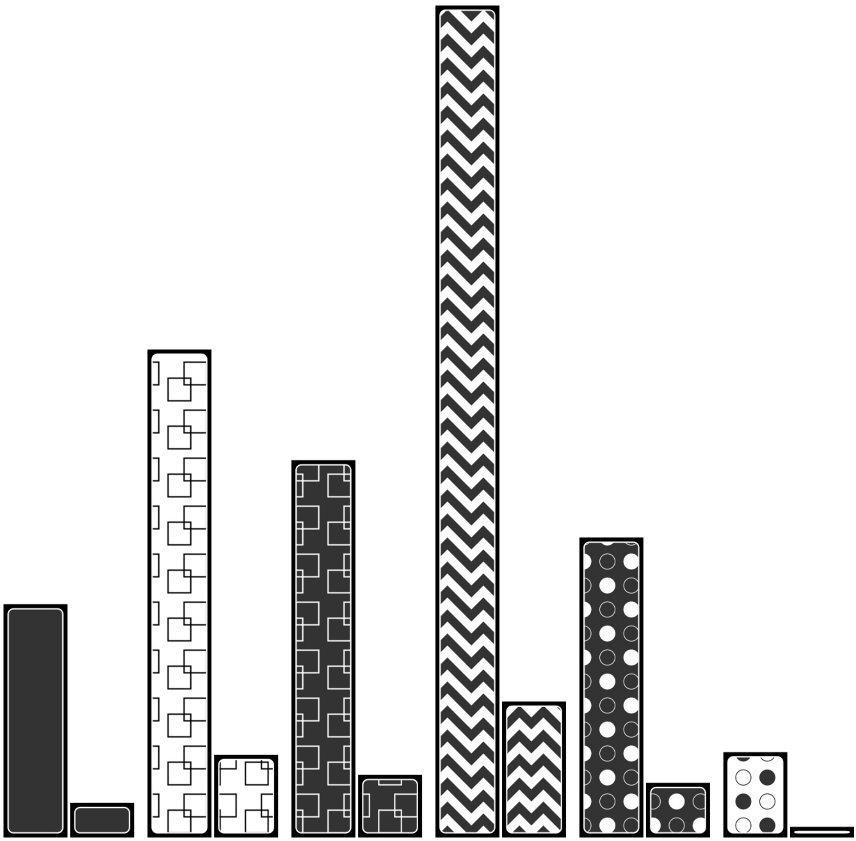
However many people there may be who use too much energy, it is not hard to see that there are far more who use *too little*. Anyone who routinely does agricultural stoop labor, or washes clothes by hand, or carries water in buckets from a stream or a well, is likely among them. Just to equalize world energy consumption at the average for the OECD (**Geographical Note**, page 15), meaning extreme austerity in countries such as the USA, with all the consequent practical and political difficulties, would still require *doubling* the overall supply.

So long as an evil seems necessary, it will not lack defenders. Take away that necessity, and support evaporates. So, once steam provided an alternative to muscle for converting stored chemical energy into mechanical work, a road opened to abolishing slavery and serfdom. Likewise, in a poor society, most people will be poor no matter what, and it may seem a small hardship that they should be poorer yet so that a very few can be wealthy. But in a wealthy society, poverty becomes

Breeder reactors offer the only means, within reasonable extensions of currently demonstrated technologies, for the generation of virtually unlimited energy within the probable resource base.

In a world that is expected to require 35 TW by the year 2030, this fact assumes particular significance. Unfortunately, the 'toggle switch' syndrome has led to the belief in some circles that nuclear can effectively be 'turned off' at about the turn of the century, and the inoffensive renewable sources of energy 'turned on'. In this manner, uranium would essentially have been utilized as merely another depletable resource, in a relatively short space of time. I do not wish to depict a horror scenario, but unfortunately this misguided precept is shared by many. The avoidance of such a scenario is a task we all share as a responsibility to society.

Energy, Electricity, and Population (2019)



World........................... 79·1 GJ per human, of which, 3260 kWh electricity
7666 million humans, 606 EJ, 25 000 TWh

OECD........................... 166 GJ / 7770 kWh (2·1× / 2·4× world average)
1357 M, 225 EJ, 10 500 TWh (18 / 37 / 42% of world)

European Union........ 128 GJ / 5900 kWh (1·6× / 1·8× world average)
515 M, 65·8 EJ, 3050 TWh (6·7 / 11 / 12% of world)

USA............................... 282 GJ / 12 700 kWh (3·6× / 3·9× world average)
329 M, 93 EJ, 4200 TWh (4·3 / 15 / 17% of world)

PR China..................... 102 GJ / 5100 kWh (1·3× / 1·6× world average)
1398 M, 142 EJ, 7200 TWh (18 / 23 / 27% of world)

India............................. 28·7 GJ / 988 kWh (0·36× / 0·30× world average)
1366 M, 39 EJ, 1350 TWh (18 / 6·5 / 5·4% of world)

difficult to defend. And a wealthy society must be a high–energy society, because energy replaces or makes up for things that are actually scarce.

Energy is the universal substitute, for land and raw materials as well as labor. With enough of it, water for cities can be taken from the seas, leaving natural sources of fresh water for agriculture — or *nature*. Valuable minerals can be won from complex mixtures such as garbage or coal ash, rather than rich ores, which have already become scarce. (Genetically–engineered vegetation may help to meet these needs with solar energy.) Food can be produced by intensive agriculture or even hydroponics, releasing marginal or remote lands from cultivation, to serve as reservoirs of biodiversity.

Forecasters at the International Energy Agency, it is true, have indicated a collapse in demand for fossil fuels by 2035, and a gradual fall of overall energy demand by 2050. They justify the latter on the basis of a global transition to post–industrial economics. Since this "transition", in the wealthier countries, has not meant any slackening in the consumption of the products of industry, but only a substitution of imports for domestic products, we wonder how this is meant to work. Even an enthusiastic L–5er must consider it a stretch. If anything, it appears that even a future in which the poor are to remain poor (which is not much of a future after all) will require *more* energy.

Energy Democracy — or Energy Feudalism?

