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H. KURT OVERLEY - HARVEY MUDD COLLEGE

Booklet Number 00383

ENERGY

That new ideas will be developed in the laboratory and commercially deployed in 25 short years is improbable. Fusion has been tossed around in the lab for decades, and construction of modern power facilities requires many years. Significant developments will therfore be limited to new applications of existing technology. Superconductors will facilitate most changes.

Superconductivity is a state of zero electrical resistance occurring in some materials near absolute zero. This allows large currents to be carried with no energy loss through resistive heating. An immediate application of superconductors is in magnetohydrodynamic (MHD) power systems. An MHD system burns coal at 5,000°F. The coal plasma is channeled through a magnetic field produced by superconducting coils, producing a potential difference across the channel. The gas, cooled to 3,000°F, is then passed through a conventional system. MHD systems are better that 10% more efficient than conventional systems. They also produce 30% less pollution by burning coal at a higher temperature and by removing sulfur from the exhaust. The U.S. Department of Energy has a new operating facility in Butte, Montana, and the Soviet Union has been operating a prototype model since 1971. The first commercial power station will go on line in 1985 in the Soviet Union (1).

Superconductors have other applications in the electric power industry. Superconducting rotors in large industrial alternators will reduce electrical losses over 50% by replacing the normal rotor cooling system with a helium refrigerator for the superconductor, and by reducing resistive losses. Stator coils could be better insulated, which may allow generation of output voltages sufficiently high to eliminate the need for costly transformers and related losses in production of transmission line voltages. Superconducting alternators are smaller and lighter than normal alternators. This makes them ideal for use on ships and planes. Superconductors cannot be used presently in the stator windings of alternators or in power transmission lines because AC current produces eddy currents and flux motion which results in unacceptable power losses. These problems may be solved by further research and discovery of new superconductors (2).

Superconducting coils could be used as stabilizing devices in power networks. During periods when surplus power is available, a coil could be allowed to draw current from the power network and build up a magnetic field. The coil would then be short circuited, storing the energy of the field. At peak demand the energy could be released back into the system. Another application of superconducting coils is in tokamak and tandem mirror fusion reactors. Superconducting coils are the only method of economically producing a field powerful enough to confine plasma (3).

Nuclear reactors are among the safest means of obtaining energy. Not one member of the public has ever been injured by a commercial reactor accident, and the probability that a reactor accident in the future will have public consequences is minute (4). Yet public fears have stifled the further development of nuclear energy in recent years. Public concern, based on ignorance, is an irrational distrust of a new technology. Fear that environmental contamination will result from radioactive waste disposal has only weak foundings. The effect of radioactive waste on the environment is absolutely insignificant when compared to toxic chemical wastes, which are far more poisonous and carcinogenic and often have long half-lives, and the burning of fossil fuels, which directly ravages the environment with acid rain from sulfur emissions and does more subtle long term damage through the greenhouse effect. However, improvements can and will be made, both in safety and in efficiency. Proposed methods of permanent disposal of radioactive waste include burial far underground in salt beds and empty gas and oil reservoirs that have been stable for millions of years and will remain stable for many millions more.

Of the 71 nuclear reactors in the U.S., all are light water rectors but one high temperature gas-cooled reactor (HTGR). In the next 25 years, construction of nuclear power

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ENERGY (continued)

facilities will shift toward HTGR's in order to appease the safety-minded public, as has already happened in Britain, where 40 HTGR's are either in operation or under construction. Gas-cooled reactors offer myriad advantages. The reactor core is cooled by a circulating gas completely confined to the reactor vessel, so the reactor cannot lose its coolant from a block or a break in pipes outside the vessel, as happened at Three Mile Island. If the circulation of the gas coolant stops for some reason, damage to the core will not result for at least 10 hours. To prevent damage to pressurized water reactors, operators must alleviate the problem in less than a minute. HTGR's achieve better thermal efficiency than light water reactors by about 6% and consume 20% less fuel over their lifetimes, 50% if the fuel is recycled. This fuel efficiency can be appreciated in light of the fact that the total cost of fuel over the life of a reactor is approximately equal to the total cost of construction. HTGR's dissipate less heat into the environment, produce less waste, and what waste they do produce is less radioactive (5). Finally, the hydrogen gas or steam explosions that were feared in the Three Mile Island incident are impossible in HTGR's.

