After examining these results it can be concluded that the highest improvement in the combined cycle city clercy is obtained with the simplest gas cycle. A combined thermal efficiency of about 47 percent is achieved by a simple gas cycle (no intercooling and no reheating) at a moderate compressor pressure ratio of about 3.6. At the same pressure ratio, when using one reheating, the combined-cycle efficiency is about 45 hacting, the combined-cycle efficiency is about 45 hacting, the combined-cycle efficiency is about 45 hacting to increasing the compressor pressure ratio is about 6. Although this is a higher thermal efficiency is about 6. Although this is a higher thermal efficiency is a bellem turbomacidine designed to operate at a pressure ratio of 6 has a relatively large number of a ages which may cause design difficulties. Second, reheating which may cause design difficulties. Second, reheating the belium writing a nuclear reactor is difficult and rather

An investigation into the effect of other operating parameters on the combined-cycle efficiency, limiting the study to the ample gas cycle as being the most far orable, shows that the combined efficiency moreuses discourty with transmin Rankme-cycle efficiency. On the other hand an ageress of about 100 F in the maximum gas cycle temperature produces an average improvement of one point in the combined-cycle efficiency.

An improvement of the combined themast efficiency as actived above the thermal efficiency of either the stational efficiency of either the station of the respective of the most favorable combined in a found to be between a simple gas cycle with no neterooling or reheating and a simple Rankine cycle the efficiency improvement under these conditions anounts to about 10 points at a compressor pressure also of the This does not represent the highest possible distinct outd be schieved through the use of one approvement could be schieved through the use of one closed, with complication in the cycle arrangement. It is believed that, for very large power outputs (i.e., and the cycle arrangement could above), such a combined cycle arrangement could be specievally and above) and above a combined cycle arrangement could be specievally and above a specievally and above a combined cycle arrangement cycle a

Melice, C. "The Exciser Wive AN Cleset-Cycle Tarkins Its stand Development and Pairine Prospects." Tasks ASME Velope A. No. 3, N

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Innotest, R., and Raign, E., "Nuclear Power Flants With High variation in the compressor pressure ratio. Both all gas-ovole thermal efficiency, so and the combined over thermal efficiency, so are represented. The maximum gas-ovole temperature in both arrangements was a lected to be 2000 R. T.g. 4 shows the results for the non-relecating arrangement, while Fig. 6 arcludes the results for single relicating. From these plots the flowing is ovident:

The thermal efficiency so is impressed appreciate over the individual cycle efficiencies through the other ing the thermal energy in the exhaust helium leading the regenerator to broat the thermal energy in the exhaust real the the limit of the thermal energy in the exhaust on the the regenerator to broat the flowing cycle.

no intercooling than eather for one of two intercooling stages because the thermal energy in the exhaust gaze's decreases as the number of intercoolings increases. For example, the thermal elliptionery of a non-reheating combined cycle (Fig. 4) at a compressor pressure ratio of 3 has increased from 36 to 46 5 percent without intercooling, while when using one intercooling the efficiency increases only from 38 5 to 43 8 percent. Even less improvement is obtained when two intercoolings are

e The compressor pressure ratio for maximum afficiency changes to a higher value through the use of
the combined cycle. The shift is smaller in the case of
non-reheating (Fig. 4) then with one reheating (Fig. 5),
and it decreases upon increasing the number of intercoolings.

c. = specific heat at constant pressure

t = specific enthalpy of steam (unlex 1, b,

nud d, Fig. 3)

m. = number of intercoolines during compression

m. = mass flow rate of steam per unbrance

flow rate of behan

que en heat added ser unit muse flow three in the gas or steam evole; respectively

T = absolute temperature (for different indices, Fig. 3)

u. w. = specific compression or axpansion work.

w. w. = specific compression or expension work respectively, in the gas cycle with w. w. = net specific work for the gas cycle or stends cycle, respectively

y = isoptropic expensed for helium

f = pressure loss factor

g = the combined-eyele thermal ethology

y<sub>0</sub> y<sub>0</sub> = isontrapic efficiency for congression or

expansion, respectively

on g = cos or itankine-eyele efficiency remain

tively

If, II, = everall pressure ratio in the case cycle

for compressor or turbine, re-redively

xs = gas-cycle representation about the mess.