The very same people (in many cases) who published tomes and pamphlets in the 1970s, proving from thermodynamics that electricity was an incorrect form of energy; gave speeches warning that projections of increased electricity demand were merely excuses to build more nuclear power plants; and publicly dismissed concerns over climate effects of fossil–fuel emissions as a red herring; are now urging the immediate electrification of all energy use in the name of

> An acceptable nuclear energy future must above all be one that recognizes and helps fulfil the aspirations of the vast majority of mankind for lives that are not poor, nasty, brutish, and short.
>
> So far in human history, this has meant the replacement of human and animal labor by mechanical energy. The burden of proof that the presently disadvantaged populations should be persuaded to renounce the energy–intensive path that has been successful for us rests heavy on the shoulders of those who propose to thus experiment with other people's lives.

"decarbonization". As most electricity today is generated by burning fossil fuels, the link is not quite obvious. The rationale seems to be that electricity can be produced by wind turbines and photovoltaic cells.

That a thing can be done does not establish that doing it is worthwhile. The use of much simpler solar collectors, requiring no exotic materials, to supply heat, which is much easier to store than electricity, seems to be ignored because it is not fashionable. The arcane elegance of photovoltaics has a tendency to capture the mind. Further, there seems to be a fascination among homeowners with "beating the system" by selling power to the grid. The question of who pays is somehow never asked, but the answer seems to be, neighbors who lack the real estate or capital to install a PV system.

Meanwhile in Germany, which has pursued the wind–and–sun path for more than twenty years, to great fanfare and at enormous expense, the lignite pits daily grow, devouring villages, ancient forests, and even wind–power installations. German emissions, per head of population or Euro of economic output, are twice those of France. And the combination of high power prices and insecure supply is driving away industries. None of this gives any color of plausibility to pursuing such policies in other countries.

The trump card of the advocates of wind and solar is what they conceive to be the self–evident and unassailable moral superiority of "distributed energy". Their ideal is that every household should be responsible for its own energy consumption: this they term *energy democracy.* Central–station power supply, they say, grows out of and reinforces a tyrannical, top–down model of society.

This falls to the ground for two reasons. The first is that much energy use, from manufacturing to street lighting, is not directly connected with any household, but must be provided for somehow. Even if that were not true, however, in their "democratic" energy system, how much energy a household can use depends on how much land and capital that

Abundant energy drives economic development, which can raise a country's standard of living and ultimately improve the prospects for peace in a region. This essential truth fuels a global escalation in energy demand that defies even highly optimistic energy–conservation projections. The world is only at the dawn of a global equalization of wealth, underlined by the fact that eighty per cent of the global population lives in developing countries, and one third currently lacks access to electricity.

household has — how much *wealth.* Since the use of energy itself produces wealth, even small disparities will tend to grow. And wealth distribution in the world today is already immensely unequal.

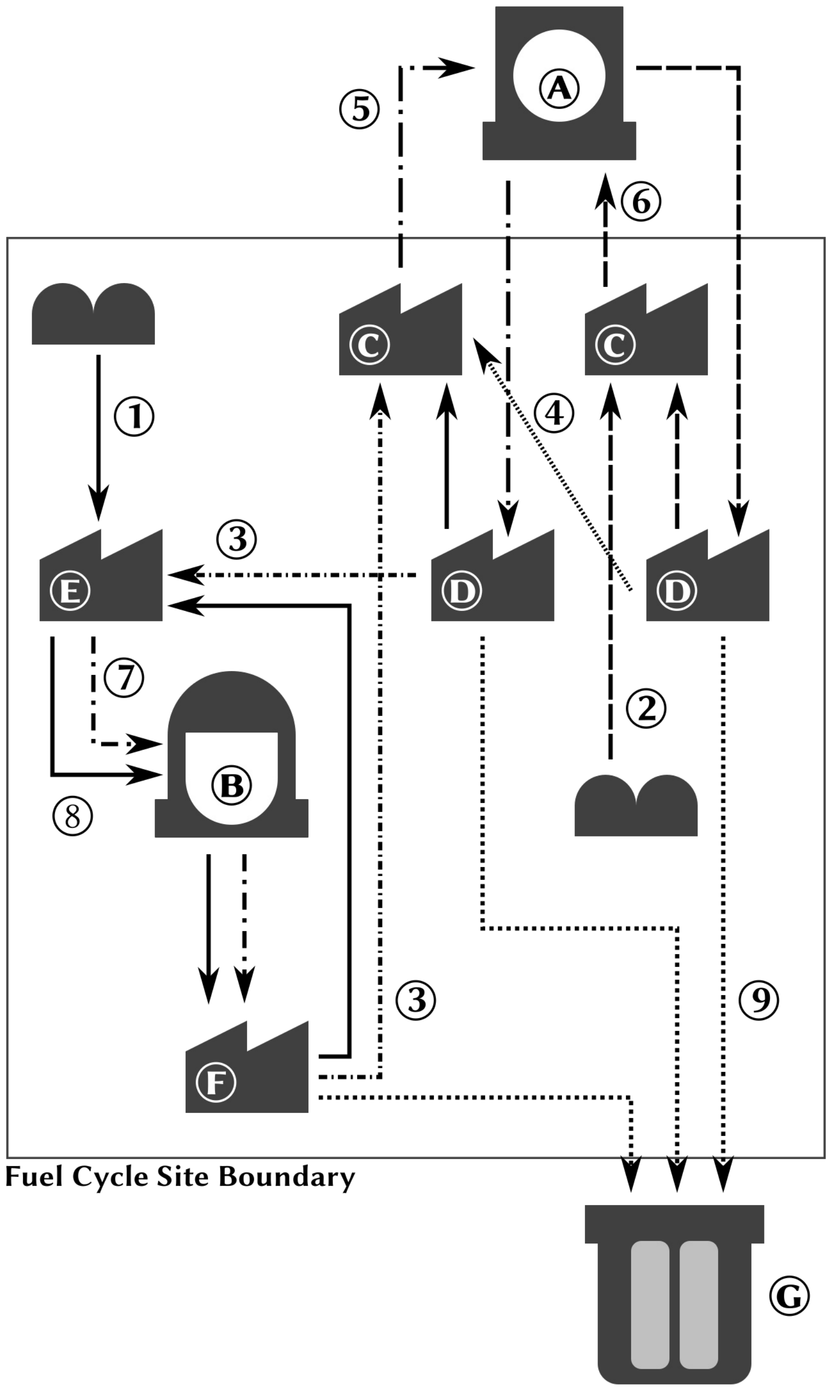
In fact, the whole history of central–station power negatives the claims made against it. Central stations were first built mostly to provide motive power to industry: a great savings, in machinery and fuel, could be made by serving a number of factories from one powerhouse, compared to the old distributed–power plan of a steam engine for each factory. With a modest additional investment, supplies were extended to business offices in the area, and even paying several times what the factories paid per kilowatt–hour, the energy efficiency of the incandescent lamp as compared to gaslight, and the superior quality of its light, made it a good bargain. Within a few years, supplies were extended to the homes of the wealthy — and not long after, the not–so–wealthy, because it was easier to serve them than not. With every new subscriber, prices fell.

