VOLUME 12 □ NUMBER 5 IEEE spectrum MAY 1975

articles

departments

MINI.™

COMPARE: THE INTERDATA 8/32 MEGAMINI VS. THE-LESS-THAN-MEGAMINI COMPETITION.

	INTERDATA 8/32	XEROX 550	IBM 370/158	DEC 11/70	DG Eclipse
WORD LENGTH	32 bits	32 bits	32 bits	16 bits	16 bits
INSTRUCTION TIMES (Register to Memory)					
Integer Add	1.25	1.8	.9	1.8	2.5
Multiply	3.54	6.2	2.0	3.9	8.8
Divide	5.8	14.4	9.9	8.3	11.2
Floating Point Add	2.3	6.1	2.4	8.25	5.5
Multiply	3.0	9.1	2.3	11.25	7.2
Divide	5.35	23.3	8.9	12.25	7.9
HARDWARE I/O	Yes	Yes	Yes	No	No
MAX. DMA RATE/SECOND	6MB	4MB	6.7MB	4MB	2MB
DIRECT ADDRESSING RANGE	1MB	1MB	16MB	64KB	64KB
GENERAL PURPOSE REGISTERS	2 stacks 16 each*	4 stacks 16 each	1 stack 16 each	2 stacks 8 each	1 stack 4 each
PRICING (Basic Configuration)					
CPU + 128KB Memory	$51,900	$128,700	N/A	$54,600	$32,500
CPU + 1048KB Memory	$179,400	$478,700	$1,905,700	$163,800	N/A

*(6 Additional Stacks Optional)

program development capabilities. Software that has an optimizing macro assembler, MACRO CAL. And software with a sophisticated telecommunications access package, ITAM, that allows you to treat remote communications terminals and computers as if they were simply local devices.

Now, with all of this available, you can concentrate your efforts on the real problem at hand – your application.

THE MEGAMINI: NOT JUST A COMPUTER – BUT A SYSTEM.

The Interdata 8/32 Megamini gives you a full range of peripherals, software and advanced features to choose from in tailoring your system: 166MB disc systems, fast line printers, 1600 BPI tapes and graphic CRT's. Plus software modules like FORTRAN, BASIC, EDIT, AIDS and many more.

FOR MORE MEGADATA, CLIP AND MAIL.

Interdata, Inc., Oceanport, N.J. 07757

☐ All that power sounds marvelous. Send me more information on the Interdata 8/32 Megamini.

☐ You may have hit on the solution to my megaproblem. Have a representative call me.

Name __________ Title ________

Company __________

Address __________

City ________ State ____ Zip ______

Telephone __________

INTERDATA®

Subsidiary of Perkin-Elmer

Oceanport, N.J. 07757, (201) 229-4040 IEEE 5/75

See us at the NCC, Booth No. 2337.

Circle No. 1 on Reader Service Card

the cover

As the energy crisis thickens, casual prognosticators drop from the forecasting scene; yet the serious remainder find the future still clouded (article, page 32). Spectrum's cover-girl crystal-gazer is our own associate art director, Janet Mannheimer.

IEEE Publications Operations

IEEE SPECTRUM is published monthly by The Institute of Electrical and Electronics Engineers, Inc. Headquarters address: 345 East 47 Street, New York, N.Y. 10017. Cable address: ITRIPLEE. Telephone: 212—752-6800. Published at 20th and Northampton Sts., Easton, Pa. 18042. **Change of address** must be received by the first of a month to be effective for the following month's issue. Please use the change of address form below. **Annual subscription:** IEEE members, first subscription $3.00 included in dues. Single copies $4.00. Nonmember subscriptions and additional member subscriptions available in either microfiche or printed form. Prices obtainable on request. **Editorial correspondence** should be addressed to IEEE SPECTRUM at IEEE Headquarters. **Advertising correspondence** should be addressed to IEEE Advertising Department, at IEEE Headquarters. Telephone: 212—752-6800.

OTHER IEEE PUBLICATIONS: IEEE also publishes the PROCEEDINGS OF THE IEEE and more than 30 Transactions for IEEE Societies and Groups with specialized interests within the electrical and electronics field. Manuscripts for any IEEE publication should be sent to the editor of that publication whose name and address are shown on pp. 95–96 of the January 1975 issue of *Spectrum*. When in doubt, send the manuscript to E. K. Gannett, Publishing Services, at IEEE Headquarters, for forwarding to the correct party.

IEEE also copublishes, with the Institution of Electrical Engineers of London, England, *Electrical & Electronics Abstracts* and *Computer & Control Abstracts*, as well as their companion titles journals, *Current Papers in Electrical & Electronics Engineering* and *Current Papers on Computers and Control.*

MOVING? PLEASE NOTIFY US 4 WEEKS IN ADVANCE

Name (Please Print)

Address

City State/Country Zip

MAIL TO: IEEE CODING DEPARTMENT
445 Hoes Lane, Piscataway, N.J. 08854

ATTACH LABEL HERE

- This notice of address change will apply to all publications to which you subscribe.
- List new address above.
- If you have a question about your subscription place label here and clip this form to your letter.

Energy's hazy future

The power forecasting game, played so avidly by so many in 1970, is now a cautious exercise with fewer, more expert participants

In the 1960s, a popular exercise in and out of the power industry was predicting the golden age that was dawning upon the world (and especially the United States) in which cheap electric energy would be the catalyst in achieving the Nirvana of unparalleled leisure and prosperity. There were glowing descriptions of nuclear power plants mushrooming up (without the familiar cloud) all over the country; plants that would fulfill every need—from fantastic labor-saving appliances that would transform homes into push-button paradises to vast industrial growth and galloping increases in GNP. All of this was based, of course, on the instant ability of that little imp, "Reddy Kilowatt," to plug into that bottomless cornucopia of electricity at bargain-basement rates.

But the no doubt well-meaning prophets had a blind spot when it came to distant early warnings in the late 1960s. Inflation, escalating labor costs, and the lowering of the oil-embargo boom by the Middle East oil-producing countries came as shocks to most of us and the few wiser heads around, who saw the folly of squandering our finite fuel resources, were ignored. Also in this time frame, the conservationists and ecologists began their task of preaching about the day of reckoning, and some of the consequences of that preaching have been expensive.

The rest, of course, is history. When the domestic oil pumps began to hiccup, the gas wells flamed out, and the price of Middle East and Venezuelan oil jumped from about $4 to $11 per barrel, the days of gay abandon and futuristic fantasy burst with the bubble of other pipe-line dreams, leaving a group of toughened energy forecasters to pick up the pieces and establish hopefully more realistic forecasts for the rest of the century.

Many scenarios

At the 1975 Winter Meeting of the IEEE Power Engineering Society, there was a session entitled "Electrical Energy Technology Forecast." Its primary areas of concern were: an overview of the state of the art in power; energy needs[1] to the year 2000; generation and storage;[2] transmission and distribution;[3] and power system automation and control—all in the 1975–85 and 1975–2000 time frames. The papers presented were the fruits of a comprehensive forecasting effort by the IEEE's Energy Forecast Working Group which, in preparation, had reviewed many of the available forecasts—both pessimistic and optimistic.

Among the pre-embargo study forecasts that had been made were those of the Chase Manhattan Bank,

Gordon D. Friedlander Senior Staff Writer

I. Summary of forecasts of U.S. electric generating capacity and electric energy use

		1985														
		Capacity–GW						Energy–10^{12} kWh							Capacity	
Source	Year Issued	Total	Oil/Gas	Coal	Nuclear	Hydroelectric	Other	Total	Oil	Gas	Coal	Nuclear	Hydroelectric	Other	Total	Oil/Gas
CMB	1972							4.4	0.75	0.5	1.3	1.5	0.35	—		
RFF															2228	984
DOI	1972	915	580	580	215	120	—	4.1	0.7	0.4	1.4	1.1	0.5	—	1880	720
SRI	1972–74							3.9	0.8	0.2	1.2	1.4	0.3	—		
FPC	1973							4.5	2.3	2.3	2.3	1.9	0.3	—		
FPC	1974	1070[A]						4.4							2250[A]	
CEQ	1974															
LLL	1974							3.4[B]	0.2	0.3	1.3	1.2	0.4			
AEC	1974	903			260			4.0	0.6	0.3	1.2	1.5	0.4	0.4	2220	
NAE	1974	982	200	330	325	120	7									
EPP	1974							2.3	0.3	0.3	1.0	0.8	0.3	—		
FEA	1974	922	291	327	204	120	120	4.0[B]	0.5	0.5	1.7	1.3	0.5	0.5		
EW	1974	781						3.6								

Notes: A—Capacity assumed to be 20 percent higher than reported annual peak load.
B—Assumes same power plant heat rate and transmission efficiency as in 1972–73.

CMB = Chase Manhattan Bank (pre-embargo study)
RFF = Resources for the Future (pre-embargo)
DOI = Department of the Interior
SRI = Stanford Research Institute
FPC = Federal Power Commission (pre-embargo, 1973; post embargo, 1974)
CEQ = Council on Environmental Quality
LLL = Lawrence Livermore Laboratory
AEC = Atomic Energy Commission

spectral lines

Society-proof design

Russell Baker, *The New York Times'* sharp-witted and sometimes acid-tongued syndicated columnist, is inclined to comment on sociotechnical issues in a way that is not complimentary to technologists, but that, at the same time, usually contains an element of truth.

Not long ago, however, he wrote the following:

"This is a telephone. It is not making a sound. See how quiet the telephone is? See how happy it looks?

"Why does the telephone look so happy? It looks happy because it makes money without doing any work. It is congratulating itself upon being such a clever machine. It is thinking that this man in whose house it is living will soon be giving it even more money to let it take up room in his house.

"Look at the man. Can you see the strange hand removing money from his pocket? It is very hard to see. You must look very closely. The hand does not belong to the man. It belongs to the telephone. The hand is collecting the money the telephone charges the man for living in his house.

"Every year the telephone charges the man $90 for just sitting there doing nothing. Is this man not dumber than any one you have ever seen? He has shelves of books which also sit in his house doing nothing, but he would be very angry if one of the books put its hand in his pocket and removed $90 for the privilege of taking up house space."

Although Baker's column went on to elaborate on the possibility of rising rates and new charges for services (like Information) that were once "free," it was shot through with a certain naiveté about the economics of building and operating a sophisticated system like the telephone network. As a result, Baker may have alienated, temporarily at least, some of his readers who admire his normally constructive satire.

On the other hand, Baker's expressed viewpoint may be symptomatic of a larger societal problem—the public's rising antagonism toward the technical establishment and its evident satisfaction at seeing it get its "comeuppance"—sometimes regardless of the source or the consequences. For example, when the New York Telephone Company suffered its recent disastrous fire (*Spectrum*, April, p. 26), many citizens promptly suspected that the blaze was started by disgruntled employees or other anti-phone company persons. In any event, a rash of telephone company fires of an unquestionably incendiary origin quickly followed. Many believe they were not the acts of a single person, but rather that the initial fire triggered several unstable persons into independent action; and that the frequency of these incidents was enhanced by a widespread tacit approval that the telephone company is "fair game" for at least some unspecified forms of retributive action. It seems the public is becoming inured to increasing destructive action on the part of even "normal" persons; such was hardly denied when a Communications Workers of America spokesman in a recent television interview suggested with some matter-of-factness that arson by employees was not to be ruled out, since widespread "employee discontent" exists as a result of their "harassment" by the company. In contrast, back in 1940, a disgruntled employee who planted bombs in Con Ed plants in retaliation for an injury suffered on the job, was committed to a hospital for the criminally insane for a period of 16 years and 8 months. (Today, perhaps, his actions would merely be categorized as employee discontent!)

An even larger segment of the general populace seems to condone nonviolent ripoffs of the utilities. New York Telephone Company recently reported evidence showing that some 25 000 subscribers during a survey period installed "blue" or "black boxes," or otherwise cheated the company of services. (The reader should not misconstrue our message to be that all technologists "ride white horses" and it is the rest of society that has gone awry. Don't we all know colleagues who would build black boxes if they had the schematic, and others who would even requisition the parts from the company stock room?)

