Sections see T of C

IBM CONFIDENTIAL

Report to the Director of Research
by the
Energy Task Force ("ETF")

January 31, 1974

Members

Arieh Aviram

Kai-Ching Chu

Edward P. Clarke

John Cocke

George J. Fan

George C. Feth

Richard L. Garwin*

P. Dean Gerber

Warren D. Grobman

Anthony A. Guido

J. B. Ian Gunn

Richard A. McCorkle

James C. McGroddy

David L. Reich

Merrill W. Shafer

B. David Silverman

J. Samuel Smart

Merlin G. Smith

Christopher J. Stephenson

Richard A. Toupin

James F. Ziegler

*Chairman

TABLE OF CONTENTS

SECTION I

RECOMMENDATIONS

	Name	Internal Zip	City & State
To:	R. E. Gomory	14-121	Yorktown Heights NY

IBM CONFIDENTIA

From

Date: January 31, 1974

Name & Tie/Ext.: R. L. Garwin/862-2556

Title/Dept. Name: IBM Fellow/General Sciences

Internal Zip/City, State: 7-045/Yorktown Heights NY

or U.S. mail address:

Subject: Transmittal of the Report of the Energy Task Force ("ETF") and my Summary Recommendations

Reference:

INTRODUCTION

At your request, and with the cooperation of the Department Directors, I organized and managed an Energy Task Force which ended its formal work January 30, 1974. My instructions to the ETF are contained in Section X of the attached report. One of the chief benefits of a task force activity is the education of individuals, and I hope that our organization in sub-groups, but with substantial (if sometimes lengthy) plenary involvement, has created a group of people both informed as to details and aware of the general problem. The task force members should have familiarity with the literature and with other sources of information, and I hope that Department Directors or others contemplating work in the field will take advantage of this information by calling on the individuals involved with a particular section of the report. Furthermore, I am making available for reading and circulation all of the background material used by the ETF. Just ask at the Yorktown Heights Library for the ETF Reading Shelf.

GENERAL COMMENTS

Aside from the very real benefits of implementing the recommendations of Section VI (Near-Term Energy Conservation), and the possibility to obtain contract support for interesting research, the impact of work by the Research Division in the energy field is somewhat problematical. The current energy crisis is a direct result of the actions of the Arab countries in suddenly reducing the amount of oil they are willing to supply and enormously raising the price at which they will supply it. Oil producers everywhere have taken advantage of this opportunity to raise their prices, although the cost of production has not increased significantly. Many of these acts have been legal -- those which are illegal may be detected, but it will be difficult to roll back prices which may have only a component of illegal action.

While there are many, many alternative sources of energy at what would eventually be reasonable prices, for the most part these require substantial capital investment (included in the eventual price) and time. Not only would energy from such alternatives, perhaps at a production cost of $6 per equivalent barrel of oil, be vulnerable to price reductions in Middle Eastern oil (in the face of continued production cost of about 20¢ per barrel for Middle Eastern crude), they would also be vulnerable to a vast influx of domestic US crude produced at costs exceeding the $3.50 per barrel which has been the recent price for natural domestic crude, but well below the $9 per barrel price which is now common.

Thus, IBM's actions should be guided by the likelihood that energy will be considerably more costly in the future than in the past (perhaps $7 per barrel equivalent, plus inflation), but there is certainly no guarantee that energy from any particular alternative source could be sold profitably five years hence at a price incrementally above that.

Nature of the Opportunities for the IBM Research Division

Category I: Research can obtain government or energy-industry contractual support for useful work in areas which IBM is not going to exploit commercially.

Category II: Research can initiate IBM-sponsored work in fields which IBM might possibly exploit commercially.

Category III: There will be a greater public awareness and easier beneficial publicity to IBM on research achievements which can be related to the energy field.

MY VIEWS ON THE SUB-GROUPS' RECOMMENDATIONS

Section II: Photovoltaic Conversion of Solar Energy

Although some tens of millions of dollars of solar cells are sold annually, and the number of installed kilowatts will probably increase substantially, I believe that photovoltaic solar power will not be a substantial contributor to the US electrical power supply unless or until a smoothing buffer is created in the form of a partial hydrogen economy. Still, the general interest in terrestrial applications of solar cells is high enough, and the actual productive applications for solar cells good enough (particularly in geographically small, arid, and energy-poor countries) that a substantial Research Division effort is warranted. I agree with Hovel and McGroddy that primary emphasis should be placed on thin-film solar cells of silicon and of gallium arsenide. We will be particularly effective if we continue to involve the support facilities of the laboratory in regard to substrate preparation, scanning electron microscope (SEM), analysis, experience in cooling the packages, environmental protection, etc. I go beyond the recommendations of the sub-group in suggesting that an additional professional concentrate on the inexpensive, sun-following, solar concentrators on which the economic viability of solar photovoltaic power depends. For the most part, previous work in this field has not considered high-capital-investment facilities which could then produce very-low-unit-cost concentrators and directors.

I recommend that Research move quickly to obtain NSF support for such work at a level of $500K to $1000K per year.

Section III: Other Solar Energy Sources

Aviram and Silverman do not make specific recommendations, and that is a deficiency in their report. I shall comment on a few of the "possibilities" they list on pages III.34 and III.35:

-- Photothermal conversion.
Since the NSF is supporting work at the University of Arizona which requires durable hot absorbers with little infrared emissivity, and since IBM is unlikely to be working commercially in this field, we could obtain contract support for the deposition, characterization, and improvement of appropriate solar-absorbing layers. We should also perform analyses (probably on our own) as to two-dimensional concentration of solar energy, because I believe that this is more promising than cylindrical concentrators with the resulting high performance necessary from the absorbing coating.

-- External-heating Rankine cycle engines.
I think Research should do no work in this.

-- Photosynthetic hydrogen production.
The work under G. Corker in the General Sciences Department could be expanded both to use the living organisms and to intensify the effort on the use of photosynthetic components of organisms. A proposal for expanded effort should be requested from Corker.

-- Use of fluorescence for concentrating diffuse sunlight.
This refers to the possibility of analysis and implementation of the scheme shown in Section IIIB. Such analysis should be assigned by the Director of Physical Sciences.

-- Computer control for tracking mirrors.
I have already recommended in connection with photovoltaic conversion that we do work on the design and experimental implementation of trackers and concentrators. Since the position of the sun in well known, "programmed mirrors" rather than "tracking mirrors" is a better term, and computer control is desirable only if it can be made cheaper than "clockwork."

-- Herd's herd.
Attached as Section IIIA is an abstract of a proposal by Harold Herd actually to implement a farm and animal herd, producing fuel from the animal wastes and recycling some of the material as fertilizer. I think that this can be done, and that there are large benefits to society in demonstrating such an operation a year or two earlier than would otherwise be the case. I believe that IBM would recover most of the money invested in such a scheme, so we might be somewhat indifferent as to whether IBM funds or government funds would be used. If H. Herd would actually do it, then I think we should go ahead with it.

Section IV: Nuclear Fusion Power

Dick McCorkle documents the large amount of excellent work being done in the AEC-sponsored programs. Of his comments, I particularly support his suggestion that plasma effects of interest "in programs other than the fusion effort, for example, in the field of X-ray lasers" will emerge from the fusion research. Certainly the plasma physics effort within IBM Research should be large enough to remain in contact with the work going on in the AEC fusion program.

Section V: Energy Storage, Catalysis, and Fuel Cells

Grobman and Shafer present detailed recommendations for work in "catalysis related to electrochemical technology." I thoroughly support this recommendation. With fuel cells coming into limited commercial use by utilities and for dispersed power generation, I believe that there are major opportunities for IBM in this field. Our office copier side-stepped the problem of developing and certifying a long-life photoconductor. Research and ingenuity can do the same thing for us in the fuel cell field. I recommend detailed reading of Section V. We may have the opportunity to be second (after Pratt & Whitney) in the utility fuel cell field, and effectively first in total power packages for large computer facilities. The inherent interest of the field, the large potential impact on world power facilities, and the possibility of IBM participation in the commercial exploitation of fuel cells make this a matter of high priority for Research.

R. E. Gomory
January 31, 1974

Section VI: Near-Term Energy Conservation

The central opportunity in energy conservation in the 801 Building is the saving of some large fraction of the 88% of our heating requirements (and similar fraction of air conditioning energy) which goes to condition the air expelled. Plant Engineering have made an excellent start on this. I recommend in addition to the substantive recommendations of Section VI that there be established a continuing oversight committee of two Research professionals in order to provide Plant Engineering with a forum and in order to help weigh the sometimes conflicting demands or traditions of economy, safety, and performance.

I support the other substantive recommendations, and especially want to emphasize the necessity to engage a professional heating, ventilating, air conditioning (HVAC) consultant "to quantify the tradeoffs in areas for improvement in the HVAC-related items identified" in the report. Ken Ellis of RECD has promised to identify for the Research Division such a consultant, and L. A. Cookman (with G. C. Feth) should see that this is done.

Finally, I recommend that the Director of Research or the Chief Scientist demand an analysis of the benefit-cost balance for improvement of the IBM tieline system and other facilities which allow access to it. While Research might participate in such an analysis -- both to ensure that technical options are not neglected and to have some comment on the quantification of benefits, the analysis is not properly a task for Research. My own view is that much travel would be saved if the tielines were busy less often, and still more if Communicating Mag Card typewriters were commonly used for document transmission. More important, of course, than the fuel used in travel is the loss of time and efficiency of the employee.

Section VII: Work-At-Home

Presents convincing evidence that at no foreseeable price of energy (if it is available) is it worth sacrificing efficiency or productivity in having people work at home. Furthermore, most of the energy saved would also be saved if people worked in "supermarket satellite offices" perhaps three miles from their home instead of the present average of 14 miles from Research Center to home.

More energy could be saved with less disruption by improved car pooling, by a shorter work week, etc.

In fact, work-at-home makes a great deal of sense in saving travel time and in bringing into the work force those people who are handicapped and cannot travel to central work locations and those who would work an awkward schedule of hours, etc. IBM Research should investigate work-at-home from this point of view, perhaps with support from the Department of HEW, HUD, Commerce, or Labor. Alternatively, the NSF Research Applied to National Needs Program ("RANN") might be a better source of such advanced support.

In connection with IBM's main business, existing IBM terminals seem inadequate for productive efficient work-at-home (even in comparison with the average loss of time in travel to the Research Division). Chris Stephenson has provided in the Appendix a sketch of a remote-computer-terminal which will do a better job. I believe that IBM Research should simulate the performance of such a terminal (within the 801 Building) and should quantify the benefits and costs of using it instead of having physical access to printouts and to 801 Building facilities.

Section VIII: Modeling of the Energy System

Chu, Fan, Gerber, and Ziegler have made a preliminary review of modeling of the energy sector. They recommend a six-month, two-man, detailed study of modeling the physical energy system of the United States, which would be done in conjunction with an interface to an advanced data base of real data. I agree with the likely utility of modeling in the energy field, but I believe that the existing energy crisis is positive proof that modeling the physical system would be inadequate. One would need a model of the system which would include a substantial number of actors, including producers, consumers, futures markets, taxes, etc., and would be sufficiently complete to include the possibility of the formation of coalitions, etc. Indeed, the implementation of the model must allow human interaction (as in a war game) in order to allow for the exercise of human ingenuity by entrepreneurs, mavericks, etc.

I believe that degree of complexity is the minimum required. Clearly, if such a model shows an opportunity for instability under manipulation, it would in no way predict exactly when such problems would arise. It would only give guidance to intuition and to the modification of the systems of regulation and incentive to avoid such instabilities. The creation and use of such a model might be of interest to the National Science Foundation (Energy Advisory Office) or to the Federal Energy Office. The improvement of modeling techniques which might go on in parallel with the use of an initial model could be supported by RANN or by the research supporting arm of the NSF.

R. E. Gomory
January 31, 1974

Section IX: Computer-Dependent Car

This group, chaired by Ian Gunn, notes that it is almost impossible to think of anything brand new in the automotive field, but on the other hand they show the plausibility of incorporating into a satisfactory passenger car the fuel economy of a diesel engine, substantially increased by the benefits of advanced control and of hydrostatic transmission. The group believes that it is unlikely that IBM will work commercially in the automotive field, and it would therefore be appropriate to seek government support for the actual implementation and demonstration of an experimental car which shows the advantages of computer control for ease of development, energy economy, and flexibility. About four persons could be involved for a period of about three years in such a program. The government has given about one-half million dollars to each of five organizations for experimental cars, and it seems reasonable to seek such support. In addition to the Summary Report, Section IX includes an "Outline and Notes" which I found very interesting.

CONCLUDING REMARKS

It has been proposed that IBM Research form a "Department of Energy Sciences." I think that this would be unwise. On the other hand, I think it would be most unwise not to have inter-departmental activities occasioned by the energy crisis. Furthermore, I believe that it would be well worth the investment of time by the Department Directors to read this entire report, to reflect on the work proposed which would naturally fit in their departments, and to use this report as a basis for the initiation of this and other work.

I recommend that you create on your staff a two-year position as Energy Sciences Coordinator, to best ensure analysis, communication, and collaboration within the existing laboratory structure.

In order to take advantage of initiative and intelligence in the individual departments, not monopolized by the Energy Task Force, it might be appropriate for each of the departments or laboratories to create a temporary group or task force of a few people to read the report and to advise the department director what specific action he should take in carrying out his responsibility within the department and in creating inter-divisional efforts. These reading groups may also find substantial errors in the report or may be able to fill gaps.

Richard L. Garwin

IBM CONFIDENTIAL

SECTION II

SOLAR ENERGY FROM PHOTOVOLTAIC SOURCES

Harold Hovel
and
James C. McGroddy

IBM CONFIDENTIAL 1/30/74

PHOTOVOLTAIC CONVERSION OF SOLAR ENERGY

Harold Hovel and James C. McGroddy

The flux of solar energy reaching the earth's surface on a clear day with the sun directly overhead amounts to approximately 1 kw/m^2. Depending on latitude and local weather conditions typical mean energies available per day[(1)] are 1.8 kw hr/m^2 day (New York, December) to 6 kw hr/m^2 day (Yuma. Arizona annual average). In this memo we briefly examine the outlook for converting a substantial fraction of this energy to electricity in an economically and technically feasible manner.

The two most promising approaches for conversion of solar energy at the earth's surface to electricity are photovoltaic conversion using solar cells, and conversion into thermal energy (subsequently used to drive conventional steam generators) via selective absorption. We conclude that several methods of photovoltaic conversion appear sufficiently promising to warrant substantial technical efforts to solve the problems associated with reducing the conversion cost to an acceptably low figure. Below we outline the key areas where we believe IBM can make an impact, both in photovoltaic conversion and in thermal conversion since the materials technology is so closely realted to that of photovoltaic conversion.

Almost all the research effort in photovoltaic conversion of solar energy has been associated with satellite applications, where the constraints and trade-offs are far different from those required for a large scale earthbound application For example, the cost of satellite solar cells is two to three orders of magnitude too high to produce cost-competitive electric power on earth. Immunity to radiation found outside the atmosphere and small weight/power ratio are two more constraints specific to satellite applications. On earth it is more important to minimize the net cost of the power produced, which leads to very different approaches to solar cell design.

If we consider covering a large area with some combination of concentrators (mirrors, fresnel lenses) and photovoltaic convertors, we can make an estimate of the total allowable cost per unit area covered based on the present value of electrical energy.

Assuming 10% conversion efficiency at a location where the solar flux is 2000 kw hrs/yr m^2 (Arizona), a value of 1¢/kw hr for the electricity produced, and combined depreciation/interest costs of 20% per annum, the allowable system cost is $10/$m^2$ including whatever storage and power conditioning is required. This is to be compared with the present cost of about $$10^4/m^2$ for satellite solar cells. Put another way, the maximum allowable cost is $500/average kw capacity.

To obtain the required reduction in cost/kw we assume that some cheap form of concentration of sunlight will be used. Low cost spherical mirrors can easily provide concentrations in excess of those required, and are easily aimed. Fresnel lenses and cylindrical mirrors provide two alternatives. Power conditioning is expected to amount to 5 - 10% of the total system cost, and is not considered in detail. Power storage-either in mechanical form, such as flywheels, or chemical such as hydrogen or batteries, will also add to the total system cost. For flywheel storage of 10000 kw hrs with an in/out power rating of 3000 kw an estimated cost of $110/ kw has been published (2).

Solar Cells

We now examine three promising alternatives for large scale power generation using photovoltaic solar cells. In each we believe IBM is in a position to make a strong impact in a relatively short period of time because of existing expertise and by extensions to present technology. The three alternatives are: polycrystalline thin film Si devices, polycrystalline thin film GaAs devices, and "ribbon"Si[3] devices.

As a preliminary we should discuss why we discard thin film CdS Ca_2S photovoltaic solar cells, since the claim has been made that these devices can provide economical electric power from solar energy. These cells have been the subject of a great deal of research in the United States and Europe for the last 8 years, but now have largely been abandoned in the U.S. The reason is that although the projected initial cost is low[4] there are severe degradation problems,[5] some of which are due to basic electrochemical instabilities within the cells, and some of which are caused by reaction with moisture, oxygen, etc. We do not believe the CdS-Cu_2S cells are as promising as Si or GaAs thin film cells, and IBM would not be able to make nearly the impact in this rather mature technology that we could make in thin film Si or GaAs, or ribbon Si cells.

Thin Film Si

If solar cells are optimized for terrestrial use instead of space, so that efficiency per unit cost is the most important parameter rather than radiation tolerance, highly efficient devices can be made using relatively small amounts of Si, and it appears that reductions in cost by two orders of magnitude over present day costs are feasible. The theoretical efficiency of 4 mil thick silicon devices exceeds 18%, and if the thickness is reduced to 10 microns, the efficiency should only drop to 15% (single crystal devices). If polycrystalline thin films of silicon are used, the existence of grain boundaries reduces the output due to loss of photogenerated carriers at the boundaries, but estimates of the device behavior as a function of grain size indicate that efficiencies can still exceed 13% for 5 micron grains and 9% for 2 micron grains (provided the grains are oriented. Polycrystalline Si films 10 microns thick with 1 - 2 micron oriented grains can be routinely obtained on SiO_2 covered Si substrates, and grain size can be increased by annealing. The use of cheap metallic or glass substrates (steel, aluminum) leads to cost estimates of \$130 - 200/average kw for the materials alone (at 1 solar intensity) using today's material prices. The cost of energy labor, produced energy storage, etc., may raise this figure by a factor of 5. but concentration of sunlight can reduce the cost by at least the same amount, making thin Si film solar cells highly competitive with other means of power generation.

Thin Film GaAs

Polycrystalline thin film GaAs solar cells are also promising for large scale terrestrial power generation. The efficiency of 2 micron thick single crystal GaAs devices exceeds 12%, and the devices are affected less by small grain size than Si devices are. GaAs devices are also affected less by high temperature than Si ones. and higher sunlight concentrations are possible. Using the present day high price of Ga metal. materials costs of $560 - 640/av kw are obtained, and if the additional labor and energy coats are balanced by the gain made by concentrating sunlight, or if the high cost of Ga is brought down by increased demand and usage of the metal, GaAs thin film cells can also become highly competitive with other means of generating power.

Ribbon Si

The third type of solar cell that has been proposed is made from Si "ribbon", 4 to 6 mil thick, 12 inch wide silicon stripe grown on a continuous basis at a fairly high rate. The elimination of crystal cutting and polishing steps and the implementation of mass production has led to cost estimates in the $500-$1000 av kw range, (without concentration), in spite of the greater silicon thickness compared to the the thin films. (The cost is predicated on reducing the cost of bulk Si, presently $50/lb, to $5/lb, or using $SiCl_4$ ($.15/lb) as the source of Si). IBM has a small effort on ribbon Si going on in E. Fishkill now. The payoff is not as high for ribbon Si as for thin films, due to higher inherent cost, but the chance of success is greater, and East Fishkill will presumably continue its effort for that reason.

A fourth promising area which does not involve solar cells but which involves very similar technology is that of selectively absorbing coating, layers of silver, GaAs or Si, and SiO, designed to absorb visible light but not emit in the infrared. Such a system is capable of becoming very hot (600°C) when exposed to sunlight and can be used to generate stream for a conventional power generation plant. Cost estimates for the overall power generation fall in the $400-500/av kw range, about the same as for solar cell systems and present day fossil fuel systems, but the technology is considerably simpler than for solar cells (doping is not important, grain sizes are not as crucial, and junctions are not involved).

PROPOSED RESEARCH

1. Solar cells consisting of thin (10μ) Si films grown by vapor deposition on cheap metallic (or glass) substrates should be studied. The device should be made using a Schottky barrier,[6] grown junction, heterojunction with ZnS or GaP, or diffused p-n junction in that order of preference. The effects of grain boundaries on devices and means of reducing these effects should be studied as well as the effects of solar concentration. Known methods of reducing surface recombination losses should be incorporated.

The studies of the effect of grains in poly Si films on device properties will also have relevance to other IBM technologies using poly Si. The goal of the program should be to demonstrate the feasibility of producing solar cells having 5 - 10% efficiency in concentrated solar fluxes of about 1 watt/cm^2 using a minimum cost technology.

2. Solar Cells consisting of thin (2μ) GaAs films grown by vapor deposition on cheap metallic (or glass) substrates should be studied. The solar cell should be made using a Schottky barrier, heterojunction with (AlAs or $Ga_{1-x}Al_xAs$), grown junction or diffused junction in that order of preference. The effects of grain boundaries and surfaces and the effects of solar concentration.should be studied. The goal of this program should be similar to that for the poly Si program discussed above.

3. Power generation by selectively absorbing film systems[7] should be studied. This project is included in the section on photovoltaic conversion because of the obvious similarity of the materials technology to the two projects discussed above, and because it is competitive with these methods. Si or GaAs films (10 or 2 microns respectively) should be deposited on steel covered with 1 micron of Ag or another I.R. reflecting metal. SiO, TiO_2 + SiO_2, etc., anti-reflection coatings should be deposited on the Si or GaAs surface. Measurements of temperature as a function of thermal load under sunlight or simulated sunlight should then be made for various films film thicknesses and film structures. The effect of solar concentration should also be studied. Theoretical studies of the absorption/emission properties of such semiconductor-metal composites should be carried out.

IBM CONFIDENTIAL

References

1. W.E. Morrow, Technology Review, December 1973, p.31 ff.

2. R.F. Post and S.F. Post. Scientific American 229, 17(1973)

3. T.F. Ciszek, Mat. Res. Bull. vol. 7, 731 (1972)

4. K.W. Boer, Proc 1972, Photovoltarc Specialists Conference p. 351

5. Proc. 1972 Photovoltaic Specialists Conference. (Contains recent results and references to earlier work.)

6. W.S. Anderson and A.E. Delahoy, NSF-RANN Energy Conference Fe. 1973.

7. See for example A.B. Meinel and M.P. Meinel, Bull. of Atomic Scientists 10/71 p. 32

General References

a) Proc. of Photovoltaic Specialists Conferences, annual, publ. by IEEE

b) Solar Energy (journal)

c) Solar Energy as a National Energy Resource (NSF/NASA solar energy panel) 12/72 available from Dept. of Mech. Eng., Univ. of Maryland, College Park Md. 20742.

d) NSF/RANN contract report abstracts.

SECTION III

OTHER SOLAR ENERGY SOURCES

A. Aviram
and
B. D. Silverman

SECTION IIIA

WE HAVE ENERGY TO BURN

H. H. Herd

SECTION IIIB

THE COLLECTION OF LIGHT FROM SCINTILLATION COUNTERS

R. L. Garwin

Utilization of Solar Energy

Despite its dilutness, the energy from the sun is plentiful. The sun radiates 92 million miles away from earth, with only two-billionths of its total radiation impinging upon earth. The radiation arrives at a rate of two calories of energy per each square centimeter of earth's sun-side hemispherical surface per each minute of time. About half of that is reflected back to the universe. The other half, i.e., one calorie per minute per square centimeter, is impounded by our planet's biosphere in ways making it available to human use.

No matter how dubious one may be of such logical realization of our potential, the fact remains that our net receipt and impoundment of cosmic energy amounts to 168 quintillion horsepower/minute or 66 septillion kilowatts/year. This is eleven-billionfold the world's present 5×10^6 kilowatt production of electric-energy power. It would obviously be to mankind's advantage to tap this vast resource of energy.

Since the late sixties, we witnessed strong concern for the environment, and yet very little activity against thermal pollution. It is an ignored fact that continued use of fossil fuels for energy could warm up planet Earth enough to cause the polar ice caps to melt. This may come about because of the release of latent heat stored in these fuels, and because of absorption of IR radiation from the sun due to the increased amount of CO_2 generated. Calculations show that the use of solar energy will neither warm up our planet nor cool it. It is a pollution-free source of energy not depleted through use as are other sources of energy.

As a nation, we are going to pay many billions of dollars for crude oil imports in the near future. The only way to reverse this trend is by development of energy sources in this country. Solar energy is a major candidate for development. The technology needed is available, therefore even if it were not competitive, economically, from a national economic point of view, a subsidy for its commercial development, would be advantageous.

Some approaches to the development of solar energy as a resource are outlined in the new few paragraphs.

Energy Crops

Plants are nature's solar energy converters. By the process of photosynthesis, green plants are able to convert carbon dioxide, water and photons into sugar, starch, cellulose and protein. Obviously animals depend on plants as a bone food source, and it has been suggested that man should consider farming plants for this energy content not as food but rather as fuel.

The average energy conversion observed in agricultural operations is about 0.3% with respect to the solar energy incident on the growing area, but some plants are known to be more efficient from the standpoint of conversion and reach an efficiency as high as 5%.

It is estimated that at 3% efficiency in conversion of solar energy which could be achieved by efficient plantation management and good fertile land, less than 3% of U.S. land area could supply the energy need for the projected 1985 U.S. consumption. Thus, an examination of farming as a source of energy is in place in order to determine the economical feasibility of the concept.

Land Plants

Yield is an expression of crop at a rate of tons/acre year and is a good measure of the productivity of a particular cultivation. Plants do not exhibit a steady growth during their lifetime, but rather will have a maximum during their life cycle.

Forests

Wood has been used as a fuel since antiquity. The productivity of forests varies and is estimated at 4-12 ton/acre year in non-tropical forests and 10-21 ton/acre year for tropical forests. The periods over which these estimates are obtained range from 20-50 years. Yearly productivity will depend on the age of the forest. Initially the productivity is low, then slowly rises to a maximum at around 20 years and then slowly declines. During their life cycle they experience good and bad years, therefore productivity of forests lags behind that of high yield annual crops. This low yield may be offset by their requirement for less attention during the growth period compared to annual crops.

Grasses

Intensive farming of high yield grasses captures more of the available solar energy than trees. The following table lists some examples:

IBM CONFIDENTIAL

Plant Productivity Data

Location	Plant Community	Annual Production (m.t/acre) Organic Dry Matter
Denmark	Phytoplankton	3·5
California	Algae, sewage pond	20·0-30·0
Nova Scotia	Sublittoral seaweed	13·0
Marshall Islands	Green algae	15·8
West Indies	Tropical marine angiosperm	12·2
Georgia	Subtropical saltmarsh	13·0
Germany	Temperate reedswamp	18·6
Sweden	Entrophic lake angiosperm	2·9
Mississippi	Water hyacinth	4·5-13·4
England	Coniferous forest 0-21 years	13·8
West Indies	Tropical forest, mixed ages	23·9
Congo	Tree plantation	14·6
Holland	Maize, rye-two harvests	15·0
New Zealand	Temperate grassland	11·8
Minnesota	Maize	9·7
Israel	Maize	13·8
Java	Sugarcane	35·2
Hawaii	Sugarcane	30·4
New South Wales	Rice	14·2
Puerto Rico	Pennisetum purpurcum	34·3
Puerto Rico	Panicum maximum	19·8
Columbia	Pangola grass	20·4
Puerto Rico*	Naplergrass	43·0

In particular, maize, sugarcane, Naplergrass, and some others are very productive. Not only do these crops exhibit high daily yields, but are the most productive on an annual basis. Data for sugar cane ranges as high as 36·7 tons/acre year, while Digituria decumbris was reported to yield to 35·8 tons/acre year. Normal cultivation of sugarcane will result in from 23·5 tons/acre year to 26·3 tons/acre year. Maize (Zea mays) is very productive over its growing season but does not compare with sugarcane on an annual basis. A productivity of 16·6 metric tons/acre year to 26·8 metric tons/acre year would result, if rice and corn could be cultivated for the whole year.

Algae

As seen from the productivity data table, algae are very efficient and productive plants. The harvesting is accomplished by floculation and centrifugation procedures. It lends itself therefore to computer controlled farming due to the possibility of directing the flow of liquids in pipes through computer directed valves and pumps.

Water Plants

Floating water plants, such as water hyacinth presently are pest plants in many rivers and lakes in tropical and semitropical areas. The rate of growth is rapid and in nutrient-rich ponds net productivity of up to 85 tons of dry product per acre per year has been reported. Present methods of harvesting these plants do not appear to be sophisticated, but interest in the plants as a cattle feed is developing and improvements may be forthcoming.

Economics of Energy Crops Farming:

Trees

Tree farming is presently practiced for the lumber and paper industry. Farming for energy may be somewhat different because the whole tree including roots and leaves should be considered as the product. Yet the price of lumber indicates that growing trees in North America for energy at present yields is not promising.