The power companies built streetcar lines, providing everybody with speedy transportation; and to sell streetcar fares on weekends and holidays, when power demand was slack, they bought parcels of land at the ends of the lines, and built amusement parks. The physician who developed the electric incubator for premature babies found that he could not get hospitals to adopt the idea, so he set up a ward as an attraction at the greatest of these “electric parks”, Coney Island, New York, and saved many thousands of lives.

Central stations, and the associated distribution infrastructure, are often owned by cooperatives of users, or by municipalities, or regional or national governments. The nature of their business brings even investor–owned power companies under the influence of democratic institutions. They are commonly required, not only to provide universal service, taking on the less–profitable small customer in order to get the large one, but even to supply poor households at concession rates, and

If we continue with the present crippling of nuclear power we will be driven very quickly into the domain of low–grade fossil fuels.

I think, none of us has really fully understood what it will mean for whole regions to be destroyed or moved. We have had a little taste of it at Jülich where artificial mountains are being built by overburdens. The largest pit in the world is being created for the sake of producing lignite — brown coal. What is at stake there is a total of less than one terawatt–year over 20 years. And that isn’t very much.


A
5
6
C
C
1
4
3
E
D
D
7
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9
F
Fuel Cycle Site Boundary
G

Closed Nuclear Fuel Cycle

A........Neutron–efficient slow–neutron converter reactor (dual fuel operation)
B........High–gain fast–neutron breeder reactor
C........ Converter fuel fabrication
D........ Converter fuel reprocessing
E........Breeder fuel fabrication
F........ Breeder fuel reprocessing
G........ Waste disposal
1........ Uranium from stockpile (past nuclear activities)
2........ Thorium from stockpile (rare earth mining)
3........ Mixed uranium and plutonium recovered from discharged fuel
4........ Uranium–233
5........ Converter U–Pu fuel, 12—15 g total fissile per kg, burnup 12—20 MWd/kg
6........ Converter Th fuel, discharged at 30—50 MWd/kg, 12—15 g ^{233}U per kg
7........ Breeder driver fuel, 80/20 U–Pu, discharged at roughly 100 MWd/kg
8........ Breeder blanket fuel, U only, discharged at 15—30 g Pu per kg
9........ Fission product wastes for disposal

The crucial fact in understanding this cycle is that, with U–Pu fuel in the converter (A), the fresh Pu produced nearly makes up for what is consumed by fission. Fuel depletion mostly occurs by the formation of ^{240}Pu, which does not fission with slow neutrons. In the breeder (B), however, this isotope fissions readily.

***Note*:** "burn–up" of nuclear fuels is here given in megawatt–days of heat (86·4 GJ) per kilogram of initial heavy elements (sum of Th, U, and Pu). 1 MWd/kg approximates to 0·1% of heavy atoms fissioned.

Geographical Note

OECD, repeatedly referred to in these pages, is the "Organization for Economic Cooperation and Development". It supports an International Energy Agency (IEA) and a Nuclear Energy Agency (NEA), to be distinguished from each other and from the International Atomic Energy Agency (IAEA), an organ of the United Nations.

OECD comprises Australia, Austria, Belgium, Canada, Chile, Colombia, Costa Rica (since 2021), the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea (Republic), Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, the UK, and the USA. This includes all members of the European Union except Bulgaria, Croatia, Cyprus, Malta, and Romania.

make easy terms for the distressed. Where every household supplies its own energy, such provisions are not easy to make. Is a world in which you have to cultivate the good will of the major local landowner, in order to receive essential services, a *democratic* one?

A Way Forward

If solar enthusiasm does more to exacerbate inequality than to solve energy supply problems, that does not prove that nuclear enthusiasm can do better. Having asked the question for the world as a whole, we will try to answer it for the United States of America, which is one of the largest users of energy, overall and on a population basis. If the USA cannot be nuclearized, it stands to reason that the world cannot.

It must be emphasized that what follows is entirely speculative. Between obstructionist attitudes at the Federal level, the sloth of the Nuclear Regulatory Commission, State measures from nuclear power bans to renewables mandates, and the reluctance of utilities to make even the most desperately–needed investments, technical feasibility scarcely has a chance to enter the picture. In the end, we can only try to answer the question, **"if sanity prevails — what then?"**

As of late 2023, the USA has 93 operating civil nuclear power reactors with an aggregate capacity of 95 835 megawatts, ranging from brand new (Vogtle 3) to 54 years old (Nine Mile Point 1 and Ginna), and rated from 560 MW (Prairie Island 1 and 2) to 1500 (Grand Gulf), all of the inefficient "light water" type. In 2022, nuclear generators supplied a total of 772 terawatt–hours, 18·2% of overall US electricity.