18 / AUGUST 1971 / MECHANICAL ENGINEERING

# POWER INTER YEAR 2001

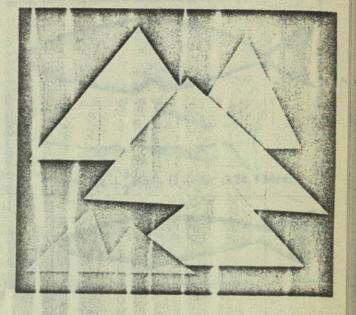
Part 1-Dawn of the olar Ag

Those bounti s of nature, our fossil fuels, wil be effectively exha sted in 200 or so years Before this c mes 1) pass, we shall burn the seas and the ocks r, ultimately, directly tap the sun's heat for ou energy needs. This is not a statement of desperation. Technologically, no insuperable problems exist. The core prob lem is rathe one of bia and inertia tha seems not to evaporate except under the hea of crisis. To place the energy picture of the not-too-distant future into focus, a series in initiated, in this issue, of major and innovative energy systems tha have his in common Any one of them, if fully exploited, could mee our ene gy ne ds for many millennia with mini mal or no insult to the environment.

### SAMUEL WALT ERS

"ENERGY," sai Jame Clerk Maxwell, ninet enthcentury British s ientist, "is the go of things." And ever since Watt' engine in the eighteenth century used the chemica energy of wo I and coal to power industrial machin's, we have be n "going" at an accelerated rate. I rior to this, for millennial time man plodded along, er ergy-wise, at a donkey walk. But between 1830 and 1860, we broke into a tro . Re: ction and impulse turbines for extracting the potential energy of water stored at high heads were develored. (1 the heels of these developments came Otto, Jaimle and Diesel. Their achievements, between 1: 74 and 1905, led to practical internal-combustion englies operating on liquid hydrocr bon fuels such as oil, gasoline and lerosene. At about the same time, Pars as developed the steam turbine and not long af er that at about the

1 Staff Editor, MECHANICAL ENGINEERING.



beginning of the twentieth century, the first steamturl me-driven electric power generating plants went into operation. We broke into a canter.

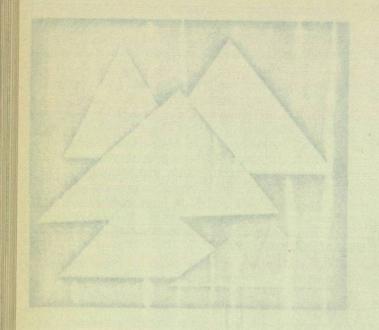
Fer capita energy consumption and population so and—together. Until recent times they have alway moved together. In fact, curves of population and per capita energy consumption over the past score of rillennia are indistinguishable from one another. The plot as a nearly horizontal line just above zero for the entire period of human history until the last the isand years or so. Then a birrely perceptible ise begins as the present is approached. Here the curve turns about 1970 orld population figure of about 3.6 billions. Curves of energy production from the fossil fuels behave similarly except that in the very recent past they begin at 2 ro [1].

Ve are probably now approaching full gallop. In terrest of Q we its of energy, the energy transformation is surfling. From the time of Christ until the middle of the last century markind used about 8 Q. In the last century 4 Q were consumed, and, extrapolating from current trends, the need in the next century will be 1 tween 100 and 400 Q. (The United States alone, with only 6 percent of the world's population, consumes 37 percent of the world's energy.) Even if all known marking and submarging the energy source would not be alleviated. The energy resources are limited—about 81 G for the United States and 452 Q for the energy planet [2].

Since the known recoverable reserves at fas il fuels are limited (6 Q for the United States and 23 C for the entire world) and the supply of uranium 235 will be in short supply within 20 year, the human population

Numbers in brackets de ignate References at end of article.

1 Q = 10<sup>18</sup> Btu or 2.93 × 10<sup>14</sup> kwn. Recall that the British thermal unit, or Btu, is defined as the heat necessar to raise by 1 deg F the temp rature of 1 lb of water. To give a plusical idea of the size of the 4 it represents the heat liberated by the combustion of 38 billion tons bituminous coal. Another example: If we head 400 million automobiles, each with a 100-bit engine, and rea them it full throttle night and day for an er tire year, we would consume an amount of gasoline equivalent to all out one 2 of energy.