Corn

Corn is regarded as a high yield plant. In 1973 the cost of farming corn in central Illinois per acre was as follows:

Investment in 1 acre of land $1000 (Use 10% of)

Investment in machinery (doubled)* $260 (Use 15.5% of)

Variable cost (doubled) $113 (use all)

Maximum yield reported on acre 26 m. tons/acre

The heat content in K calories: (4 Kcal/gm)

$= 1.04\ 10^8$ Kcal/acre

1 Kcal (mean) = 3.9683 BTU

The heat content in BTU = $4.16\ 10^8$ BTU/acre

Since 1 gal oil contains 150,000 BTU, the heat is therefore an equivalent of 2800 gal. oil. The heat value converted to gal. of oil is 9¢ gal.

Projected variable prices for 1974 are expected to rise by 50%. It is also important to note that the input of energy in farming corn is equivalent to 80 gal. per crop. One has to bear in mind that the corn plant is not in a convenient usable form, and conversion to ethanol, methanol or other forms will add inevitably to the price. Ethanol

*Investment and variable cost should double if the whole plant would be collected.

received from corn by fermentation is given in the following table:

(Basis: 2.7 gallons 200° proof alcohol/bushel)

(May 1973)

Corn Price/Bushel, Dollars	Alcohol Cost/Gallon, Cents		
	Corn	Conversion[2]	Total Base Cost[1]
1.00	37.0	10.2	47.2
1.25	46.3	10.2	56.5
1.50	55.5	10.2	65.7
1.75	64.8	10.2	75.0
2.00	74.0	10.2	84.2
2.25	83.3	10.2	93.5
2.50	92.6	10.2	102.8

[1] These costs do not include profits, packaging, and sales expenses.

[2] Byproduct grains credited at $100/ton in conversion cost, although the value could be lowered by oversupply.

Wall Street Journal reports the price of corn/bushel on January 11, 1974 at $2.88.

Algae

Price of dried product in 1972 was $0.05 per lb. of algae and it contains about 10,000 BTU. This is equivalent to 7.5¢/heat of a gallon of oil. These numbers have not been confirmed. Growing algae may not be acceptable from an ecological and health point of view (mosquitos).

A Stanford Research Institute report by Dr. R. E. Inman came to the following conclusion:

Each pound of dry plant tissue has an approximate heating value equivalent to 7500 Btu. If burned directly as fuel, this amount of heat would be liberated. If converted to natural gas via biological or chemical processes, approximately 5 standard cubic feet, equivalent to 5000 Btu, could be obtained per pound of tissue. A yield of 30 tons/acre would therefore yield an equivalent of 450 million Btu/acre if burned directly, or 300 million Btu/acre if converted to pipeline quality gas. At $10/ton dry tissue in plant production costs, 1 million Btu would cost 67¢ for direct burning, and $1 for pipeline quality gas. At $15/ton, costs would be $1 and $1.50 per million Btu for direct burning and conversion, respectively. If the heat from direct burning were used for generating electricity at 35% efficiency, the cost per million useful Btu would be $1.91 and $2.86 at costs of $10 and $15/dry ton, respectively.

It may be therefore that growing energy crops could provide a solution to energy requirements provided that enough good fertile land will be found for this purpose. The contention of some officials in the agricultural department is that these crops would in fact compete for the presently available farming land. One also has to think of the political consequences of burning food in the U.S. when more than 1/3 of the world lives below the starvation level!

Solar Energy Through Wind Power

It is estimated that the power potential in the winds over the continental U.S.A., the Aleutian area and the Eastern seaboard is about 10^{11} Kilowatts electric. The following chart summarizes the possible electricity production by way of momentum exchange machines (windmills):

IBM CONFIDENTIAL

Maximum Electrical Energy Production From Wind Power Possible

Site	Annual power production	Maximum possible by year
(1) Offshore, New England	159×10^9 kWh	1990
(2) Offshore, New England	318×10^9 kWh	2000
(3) Offshore, Eastern Seaboard, along the 100 meter contour, Ambrose shipping channel south to Charleston, S.C.	283×10^9 kWh	2000
(4) Along the E-W Axis, Lake Superior (320 m)	35×10^9 kWh	2000
(5) Along the N-S Axis, Lake Michigan (220 m)	29×10^9 kWh	2000
(6) Along the N-S Axis, Lake Huron (160 m)	23×10^9 kWh	2000
(7) Along the W-E Axis, Lake Erie (200 m)	23×10^9 kWh	2000
(8) Along the W-E Axis, Lake Ontario (160 m)	23×10^9 kWh	2000
(9) Through the Great Plains from Dallas, Texas, North in a path 300 miles wide W-E, and 1300 miles long, S to N. Wind Stations to be clustered in groups of 165, at least 60 miles between groups (sparse coverage)	210×10^9 kWh	2000
(10) Offshore the Texas Gulf Coast, along a length of 400 miles from the Mexican border, eastward, along the 100 meter contour	190×10^9 kWh	2000
(11) Along the Aleutian Chain, 1260 miles, on transects each 35 miles long, spaced at 60-mile intervals, between 100 meter contours. Hydrogen is to be liquefied and transported to California by tanker.	402×10^9 kWh	2000

Estimated Total Production Possible: 1.536×10^{12} kWh by year 2000

1.25 Mw experimental wind power generator (Vermont 1945).

Extraction of the solar energy by way of the winds has the advantage that it is not limited to daylight or to geographical locations, but rather can be carried out almost everywhere. It is obviously desirable to locate a site where the wind velocity is steady, predictable and not turbulent. The preferred site for such installations is on elevated terrain with smooth curvatures. The reason for seeking high elevations for wind turbines is that wind velocity increases with height.

Wind turbine technology was widespread up to about 60 years ago. In Denmark 100 Mw of electricity was generated up to 1915 by wind power, but the powerplant was closed due to competitive cheap hydroelectric power imported from Sweden. Though displaced by new sources of power, wind power technology never completely disappeared. Windmills are used to this very day in different places in the world. There are five companies in the world that manufacture wind driven generators, among them one American company. The largest converter offered today commercially is a 12 Kw unit that sells for $17,500 (retail price) for single unit. (Unit includes storage capacity.)

For large scale power generation larger units would have to be built in order to become competitive with other power sources. During the period from 1941 to 1945, an attempt was made in Vermont to build a 1.25 Mw wind powered generator. This particular experiment failed due to improper design, and due to the failure, the whole idea was abandoned.

Principal disadvantages to wind power are the variations in wind speed and direction, which cause electrical output to fluctuate.

Efficient utilization of wind energy must incorporate an energy storage possibility. Two main streams of thought exist today in this respect. One suggests the electrolysis of water and generation of hydrogen for storage, while the other suggests pumping of water to elevated lakes and regeneration of electricity by hydroelectric plants at desired times.

The U.S. Government is spending $800,000 this year on wind energy research. Using National Science Foundation funds, NASA's Lewis Research Center is developing a wind generator that would have a maximum output of 100 kw. in an 18-mph. breeze. The glass fiber blades would turn at 40 rpm. First tests of this generator are scheduled for 1975. NSF and NASA also are studying a 1-megawatt generator that would be ready for test in 1977/78. Capital cost of wind systems are estimated at twice as high as conventional generating plants, but pending favorable research results the cost may fall in the right ball park by 1980.

Hydrogen Production Cost

Production of hydrogen by electrolysis of water is a well established technology. To produce 1 lb. of hydrogen, 26 kwh electricity are required and an investment in plants and storage of $90 per lb per day. About 16 kwh could be regenerated by fuel cells and therefore the investment for storage is $5.6 per kw plus cost of fuel cell (estimated at $200 per kw).

The Sea Plant

An attractive scheme for developing large quantities of power from the Sun's energy that is economically and technologically feasible today, involves the use of the thermal gradients in the equatorial oceans for the operation of a Carnot engine. The ocean covers 70 per cent of the Earth's surface. It stores the Sun's energy in the surface waters and creates the vast major ocean currents, such as the Gulf Stream in the Atlantic and the Japan Current in the Pacific. Since these currents flow north from the Equator, the water must be replaced from the Northern Ocean. This causes currents of cold water to flow south toward the Equator deep in the ocean. As a result we have in many parts of the ocean a layer of warm water directly over a vast reservoir of cold water at temperatures just a few degrees above freezing. The temperature of the tropical waters is a steady 82°F while 2000 ft. beneath it the temperature is about 42°F. This distance between the cold sink and hot source is regarded as short and hence the feasibility of the concept.

The idea of utilization of sea thermal gradients was forwarded by d'Arsonval in 1881 and in 1930 Cloude developed the first technical approach to the idea by building a turbine that operated in vacuum. The "Cloude Cycle" was not successful and was doomed to failure due to economics.

An alternate scheme had been proposed in 1966 based on the basic Rankine cycle, similar to that in the simple stream power plant. There are, however, important differences. Instead of steam as a working fluid, this plant uses propane. Other authors suggested Freon as a possible gas.

The power plant is proposed to be on a floating platform located in the open sea, where warm water is available in ample quantities, and water is available at depths of 2000 feet or more. A cold water pipe is suspended from the floating platform deep enough to reach cold water. The cold water is pumped to the plant from this depth. For a typical plant of 100,000 kW capacity, the cold water pipe might be 35 to 40 ft. in diameter.

The warm water is taken from the surface through screens around the periphery of the floating plant, and is pumped through boilers, where the propane is boiled at high pressure of approximately 131 lb/in.^{2}. The heat taken from the water lowers its temperature from approximately 82 to 79°F. The heat transferred from the water to the liquid propane evaporates it into high-pressure vapor at a temperature of approximately 74°F.

The propane vapor flows from the boiler to the turbine where it expands to a high velocity and lower pressure, giving up expansion energy to drive the turbine, which in turn drives an electrical generator to generate power.

From the turbine exhaust the propane vapor flows to the condenser where it condenses into liquid at approximately 54°F. The heat of condensation flows into the cold water which is heated from 43 to 49°F.

The condensed liquid propane is returned to the boiler by a boiler feed pump and the cycle of boiling, expansion, and condensing is repeated, using the same propane continuously circulated through the power cycle.

Some critics have pointed out several problems associated with the scheme as corrosion, microbial fouling, weather conditions, but none of these should be regarded as insuperable.

Other critics point out that the balance of oxygen and nutrients in the waters around the sea plant will be altered. Such a redistribution has the potential of benefits as well as harm, that may manifest itself in increased fish population and an altered local ecology.

A collection system of units moored on one mile spacings along the length and breadth of the Gulf of Florida Stream, could produce an annual amount of energy estimated at 700.10^{12} kwh.

A preliminary estimate of the capital cost of those huge floating generators is estimated between $165-440 per kw of capacity. In spite of the range of estimated costs, they are in the range of economical feasibility.

The cost of electricity would be between 3 Mills/kwh and 6 Mills/kwh compared to 13.2 Mills for conventional fossil fuel power plants and 12 Mills/kwh for nuclear power plants.

About $600,000 is being spent this year for research on energy from oceans thermal differences. It seems that the sea plant could become a reality before 1990.

Solar Thermal Conversion

Solar thermal conversion devices and systems utilize the temperature increase generated by the incident solar energy to drive a working media which produces work (in most cases, electricity) as its output. The total system efficiency can usually be written as a product of a material system factor multiplied by the ideal Carnot efficiency. Such devices can be roughly divided into three categories, high, intermediate and low temperature operation devices. High temperature operation offers the potential of high conversion efficiency. The conversion to electrical power can be upwards from 20% for thermionic emitters and conventional steam generators. Also, the rejected heat can be used for various purposes to increase the overall system efficiency. One difficulty, however, with a high temperature technology is that the enhanced temperatures pose severe operating and lifetime constraints on the materials that are used to absorb and transfer the solar energy. Since our experience with such devices is limited, the introduction of a high temperature technology will require significant prototype development before total system reliability, lifetime, and costs can be accurately measured. Present oil price increases coupled with uncertain availability of oil do, however, make the initial rule of thumb cost estimates for high temperature conversion sufficiently attractive to warrant further investigation.

The intermediate and low temperature devices are characterized by low efficiencies of fractions of a percent to about 20%. Thermoelectric devices have, however, been commercially developed in the Soviet Union for providing the energy for small appliances in locations where electrical energy hasn't been readily available. Remote power sources have also been marketed in this country to a lesser extent. Other than thermoelectric conversion units used to power portable devices, it is difficult to project any widespread use in this country due to the general availability of electrical power and the small cost associated with running most small appliances. Large scale power generation is possible and has been proposed by stringing many thermoelectric elements together. The difficulty with most such schemes proposed in connection with the intermediate - low temperature devices, is that the generation of an amount of energy equivalent to that generated in a high temperature device requires significantly more device material volume. With current materials this necessarily dictates higher system costs. One intermediate - low temperature application, however, the solar sea plant, appears to provide a potentially practical scheme for solar energy conversion. This is due to the relatively large system size that can be simply fabricated along conventional lines with relatively simple structure and no expensive degradeable working material. Future developments could also make other intermediate - low temperature systems potentially attractive. In the same sense that one should not rule out the possible future large scale application of photovoltaic conversion as a result of current projected costs, one should not completely discount the future potential of a low efficiency solid state conversion technology. If materials and system cost become sufficiently cheap, such a system might become practical.

Thermionic Converters

The thermionic converter converts solar heat to electricity directly by the current that is produced by boiling electrons off a solar heated cathode. Current flows since the anode is chosen to have a work function that is lower than that of the cathode. Electrically, the converter is a constant current generator capable of a maximum output voltage equal to the contact potential difference between the cathode and the anode. A high efficiency device must satisfy essentially two conditions, namely, high work function difference between the cathode and anode, and must exhibit minimal space charge effects in the interelectrode space. Materials such as a tungsten cathode and a nickel anode will provide an output voltage of 2.5 volts. A number of different schemes have been proposed and investigated in connection with reducing the interelectrode space charge. Two of the more practical and potentially useful schemes involve the reduction of the interelectrode spacing and the addition of a gas that produces positive ions easily.

Several small firms have been actively engaged in attempting to make a market for this sort of device. One of these, the Thermoelectron Corporation, of Waltham, Massachusetts has provided the following information for a 10 kilowatt system that they could presently put together. Such a unit would consist of 10 one kilowatt thermionic converters and operate at an efficiency of 24%. Their device would require a cathode temperature of 1000°C and an anode temperature of 200°C. Device efficiency would be 24%. If the rejected heat used in cooling the anode was used for conventional heating purposes, the overall efficiency could be increased to 60%. The cost of the system would be $1,000 and the projected lifetime is approximately ten years. There would be additional costs associated with tracking mirrors and structures required for mirror stability. Total estimated system costs are sufficiently close to the few hundred dollars per kilowatt typical of bulk electrical power systems that they should be followed as the technology develops cheaper, more reliable and longer lifetime devices.

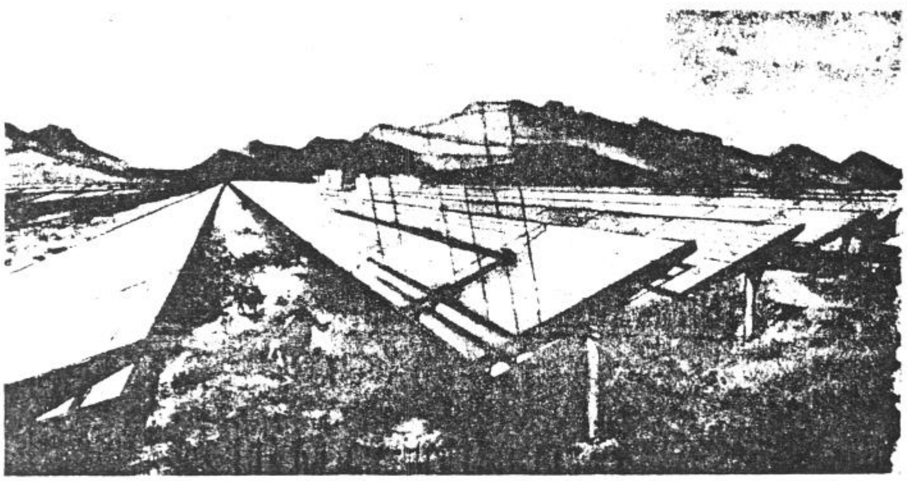
Solar Farms

No major technological innovation would be required if solar energy was converted to electricity by heating modern steam power turbines to their working temperature by the concentration of sunlight. Such a system could utilize steel pipes suitably coated and containing a liquid metal as a heat exchanger. The concentration of sunlight could be activated by cylindrical Fresnel lenses or parabolic reflectors. Estimated conversion efficiencies range about 30%. The coating of the pipe must be designed to be absorbing over the spectral range of sunlight but to be mirrorlike or poorly emitting for the spectral distribution of black body radiation of approximately 500°C. Absorber coatings recently developed for the space program can achieve high temperature with relatively little solar concentration, but these coatings as well as others must be able to withstand high temperatures for a relatively long period of time to make this technology economically feasible. At 30% efficiency, such a solar collection and conversion system could produce the total energy expended in the U.S. for 1970 (6.45×10^{16} BTU) with use of only 1% of the land that is now devoted to farming ($\sim$ 500,000 mi^2).

Such systems could be built most appropriately in the Southwest of the country where there is high yearly average insolation. Excess heat could be used to desalinate water (a much needed commodity in that part of the country) and therefore increase the overall system efficiency.

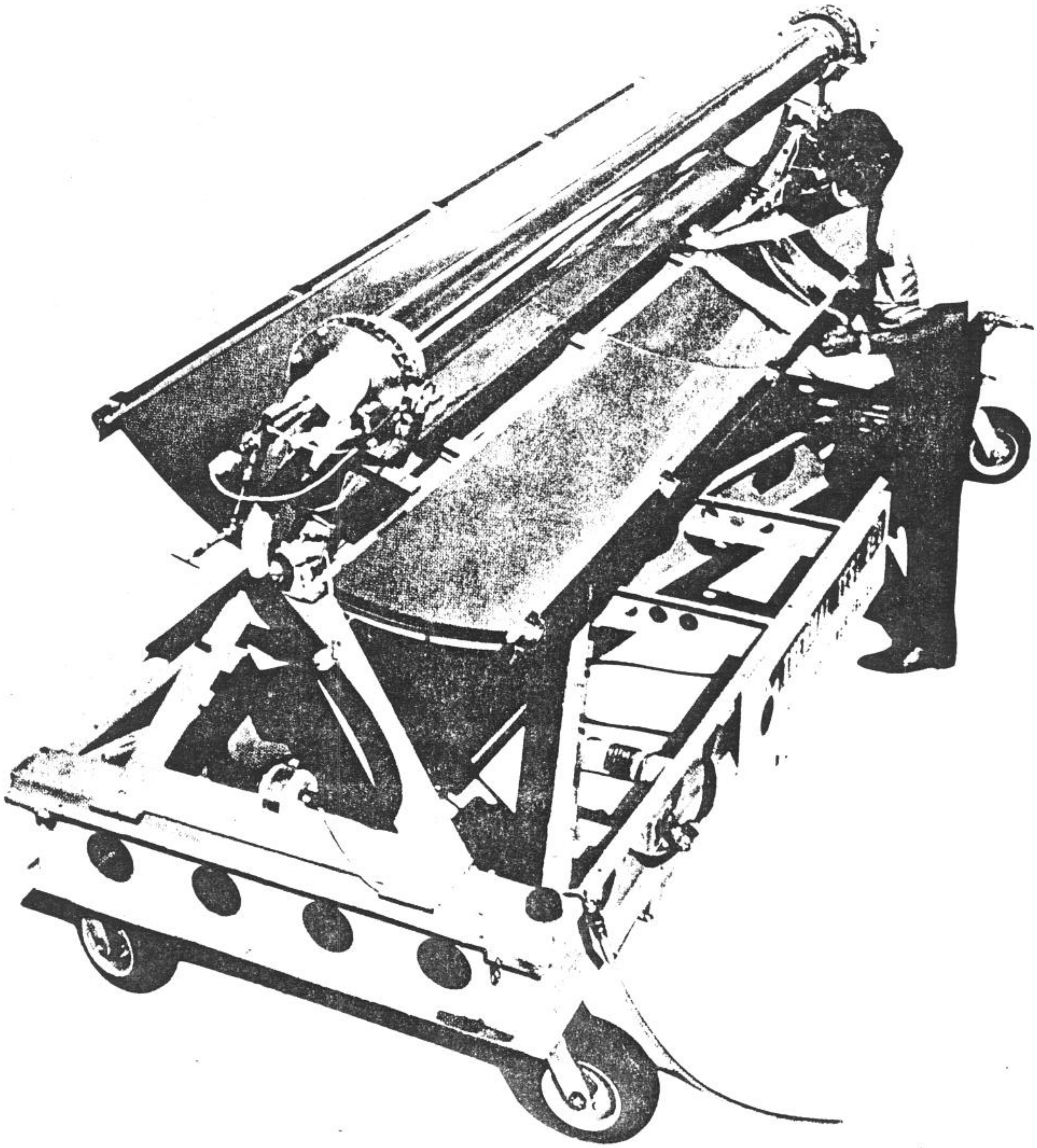
As with all solar energy conversion schemes, storage of energy is required since the sun doesn't shine all the time and since energy demand

IBM CONFIDENTIAL



Solar Farms - Painting by Don Cowen.

IBM CONFIDENTIAL



University of Arizona high temperature solar energy collector.

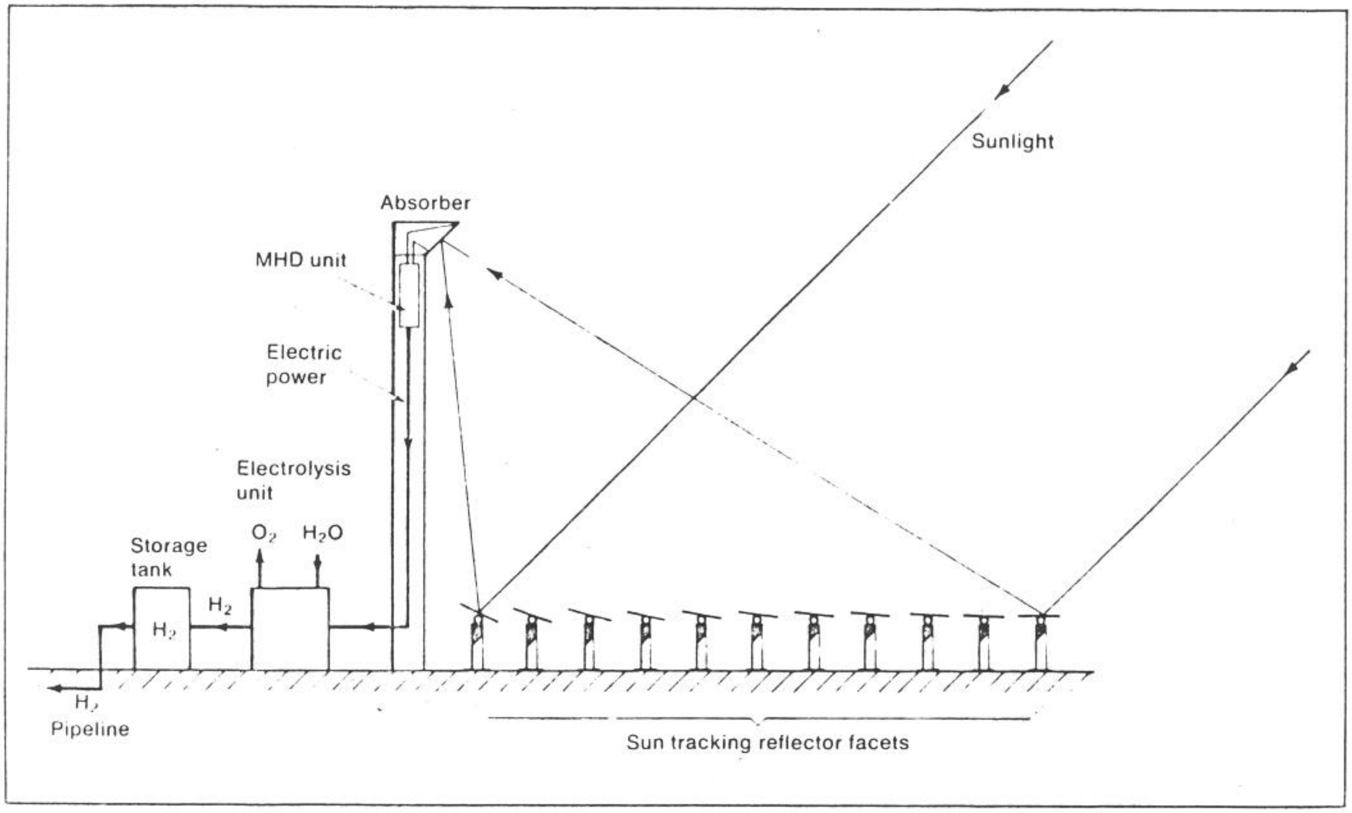
is a function of time. There are several ways of doing this, namely, hydro-storage, thermal storage, conversion to hydrogen, rotating flywheel's, etc. Any solar energy conversion technology will have to be evaluated in connection with storage feasibility and costs.

According to Drs. A. B. and M. P. Meinel of the University of Arizona[11] parameters of a 1000 Mw plant would be

Area of plant		30 km.^{2}
Area of collectors		16 km.^{2}
Outlet temperature of collectors		550°C
Collection efficiency		∿60 per cent
Thermal storage	rock:	2×10^7 m.^{3}
Thermal plant efficiency		∿40 per cent
Overall efficiency		∿25 per cent

Cost estimates are not precise. NSF/NASA 1972 estimate puts it at $750/kW with cost of kWh of ∿ 12 mills, compared with 13.2 todays cost. On the other hand, Dr. Meinel's estimates are $1,400/kW.

Another approach would be to use mirrors to focus the sun's radiation. This concept requires that the mirrors follow the sun's location constantly by clock motors that are perhaps, computer controlled. Since the energy would be concentrated in one spot, it would render itself to be converted to electricity by a variety of methods. Among these, steam plants, thermionic emission, magnetohydrodynamics and others.



The tracking mirrors concept of solar farms.

Typical parameters for a plant with 1,000 Mw continuous output might be as follows:

Area of plant	17 km.^{2}
Area of collector	17 km.^{2}
Collector efficiency	∿60 per cent
Conversion efficiency to electricity	∿60 per cent
Conversion efficiency to hydrogen	∿90 per cent
Overall efficiency to hydrogen	∿32 per cent

Detailed cost estimates for this class of system are not available, but costs would probably be of the same order as for the previously described ground-based system. This estimate is based on a 40 year life-time for the system and must include maintainance costs that are sure to arise in connection with periodic cleaning of the reflectors and other damage or natural decay of the working system. It would be difficult to assess the overall economic feasibility of such a large scale system without a working prototype. However, the initial numbers make it sufficiently attractive for someone to build such prototype.

<u>Thermodielectric Conversion</u> - A low temperature thermal conversion technique.

Solar energy can be converted directly to electricity by utilizing the temperature dependent change of an insulating dielectric material. The charactersitics necessary for good thermodielectric conversion are high electrical breakdown field strength, large change of dielectric constant with temperature and an absorption sufficient to provide the required temperature variation. In principle, the device works as follows. A capacitor is charged at ambient temperature with the largest field strength conveniently available. A shutter is then opened to allow the sunlight to heat up the dielectric and the dielectric constant drops. The temperature dependent variation of the dielectric constant can be most conveniently obtained on the high temperature side of the transition of a ferroelectric material. Since the dielectric is under open circuit, the induced charge is constant, hence a decrease in dielectric constant leads to an increase in voltage. Discharging the capacitor then provides energy above that required to charge it initially. By opening and closing the light shutter periodically one can obtain an ac output from the device. To achieve a desired ac frequency will involve the tailoring of the device dimensions and total package design. Since most dielectric materials are fairly transparent in the visible, one would have to provide absorption by a suitable electrode - dielectric interface or by selectively doping the dielectric material. Most stringent present limitations are related to finding materials that exhibit large changes of the dielectric constant with temperature and also support large electric fields. Breakdown fields in ferroelectric materials are generally an order of magnitude or more lower than the breakdown fields of certain polymer type materials. This makes this latter type of material also a strong candidate for this application even though the change of dielectric constant with temperature is much less than for the ferroelectrics. Efficiencies are in the range of 1 per cent, however, research on materials and structures could increase this figure to 3%. The potential advantage of such a device is the relatively low cost over other solid state conversion devices such as photovoltaics. Recent investigations are turning up many organic materials with ferro-electric as well as thermodielectric anomalies. Presumably, such materials could be deposited relatively inexpensively over large areas and hence provide the potential for an inexpensive solid state solar conversion technology.

Organic Waste - A supplemental Source of Power

Organic waste can be utilized directly by burning or can be converted by anaerobic fermentation to methane. The city of St. Louis has recently installed an electric power generating plant that burns garbage to produce electricity. This also partially solves their waste disposal problem. The scrap metal that is salvaged from the residue is sold.

The total organic waste output of the country, if collected and converted to methane would yield roughly 25-40 percent of the current demand for natural gas. This is therefore not a source that will totally provide for the future projected energy needs of the country. It does, however, represent a significant source of energy. This, coupled with the fact that future waste collection and disposal systems will be more fully developed, the problem of collection will not be as difficult as at present. It is interesting to note that current cattle feed operation is presenting the industry with pollution problems that will have to be solved by systematic large scale waste disposal (Business Week, January 19, 1974). Table I

Table 1. Generation of Dry Organic Solid Wastes

Source	Million tons/yr	x	Dry fraction	=	Corrected quantity (Million tons/yr)
Urban	276.0		0.50-0.70		138.0-179.2
Industrial	110.0		0.50-0.70		55.0-77.0
Agricultural					
Vegetation	552.0		0.20-0.30		112.0-165.0
Animal	1563.0		0.10-0.25		156.0-391.0
Federal	43.0		0.70		30.1
			Total		491 - 841 million tons/yr

shows the total generation of dry solid organic wastes in this country. It is seen that animal wastes account for a significant fraction of the total. Such wastes, along with other refuse could be used, as in St. Louis, to supplement the conventional generation of electricity by burning or be used as a supplement to natural gas. Electric companies are also planning to supplement their present energy sources by other sources such as fuel cells (Business Week, January 12, 1974). These sources will require hydrocarbon fuels. Methanol, a fuel that is especially suited for use in fuel cells can be obtained from municipal and agricultural refuse. Hence, local collection of animal and other refuse could be used locally to support supplemental electric power fuel cell systems. A number of other uses could be developed to solve the dual problem of waste disposal and needed supplementary energy sources.