If grid–scale power storage were readily available (even if it were not also very cheap, as renewables promoters usually assume), the impressive annual load factor of 93·1% could presumably be maintained, and the whole electrical load served by 520 GW of nuclear plants. In the real world, system load varies through the course of a day, from day to day within the week, and with the turning of the year, so

> Renewables represent a fascinating and tantalising aspect of the energy scene. They have considerable potential — just a part of the sunlight falling on the UK, or of the heat locked in basement rocks less than 10 km below the surface of the ground, could meet all our national power requirements. The problem is that this energy is either spread out very thinly or is hard to get at or both. We have to be practical about this, tempting though it always is to be starry–eyed about such matters. For us the central question has to be, "at what cost can this energy be produced in a useful form?"

that about half again this amount of plant would be needed. Projections from usually–responsible sources are that electrifying transportation and space heating, the two largest categories of energy end–use primarily served by fuel, will double or triple the total annual power consumption. To produce about 12 500 TWh a year, equivalent to a continuous load of about 1450 GW, would require about 2200 GW of power plants. This is on the scale of nuclear–industry projections of the present day from the late 1960s and early '70s, but they expected to have fifty years to get there.

Certainly, to build as much nuclear power, every year for 20 or 25 years, as the total current installation seems daunting. But what of the alternatives? It is often said that wind and solar are quicker to install than nuclear, but that is difficult to substantiate. Nuclear construction, although involving some very large steel erections and concrete pours, requires much less in total per installed kilowatt than wind and solar, and is a largely conventional engineering job, with workmen and equipment concentrated in a few spots where they can work efficiently, rather than scattered across the countryside.

In the years 1977 to 1990, inclusive, France started up 52 nuclear generating units with a total rating of 56·8 GW, eight of them (7600 MW) in 1981 alone. In Canada, the four 550 MW units of Pickering A station started up between April 1971 and May 1973, and ten units (aggregate 7050 MW) came on the line between September 1982 and March 1987. This record of achievement gives us some hope that industry is equal to the challenge.

Furthermore, a kilowatt of nuclear generating capacity will typically generate three to five times as many kilowatt–hours in the course of a year as a "nameplate" kilowatt of these other sources, and will probably last forty to sixty years, as against twelve to twenty. It appears that a given rate of nuclear capacity addition is equivalent to at least six, and perhaps as much as twenty–five times the rate of renewables installation.

What of the fuel supply? Uranium has been mined in the United States for well over a hundred years, but production today is very small, and industry does not count on recovering more than about 50 000 tonnes from known deposits. Used in efficient and easily–built CANDU reactors, this would give about 290 gigawatt–years of electricity, or about three months' consumption at the rate we estimated for a level of electrification consistent with "net zero" pledges. Certainly there is no future in that! But we anticipated such a result.

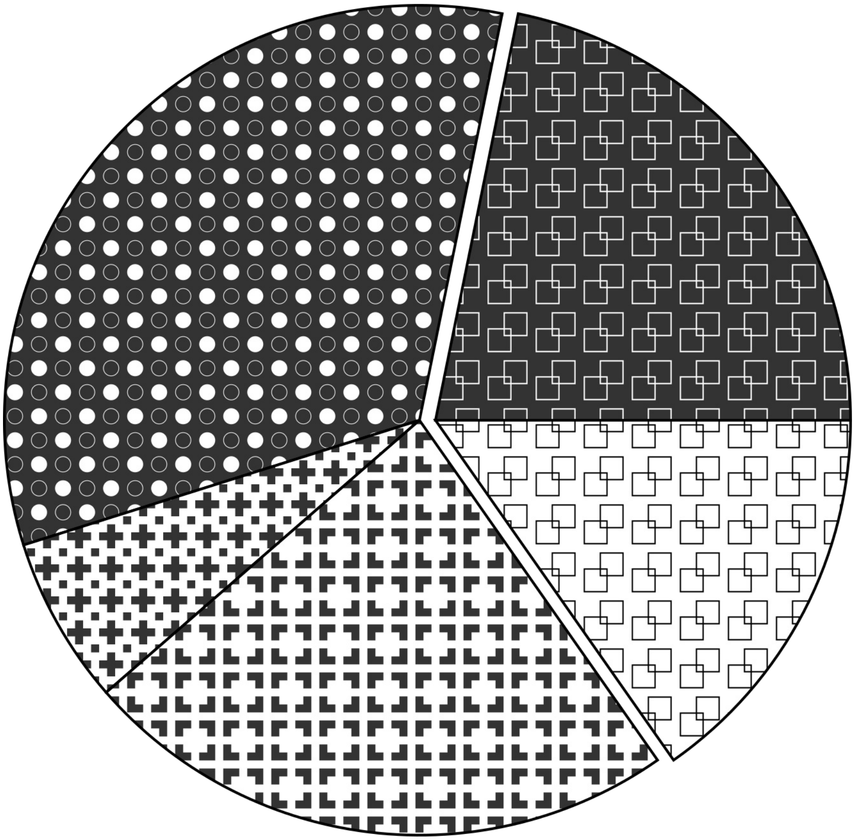
Fifty thousand tonnes of discharged CANDU fuel should contain about 180 t of plutonium, and this gives a hint where we should look. The USA possesses, as the residue of over 60 years of nuclear power, about 80 000 t of spent LWR fuel, of which about 95% is unused uranium, 4% fission product wastes, and 1% plutonium. The uranium, averaging about 1% ^{235}U, will produce about another 450 t Pu when used in CANDU, along with a further 1250 gigawatt–years of electricity. There is also something like 750 000 t of "depleted" uranium, containing perhaps 0·25% ^{235}U on average, which could be reworked to give about as much 1%–enriched uranium as the spent fuel. Various stocks of separated plutonium, including surplus weapons plutonium, have become political footballs, and in some cases have been subjected to ill–conceived attempts at disposal.

In extremely rough figures, then, we have two years of total electrical supply from uranium already mined and to be mined, and at the end of that, 1900 tonnes of plutonium. The General Electric "Super PRISM" fast–neutron reactor design (based on the successful EBR–II) requires 3·6 t Pu for each gigawatt of electrical capacity, so initial fuel charges for a little more than 500 GW of these breeders could be furnished, which is just enough to provide for existing electrical needs. One of these reactors produces an annual plutonium surplus of about 5% of its core loading, so (the phenomenon of compound interest applies here) the installed power could be quadrupled in about thirty years. This is not quite satisfactory, but gives us some hope.