The possibility that commercial fusion reactors will be built in coming decades is quite exciting. Enough hydrogen exists in the world to supply energy for ten million years at current world consumption rates (6). Fusion produces no pollution other than small amounts of low-level radioactive waste that can be disposed by shallow land burial (7).

Amazing progress has been made in developing fusion reactors in recent years. An experimental reactor has been built in Princeton and has operated successfully for a year. Europe also has an operational reactor, and Japan is nearing completion of one. All three reactors are tokamak reactors which confine plasma in toroidal magnetic fields. A large electric current passes through the plasma to help shape the field and to heat the plasma (8). However, fusion is still a long way from economic practicality and even farther from commercial exploitation, possibly as much as 50 years (9).

An attractive alternative to nuclear power is solar power. Solar power stations produce no pollution, and a nearly unlimited supply of energy is available. There are also severe drawbacks. Terrestrial systems are best suited for the Southwest, where solar energy is intense and infrequently interrupted by unfavorable weather. A photovoltaic system requires 23 liters of water per watt total capacity to clean ground collectors and a thermal system requires 27 liters per watt total capacity to clean reflectors and operate its steam generator (10), but in the Southwest water is very scarce. A space based facility does not depend on atmospheric conditions, but construction costs are enormous. In either type of photovoltaic system, the cost of photovoltaic cells is prohibitive. Unless remarkable advances are made, solar energy will not be competitive.

The future promises no startling changes. The introduction of superconductors will make energy production more efficient. MHD systems will be included in future fossil fuel generators and will perhaps be added to existing facilities. Construction of fission generators will shift toward safer, more efficient gas-cooled reactors. Fusion and other methods of producing energy will continue to be developed in the lab, but will probably see no commercial application in the next quarter century.

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00388

COMPUTERS

Booklet Number 00388

For the past 24 years computers have continually dropped in price and size and increased in performance. The following analogy gives one an idea of how dramatic these changes have been: "If the science of air conditioning had made the same advances in price and efficiency since the 1960's, one would be able to purchase three room sized air conditioners for one penny, and these units would be capable of heating the entire Empire State Building (1)." These exponential gains should continue for the next decade, and substantial gains will follow for the next 10 to 25 years. Not all aspects of the computer industry have taken giant strides forward. Software development lags far behind that of hardware. Since 1955, programmer productivity has only increased by a factor of 2.7. The main reasons for this slow growth arise from the haphazard evolution of old systems programs not originally designed for maintainance (2). Most system control programs are written by a large number of programmers over a period of several years, which explains why two-thirds of currently employed engineers spend their time maintaining and updating old code rather than creating new programs.

However, the future holds promise. New operating systems such as UNIX allow one to add functions in a systematic and modular way (3). Higher level languages will free the user from concern with the detailed operation of the program. An expample is VISICALC which allows the user to tailor a graphic representation of a worksheet to his own needs and ask "what if" questions by changing a single entry. Other programs will allow the user to ask questions not directly forseen by the programmer. The data management system, QUERY-BY-EXAMPLE, represents a step in this direction.

Advances in artificial intelligence will accelerate the trend in programs toward "user friendliness." Language understanding programs combined with hardware developments in speech synthesis will allow a user to develop his own programs through an interactive dialogue with a computer. This fantastic claim is reasonable if one examines the progress made in Blocks World by goal-oriented, backwards chaining programs such as STRIPS and HACKER (4). These programs accomplish a goal such as stacking a red block on top of a green block by choosing a sequence of actions that overcomes all the obstacles, and have a limited ability of learning from past mistakes. Such self-programming programs will not become commercially available for at least 10 years due to the difficulties with the semantic structure of sentences, and even then such programs will only be available on the larger, super-fast systems.

Other artificial intelligence programs called "expert systems" will enjoy an increasingly important role in industry. These consultation programs, though of limited versatility, have already performed well in several fields: MYCIN performs at or near the level of an expert physician for recommending antibiotics for patients with severe infections. DENDRAL uses mass spectroscopy to suggest the chemical structure of unknown compounds and has led to nearly fifty publications in chemistry literature (5). Expert systems result from work in AI which shows that computers are not merely number crunchers, but manipulators of general purpose symbols. Developing successful chess, symbolic integration, and theorem proving programs has identified techniques for representing information in symbolic data structures, general methods for manipulating these structures, and generating heuristics for searching them.