Solar House Heating - The Most Imminent Large Scale Solar Technology

A number of solar heated houses have actually been built, tested and lived in. There also exists a relatively large literature concerning the feasibility and description of solar heating. At present, significant cost minimization requires that solar heat is supplemented by some other source of heat. This is necessary since the cost of solar heat is almost all in the initial fixed capital investment and additional capacity beyond the least cost levels would be used with ever decreasing frequency. Solar heating should therefore only become attractive when the cost of amortization of the initial investment becomes significantly less than the recurring costs of the fossil fuels (this, of course, assumes that at any time the fossil fuels will be available at a given price). The current estimated cost of a least or optimum cost solar heating system is between two or three dollars per 10^6 BTU. Recent price increases in home heating oil and natural gas have placed these fuels in a similar price range, namely

1 gallon (#6) heating oil = 150,000 BTU

at 70% efficiency

1 gallon oil $\sim$ 100,000 BTU

at 29¢ per gallon (Hoffman Fuel, Ridgefield, Conn., December 1973)

10^6 BTU $\sim$ 10 gallons of oil $\sim$ \$3.

Even though recent price increases have been mainly the result of world politics, environmental constraints placed upon domestic exploration and utilization of fossil fuels can only lead to additional price increases as well as a more limited availability of these fuels in the future. As this occurs, the solar home heating system will have a greater chance of large scale introduction into the more temperate regions of the country.

A solar heating system consists of a roof collector, storage unit (usually a large water tank), pipes, fittings, motors, pumps and heat exchangers as well as a supplementary conventional heat source. The collector area needed is determined essentially by the size of the house and the optimum ratio of solar/conventional heating required. Roughly, half the roof area is required to heat a one story house. Current system prices charged range from \$5.95 to \$15.00 per square foot of collector area. A well designed collector should be able to convert 50-70% of the incident energy into hot water which is then circulated or stored in the system. Future roof collector development will include the optimization of heat collection and transfer from the absorbing medium to the circulating fluid under architectural, cost, and aesthetic constraints. The size and cost of the storage unit is primarily determined by the number of days that storage is required. This, in turn, is determined by the local climate as well as the estimated % usage of the supplementary heat source. A large water tank (5,000 gallons or more) has been a common means of storing the heat. Other schemes have involved the use of rock bins and the utilization of the latent heat in hydrated chemicals such as sodium sulfate. Less than half the storage volume of water is required if sodium sulfate is used in its place. There is certainly room for innovation and development with regard to the storage unit as well as the collector. Whereas, the other parts of the heating system will not differ much from that found in conventional heating systems, innovative total system design will also be required.

One significant potential advantage of solar heating is that, with slight modification, (the addition of heat radiators) the same system can be used for cooling. This is achieved by pumping the water to the radiators at night and recirculating it during the day. Such operation will require little electricity and would significantly reduce electric peak power loads required during summer hours if such systems accounted for the majority of on line air conditioning systems. Taking note of the fact that our major fuel usage for the Research building does not occur during the winter months but during the "air conditioned summer months" one would project potentially significant summer energy savings.

Solar heaters have been commercially manufactured in Australia, Israel, Japan, the USSR and on a small scale in the U.S., but they have not had a major impact on the home heating market. Up to the present, this has been mainly due to the availability and low cost of the fossil fuels. As mentioned previously, this availability and cost is changing for a number of reasons. At present, major resistance or inertia holding up the widespread introduction of a solar heating technology is due to the lack of good commercial development, engineering, and marketing. Designs should be generated, systems tested and cost reduction from mass marketing developed. Since the main cost is in the initial fixed capital expenditure, mass production techniques along with the use of new materials and manufacturing processes could make an important impact on the large scale launching of the solar house heating business.

About $1.32 million is being spent by NSF on solar energy research in the current fiscal year. This total is up from $3.96 million in Fiscal 1973, $1.66 million in Fiscal 1972 and $1.20 million in Fiscal 1971. In the 20 years before that, Herwig estimates that the federal government spent an average of $100,000 annually on solar energy research.

Last fall, the agency awarded eight-month contracts totaling $1.54 million to three teams of aerospace companies and universities for the initial phase of proof-of-concept experiments in the heating and cooling of buildings. In Phase 0, the three teams - headed by General Electric, TRW Systems and Westinghouse Electric will study the heating cooling and hot water requirements of different types of buildings in various regions of the U.S. in an effort to determine which solar energy systems could meet more than half of these needs. The teams will examine the economic feasibility of different applications and recommend which should be carried over into Phase 1.

While these studies are under way, the National Acronautics and Space Administration is examining different types of solar collectors that might be used. Most of this work is being carried out at the Lewis and Langley research centers. The space agency will spend about $1 million in its funds on solar energy research this fiscal year.

Work at Lewis includes initial standardized tests of the most promising solar collectors. A 4 x 4-ft. chamber produces simulated sunlight at varying intensities and angles and will be able to provide comparable test and performance data on different collectors. Such data currently are not available, Woodward said. The Lewis facility is available to industry, he added.

Lewis also is building a small 3-kw, facility that will test the several heating and cooling components as a system in order to obtain data on interactions and overall performance.

The Marshall Space Flight Center plans to have in operation by June a 1,5000-sq.-ft. solar collector installed as a "roof" over three surplus trailers to simulate a small house. The collector will have a cover of Tedlar plastic instead of glass because Marshall engineers have found that Tedlar provides the same transparency at less cost. The thermal coating to be used was developed in the Skylab program and features a high 15:1 absorption-emission ratio.

NASA's biggest solar energy test project will get under way at the Langley Research Center in mid-1975. A 53,000-sq.-ft. solar collector next to it.

On January 16, 1974 RCA announced that it is expanding its Rockefeller Center office building in New York City. The expanded portion planned for the twelfth floor setback will utilize solar energy as a substitute for other forms of energy. RCA is still uncertain as to the actual conversion technology they will use but it is apparent that they plan to make this project a model prototype of what one can achieve with solar heated office space.

All this points out that large scale introduction of a solar house heating technology is near and should significantly extend our fossil fuel supply (at present the household and commercial use of energy accounts for approximately 20% of our total energy utilization) and significantly reduce the creation of environmental problems. Indeed this is the one solar technology whose introduction could well be imminent.

Conclusions and Recommendations

The large scale utilization of solar energy is near. It should be recognized that now is an opportune time to get access to the energy business.

The Federal Government has appropriated $13.2 millions for research of solar energy in 1974 and a total of $200 million through the year 1980. This company, should it decide to explore in greater depth the possibility of entering the profitable energy business, should take advantage of the financial opportunities by advancing to the Federal Government a series of proposals for construction of pilot plants that would test various concepts for harvesting the solar energy. These pilot plants would be financed by the Federal Government and on the basis of the results the best method should be chosen.

In addition to this, it must be stressed that development of solar energy for large scale consumption would be a boost to the image of those companies involved since the public demand for a clean energy source is increasing.

For the Research Division there is plenty to do. To name a few possibilities:

Photothermal conversion (selective coatings, thermodielectrics, etc)

Photomechanical conversion

External heating Rankine cycle engines

Photosynthetic hydrogen production

Photosynthetic components hydrogen production

Use of fluorescence as a means for harnessing diffused sunlight

Thermionic emission energy conversion

Magneto hydrodynamic energy conversion

Computer control for tracking mirrors

Modeling of various energy conversion techniques, e.g. energy crops farms, solar house heating and cooling, windmills, solar farms, sea plants

Recent References concerning Solar House Heating

'A Feasibility Study of Solar Heating in Iran,' M. N. Bahadori, Solar Energy.

'Environment, Energy and the Need for New Technology, V. Dalal, Energy Conversion 13, 85 (1973).

'Solar Energy Applications in India,' S. D. Gompale and R. L. Datta, Solar Energy 14, 321 (1973).

'Cost of House Heating with Solar Energy,' G. O. G. Löf and R. A. Tybout, Solar Energy 14, 253 (1973).

'Solar Energy: Its Time is Near,' W. E. Morrow, Jr., Technology Review, December 1973.

'Solar House/Heating and Cooling Progress Report,' H. E. Thomason and H. J. L. Thomason, Jr., Solar Energy 15, 27 (1973).

'An Assessment of Solar Energy as a National Energy Resource,' prepared by NSF-NASA Solar Energy Panel, December 1972, chairman, P. Donovan.

Report on the Committee on Business Opportunities in Solar Energy,' M. H. Brodsky, G. Feth, R. W. Keyes (chairman), and J. M. Woodall, June 16, 1972.

'The Use of Solar Energy for Residential Space Heating,' H. G. Lorsch, Energy Conversion 13, 1 (1973).

'The Energy-Environment-Economic Triangle,' D. C. White, Technology Review, December 1973.

'Single Element ΔT_{max} Thermoelectric Measurement Technique, M. L. Stanley et al, Energy Conversion 13, 7 (1973).

'Solar Sea Power,' C. Zener, Physics Today, January 1973.

'Environment, Energy, and the Need for a New Technology, V. Dalal, Energy Conversion 13, 85 (1973).

'Energy Crisis in Perspective,' J. C. Fisher, Physics Today, December 1973.

'Methanol: A Versatile Fuel for Immediate Use,' T. B. Reed and R. M. Lerner, Science 182, 1299 (1973).

'Solid State Physics and Solar Energy,' R. W. Keyes, Comments in Solid State Physics 4, 183 (1972).

'Solar Energy,' A. R. Tamplin, Environment 15, 16 (1973).

R. E. Immun's Report: Effective Utilization of Solar Energy to Produce Clear Fuel, Stanford Research Institute, October 1973.

Chemical and Engineering News, July 3, 1972.

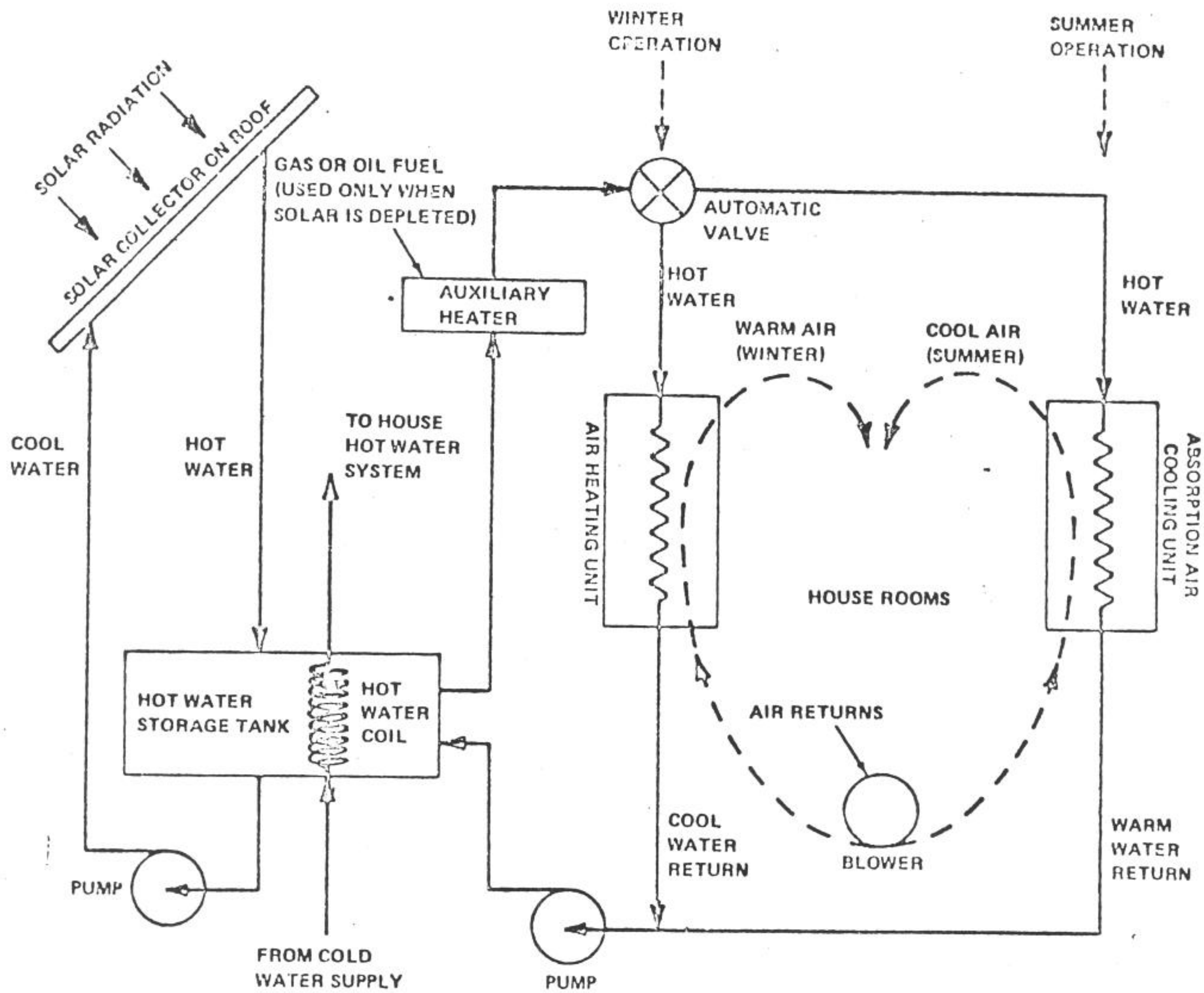
J. H. Anderson, Solar Energy 14, 287 (1973).

Costs of space heat (United States)

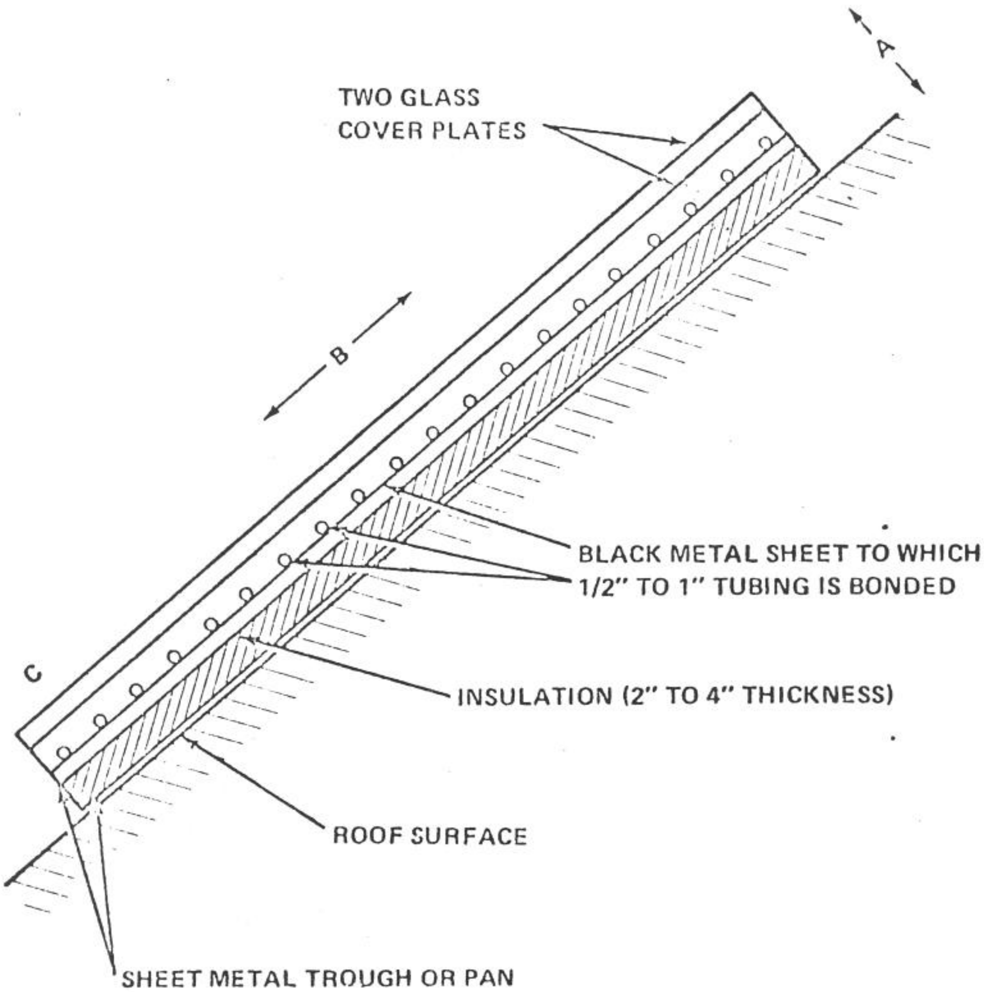
	(1)	(2)	(3)	(4)	(5)	(6)		(7)	(8)
	Least cost solar heat, [$/10^{6}BTU(1961)]				Electric heat, Electricity cost only, [$/10^{6}BTU (1967)]			Conventional heat, fuel cost only [$/10^{6}BTU (1962)]	
	15,000 BTU/DD House Low	15,000 BTU/DD House High	25,000 BTU/DD House Low	25,000 BTU/DD House High	20,000 kWh/yr	30,000 kWh/yr		Gas	Oil
Santa Maria	1.35	1.84	1.10	1.59	4.51*	4.36*	California	1.43	1.62
Albuquerque	1.70	2.31	1.60	2.32	4.89	4.62	New Mexico	0.89	2.07
Phoenix	2.55	3.55	2.05	3.09	4.56	4.25	Arizona	0.79	1.60
Omaha	2.65	3.16	2.45	2.98	3.30	3.24	Nebraska	1.05	1.32
Boston	2.70	3.15	2.50	3.02	5.49	5.25	Massachusetts	1.73	1.76
Charleston	3.15	4.16	2.55	3.56	4.50	4.22	South Carolina	0.96	1.55
Seattle-Tacoma	2.85	4.05	2.60	3.82	2.26†	2.31†	Washington	1.83	2.00
Miami	5.85	6.48	4.05	4.64	5.16	4.90	Florida	2.81	1.73

*Electric power costs are for Santa Barbara, Electric power data for Santa Maria were not available.
†Electric power costs are for Seattle.

Source: Solar heat costs are from optimal design systems by interpolation of Figs. 10-13. Electric power heat costs are from U.S. Federal Power Commission. All Electric Homes (1967), Table 1. Conventional heat fuel costs are derived from prices per million BTU reported in P. Balestra, The Demand for Natural Gas in the United States (North Holland Publishing Co., 1967), Tables 1.2 and 1.3. Fuel prices were converted to fuel costs by dividing by the following national average heat (combustion) effeciencies: gas, 75 per cent; oil, 75 per cent. Heat efficiencies are from American Society of Heating, Refrigerating and Air Conditioning Engineer, Guide and Data Book 692-694 (1963 Edition).



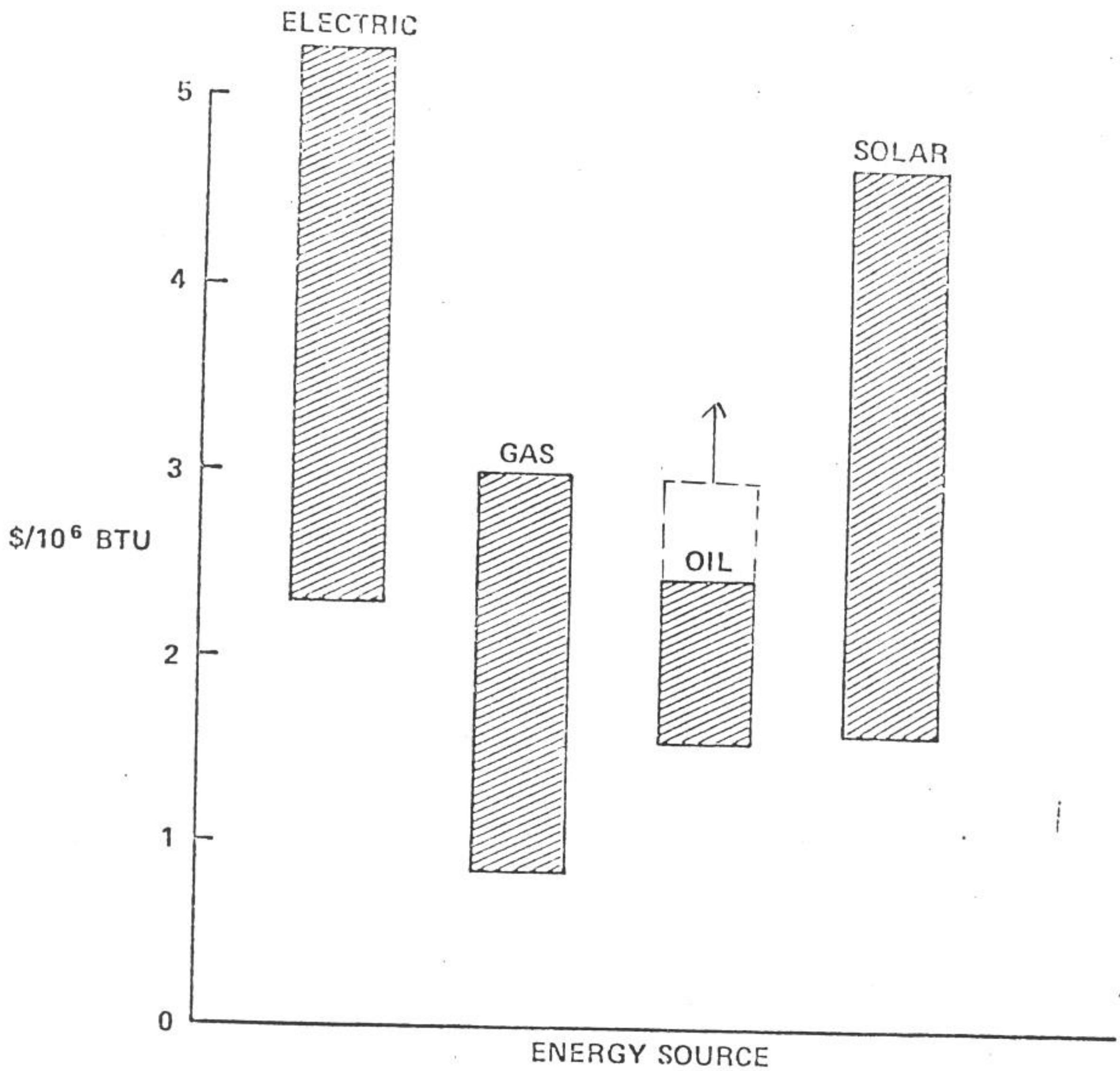
RESIDENTIAL HEATING AND COOLING WITH SOLAR ENERGY: SCHEMATIC DIAGRAM OF ONE ALTERNATIVE



NOTES: ENDS OF TUBES MANIFOLDED TOGETHER
ONE TO THREE GLASS COVERS DEPENDING
ON CONDITIONS

DIMENSIONS: THICKNESS (A DIRECTION) 3 INCHES TO 6 INCHES
LENGTH (B DIRECTION) 4 FEET TO 20 FEET
WIDTH (C DIRECTION) 10 FEET TO 50 FEET
SLOPE DEPENDENT ON LOCATION AND ON
WINTER-SUMMER LOAD COMPARISON

. SOLAR COLLECTOR FOR RESIDENTIAL HEATING AND COOLING
DIAGRAMATIC SKETCH OF ONE ALTERNATIVE
(elevation-section)



COSTS OF SPACE HEATING

WE HAVE ENERGY TO BURN

by

Harold H. Herd

ABSTRACT

The first of the eight chapters of this work states the problem: Because of recent infatuation with massive and tawdry technology based on petroleum at pennies a barrel, we are on a collision course with starvation and war. With the techniques we are currently using and also exporting to the rest of the world, agriculture is a vast sink for petroleum and hence the more we eat the faster this resource vanishes forever. By regarding agriculture as a large, integrated solar energy machine it is feasible to construct readily a system wherein the more food we have the more energy we can generate and for as long as the sun shines.

Two chapters are a spoof comparable to covering Arizona with solar cells or pushing the Mississippi through turbine condensers.

The bulk of the work is dedicated to showing that by taking some of the fad out of physical devices and putting effort into the living creatures which have run the show for millenia, relatively simple and cheap course-corrections will unlock a large wasted supply of both food and energy.

The final chapter is devoted to pessimism regarding the outcome.

WE HAVE ENERGY TO BURN

by

H. H. Herd

IBM Thomas J. Watson Research Center
Yorktown Heights, NY

ABSTRACT - American agriculture, as the single largest industrial consumer of petroleum, currently requires close to one pound of gasoline equivalent for every ten pounds of food delivered. This madness, together with the escalating costs of fossil fuel results in a situation which has the potential for a huge disaster, accelerated and made global in scale by the exportation of petroleum-based food products and techniques. By relatively simple changes, this vast sink for petroleum can be converted to yield a net energy surplus while supplying even more food than at present.

I. INTRODUCTION

Most thinking concerning the availability of energy in our highly industrialized society seems to be confined to schemes for harnessing large sources of power into an existing grid binding us all to a fixed, immutable way of life. In various stages of consideration, experiment, and planning there are certainly proposals to cover large areas of the earth's surface with mirrors or with silicon generators and tanks of molten salt, high technology fast breeders, future technology fusion reactors, schemes to put solar collectors into orbit, to yoke the tides, the heat of the earth, to harness thermal gradients in the oceans and terrestrial depressions in and near the sea. These projects are all strictly physics. The engineering for most of them is beyond the capacity and stability of most of the governments on the face of the earth. The underlying assumption seems to be that, if any or all these enormous projects can be brought to fruition, the resulting energy retailed to a burgeoning sink of customers will automatically lead to various amenities of life. Physics is undoubtedly great and great fun, but madness is not a prerequiite for dominion over the earth.

The ideas presented here were set in motion by a flight over Indiana in full summer shortly after reading a report by a prestigious atomic physicist claiming our prospects for the future are limited by the availability of fossil and atomic fuels. Solar energy was dismissed as impractical because, to quote the report, "solar radiation would have to be collected over an area of about 30,000 square kilometers, which is hardly promising from a technical point of view". Further reading showed the writer was estimating six times this area requirement by 2050 A. D. Nonsense! The trouble is clearly with his point of view. Let's change the units to something we know about. 30,000 square kilometers is only 7.5 million acres. Anyone appalled by this area in solar production must just never have flown over the U. S. corn-belt with his eyes open. There was once a pair of newly-arrived Swiss visitors on a trip to California: "We've been on this plane five hours and we still are not across this country." Corn is grown on 200 million acres of the earth's arable land, an area substantially greater than the physicist's prediction for 2050 A.D. Wheat and rice occupy greater areas than corn. These crops cannot exist without collecting solar radiation.

II. PETROLEUM AGRICULTURE

We are already in the business of collecting and storing solar energy on a vast scale, some 300,000,000 acres of it in the U. S. in agriculture alone. The disastrous aspect of this situation comes about because American-type agriculture, instead of being a net producer of energy, <u>is the single greatest industrial user of petroleum in the country</u>, accounting for something like 10% of our entire use of this fuel. No matter how you look at it, this is a monstrosity left over from the economics of an era whose end has arrived.

During the years 1939-48, the average area of land devoted to corn in the U. S. was 88 million acres. Production was 3 billion bushels per year or 34 bu/acre of shelled corn, exclusive of the stover. Stover is the corn plant with the ears removed. It contains about two thirds of the energy stored in the crop. A bushel of shelled corn weighs 56 lbs and unless it contains less than 13% water it won't keep in storage. Of this corn production, actually 85% was fed to animals, mainly hogs. A pound of carbohydrate has a fuel value of about 1800 kilocalories. In 1950 the U. S. produced 2.87×10^{11} kwh of electrical energy from all sources, about one third of the world total. Simple arithmetic on the above numbers shows that the energy in the U. S. shelled corn corp would have been about 3.3×10^{11} kwh or somewhat more than the entire electricity production of the country for the same year.

By 1970, the U. S. national average yield of corn had been driven up to 81 bu/acre. On the surface, this looks like an impressive agricultural achievement as indeed in some sense it is. However, this great increase in yield was paid for by the use of the equivalent of 80 gallons of gasoline per acre of corn, or, taking corn as typical of U. S. agriculture, we now use about one pound of petroleum for every ten pounds of raw food produced, before that food ever gets into your kitchen. In addition, we are in the process of exporting not just American agricultural products but also agricultural techniques, notably in the so-called Green Revolution. If all the world's food were to be produced by the current American foolishness, the entire petroleum supply of the planet would not last out the century. With this vast fossil energy input to agriculture the Green Revolution will merely disappoint the hopes of the masses out there and accelerate the day when we will all starve to death at the time we run out of gasoline. Dissappointed hopes and starvation may well lead to unfriendly people and revolutions which are not necessarily green. Isn't this a fabulous state of affairs for an industry whose basic, innate reason for existence rests squarely on collecting and storing solar energy? Imagine! The U. S. food crop is a solar energy device on a multimillion acre scale running at a very satisfactory 1.26% efficiency in the case of our most important crop and yet to keep it going we have to pour into it something like 10% of all our petroleum and most of that just to make fertillizer!.