Fuel cycle studies indicate that fast–neutron "breeder" and slow–neutron "converter" reactors can work together in synergism. Rather than attempt a tedious and confusing explanation in words, this has been given in the form of a diagram. ***(See centerfold.)*** The important thing is that each gigawatt of installed capacity of reactors like the

> It would be contrary to all of mankind's experience, throughout the course of history, if the utilization of the tremendous potential of nuclear energy, despite all initial difficulties, did not reach such a degree of development as to overtake other known forms of power. This possibility lies in its high concentration, which distinguishes nuclear energy from other present unusual types of power, the latter having low concentration and spreading over tremendous areas or amounts of mass, so that their use will always require voluminous equipment. The problems of utilizing nuclear power, on the contrary, are problems of high–quality equipment.

World Energy Distribution (2019)
Overall: 606 EJ, 7666 million humans
79·1 gigajoules per human



OECD except USA..... 22% of world energy (132 EJ)
13% of world population (1029 millions)

USA............................. 15% of world energy (93 EJ)
4·3% of world population (329 millions)

PR China.................... 23% of world energy (142 EJ)
18% of world population (1398 millions)

India........................... 6·5% of world energy (39 EJ)
18% of world population (1366 millions)

Everyone Else............ 33% of world energy (201 EJ)
46% of world population (3545 millions)

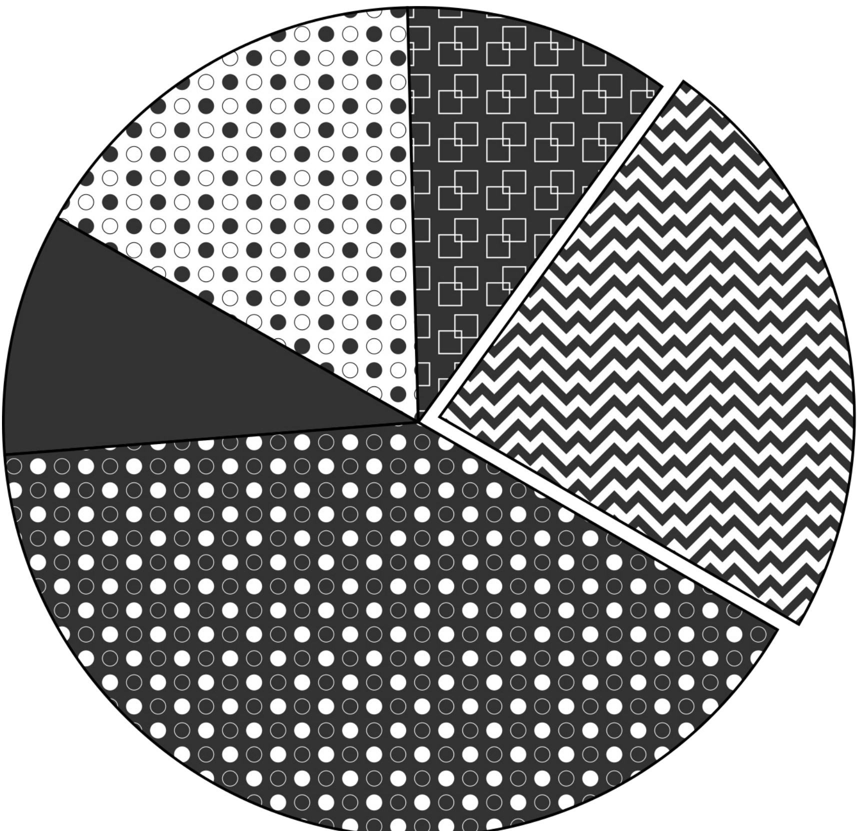
S–PRISM should be able to keep 1·5—2 GW of CANDU reactors (operating at the same load factor) fueled, when uranium and plutonium are recycled. With help from thorium, that "support ratio" becomes 2·5—3.

When we recall that none of this is happening overnight, the picture begins to clear. Build breeders as rapidly as the plutonium supply will allow, and converters two or three times as quickly as that, and we will never run short of fuel. A plant for processing the LWR fuel over 20 years will produce 40 t of plutonium each year. In the first year, then, we build 11 GW of breeders, and 28 GW of converters. The 7600 t of 1%–enriched fuel, from reprocessing and the upgrading of depleted uranium, would generate 125 GW–years, so the bulk of it is put by for later use. That first year, the breeders produce two tonnes of plutonium, and the converters ten, so the second year, 14·5 GW of breeders and 36 GW of converters can be started up. More realistically, the converters would be used for load–following, so the number of units and rated output would be greater for the same overall fuel consumption.

As the installed base of converters grows, they need more fuel every year, until they start to consume the plutonium from the breeders. Then the installation of both types slows, keeping everything in balance. At the end of 20 years, when all the already–mined uranium has been processed, there are about 700 GW of breeders and 1800 GW of converters in the system, and enough surplus plutonium to continue adding about 25 GW of total capacity each year. Although it necessarily represents a very simplified "toy" system, the result of this analysis certainly suggests that the thing can be done. **We have a future**.

Nuclear fuel has one advantage that is immediately apparent and which may have far–reaching impact. From a weight standpoint it is the most portable of energy sources. Hydraulic sources are absolutely fixed geographically. As to coal, oil and gas, there are economic limits to the distances over which these conventional fuels may be transported. With nuclear fuels, however, tremendous quantities of energy are contained in exceedingly small volumes which can easily be moved. Thus, ultimately, the immobility of hydraulic resouces and the transport problems presented by conventional fuels should no longer be limiting factors in energy supply. Moreover, the ease of movement of nuclear fuels could largely compensate for the differences in the availability of conventional energy resources among nations.