The utilities are not alone in their vulnerability to attack by the more antisocial elements of society. Consider, for example, the airlines. The air traveler of the Fifties would have given no credence whatsoever to forecasters had they told him that by 1975 he'd be paying a surcharge for the "service" of having his baggage and his person searched in order to provide "security" during his flight.

One can speculate on the reasons for society's apathy in the face of physical and/or economic attacks on The System. Surely there has been a rise in consumerism, a broader application of civil disobedience, and a feeling by more segments of society that unjust or obsolete laws or regulations can be changed *de facto*, by simply disregarding them. Whatever the reasons, the impact on the technologist himself is clear. He must consider new constraints, occasionally even thinking the unthinkable. His designs must not merely be reliable, environment-proof, and internal failure-proof; they must also be saboteur-proof, foolproof, vandal-proof, criminal-proof, and idiot-proof. And, as in the case of any superior design, he must do his thinking and planning at the outset, or else become caught up in "fixes," or in trying to design costly and complex auxiliary systems to protect existing plant.

Ironically, today's technologists may thus be required to produce equipment and systems that not only perform socially desirable functions, but that are designed in such a way as to protect society from itself, or at least from a hitherto insignificant segment of itself that now seems to be growing in size and impact.

Donald Christiansen, Editor

Resources for the Future, Department of the Interior, Stanford Research Institute, and Federal Power Commission. Coming into the act in the post-embargo era were the Council on Environmental Quality, Lawrence Livermore Laboratory, Atomic Energy Commission, National Academy of Engineering, Energy Policy Project of the Ford Foundation, the U.S. Federal Energy Administration, *Electrical World* (magazine), and a 1974 FPC projection that updated its pre-embargo outlook. Table I is a summary of these recent (1972–74) forecasts of U.S. electric generating *capacity* and electric power generation and detailed summaries of the post-embargo studies are discussed in the box on pp. 36–37.

Consensus for 1985

Several of the more recent projections were reviewed by IEEE's Energy Forecast Working Group in advance of its "report" to the Winter Power Meeting. The group freely admits the difficulties inherent in preparing forecasts because

- The U.S. is in a transitional stage with regard to energy sources and use.
- Increased Government involvement (possible rationing, price-controls, and/or fuel allocations) present uncertainties now and in the future.

Recognizing these and other difficulties, the Working Group's prognostications show that the energy use in the U.S. may increase from 75.6 quads (a "quad" is equivalent to one quadrillion—10^{15}—Btu's) in 1973 to 111 quads in 1985—equivalent to a growth rate of 3.2 percent/year over the 12-year time span. Its forecast for the increase in electric generation, based on 1.85 trillion kWh in 1973, is 3.8 trillion kWh in 1985, for a load-growth rate of 6.2 percent annually in this period.

Over the 1973–85 time frame, the group expects little change in the relative portions among the principal electricity-consuming sectors: residential, 31 percent; commercial, 25 percent; industrial, 44 percent.

Requirements for generating capacity, projected to 1985, are 850 GW (of which 25 percent would be nuclear). This statistic assumes that the present weaknesses in the utility industry (construction cutbacks, long lead times in nuclear plant licensing, etc.), resulting from adverse economic conditions and environmental restrictions, will be rectified. Unfortunately, however, it appears that a dearth of generating capacity by the late 1970s and early 1980s is *already inevitable* and that substantial cuts in acceptable reserve margins may occur.

2000										
-GW				Energy-10^{12} kWh						
Coal	Nuclear	Hydroelectric	Other	Total	Oil	Gas	Coal	Nuclear	Hydroelectric	Other
984	956	288	—	10.8	0.4	1.1	2.8	5.9	0.6	—
720	960	200	—	9.0	0.6	0.3	1.9	5.5	0.7	—
				11.0	3.6	3.6	3.6	6.9	0.5	—
				10.2						
				6.0	—	—	1.2	4.1	0.5	0.2
	1200			10.1	0.9	0.2	1.5	7.0	0.5	0.5
				3.3	0.1	0.1	1.1	1.1	0.4	0.4

NAE = National Academy of Engineering
EPP = Energy Policy Project (Ford Foundation)
FEA = Federal Energy Administration
EW = Electrical World (magazine)

Outlook for 2000

The IEEE's "task force" claims less certainty in its forecast for the turn of the 21st century. Its disclaimer is that if any, or all, of its assumptions are incorrect, the forecast becomes inoperative! So, with that in mind, let's go to the demographic, technological, and social trends of the foggy future:

Demographic assumptions are not perceived as critical to the forecast up to 1985, because the people who will have the greatest impact on energy consumption (the 18–64 year olds) have already been born. But future birth rates can crucially affect our needs for energy and electricity in 2000. The consensus assumption is that birth rates will remain near the replacement level, as they are at present. (However, this still results in substantial population growth during the next 25 years.)

Technological and social trends are still more difficult to anticipate and evaluate. Consequently, the IEEE Working Group's ballots on the year 2000 ranged from 152–203 quads of total energy use and from 8.3–9.9 × 10^{12} KWh of total electricity requirements.

A general feeling is, that during the next quarter century, electricity will be increasingly important in the U.S. energy supply as the nation shifts from petroleum and gas toward coal (our most abundant domestic fossil fuel) and nuclear energy. The consensus forecast for *total* energy use in 2000 will be about 171 quads. This is equivalent to an annual growth rate of 3 percent from 1973 to 2000. The concomitant generation of electricity in 2000 is pegged at an average of 9.0 trillion kWh, which would represent a 6 percent/annum growth over the same 27 years.

By 2000, nuclear energy will furnish about one third of the total energy supply of the U.S., and about 60 percent of all fuel for the generation of electricity. And, finally, electric generation capacity is expected to reach 1820 GW nationwide.

Power generation, storage, etc. 1975–2000

Some further inputs and prognoses regarding electric power generation and storage technology have been supplied by six well-known professionals who represent the power and fuel industries. Their purpose, as promulgated in a paper[2] presented at the 1975 PES Winter Power Meeting, was to discuss the probable future trends in these areas over the remainder of the 20th century. The paper outlines the existing list of alternatives. Although the list is long, two major questions loom large: Which alternatives will

Spectrum's controlled growth scenario for the U.S.*

	1975	1980	
Generation			
Sources			
Oil and gas			Arctic pipeline gas supplies; synthetic gas ... oil is imported oil
Percentage of power needs met by oil		40	
Percentage of power needs met by gas		30	
Coal			High-BTU coal gasification and liquefaction
Percentage of power needs met by coal		20	
Nuclear			
Percentage of power needs met by nuclear		10	
Hydro			
Percentage of power needs met by hydro		3	
New generation technologies	More geothermal plants put on line		Tidal power plants are built
Size of plants			
Size of generating units			
Transmission	500–765-kV transmission installed in major power grids and networks		Overhead transmission voltages —
			UHV transmission Resistive cryogenic 1700–10 000 - MVA (138–345 - kV)
Distribution	Linear increases in installed distances		
Primary distribution voltages		12-15 kV	

Spectrum's worst-case, low-growth, high-cost scenario for

Generation		
Sources		
Oil and gas	Increasing dependence upon imported oil and gas supplies	Extraction of oil
Coal		Environmental considerations and political action costs of coal liquefaction uneconomical
Nuclear		Fast-breeder reactor program will be curtailed because of only a few reactors will be operational
Other		Developments of geothermal power will be limite
New generation technologies	MHD will prove impractical, except in small installations	
Size of plants		3000 MW

*Spectrum's extreme-case forecasts are syntheses based on scenarios detailed in the text.

985 1990 1995 2000

:o… +% of Extraction of oil from shale and tar sands

35 30

25 20

"Barely scratched" the surface of domestic supply

15 15

Commercial fast breeder reactors introduced Breeder reactors on line in large numbers Prototype fusion reactors

25 35

2.5 2.5

MHD generation becomes practical on large scale; start of "hydrogen economy"

50% thermal efficiencies in combined cycle plants; 40% in average plants

Relatively small sub station fuel cell

00… MW 10 000 MW 15 000 MW

2000-2500 MW 3000 MW

500 kV (with capacities of 9000–10 000 MW) 2000 kV

or 1100–1500 kV
3000–4000 - MVA cable
superconducting cable

Increasing use of underground cables in suburban areas

New installation in urban and suburban areas will be underground; gradual conversion of overhead to underground

25-35 kV 50–7

the U.S.

om shale and tar sands proves too costly

Virtual exhaustion of domestic oil and gas by 2000; almost complete dependence on imports

sharply curtail extraction of coal by strip mining;

High-sulfur coal, in limited amounts from deep-pit mining

hazards and/or environmental considerations;

Significant breakthrough on fusion reactor still 10–20 years in future

nsufficient amount of new steam fields tapped

Available hydropower facilities already will be in use

Development of large-scale solar-energy "farms" will be pushed as emergency alternative

3500 MW 5000 MW

be developed? When will they become commercially available?

Prime movers

Steam, gas, and water turbines ("fluid" turbines) are the most prevalent prime sources now in use. These machines will doubtless improve in performance and efficiency in the normal course of design and development evolution; they will continue their dominance of power generation over the next 25 years. Wind turbines, on the other hand, will attain limited application (windmills for air compression for air turbines, for direct power generation, and trickle-charging of storage batteries) by the 1980s.

Another possibility is magnetohydrodynamics. MHD's potential impact on future power generation could be higher energy conversion efficiency and the simultaneous reduction in demand for prime energy. However, much more R&D will be required to overcome existing problems before a reliable and practical MHD generator will be put on the line. Some of the salient problems are:

1. High temperatures (up to 2500°K) in combustion and ionization chambers, air preheaters, and heat exchangers.
2. Recovery methods for the reclamation of ionization seed.
3. Development of long-life MHD ducts.
4. Development of a durable electrode material.
5. Corrosion prevention and the development of methods to control or reduce high NO_x levels.

The higher electrical conductivity of coal's combustion products (as compared to oil or gas) makes MHD more attractive in its coal-fired version. To date, R&D funds for MHD have been scarce; therefore progress has been slow in coming. But, with an imminent increase in Federal funding, more advances can be anticipated. Yet, it is only realistic to observe

Post-embargo forecasts and studies[1]

Federal Power Commission. This study was prepared by the Technical Advisory Committee on Power Supply for the forthcoming National Power Survey. Included are three scenarios of electricity output (upper estimate, most probable, and lower estimate) and peak demand in 2000, as indicated in the following table:

	Peak Demand (GW)	Electricity Generated (trillion kWh)
Upper estimate	2087	11.70
Most probable	1874	10.18
Lower estimate	1566	8.23

The statistics shown in Table I (in the text) reflect the committee's median (most probable) estimate, using an assumed 20 percent reserve margin to arrive at the capacity estimate.

Council on Environmental Quality. Presented in March 1974, the plan requests a spartan program of energy conservation that would restrict the average energy growth rate to 1.8 percent per annum to the year 2000, when U.S. energy consumption would be 121 "quads" (quadrillion Btu) per year. At the same time, it envisions electricity growth of less than 1 percent/year from 1973 to 1985; but, a 6–7 percent growth rate per year from 1985 to 2000. (This averages out at about 4.5 percent for the 1973–2000 time period.)

The study recommends eliminating oil and gas for power generation by 1985, with little concomitant increase in coal use prior to 1985, but increased use thereafter; and steadily increasing reliance on nuclear power over the final quarter of this century.

Lawrence Livermore Laboratory. Published in September 1974, it presents six options for U.S. energy supply from now to 1985:

Option A—(on which LLL's 1985 forecasts in Table I are based)

1. Because of present high prices, there will be a significant increase in domestic oil production.
2. Continued price controls on natural gas.
3. Increased coal production (at the rate of 5 percent/year).