III. DUNG

From Chemical Abstracts 50 9666 1956, even a non-farmer can learn that a rabbit gives 128 grams of dung a day, 60% carbohydrate. In the same volume, one will find that an average large farm animal gives 30 kg/day of manure: excrement and bedding. At only 50% utilization, the dung from one good cow is worth more than 200,000 Btu/day to heat a house. In 1964 in the USA 31.6 million cattle were slaughtered to feed people and cats and dogs. Depending on the modernity of the technology or the purpose which engendered them, these cattle were full grown animals anywhere from 15 months to 10 or more years old. Beef cattle can be brought to market size in as little as 15 months, a milk cow does not mature to full production until 6 years old. In addition to these 31.6 million cattle slaughtered, 7.6 million calves went to market out of a beef population of 106.9 million animals. In addition to these cattle, there were slaughtered, 86.6 million hogs and 14.9 million sheep and lambs. The droppings from millions of chickens in the same period were a serious disposal problem and we were complaining about the B. O. D. and eutrophication of our water supplies. The total dung production from American farm animals is estimated to be presently at the rate of 1.7 billion (1.7×10^9) tons per year, about 50% of it dropped in feedlots and other situations of confinement nurture. Any way you pile it, this is 5 million tons a day, every day, year in and year out. That, my friend, is a lot of dung. That is a pile of manure a mile long, a mile wide and a quarter of a mile deep, each and every year. If only 50% of it is carbohydrate, that manure pile contains about one fifth of the entire annual energy consumption of the USA, about one fifteenth of that of the whole world! That resource makes North Slope oil, plus all the atomic energy in operation in the world, look like kid stuff and do you know what we do with it? Most of it is regarded as a disposal problem and at best we merely plough it under. Truly, madness is a way of life.

IV. METHANE

Right now, bacteria and yeasts are used in large-scale industrial production of liquid and gaseous fuels, in gin distilleries and sewage disposal plants to name two examples. Alcohol production is too old an art to need reference to the literature. While alcohol is an excellent propellent for vehicles, it has to be concentrated by distillation or other treatment before it is suitable for fuel. A day with the chemical literature will turn up the basic facts relative to methane production starting with vegetable material. Because methane is a somewhat less familiar commodity than "eatin' alcohol" a few facts are given relative to it.

Methane (CH_4) is a gas and thus has all the conveniences and inconveniences of a gas in transportation and use. It burns with air to give close to 1000 Btu per cubic foot at atmospheric pressure. Methane gas is produced by the action of bacteria on almost any wet plant or animal material when the fermentation proceeds in a tank which excludes air. Bacteria which carry on their life work in the absence of air are called anaerobic bacteria. No particular pure culture of anaerobic bacteria is required to carry out methane fermentation. Studies have shown that the mixture of bacteria in a scoop of garden soil or septic tank sludge works just as well as a carefully purified culture. In this respect, methane fermentation differs from champagne production although both processes have the property of working in tanks from which air is excluded. Methane fermentation and alcohol fermentation differ significantly also in that the former proceeds very precisely to completion, perhaps because the products, being insoluble, automatically leave the reaction mixture, while alcohol fermentation of sugar solution proceeds only until the alcohol accumulates to 12-15% and then the reacting organisms die in their own waste product. While there are strains or races of methane producing bacteria which will work at temperatures all the way from freezing to 70°C, temperature is one of the most important factors controlling the rate of generation of gas just as with chemical reactions in general. There are of course, other production variables to be controlled to optimize the speed of the reaction and the quality of the product.

Carbohydrates are typical of materials anaerobic bateria will ferment. Sugars are typical carbohydrates. Carbohydrates are universally present in large proportions in all plants. Some plants such as corn, sugar beets, and mangolds, produce by photosynthesis more carbohydrates per acre per year than others. A field of mangelwurzels is said to be capable of yielding 45 tons per acre per year, 8% sugar. A crop of natural hay may be only a ton or two per acre. The carbohydrates of some plants species or parts of plants are more readily and hence more rapidly fermented than others. Thus, the juice of the sugar cane ferments much more rapidly than the bagasse left from pressing. For most woody plants, other factors being constant, the rate at which the bacteria decompose them depends very strongly on how finely the material is ground up.

One pound of virtually any low molecular weight carbohydrate will give by the action of bacteria about 6 cubic feet of methane mixed with an equal volume of carbon dioxide. The combustible methane is easy to separate from the carbon dioxide, if anyone wants to do it, but even the raw mixture of gases from a pound of carbohydrate has the heating value of nearly 2 kwh of energy derived from any source. When mixed with a suitable volume of air, the raw methane fermentation gas, or methane alone, is explosive and hence makes an excellent fuel for internal combustion engines, for example to power tractors of which there are currently 4.5 million on American farms. So much for methane.

V. STORAGE AND GRINDING

Convenience in the use of solar energy, or any other form of energy depends critically on storage to smooth out diurnal and annual cycles.

Because day is when the sun shines and winter is when the noon sun is low on the horizon, we need heat when it isn't there. We like to be cooled on hot summer days. The chap living on the four acres the local zoning board demands, mainly to give him room to let methane bacteria get rid of his sewage, is in financial but not technical control of about 16,000 horse power at peak insolation and perhaps something less than zero power 12 hours later. The major problem with solar energy is not collecting it since we are already doing it on a global scale. The real problem is storage over night and over winter. The same problem would be present if Arizona were already paved with solar cells.

Carbohydrates are the main storage medium which has been on earth since long before the ape got wheels. The sun shines on the trees and the grass and the turnips and by photosynthesis they grow. Averaged over the whole year the conversion efficiency from sunlight to corn or turnips may be only a little better than that of a laser or a boob tube or other devices we get excited about. However, efficiency may not be the right parameter to evaluate something which comes for free and which we can't do without. Some wit once said, "Anything which is always and everywhere available is worthless". What we really want is a decent place where a man can work and live and bring up his kids. When the chips are finally down, we must have food, and that regularly. Our basic source of food is vegetation. It is also a huge storage medium for solar energy. To restrain fermentation cheaply in storage, vegetation can be left in bulk. To accelerate the useful reactions the material must be disintegrated. Thus, a whole log may endure for centuries--ground up to sufficiently fine wood flour it can be digested in a few hours. Nowadays, as long as the petroleum lasts, we can mechanically shred up almost anything. On the other hand, animals too are effective grinders of vegetation. They take a toll from the easily available components, but in return they pay for the privilege of grinding by a yielding a by-product, namely meat. At the end of 1973, the price of beef on the hoof was about \$45.00/100 lbs. In January 1974, people were paying 50¢ for a gallon of gasoline with an energy equivalent of 36,000 kilocalories. Forty pounds of carbohydrates, whether from supermarket sugar or steer manure is worth about 72,000 kilocalories or just two gallons of gasoline or about \$1.00. On this basis, it is not difficult to estimate that a steer at the time it goes to market is worth just about as much for the fuel it has ground up as for the meat on the grinder. The time may come when animals will be bred to produce the most manure rather than the most meat.

Associated with the use of animals as fuel grinders is the matter of collecting and maintaining control over their product. After all, flush toilets on the current pattern were only invented toward the end of the previous century so it is perhaps to early to expect them to be scaled up to cattle size and sufficient hydraulic head to propel gases through pipes. Cattle roaming at large is a prehistoric luxury we can no longer afford. On modern dairy farms cows are confined for feeding and milking in double lines on a concrete deck between troughs arranged for flushing out with water. Recent literature, for example, "Is Agriculture Cruel?" in the New Scientist for October 18, 1973 makes clear the trend to battery production for all farm animals similar to what has long been practiced for rabbits and chickens. Feed-lots run from computer terminals may be regretted in comparison to the old ranch where the hired hands got ten dollars a month and board but change is inevitable. Computerizing a feed-lot is still enough of an innovation to have made the front page of the Wall Street Journal in December 1973.

VI.[1] GREEN MANURE

Animals as fuel grinders have the useful property of rejecting most of the mineral fertillizer of the crop with the manure, especially the nitrogen whose production, transportation and application is the single greatest energy input to modern American petroleum-based agriculture. This rejection is the chief excuse given for the ploughing under the fraction of dung which is not merely wasted. The carbohydrate fraction is said to improve the tilth of the soil. In 1945 the corn crop, taking it as more or less typical agriculture, used only 19 lbs per acre of artificial fertillizer: 7, 7, 5 of nitrogen, phosphorus and potassium. By 1970, the use of these had risen to 112, 31, 60 pounds per acre, respectively, their production and application accounting for roughly half the one pound of petroleum per ten pounds of grain. It happens there are alternate ways to get the nitrogen with far less use of petroleum. It has long been known that rotation with legumes will supply fields with even more nitrogen than the 112 lbs/acre currently used in corn. Recent experiments in the Northeast have shown we don't really even need to take the land out of production half the time to grow a crop of nitrogren-fixing legumes. It has been shown experimentally that fall seeding with vetch ploughed under the following April will also return as much as 133 lbs of nitrogen per acre in place of the 112 lbs now being used of the petroleum-generated variety. This technique has been used recently in other parts of the country, not specifically for nitrogen-fixation but as a soil conservation measure to limit winter erosion from bare fields and thus to limit stream pollution. Take a ride through New York State and look at the corn fields. They work about 100 days of the year. The rest of the time they are left cleaned off bare to quietly erode away. The so-called green manure is as effective as animal manure in maintaining tilth and is superior for weed control. With animal manure you get all the weed and grass seeds which were not digested. A winter cover crop crowds out the weeds in the spring because it has a head start. In addition, if the carbohydrate in the animal manure is fermented off as fuel, what runs out from the fermentation tanks contains the mineral components of the crop and may be piped back to the fields, so that the combination of cover crop and controlled fermentation makes possible even more nitrogen than currently derived from costly petroleum and hence potential corn yields in excess of 100 bushels/acre. Thus, it is clear we can have even more food than at present with no dependence on petroleum whatsoever.

One ingredient is lacking in the discussion so far. It would be advantageous to free the energy supply from the umbilicus of piping, either by compressing methane into tanks or converting it to higher molecular weight liquids for vehicle convenience. Neither of these seems to be either difficult or expensive in energy and there would appear to be several routes to this end in the diversity of an industrial state, including merely exchanging gaseous fuel for liquid fuel generated elsewhere.

VII. LET'S INVENT A BARN

Attached is a drawing of a dairy barn on the present, approved, 'modern' plan. It lacks a cellar - a cellar about equal to the area the cows are standing on and 8-10 feet deep, constructed as a buried, gas-tight concrete tank. The tank would have hydraulic, trapped entrance and exit ports similar in operation to a suburban household toilet and septic tank system. There would be facilities for cleaning it every 10 years or so. Associated with the tank cellar would be piping to lead its clear effluent liquid to the fields. Connected to the main tank would be a small gasometer - a tank inverted in a tank, or some other even simpler arrangement of tanks and hydraulic head, rising and falling with variations in the modest gas pressure and fitted with regulators and instrumentation. From the gasometer and controlled by it, the effluent gas would be compressed, separating the methane from carbon dioxide, and stored in cylinders for tractor fuel if the enterprize must be self-contained. The excess raw gas or all of it can be piped away to a collecting point for general use in the gross energy network.

VIII. SUMMARY

That agriculture, our largest man-made solar energy converter, should use 10% of our petroleum is a potential disaster. To rectify this state of affairs, three things are needed: green manure, methane generators and compressors or catalytic liquifiers. With these changes, agriculture can be converted from a sink of energy to a net surplus, and at the same time it will produce more food than it does now. Virtually nothing else in the food producing system need be changed to achieve the advantages of energy self-supporting agriculture. Existing installations can be modified by adding the missing components, or at the prices to which petroleum is headed, they can be forgotten as uneconomical and hence will cease to exist. New installations will integrate these changes rationally to suit their own special conditions and terrain. By the nature of the proposed system scale makes little difference. It works in the same manner for 1 cow or 1000, scaling essentially with the area they are standing on. These changes are small relative to the conversion from steam locomotives to jet airplanes and other upheavals men have accomplished. With these modifications, the price of food is independent of that of petroleum and there is some hope the population of India can eat as well as that of the U. S. A. provided neither we nor they continue to procreate beyond the bounds of even the sunshine.

IX. CONCLUSION

It is possible then, and practical, to have even in my own back yard, a mix of crops and animals and tanks which is essentially self-contained and even enclosed. Energy comes in from the sun and is stored in bulk in carbohydrates by the elemental natural processes of photosynthesis. The stored fuel is ground, mixed and preprocessed by an assortment of animals, fermented in one or another of several tanks to be altered to a more convenient liquid or gaseous form. Heat from the combustion of the fuel and the exhausts of its compressors is used for heating or cooling the system. The carbon dioxide, mineral nutrients and wastes go back to the solar accumulator. I live as a little parasite draining off a small fraction from the accumulator. I am not compelled to change my manner of living to accommodate a burden of junk or change my taste to be satisfied with reconstituted algae. Isn't this just what was going on in the world in the millenia before we decided the handiwork of the gods needed a few technological improvements? Here we are living off the avails of a few piles of old garbage left around in the rocks in past eons and we are frightened that when we have gutted these little dung piles the world is going to collapse. Silly, isn't it? Clearly the problem is not technical but social and political.

The Holstein-Friesan, with its nonblending black and white markings, is the most popular breed of dairy cattle in the United States. Mature cows average over 1,300 pounds and some may weigh as much as 1,600 pounds. The Holstein cow is a large and efficient user of roughage and is the heaviest milk producer, although the milk fat content is about 3.5 per cent. Herd Improvement Registry data show annual average yields of 11,500 pounds. The record high single year yield of over 38,500 pounds is held by a Holstein.

Jersey cattle have solid colors with black points. The breed is the smallest of the major dairy types, being somewhat smaller than the Guernsey; a mature cow seldom exceeds 1,000 pounds in weight. She has the ideal dairy wedge-shape conformation, a large barrel, and a well-developed udder. A Jersey cow is a very efficient converter of feed to milk. She is an easily kept cow if properly cared for, but is inclined to nervousness and low yield if carelessly handled. A yearly milk yield of 6,500 pounds is average and a fat content of over 5 per cent is not unusual.

Among the minor breeds, the Dutch Belted cow is probably descended from the original Holland Holsteins. The French-Canadian breed is a native of Normandy and closely related to the Guernsey and Jersey breeds. The Kerry and Dexter breeds originated in Ireland and are the smallest of dairy cattle. The Devon is a small but hardy and strong dairy animal from Britain. The Red Danish breed was first imported by the United States Department of Agriculture in 1935.

A dual-purpose cow produces a fair amount of milk for a dairy cow and will fatten readily and sell at a fair price for a beef animal. The Milking Shorthorn, of English origin, and the Red Poll breed, a hornless variety, are popular in areas where fattening out grains are produced. See also CATTLE—*1. The Cattle Family.*

Dairy Farms.—Since the turn of the century dairying has developed from a family cow business to a highly specialized industry. The degree of specialization is often due to physical as well as economic factors. The climate, topography, soil, the type and location of markets are all important in determining the type of farm operation.

Regardless of size, in order to ensure quality milk production, proper management (husbandry) practices must be followed. The barn area must be well planned and well equipped and efficiently maintained to ensure a healthy herd. Adequate fresh water must be available. Palatable feed and roughage, supplemented by concentrates, should be fed in balanced rations. Hay and silage space must be available for crops which should be harvested and stored to maintain the optimum nutrient values.

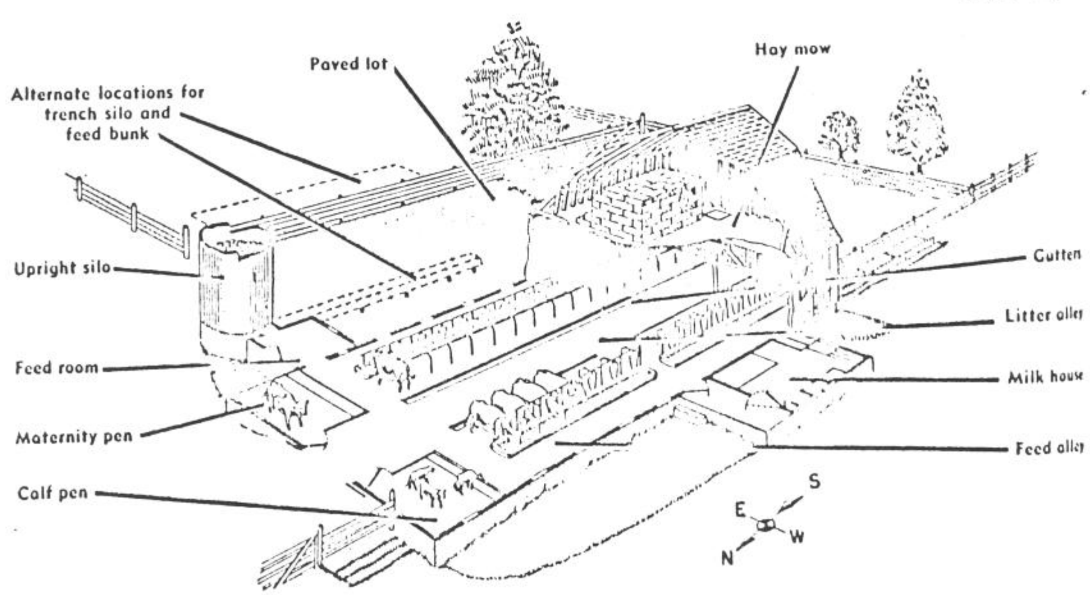
Two general housing methods are the stall barn and the loose-housing system. In the stall method cows are maintained in individual areas, usually with stanchion arrangements. Here, during inclement weather, they are rested, fed, watered, and possibly milked. In the loose-housing procedure, the cows are free to move about in either open or closed type structures.

In the latter type of accommodations, a separate milking shed or milking parlor must be provided. Such a structure is also preferable to stall milking; in some instances local health codes require separate milking facilities regardless of the housing. An adjacent milk room should be available for the straining, cooling, and storing of the milk until delivery to the plant. The room may also serve for the cleaning and storing of utensils and the milking machine.

In the industrialized countries, the milking machine is gradually replacing the milking of cows by hand. The cow's udder is first cleaned and a small amount of milk is "stripped" from the teat. Teat cups are connected to each teat and the milk drawn by vacuum suction through the action of pulsators operated electrically. With a machine, a cow may be milked in 3 minutes. In some instances each cow's milk is drawn separately into a pail, but in large dairy farms the milk from each of several machines goes di-

Diagram shows the principal parts of a dairy stall barn. Pen shown is for the youngest calves; other young stock would be housed separately.

Hoard's Dairyman



Reprinted from THE REVIEW OF SCIENTIFIC INSTRUMENTS, Vol. 31, No. 9, 1010–1011, September, 1960
Printed in U. S. A.

The Collection of Light from Scintillation Counters

RICHARD L. GARWIN*
IBM Watson Laboratory, Columbia University, New York 27, New York

(Received June 14, 1960)

SOME time ago[1] I discussed the limits imposed by thermodynamics (or phase-space) on the collection of light from scintillation counters. In particular, without multiple traversals of the source region one cannot arrange to transfer more than A_p/A_s of the isotropic emitted light from a source of projected area A_s to a photocathode (or window) of area A_p. Were such a thing possible, by replacing the scintillator crystal by a blackbody radiator (with filter or without) at temperature T, one would find at the window A_p a larger brightness than at the source, and another blackbody at A_p would be heated above temperature T by the radiation. It is, however, clear that a single phototube viewing a large tank of liquid scintillator in an otherwise perfectly reflecting enclosure will eventually collect all the light emitted anywhere in the tank, but this takes a long time and does not contradict the theorem, since it requires multiple traversals of the source region.

It is interesting to note that thermodynamics which prohibits one from reducing the entropy of the set of photons leads one to a method which in principle allows one to concentrate the light energy to any degree practically desired.

In brief, one can use a fluorescent material to reduce slightly the photon energy—for each kT_{ambient} by which the photon energies are reduced, one is allowed a factor e in area into which the light can be concentrated. The fluorescent light has no reason to be strongly absorbed, if it is not very close in energy to the scintillation spectrum, and thus one is permitted to use an arrangement like that in Fig. 1.

In the figure one sees a conventional light-pipe from a scintillation counter at the left (or even a vat of liquid scintillator). The light is carried without loss by multiple total internal reflection down the pipe. At the end of the light-pipe the light is refracted to fill the hemisphere, and a large part of it is transmitted into the first converter. Here if the converter were a nonabsorbing material like the first light-pipe, the photon would be transmitted, since by having entered, it is by definition not within the total reflection angle. However, the first converter is thick enough to absorb the photon, which excites fluorescence. The fluorescent light, wavelength shifted by the fluorescence, is now isotropic, and a portion of it (typically $\sim\frac{1}{4}$)

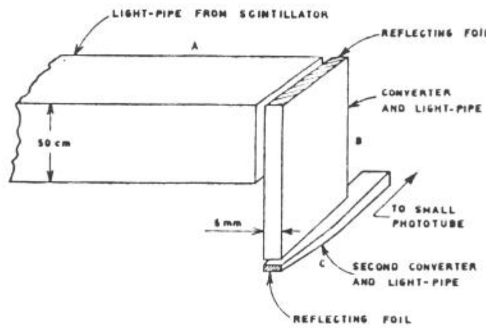


FIG. 1. Light from the light-pipe or scintillating vat (A) strikes the converter (B), in which it produces fluorescent light of slightly lower photon energy. Some of this light, being isotropic, can now be piped along the converter without further loss; and, in principle, can be used a second time to produce fluorescence in the second converter (C) to concentrate further the light onto a small phototube.

is trapped and carried down the second light-pipe to the second converter where the process is repeated.

Thus, by sacrificing a factor ~ 4 in total light energy at each conversion (a negligible fraction from photon energy loss in fluorescence and the rest from that part of the isotropic fluorescence which is outside the cone of total internal reflection), one might be able to achieve a factor ~ 100 or more (ratio between first guide height and photon absorption length in first converter) in light intensity. Of course there are practical difficulties involved in this scheme; it is necessary to find fluorescent materials of unit quantum efficiency to be used, probably in low concentration (like "wavelength shifters") in solution in liquid or plastic. The optical emission of visible photons adds a few nanoseconds delay and dispersion in each stage, but this may well be less than the spread in transit time from a large counter.

The scheme may also be applied, in principle, in fields quite distinct from that of particle counting—for example, one can presumably make a light source of extremely high relative brilliance simply by allowing the exciting radiation (sunlight, moonlight, or artificial light) to fall on the broad face of the first converter—if the sheet is quite thin a very obvious increase in brilliance will be observed by viewing the edge and this will be even more noticeable if a good second-stage converter is used and its end observed.

* Temporarily at CERN 1959–1960.

[1] R. L. Garwin, Rev. Sci. Instr. 23, 755 (1952).

SECTION IV

REPORT OF THE SUB-COMMITTEE ON NUCLEAR FUSION POWER

by

R. A. McCorkle

I. ECONOMICS

In order to demonstrate attractiveness, fusion power systems need to be shown to be competitive, economically, with the closest potential competitor (the latter most likely being the fast breeder fission reactor). To attempt a comparison at present, fusion reactor feasibility still being quite remote, may be nothing more than a game that must be played. Estimates have been made of fusion reactor costs and some results of these studies are now given.

Using as a reference system a commercial 2 x 1250 MW (e) fast breeder sodium-cooled reactor using carbide fuel with a load factor of 65% and a 25 year life, comparison is made to a potential laser-ignited fusion reactor of the implosion type assumed to be of expected design (Blascon, wetted wall, or dry wall). As reasonable assumptions, fuel inventory and replacement and refueling penalties are estimated as 1/4 of those of the fast breeder. Then the allowable plant costs (excluding buildings and civil works) are ∿ $220/kW(e) at 1971 prices. Relying on the aforementioned simple vessel designs, fusion vessel costs/kW(e) should be ∿ 2/3 fission vessel costs/kW(e) with auxiliary costs being about equal (i.e., liquid sodium systems being compared to liquid lithium blankets). Moreover, fission fuel handling equipment costs may be equated with tritium separation plant, pellet manufacture, and injection system costs. The modest savings of the fusion system is then offset by the cost of the laser system and its energy storage unit (capacitor bank).

Since pellet burn will yield low energy per shot, high repetition rates are needed. The repetition rate may be determined by:

a) laser/capacitor lifetime

b) vessel vacuum pump time

c) cost of vessel as a function of average power

d) cooling of laser and optical components.

Emperically, capacitor costs/joule stored scales as the frequency usage to the power 1/3. Since thermonuclear output should scale directly as the frequency, high values of this parameter are desirable. The upper limit on vessel pump time of ~ 1 sec means that several vessels are needed (thus demanding low capital cost/vessel), practicality restricting this number to some low value. Assuming the final stages of the amplifier may use fast-flow fluids as a lasing medium and window-less aerodynamic component designs, each reaction chamber will contain surrounding laser assemblies. Operation should then be at about a 50 Hertz repetition rate and thus, in order to be competitive on a 25 year basis, laser system reliability for 4×10^{10} shots is needed.

A cost breakdown for an estimated competitive laser-ignited fusion reactor becomes:

Item	Cost (1971 dollars/kW(e))
Turbines	75
Steam Generation	34.6
Reactor Vessel	32
Electrical Plant	25.4
Capacitors and Lasers	17.8
Reactor Auxiliaries	12
Control	12
Liquid Lithium	5.4
Fuel Processing	1.6
Total	$215.8/kW(e)

This breakdown assumes a laser efficiency of 30%, turbine (handling reactor output) efficiency of 40%, turbine (handling laser system losses) efficiency of 20%, energy storage efficiency of 95%, a 50 Hz rep rate, gain (i.e., fusion energy/incident light energy) of 33.3, ratio of thermonuclear power/useful output power being 1.25. Typical burns are considered to be ignition of D-T at 5 keV which rises to 100 KeV during burn, the mean energy per reaction being 22.4 MeV (which includes neutron-lithium blanket yield and ignores D-D reactions). The most expensive components are seen to be the turbines, steam generators, and reactor vessels (since these units handle the total thermonuclear power). An approximate reactor criterion for competitiveness becomes

$$A > (3 + 14\, C_\ell / f)/\eta_\ell\, \eta_{t1}\, \eta_s$$

for A $\equiv$ gain

C_ℓ $\equiv$ cost of laser and capacitors in 1971 \$/pump joule

f $\equiv$ operating frequency

η_ℓ $\equiv$ laser efficiency

η_{t1} $\equiv$ turbine efficiency handling thermonuclear output

η_s $\equiv$ energy storage efficiency.

High thermonuclear gain ($\sim$ 50% burnup) and high laser efficiency is needed to minimize circulating power, since steam generation and turbines are expensive. High repetition rates are needed to cut capital costs of laser components.

The Atomic Energy Commission estimates of fusion power economics, reactor designs being based on the four main fusion concepts (tokamak, theta pinch, magnetic mirror, and laser-fusion), involve materials costs based on 1972 prices. The estimates yield capital costs for plants on the same order as projected costs for other plants in the year 2000. Warning is given that cost estimate comparison judgments would be premature. Reasonably detailed prototype cost summaries are given, the results being, for total cost estimates; Ormak \$350/kW(e), theta-pinch \$100/kW(e) to \$1000/kW(e) (the variation due to duty factors chosen to give differing values of wall loading), Princeton Tokamak \$320/kW(e), Lawrence Livermore DT mirror \$320/kW(e), complete estimates for laser-ignited systems not being given. The above values do not include engineering @ 20% and overhead @ 30%. Fuel costs, determined by the costs of deuterium and lithium, are considered to be negligible (20¢/gram and 2¢/gram respectivley, for a cycle cost of 7 x 10^{-3} mills/kWh).

It is pointed out that safety and environmental characteristics may allow advantageous seting of fusion plants, thereby effecting a savings in transmission costs as well as allowing sale of waste heat for building heating and cooling and/or industrial processing. For a reference system (based on the ORNL Tokamak) with power output of 564 MW(e), tritium is considered to be the only radioactive effluent, the atmospheric leakage rate being 0.0001%/day for a system inventory of 6kG. Discharged through a 200 fast stack, the maximum ground level concentration gives a dose rate downwind of 1 mrem/yr (1% natural radioactivity). Radioactive waste from the reactor will be activated structural blanket material having a finite lifetime due to radiation damage. Using niobium gives ∿ 9000 Ci/MW yr. of longlived radioactivity, a reduction by a factor of 10^3 to 10^4 being possible if vanadium is used. A runaway reaction not being feasible, the greatest accidental hazard would involve the volatile radioactive inventory (tritium). By holding the tritium concentration to 1-10 ppm and isolating and monitoring the lithium and tritium handling equipment, the hazard level may be maintained sufficiently low. Loss-of-collant acidents are of no consequence. The effects of fusion plant construction on nonrenewable resources are considerable. Niobium requirements could possibly be met, conflicts also exist in projected usage of beryllium, titanium, helium, lead, vanadium, and molybdenum.

Various estimates to date seem to justify program increases for fusion research. Critics offer words of caution and suggest an approach of orderly progress with continued re-evaluation.

References

Hancox, R. and I. J. Spalding, Nucl. Fusion 13, 385 (1973).

"Fusion Power: An Assessment of Ultimate Potential", U. S. A. E. C. Report, WASH-1239 (February 1973).

Nuckalls, J., L. Wood, A. Thiessen, and G. Zimmerman, Nature 239, 139 (1972).