World Final Energy Consumption (2019)
418 exajoules
Loss in conversion : 188 EJ
or 31% of primary energy



Oil Products............... 40% – 169 EJ

Solid Fossils................ 9·5% — 40 EJ
Includes coke, patent fuels, coal gas and liquids

Fossil Gas.................... 16% — 69 EJ
Includes gas–to–liquids

Biofuels and Waste... 10% — 43 EJ
Total Combustibles : 77% — 321 EJ

Electricity + Other..... 23% — 97 EJ
Includes district and solar heat

We have not considered importing uranium, which is today considerably cheaper than oil (per unit of heating value, as used in converter reactors). Any serious global movement away from fossil fuels is likely to initiate a scramble for the vital element, and send the price soaring. A better route for wealthy fuel–importing countries might be to finance the building of converter–reactor power–plants in countries, such as Australia and Canada, which have very large reserves of uranium ore in proportion to their populations (and so will not need breeders in the near future), on condition of receiving the spent fuel. CANDU using natural uranium produces over 600 kg Pu per GW–year, and the discharged uranium still contains a similar proportion of ^{235}U to the enrichment tails which we assumed would be worth reworking.

Where are we to put all these power plants, even if we can build and fuel them? A nuclear station disturbs its surroundings less than almost any other industrial facility. There is no smoke or fume, no constant rumble of coal trains. The safety record of CANDU, in particular, fully justifies locating it in the environs of even the largest cities. The Pickering accident of 1983 showed vividly that, even in an extreme scenario, there is no realistic chance of consequences beyond the plant boundary fence.

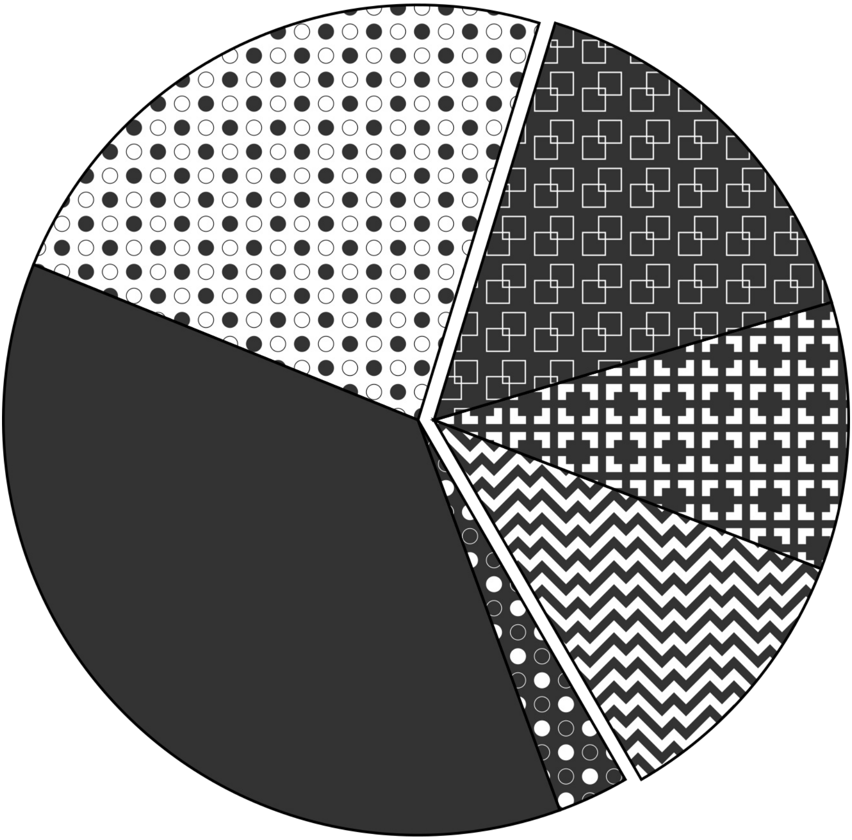
Siting near the load centers has two great advantages. First, it minimizes the acrimony over long–distance transmission lines. Second, it allows running hot–water pipelines to the heavily built–up areas. Not only winter heat, but also summer cooling (the necessary "absorption" chillers are in wide use on the Manhattan steam system), can thus be provided using what would otherwise be waste energy. Low–grade heat also finds wide use in industry. This is conservation at its best.

Solar energy is widely acclaimed as the ideal energy option. Sunshine is delivered directly to where you live, and it is free. These words are often heard, but they are only partly valid.

We are concerned that this public conception of solar energy and reality are not the same. After seeing the amazing solar machines of Pifre and Mouchot, a French government study concluded that solar was (1) undependable and (2) expensive. Solar energy is still undependable and expensive. Ericsson, the American inventor of the ironclad battleship, after many years of building and testing his solar machines, sadly concluded that solar was uneconomic. So did Bessemer.

World Sources of Electric Power (2019)

26 936 terawatt-hours = 97·0 EJ



Oil................................2·8% – 750 TWh

Solid Fossils................37% — 9890 TWh
Coal, lignite, oil shale, and peat

Fossil Gas.................... 24% — 6360 TWh
Total Fossils: 63% — 17 000 TWh

Other............................11% — 2910 TWh
Biofuels, waste, and non-hydro renewables

Fission..........................10% — 2800 TWh

Hydroelectricity........ 16% — 4230 TWh

Breeder reactor plants, on the other hand, might best be located in remote areas already served by transmission lines. The objective is to create fuel–cycle centers where ore concentrates and spent fuel come in, and fresh CANDU fuel goes out. All the most sensitive materials and operations in the nuclear fuel cycle are thus behind one fence, where they can be safeguarded and audited most economically. This contrasts with the current situation, where enriched uranium hexafluoride is routinely trucked from New Mexico to the Carolinas.

It has been estimated that the Hanford site in eastern Washington State, on the Bonneville Power Authority hydroelectric system, could accommodate thirty to forty gigawatts of nuclear generation. This in turn would support 60—120 GW of plants spread across the Mountain West and Pacific Coast. One or two rail–car loads of spent fuel would arrive in a typical day, and the heavily–shielded transport flasks would be sent back with the fresh fuel in them. The USA would require fifteen to twenty such sites.