The pace of hardware development has accelerated into a worldwide race for the fifth generation supercomputer. The Japanese touched off this race by announcing two national "Beat the Americans" projects - the National Superspeed Computer Project dedicates 10 years and $200 million to develop a computer a thousand times faster than current supercomputers, and the Fifth Generation Computer Project which emphasizes artificial intelligence functions.

On the American scene the Cray I and Cyber 205 reached the limits in computing speed for single processor systems that execute instructions step by step (8). The next generation must use many processors aligned in parallel, so that instruction streams as well as data streams will be processed simultaneously. The Cray 2 uses a limited form of parallelism with four pipelined processors, each of which attacks a different portion of a problem. Further advances

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COMPUTERS (continued)

will rely on massive parallel alignment of processors. One possible scheme is a binary tree in which each processor is followed by two successive processors. The NON-VON computer project on completion will have 19 branches containing a million processors in parallel. Other schemes will be developed because the binary tree is susceptible to processor failure which would wipe out thousands of processors below the failed processor (9).

In the quest for ever faster computers, designers must place the circuit elements closer together to reduce signal transmission time. However, in doing so, heat dissipation becomes a serious problem. The Cray 2 must be submerged in a bath of liquid fluorocarbons to remove excess heat. Superconducting Josephson junctions offer an attractive alternative for future machines. These junctions consist of an oxide layer sandwiched between two superconducting lead or niobioum alloy films with a third control line on top of the entire assembly separated with a much thicker strip of insulation (10). Josephson junctions switch ten to one hundred times faster than conventional transistors, and consume only a few microwatts of power. IBM has fabricated all the necessary logic circuits, even entire chips. The remaining problems arise when the chips are warmed from the temperature of liquid helium to room temperature because the silicon substrate and lead alloys have different coefficients of expansion which tends to rupture the oxide layer. Niobium alloys seem to withstand an indefinite number of warming and cooling cycles, but have slower switching speeds than junctions made with the lead alloy (11). Scientists will resolve these problems, allowing Josephson junction computers to go on line within the next twenty five years.

An even more promising development is the transphasor, the optical analog of a transistor which is based on the refractive properties of certain crystals. Small changes in the intensity of an incident laser beam produce large chages in the intensity of the output beam. Low transmitted intensity and high transmitted intensity represent the logical 0 and 1, respectively. Transphasors using indium antimonide have already been constructed and have a switching time of a few picoseconds. One may reasonably predict the construction of an optical computer capable of a trillion operations per second even without massive parallelism!

Much work has been done on using thin films as waveguides for laser radiation, which would form the connecting elements of optical chips. No one has yet attempted to construct such a chip, but it will be done in the next two decades. Optical computers might even be capable of a many-valued logic system, since the crystals in use can yield successively higher levels of tranmitted light intensity with corresponding increases in incident light intensity. Furthermore, because laser beams may be split, one might carry out three different logical operations simultaneously on the same input signal. This capability might lead to even more dramatic increases in computational speed (12).

Regrettably, overwhelming problems will prevent the development of nanocomputers from organic molecules in the next twenty five years (13). One problem results from the inability of light to address, interrogate, or switch individual molecules separated by aproximately 100 angstroms because the shortest suitable wavelengths of light are 2500 angstroms. Scientists desire to use molecules capable of reversible changes in the positions of hydrogen atoms as memory devices, but these hydrogen atoms can unpredictably tunnel back to their original positions, resulting in memory losses. A more serious problem develops from "crosstalk" between molecules. As the individual logic components are placed closer together, electrons begin to tunnel between adjacent molecules uncontrollably (14). Also, stray radiation and random motion of molecules due to heat could wreak havoc among the well-ordered circuitry.

The next quarter century will see expert systems spread throughout industry. Advanced AI language programs will allow self programming dialogues, an unprecedented level of "user friendliness." Parallel processor alignment used with Josephson junctions and transphasors will form the basis of supercomputers attaining speeds in excess of a trillion calculations per second, perhaps using multi-valued logic systems.