II. PLASMA RESEARCH

Assuming the competitiveness of potential fusion reactors, questions of scientific feasibility and the time-table for realization of such arise. The major programs sponsored by the Atomic Energy Commission to demonstrate scientific feasibility are the magnetic confinement program (tokamak, theta pinch, magnetic mirror) and the laser-fusion program. Away from the mainstream are less well-known and highly-funded programs including electron-beam solid-target heating and/or pellet implosion, the stabilized z-pinch, RF and microwave confinement, mirror-focus systems, multiple-mirror systems, dense plasma focus devices, exploding wire systems, shock-heated wall-confined systems, and non-plasma systems such as the Migma cell. An attempt to review all of these programs is futile as well as undesirable. An attempt to provide a perspective of benefit to IBM on plasma research as it relates to fusion and/or other programs of interest to the company is now given.

Although there exist many variations for energy balance in fusion systems, deviations from the well-recieved "Lawson Criterion" are generally not too great. For the most promising DT reaction, a rough rule-of-thumb is that the product of ion density with containment time must exceed $\sim 10^{14}$ sec/cm^3 with the ion kinetic temperature $\sim$ 10 keV or greater. Magnetic confinement schemes have revealed numerous difficulties in attempting to realize energy-breakeven: macro-and micro-instabilities, turbulence effects, cooling mechanisms and failure of many heating mechanisms near the temperatures and densities of interest. Ample review of these problems and their solution has been given and may be obtained from the indicated references at the end of this section. By way of summary, a majority of the non-classical effects (i.e., Bohm diffusion) are either now understood and controllable or their influence can be minimized. As a result, magnetic confinement programs are within two, and perhaps one, order of magnitude of satisfying the density-time Lawson Criterion and temperature values are comparable to those needed. Moreover, many confinement systems show scaling behavior typical of that to be expected for classical plasmas. Potential payoff from these systems seems to be a matter of time and money both of which are reasonably certain at present. Nevertheless, fundamental questions still need answering in scaling some of these devices with respect to possible instabilities that have not yet been encountered. Most estimates agree in placing scientific feasibility demonstration likely during the 1970's. Atomic Energy Commission plans include plasma test reactor design and construction in the late 1970's with operation extending into the 1980's, followed by experimental power reactor development initiated in the early 1980's and prototype power reactors constructed during the late 1980's and early 1990's. It is felt that the success of such a program will lead to power plant operation around 2000 and, assuming competitiveness with fast breeder systems, have an impact (18% of electrical energy generation) on energy resources by 2020. Latest estimates by the AEC shorten this timetable, but advice by study groups such as the Cornell Workshop caution against programs not based on successive stages of development.

It should be emphasized that experimental plasma fusion work is still very much physics research. Research requirements for the mainstream programs are given in the indicated references and are not detailed here. However, in order to stress the fundamental nature of the work, a partial list of some problems of interest to the laser-fusion program is given:

1) strong stimulated back-scatter of incident laser radiation,
2) supra-thermal electrons prematurely heating the core
3) difficulty of having to use long wavelength lasers
4) effects of density gradients on plasma instabilities,
5) absorption of radiation at sub-critical frequencies due to stimulated Compton scattering,
6) self-focusing,
7) harmonic generation,
8) overdense propagation in the presence of density gradients,
9) polarization induced velocity anisotropy,
10) magnetic fields produced by radiation pressure asymmetries,
11) inverse Faraday effects,
12) lack of spherically symmetric polarized fields,
13) pulse-shaping difficulties for unpolarized laser beams.

With less basic problems being:

1) chambers capable of thermal cycling for more than 10^{10} pulses,
2) highly efficient pulse-shaped lasers,
3) high average power (∿ 50 MW), appropriate wavelength lasers,
4) high repetition rates with long life
5) energy storage at from \$3 to \$30 per laser joule,
6) windows compatible with nuclear environment and having minimum distortion at high laser intensities,

7) means of generating and positioning spherical pellets of controlled size,

8) adequate symmetry of laser flux.

Such problems are indicative of current research areas in laser imploded pellet work. In addition, other approaches to laser ignited fusion are being investigated; super-heating of magnetically confined plasmas and utilization of the flow that develops from laser irradiation of solid DT-target with control of lateral expansion by magnetic fields.

Mainstream plasma fusion research is a well-developed, extensive, costly pursuit that enjoys the sophistication of large scale laboratory efforts and extensive theoretical/calculational backup. This reviewer concludes that IBM Yorktown research is not now well disposed to contribute to this effort nor can he see the benefit to IBM in this work. However, there are areas of overlap of current IBM research (i.e., laser development) with these fusion programs. There currently exists an awareness, on the part of the scientists involved in these areas, of the potentialities of their work relative to the fusion effort.

Among the less well-publicized fusion research efforts can be found exciting, higher-risk attacks that are amenable to "laboratory size" experimental investigation. Moreover, some of these programs lend themselves to applications in other areas of interest to IBM; for example, short wavelength laser research and ion-implantation. Some of these alternatives will now be mentioned with possible research programs suggested. In general, the reviewer feels that strong inductive and structural plasma effects offer great promise, both with potential regard to fusion as well as in other applications. However, again it is felt that IBM's research effort cannot be seen to be directly coupled to these phenomena.

An attractive example of lesser known fusion schemes is the shock-heated wall-confined fusion cycle proposed at Columbia University. The device, analogous to a diesel engine, uses a shock-heated, partially wall-confined plasma. A magnetic piston formed by a large current in cylindrical geometry drives a shock in a coaxial cavity. The shock reflects from an end wall and heats and compresses the plasma. A switched-on cusp field confines the plasma near the end wall. Plasma cooling occurs due to the wall contact. For a D-T fill at 30 mTorr, and with an initial azimuthal field of $\sim$ 10 KGauss, a piston field of 70 kGauss results in a shock speed of 3×10^8 cm/sec. Upon reflection from the end wall, the plasma should be near 40 keV in temperature, occupy $\sim$ 10% of the initial volume and contain $\sim$ 95 kGauss of embedded magnetic field. Then the 3.5 MeV ^4He fusion product would be retained by the plasma, this energy exceeding radiation losses by a factor of $\sim$ 40, thus heating the plasma until wall cooling quenches the process. High magnetic shear is provided by the cusp and azimuthal fields. Typically densities of 10^{16} cm^{-3} and a cooling time of 1.4 sec over distances of 7.5 cm are expected. Questions of influence of turbulence and instabilities in the plasma-wall boundry layer are of central importance. However, the burn temperature should allow avoidance of energy balance instabilities and a high burn ($\sim$ 60% to 80%) could make such a device economically attractive. It is estimated that $\sim$ 80% of the fusion energy yield could be realized by interaction in the breeder blanket (14.1 MeV neutrons with lithium). Nearly half of the input energy would go into the magnetic dam, the total magnetic field energy approximately balancing the blanket energy yield. (Direct conversion at high efficiency, as proposed at Los Alamos, is not included in this device.) With a turbine efficiency of 33%, typical cylinder dimensions $\sim$ 1 meter, energy input per firing $\sim 6 \times 10^8$ joules, gives a fusion energy of 2×10^9 joules and a blanket release of $\sim 5 \times 10^8$ joules. With of frequency of $\sim$ 1 shot/sec (realized by use of several cylinders), thermal power output would be 3200 MW, total electric power output $\sim$ 1080 MW, thus netting 440 MW for sale. To indicate the energy storage facility needed to run the device, the magnetic piston supply is estimated at 6 MV, 39 MA. (Shock speeds of above 10^8 cm/sec at a plasma temperature of 10^7°K and a density of 10^{16} cm^{-3} have already been realized in a laboratory device of the general nature discussed above.)

Electron-beam ignited fusion approaches are just entering the stage of experimental feasibility study. Early ideas involved direct heating of a solid D-T target by a pinched relativistic electron beam, the target being surrounded by a high Z tamp and situated within a magnetic mirror. The strong magnetic field reduces the electronic heat conduction losses in the target and quench the range of the charged fusion products. Another, more recent, approach is based upon observed focusing effects of intense (over 1 MA/cm^2) relativistic electron beams in high current diodes. It is expected that self-focusing will occur in the target and permit short distance beam stripping. Electron beam power densities of 10^{14} to 10^{15} watts/cm^2 are in the near future. With scaled up pellet sizes, breakeven energies of several hundred kJ with deposition times of $\sim$ 10 nsec are possible for pellets several mm in diameter. Longitudinal electric fields in a resistive plasma combined with the self-magnetic field of an intense beam in a diode geometry result in the formation of a "super pinch" producing a large spread in angles of the beam incident on the target. The beam then behaves as if it were a high-temperature electron gas rather than as a parallel flux of particles. Thereby a symmetric implosion may be realized by employing only two beams.

Dense plasma focus devices have been operative for some time with large thermonuclear neutron yeilds. It is hoped, by those currently involved in scaling these devices to larger values, that promising results will ensue. However, one particular aspect of DPF work, championed by the research effort at Stevens Institute of Technology, is particularly attractive in a general sense. From this work, evidence has been given that self-contained toroidal vortices are generated which constrict to a very dense, high temperature state capable of producing significant thermonuclear yield - as well as a copious supply of intense, hard x-rays. Various models for the generation and annihilation of these structures have been advanced. However, fundamental work needs to be done in order to clarify what mechanism (or mechanisms) could give rise to these structures as well as to assess their ultimate potential with regard to net thermonuclear output. Data from small scale devices indicate values competitive with mainstream systems in meeting the Lawson criteria (i.e., densitie's near - or perhaps over - $10^{20} cm^{-3}$ for tens of nanosecond times at keV temperatures). However, the ability to scale these results to more significant values may be highly questionable. In contrast, if such structures could be produced in reasonably large scale, well confined plasmas (such as the baseball geometries) by one of many possible schemes (filamentary driven currents, inverse Faraday effects, beam filamentation due to Weibel type instabilities, spiral non-linearities in electron beam propagation) coupled with magnetic field shock-produced annihilation, much new physics could result. An assessment of the fusion reactor potential of such systems is extremely speculative.

Many such peripheral programs contain high risks but offer high rewards. Moreover, from such studies are likely to emerge rich plasma effects of interest in programs other than the fusion effort, for example, in the field of x-ray lasers. Perhaps a gradual increase in the size of our IBM effort in plasma physics is warranted to allow us to explore some of these possibilities and assess any larger role they might play in our research plans.

References

Fusion Reactor Breakeven:

Lawson, J. D. Proc. Phys. Soc. London B70, 6 (1957).

Glasstone, S. and R. H. Lovberg, Controlled Thermonuclear Reactions, Van Nostrand, New York (1960), Chapter 2.

Rose, D. J. and M. Clark, Jr., Plasmas and Controlled Fusion, MIT Press, Wiley, New York (1961), Chapter 13.

Assessment of Confinement Programs:

Gough, W. C. and B. J. Eastland, "The Prospects Fusion Power", Sci. Amer. 224, 50 (1971).

Kenward, M. "Fusion Reactors - The Ultimate Solution?" New Scientist (27 December 1973), 896.

Glasstone, S., Controlled Nuclear Fusion, U. S. AEC Division of Technical Information, Oak Ridge (1968).

Post, R. F., "Prospects for Fusion Power", Physics Today, (April 1973), 30.

Ohkawa, T. and N. Rostaker, "Plasma Confinement in the Toroidal Multiple", Physics Today (December 1967), 48.

"Fusion Power: An Assessment of Ultimate Potential", U. S. AEC Report WASH-1239 (February 1973).

"Fusion Power: Research and Development Requirements", U. S. AEC Report WASH-1267 (July 1973).

Kolesnichenko, Ya. I. and S. N. Reznik, Nuclear Fusion 13, 167 (1973).

Oliphant, T. A., F. L. Ribe, and T. A. Coultas, Nuclear Fusion 13, 529 (1973).

Tamano, T., "Experiments on Plasma Diffusion in Toroidal Confinement Systems", Bull. APS 19, No. 1, 73 (1974).

Pyle, R. V., "Intense Neutral Beam Sources", Bull. APS 19, No. 1, 74 (1974).

Furth, H. P., "Magnetic Confinement of Thermonuclear Plasmas", Bull. APS 19, No. 1, 85 (1974).

Ribe, F. L., "Physics Problems of Thermonuclear Reactors", Bull. APS 19, No. 1, 85 (1974).

Hoven, G., "Nonlinear Plasma Wave Excitation", Bull. APS 19, No. 1, 99 (1974).

Thomas K. S., "Scylac Theta Rinch Experiments", Bull. APS 19, No. 1, 99 (1974).

Davidson, R. C., "Equilibrium and Stability Properties of Intense Relativistic Electron Rings and Nonneutral E Layers", Bull. APS 19, No. 1, 99 (1974).

"Ormak Nears Collisionless Regime", Phys. Today, 17 (June 1973).

"Princeton Tokamak Exceeds Supposed Density Limit", Phys. Today, 17 (January 1973).

An international status report on magnetic confinement devices as well as other fusion developments is reported in:

Fifth European Conf. on Controlled Fusion and Plasma Physics, Vol. II, Grenoble, 21-25 August 1972, Association EURATON-CEA, Grenoble, France.

Laser-Ignited Fusion:

Fundamental and Applied Laser Physics: Proceedings of the Esfaham Symposium, August 29 to September 6, 1971, ed. by M. S. Feld, A. Javan, and N. A. Kurnit, John Wiley, New York (1973), pp. 105-220.

Lubin, M. J. and A. P. Fraas, "Fusion by Laser", Sci. Amer. 224, 21 (June 1971).

Nuckolls, J., J. Emmett, and L. Wood, "Laser-Induced Thermonuclear Fusion", Phys. Today, 46 (August 1973).

Nuckolls, J., L. Wood, A. Thiessen, and G. Zimmerman, Nature 239, 139 (September 1972).

Clarke, J. S., H. N. Fisher, and R. J. Mason, Phys. Rev. Lett. 30, 89 (1973).

Brueckner, K. A., IEEE Trans. on Plasma Sci. PS-1, 13 (1973).

McCall, G. H., F. Poung, A. W. Ehler, J. F. Kephart, and R. P. Godwin, Phys. Rev. Lett. 30, 1116 (1973).

Katz, J. I., Appl. Phys. Lett. 23, 342 (1973).

Saleres, A., F. Floux, D. Cognard, and J. L. Bobin, Phys. Lett. 45A, 451 (1973).

Hancox, R. and I. J. Spalding, Nuclear Fusion 13, 385 (1973).

Bobin, J. L., D. Colombant, and G. Tonon, Nuclear Fusion 12, 445 (1972).

"AEC Opens up on Laser Fusion Implosion Concept", Phys. Today, 17 (August 1972).

Brueckner, K. A., "Laser Driven Fusion", Bull. APS 19, No. 1, 85 (1974).

Shock-Heated Wall-Confined Plasmas:

Gross, R. A., Nuclear Fusion 13, 295 (1973).

Gross, R. A., "A Shock-Heated Wall-Confined Fusion Power System", Plasma Physics Lab. Rep., Columbia University (May 1972).

Electron-Beam Ignited Fusion:

Winterberg, F., Phys. Rev. 174, 212 (1968).

Winterberg, F., Nuclear Fusion 12, 353 (1972).

Bradley, L. P. and G. W. Kuswa, Phys. Rev. Lett. 29, 1441 (1972).

Yonas, G., K. R. Prestwick, J. W. Poukey, and J. R. Freeman, Phys. Rev. Lett. 30, 164 (1973).

Yonas, G., "Applications of High Intensity Relativistic Electron Beams to Pulsed Fusion and Collective Ion Acceleration", Lectures presented at the International Summer School of Applied Physics in Erice, Sicily, June 4-16, 1973.

Miller, P. A., J. Chang, and G. W. Kuswa, Appl. Phys. Lett. 23, 423 (1973).

"Many Laboratories Try for Fusion with Electron Beams", Phys. Today, 17 (April 1973).

Yonas, G., "Electron-Beam Induced Fusion", Bull. APS 19, No. 1, 85 (1974).

Condit, W. C., D. O. Trimble, G. A. Metzgar, D. G. Pellinew, S. Heurlin, and P. Creely, Phys. Rev. Lett. 30, 123 (1973).

Dense Plasma Focus Devices and Other Methods Whereby Torodial Vortices may be Established:

Bostick, W. H., L. Grunberger, V. Nardi, and W. Priov, ASME Fifth Symposium on Thermophysical Properties (ASME New York), 495.

Bostick, W. H., V. Nardi, and W. Priov, "Formation and Decay of Vortex Filaments in a Plasma Current Sheath", in Dynamics of Ionized Gases, Eds. M. J. Lighthill, I. Imai, and H. Sato, University of Tokyo Press (1973), p. 375.

Bostick, W. H., V. Nardi, and W. Prior, "Simularities Between Solar Flares and Laboratory Hot Plasma Phenomena", from Cosmic Plasma Physics, Ed. K. Schindler, Plunum, New York.

Bostick, W. H., V. Nardi, and W. Priov, J. Plasma Physics 8, 7 (1972).

Bostick, W. H., V. Nardi, and W. J. Priov, "Study of Vortex Annihilation and Neutron Production", Final Report to AFOSR, SIT-P274, Stevens Institute of Technology (1972).

Irving, J., W. M. Deuchars, and I. Thomson, "The Initial Stages of a Pre-Ionized Liner Theta-Pinch Plasma", in Dynamics of Ionized Gases, Eds. M. J. Lighthill, I. Imai, and H. Sato, John Wiley and Sons, New York (1973).

Khodataev, K. V., ZhETF Pis. Red. 18, No. 3, 184 (1973).

Steiger, A. D., And C. H. Woods, Phys. Rev. A 5, 1467 (1972).

Benford, G. Plasma Physics 15, 483 (1973).

Webster, H. F., T. J. Hallinan, Radio Science 8, 475 (1973).

Lee, R. and M. Lampe, Phys. Rev. Lett. 31, 1390 (1973).

Bernstein, M. J., C. M. Lee, and F. Hai, Phys. Rev. Lett. 27, 844 (1971).

Paassen, H. L. L., R. H. Vandre, and R. S. White, Phys. Flds. 13, 2606 (1970).

Lee, J. H., and D. R. McFarland, "Hypocycloidal Focus", Bull. APS 18, 1369 (October 1973).

Migma Device:

Maglish, B. C., Nuclear Inst. Mthds. 111, 213 (1973).

Maglic, B. C., J. P. Bleuett, A. P. Colleraine, and W. C. Harrison, Phys. Rev. Lett. 27, 909 (1971).

Miller, R. A., Phys. Rev. Lett. 29, 1590 (1972).

III. FUSION TECHNOLOGY

Fusion reactor technology may be seen as an area in which widely varying applied research interests, many within the scope of existent IBM Yorktown programs, need development. Some possibilities have been mentioned already, other include computer simulation studies, energy storage development, and the behavior of collants, pressure vessels, structural materials, superconducting materials in response to high energy (and low energy) neutron flux at elevated temperatures (understanding effects of brittleness, enhanced creep, and swelling leading to complex deformations and induced stress in terms of displaced atoms, point defects, dislocations, disordered regions, voids, and transmutation-induced impurities). However, to assume that such an undertaking would be an easy task since not much work in these areas has been reported to date would be to misunderstand the scope of efforts that have been carried on quietly until very recently.

Elaborate computer codes exist to study plasma behavior in detail by simulation, modeling, calculations, and "computer experiments". The IBM Scientific Center at Palo Alto has experience in this area and should be consulted prior to initiation of any effort at IBM Yorktown.

The Princeton Plasma Physics Laboratory has been involved in an 18-men, 8-man-year Tokamak reference model study. This work as well as many others, is a complete systems study involving reactor design, blanket materials, cooling, and reactant inventories, structural material selection and performance, control of thermal runaway due to trapped α-particles by high Z-materials, and magnetic field design. Injector systems studies are well developed at Lawrence Livermore. Los Alamos and MIT have conducted studies in superconducting energy storage and transfer systems involving direct conversion techniques in the reactor design. At the Max Planck Institut für Plasmaphysik at Garching, Germany, work is underway on the solubility of tritium in various metal powders as a tritium recovery method. Additional studies are conducted in inductive energy storage as well as superconductor response to high neutron doses (10^{23} N/cm^2 decreasing the critical current by 30-40%, partial recovery being effected by cycling to room temperature). A 15 physicist study of neutral particle and ion interaction up to 2 MeV on surfaces involves an 80 keV, 5 A neutral particle injector and measures sputtering distributions. A 1 kJoule, 1 nsec iodine laser is expected to be operative this year at Garching. At Lawrence Livermore, a sizeable effort is underway on energy removal studies involving a Li-C-Fe-Ni blanket with a 1.21 tritium breeding ratio and a 1.2 energy multiplication factor, stainless steel being used for the first wall. The wall loading is 1.63 MW/m^2. Other cooling studies are investigating various liquid metals and salts. Coolant pumping transverse to magnetic fields involve boiled potassium, sodium, or molten salts (e.g., Flibe). Flow channel and header studies indicate workable systems are realizable for 0.85 MW/m^2 wall loading with radial lithium flow. MHD feedback systems utilizing optical plasma position signals and amplifier modules to drive magnetic coils at 15 MW average power are on-line. At Oak Ridge, 20 people are involved in fluid dynamic and cyclic stress problems of the Blascon device utilizing scale models (an output being that bubbles reduce the wall strain by a factor of 8). Also, the chemical compatibility of blanket, structural materials and insulators (Li, Li_4 Be F_2, K, Nb, Mo, steel) is examined using forced convection loops. Tubes of Nb-1% Zr coated with Y_2O_3 are being tested for MHD applications. Neutron and x-ray production cross-sections in vanadium have been re-evaluated, recovery of tritium from potassium using solid sorbents is underway. Systems studies evaluation has involved a data tabulation and survey of some 25 fusion-reactor studies. Other studies are underway (or have been completed) on neutron-flux and reaction-rate distributions in blanket material, detailed tritium production in lithium (0.56 $\pm$ 0.06 T/n in ^{6}Li and 0.40 $\pm$ 0.04 T/n in ^{7}Li), graphite dimensional and properity changes following irradiation (with temperature influences), and the fatigue characteristics of helium implanted stainless steel. In addition to these studies, laser optics and pulse shaping systems previously mentioned are being pursued.

It is thus seen that initiation of a program in fusion technology would be of a supplemental nature and would involve, in experimental studies, sizeable materials and/or irradiation studies - unless unique contributions could be elicited from those at Yorktown knowledgeable in such areas (this latter possibility being considered to be the most attractive alternative to this reviewer).

References:

Oliphant, T. A., F. L. Ribe, and T. A. Coultas, Nuclear Fusion 13, 529 (1973)

Vineyard, G. H., Bull. APS 19, No. 1, 71 (1974).

Kristiansen, M., Nuclear Fusion 13, 281 (1973).

Gruber, J. E., Nuclear Fusion 13, 451 (1973).

Gazdag, J., J. Canosa, and B. H. Armstrong, "The Role of Computers in Thermonuclear Research", IBM Palo Alto Scientific Center Report 320-3294 (1971).

SECTION V

FUEL CELLS AND CATALYSIS - Their Relation to National Energy Needs and to IBM's Research and Businesses

by

Warren D. Grobman
and
M. W. Shafer

January 28, 1974

IBM CONFIDENTIAL

TABLE OF CONTENTS

A. SUMMARY

Research into electrochemical and fuel catalysis could lead to new fuel cell technologies needed for energy storage (electrolysis cell in a solar power economy), automotive power, emergency computer power, and peak load (suppl-mental) commercial power applications. Development of a cheap catalyst would remove the objections to fuel cells for total national electrical production. In such a case their high efficiency and extremely attractive environmental characteristics will offer a crucially needed technology for the nation's energy needs. For this reason, the limited chance of a breakthrough resulting from a research program is offset by the tremendous payoffs. This fact coupled with the possibility of strong IBM involvement in photo-voltaics and with the untapped IBM market for standby com-puter power are strong arguments for implementation now of a Research Division program in this field.

Consequently, our major recommendation is that an effort in catalysis related to electrochemical technology be instituted at the Research Division. This effort should be supplemented by some work on solid electrolytes, both experimental and theoretical and both organic and inorganic. Also, a capability for design, fabrication and operation of simple electrolysis cells and/or fuel cells to test the catalytic properties of the materials studied should be included. Supplemental to our effort should be corrosion studies related to electro-chemical systems.

B. FUEL CELLS

I. Introduction - Fuel Cells[1]

The present report attempts to assess the present state of fuel cell technology and the consequent possible present and future use of fuel cells commercially, to determine ways in which IBM could use this technology and to recommend the role IBM Research should play in fuel cell research and development.

The main conclusions and recommendations are briefly the following (see also Section XI):

1. Fuel cells will probably not be competitive with conventional power plants in the near future for electric power production.

2. With significant improvements in technology, notably catalysts, they may be used for peaking power and/or vehicular power.

3. In a solar (e.g., photovoltaic) -based energy economy, of great possible interest to IBM, fuel cell technology is crucial because of its application in electrolysis units.

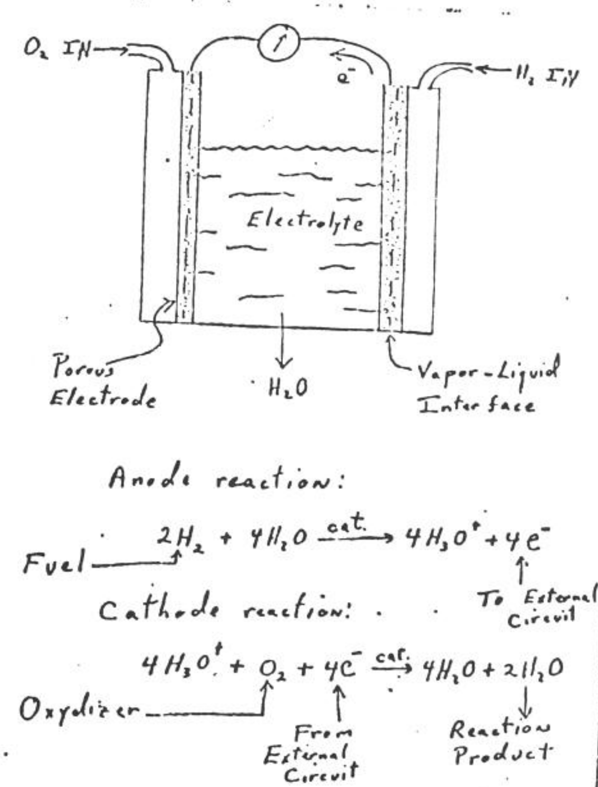
4. With forseeable future technology, the fuel cell may find a potential IBM market as a standby computer power source.

5. Research but not development in the fuel cell technology-related areas of electrochemical catalysis, corrosion, solid and polymer electrolytes, and others is extremely important and should be undertaken.

II. Fuel Cell Power Supply Systems - General Description

The fuel cell is an electrochemical device in which the chemical energy of a continuously supplied fuel and oxidizer are transformed continuously and directly into reaction products and electrical energy which can be expended in an external circuit. An example is shown in Fig. 1, which illuminates some of the important features of a typical device:

Fig. 1 Schematic of the electrochemical reactions and construction of a simple fuel cell.



1. Specially designed electrodes must be developed which
   a. are catalytically active,
   b. maintain a stable fuel (vapor)-electrolyte (liquid) interface, and
   c. have low electrical resistance, both internal and at the electrolyte--electrode interface.
2. Fuel and oxydizer compatible with the electrode chemistry are required--contaminants in the fuel must not poison the catalyst.
3. Waste product (usually H_2O) removal must be provided to prevent electrolyte dilution.
4. Temperature control is essential
   a. Elevated temperatures required for chemical reaction at electrodes BUT
   b. Too high temperatures lead to rapid corrosion and cell failure.

Many of these various fuel cell features are amenable to large basic research efforts since most current cells use extensively engineered materials and configurations which possess significant fundamental failings. For example, the most heavily funded effort for development of commercial power-producing cells is based on a hot H_3PO_4 electrolyte--nickel electrode configuration in which corrosion will probably limit the extent to which the technology can be pushed. Thus, basic research in new catalysts, corrosion mechanisms, and electrolytes (especially solid electrolytes) represent areas of important research to which the Research Division could contribute.

Before considering commercial prospects for fuel cells, we note some of their characteristics in a total power-production system. Most individual cells have output EMFs of the order of one volt, and output currents of ~100 to 400 ma/cm^2 of plate area. Thus, large arrays are arranged in a series-parallel configuration (a fuel cell battery) in a power generation system. Other components of a power generation system are shown in Fig. 2. Fuel is usually H_2 for the most successful currently available technologies, in which case a reformer is needed to convert hydrocarbon or other fuels into H_2 (another area where catalysis research can make a large contribution). Finally, the dc output of the fuel cell battery must for many applications be converted to ac power in an inverter. Of all of these components, it is the basic fuel cell itself which constrains the presently achievable life, weight, volume, cost, and efficiency of the fuel cell power supply system.

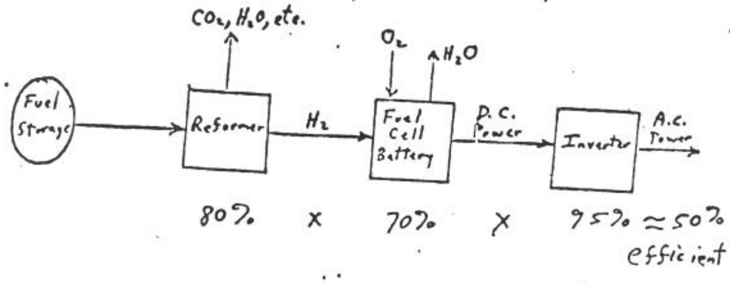


Fig. 2 Schematic of a total fuel cell-based commercial power generator system using hydrocarbon or other complex fuels.