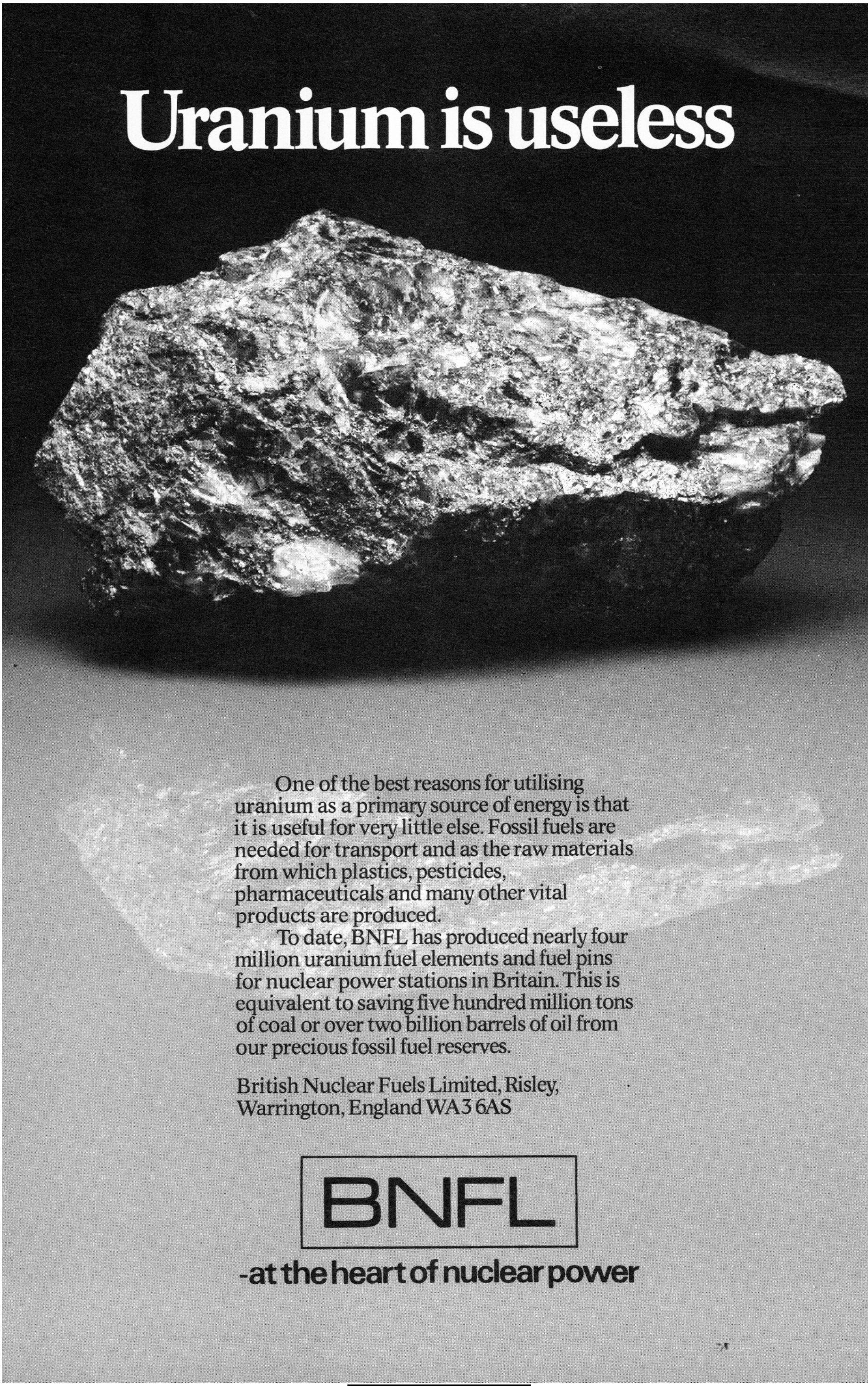
Let Sanity Prevail

"Climate crisis" is the leading political, social, and even artistic theme of our day. On every hand, we meet with calls for rapid and radical action. And yet, bringing in aid the strongest force known to physics is met with caution at best. Many of the loudest voices seem to insist that the most urgent and vital of needs be met only with *ineffective* measures.

Three hundred fifty years since the global transition from renewable energy to fossil fuels began, most of the reasons that drove it are still valid, if not stronger than ever. Already by 1971, when meteorologists were just beginning to find ways of studying the global climate, the fourth (and so far last) United Nations Conference on the Peaceful Uses of Atomic Energy was held at Geneva. At this "Atoms for Development" conference, the benefits of a further global transition, *onward* from fossil to fission energy, were clearly to be seen — and so was an industrial and economic path for that transition.

If we lose the attitude that nuclear energy is a morally suspect last resort, requiring exceptional justification even to be considered, we may find a way forward for the world.

If nuclear energy is not going to fill the gap, what can? The immediate answer appears to be — nothing.


Uranium is useless
One of the best reasons for utilising uranium as a primary source of energy is that it is useful for very little else. Fossil fuels are needed for transport and as the raw materials from which plastics, pesticides, pharmaceuticals and many other vital products are produced.
To date, BNFL has produced nearly four million uranium fuel elements and fuel pins for nuclear power stations in Britain. This is equivalent to saving five hundred million tons of coal or over two billion barrels of oil from our precious fossil fuel reserves.
British Nuclear Fuels Limited, Risley, Warrington, England WA3 6AS
BNFL
-at the heart of nuclear power

Reminiscences of an Atomic Kid

A Day in the Desert

or, how I was bored to death by the first atomic bomb

Everyone has their thoughts shaped by things they learn. Sometimes one may not trust all that one reads, sees, or hears from others, but if you are present when you hear and see things, well that carries a lot of weight.

Okay, so comes the question, how can anyone say an atomic explosion could be boring?

When I was in high school sometime in the late 1970s, I went on a fairly rare tour. This was to the site of the first nuclear explosion. The first bomb was tested in the desert of southern New Mexico, on the 16th of July 1945. The place this first–ever detonation took place has since been known as the Trinity site.

Since September 1953 the area has been regularly opened to visitors. Trips to the site are carefuly controlled, but still there have been many visitors. I have made this trip twice.

While I remember this second visit pretty well, it did not have the impact of my first visit. While I thought it was very interesting and somewhat moving, it was still not such a big thing to me. This was because my memories of that first visit still carried a far greater impression on my mind, such that it shapes to this day how I think about what happened there.