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Booklet Number 00388

SOCIETAL IMPACT

Computers will certainly effect major societal changes - many for the better, but some for the worse. Expert systems offer substantial economic savings by giving smaller companies access to expert information they might be otherwise unable to obtain. Yet expert systems may do substantial harm. As Joseph Weizenbaum of MIT notes, "To think that one can take a very wise teacher, for example, and by observing her capture the essence of that person to any significant degree is simply absurd." Indeed, commercial and industrial interests, showing unrealistic expectations of limited artificial intelligence programs, have led to a shortage of appropriately trained and motivated professionals (1).

Supercomputers will play a growing role in the economy because of their ability to numerically simulate continuous fields with tens of millions of data points. Currently they are employed in aerodynamics design by Boeing, in seismology, in meteorology, and even in moviemaking by Digital Productions. The next 25 years will see computers reducing aviation accidents by assisting traffic controllers. Environmentalists will be glad of the impending use of supercomputers to design aerodynamic, fuel-efficient cars (2).

The ever-shrinking microprocessor will also have a major impact on the economy and the environment. Air pollution will decrease because of the upcoming proliferation of low cost microprocessors which will regulate the internal combustion of automobiles for higher efficiency. Microprocessors will also increase home utility savings for heating and refrigeration by running electric motors and compressors at optimum efficiency. Probably the most revolutionary economic changes will result from the introduction of the "smart card" which contains a microprocessor and a memory chip. By eliminating much of the paperwork involved in transactions, this redistribution of processing chores from the bank mainframes to millions of wallet microprocessors could yield a substantial reduction in the cost of the current 40 billion dollar per year payment system. Also, since one needs exotic equipment to read the cards, they are nearly impossible to forge. Hence, these cards might save billions of dollars in Welfare, Social Security, and Medicare fraud (3). Even with all these economic savings due to computers, one should realize that it is only a question of time before the financial community faces a catastrophic computer crime, as the recent tamperings with the Sloan-Kettering computer system suggest (4).

Unfortunately, the structure of society will suffer drastic alterations. The developments in AI and hardware will replace the current simple pick and place industrial robots with highly sophisticated models combining sensors and effectors to deal with incorrect parts and improper sequences of assembly operation (5). Unless companies offer retraining programs in computer servicing and repair, the new robots will eventually displace most blue collar workers. Even today a typical factory job done by a human worker for $14 an hour can be done by a robot for $4.60 an hour (6). Although the total unemployment rate should decrease due to openings in technical positions, a much greater percentage of those unemployed will be blue collar workers. This widening gap between the well-educated and the poorly-educated might result in extreme reactions similar to the Watt's riots of the 1960's. To further aggravate this situation, the gender gap may also be widening. Dr. Keisler at the Robotics Institute of Carnegie-Mellon University points out that in computer arcades, computer camps, and in computer classes in schools, boys receive more encouragement than girls. In an increasingly computerized society, this trend might undue the progress women have made to date in the job market (7).

Advancements in computer technology will bring mixed blessings. Computers will make industry more productive and provide new luxuries and savings, but will also have the potential to cause social upheaval.

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SOCIETAL IMPACT (continued)

On the other hand, impending developments in the field of energy will have little societal impact. Rather, society will have a large impact on the development and exploitation of our energy resources. Society's safety fears will lead to a shift toward the construction of gas-cooled nuclear power reactors. As the public becomes aware that such facilities are indeed safe, production of the reactors will increase, stimulating employment. Magnetohydrodynamic systems employed with coal-fired generators will help break our dependence on foreign oil. This will not displace any American workers. Increases in efficiency will be offset by construction cost increases from inflation, resulting in little change in power rates.

Environmental improvements will be dramatic. Sulfur emissions from coal-fired power plants will be nearly eliminated, leading to a sharp decrease in acid rain. Total atmospheric pollution by these plants will decrease by 30% (8). Gas-cooled reactors release 25% less heat into the environment to destory fragile ecological balances than light water reactors. Of the less than 2,000 cubic feet of solid radioactive waste produced each year by a typical gas-cooled reactor, 80% is low-level waste and could be incinerated with practically no effect in the environment (9).

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