III. Fuel Cells in the Energy Economy

This section attempts to evaluate the significance of fuel cells for total commercial power generation and automotive use compared to other commonly considered power sources. The following section considers the roles fuel cells could play in the future within IBM business enterprises. The conclusion will be that the most important probable use for fuel cell technology in the future will be in electrolysis cells for conversion of water to H_2 and O_2.

Many types of fuel cells have been developed for certain special applications, notably in power supplies for space probes, vehicles, submarines, and other special military applications. Only two types have received extensive consideration for large scale commercial power generation--Pratt and Whitney and the General Electric designs. A third developed by the French Alsthom Corp. in conjunction with Esso is under development as an automotive power source. (Other types have appeared in the past, sponsored by Allis Chalmers, Union Carbide, and others, but do not appear to be under extensive investigation at this time.)

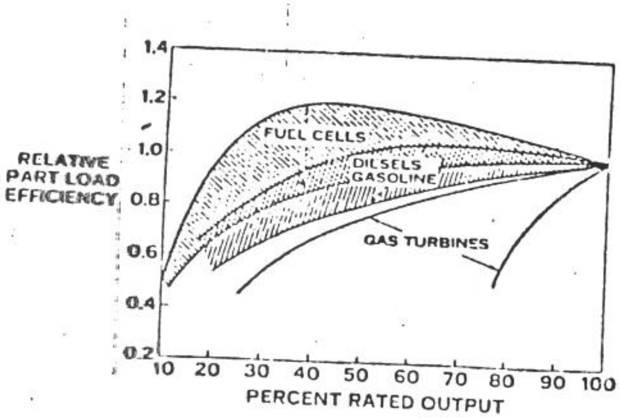
Pratt and Whitney's Efforts - These are by far the most heavily funded and widely reported. Much of the Pratt and Whitney publication of their results has been more in the nature of advertising than hard facts. Two fundamental problems they refuse to discuss publicly are the cell lifetimes and catalyst loading and type. The consensus of the people I spoke to was that their cell lifetimes may never achieve the >5 years needed for the Pratt and Whitney figure of ~$150/kw. (One-year lifetimes may be more like what they will achieve.) If they use a Pt catalyst now, then at any significant fuel cell electrode plate loading the cost for production on a national power need scale is too great (see Section VII).

GE Fuel Cell - The GE concept is technologically much more advanced than most, using a H_2O saturated porous polymer electrolyte with mobile radical side groups in the polymer. In the most recent cells with a sulfonated teflon electrolyte, individual cell lifetimes of ~20,000 hours or better have been achieved--much more than in any other technology. With H_2-O_2 fuel, GE estimated costs of ~$300/kw by 1980. However, to supply the nation's 1970 consumption of electricity this way would require 100 year's worth of the world total production of Pt!.

Alsthom Fuel Cell - This French-designed fuel cell uses hydrazine and H_2O_2 and Co or Ag as catalysts. It is attractive for automotive use due to its high power density per unit weight and volume, and its low cost to fabricate. Lifetime is not such a problem as in commercial power generation since only about 2500 hours total life is required for automotive use. The drawback is its use of hydrazine, which is too expensive unless a catalyst to produce it from H_2 and N_2 is developed. An alternative route is being explored by Esso Research Labs in collaboration with Alsthom. Esso is trying to make a catalyst which will enable the Alsthom cell to utilize methanol as the fuel.

The overall situation is well illustrated by the above three examples. For low temperature, low corrosion operation, good cheap catalysts are needed in commercial power production cells if the total energy needs of the nation are to be satisfied. For automobiles, with shorter lifetime requirements, we are closer to the right technology, but using an expensive fuel (hydrazine). For automotive use, either hydrazine must be more cheaply synthesized or catalysts for methanol or other cheap fuels must be devised.

For large scale commercial electrical production, Pratt and Whitney's studies have shown the pollution and efficiency advantages of fuel cells over conventional power sources. The Pratt and Whitney figures and tables showing these advantages are reproduced here in Fig. 3. The advantages are large enough that research in new catalysts and electrolytes has large payoffs to offset its limited chance of success.



	POUNDS PER THOUSAND KWH	
	GAS-FIRED CENTRAL STATION	FUEL CELLS*
SULFUR DIOXIDE	0.3	0.0003
NITROGEN OXIDES	4	0.24
HYDROCARBONS	2.0	0.23
PARTICULATES	0.1	0.00003

* BASED ON DATA FROM EXPERIMENTAL FUEL CELLS

Fig. 3a) Efficiency of various types of commercial power generator systems as a function of partial loading.

b) Typical low sulfur hydrocarbon fueled power plant emissions for a gas-fired vs. a fuel cell based system. (From Pratt and Whitney--see bibliography)

One brief comment is that one possible advantage to fuel cells as power producers--namely their ability to supply potable H_2O, is not significant. A crude calculation shows, for example, that supplying all the U.S. energy from H_2-O_2 fuel cells will only produce about 5-10 gallons H_2O/day per capita, compared to domestic needs of 40-80 gallaons/day per capita and many times that in industry.

Solar Power and the Electrolysis Cell - A further reason for more fuel cell-related catalysis work at IBM is the following. Our power source interest in the future may be extensively concerned with photovoltaic solar power. Such a power source, however, must be used in conjunction with some sort of very large scale energy storage system. One low pollution, efficient and attractive system is one in which sea water is electrolysed by solar-produced electricity and the resulting H_2 shipped in pipelines to relatively conventional power plants. For such a system, efficient electrolysis cells are needed (fuel cells run in reverse). A given technology can be run at ~5 to 10 times greater power density for electrolysis compared to power production, so the costs are way down. For example, the GE type cell can cost ~$50/Kw as an electrolysis cell. This application of fuel cell technology should not be overlooked if IBM Research goes into solar cell research on a large scale. In such a case, a fuel cell catalysis and electrolyte research project would be a useful adjunct to the solar cell effort.

IV. Fuel Cells and IBM's Business

The most likely use within IBM's product lines for fuel cells would be in a standby power system supplied with a computer. There are possibly enough IBM computer customers who want such a device to justify its supply by us if it is something unique (a power source not available commercially elsewhere). There are less severe constraints on fuel cells for such an application--namely short life, weight, and Pt catalyst cost are not subject to the same constraints here as in the case of supplying power to the whole nation. A cell of the GE-type, based on the sulfonated polymer electrolyte principle is especially attractive, as it has no free liquid electrolyte, is very compact, and can have quite a long life. Even though it uses Pt as a catalyst, a battery of these cells could produce a few hundred Kw (enough to supply an IBM 360/158 for example) using ~2kg of Pt (costing a few x $\$10^4$ total). Unfortunately, while the basic technology is perhaps available here, a large scale engineering effort might be needed to develop it into a useful product. More detailed study, beyond the scope of this report, is needed to determine how large an effort would be needed and whether such an effort is worthwhile to IBM.

Along the above lines, we note that Pratt and Whitney was approached by IBM representatives from DP and SPD in January 1973 to discuss the possibility of a Pratt and Whitney sale or lease to IBM of a fuel cell for experimental purposes. The Pratt and Whitney representative was reluctant to make such an arrangement.

C. CATALYSTS

V. Introduction

In this section the importance of catalysts and their relationship to certain aspects of energy creation and conservation will be discussed. We will be primarily concerned with catalysts and catalytic effects as they relate to fuel cells.

The operation and advantages of fuel cells have been previously discussed. The part they play in IBM's future, as well as their place in our overall energy system, will depend greatly on how they compare with other sources of standby power and generating systems. Presently cost and reliability are the main stumbling blocks but some minor breakthroughs could change these and their competitive position would change dramatically. The obvious place for this breakthrough to occur is in the catalysts! If a cheaper catalyst capable of high reliability and efficiency were developed, fuel cells would certainly become attractive as power generators. It is felt that IBM Research can make significant contributions toward the understanding and development of catalysts, not only for fuel cell technology but also for fuel production.

VI. Catalysts and Their Significance

The general definition of a catalyst is a material, in our case usually a solid, which by its presence in a reacting system alters the velocity of a reaction, and may be completely recovered unchanged at the end of the reaction. In practice, however, we usually find there is some overall loss as well as contamination of the catalytic material.

Catalysts have widespread use throughout industry but it is in the area of energy production and control where our interest should be. Here there are three areas we could consider:

1. Energy conversion (fuel cell electrode reactions)
2. Fuel production processes
3. Pollution control

We feel that the first two should have priority in any initial study since the widespread use of fuel cells would greatly diminish the air pollution which is due to the combustion of hydrocarbon fuels.

Some of the currently exciting processes in fuel production where improved catalysts would have significant impact are:

1. Liquid fuels from shale
2. Liquid fuels from coal
3. Hydrogen production
   from: coal
   shale
   hydrocarbons
   water electrolysis
4. Methane or Methanol Production [2]
   from: $CO+H_2O$
   Liquid fuels
5. Hydrazine from H_2 and N_2

Table I shows the current status of the first two processes:

Table I. Liquid Fuels from Shale and Coal[3]

	Process		Capacity ton/day	% Assay Yield (liquid)	Cost
Shale	BU Mines	(1979)	260	84	1.00-1.25/10^6 btu
	Union Oil	(1976)	1000	70	1.00 " "
	Tosco	(1976)	1000	95-100	
Coal	Lurgi	(1979)		30	2.10 " "
	Pyrolysis (Toscoal)	(1979)		15	
	Exxon Donor	(1983)		80	1.50 " "
	Liquid hydrocarbon cost today			--	~1.00 @ 7.00/barrel

Raw shale oil contains 2% nitrogen and ~1% sulfur--impurities which cannot be tolerated in most combustion processes, and one-third of the production cost (Table I) is the cost of their removal. This is an obvious place for the development of a catalyst which would more effectively remove these impurities. Only slight improvements would have great economic significance.

The desirability and the potential increased demand for hydrogen as a fuel has been discussed previously so the impact of lower cost hydrogen on our economy is also obvious. Our current major sources of hydrogen, i.e., natural gas, petroleum refinery, and the coal gas process ($C + H_2O$), are sources in which the processes are rather well developed and we can only expect small improvements through improved catalysts. However, as we move toward a hydrogen economy and the production of hydrogen is greatly increased, even small improvements will have more significance. Since these sources will be inadequate, alternate sources will be necessary. Some possibilities are: the shale or coal liquification processes can be altered to produce hydrogen--certainly catalysts would play a major role here; another would be electrolysis of H_2O. Here it has been proposed that nuclear power plants located along the oceans could be used to produce massive quantities of hydrogen from sea water from where it would be transported inland via large pipelines from where it would be further distrubted to hydrogen-air fuel cell power generating systems.[4] It is generally agreed that such a scheme would be highly desirable but whether it is economically feasible depends to a large part on the cost of power obtained via the cell. Obviously this is a function of many things; among the most important is the entire cost of the cell and how effectively the H_2 and O_2 are converted to electrical energy at the electrodes within the cell. It is here where catalysts are important and research in developing cheaper and better ones may lead to the development of fuel cells which are competitive with other sources.

XII. What Should Be the Goals of Catalyst Research?

Here there are two basic objectives we should work toward:

1. Want a catalyst made from relatively abundant elements but having the performance at least equal to that of the platinum series.

2. Design and fabricate electrodes which will give us optimum performance with the minimum of active material.

Slaughter and Gilvarry[5] have considered item one above and their results are rather startling. It is seen in Fig. 4 that the entire world production of platinum, diverted from its normal channels of consumption and used in hydrogen-oxygen fuel cells, could supply only about 5% of the total current U.S. demand for electrical power. In the case of nickel, a similar diversion would yield only about 15% of the demand for electrical energy. In principle however, the annual increase in electrical power demand could be met by fuel cells if current nickel production were increased about 35-50% and this increase allocated to the

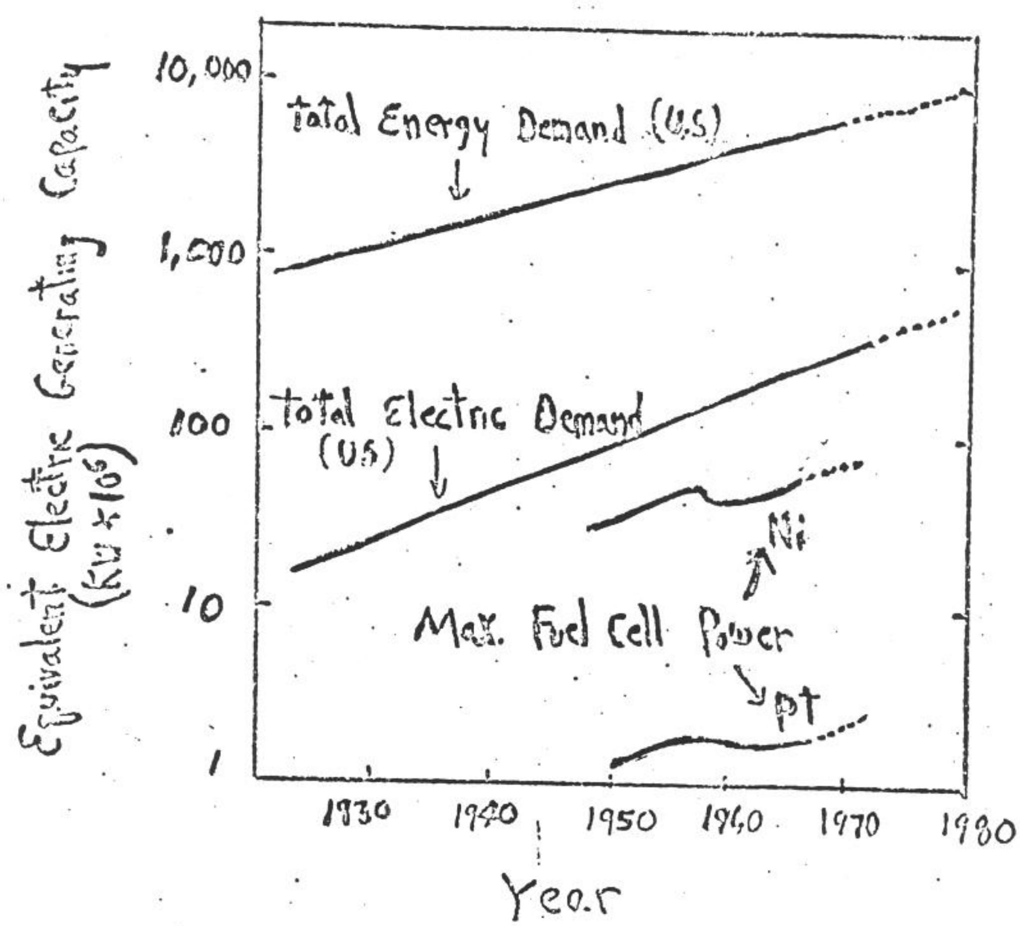


Fig. 4 Total electric power consumption for U.S. 1920-1970. Shown also are curves for maximum amount of power derivable from fuel cells, if the world's production of platinum and nickel for the years 1950-1970 were diverted completely to use as catalysis in hydrogen-oxygen cells.

construction of cells. Improved electrode fabrication techniques where small quantities of the active element, i.e., Pt or Ni, are used to achieve the same catalytic effect would also permit greater use of these elements in fuel cells. In any case, it is clear that the widespread use of fuel cells using the noble metals as catalysts cannot be expected. The implications are obvious--that is, the need for a cheap and abundant catalyst to replace the noble metals. A quote from Slaughter and Gilvarry is, "...effort should be channeled in the direction of finding better and cheaper catalysts, because only by advances in catalysis can the competitive position of the fuel cell be improved..."

XIII. What Can Research Do in Catalysis?

Very few problems in chemistry have been more thoroughly studied than the reaction of gases on surfaces; and despite this, there are few reactions types that are less understood than these. A good part of our current understanding of catalysis has been obtained by empirical approaches, and in many cases catalysts have been developed to their optimum. In many other cases, an understanding of a process will undoubtedly result in the development of improved catalysts, whether it will be the order of magnitude type improvement we desire, cannot be predicted. The question is: Are we in a position now to understand many of the common catalytic effects? The answer is: Definitely yes! The reason is that many tools and techniques have recently become available for probing the surfaces of materials that we did not have just a few years ago. Some of these are:

1. Improved ultrahigh vacuum techniques
2. UV photoemission
3. X-ray photoemission
4. LEED (Low Energy Electron Diffraction)
5. Auger spectroscopy
6. Improved mass spectrometer techniques
7. New techniques for determining adsorbate positions
8. Theoretical advances in understanding surfaces.

In fact, it is because of these techniques that the following statement could be made: "More progress has been made in the past year in understanding catalytic effects than had been made in the previous 50."[6]

IBM Research currently has considerable expertise in surface physics and material science, in Yorktown as well as in San Jose. These efforts need to be only slightly redirected and strengthened to form a group capable of understanding the key problems in catalysis, particularly as it applies to fuel cells. It should be pointed out that this is a very appropriate time for us to organize such an effort because surface studies are now one of the most popular areas of physics and chemistry. Furthermore, the fact that a surface studies group is oriented toward catalysis does not mean that its contributions to pure sicence would be diminished.

IX. What Are Some Specific Areas to Study?

The exact program such a group would initiate would of course be mainly determined by the interest of the group. However, it would be desirable if an understanding of the fuel cell processes was kept as the objective. This would mean concentrating on gases/liquids we would prefer to use in cell reactions, such as hydrogen, oxygen, and perhaps Methane or Methanol. Within this context some of the areas to be considered for study should be:

1. Gas Reaction on Metal Surfaces

This is a broad area and I would include hydrocarbons, hydrogen oxygen, and the other chalcogens. Since the main criterion for an active catalyst is weak, but rapid chemisorption of the fuel gas on the fuel electrode, the relationship between bonding and chemisorption must be considered. At the oxygen electrode, if we use basic electrolytes where peroxide and hydroxyl ions are produced, it is essential that the catalyst increase the decomposition rate of the perioxide ion. These effects must be considered and studied as a function of other parameters such as:

a. crystallographic orientation of the substrate

b. surface roughness or steps - recently Somorjai[7] and his students at Berkeley showed some interesting relationships between the size of surface steps and the rate of dehydrogeneration of ethylene.

c. effect of doping - What effect do small concentrations of impurities have on the chemisorbed species, i.e., rate, bonding, reaction?

d. interfacial effects - What is the role of the interface between the active element and the supporting substrate? It has been shown in some cases that the catalytic effect is initiated at this interface, e.g., between the Al_2O_3 support and the Pt catalyst. This type of mechanism is particularly important in the fuel cell electrode because we are usually dealing with supported porous electrodes.

e. What about catalytic effects of amorphous alloys? An area which has not been studied.

2. Non-Metal Surfaces as Catalysts

Although these are more complex than metals, it is probably here where the major breakthrough will occur. Transition metal oxide catalysts have been used extensively in the petroleum industry but little has been done with them in fuel cells. Bell Labs has recently reported on the $LaCoO_3$ and $La_{1-x}Sr_xMnO_3$

systems as replacements for platinum in CO conversion to CO_2.[8] There has been experimental evidence showing the effect of ordering of magnetic spins on the catalytic effect of these oxides. Some other areas on non-metal catalysis studies could include:

a. chalcogenides other than oxides

b. spin ordering effects, including a study of the catalytic effect as a material is cycled through a magnetic or ferroelectric transition point. Selwood[9] and his coworkers have recently reported order of magnitude changes in the parahydrogen conversion as the temperature is raised through the Neel point of an antiferromagnet. The effect of 4f as well as 3d electrons could be considered here.

c. particle size effect - perhaps there is something here we could study by photoemission.

d. photoinduced catalytic effects

e. magnetic or electric field effects

f. other

3. New Materials Studies

A part of this study should be the development of new materials as potential catalysts. This would involve an inorganic or crystal chemist working closely with surfaces physicists with the objective being to design materials which are active catalytically. Some materials we may want to further explore are:

a. transition metal chalcogenides

b. rare earth magnetically ordered materials

c. zeolites

d. carbides and nitrides

e. new alloys, i.e., Au-Cu-Al system

4. Fabrication Studies

In addition to understanding the mechanisms of gas-solid reactions, it is also vital that we are able to produce active elements on which the catalytic effect is optimized. Presently we have very little, if any, experience in the fabrication of porous electrodes for fuel cells, or even in the preparation of active catalysts. We do, however, have expertise in depositing and characterizing materials in thin layers and special shapes. A desirable arrangement would be to try to transfer some of this competence to the area of fuel cell electrode development. This would be an essential part of any research program we initiate on fuel cells or catalysis. In fact, it could be argued that any major breakthroughs in fuel cell development will be via improved electrode design and fabrication rather than in the development of new catalysts. For example, there would be obvious savings if the amount of platinum used in a H_2-O_2 fuel cell could be reduced without decreasing the catalytic effect. Likewise, savings would be realized by developing an electrode with improved lifetimes--this is in part a fabrication problem.

5. Corrosion Studies

This is just one aspect of surface science and has particular significance in any program on fuel cell development. Fortunately, similar experimental techniques are used in both corrosion and catalysis studies so little additional equipment will be needed. What are some of the problems in fuel cells where corrosion studies would be helpful?

a. electrode passification - here the surface becomes inactive for a variety of reasons. Among them are: impurities in the fuel, inability to remove undesired reaction products, e.g., carbonates when alkali electrolytes are used, recrystallization of the element, and many others.

b. high temperature cell operation - currently the operation of a cell at high temperature (~600-900°C) allows the use of gaseous hydrocarbon fuels such as CH_4, natural gas, etc., without the need for an initial reforming step. This is economically desirable but there are corrosion problems at these temperatures.

c. corrosive electrolytes and fuels - some of the reactions between the less common electrolytes and the common/exotic fuels are not known in detail. Should these systems prove promising it is essential that we understand these processes.

D. RECOMMENDATIONS

X. Personnel Requirements and Funding

In this section we suggest the composition(s) of a research group(s) we think will be necessary to carry out the above program:

Ideally the group should consist of:

2 Physicists

- 1 1/2 surface physicists
- 1/2 theorist

2 Chemists

- 1 electrochemist
- 1/2 physical organic chemist
- 1/2 cyrstal chemist or metallurgist

1 Engineer - to develop and fabricate electrochemical and other types of test facilities

We estimate the capital equipment outlay for such a group to be 35-40K. This assumes the use of some of the equipment now being used in the surface studies area. We also estimate an annual materials budget of 15-20K--a number which could be significantly reduced if the major effort is in non-noble metal materials. It is expected that considerable use will be made of the CSS facilities.

Post doctoral assistance is also worth considering (i.e., addition of an electrochemist and/or an organic, polymer chemist) since this effort has a good chance of obtaining government funds. Funding agencies who have recently let sizable contracts in this area are: NASA Lewis Research Center, NASA Marshall Space Flight Center, AFOSR and other DOD agencies, and the EPA. Also, NSF funds under the RANN program are a possibility.

XI. Conclusions and Recommendations

Our major recommendation is that an effort in catalysis related to electrochemical technology be instituted in the Research Division. This effort should be supplemented by some work on solid electrolytes, both experimental and theoretical and both organic and inorganic. Also, a capability for design, fabrication and operation of simple electrolysis cells and/or fuel cells to test the catalytic properties of the materials studied should be included. We emphasize that what is needed is essentially basic research in electrochemical catalysts--not at this stage advanced engineering work. The major fault in the fuel cell industry is that old technologies are being pushed to their rather restricted engineering limits. Our role would be to attempt new starts in the area. Supplemental to our effort should be corrosion studies related to electrochemical systems.

To conclude, research into electrochemical and fuel catalysis could lead to new fuel cell technologies needed for energy storage (electrolysis cell in a solar power economy), automotive power, emergency computer power, and peak load (supplemental) commercial power applications. Development of a cheap catalyst would remove the objections to fuel cells for total national electrical production. In such a case their high efficiency and extremely attractive environmental characteristics will offer a crucially needed technology for the nation's energy needs. For this reason, the limited chance of a breakthrough resulting from a research program is offset by the tremendous payoffs. This fact coupled with the possibility of strong IBM involvement in photovoltaics and with the untapped IBM market for standby computer power are strong arguments for implementation now of a Research Division program in this field.

References

1. Much of the material in Sections I through IV can be found in the appended bibliography.

2. T. B. Reed and R. M. Lerner, Science 182, 1299 (1973).

3. J. Longwell, unpublished presentation to Nat. Acd. Sci., Solid State Science Panel Meeting, Detroit, Oct. 22-23 (1973).

4. D. P. Gregory, Scientific American 228 13, Jan. (1973).

5. J. I. Slaughter and J. J. Gilvarry, Electrochemical Tech. 2 251 (1964).

6. P. Emmett, Presentation, Mid-winter Solid State Research Conf., Irving, Calif., Jan. 7-11 (1974).

7. G. A. Somorjai, Catalysis Reviews 7 87-120 (1972)

8. R. J. H. Voorhoeve, J. Remika, B. T. Mattias and P. Freeland, Science 177, 353 (1972); Science 180, 62 (1973).

9. J. A. Arias and P. W. Selwood, J. of Catalysis 30 255-259 (1973).

Fuel Cell Bibliography

1. Cohn, E. M., "A Survey of U.S. Activities Relating to Fuel Cells," 1972 (unpublished) (W. Grobman has a copy).

2. Proceedings of Power Sources Symposia (PSC Publications Committee, Red Bank, N.J.)

3. Austin, L. G., "Fuel Cells - A review of Government-Sponsored Research, 1950-1964," (NASA, SP-120, 1967).

4. Crowe, B. J., "Fuel Cells - A survey," (NASA, SP-5115, 1973).

5. Lueckel, W. J., et al, "Fuel Cells for Dispersed Power Generation," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-92, No. 1, page 230 (1973). Pratt and Whitney economic study of fuel cells.

6. Peekema, R. M. and Beesley, J. P., "Fuel Cells and Their Application to Computor Power Needs," IBM SDD Technical Note TN 21.575-07 (1966).

IBM CONFIDENTIAL

SECTION VI

NEAR-TERM ENERGY CONSERVATION

G. C. Feth
and
A. A. Guido

ENERGY USE IN RESEARCH COMPUTING AT THE T. J. WATSON RESEARCH CENTER

E. P. Clarke

IBM CONFIDENTIAL

SECTION VI

NEAR-TERM ENERGY CONSERVATION

G. C. Feth
and
A. A. Guido

ENERGY USE IN RESEARCH COMPUTING AT THE T. J. WATSON RESEARCH CENTER

E. P. Clarke

ENERGY TASK FORCE: NEAR-TERM ENERGY CONSERVATION

This report summarizes the work done in the month of January 1974 as part of the Energy Task Force in Research by the sub-committee with responsibility for near-term energy conservation. The major subjects are:

1. Effective use of energy at the Bldg. 801 site,
2. IBM equipment design and use to reduce energy consumption,
3. transportation for employees,
4. tips to employees.

Due to the very limited time available for this work the scope has been limited to trying to identify the potential areas for energy conservation and obtaining some quantitative measure of their importance so that the more significant areas could be singled out for more complete study and implementation.

1.0. Effective Use of Energy

Annual usage of energy at the 801 Building site is shown in Table 1. Of the energy usage at the site 65% is in the form of oil (assuming the "higher heating value" of 140,000 BTU/gal.), the other 35% as electricity. However, considering the efficiency of generation and transmission of electrical energy (here taken as 34%) then 61% of the overall fuel energy expended is for electricity. Thus, conservation of both forms of energy is important. Actually, conservation efforts have begun and there are significant results already.

Oil is used for essentially all heating, via steam for space heating and for hot water; it is also used for driving 2 turbine-compressors for the air-conditioning. Electricity is used for lighting, for mechanical equipment for the building (including one air-conditioning unit) and for lab apparatus and computers. Electrical energy usage is presented in Table 2 for 1973, and present usage is projected from the information that total electricity usage has been reduced by 14%, nearly all due to reduced usage for lighting. This data does not include any projection for usage in the "modules" which are to be constructed.

Some items worth highlighting from the statistics of Tables 1 and 2 are:

a). 50 % of present electrical usage is for building mechanical equipment;

b). 1972 and 1973 data for the 801 Bldg. are nearly equal and seem to be reasonably representative - not a pathological case;

IBM CONFIDENTIAL

TABLE 1. Annual Energy Usage at 801 Bldg. Site

A Structure	B Year	C Oil (K gals)	D Electricity (MWH)	E Oil Equivalent of Electricity* (K gals)	F Total Expenditure of Energy** Potential (MWH)	G Area (K ft^2)	H Occupants	I Total Energy/ft^2 F ÷ G (KWH/ft^2)	J Total Energy/Occupant F ÷ H (MWH)	K Area/Occupant G÷H (ft^2)
801 Bldg.	1973	1307	28,350	2030	137,000	463	1250	296	110	370
	1972	1430	28,800	2060	143,000	463	1250	309	114	370
Flewellyn House	1973	3.18	36.3	2.6	237	∿ 3	∿ 20	79	12	150
Bernen House	1973	5.12***	27.3	1.96	290	∿ 2 (incl. ∿ 0.5 office)	3	***	***	(office ∿ 167)
Modules	Projected	None	1200	86	3,530	25	130	141	27	192
Total	1973 + projected	1315	29,614	2120	141,000	492	——	——	——	——

* Equivalent oil burned at generating plant; efficiency assumes: 98% in transport of fuel to generating plant, 38% in conversion from energy potential of fuel to electricity, and 91% transmission and distribution, overall 34%. Then for columns headed E and D:

$$E \doteq D \times \frac{1}{0.34 \text{ (efficiency)}} \times \frac{1 \text{BTU}}{0.293 \text{ WH}} \times \frac{1 \text{ gals oil}}{140 \text{ KBTU}} = D \times 71.7 \frac{\text{gal oil}}{\text{MWH}}$$

** $$F \doteq (C + E) \times \frac{140 \text{ KBTU}}{1 \text{ gal oil}} \times \frac{0.293 \text{WH}}{\text{BHU}} = (C + E) \times 41 \frac{\text{KWH}}{\text{gal oil}}$$

*** Energy values, especially for oil, are inflated by recreational usage of facilities, especially by heating water for showers, estimated at 50/day in summer, 15/day in winter.