Thus, in 1985, total U.S. energy use is forecast at 112 quads, of which more than 18 quads would be imported gas and oil. Fuel for the generation of electricity is forecast at 36 quads for 1985 (this is the equivalent of approximately 3.4 trillion kWh), which would represent an annual growth rate of 5.2 percent from 1973 to 1985.

Option B—This assumes a substantial increase in natural gas prices, thus raising domestic gas production to 30 quads and lowering gas/oil imports by 14 quads in 1985.

Option C—Coal production expansion is scrutinized in addition to increased gas prices; however, no change in Option B's gas/oil imports is forecast.

Option D—Examines the impact of accelerating the production of synthetic fuels (i.e., gas and oil derived from coal). Conclusion: it would have only a minimal effect upon imports; also, it would probably be uneconomical.

Option E—This option scrutinizes the accelerated installation of offshore domestic oil-drilling rigs, which may —potentially—allow for a significant reduction of imports by 1985.

Option F—Explores a revised transportation philosophy, in which new cars would reduce their average gasoline consumption by about 50 percent. This would reduce domestic energy use by about 4 quads in 1985.

Atomic Energy Commission. Published in February 1974, this study explores energy and electric power (assuming four different scenarios) to the year 2000. All scenarios project a U.S. population of 264 million. The scenario upon which Table I statistics are based envisages a continuation of the conventional relationship between energy consumption and GNP, a continued increase in the use of electric energy, and a lead time of eight years for the construction and commissioning of a nuclear plant. AEC's predictions show an energy growth of 3.6 percent/annum (1973–2000), and a corresponding 6.5-percent per year growth of electricity consumption over the same 27 years. Projected domestic nuclear capacity would be 260 GW in 1985; 1200 GW in 2000.

National Academy of Engineering. This study, released in May 1974, indicates that "if major efforts are made to conserve energy, the domestic demand might be reduced to about 106 quads in 1985." Further, by reducing demand via conservation, while simultaneously augmenting domestic supply, fuel imports can be virtually eliminated by 1985.

By that date, "through great effort and expenditure," shale oil could supply 1.0 quad; synthetic fuels from coal, 3.6 quads (requiring an additional 300 million tonnes of coal to be mined in 1985).

The report envisages more than 60 percent of all energy growth in the 1973–85 time frame in the form of electric energy. Generating capacity is projected to increase to 982 GW in 1985, of which about 330 GW will be coal-fired; 325 GW, nuclear; 200 GW, oil/gas fired; and, 120 GW would be hydroelectric. This assumes that lead times for nuclear plant construction can be reduced to 6–7 years. The generating capacity projection is equivalent to a growth rate of that, because of the tough problems remaining to be solved, MHD will not be a viable competitor in power generation before the 1990s.

Photovoltaics is an alternative technology that involves the direct conversion of the electromagnetic energy in light waves to an electrical potential that can furnish electric energy; it is one of the options for the conversion of solar energy into electric power. Although considerable R&D is being conducted for terrestrial applications, two rough roadblocks have yet to be bypassed: the very high capital costs—and space—required for such a plant, plus the low conversion efficiency—2 to 15 percent.

The panel of experts believes that, although considerable performance improvements will be accomplished, it is unlikely that photovoltaic systems will become competitive in this century.

As for direct thermal conversion, thermionic conversion of heat directly to electricity depends upon electronic emissions at very high metal temperatures. These electrons are then collected on another and cooler metallic surface that is adjacent to the emitting surface. The concept has been suggested for use as a "topping" unit for a conventional thermal plant to increase the overall efficiency of the plant an additional 5–10 percent. At present, nuclear thermionic research has very little funding. Because of seemingly insurmountable material and structural design problems, it seems doubtful that even substantial funding would produce promising results in this effort.

New types of batteries, such as lithium-sulfur, nickel-cadmium, etc., that are either presently available or being developed, may have future applications for high-load-density inner-city substations for peak power demands. Fuel cells may also generate electricity by chemical reaction; however, the fuel cell functions on hydrogen-rich fuel. Thus, it is necessary for a fuel "reformer" to process natural gas or oil into hy-

---

7 percent per annum.

Ford Foundation. The two-year study, in three scenarios (covering the period 1973–2000), is dated October 1974; two supply versions of the "technical fix" scenario are considered here:

Technical fix (self sufficiency)—in which projected energy growth will be 1.7 percent/year from 1973 to 1985; and, 1.9 percent/year in the 1985–2000 time period. Electricity growth rate in these periods would be 1.9 percent and 2.2 percent per annum, respectively. This scenario also calls for an increase in U.S. dependence upon gas and oil (from 77 percent in 1973 to 80 percent in 1985). It foresees little growth in coal use by 1985, and *no* additional nuclear capacity beyond those plants nearing completion and licensing. Furthermore, it predicts little growth in nuclear power from 1985 to 2000. Sixty percent of the 124 quads of energy use (projected to 2000) will be furnished by oil and gas; 23 percent by coal; less than 9 percent, nuclear; and the remaining 9 percent will come from geothermal, hydro, shale oil, and other energy sources. Imports in 2000 would be 6 quads of oil.

An alternative Technical Fix scenario (subtitled, "environmental protection") envisages virtually the identical total energy and electricity generation levels—but looks into a variety of energy sources. For example, 5 quads of nuclear power are foreseen in 1985, with a reduction to 3 quads by 2000. To compensate for this attrition, 83 quads of energy would be derived from oil/gas in 2000 (this would represent 68 percent of total energy use, of which 16 quads would be imported).

FEA Project Independence. Dated November 1974, this report of the Federal Energy Administration examines the viable choices open to the U.S. in dealing with the energy problem through 1985.

Predicated upon "price-elastic" econometric models of worldwide petroleum supply/demand, the thesis reasons that the Organization of Petroleum Exporting Countries (OPEC) must restrict production to support present oil prices at about $11/bbl. (They have an economic incentive for this: their revenues at this price are greater at reduced production than they would be under full production in the price range of $4–$7/bbl). In view of the uncertainty of future oil prices—which may be affected both by politics and economics—the report analyzes strategies at two prices for imported oil: $7 and $11 per barrel.

The report assumes that U.S. population in 1985 will be 236 million and that real GNP will increase at an annual rate of 3.5 percent through that year. The "base case" projections ($11/bbl) also assumes that (1) newly discovered natural gas will be deregulated, (2) price controls on oil will be removed, (3) the provisions of the Clean Air Act will be eased, and (4) energy conservation will be voluntary or price-induced. Under these assumptions, the projected total energy use growth rate will be 2.7 percent/annum from 1973 to 1985. This would be 103 quads of energy in 1985.

At $7/bbl, oil energy growth is forecast at 3.2 percent per year, resulting in consumption of 109 quads in 1985. Electricity use is projected at a yearly rate of 6.7 percent in the "base case," resulting in 922 GW of generating capacity and the generation of 4.0 trillion kWh of electricity in 1985. (1985's oil imports would be 25 quads, assuming a price of $11/bbl; 6.5 quads at a price of $7/bbl.)

The "built-in" problems of the base case are not ignored, however—especially the United States' vulnerability in the event of future oil embargoes. Also, there are large uncertainties, such as the assumed price elasticity in the energy-demand model, and the maximum domestic oil supply potential.

Another viable option is "accelerated supply"; this would involve intensive efforts to increase domestic oil/gas production and, simultaneously, expedite nuclear power facility construction. However, under this option, total energy and electricity demand would not be changed significantly.

Coal production in 1985 will be somewhat lower because more nuclear facilities will be on line. Imports of $7 oil would be decreased from 25 to 17 quads—and entirely eliminated in the case of $11 oil.

The "demand management" strategy zeroes in on coal being substituted for oil and gas for utility and industrial use. This option would eliminate some 40 percent of utility oil/gas consumption. Thus, the growth rate of electric generation would go up from 6.6 (base case) to 7.4 percent.

Assuming there is an accelerated mandatory conservation program, the energy growth rate can be cut from 2.7 to 2.0 percent (assuming $11 oil), thereby saving about 9 quads in 1985. Electricity distributed in that year would be dropped from 12.3 to 11.0 quads; and, the resultant growth rate would slip from 6.6 to 5.7 percent from 1973 to 1985. This option would have little effect in conserving scarce resources, since oil/gas use would be reduced by only 5–6 quads. However, coal usage would be lowered by 3 quads.

Electrical World. This survey of power plant capacity and electric generation, through 1995, was published in September 1974. In it, real GNP is projected for the next 20 years at 3.0 percent/year—a downward revision from its pre-embargo (1973) forecast of 3.7 percent. The study foresees electric energy generation of 3.6 trillion kWh in 1985, and 6.3 trillion kWh in 1995. And it predicts generation capacity at 781 GW in 1985; 1349 GW in 1995.

drogen. But because electrochemical conversion produces direct current, an inverter is needed to transform the direct current to alternating current for use in a power system.

The overall efficiency of fuel cells ranges from 30–35 percent. One disadvantage of these devices is that the platinum catalyst in the electrodes is short-lived by power industry standards. Furthermore, unit cost is high by comparison with conventional systems.

The fuel cell is an almost nonpolluting power generating system. Therefore, it is environmentally acceptable for inner-city siting. One suggested concept is to locate 12–25-MW substation-sized units in high-density areas for supplemental load generation. At present, test installations of substation-size units are being evaluated.

Energy sources: depletable

The three fossil fuels (coal, oil, and natural gas), plus U_{235}, are the four depletable energy sources presently employed to generate electric power. Of these, natural gas has been steadily diminishing. Oil is also declining, especially in domestic production. Over the next decade—at least—a herculean effort must be made in land and offshore exploration if the U.S. intends to cut its reliance on expensive imports of this fuel.

On the other hand, coal is the one fossil fuel still plentiful in the U.S.; it is rated as the prime "replacement" fuel for oil and gas in power generation. Paradoxically, however, the use of coal as an energy source in electric generation has diminished since 1965—largely because of the costs of mining and transportation, its adverse environmental impact, and the almost prohibitive costs of converting oil- and gas-fired boilers to accept coal as fuel.

Large-scale funding (and a lot of convincing!) will be needed to restore coal to its former share of power generation. The downward trend of its use can be reversed by 1980—if firm commitments are authorized by the Federal government, private industry, and the electric utilities. As of now, such commitments have not been made.

Coal, obviously, is a fuel that raises the hackles of a large segment of the public as well as the environmentalists. Coal may be environmentally acceptable if its harmful pollutants (SO_2, flyash, particulates, and nitrogen oxides) can be removed by (1) conversion to a liquid or gas prior to combustion, (2) removal of the pollutants during the combustion process (fluidized beds, etc.), and (3) removal of pollutants after combustion (electrostatic precipitators, scrubbers, etc.).

Nevertheless—and irrespective of the problems that loom large—coal will be a primary energy source, at least until the beginning of the next century.

Uranium is a further alternative—one that can be used in various ways. One method is to extract the elemental U_{235} found in U_3O_8 in a fission reactor. Our current light-water reactors (LWR) do this, but they extract only a fraction of the total potential energy in the uranium ore. According to some estimates, the domestic supply of this fuel source may become scarce by 1990.

Plutonium (Pu_{239}) is an isotope of uranium, capable of fission and is rated as most suitable for use in breeder reactors. Plutonium can also be reclaimed and recycled in a conventional LWR.

The element thorium (Th_{232}) can be subjected to neutron bombardment; in the process, it collects one neutron to be transformed to U_{233}—a fissionable isotope. Thus, the thorium fuel cycle can be employed in gas-cooled reactors. However, the heavy capital expenditures necessary for constructing fuel reprocessing facilities is a definite disadvantage to the concept. Although U_{233} will certainly contribute to our domestic electric power generation before 2000, its widespread usage will be curtailed by the cost involved.

LWRs are, today, viable and competitive generating facilities; the breeder reactors and fast-breeder reactors (FBR) should be coming on line by the end of the next decade.