POWINE TUNE TO SOUTH THE S

24 1440 Side (4 1842)

be effectively exhe sted in 200 or so years Before this comes a pass, we shall burn the seas and the ocks r, uitin stely directly tap

the stars need for our energy leads. This is not a statement of desi gration. Technolog cally no insuperable problems exist. The core prob

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used the chemics course of we had east to some industrial machines, we have by a "going" at a recelerated rate. I rice to this, for militarines tone maplodded along, as expressed, at a dones, while Bubetween 1830 and 1833, we broke two a tro-

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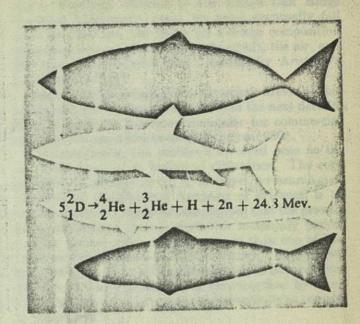
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DIRECTION OF EARTH AROUND THE SUN

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thermal leg F the resize of 38 billion remillion throttle A continued rise for a brief period followed by a radual leveling to some stable figure which the world's nergy and material resources are capable of supporting for a long period of time.

• An overshoot of any possible steble level and a drop downward to eventually stabilize at some level compatible with the world's resources.

• Resource exhaustion and a general cultural decline.

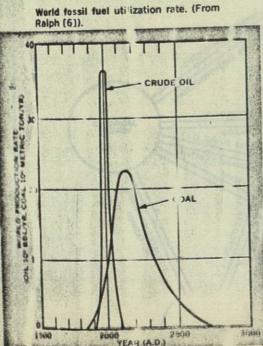
The curve would then reflect a population corresponding to the lowest energy consumption level of a primitive existence.

What is not possible is an unlimited population growth. Consider this: If the luman doubling time of about 100 years were to perset, then in the year 2970 there would be about 10<sup>12</sup> persons on eartly Infact, if the present world population were to double

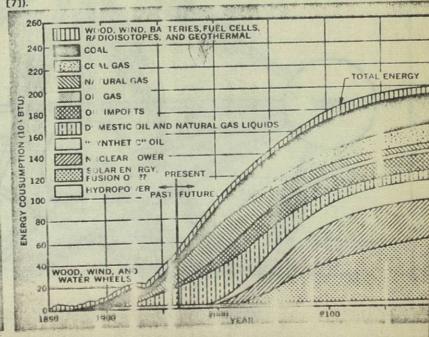
# TABLE Reserves in Fossil Fuels

Fuel	U.S., Q	World, Q
Coal	4.600	18.00
Natural gas	0.310	2.11
Petroleum	0.278	1.70
Oil	0.298	1.70
Total	5.486	22.91

(From Duncan and McKelvey, U.S. Geological Survey, 1964 [5]).



Energy or isumption in the United States, past, present, and future. (From Gaucher [7]).



MECHANICAL ENGINEERING / SEPTEMBER 1971 / 28

one man for each square meter on all of the land areas National Laboratory, notes, we must eventually fall of the earth, including Antarctica, Greenland, and the back on "the sea, the rocks (of average composition Sahara Desert." [1].

trialized world through thermonuclear war, one must fou elements ["[4]. assume that humanity will opt for the second alternaraphers [3]) are that the population of the earth will stabilize at about 7 × 10° sometime within the next century [3, 4]. But where then are the sources of energy of appropriate magnitude to sustain a highenergy-dependent world culture?

Some energy sources -falling water, the tides, and under which they can be utilized are limited. The world's potential supply of water power, for example, is comparable in mag itude to the present rate of energy consumption from fossil fuels. However, most of this occurs in the industrially undeveloped areas of only be utilized by a parallel industrialization of these areas. In addition, although water power is capable of continuing for periods of geologic time, a practical limit in the case of large dams and reservoirs is set by the period of a few centuries required for the reservoirs to fill with sediments.

Geothermal and tidal energy are now being exploited in a few suitable sites around the world, but the ultimate amount of power from these sources does not promise to be larger than a small fraction of the world's present / requirements. This leaves us with: nuclear energy, rock burning (fission) and sea burning (fusion); solar 7 Gaucher, L., "Energy Sources of the Future of the United radiation; and the thermal heat of the oceans. As States," J. Solar Energy Soc., Vol. 9, 1965.

but 15 or more times, "there would be in the year 2500, Alv in Weinberg, director of the AEC's Oak Ridge since true ores will have been exhausted), the air, and Barring the apocalyptic destruction of the indus- the sun (equated with fire) ... essentially Aristotle's

f ea burning, although still a physicist's dream at this tive. Predictions (by consensus of leading demog- stage, may yet become a reality within the next decade. If o it could be a serious contender for commercial po ver in the quantities needed by the year 2001.