TABLE 2. Electrical Energy Usage

	Former (1973)			Present	
Use	%	GWH/yr	Δ%	GWH/yr	%
Lighting	25	7.1	-14	3.1	12.8
Bldg. Mech. Eqpt.	45	12.8	0	12.8	52.2
Lab. Eqpt and Cptr.	30	8.5	0	8.5	35.0
	100	28.4	-14	24.4	100

c). Energy usage per unit area and per occupant in the 801 Bldg. are very high compared to the Flewellyn House, respectively 3.7x and 9.2x, while area per occupant is 2.5X.

d). Projected energy use in the modules is also large compared to the Flewellyn House, respectively 1.8X and 2.2X for area/occupant 1.3X; this is due to electric heating and probably, also, the one-story vs. two-story construction.

e). The major use of energy is for heating, ventilating, and air-conditioning (HVAC), which accounts for about 2/3 of the oil equivalent.

1.1 Heating, Ventilating, and Air-Conditioning - HVAC

There appear to be numerous areas associated with HVAC where substantial energy is lost; they are treated in the following sections.

1.1.1 Chemical Fume Hoods (A. Guido)

Approximately 88% of HVAC energy is lost through the fume hood exhausts, the other 12% being lost by convection, conduction, and radiation through windows, doors, walls and roof. The fume hood exhausts run continuously, whether the hood is in use or not. Thus, there is a major energy loss which, in principle, could be avoided or recovered.

Two approaches to saving a substantial part of this energy are apparent; one is to reduce the total volume of air flow through the hoods and the second is to exchange the heat with the incoming make-up air. We examine these further.

1.1.1.1 Reduced Air Flow

The air flow through the exhaust hoods is in excess of the 20% of air flow which would normally be expelled and made up by outside fresh air; we have not been able to ascertain this excess accurately, but a rough estimate indicates that the ratio is bounded between 1.3 and 3 times. Thus, potential savings of 23 to 66% of the exhausted energy are conceivable by reducing the total air flow; a major fraction of this could be saved by reducing the air flow when the hoods are not in actual use. This corresponds to potential savings of 65 to 186 K$/yr., figuring savings as the above percentages of 88% of 1.3 M gals of fuel at 25¢/gal.

There are 150 hoods, 4 feet to 8 feet in width. State law requires a minimum air flow rate of 70 lineal feet per minute whenever the hood is in use. This flow rate is usually maintained at approximately 80 lineal feet by Safety. On average, approximately 800 to 1200 cubic feet per min. are exhausted per hood. One or more hoods may be exhausted by a single roof fan (∿ 120 fans). Safety indicates that when the hood is not actively in use, there is no State law defining the minimum flow rate required to exhaust chemical fumes.

Plant Engineering is now planning to replace the present exhaust fans (typically ≈ 3HP) with two-speed units. Whenever any one fume hood connected to an exhaust duct is actively in use, the new fan will operate at a speed sufficient to maintain a minimum of 80 lineal feet exhaust from each hood connected to the duct. However when all hoods to a duct are not in use, the fan will operate at a speed to exhaust 30% to 40% of that normally exhausted. At present, cost figures and the possible fuel oil savings have not been computed.

Assuming that all fume hoods are in use during prime shift hours (a worst case assumption) approximately 27% of the energy loss is now attributable to our normal 40 hour work week; 46% to non-prime-shift time. Thus, a fan speed reduction of 60% would result in a 38% reduction of the energy loss. It would also reduce the energy to drive the fans, as sized later. It seems to us that a more dramatic savings could be achieved by any one of the following mechanisms:

1. Pressure transducers in the side wall of exhaust ducts and control of a louvred shroud assembly to be installed on existing roof structures. Thus, outside air is used to compensate for the reduced duct flow due to the closure of any hood.

2. Pressure transducets in the duct and speed control of DC motors or variable-speed AC motors would save some fan KWH as well as heat losses (replace exisiting units). This also seems logical since the fans are to be replaced anyway.

3. Pressure-transducer control of SCR's for speed (frequency) control of present fans would save some fan KWH as well as heat losses.

A review of the literature reveals a myriad of companies manufacturing a wide range of pressure transducers capable of withstanding hostile environments. Typically such companies as:

Amphenol Connector Div./Bunker Ramo
Fairchild Industrial Products
Hamilton Standard
Honeywell
Amtek

Supply a wide range of pressure transducers. Companies such as the Inland Motor Div. of Kollmorgen Corp., Cleveland Machine Controls, Inc. and Roticon Corp. supply complete SCR-controlled motors in the speed and horsepower range for our application. Some of these companies provide complete systems.

1.1.1.2 Heat Exchange Between Exhaust and Make-up Air

We have surveyed the literature investigating heat pipes as a viable method of recovering energy losses due to the fume hoods. (The heat pipe employs a fluid which vaporizes at the temperature of the warm-end and carries the heat to the cool-end, where it condenses; it returns to the warm end through a wick.) Using heat pipes one is not limited to saving the heat by not expelling the air, but can recover heat from the expelled air as well.

The Q-Dot Corp. of Texas has installed heat-pipe bundles in several hospitals throughout the country. Recovery rate of 62% has been achieved. However George Grover of Q-Dot indicated that the fresh-air inlet and exhaust ducts must be adjacent to each other (a few feet at most) to economically achieve a satisfactory recovery rate. In this building (801) the fresh air inlet and exhaust ducts are drastically separated: fresh-air inlets in the Japanese-garden level and hood exhausts on the roof. In addition, State regulations indicate a minimum of 50 feet must separate fresh air ducts from those carrying chemical fumes. Thus, heat pipes are not suitable for this location for saving heat from fume hoods. However, when the hood-exhaust volume is reduced, the remaining air expelled to allow 20% makeup of fresh air could use heat pipes for energy recovery. Of course, heat pumps could also be used rather than heat pipes to exchange this energy and could operate over a greater distance between incoming and outgoing air.

1.1.1.3 Recommendation

1. Reduction of energy loss by way of the fume hoods should be implemented. Reduction of total air volume appears to be most practical for this building, and can reaonsably be accomplished by order of magnitude reduction of the air flow when the hoods are closed. A control system

using pressure sensors or hood position sensors to control fan speed (2-speed) appears to be within the state of the art and justified by the potential savings (∿ 100K$/yr). Implementation can proceed on a fan by fan basis, with minimum simultaneouus shutdown and installation labor involved. There may be some need for dynamically rebalancing the HVAC system when hoods are opened and shut. This action can serve as a model for other labs with similar circumstances. (We recommend below, engaging the servies of a consultant with professional expertise in HVAC; his services might well be employed in implementing this recommendation.)

2. Further savings by heat exchanging between makeup air and expelled air should be sized for the case where hood exhuast has been reduced, and a suitable energy-recovery installation, such as heat pipes or heat pump, should be made, if warranted.

1.1.2 Reheat

A crude sizing of the energy required for reheat is that about 1/3 of the oil used for air conditioning is used for reheat. The air-conditioning system in the 801 Bldg. first passes incoming air over a chilled-water heat exchanger to cool it below the dew point and condense excess water vapor in order to control the relative humidity; the air temperature is then too low to circulate it directly into offices and labs, and it is reheated by passing it over steam-heated exchangers to provide the desired temperature control. In principle, the same refrigerant fluid used to cool the incoming air below the dew point (in the evaporator) can be used to reheat it (in the condenser - which would require somewhat larger heat-transfer contact area) to any temperature up to somewhat larger than its original temperature, thus eliminating additional reheat energy. Other sources of reheat energy are also possible, e.g., computer-room waste heat, solar-energy, or outside air. Implementation of this saving would require some modifications to the air-conditioning system, primarily additional heat exchangers and a change of the coolant for the incoming air from chilled water to the basic refrigerant.

1.1.2.1 Recommendation

A consultant with expertise in HVAC should be engaged to assess the savings possible from the use of waste heat for reheat, and if warranted, to design a retrofit system, which should be implemented.

1.1.3 Reduce Heat Gain in Summer

Heat gain in the summer can be reduced by spraying water on the roof of the building. Since the roof is already insulated the heat gain may be modest, but this is a relatively simple action. In addition, sun shades or louvres could be used to reduce heat gain by radiation in the large expanses of windows; a practical and architecturally acceptable proposal would be quite challenging, probably.

1.1.3.1. Recommendation

1. Spraying water on the roof in summer to reduce heat gains should be assessed and implemented.

2. The HVAC consultant should be engaged to size the savings possible by sun shades or louvres, and if warranted, an architect should be engaged to devise a means of implemention which would be practical and architecturally attractive.

1.1.4 Waste Heat and Heat Loss

1.1.4.1 Computer Waste Heat

Heat from the computer room is removed from the building in both summer and winter. A portion of it is removed by chilled water, but most of the equipment is air-cooled. The air from the computer room is warm and humidity-controlled and could be used for space heating elsewhere in the building, preferably nearby.

1.1.4.2 Hot Water

Hot water for use in the building is presently heated from steam in a single location. A rough sizing of the energy usage, assuming 10% of the water usage in the building is hot water (at 100°F raised from 60°F), shows 2% of the oil consumption or 6 K$/yr. In the summer the water could be heated at least partially from the low-temperature side of the steam turbine, which ultimately rejects heat to the cooling tower at 85 to 95°F. Additional possibilities include using hot flue gases or solar energy collectors. Some additional equipment would be required for each of these possibilities, and the relatively small potential savings make the priority fairly low.

1.1.4.3 Radiation Losses

Radiators on the perimeter of the building are placed in front of windows where they radiate directly to the outside. A crude sizing of the wasted heat, assuming half the 12% heat loss of the bulding, 15% of the heat transfer by radiation, and half the radiator radiating to the outside, indicates about 0.5% of the heating energy is lost or about 1.5K$/year. A substantial fraction of this could be saved by using a relective surface on the window side of the radiator, either on its grid-like housing or in metallized Mylar adhered to the window. While the potential savings is small, the installation expense should likewise be minimal. (Conductive losses from the radiator structure to the metal columns, with which they are in contact, may well be comparable and could be reduced by interposing an insulating spacer.)

1.1.4.4. Thermopane

Retrofitting with thermopane or double glazing has been sized by others, the conclusion being that it is definitely impractical.

1.1.4.5. Reduced Air Flow

At present, the nominal air flow changes the room air 4 times per hour, which at 20% makeup air implies 0.8 fresh air change/hr.; the minimum required is 0.075. Thus, in unoccupied offices and perhaps some labs airflow could allowably be reduced by an order of magnitude. To implement this requires movable (2-position) dampers on the air vents to the rooms. Some dynamic rebalancing of the HVAC system may also be desirable. Some of the potential savings are already being sought by reducing the airflow to the whole building during off-hours. Probably some reduction of airflow below the present nominal could be suitable even during occupancy; of course, tobacco smoke and laboratory odors would present some lower limit from a desirability point of view.

Consistent with the rough sizing of possible savings made in Section 1.1.1, reduction of the flow rate to half as much (at 20% makeup or alternatively 10% makeup at the same flow rate) could allow further fuel savings of approximately 30% of '73 oil cost for the lower figure or 9% with the larger figure, for overall savings of 53% to 75% on the total oil cost, i.e., 150 K$/yr to 213 K$/yr savings. These potential additional savings of 27 to 85 K$/yr. might justify the costs of modifying the vent system with a 2-position damper at the vents, controlled from the light switch, for instance.

1.1.4.6 Recommendations

The HVAC consultant should assess the following areas to determine what savings are realizable in practice and what investments are needed to obtain them; if warranted they should be implemented:

1). Use of air from the computer room during the heating season to heat nearby parts of the bulding.

2). Heating the building hot-water supply from waste heat, e.g., hot flue gases, the low-temperature side of the steam turbine or cooling-tower water in summer, or solar energy collectors on the roof.

3). Reduction of radiation losses from perimeter radiators directly to the outside by using reflective shields on the window side of the radiators, and in addition, thermally insulation spacers between the radiators and the metal columns which they contact.

4). Reduced air flow from the ventilating system when rooms are unoccupied (requiring a 2-position controllable damper system for the vents, controlled, for example, from the light switch) and, perhaps, reduction of the nominal air flow.

1.1.5 Heating of Modular Building

The modules are planned for electric heating. Electric heating is inefficient of fuel because of the losses in conversion of heat to mechanical work and subsequent conversion to electricity and its transmission and distribution; nominal efficiency for a large fossil-fueled thermal plant and system is 34%. We could much more efficiently burn oil on premises and heat by steam or hot water. Present boiler facilities (whose capacity is set by the higher steam requirements for summer) should be adequate. The modules would have to be modified for the revised heating system. Assuming 20% of input energy is for heating, electric heat costs 9 K$/yr., oil $1.7 K$/yr. (at 90% efficiency for oil and current prices for both); estimated saving is 7.3 K$/yr with oil.

1.1.5.1 Recommendation

In the interest of overall energy conservation, conversion of the heating system in the modules to an oil-fired steam or hot-water system should be assessed, designed, and implemented, unless prohibitively expensive.

1.1.6 Energy Monitoring and Automatic Control System

Experience suggests that with improved information and attention to control 10-15% of the energy for cooling can be saved. We estimate that a 5% saving in the 801 Bldg. corresponds to about 60 K$/yr. at current prices and current high energy usage. (Note that a successful program of energy reduction as recommended above will reduce these costs of air conditioning substantially.) A System 7 internally rents for about 16 K$/yr; net savings would be about 44 K$/yr. However, about 3 man years of programming effort is needed to personalize the existing programs for use in this building for monitoring. Break even time then, is about 3 years. Automatic control would require further investment in control equipment and programming.

The FMAC system, now operational at the East Fishkill facility, uses a System 7 to monitor the total energy consumption. At present, the system does not control the chillers, boilers, etc.; plans to do so are being formulated.

It would be desirable to have an energy-system-management capability; it would require an intermediate-term effort to accomplish it. First, it should be ascertained whether the savings from other recommendations above will be so large as to remove the economic justification and reduce the potential additional energy savings to a negligible amount.

1.1.7 Tradeoff Assessment: Energy, Space, $

Almost every attempt to save energy involves a variety of tradeoffs between energy sources, heat exchangers, fans and pumps, heat pumps, capital costs and operational costs. With heat exchangers the temperature differentials, pressure differentials, space requirements, flow rates, and costs can be traded off. Well-balanced tradeoffs are the work of experts in this field, an attribute which we lack.

1.1.7.1 Recommendation

A professional HVAC consultant should be engaged to quantify the tradeoffs and areas for improvement in the HVAC-related items identified above.

1.2 Lighting

Before conservation efforts were undertaken lighting accounted for about 25% of the electricity usage in the 801 Bldg.; it is now estimated at about 13%. Possibilities for further reduction are outlined below.

1.2.1 Desk Lamps

Individual desk lamps can be used rather than full office or lab lighting for desk-work or terminal-work activities. At best, this can only be practical for part of the staff and part of the time. For a sizing of the potential savings, if a nominally 30W desk lamp replaces office lighting of 4 fixtures x 2 lamps/fixture x nominally 40W, but actually 52 volt amps per lamp, on an average of 20% of the time and lighted area, then an overall savings of 2 to 3% in electrical energy would be realized. Probably the 20% figure is optimistic, 10% being more realistic, and the savings potential being more like 1%.

Characteristics of several models of appropriate Dazor lamps are listed in Table 3. These lamps have 3-wire cords and are OSHA approved. They are available in a variety of forms: with either fluorescent or incandescernt lamps, in several colors, and with desk lamp, screw on,

TABLE 3. Dazor Desk Lamps

Model Type			Wattage	Price
Gooseneck		1000-3C	2 tubes x 15W fluorescent	$ 27.00
Floating arm	24"	2324-3C	2 tubes x 15W fluorescent	$ 43.86
Floating arm	18"	318A3-C	3 tubes x 15W fluorescent	$ 51.51

or clamp-on bases. Estimating the annual savings for two cases: a) maximum likely and b) minimum worthwhile - yields:

a) $450W \times \frac{8\ hr.}{day} \times 300\ \frac{days}{yr.} \times 3.5\ \frac{¢}{KWH} \cong \$40/yr.$

b) $300W \times \frac{4\ hr.}{day} \times 240\ \frac{days}{yr.} \times 3.5\ \frac{¢}{KWH} \cong \$\ 10/yr.$

one sees that a 1 to 5 yr payout exists at present electric rates. However, it is probably not worthwhile unless the desk lamp will replace office or lab lighting about 1/2 or 1/3 of the time, minimum.

1.2.1.1 Recommendation

1). The possibility of using desk lamps to replace office or laboratory illumination should be publicized; exercise of this option should be on a completely voluntary basis.

2). A sample or samples should be available for inspection in a realistic environment so people can evaluate the acceptability for their purposes.

3). Ordering procedure should be simplified so that an ordinary PR with manager's sign-off is adequate, with the understanding that the lamp should replace office lighting at least 1/2 of the time or lab lighting 1/3 of the time, nominally. (The present approval procedure, designed to limit the purchase of desk lamps, should be discontinued.)

4). Quantity purchasing should be undertaken to achieve quantity discount, if available.

1.2.2 Presence Sensor

It has been suggested that a "presence sensor" be used to turn off room lighting when unoccupied. Further suggestions include extending this to control the HVAC, as discussed in Section 1.1.4.6, to reduce air flow to unoccupied rooms. Further, combination with an individual paging system has been suggested. In addition to the attractive features of these suggestions there are some unfavorable and possibly objectionable aspects. Cost is probably not justified for lighting alone (especially where desk lamps are used), though HVAC control could make it pay, perhaps. Some inflexibility in lighting and HVAC control might be objectionable; also excess switching of the lamps may result, reducing their life, unless a time delay of perhaps several minutes is used before turn off. If an ultrasonic presence sensor were to be used, as in some burgular alarms, individuals might feel that continual exposure to ultrasonic waves is unattractive. With respect to individual paging, this represents an additional cost increment, and besides, sometimes one doesn't want to be found. The most practical aspect appears to be control of HVAC; advantages beyond combining HVAC control with the light switch seem minimal. Actually, there is a fair amount of volunteer effort contributed to presence sensing and extinguishing unused lighting in neighbors' offices.

1.2.3 Higher Efficiency Lighting

There are higher efficiency lights than fluorescents, but due to their intensity and color they are not used for office lighting (with low ceilings). Higher frequency operation of fluorescent lights is also possible: 360 Hz, 400 Hz and 840 Hz are indicated. The same lamp can be used, giving more light per tube; it uses a smaller ballast and losses in the ballast are reduced to 1/2 to 1/3 the losses at 60 Hz. However, this does not seem to be a major increase in overall light efficiency, i.e., lumens/watt. In addition, it requires installation of new ballasts, a frequency converter, and may produce some audio noise.

1.2.4 Skylights, Light-Pipes

It has been suggested that skylights or a modern technology improvement in the form of light pipes could be used to reduce lighting energy. However, these appear less practical than individual desk lamps in light availability and cost.

1.3 Building Mechanical Equipment

Building mechanical equipment now represents about 50% of the electrical load in the 801 Bldg. or about 30% of the total oil equivalent. Most of this equipment is for the HVAC system. The load divides roughly equally between fans, pumps, and chiller. Reduced hood exhaust and reduced lighting energy should reduce air-conditioning requirements and result in across the board reduction of building-mechanical-equipment loads. In using equipments at less than capacity rating one may have some choice in fulfilling loads from various pieces of equipment. The most efficient equipment should be used to minimize energy; this requires knowing the characteristics of the equipment and, perhaps, deciding between alternate energy sources, e.g., the oil-fired steam turbine or the electric chiller for air conditioning. Such information could be programmed into the monitoring system of section 1.1.6. In addition, if substantial changes in air flow are achieved fans with smaller ratings may be desirable so as to handle the reduced load efficiently, i.e., without the larger losses of oversized equipment.

1.3.1 Recommendation

If substantial reduction of the air flow from the bulding is achieved resulting in significantly lower air conditioning load, the configuration of HVAC equipment and the capacities of building mechanical equipment should be reviewed to assess the optimum system for the new conditions. The HVAC consultant or Plant Engineering should carry out this assessment.

1.4 Laboratory Equipment

Laboratory electrical equipment, including computers, now represents about 35% of the electrical load. Computers are treated separately in a report by E. P. Clarke, Jr., who finds that they represent 17% of the electrical load. Thus, lab equipment itself represents about 18%. It is not obvious that any single action can be taken to reduce power usage without hampering the actual work of the laborattory. However, equipment is often energized when it is not obviously in use. It seems that a greater awareness to the importance of energy conservation would be desirable. For instance, commonly a high-quality vacuum system including forepump, diffusion pump, and refrigerator has a rating of about 3KW, an oscilloscope 0.2 KW.

1.4.1 Recommendation

A survey of the energy usage and potential energy savings in laboratory equipment should be made by managers throughout the laboratory, including CSS. Individual professionals and technicians should be encouraged to think through a rationale for optimum practical use of their equipment and to carry through on reasonable approaches to energy conservation.

1.5 Total Energy

One of the advantages of a total energy system is that in the winter waste heat can be used for space heating and better overall efficiency may be achievable. Other advantages may accrue in terms of reliability, quantity cost break, etc. However, in a period of energy crisis it may not be possible to change energy sources freely. Moreover, cooling, pollution, safety, and a single energy source may present some formidable problems. Since the major energy requirement here is in the summer the winter savings on waste heat are less important. A total energy system, then, might begin to appear attractive if overall energy consumption could be reduced from the total oil equivalent of 3435 gallons (projected for Bldg. 801 site with modules) to of the order of the 1315 gallons 1973 consumption, i.e., only 40%. It seems that only the most stringent energy conservation would be able to achieve this, and in addition, it would assume energy conversion efficiency at this site's power level to be of the order of 34%. The idea of a total energy system, then, seems marginal.

Short of a total energy system, partial independence may be increasingly important, especially if blackouts and brownouts increase in severity and frequency. Present standby generating equipment consists of a 185 KVA, propane-fueled, internal-combustion engine generator. This is used for emergency lighting of corridors and exits, equipment for one boiler and its fans and pumps, the public-address system, and gas-detector alarms. (Fume hood fans are not on this system, and the possibility of fumes entering the building during blackouts does exist.) Its loading is considered to be close to rating. Average electric power usage in the 801 Bldg. is about 3200 KW overall and probably about 4500 during working hours; peak feeder capacity is 9000 KW. Thus, the standby equipment capacity is a small fraction of normal demand. Moreover, propane seems to be in even scarcer supply than other fuels.

1.6 Non-Territorial Office

One way to increase the efficient usage of HVAC energy is for more people to occupy a given building. An experiment was undertaken in Burlington in a laboratory and office environment where individual offices and labs were not delineated by partitions and where individuals did not have assigned compartments and furniture. While I do not have at hand a reference which reports results I understand that the experiment was considered successful in achieving about a doubling of density of occupants, but did not work for a 2.5 x increase. This approach is in use in some IBM sales offices (I believe in WTC) where salesmen spend much of their time away from the office anyway.

It is conceivable that at least for certain types of activities at the 801 Bldg. site additional density of occupants or time sharing of facilities could be achieved by a non-territorial approach.

1.6.1 Recommendation

Experience and applicability of a non-territorial approach for the 801 Bldg. site should be evaluated by Personnel with consultation of the managements of both administrative and technical areas to ascertain the appropriateness of such an approach. This information should be available before any further expansions are undertaken and, in fact, in case of worsening energy crisis.

2.0 IBM Equipment Design and Usage to Conserve Energy

2.1 Low-Drop Diode

Schottky-barrier diodes (SBD) in the output rectifiers of low voltage power supplies can increase their efficiency substantially. PN junction rectifiers normally have drops up to 1.4 volts at high current whereas SBD's may have drop in the 0.5 to 0.7 volt range. Assuming a savings of 0.5 volt with SBD's could save about 14% of the losses in supplies which provide about 25% of the power in FS systems; this amounts to about 3.4% of the power of the system (not including air-conditioning.) The SBD technology is available in E. Fishkill, but packaging technology is not. The present plan calls for using lower drop PN junction rectifiers (nominally 0.8 to 0.9 volts); if this is successful the additional energy savings of SBD's alone would not warrant a strong recommendation for their development as a product (though they have additional advantages.)

2.1.1 Recommendation

Rectifying diodes with small forward voltage drops should be used in low-voltage power supplies.

2.2 Computer Dormancy

De-energizing computers to save energy and/or peak power is possible, in principle. In some older equipment, notably S360/M67 and 91 CPU's this is impractical, since card failures present simply starting up the machines.

2.2.1 Recommendation

Product test requirements for all IBM equipment should include reliable startup after shutdown, probably for several thousand shutdown-restart cycles.

2.3 Partial Powering During Brownouts

Local powering can be achieved during blackouts or brownouts; energy storage and conversion is the main problem. Recent developments in flywheels appear promising for high density energy storage and should be investigated for practical application. FS products are to be designed with a dc bus suitable for battery powering for short intervals for orderly shutdown. Flywheels may be suitable for longer term storage, perhaps several hours or a day.

2.3.1 Recommendation

A program to evaluate the energy storage potential of flywheels for IBM equipment should be undertaken by SPD Power Products.

2.4 Optimum Availability of Computing Power in a Multi-Machine Environment

The power used by data processing equipment can be an important fraction of the total power requirement of an installation. Full capability is probably not needed during off-peak hours, weekends, etc., in many facilities. Users may save energy and operator time without much degradation of capability during these times by suitable re-structuring of the system during such times. For terminal systems automatic activation of parts of the system on demand is conceivable. Models of computing systems for availability, delays, throughput, costs and energy usage could be devised.

2.4.1 Recommendation

Reduced operation of computing systems in a multi-machine environment should be modelled for energy conservation, availability, and costs and made available by DP as a product.

3.0 Transportation

3.1 Tie Line

To some extent travel can be replaced by long distance communication, and telephone communication is certainly less costly in energy than transportation between locations. Thus, we should facilitate communication, even for extended periods of time for working sessions or small internal conferences, by up-grading interlocation telephone communication. The present tie-line facility is frequently blocked during substantial portions of the day, and lacks in performance and reliability in other respects as well. In addition, alternate numbers or message centers should be available at all facilities.

3.1.1 Recommendation

The present inter-location telephone communication facility should be upgraded in availability, function, and performance. In addition, alternate numbers or message centers should be available at all facilities.

3.2 Employee Transportation to and from Work

3.2.1 Car-Pooling Aids - Recommendation

1. For those who are interested in car-pooling, a data base on residences, schedules, and existing groupings should be established and maintained in order to continue to encourage car pooling. The IBM Club should provide this service, perhaps with voluntary help for setting it up and maintaining it.

2. In addition, data on individuals' travel plans to and from the airports in this area, to IBM locations within driving distance, and to forthcoming conferences within driving distance should be accepted in a data base designed to facilitate car-pooling to the airports and to such conferences on a voluntary basis.

Such a service could well fall within the purview of Office Services/Reservations, and in fact, might have the overall car-pooling data base integrated with it.

3.2.2 Buses

A number of suggestions have been received concerning transportation other than in private automobiles. Some of these are repeated below.

1. Regular transportation by bus between major residential centers and the 801 site

2. Shuttle service between IBM locations to carry commuting employees as well as mail. Thus, an employee would need to drive only to the nearest IBM location and thence be transported to his assigned location.

3. Shuttle service between public transportation centers and the 801 site; especially, transportation from the Croton-Harmon or Ossining train stations, Grand Central Station, and/or Mt. Kisco train station could reduce substantially the present amount of automobile mileage.

Other suggestions have been received concerning incentives to encourage group transportation.

1. IBM could supply small buses for employees who would in turn bus fellow employees to and from work.

2. IBM could supply venture capital and computer time to help establish a free-enterprise "Dial a Ride" business which would seek to provide flexible transportation for employees, yet make such business, which cannot be self-supporting only on a rush-hour basis, economically viable by providing all-day service, also to the general public.

These and other suggestions have some element of merit, but may also have other ramifications and drawbacks. None of them are obviously, unquestionably practical. To some extent their importance will depend on the severity of the shortage of gasoline, though some might be desirable even if there were no shortage.

I understand that some local company has arranged with a gasoline company to have employees cars provided with gasoline while parked in the employee parking lot during working hours. With the present scarcity of gasoline and long waiting times this could be an outstandingly attractive opportunity.

3.2.2.1 Recommendation

Further study of alternative means of providing transportation for employees should be undertaken by the Personnel Department in order that a strategy will be ready for implementation should the situation become critical, e.g., in the event of gasoline rationing. Implementation of the data bases recommended in 3.2.1 would provide helpful statistical input to such a study.

IBM should negotiate with a gasoline vendor to provide gasoline to employees' cars in the IBM parking lot on a voluntary, employee-billed basis.

4.0 Tips to Employees

A number of items of information which could be useful to employees for energy conservation in their homes have been suggested; several have been studied by J. Ziegler and are planned for publication in the Research News. It has been suggested that a formula to calculate the benefits of increasing one's home insulation be worked out and published in easy-to-use form. Further, it has been suggested that IBM might provide interest-free loans for home-insulation improvements. The fall-out shelter program would provide a precedent for such a plan, but the home-insulation program would have immediate and continuing value.