Finally, lithium and deuterium are the materials that will be employed in fusion process reactors. A vast amount of R&D must be accomplished before controlled fusion can even be demonstrated to function in a practical manner for power generation. Unless some dramatic breakthrough occurs in this area, practical generation by nuclear fusion will probably not be realized in this century.

Energy sources: renewable

Renewable resources must be evaluated on a different basis than depletable resources: depletable resources are, by definition, finite; renewable resources are generally *time based*. Thus, a complete energy cycle of winds, tide, sun, hydro flow, etc. are quantified on a daily or annual basis (or some intermediate time frame).

Hydropower in the U.S. has just about reached the "saturation point" insofar as new development run-of-the-river sites are concerned. It may grow slowly, especially in Canada, over the next 20 years; but, its percentage vis-à-vis total power generation will decline over the next 25 years.

Solar energy is still elusive. Although numerous concepts have been devised and investigated to utilize this source for the heating and cooling of commercial and residential buildings, as well as for power generation, a lot of heavy R&D is still necessary before functional systems become operational on a large scale. Progress *has* been made—and is continuing—in solar collector designs for practical domestic applications of heat energy. However, the advances in adapting solar collectors to electric power generation have not been so rewarding to date. As is often the case in a new technology, the problems associated with the technological feasibility of flat-plate collectors, concentrating collectors, reflecting heliostats, etc., boil down to three basics:

- Very high capital costs (about an order of magnitude higher than conventional plants, at present).
- Large land areas must be acquired (up to 65 km^2) for solar collector "farms."
- Variations in seasonal solar intensity and variations of received solar energy on clear and cloudy days, etc.

Nevertheless and despite the big problems and obstacles to be overcome, the consensus is that, over the long haul, we *must* come up with an economically feasible technology for converting the sun's energy into electric power. But the timetable for such an eventuality seems to be in the same ballpark as fusion power—beyond the year 2000.

Tidal power has been a challenging prospect for centuries. In the present era, the best-known functioning tidal power plant is that on the Rance estuary, near St. Malo in Brittany. This French facility was completed in 1966; it uses 24 bulb turbines with reversible Kaplan wheels, and generates 240 MW. The plant has an averge net output of 544 GWh.

In the U.S.S.R., a pilot scheme has been in operation on Kislaya Bay in the White Sea. Construction techniques used successfully there included precasting the power station and installing generating units in floating docks. And a much larger tidal-power scheme is reportedly presently under construction.

In 1966, the Federal government of Canada, together with the provincial governments of Nova Scotia and New Brunswick, created the Atlantic Tidal Power Programing Board to make a study of tidal power possibilities in the upper reaches of the Bay of Fundy (where phenomenal tide differentials can exceed 20 meters).

Surveys of tidal power feasibility are not new to the Fundy area: from 1932 through 1966, considerable sums were spent in various periods by the U.S. Government for a possible tidal power project at Passamaquoddy, a site at the international border near the mouth of the bay. But previous studies have been less than optimistic concerning the economic tradeoffs of such power schemes. One negative factor (affecting almost all of 55 possible tidal power sites throughout the world) is the continuous change in the time of high tide by about 50 minutes per day; therefore, any power generation that was totally dependent on the time schedule for the tides would only rarely coincide with the load patterns of energy demand. But more recent planning envisages "retiming" facilities such as pumped storage and/or underground compressed-air storage to be coupled with the tidal scheme so that base loads could be met on an uninterrupted basis. Nuclear generating facilities could also be included to provide additional energy, as required, to supply future anticipated load growth.

On the "plus" side of the ledger, new methods of barrier construction, developed in Holland, are being examined for Fundy application. These latest techniques involve the construction, or prefabrication, of large floating caissons. These would be towed to the site and then flooded to sink them onto prepared underwater foundations. Clearly, there is a future for tidal power—but how much of a future and what impact it will have, time alone will tell.

We know that geothermal energy, to a limited extent, is both practical and economical. Such fields are produced when superheated rocks come in contact with cold water from underground aquifers. Successful steam wells, in other words, are drilled in areas where the *magma*, or molten mass—ordinarily deep within the earth—is close to the surface. Where this occurs, steam formed from the water in the magma is emitted through underground fissures. The steam from such wells is gathered in large pipes and carried to nearby plants where it is introduced to low-pressure turbines to generate electricity.

The pioneer steam well was drilled at Larderello, Italy, in 1904, and a small experimental dynamo was installed. By 1931, commercial blocks of electricity were being transmitted to the Italian railway system. Today, Larderello generates enough electricity to supply a city of 600 000 population (by U.S. consumption standards). Until it was surpassed by the U.S. in 1973, Italy was the prime producer of electricity from geothermal steam.

New Zealand became the second country to harness geothermal energy to generate electricity. Its first generating operations began in 1958. The main area in the U.S., which proved to be successful (back in 1960) was The Geysers, situated about 130 km northeast of San Francisco.

The ideal geothermal field is one where dry steam emerges free of corrosive minerals and can be injected directly into low-pressure turbogenerators. As of now, the two dry steam fields are those at Larderello and at The Geysers. The latter station supplies Pacific Gas & Electric with enough steam to generate large blocks of electricity. By the end of 1973, PG&E had 12 geothermal units in operation, for a total generating capacity of about 400 MW. The Geysers field is expected to produce sufficient steam to generate about 1350 MW in 1981. The Larderello fields operate at a generating capacity of about 350 MW.

At this point, it should be reemphasized that geothermal energy is available in three forms: (1) dry steam, (2) wet steam or vapor—with high mineral content—and (3) hot rock. Superheated steam, such as is available at The Geysers, can be fed directly into turbines with little associated problems. However, very few of these dry steam fields have been located to date. The wet steam, or hot brine, fields are much more common. Only about 20 percent of the (pressurized) superhot water emerging from these latter fields "flashes" into usable steam, and it must be cleaned in centrifugal separators before it can be introduced to turbines. Also, the hot water must be disposed of without damaging the surrounding environment.

Some geothermal experts believe that compatible plants, using other than hot dry steam, will be in operation after 1985 (provided the equipment and material problems are solved).

Transmission

In the short and long haul, overhead ac EHV power transmission lines will be the primary method of transmitting large blocks of electric energy over intermediate and long distances, according to a paper[3] presented at the Winter Power meeting. The employment of 765-kV transmission lines (such as those on the American Electric Power system) meets present-day utility demands. However, the first UHV (at 1 MV or above) transmission line will be required in the 1980s. The introductory lines will probably be in the 1100–1200-kV range and will serve as an overlay for existing 500-kV transmission. Between 1980 and 1990, these levels may be raised to 1500 kV or more as an overlay to installed 765-kV systems.

R&D projects for ac UHV overhead transmission have been established. "Project UHV," sponsored by EPRI is the most advanced in the U.S. Also, a test facility operated by Hydro Quebec is trying to set the upper limits of air insulation and to acquire sufficient know-how to design systems of 1500 kV and higher.

Work at Project UHV indicates that no technological limitations of ac transmission have been found—so far. But it is known that engineering and physical problems become more complex at operating voltages above 765 kV.

Underground transmission will be increasingly important in the future; but, new insulating materials and cooling techniques—as well as more economical means of installation, maintenance, and repair—must be found to increase both the transmission and current-carrying capacities. At the present time, 345 kV is the highest operating voltage in service in the U.S. However, high-pressure oil-filled (HPOF) cables have shown good testing results at 500 kV; they are now being tested at 800 kV.

The way of the future, though, for EHV and UHV transmission seems to be in the direction of cryogenic systems of two types: cryoresistive and superconducting. Two types of cryoresistive cable systems have been proposed, both of which are cooled by liquid nitrogen at a temperature of 80K. Similarly, two superconducting ac systems are under development, in which liquid helium acts as the coolant and dielectric at an operating temperature of about 5K.

But there are problem areas: for example, significant advances in circuit-breaker technology are necessary because present circuit breakers are not up to protecting cryogenic resistive or superconducting cables that have current ratings three to five times more than those of conventional underground or overhead lines. Similar difficulties may arise with terminal equipment such as potheads, surge suppressors, disconnect switches, etc.

Regarding the projected development of underground systems, the experts are a bit vague: as to future capacity requirements, "they can best be identified only in terms of ranges." But they add, "Even the minimum of these ranges requires substantial increased capability." This substantial increase in circuit capacity will occur within the next 25 years.

One other area in power transmission that is worthy of discussion is the dc system. Since the 1890s, alternating current has been predominant in power transmission. Nevertheless, direct current has some advantages: lower losses for a given line resistance, no reactive impedance effects in the line, and lower overhead line construction costs. But, the requirement for expensive terminal conversion equipment (ac to dc, and vice versa) put the damper—until recently—on the development of dc systems.

However, in recent years, the high-voltage mercury-arc-rectifier valve permitted the practical use of EHV direct current. Since 1954, 11 major EHV long lines have been installed, and several others are either under construction or in the design phase throughout the world. Today, silicon-controlled rectifier (SCR) elements represent an improvement over the original mercury-arc valves. Each SCR has a peak voltage rating of about 3 kV and a current-carrying capacity of 600–1200 amperes.

Many studies, conducted over the past decade, concerning the competitive economics of ac and dc transmission, indicate that the economic "crossover point" occurs at line lengths of 640 km, or more. Thus, dc transmission is most practical where the transmission of bulk power is required over long distances. It is also feasible where it is necessary to transmit electric energy over long distances via underground or submarine cable. In addition, there are two other practical uses of dc transmission:

- It can furnish an asynchronous tie between two independent ac systems.
- A dc link inserted into an all ac network can provide a method of controlling power flow and damping ac system disturbances.

But if the potential future benefits of EHV dc systems as supplements to existing ac grids are to be attained, R&D in three areas must be conducted:

1. Solid-state valve technology—to produce a self-protecting cell to resist high stresses.
2. Development of smaller, more reliable, and economic conversion elements.
3. Improvement in terminal station system design.

Distribution

Also discussed in the previously referenced paper,[3] distribution systems represent 40 percent of U.S. electric utilities' investments—the figure can reach 60 percent in urban areas. Future distribution systems will be far more complex than those presently in use and will probably account for an even higher percentage of total investment. If tomorrow's distribution system is to function at power levels of 20 to 50 MVA (with primary voltage levels at or above 34 kV), substantial improvement in surveillance and control is necessary to maintain improved reliability. To attain this, considerable R&D will be necessary on concepts and equipment for self-adaptive response systems and/or remote surveillance and control systems.

"Exotic" electric transmission

In the "far out" realm of futuristic transmission methods, microwave and lasers have received the most investigative attention. Realistically, however, both the microwave and laser schemes are far down the road and the techniques, today, are in their embryonic stages.

Similarly, though hydrogen has transmission potential, it is presently both economically prohibitive and hazardous. Not before the year 2000 are any of these technologies—hydrogen, microwave, and lasers—likely to come into their own. ◆

Information for this article came from several sources. Major contributors were: L. K. Kirchmayer, General Electric Co.; C. A. Falcone, American Electric Power Service Corp.; L. G. Hauser, Westinghouse Electric Corp.; and A. S. Vertis and R. A. Bell, Consolidated Edison Co.

REFERENCES

1. Falcone, C. A., "Electric energy technology forecast—energy needs" (presented at the 1975 Winter Meeting of the IEEE Power Engineering Society) Jan. 1975.

2. Hauser, L. G., "A forecast of electric power generation and storage technology 1975–2000" (presented at the 1975 Winter Meeting, PES), Jan. 1975.

3. Vertis, A. S., and Bell, R. A., "Electric energy technology forecast/transmission and distribution" (presented at the 1975 Winter Meeting, PES), Jan. 1975.