'echnologically, the problems involved pose no insuperable physical or biological difficulties. The core problem, to paraphrase M. K. Hubbert, a research geophysicist of the National Academy of Sciences, is to the winds-are self-rer ewing, but the circumstances up root the deeply ingrained assumption that the growth rates which have characterized this temporary period are the normal order of things rather than one of the most abnormal phases of human history. This period is, he believes, "a brief transitional episode between two ve v much longer periods, each characterized by rates Africa, South America, and Southeast Asia, and could of change so slow as to be regarded essentially as periods of nongrowth."

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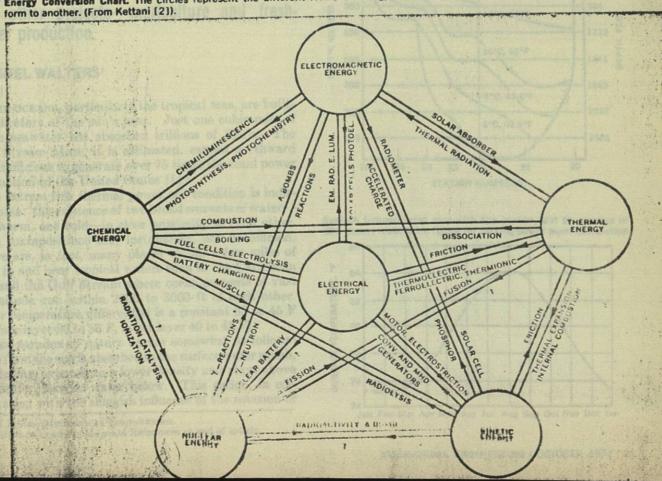
Vi cing Press, New York, N. Y., 1957.

i Weinberg, A. M., Physics Today, Nov. 1959.

5 Cambel, A. B., Energy RD and National Progress, U. S. Gevernment Printing Office, Washington, D. C., 1964.
3 Ralph, E. L., "A Plan to Utilize Solar Energy as an Electric

Power Source," Proceedings, Eighth Photovollaic Specialist Conference, Scattle, Wash., 1970.

Energy Conversion Chart. The circles represent the different forms of energy and the arrows the ways of converting energy from one



energy of appropriate magnitude to sestain a highenergy dependent world entered.

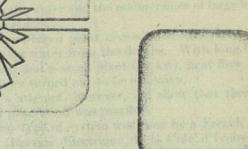
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but 15 or more times, "there would be in the year 2500. Alv a Weinberg, director of the AEC's Oak Ridge one man for each square meter on all of the land areas National Laboratory, notes, we must eventually fal one man for each equare maker on an or the land the back on "the sea, the rocks (of average composition of the earth, including Antareties, Greenland, and the back on "the sea, the rocks (of average composition



Part 2-Thermal Sea Power





Advances in underwater technology can now realize the old idea of generating power from temperature differences between tropical surface waters and colder currents flowing directly beneath. Such a tantalizing project is now underway in the Caribbean in combination with two other projects-mariculture and freshwater production.

## SAMUEL WALTERS

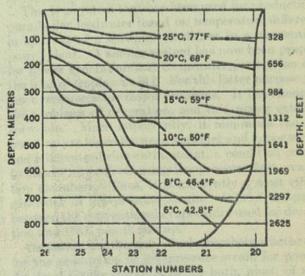
THE OCEANS, particularly the tropical seas, are builtin collectors of the sun's heat. Just one cubic mile of warm seawater has absorbed trillions of Btu's. The Gulf Stream alone, it is estimated, carries northward heat sufficient to generate over 75 times the total power production of the United States [1].2

To extract this thermal power one condition is indispensable: the existence of two broad currents of waterone warm, one cold-in close proximity to each other. Such juxtapositions are, fortunately, not uncommon. There are, in fact, many places within a few miles of land in and near tropical waters such as the Caribbean Sea and the Gulf Stream where ocean currents of vast magnitude run within 2000 to 3000 ft of each other. Their temperature differential is a constant 35 to 45 F (surface layer 80 to 85 F, lower layer 40 to 45 F).

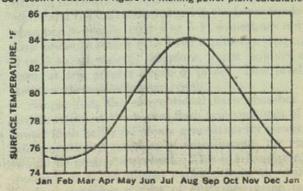
This paradox of nature occurs somewhat as follows: Heat from the sun is absorbed in the surface water which, on heating, expands to a lower density and stays above the colder, heavier water below. This action, in col-

laboration with the sluggish influence of the rotation of

Underwater temperatures in the straits of Florida, 30 miles from Miami, At 400 meters (1312 ft) the temperature is 43 F.



Surface temperatures vary with the season, but an average of 80 F seems reasonable figure for making power plant calculation



Staff Editor, MECHANICAL ENGINEERING.

Numbers in brackets designate References at end of article.