Let me tell you a tale of my first trip to Trinity Site. In the late 1960s, my family lived at Holloman AFB. While I had two older brothers and one older sister, for a reason I don't know I was the only one to go with my parents that day. I would guess my parents figured that my siblings could take care of themselves for the day. So I would be the only kid in a swamp of adults.

Hours of riding in the car was no fun at all. After a long drive through the desert north of Alamogordo, we arrived at what looked to me as no place at all. My memories of that time are still fair. My one thought that has always run through my mind was that we had taken a long dull ride in the desert to come see a pile of rocks with a plaque on its side. As this monument bored me at the time, I spent my time looking around.

The one thing that struck me was how many plants there were about. For most people it would and still does look very bare. But where I grew up, near the air base, there are great alkali flats. Heck, one time I hurt my hand by just pressing it on the ground : the very dust burned me. On the other hand, here at the atom bomb site there was brush and cactus flowers. I remember how the whoever was giving a talk did not interest me much, as my mother was holding on to me to keep me from running around. This gives you an idea how young I was, or how boring it all was to me. Okay, so as a kid I was looking everywhere but where the grown–ups were. So where was I looking? Truly, by this point I was looking at my feet. This is where the one thing that sticks in my mind to this day happened. As I looked down, there was this horny toad. It ran over my shoe. I tried to chase it, but Mom held me back.

Many years later I was told how bad the atom bombs were, and while I have watched many films of nuclear explosions and I know that being blown up is a *very* bad thing. I was also told how they made the ground dead forever. This is something I just can't believe. I have been to where an atom bomb blew up, and while the site may look rather barren, it's about the nicest spot in the surrounding desert.

That horned toad and those flowers tell me that the Earth recovers from these things. Perhaps people will not persist, but the Earth will.

—Lisa Hayes

Quotations

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inside front..... Sir Fred Hoyle FRS and Geoffrey Hoyle, Foreword to **Commonsense in Nuclear Energy** (1979)

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16........................David Mellor, United Kingdom Parliamentary Under–Secretary of State for Energy, addressing the Parliamentary Liaison Group for Alternative Energy Strategies, 29 June 1982

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inside back......Dr Glenn Seaborg (sometime Chairman, United States Atomic Energy Commission) and William Corliss, Foreword to **Man and Atom: Building a New World Through Nuclear Technology** (1971)

Illustrations

front cover...... from a Hispano–Suiza brochure describing the company's nuclear activities, dated 1969

2.........................advertisement in **Power Farming** magazine, 1921 March

4,10,19,21,23....Data: OECD–IEA, **Key World Energy Statistics 2021**

8, 25.................. advertisements in **Atom** magazine (published by the United Kingdom Atomic Energy Authority), numbers 325 (1983 November) and 283 (1980 May)

The work of the Society shall be to advance and promote the wise and vigorous use — simply holding back, out of a superabundance of caution, is no more wisdom than is blindly rushing ahead — of scientific technology, and in particular the technologies of nuclear energy and space travel, “in peace for all mankind”.

This means, first and foremost, conducting a vigorous propaganda: entering into personal contacts, both with the influential who can be influenced and with ordinary people in the streets; mounting fixed or traveling exhibits; and publishing and advertising in a variety of media. When the opportunity arises for acting directly, it should be seized. Likewise, when there is something definitely to be gained by political action, the Society should engage in it. Actions may be taken, depending on the situation, as individuals or in a body, alone, joining in work already undertaken by others, or initiating co–operation.

This will all require money as well as goodwill. It is a vital question whether this money should be sought in the form of membership dues, or whether these should be minimized or avoided, in the interest of attracting and retaining the largest possible number of members. It might prove best to offer an associate membership, secured by a modest one–time contribution, and a supporting membership with recurring dues, and to permit either to be commuted on the basis of notable actions or contributions in kind. Governance must also be considered.

Broadly speaking, a deficiency of public understanding of science poses a problem in a democratic society — especially one that is also a technological society so dependent for its human progress on scientific progress. But in recent years we have become impressed with the fact that public understanding of the atom specifically is an even more urgent problem, as to a growing extent our very future may hinge on how wisely we manage this great new source of energy and its myriad applications.

Human civilization is rapidly approaching a series of crises that can be managed only through some radical departures in Man’s dealings with the relationship between energy and matter. Nuclear energy holds one key — a crucial one — to the successful resolution of these crises. Without it there is no doubt that civilization, as we know it, would slowly grind to a halt. With it not only will we be able to raise a greater part of the world’s people to a decent standard of living, but we will be able to move all mankind ahead into an era of new human advancement — human advancement which takes place in harmony with the natural environment that must support it.

Prospectus of the
Man and Atom Society

Few today would believe that the means are at hand for every human on Earth to live in peace and prosperity, amid a thriving biosphere. And yet it is so. Through the development of scientific technology, humanity has gained (and begun to exercise) immense power to alter the conditions of life on Earth — for good or ill.

The nuclear fission chain reaction and the high–speed rocket do more: they fundamentally change the relation between Man and the Cosmos. The forces which light the stars and shape the galaxies are gathered into our hands. The dread inspired when these powerful instrumentalities literally burst upon the world in the horrible forms of V–2s falling on Antwerp and London, and atomic bombs on Hiroshima and Nagasaki, and by their constant use since that time to menace civilization itself with utter ruin, has kept them from being allowed to do good that the world has sorely needed.

The object of the Society, then, is liberation — from want and fear, from toil and drudgery, from wars over scarce resources, and ultimately from the bonds of planetary existence.

(continued inside)

**The control of intra–atomic energy,
through the nuclear fission chain reaction,
stands in the foremost rank among the
accomplishments of the human intellect.
That the energy so released now lights and heats
homes, and turns the wheels of industry,
from Argentina to Korea,
is a true sign of hope in our times.**
And this world needs hope.

Preliminary Version — Not Revised
Produced by C.D. Carson for the Man and Atom Society
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ATOMIC POWER TO THE PEOPLE!