Cash crunch: its ripple effect

How the financial difficulties of U.S. electric utilities threaten to erode diverse segments of the economy

North Star Steel, operating out of St. Paul, Minn., is a U.S. steel producer not known to the general public. Desiring to expand its operations by the construction of a new mill, North Star studied its needs—the location of the probable market and the availability of resources, labor, and transportation—to determine the best possible site for its new plant. From nearly every point of view, southeastern Michigan, specifically the Detroit area, seemed ideal. But operating a steel mill means hefty power requirements. In the case of North Star's planned facility, the projected high-powered 100-ton furnace would require about 40 MW of electric capacity. The question in the minds of management was: Could either Detroit Edison or Consumers Power (the two troubled Michigan utilities—see *Spectrum*, March, pp. 40–44, and April, pp. 62–65) be depended on? Said North Star vice president Theodore Leja:

"We've tried to get a commitment but we can't get a definite answer out of them. They'll tell you, 'Sure, the power's available,' but you read *The Wall Street Journal* and you wonder."

What has Leja and North Star worried is the question of reserves. Like the vast majority of the U.S. utilities, both Detroit Edison and Consumers Power have had to curtail much new-capacity construction. Such cutbacks may have suited the no-growth economy of 1974, and they may be appropriate to the recessionary trend predicted by many to last at least through 1975. This fact of life is neatly exemplified by the declining power requirements of the recession-wracked auto industry. This decline has, in turn, contributed to the reduced earnings and low bond ratings of the Michigan utilities—the very problems that have led to construction cutbacks. And to make matters still more complicated, Elliot M. Estes, president of General Motors, asserts that: "In at least some of General Motor's plants, we're convinced that today we would be hard-pressed to secure all the energy we need to achieve production rates equal to those we enjoyed in the peak years of 1972 and 1973. Natural gas deficiencies are now widespread and some of our plants have experienced curtailments as high as 55 percent of normal supply. We are also concerned that in view of recent cutbacks in power plant construction, the electric utilities may not be able to handle the load growth in future years."

Thus, what is seen in Michigan is a classic example of the vicious circle of recession as it affects supplier and customer alike. Before this article is concluded, we shall explore the relationship that exists between the utility as customer and the major power equipment manufacturers, General Electric and Westinghouse, as suppliers. But first, the utility as supplier and industry as consumer . . .

Facing facts in Michigan

Burkhard Schneider is in charge of planning at the Detroit Edison Company. A realist, Mr. Schneider predicts that, unless something is done quickly, there will be brown-outs or worse by about 1980. "Soon," says Mr. Schneider, "service will begin to deteriorate gradually—frequency and duration of outage will become greater due to the fact that distribution systems will be stretched to the limit." Naturally, the Michigan utility has a recovery plan. This program consists of six "restarts": one 800-MW residual-oil-fired plant, a 100-MW nuclear facility, two 675-MW western low-sulfur coal-fired installations, and two 1100-MW nuclear plants originally planned for the longer term. But all of these plants have been stopped in their tracks for lack of capital and Mr. Schneider looks to the next decade with trepidation: "When normal economic growth pressures begin to develop again, will Detroit Edison be able to supply the needed power?" Mr. Schneider's feeling is that, without immediate rate relief and access to new sources of capital, all of Detroit Edison's customers may begin to suffer. "How do you decide when to stop connecting customers?" he asks. And, of course, what would be the larger implications for the entire southeastern Michigan area of a *forced* no-growth economy?

It is at this point that North Star Steel enters the picture. North Star's Leja told *Spectrum:* "We asked about reserves and got unsatisfactory answers that had to be rechecked." To do this, North Star hired Ferrco Engineering of Whitby, Ont., Canada. Acting as North Star's consultant, Ferrco found the Michigan utilities cooperative, but the harsh facts were that, according to James Orr, a Ferrco senior engineer, "Detroit Edison was putting out pretty negative statistics" and Ferrco found it difficult to "estimate what the Michigan Public Utility Commission would do to assist its state's utilities." But Ferrco's crucial worry in its client's behalf was the tie agreement that exists between Consumers Power and Detroit Edison—one that, in Ferrco's opinion, had been written so rigidly that if one utility "were to suffer a major fault, the other would be dragged along with it." This risk led Ferrco to append reservations to its eventual recommendation of a Michigan site for the North Star plant. Ferrco's reservations, needless to say, concerned the future uncertainties of Michigan's electric utilities' fortunes (or lack of them). As a result, North Star is still debating where to locate its new facility.

If this case were an isolated one, it might be overlooked, but rumor has it that as many as four other large companies have shied away from Michigan loca-

Ellis Rubinstein Associate Editor

tions for the same reason in recent months. The consequences of such actions may well be having a serious effect on the local economy. Says North Star vice president Leja, aptly describing more than his company's particular predicament, "Boy, it's a mess."

Reliability over power

The kinds of cost/benefit decisions being faced by North Star Steel are also being faced by companies in many segments of the national economy. It would take a multivolume, million-dollar study to determine, as was suggested by one rather optimistic *Spectrum* source, the effects of an energy-short economy on U.S. society as a whole. We appreciate the compliment to our resourcefulness, but the best we can do is report on trends. One such trend may involve the semiconductor industry. Long associated with the California Bay Area's "Silicon Valley," Intel has just completed a wafer-fabrication plant in Portland, Oreg. The motive behind the relocation is not fear about future power shortages *per se*, but rather the need for *reliable* power.

Fabricated at 1100°C, the wafers depend on a manufacturing process that is extremely vulnerable. The tubes in which the wafers are diffused must be cooled off over at least a 24-hour period; otherwise they will shatter. Thus, a blackout of even short duration would destroy these diffusion tubes, and not only would replacements have to be ordered from suppliers not geared to sudden orders for their normally long-lived product, but the furnaces would have to be rebuilt—a monumental job.

Consequently, the hazard to the semiconductor industry of remaining bunched together in one location, dependent on a single utility, is staggering. As an Intel spokesman puts it: "If a blackout hit Silicon Valley, there aren't enough diffusion tubes in the world to refit in less than three to four months. And the consequences of that long a shutdown on other industries, like the automobile industry, are incalculable."

It is for this reason that Intel opted for the "liberal amounts of power available from Oregon's Columbia River"—at least for its newest plant. The company feels that its decision will bring greater security than could be offered by Silicon Valley's Pacific Gas and Electric Company. And the key question in terms of the aims of this article is: If the other semiconductor manufacturers were to follow Intel's lead, what would happen to the Bay Area economy?

A second case in point is provided by Sprague Electric, headquartered in North Adams, Mass. New England is, of course, the area of the U.S. that has been hardest hit by rising fuel prices. The New England utilities are presently producing electricity at price rates well above the national average. With this in mind, *Spectrum* asked a Sprague spokesman whether his company had considered relocation. While the answer was negative, the spokesman noted that Sprague had built a plant for the manufacture of capacitors in Clinton, Tenn. The reason: electric rates there permitted a considerable savings per capacitor.

Energy-intensive industries

The serious consideration of utility finances in industry plant siting may be relatively new to electronics companies, but the energy-intensive metals and petrochemical industries have long taken into account, at the very least, local rates. As a result, they have tended to congregate wherever "cheap" hydro power is available. The automobile industry, on the other hand, had never concerned itself with utility finances until the last year or so—perhaps because the U.S. manufacturers always felt they could pass on whatever additional costs might accrue to them from increasing electric rates. Certainly, the recession has changed all that and a spokesman for one of the "Big Three" auto-makers told *Spectrum* quite frankly that while his company is not yet ready to desert the state of Michigan, the likelihood is that no further plants will be constructed there unless the condition of the local utilities—both gas and electric—improves.

An interesting example of the lengths to which the auto-makers can be, and have been, pushed to protect themselves against utility supply problems is afforded by General Motors' decision to drill its own natural gas wells. Prompted by the dearth of natural gas in the U.S., GM discovered that it could hedge its bets by exploiting natural gas resources on its own land in the Lordstown, Ohio, area. The problem was: Would the Ohio regulatory commission force GM to share its gas with the public, and if so, how much would be left for GM? After a fairly hot legal battle, an arrangement was made whereby GM was allowed 50 percent of the gas it mined—an amount that satisfactorily supplemented the otherwise strict diet imposed by GM's traditional suppliers.

Nothing quite like this has happened in the area of electric energy supply, but the current financial debility of the Michigan utilities has the major auto manufacturers worried and they are pressing hard for Federal action. Off the record, a spokesman for one manufacturer insists that his company is increasingly inclined to nationalized power, with all its implications.

The utility suppliers

While the economic interactions between the utilities and their industrial customers are easily discerned, the effect of electric utility financial problems on suppliers is more difficult to pinpoint. It might be expected that new construction cutbacks and constricted capital budgets would uniformly act as depressants on the finances of the electric utility suppliers. But, understandably, most suppliers would prefer to "accentuate the positive" for fear that negative forecasts will become self-fulfilling prophecies.

Westinghouse Electric is one supplier that candidly admits current market weaknesses. In an interview with *Spectrum*, a top executive in the Westinghouse power systems division conceded that delays and cancellations in orders have resulted "in a mild layoff condition, more accommodated by attrition than by drastic cutbacks in personnel." At the same time, the company is optimistic enough to predict an upswing in the economy beginning next year. But as Westinghouse sees it, the utilities are currently being forced into a "brinksmanship situation" that makes precise forecasting especially difficult. "We can see upper and lower bounds of required additional capacity through the 70s of from 150 to 300 GW," the Westinghouse executive told *Spectrum*. "A swing of 150 GW over that length of time is a very significant difference in annual rate of addition." Consequently, Westinghouse has apparently decided to take a cautious stand on the future. An excellent example of this policy can be seen in a recent reorganization of Westinghouse's gas turbine operation.

Planned and constructed during the peak years of gas turbine ordering, Westinghouse's Round Rock plant, located just north of Austin, Tex., had for two years been manufacturing the company's larger rated gas turbines, thereby supplementing the gas turbine manufacturing that had been going on since 1948 at Westinghouse's Lester, Pa., facility. Last year's swift downturn in gas turbine orders forced the company to announce, in January of this year, that it would have to phase out, by mid-1975, all gas turbine manufacturing operations at the Round Rock facility. The still-new plant was to be taken over by the company's heavy industry motor division and all remaining gas turbine manufacturing operations were to be "consolidated at the division headquarters in Lester."

Further, Westinghouse decided that it could no longer build gas turbines for stock, but only upon receiving an order. According to Theodore Stern, executive vice president of the power generation group, "As a result, the lead time from date of order to commercial operation will approach 26 to 32 months for an intermediate-duty, combined-cycle plant." This represents at least a doubling of delivery time, according to a *Spectrum* source in Westinghouse's power division, and together with the company's gas turbine manufacturing retrenchment, prompts an interesting question: What happens if a sudden change in the financial fortunes and capacity requirements of the U.S. utilities dictates a "run on" gas turbines?

One Westinghouse executive believes that that possibility does exist—that, in 1977, the utilities might suddenly all order gas turbines at once, to be delivered in 1979. But he feels that Westinghouse must consider such a possibility as "highly speculative" and, from a business standpoint, the company cannot afford to be prepared for such an eventuality. He went on to tell this reporter that "the utilities simply cannot indulge in the luxury of thinking they can get an Operation Bail-Out by fast delivery of gas turbines to ride them through a mismatch of demand/supply."

Another indicator of the change in the supplier/utility relationship as a result of the power industry's financial problems may be surfacing in the Westinghouse consultative Advanced Systems Technology Group. At present, there seems to be some question as to whether or not financially strapped utilities are cutting back on money expended for outside consultation in regard to planning. A consensus of opinion agrees that the sudden unpredictability of load growth has forced the U.S. utilities to invest more heavily than ever before in planning. But one member of Westinghouse's Advanced Systems Technology Group suspects that "we may be losing some business because their [the utilities'] budgets are cut." Elaborating, this *Spectrum* source said that, for a number of utilities, "right now, it's academic to study what they ought to have because they can't get it installed. ... What's happening, I think, is that people are just installing what they can afford—not what they need. They've got more to do with less—especially in the transmission area—but, naturally, the first thing you cut is outside budgets and that's either construction budgets or analytical services."

General Electric, too, has been affected by the miseries of the utilities. In a recent statement to the press, GE chairman Reginald H. Jones, speaking of the industry-wide picture, noted that "the combination of energy conservation activities and the economic slowdown in 1974 resulted in a year without growth in electric utility load. This fact, together with the financial crunch on the utilities, set off extensive deferrals and cancellations of power equipment orders in the second half of 1974."

In spite of this, Mr. Jones maintains that GE's corporate picture is healthy. "Cancellations," he said, "have not so far posed a major problem to General Electric. We ended 1974 with a record power generation order backlog of $13.7 billion, $4.1 billion higher than at the end of 1973." Further, he and the company are outwardly very optimistic about what they consider to be current signs of a turnaround in the U.S. utilities' ability to raise capital. (In recent weeks, utility stock prices have been rising sharply and utility bond issues have been sold at interest rates as low as 8¾ percent.)

However, if General Electric's optimistic forecasts turn out to be wrong, the company could be headed for trouble. As it is, GE chairman Jones concedes that "deferrals ... will have a near-term impact on steam turbine shipments and we are presently expecting 1975 turbine shipments to be about 20 percent below the 1974 level. Because of the very long cycle of the nuclear business, the deferrals which have taken place primarily affect the early '80s. Gas turbines, which have a short delivery cycle, were seriously affected by the utility downturn. The 1974 gas turbine earnings were down sharply from 1973 levels and we do not expect any improvements in 1975."

What is General Electric doing about these problems? For one thing, a company spokesman pointed out to *Spectrum* that "when we're taking turbine orders for 1980, 1981, and 1982, we can wait two or three years to see if those orders are going to hold up and then build a factory to handle the capacity." When asked if the wait, in itself, might not be causing dislocations, particularly in personnel, the spokesman insisted that GE had not had layoffs "of any major consequence in utility product areas." In fact, "the employment level right now in some product areas (the nuclear areas and areas involving new generation technologies, for example) is probably higher than it was a year ago."

But what about GE's gas turbine manufacturing operation? "I guess it's well known that the place where we do have serious cutbacks is in our utility orders for gas turbines," the spokesman admitted, but "we're shifting from domestic utility orders to, in most cases, smaller units for industrial, petrochemical, and international customers." This, the spokesman added, has not entirely solved the problem but it has mitigated its effects.

Seeking a third viewpoint on the intimate relationship between the financial state of the power industry and that of its suppliers, *Spectrum* contacted Allis-Chalmers. The company declined to respond to any of *Spectrum*'s questions, and further refused to explain its sensitivity on this topic. ◆

Inventing at breakfast

The senior partner of a father–son team creates over toast and coffee, while his son prefers to burn the midnight oil

"When they call, it's the voice of God, and we little guys jump." The "little guy" is Boston inventor Lyndon Burch; "they" is one of his corporate clients. A courteous, gentlemanly individual, who, at 76, still looks as if he could have been a college football tackle, this successful inventor of thermostats, circuit breakers, and precision electromechanical switches is jumping a lot these days. Burch belongs to that select breed of talented people who are able to make careers for themselves as independent inventors, avoiding the tempting embrace of industrial team research while carving their own niches as essentially autonomous individuals.

Once the main source of new U.S. patents, the independent inventor's relative input has been dropping. There is some concern that if he is not actually an endangered species, he is an increasingly discouraged one for whom such perennial problems as the resistance of corporate project engineers to outside ideas have been compounded by the trend toward "Big Science," the increased costs of patent litigation, and other factors.

But these developments don't seem to be hurting Lyn Burch, who with his inventor-son Hadley has derived a very comfortable income over the past twenty-five years from such devices as an economical case-operated thermostat for immersible frying pans or coffee makers, and shock-resistant snap-action limit switches used on the Apollo spacecraft.

Michael F. Wolff Contributing Editor

Ideas at breakfast

The collaboration between Lyn and Hadley Burch has several unusual facets, not the least of which is that Hadley works out of his own shop on a remote Vermont mountaintop, while his father invents at home in the center of Boston.

Lyn Burch's home is a 200-year-old sail loft he and his wife refurbished on a quiet tree-lined mews at the foot of Boston's fashionable Beacon Hill. There in a cozy basement workshop, amidst the model trains, steam engines, and miniature soldiers he collects, Burch may be found carefully cutting business cards into the shape of a new switch blade—an idea that came to him during the leisurely two-hour breakfast with which he starts every work day. Like most inventors, Burch has a particular time or place when ideas seem to come most readily. While there have been periods of his life when his best ideas came as the result of pressure or tension, right now his most creative time comes between seven a.m. and nine a.m. when he just sits and thinks.

What he thinks about, basically, is shape and pattern. As he explains: "Most of my work really involves geometry—simple geometric structures to perform a function. So I'll start with a geometric pattern in my mind. I see the whole picture and very seldom have to draw it, unless, of course, I have to get di-

Surrounded by memorabilia from his World War I flying days, inventor Lyndon Burch works on his latest switch design in the basement shop of his Boston townhouse (a refurbished 200-year-old sail loft), while at the same time...

mensions. After I see the pattern, I'll try to find fault with it, and nine times out of ten, I *can* tear it to pieces, so I'll start again. But when I've got the right pattern, somehow I just know it's right. I think this results from plain intuition, as well as long experience. When the average young engineer sees something new, he's got to go back to his textbook training and his slide rule and his mathematics and wonder whether what he has done is really right. I'll know simply by looking at it, although it's true I'm thinking of something quite simple like a thermostat.

"I always have four design objectives: Number one—does it do the job? Number two—is it what the engineer wants? In the auto industry, for example, this means: Can it be automated? Number three—is its cost going to be attractive to the manufacturer? And number four—are your tolerances loose? (Anybody can make something complicated, making things simple is more difficult.)

"When I get a good idea, I'm all hepped up. I'll put it on the board or else try to make something and actually test it out. That's when I'll take a pair of scissors, cut up a piece of cardboard and ask myself how it looks. This is my model—actually, my hardware—and to me it's worth thousands of drawings. This is what sparks me—if it demands a drawing, I'll do the drawing; if it demands a rough test setup to see how it works, I can do that in a couple of hours."

Lyn Burch generally works in his shop until half-past five or six o'clock and then knocks off completely to watch television or read (mostly history). Although he doesn't work nights, he will put in a ten-hour day, six days a week, with only occasional weekends off for a trip with his wife, Sally. The routine presents a series of emotional highs and lows: "If I've sat at breakfast and thought and thought without getting an answer, then it's a bad day and I'm just knocked down. But if I get the answer, my day is made."

Lyn Burch has been inventing ever since he was a young man. As a boy in the decade before World War I, when "every spare moment was spent making model airplanes and wireless sets," Burch grew up in comfortable circumstances. He lived with his grandfather who was a prominent New York City clergyman, and the family traveled widely in Europe. Burch attended school (which he hated) in Germany and Switzerland, and in 1917 he joined the British Royal Flying Corps after learning to fly in Glenn Curtiss' aviation school. After the war, 19 years old and desiring to run his own business, Burch started a truck line. "It was a fiasco, failing due to my inexperience." After that came a year studying electrical engineering at Berkeley, following which Burch returned East to spend the "Roaring Twenties" working on "very foolish inventions, silly things which were not successful in any way." There were gadgets for steam locomotives (Burch loves steam engines and at 21 was a fireman on the Lackawanna) and a camera that could thread the film automatically. Burch remembers the camera well: "I wangled an introduction to the president of Ansco but he turned me down. He said nobody would ever pay more than $15 for a camera. I was a youngster and this discouraged me so completely I dropped it. Soon afterwards Leica came out with their expensive camera."

Other ideas that met a similar fate included a radio station synchronizer, a contraption that allowed an automobile driver to extract a little more gas from the bottom of an almost empty tank, and a fancy two-tone auto horn (three feet long, it sat on the running board and operated off the exhaust gases).

By the time the Depression hit, Burch's grandfather had died and Burch was left with very meager resources on which to support his mother and his two children. (His wife had left him in a divorce case that made newspaper headlines because of his grandfather's high church position.) "I had a hell of a time. We lost our home and for a year I had a dollar a day to eat on. My ribs looked like a picket fence. I did everything I could to make money. I was a mechanic, I repaired cars and radios, anything I could lay my hands on." But in 1931, Burch's luck changed—he landed a $45-a-week job as a design engineer with a New Jersey thermostat manufacturer. Though Burch was not particularly interested in thermostats, they soon had him "fired up." Burch figures that between 1931 and the time he joined the U.S. Army as a tank project officer in World War II the company probably obtained thirty patents on thermostats, snap-action switches, and related devices he had helped invent. During World War II, Burch served in the Army and, later, the Air Force, designing circuit breakers, waterproof switches, fire detectors, electrically heated clothing, the inverter change-over system for the B-17 aircraft, and other such devices. After the War, he started his own company where he continued his ordnance-type work, developing, among other things, tank turret and gun firing switches rugged enough to become accepted as a standard.

It was during this post-war period that Burch began looking for a way to build what would ultimately prove to be one of his most successful products—a thermostat that would allow an appliance such as an

... his son Hadley may be found collaborating on the same invention from his mountaintop workshop deep in the Vermont ski country.

electric frying pan or coffee-maker to be immersed in water for washing.

Father–son collaboration

The search for the immersible thermostat (described in the box) was what initiated the inventive collaboration between father and son that has continued ever since. I questioned Hadley about it while visiting him in his well-equipped home machine shop overlooking 1500 acres of Vermont pond and woodland he purchased out of his share of the royalties from Burch patents. A sturdy outdoors type of 52, Hadley Burch piloted blimps during the Second World War, taught science at a Connecticut prep school, and at one time had an ambition to be a commercial explorer. He has the calloused hands of an accomplished machinist, and his jeans and moccasins are a striking contrast to his father's tweed jacket and conservatively monogrammed shirt with matching tie and handkerchief. Hadley Burch and his wife, Donnalyn, an electrical engineer's daughter who studied architecture and helps prepare Burch's drawings, appear to thrive on the beauty and isolation of a spot accessible only by snowmobile between December and March. Hadley Burch puffs reflectively on his pipe while he explains that there are basically two ways he and his dad work together.

"One way is that he will have an idea which he drops for lack of interest, and I'll pick it up and run with it—or else I'll have an idea which I don't think much of but he gets enthusiastic over and works with. Another way is that he'll start on something, and in certain areas where I'm better than he is I'll take over and work on that aspect. You see, Dad is fantastic on initial concepts and the willingness to go into new ground. He will get a simple idea and plug very, very hard at it—much harder than I would. He'll cut and try, and come up with some amazing ideas. But while neither of us are engineers, of course, Dad's even less so. So beyond a certain point, when it gets to an engineering type of problem where we may, for example, simply need to accumulate figures, I have to take over, simply because he just doesn't like it (which is really why he doesn't do it I think).

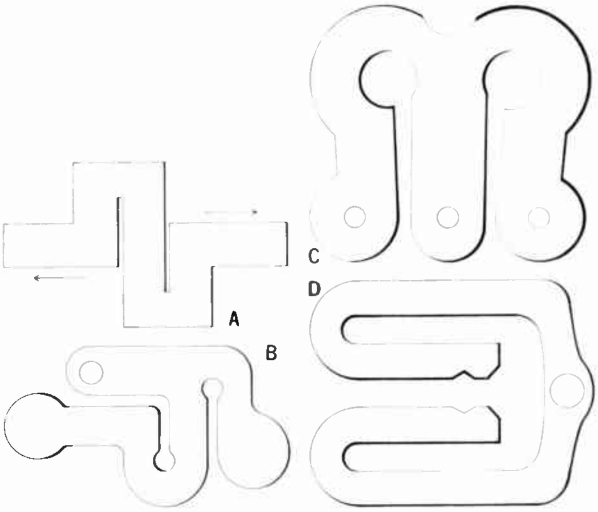
From the furnace door to the M-switch

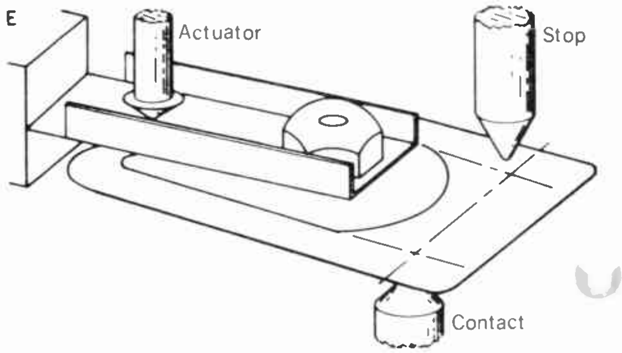
The best introduction to the Burches' approach to inventing is the story Lyn Burch loves to tell of Al Spencer and his snap-action disk. Al Spencer was an M.I.T. student who, during the 1920s, had a nighttime summer job tending a sawmill furnace in Maine. One night, he noticed that the sheet metal door snapped when the fire got very low. The snapping set him thinking, and eventually he hammered a can out of bimetal that would snap hard enough to jump off a table. Not knowing what this might be good for, Spencer approached one of his professors, who eventually suggested turning it into a toy. Spencer did just that, making little crickets for street vendors to peddle. One thing led to another until Spencer took his idea to the Metals and Controls Company in Attleboro, Mass. The firm decided the "Spencer disk" had potential as a snap-action thermostat and, by the 1940s, a multimillion dollar industry had been born.

Meanwhile, during the 1930s and the war years, Lyn Burch had been designing thermostats, switches, circuit-breakers, and associated devices, and so had naturally become familiar with the Spencer disk. "However, making a disk for a thermostat or a switch requires preforming metal, and this is something we avoid because neither Hadley nor I are good at making fine tools. Our approach is to try to produce a mechanical deformation *after* the metal has been mounted. In other words, we work with a perfectly flat piece of metal, and instead of getting over-center switching action by snapping from, say a concave to a convex shape, we get it from the way we mount and stress our blade."

The Burches first applied the concept of a metal blade mounted in tension in the late 1940s. It came about aft Lyn Burch "happened" to cut out a sinusoidal shape like that shown in Fig. A. For some time he had been seeking an all-welded, case-operated thermostat that would be simple enough to be manufactured and sold for less than a dollar. In searching for a suitable amplifying element, he would cut paper in different shapes to see how they would respond. This particular shape looked good to him because it could be fastened solidly at both ends, and when those ends were pulled in the direction indicated by the arrows, there would be a substantial twisting motion in the plane perpendicular to the plane of the pulling motion. After some more experimenting, Lyn Burch found that this twisting motion could be greatly enhanced by adding an arm so that the shape of Fig. B resulted. He discovered that if he pulled the ends a distance of one thousandth of an inch, the arm would move about seven thousandths of an inch.

He soon contacted Hadley who was then studying mathematics at the University of Colorado. "We did a lot ot talking on the telephone, as we always do, and Hadley played





"A great deal of this is done on the phone, of course, but every few weeks we'll sit down together and play with an idea, cutting out pieces of paper, and so on. As a result, when we get into a patent situation later on it's very tough for us to figure out who actually got a particular idea."

Hadley Burch did not think seriously about going into the business of inventing until he had begun collaborating with his father, but he has always worked with his hands. "As a boy I built a lot of models and things like paper-folding machines where I would see a problem and have fun trying to figure a way around it. But I think my real forte is that I have a good sense of materials—that is, I have an intuitive feeling for what can and cannot be manufactured economically. This has kept me from going off on all kinds of wild goose chases, and I think a person develops it only by working *with* things and enjoying working with things."

Hadley is not the only person who has worked with Lyn Burch. A number of the gadgets developed during the 1920s were done in collaboration with a free-lance tool designer and inventor named Malcolm Parkhurst. Now 81, a spry, white-haired slip of a man, Parkhurst recalls how he and Burch first met at a bookbinder's when "we were both hard up and looking for any type of job we could get." At one point they were even painting houses together. Today, some of Burch's models and package designs are still made by Parkhurst in the three-room machine shop on the top floor of the weather-beaten Bronx, N.Y., home, where he came to live fifty years ago.

Parkhurst, who speaks proudly of "accepting the challenge to build one of the smallest switches in the world" for Lyn Burch, feels a close link between science and esthetics, a "harmony" between science and pictorial art. Parkhurst studied decorative and applied design at Pratt Institute and is presently writing poems for a volume of photographs he has taken of blind children.

The art of inventing

Both Lyn and Hadley Burch share a deeply felt concern for simplicity as well as for craftsmanship

---

with it awhile. One day, he discovered it had very good snap-over-center properties. As a result, we worked together to develop it into a switch. I don't believe it was ever used in a thermostat, but it did become our basic switch element."

A former executive of Metals and Controls, which manufactured "fairly large quantities" of the so-called sine-switch, describes the idea of mounting a blade in tension as being a unique approach at the time and one that gave definite advantages over the existing switch technology in terms of cost and resistance to shock and vibration. The sine-switch was widely used, finding its way into tanks, automobiles and several NASA programs including the back-up manual control system for the Mercury astronauts.

The invention of the W-switch

The Burches' second switch utilized the W-shaped blade shown in Fig. C. It was invented a few years after the sine-switch by Hadley Burch who "thought I had better see if I could actually sit down and design a switch since I felt our first switch was a bit too accidental. Also, I wanted something that would be simpler to manufacture than the sine blade."

With its low-mass snap-action element, the W-switch came to be widely used as a pressure and limit control switch in spacecraft and other applications where a premium is placed upon small size and high resistance to shock and vibration. Lyn Burch is particularly proud of the fact that hundreds of switches incorporating the element flew to the Moon for the first manned landing in 1969.

After ten years, the immersible thermostat

Meanwhile, during the years when the sine- and W-switches were being perfected, Lyn Burch continued his search for an economical case-operated thermostat. By 1954, some ten years after he had started experimenting, he and Hadley had what they wanted. It evolved from a series of steps Lyn Burch no longer recalls except that they were "sort of progressive; we had a complicated structure we kept trying to simplify." The device employed a simple actuating arm to amplify the difference in expansion rates between a tubular, high-expansion case and a low-expansion rod within the case. With none of the mating parts common to other thermostats of its day, it provided good amplifying action and temperature response without the contact wear that would upset calibration. The new device found its application when, in the course of his travels, Burch visited a frying pan manufacturer who wanted just the kind of thermostat the Burches had invented. In the years that followed, Burch estimates that some 22 million were sold to appliance manufacturers, making it probably safe to assume that more than $500 000 in royalties were received from this one invention.

Both the thermostat and the sine-switch were licensed to Metals and Controls, and, in 1954, Burch left his own company to spend six years with Metals and Controls as a full-time consultant working on both the marketing and the engineering associated with these as well as other products such as the W-switch.

Now, the M-switch

After the invention of the W-switch, Lyn Burch set out to develop a switch that would have a more even distribution of stress and be easier to manufacture. He accomplished this with the M-shape shown in Fig. D. As with the other switches, the basic idea was to mount the blade in such a way that the loops are stressed to an unstable condition. When a force is applied, the loops can then snap from the plane in which they are mounted to another plane, making or breaking a circuit in the process. The M-shape, however, allows mounting and stressing the blade at a single point (the center of the M), with the result that there is only one critical tolerance to deal with in the manufacturing process. Hadley Burch relates how despite these advantages nothing much came of the M-switch: "Among other things, we got off on the wrong foot with a small company that went bankrupt."

Today, the Burches are as busy as ever, with new projects claiming their attention. One of these is a resettable fuse for automobiles; another is a switch Hadley discovered when "I started playing around with Dad's M-switch, and, for some reason I can't explain, asked myself what would happen if I moved the contacts from the center of the blade to the outside, making them asymmetric." According to Hadley, this configuration, shown in Fig. E, has several important advantages which he describes with great enthusiasm: "Fantastically high pressure before break (some 15 to 20 times greater than that of other switches tested), a high dynamic contact gap, extremely low bounce pattern, and a greater resistance to shock and vibration. I don't think I ever had as much come out of one change in my life as this," he concludes.

—for what they call the esthetics of a device. "I think there is very little room these days for craftsmanship *per se*," laments Hadley Burch. "I am really talking about esthetics here, about a device that *feels* right. Just look at these two circuit breakers. One is American and the other was made in Germany during World War II. The German one is obviously horribly over-engineered and probably doesn't work any better than the American, but there is a nicer feeling about it—a feeling of quality. For example, if you are wearing gloves and push the toggle on the American one, there's nothing to tell you that 'bang—it has snapped in.' But you could work the German one with mittens and you'd know damned well the thing had snapped. And Germany was building this while they were fighting for their lives! There really isn't room any more for that sort of thing, but I'd like it if there were."

Lyn Burch will express, with considerable feeling, his belief that no matter how humble a man's job the most important thing in his life is to feel he has done that job well. Although he appreciates the need for economy, he is troubled by what he sees as a spreading philosophy of "How cheap and rotten can you make it?" He admits that his personal preference is for simply trying to make something "better," and that emotionally he finds it difficult ("though I'm getting used to it") when his customer's overriding concern is with lower cost and automated manufacturing. Nevertheless, a large measure of the Burches' success is undoubtedly due to their ability to go beyond the idea that is clever and original to the idea that is practical in that it can meet a customer's requirements for cost and manufacturability. Indeed, the failure to truly appreciate these requirements is one of the major reasons so many outside inventors have trouble selling their ideas to companies.

Inventors at work

The Burches are not reticent about discussing the advantages they feel they can offer a company. Citing one time when he was asked for help, Hadley Burch tells how he was able to get a model to the company within two days. "There may have been a certain amount of luck in that I got the idea quickly, but the point is that I can find out very, very quickly whether an idea is worth pursuing or not. I've worked with enough companies to know that this step alone could take a person a month. He would have to justify the idea, discuss it, get it through the model shop—which is always overloaded—verify his findings in a systematic fashion, and then write them up. From the company's standpoint this is all necessary, of course. On the other hand, if I have an idea I will often work through the night and in the morning I'll know whether it's worth pursuing or not. I don't need drawings—only sketches as I'm working. I'll get a breadboard model which I can put on my oscilloscope, or whatever I need for testing, and while I won't get the final answer, I will learn enough to know whether the idea is worth pursuing. Of course, there is a big difference between the idea I bring in on a breadboard and a finished product. I am really only a small contributor, and the guy who designs it deserves more credit than I do."

In raising the question of time, Hadley Burch brings us to the crux of what the independent inventor can offer a company that its employees rarely can. This is time—not just the spurts of all-night activity that engineers are capable of too, but time that is essentially unlimited, that will stretch on for years. As Richard Walton, a prominent independent, has written: "The independent inventor is the risk-taker *par excellence:* He has staked his whole life on the success or failure of his ideas. In the process, he brings to the company willing to use him one crucial commodity its engineers can never possess—unlimited times."

Lyn Burch worked for ten years until he succeeded in inventing the thermostat he was after. His neighbor Richard Walton worked for 25 years before his experiments on compaction paid off with volume applications in the field of nonwoven apparel. "No self-respecting company would ever have allowed me to pursue this for so long. There would have been no justification. I had to do it on my own...," says Walton.

An endangered species?

Not withstanding the determination and persistence of individuals like Walton and the Burches, there is some evidence that the independent inventor may be vanishing. Fifty years ago, a majority of U.S. patents went to independents; twenty years ago, the figure had dropped to 37 percent, and it has kept on dropping until the past couple of years when it has been hovering around 23 percent.

This steady decline does not alarm some observers who point out that since 1954 the total number of U.S. patents has almost doubled and the actual number granted to independents has remained roughly the same. However, the fact that this increase represents patents granted to corporations, particularly foreign ones, and educational institutions is precisely what troubles other observers, such as Jacob Rabinow. Mr. Rabinow is one of the world's most prolific and versatile inventors, responsible for the magnetic fluid clutch and the clock regulator, among many other devices. A close observer of the patent scene (he headed the Bureau of Standards' Office of Invention and Innovation from 1972 through 1974), Mr. Rabinow believes that if conditions were healthy for independents, their numbers should have grown over the past twenty years because of the increase in education level of the overall population. Moreover, he feels the decline in relative activity is serious because it signifies more competition for the independent from in-house inventors and, hence, a tougher selling environment. This is borne out, he says, by the many inventors and patent attorneys who tell him they find it increasingly difficult to sell to big companies.

"With the high cost of money and the trend toward larger size and multinational activity, the big companies are getting more conservative and putting their resources into improving existing products rather than inventing new ones." Furthermore, adds Mr. Rabinow, "I've been reading the U.S. Patent Office Gazette for many years and these days I find the number of ideas that startle me is less than it used to be. More and more of the patents issued seem to be not so much the breakthrough ideas as they are improvements on existing technology—defensive patents, if you will. Maybe the real pros are getting dis-

Dynamic braking

The kinetic energy of rapid transit trains that is normally dissipated as heat during braking can be converted to potential energy

"Reusing" the kinetic energy of trains in rapid rail transit systems through the use of flywheel energy storage systems (FESS) is an old idea that has recently been revived. A competitive idea being advanced is the thyristor inverter-recuperative system. While extensive operational experience is not yet available for either system (both are currently being experimented with—the former on the New York City Transit System, and the latter on the São Paulo, Brazil, Metro), it appears that the latter is more efficient and requires less maintenance, and therefore justifies additional capital investment.

Rapid rail transit systems generally use dc traction-driven motors, in which cam controllers or choppers control the operation of the motors during train starts and stops. In the dynamic-braking mode, the motors act as generators, dissipating kinetic energy into resistor-bank loads. When dynamic braking is inoperative, friction braking is employed, at lower speeds, to absorb this kinetic energy.

An opportunity exists for effecting savings in total energy expended, and in reducing heat generated during braking, if the train's kinetic energy can be utilized in some useful form during braking. Energy savings possible are especially important for train systems in which interstation distances are small, and station stops frequent. Aside from the energy savings, the reduction in heat generated reduces the ventilation and air-conditioning requirements in tunnels and underground stations.

How energy is saved

Possible energy savings for a particular train depend on its weight and the maximum speed it reaches during interstation runs. Figure 1 shows the energy savings possible, in kilowatthours per station stop, for various weights of trains and maximum speeds. It is assumed that the energy can only be regenerated down to a minimum speed, and is fully utilized. The energy savings are directly proportional to train weight and to the square of the maximum speed.

The total energy savings for a particular system depends on the headway during different times of the day and the number of station stops. Based on studies, calculations for the New York City Subway "A" line (NYCTA) and the São Paulo, Brazil, Metro (SPM) show that energy savings of up to 30 to 40 percent are possible on typical rapid-transit systems.

As can be seen from Fig. 2, when a train leaves a station, the power demand reaches a peak. This peak remains, until the maximum speed of the train is reached, after which the power demand falls to a level required to overcome the drag on the train due to friction and wind resistance. Before the train comes to a stop at a station, the kinetic energy of the train has to be absorbed in a short time span. If the kinetic energy lost during braking can be utilized, then the average power consumption for the typical station-to-station run will be appreciably reduced.

From the typical station-to-station run curve, it is clear that two ways to utilize the kinetic energy of a train, while braking, are either to supply this energy to another train (accelerating at that instant) on the system, or to store the energy and use it during acceleration after the station stop. This would not only utilize the kinetic energy of the train while braking, but it would also reduce the peak power consumption from the supply. As the cost of electric energy depends partially on the peak power consumed, substantial savings in energy costs can be achieved.

The simplest method of utilizing the kinetic energy of trains, while braking, is to allow an energy exchange between them. However, there are severe practical limitations involved in achieving this objective, since power and running rails have dc resistances, on the order of 0.02 ohm/km, that contribute to voltage drops which depend on separation distances between the trains. The efficiency of energy exchange between trains would therefore depend upon voltage-versus-current output characteristics of the chopper control during braking, and on the relative position of the accelerating train receiving energy with respect to the braking trains and the substation supplying energy.

In addition to the problems of chopper-regeneration characteristics and rail-voltage drops, there is the problem of synchronizing all trains on a system. For successful energy exchange, another train must be accelerating and consuming energy at the very instant when one train is braking and generating energy.

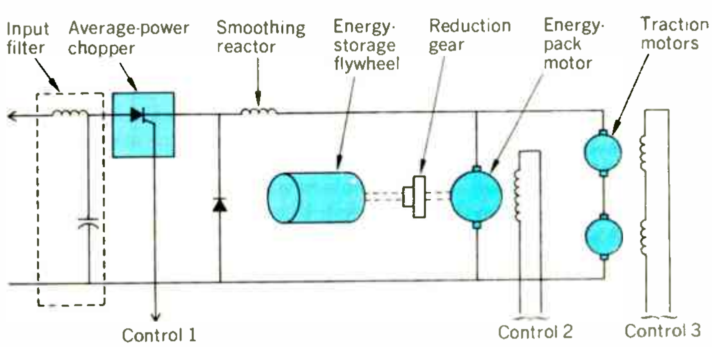
Since it would be too restrictive to synchronize the operation of trains for energy exchange, this process can be assumed to occur in a random manner. There is also a greater opportunity for efficient energy exchange between trains traveling in opposite directions on parallel tracks, than between following trains on the same track. This is because trains on the same track are separated by safe braking distances to avoid rear-end collisions.

Another factor governing the extent of energy exchange between trains is the headway at which the trains are operating. If the headway is small, the density of trains on the system increases, increasing the opportunities for energy exchange. Calculations on the SPM show that even for 90-second headways, the efficiency of energy exchange is limited to about 25 to 35 percent of the total potential savings, due to the previously stated reasons. For longer headways, the exchange of energy between trains will be even small-

Paul Kalra Bechtel, Inc.

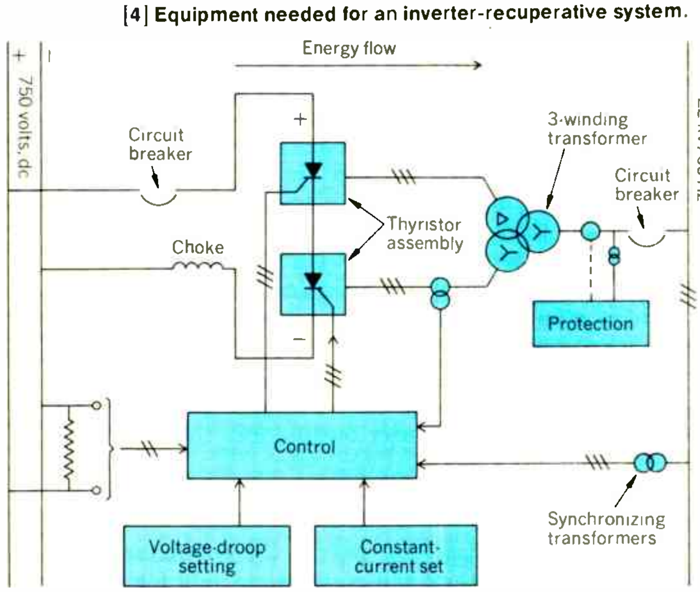
voltage three-phase energy, and fed into the three-phase high-voltage distribution system. This has two distinct advantages. First, energy can be shared by all the trains on the system, independent of the voltage drops in the low-voltage distribution system and regenerative chopper-control characteristics. Second, if the energy generated by all the braking trains on the system exceeds the energy requirements of the rest of the trains, then the energy can be supplied to the other loads supplied by the same utility. This guarantees that a load is present to receive energy from braking. And with an inverter recuperative system, an exchange of energy between trains, through the low-voltage dc distribution system, can still take place.

An inverter-recuperative system is being considered for the SPM (Fig. 4). The low-voltage dc supply is connected through a circuit breaker and a choke to two series-connected thyristor assemblies. Each thyristor assembly is a three-phase full-wave bridge configuration, individually providing six-pulse dc operation. The outputs of the thyristor assemblies feed into separate low-voltage windings of a three-phase transformer. One of the low-voltage windings is connected in a wye configuration, while the other is connected in a delta configuration. The third winding is connected in a wye configuration to the high-voltage line. This arrangement results in a 30° phase displacement between the outputs of the thyristor assemblies, allowing a combined 12-pulse operation for the inverter. Forced-air cooling is provided through the thyristor heat sinks.



[3] The on-board flywheel energy storage system (FESS), as used by Garrett Airesearch, in experimentation, on the New York City Transit System.

[4] Equipment needed for an inverter-recuperative system.



Two modes of control—constant current and constant voltage—are available. While the dc supply is below the nominal voltage, a constant current of approximately 100 amperes is fed into the ac system to maintain synchronism. If the voltage of the dc supply tries to rise above the level of the nominal voltage, then the constant-voltage mode overrides. Under the constant-voltage mode, if the dc voltage tries to increase due to a braking train in the regenerative mode, the control allows dc current to increase, thus allowing excess energy to be transferred to the ac network. In this way, the dc rail voltage is prevented from rising to unacceptable levels.

Looking ahead

In the future, the technologies available may change along with the relative costs. It is possible that fast-rechargeable, low-cost batteries may become available. Another possibility is that with developments in cryogenic technology and superconducting materials, it may be possible to store energy in magnetic inductors. In this way, superconducting inductors could replace rotating flywheels. However, such ideas are far out into the future and cannot be contemplated within the next few years. ◆

BIBLIOGRAPHY

Armagnac, A. P., "Flywheel brakes: store new train's energy for electricity saving starts," *Popular Science*, pp. 70-73, Feb. 1974.

Garrett Airesearch Mfg. Co., "Energy storage system," *Technical Description*, 73-9723, Oct. 31, 1973.

Gilbert, R. R., "Optimum energy storage means for low-emission vehicles," *Proc. of Second International Electrical Vehicle Symposium and Exposition*, Atlantic City, N.J., Nov. 1971.

Hoffman, G. A., "Which are better for electrical vehicles: flywheels or batteries?" *Proc. of Second International Electrical Vehicle Symposium and Exposition*, Atlantic City, N.J., Nov. 1971.

De Koranyi, L., "Energy requirements of high-speed trains," *The Railway Gazette*, July 1, 1966.

Phillips, R. L., and Brown, P. F., "A parametric approach to regional surface-transportation systems," *Proc. of Intersociety Conference on Transportation*, Washington, D.C., 1972.

Post, R. F., and Post, S. F., "Flywheels," *Scientific American*, vol. 229, Dec. 1973.

Robenhorst, D. M., "New concepts in mechanical energy storage," *1970 Intersociety Energy Conversion Engineering Conference Proceedings*, vol. 1, Society of Automative Engineers, Inc., 1971.

Paul S. Kalra (M) is with Bechtel Inc., San Francisco, Calif., working on the São Paulo, Brazil, Metro Project (SPM), where he has completed a feasibility study for the SPM evaluating different alternatives for an energy-storage, recuperative system. He has also worked on the design of speed profiles for safe separation of trains, train control noise interference from power-chopper harmonics, overall system grounding for personnel safety, and central-computer-control software acceptance testing. Mr. Kalra was previously involved in the design of the BART automatic train-control system while employed by the Westinghouse Electric Corp. of Pittsburgh, Pa. He received the B. Tech. E.E. degree from the Indian Institute of Technology, Kharagpur, India, in 1965, and the M.S.E.E. from the Illinois Institute of Technology, in 1966. In 1970, he obtained a M.B.A. from the University of Pittsburgh.