4.1 Recommendation

A plan to provide interest-free loans to IBM employees who decide to undertake a home-insulation improvement should be considered by the appropriate corporate department and implemented, if warranted.

George C. Feth

George C. Feth

A. Guido

A. Guido

GCF:cmh

ENERGY TASK FORCE: NEAR-TERM ENERGY CONSERVATION

EXECUTIVE SUMMARY

Heating, Ventilating, and Air-Conditioning

The potential for energy savings in the 801 Bldg. HVAC system appears very large - of the order of 50 to 75% - by our rough sizings. Moreover, the pay-back period of the additional equipment appears to be but a few years, even at present energy prices, which are likely to increase. Consequently, it is recommended that a consultant with professional expertise in HVAC systems and building design be engaged to thoroughly assess the present system and to design optimum modifications to realize the potential energy savings. Specific areas to be treated are as follows:

1. Modification of chemical hood exhaust systems to operate at full flow only when the hood is in use (potential savings: 23% - 66% of exhausted energy or 65 to 185 K$/yr on oil plus about 5% of electrical energy or 50 K$/yr).

2. Reduced air flow by installing 2-position dampers on air vent inlets to rooms (operated, e.g., from the light switch) to reduce air flow when unoccupied; also, reducing the percentage of make up air and providing heat transfer between the building's incoming fresh air supply and expelled air (overall potential savings, together with item 1 above of 50 to 75% of total oil cost, or 150 to 210 K$/yr).

3. Use of waste heat for reheat in the air-conditioning system (potential savings: about 1/3 of energy for air-conditioning)

4. Reduction of heat gain in summer by spraying water on the roof.

5. Reduction of radiated heat gain in summer by sun shades or louvres.

6. Use of waste heat from the computer room for space heating nearby rooms in winter.

7. Heating the building hot-water supply from waste heat, e.g., hot flue gases, the low-temperature side of the steam turbine or the cooling-tower water in summer, or solar energy collectors on the roof (potential savings: 2% of oil or 6 K$/yr.)

8. Reduction of radiation losses from perimeter radiators directly to the outside by using reflecting shields on the window side of the radiators (potential savings: 0.5% of heating fuel or 1.5 K$/yr).

There is some interrelationship among the items above, so that savings on some will reduce potential savings on others, but will increase the potential percentage savings of still others (on the smaller base).

Other recommendations are as follows:

9. If major energy savings are not achieved in the above areas, then a computerized energy-management-system capability for monitoring should be undertaken jointly by Plant Engineering and Lab. Automation as an intermediate-term effort (potential savings at 5% of cooling energy: 60 K$/yr).

10. In the interest of overall energy conservation (34% efficiency from fuel to delivered electricity), conversion of the heating system in the modular building from electrical to an oil-fired steam or hot water system should be assessed, designed and implemented, unless prohibitively expensive.

Lighting

Energy for lighting has already been reduced substantially to only about 10 to 15% of the electricity usage. Some further reduction by 1 to 3% of total electricity usage could be achieved by use of individual desk lamps. It is recommended that such lamps should be made available on a voluntary basis; publicity, available demonstration units, simplified approval procedure, and quantity purchasing should be instituted.

Building Mechanical Equipment

This equipment now represents about 50% of the electrical load in the building. If major changes are achieved in the items above then this area should be reviewed for optimum capacities and configurations for this equipment.

Laboratory Equipment

Laboratory equipment now represents about 35% of the electrical load, and is about equally split between computer equipment (treated separately in a report by E. P. Clarke, Jr.) and lab apparatus. It is recommended that energy usage and potential energy savings should be assessed by a survey made by managers throughout the laboratory, and a program to increase awareness and encourage conservation should be implemented.

Non-Territorial Office

A non-territorial office approach has been experimented with and is in use in certain locations; it has potential for higher density of occupants and time sharing of facilities, thereby reducing the overall facilities which must be powered. It is recommended that experience with this approach be evaluated and the applicability for Research be assessed by Personnel in consultation with the managements of both administrative and technical areas.

IBM Equipment Design and Usage to Conserve Energy

Recommendations are as follows:

1. Rectifying diodes with small forward voltage drops should be used in low-voltage power supplies.

2. Product test requirements for all IBM equipment should include reliable startup after shutdown, probably for several thousand shutdown-restart cycles.

3. A program to evaluate the practical energy storage potential of flywheels and conversion to electricity for standby powering of IBM equipment should be undertaken by SPD Power Products.

4. Reduced operation of computing systems in a multimachine environment should be modelled for energy conservation, availability, and costs and made available by DP as a product.

Transportation

Recommendations are as follows:

1. The present interlocation telephone communication facilities should be up-graded in availability, function, and performance to better facilitate by replacing transportation communication for extended periods of time suitable for working sessions and small internal meetings or conferences. In addition, alternate numbers or message centers should be available at all facilities so that all phones are "covered".

2. For those who are interested in car pooling a data base on residences, schedules, and existing groupings should be established and maintained.

3. Data on individual travel plans to and from the airports in this area, to IBM locations within driving distance, and to forthcoming conferences within driving distance should be accepted in a data base designed to facilitate car-pooling to such on a voluntary basis. Such data base services could well fall within the purview of Office Services/Reservations.

4. The Purchasing Department should negotiate with a gasoline vendor to deliver gasoline to employees' cars in the employee parking lot on a voluntary, employee-billed basis.

IBM CONFIDENTIAL

5. Further study of alternative means of providing transportation for employees should be undertaken by the Personnel Dept. in order that a strategy will be ready for implementation should the situation become critical, e.g., gasoline rationing.

Aids to Employees

A number of items of information useful to employees for energy conservation are planned for publication in the Research News.

It is recommended that a plan to provide interest free loans to IBM employees who decide to undertake a home-insulation improvement program should be considered by the appropriate corporate department and implemented, if warranted.

G. C. Feth

G. C. Feth

A. Guido

A. Guido

GCF:AG:cmh

IBM CONFIDENTIAL

Energy Use in Research Computing

At the

T. J. Watson Research Center

by

E. P. Clarke

Computing Systems Department
IBM Thomas J. Watson Reserach Center
Yorktown Heights, New York 10598

Energy Use in Research Computing

At the

T. J. Watson Research Center

This study was initiated in the Computing Systems Department as a result of a request for a plan to conserve energy during the present crisis. This paper will also be a part of the work done for the Research Energy Task Force chaired by Dr. R. L. Garwin.

Two aspects of computer usage in Research will be considered - energy expenditure and dollar costs. The first, energy, is the critical component at this time since we may come to the point where no amount of dollars will allow us to get the requisite power to operate our computers. The second, dollar costs, is the component of computing systems operation with which management is traditionally most concerned, particularly in the cost of providing complete service at all times. This paper will attempt to pin point the energy usage and direct management to alternate modes of operation which will provide the maximum service for the least energy expenditure. At the same time, should the energy crunch not materialize to the point of mandatory curbs on computing service, the study of dollar costs may indicate ways to provide suitable service at less cost than we now incur.

Energy Considerations

When we first began to study the computing energy requirements at the T. J. Watson Research Center, we made an attempt to measure the energy usage at each device directly using voltmeters and clamp-on ammeters and guessing at power factors. The accuracy of this approach to measuring energy usage is open to many questions, so it was abandoned in favor of using the System Power Profile Program[1] which is available under APL on the 'BUSTER' system at the Poughkeepsie IDS Laboratory. A system power profile developed for each configuration by this program has been proved to be accurate tc approximately 5% in most cases except for System/7 configurations where a worst case figure generally inflates the values of power required.

Table I is developed from the SPP data and estimates made on required power for Heating, Ventilation, Air Conditioning and Lighting (HVACL). In the column marked 'SYSTEM' the item called 'SUPPORT' is an accumulated value for all key punches, sorters, reproducing punches, interpreters and miscellaneous terminals such as 1050's, 3275's, Tektronix 40XX, etc.. The column marked 'KW/SYS' lists the kilowatts required for each system when powered on in its full configuration.

The columns in Table I marked 'EQUIVALENT KW/HVACL' and 'NON-OPER KW' require some explanation since direct measurement again is virtually impossible in the configuration of A/C used in the Research Computing Center. The following estimates were used:

1.) HVACL requires an additional 75% of the base electrical energy used computing system operation(2);

2.) during "power off" status a computing system environment requires 20% of the "power on" HVACL energy to maintain safe temperature and humidity conditions(3);

3.) most support equipment not in a computer environment requires 50% of the base energy for HVACL when operational and 20% of the HVACL energy when powered off(3);

4.) 60% of EQUIVALENT KW for HVACL is provided by direct burning of fuel oil to provide steam for heating and turbine A/C units. The remaining 40% is direct electrical energy used for lighting, fans, pumps and controls(4).

The above estimates, taken from the cited sources, are year averages. Obviously, at any one point in time, one may be using a peak amount of energy to cool and dehumidify the computer environment, such as during a 95°F, 55% R.H. day in summer. Then again in the winter only a small amount of power is used to heat make up air and control humidity.

In general, the NON OPERATIONAL or 'powered off' requirement of a system as shown in Table I is made up of that power required to maintain suitable environnmental conditions except for that shown opposite the large 360 systems - the 360/91 and 360/67. These systems do not respond very well to powering down the CPU. Therefore, the 'power off' conditions for these two systems includes CPU power as well as HVACL power. This 'NON OP' energy is provided 60/40 by oil/electricity except as noted.

SYSTEM	KW/SYS (KW)	EQUIVALENT KW/HVAC&L (KW)	TOTAL OPER. KW (KW	NON-OPER. KW (KW)	OP — NON OP Δ (KW)
370/145	61.4	46.1	107.5	9.2	- 98.3
370/158	132.9	99.7	232.6	19.9	-212.7
360/67	69.5	52.1	121.6	39.7	- 81.9
360/91	180.6	135.5	316.1	171.4	-144.7
360/20	4.3	3.2	7.5	0.6	- 6.9
(10) S/7	54.7	41.0	95.7	8.2	- 87.5
(8) 1130	23.4	17.5	40.9	3.5	- 37.4
(2) 1800	24.3	18.2	42.5	3.6	- 38.9
360/30	17.6	13.2	30.8	2.6	- 28.2
(238) 2741	26.7	13.3	40.0	2.7	- 37.3
SUPPORT	41.0	20.5	60.5	4.1	- 56.4
370/168 (est.)	107.6	80.7	188.3	16.1	-172.2

TABLE I. RESEARCH COMPUTING AND COMPUTING SUPPORT EQUIPMENT POWER REQUIREMENTS - January, 1974

Table II is designed to compare the computing energy usage with the total energy used at Yorktown for an average semi-month period. From this data it may be seen that computing requires some 23% of 1973's total demand for electrical energy in the Research Center. To maintain the environment of the computing equipment safely requires only 2% of that same demand. Thus, there is a leverage of 1 to 5. It is possible to effect a 2% change in total average demand with a 10% change in computer power on time.

A rough approximation of the fuel oil requirement for HVACL can be made from the following:

$$\text{GALLONS} = \frac{(\text{KwH})\,(3410\text{BTU/KwH})}{(70\%\ \text{EFF.})\,(150\text{KBTU/GALLON})}$$

This evaluates to 3100 gallons of fuel oil for our average semi-month to supply 60% of computing HVACL energy. To supply the environment of the computers in a non-operational mode would use about 600 gallons semi-monthly. These figures are approximately 5% and 1%, respectively, of the total semi-monthly average fuel oil consumption of 60K gallons in the Research Center.

This completes the section on energy considerations by roughly sizing the energy consumption for computing and fairly accurately sizing the relative magnitudes of the power sinks at each individual computing system. Certain recommendations for conservation, beyond the obvious one of complete shutdown, will be made in the final section of this paper

Computing Cost Considerations

As stated above, in order to make rational decisions on how to provide a complete computing service, management of a computing center should have at the least a good first approximation to the cost of providing that service. In most foreseeable circumstances base service of 176 hours per month (22 eight hour shifts) will always be provided, so one must look to the displaceable or curtailable service - the additional use on off-shifts and weekends - for means of saving dollars or energy by limiting or combining service.

Total time/period..	365 Hrs.
Total Yorktown Usage/period..	1,180,000 KwH
'Power on' time (all systems except 2741's and support)....	360 Hrs.
Energy consumption (@568.7Kw)..............................	205,000 KwH
% of total energy consumption..............................	17%
. Electrical portion (40%) of HVACL energy for systems.......	64000 KwH 5%

(40% of'power on' HVACL EQUIV) X (360 Hours)
+ (40% of NON OPER) X (5 Hours)

. 'Power on' time (2741's and support).......................	150 Hrs.
Energy consumption (@67.7 Kw)..............................	10,000 KwH
% of total energy consumption..............................	0.8%
. Electrical portion of 'power on' HVACL energy for 2741's and support..	2600 KwH 0.2%

(40% of 'power on' HVACL EQUIV power) X (150 Hours)
+(40% of NON OPER power) X (215 Hours)

ABLE II. ELECTRICAL USAGE - AVERAGE SEMI-MONTH PERIOD - 1973

Table III has been generated to show the present displaceable additional use cost for the five major systems in the Research Center. The major systems have been considered alone for two reasons. Initially, the major systems are the largest power and dollar sinks. Then there is a second effect that curtailing service on most of these systems also curtails some use of other interconnected systems such as S/7's, 1130's and 1800's as well as use of terminals and support equipment.

In Table III the base cost/hour for the first 176 hours of use each month is put down for comparison purposes only. All management, program support and other generally fixed costs have been omitted. A typical weekend - Saturday, 8:00 A.M. to Monday 8:00 A.M. - using the four major systems to provide batch APL, VM and TSS might cost a total of some $7,000, if all systems are in operation. Keeping a VM 370/158 up from 2400 hours to 0800 hours daily for one or two users would and does cost $290/day in displaceable costs. Clearly close study of this usage cost, both in dollars and energy, must be made.

SYSTEM	BASE COST (176 Hrs.) $/Hr.	AVE.ADDL. USE COST $/Hr.	OPERATOR COST $/Hr.	OPNL.ENER. COST $/Hr.	NON-OP ENER. COST $/Hr.	DISPLACEABLE ENER.COST $/Hr.	ADDL. USE DISPL.COST $/Hr.
360/91	$360.46	$32.59	$14.75	$9.48	$5.14	$4.34	$51.68
370/158	$182.54	$15.09	$14.75	$6.98	$0.57	$6.41	$36.25
370/145	$ 33.15	$ 7.36	$14.75	$3.23	$0.28	$2.95	$25.06
360/67	$206.58	$19.17	$14.75	$3.65	$1.19	$2.46	$36.38
360/30	$ 42.94	$ 2.94	$14.75	$0.92	$0.08	$0.84	$18.53
370/168 (est)	$212.34	$17.55	$14.75	$5.65	$0.48	$5.17	$37.47

TABLE III. RESEARCH MAJOR COMPUTING SYSTEMS - DISPLACEABLE ADDITIONAL USE COSTS

Conservation

In any conservation plan for computer usage one must have not only a good feel for the dollar cost and energy expenditure as described above, but one must fully understand the services provided and more important the way in which each user makes use of those services. It is not enough to say a service is too expensive in energy or dollars, therefore, we will curtail or eliminate that system or service. One must understand the reasons for the usage patterns we observe for all types of batch and interactive services and also understand the impact of reducing those services on the ability of each scientist, mathematician or programmer to carry out his research program. Only at that point can we carry out a sensible conservation program.

The outline of studies and actions to be taken which follows is a first attempt to point out the areas of computer operation where conservation can be applied and to point out the kinds of information we need to carry out a conservation program without arbitrarily wrecking research programs. This outline is divided into five parts - environment, hardware, computer usage, software and miscellaneous. The latter is not an afterthought, but is a list of two longer range programs, which might be carried out and which have already had some consideration.

The environment is always a prime candidate for savings since we have historically wanted our computer rooms to be show pieces - well lit, cool, etc.. However, one must proceed with care since safety of personnel and the well being of the computer is also a prime consideration. The program outlined is designed toward two ends - determining the limits of safe operation of the environment and eliminating those computing systems which are most sensitive.

In order to be able to power down a computing system one must have some assurance that the system will work when it is powered on again. In the past here in the computing center two things have prevented this operational revival - so called "morning sickness" and the fact that much of the power sequencing did not work properly. In both cases the services of a Field Engineer was required to restore service. The Engineering Services Group will remedy the power sequencing problem and study the problem of system failures to make recommendations as to what systems or devices may be powered off without difficutly.

Computer usage patterns require much more study and evaluation. Obviously, in any conservation program we would want to cut back on systems which are lightly loaded - particularly on third shifts and weekends where additional operators are required. However, this is a difficult problem to evaluate. We, at this time, do not have a clear picture of who is using the systems at what time. Even more important, we do not fully understand the motivation of the user to come in on third shift, or Sunday, or whenever. Is the user motivated by technical reasons of system loading or response or is he motivated by personal preference? We must at least make an attempt to answer these questions before we embark on or are forced to embark on a computer service cut back.

Software is, or should be, a fertile area for providing the means to cut back on hardware operation. Combining systems, expanding systems improving response all are ways toward reducing hardware use. This is included in this outline even through it may be more of a long range program due to its technical difficulty.

Other longer range programs might include a system (S/7?) to "wake up" or "power on" a VM/158 upon demand from a remote user. Another program might be directed toward computer control of the environment. These are not afterthoughts, but have been given some serious thought and certainly will be given more thought in the future.

Conservation Planning

The basic plans and actions for conservation of computer usage, computing energy and computing money will fall into three parts:

1.) Information gathering by implementing those experiments noted under Environment in the outline and usage studies as noted under Computer Usage in the outline;

2.) prudent conservation by implementing the plans outlined under Hardware and looking for other ways and means of saving without crippling service;

3.) mandatory plans for cut back of 10%, 20%, 30% etc of service must be provided based on information gathered in 1.) above.

Clearly this work must be initiated as soon as possible and completed with dispatch. If the fuel and energy crunch continues as it has for the past few months, the warm summer months may provide us with a serious problem

APPENDIX A

Conservation Outline - Studies and Action

I. Environment

A. Lighting in Computing Center
1. Partial zone control implemented 12/73
   Savings approximately 20 Kw out of 58 Kw
2. Need finer zone control
   Light only immediate working areas
   Possible additional 20 kw savings average
3. Operator indoctrination - energy conservation
   Emphasis on prompt elimination of unneeded light

B. Temperature control in Computing Center
1. Experiment with higher average temperatures
2. Eliminate/Replace 360/67 and 360/91
   These systems are less tolerant of high T
   360/67 due to be replaced by 370/158 - 3/74
   *Study and proposal for early replacement of 360/91

C. Humidity control in Computing Center
1. Very careful experiment with wider range
   Problems - low R.H. in winter
   - high R.H. in summer

D. Emergency Plans
1. Upgrade environmental maintenance plan
   -for disaster loss of power
   -for mandatory power shut down
   -for mandatory power cut back

II. Hardware

A. Power Controls
1. Insure all power controls operate properly
   Test for ability to power off and on
   -complete system
   -partial system
2. Study effects, if any, or prolonged shut down
   Questions

- will system or device revive w/o trouble?
- if trouble, what is cause, result, fix?
- what is effect on environment control?

B. Power Management
   1. Operator indoctrination
      Program to instruct operators on what, how, when
      - to power off system
      - to power off devices
   2. Management program
      Scheduling power off to meet
      - prudent savings mode of operation
      - mandatory 10%, 20% or 30% savings mode

III. Computer Usage

A. Identification of usage patterns
   1. Interactive users of VM, TSS, APL
      Timing
      - Connect time
      - CPU time
      - Time of day, day of week
      Resources used
      - CPU/Core
      - I/O, Tape, Disc, Drum, Card, Print
      - Communications
      Function being performed
      - editing
      - compiling
      - executing
      - other

   2. Batch users of VM, TSS, OS
      Timing
      - Time of day, day of week
      - CPU time used
      Resources used
      - CPU/Core
      - I/O required
      - RJE

   3. Laboratory automation users VM, APL
      Timing
      - Time of day, day of week
      - CPU and connect times
      Resources used

B. Separation of usage times
   1. Class of user by time of use
      Prime shift
      2nd & 3rd shifts
      Weekends
   2. Resources used by time of use
   3. Cost/User by time of use

C. Motivation for use pattern
   1. Weekends
   2. 2nd, 3rd shifts

IV. Software

A. Combinations of operating systems
   1. Run OS under VM on one system
      -to provide for low use odd time requirements
   2. APL under VM

B. Expand operating systems function VM, TSS
   1. Goal to gather more users under fewer systems
   2. Possible eventual elimination of TSS, APL as separate systems

V. Miscellaneous

A. Wake up system
   1. Hardware/software systems
      -to wake up main op. sys. on demand
      -to control power up/down on main hardware
   2. Hands off system
      -scheduler
      -controller

B. Environmental Monitor & Control System
   1. Monitor
      -Power input and use
      -temperature, humidity
   2. Control
      -by feed back to control center
      -by automatic system

SYSTEM POWER PROFILE

IBM RESEARCH 370/158 ONE
2/4/74 12:0

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	3272- 2	
32	3277- 2	
1	1052- 7	
1	2150- 1	
39	2260- 1	
2	2305- 2	
1	2314- 1	INCLUDES 9 DISKS
1	2312- A1	
2	2313- A1	
1	2314- A1	DOES NOT INCLUDE DISKS
1	2402- 3	
4	2420- 7	
1	2501- B2	
1	2540- 1	
2	2701- 1	
2	2703- 1	
1	2803- 1	
1	2803- 2	
1	2821- 6	
1	2835- 2	
4	2848- 3	
1	3158- K	
2	3211- 1	
1	3213- 1	
1	3215- 1	
9	3330- 1	
2	3333- 1	
1	3705- F3	
2	3811- 1	
1	7412- 1	

SYSTEM DATA

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =417 AMPS
POWER FACTOR...........................=0.885
REAL POWER.............................=132.892 KW
REACTIVE POWER.........................=¯69.863 KVARS
APPARENT POWER.........................=150.137 KVA
HEAT DISSIPATION PER HOUR..............=453.559 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW ÷ SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

CONFIDENTIAL

SYSTEM POWER PROFILE

IBM RESEARCH 370/158 TWO
2/4/74 12:6

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	3158- J	
1	2835- 2	
2	2305- 2	
2	3830- 1	
7	3330- 1	
1	2821- 1	
1	2540- 1	
1	2803- 2	
5	2420- 7	
1	3213- 1	
1	7412- 1	

SYSTEM DATA

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =216.2 AMPS
POWER FACTOR..........................=0.899
REAL POWER............................=69.97 KW
REACTIVE POWER........................=¯34.064 KVARS
APPARENT POWER........................=77.821 KVA
HEAT DISSIPATION PER HOUR.............=238.807 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW : SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

THANK YOU

SYSTEM POWER PROFILE

IBM RESEARCH 370/145
2/4/74 12:21

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	1403- N1	
1	1403- 2	
1	2305- 2	
3	2401- 3	
1	2540- 1	
2	2701- 1	
1	2703- 1	
1	2803- 1	
1	2821- 5	
1	2835- 2	
1	2955- 1	
1	3046- 1	PWR INCLUDED IN ATTACHED UNIT
1	3145- I	
1	3215- 1	
4	3330- 1	
1	3345- 1	INCLUDES 3046 POWER
1	3345- 2	INCLUDES 3046 POWER
1	3830- 1	

SYSTEM DATA

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =220.5 AMPS
POWER FACTOR...........................=0.861
REAL POWER.............................=68.389 KW
REACTIVE POWER.........................=¯40.316 KVARS
APPARENT POWER.........................=79.388 KVA
HEAT DISSIPATION PER HOUR..............=233.412 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW ÷ SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

THANK YOU

SYSTEM POWER PROFILE

IBM RESEARCH 370/168
3/4/74 13:15

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	3168- K	INCLUDES M/G SET PWR.
1	2870- 1	
2	2880- 2	
1	3066- 2	PWR INCLUDED IN ATTACHED UNIT
1	3067- 2	PWR INCLUDED IN ATTACHED UNIT
1	3333- 1	
3	3330- 1	
2	3811- 1	
2	3211- 1	

SYSTEM DATA WITH 3165/3168 MG SET(S)

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =327.2 AMPS
POWER FACTOR...........................=0.914
REAL POWER.............................=107.595 KW
REACTIVE POWER.........................=¯47.899 KVARS
APPARENT POWER.........................=117.775 KVA
HEAT DISSIPATION PER HOUR..............=367.221 KBTU/HR

SYSTEM DATA LESS 3165/3168 MG SET(S)

AVG. STEADY STATE RMS CURRENT PER LINE =138.1 AMPS
POWER FACTOR...........................=0.892
REAL POWER.............................=44.33 KW
REACTIVE POWER.........................=¯22.511 KVARS
APPARENT POWER.........................=49.718 KVA
AIR HEAT DISSIPATION PER HOUR..........=187.35 KBTU/HR
WATER HEAT DISSIPATION PER HOUR........=132.615 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW : SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.
2) THE SYSTEM DATA SHOWN LESS THE MG SET, DOES NOT INCLUDE THE PRIMARY LINE POWER REQUIRED FOR THE 400 HZ INPUT TO THE PDU. THE HEAT DISSIPATION HOWEVER, DOES INCLUDE THE 400 HZ POWER AT THE PDU. HEAT SHOWN IS FOR THE 3165/3168 WITH MAX. FEATURES.
3) SYSTEM DATA SHOWN IS FOR A 3168 THAT DOES NOT HAVE 60 HZ. SERVICE TO FRAME 08 AND HAS A 3067-2 WITH A SERIAL OF 61000 AND ABOVE. FOR 3168'S WITH SIMILAR SERVICE,BUT WITH 3067-2 SERIAL BELOW 61000, ADD 1.7 TO THE KVA SHOWN WITH (AND WITHOUT) THE MG FOR EACH SUCH MACHINE.

THANK YOU

SYSTEM POWER PROFILE

IBM RESEARCH 360/91
2/4/74 12:32

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
1	1052- 7	
3	1403- N1	
1	1443- N1	
2	1627- 1	
1	2150- 1	
3	2314- 1	INCLUDES 9 DISKS
2	2314- A1	DOES NOT INCLUDE DISKS
4	2313- A1	
2	2312- A1	
2	2301- 1	
1	2922- 3	
1	2922- 2	
1	2922- 1	
8	2401- 6	
2	2401- 3	
1	2501- B2	
3	2540- 1	
3	2701- 1	
1	2703- 1	
9	2740- 1	
2	2803- 2	
1	2820- 1	
2	2821- 1	
1	2821- 3	
1	2840- 1	
1	2860- 3	
1	2870- 1	
1	3211- 1	
1	3811- 1	
1	ADDED OEM UNIT	

SYSTEM DATA

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =567 AMPS
POWER FACTOR..........................=0.864
REAL POWER............................=176.183 KW
REACTIVE POWER........................=¯102.885 KVARS
APPARENT POWER........................=204.024 KVA
HEAT DISSIPATION PER HOUR..............=601.313 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW ÷ SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

THANK YOU

SYSTEM POWER PROFILE

IBM RESEARCH 360/67 SIMPLEX TSS
2/4/74 12:14

60 HERTZ SYSTEM

EQUIPMENT LIST

QTY	UNIT-MOD	REMARKS
2	1052- 7	
2	1403- N1	
1	2067- 1	
17	2260- 1	
2	2301- 1	
1	2312- A1	
3	2313- A1	
2	2314- A1	DOES NOT INCLUDE DISKS
1	2314- B1	DOES NOT INCLUDE DISKS
1	2314- 1	INCLUDES 9 DISKS
1	2319- B1	
2	2319- B2	
4	2365- 2	
4	2401- 3	
1	2403- 2	
1	2540- 1	
1	2701- 1	
1	2703- 1	
1	2820- 1	
1	2821- 1	
1	2821- 2	
2	2848- 3	
1	2860- 3	
1	2870- 1	
1	3272- 2	
24	3277- 1	

SYSTEM DATA

SYSTEM VOLTAGE (LINE TO LINE)..........=208 VOLTS
AVG. STEADY STATE RMS CURRENT PER LINE =212.8 AMPS
POWER FACTOR...........................=0.907
REAL POWER.............................=69.501 KW
REACTIVE POWER.........................=¯32.211 KVARS
APPARENT POWER.........................=76.603 KVA
HEAT DISSIPATION PER HOUR..............=237.208 KBTU/HR

SYSTEM NOTES

1) POWER FACTOR = SYSTEM KW ÷ SYSTEM KVA; IT IS NOT EQUAL TO COSINE PHASE SHIFT ANGLE FOR MOST WAVEFORMS. IT IS EQUAL TO COSINE PHASE SHIFT ONLY FOR BALANCED SINUSOIDAL CURRENTS.

THANK YOU

References

(1) TR 27.103, Laird, J. A., APL Power Profile Programming System.
TR 27.102, Laird, J. A., APL Power Profile Terminal Users Guide.

(2) Energy Crisis Assessment - Initial Report of the IBM Energy Council, 9/17/73. Page 21, Figure 4, average additional HVACL power for all installed IBM equipment 1972 - 1975 is approximately 75% of equipment power.

(3) Rough calculations made from computer room data and data on heating, cooling and lighting in ASHRAE guide, and various IBM Installation Planning Manuals.

(4) Estimates by Research Plant Engineering

SECTION VII

WORK-AT-HOME

D. L. Reich
J. S. Smart
M. G. Smith
C. J. Stephenson

APPENDIX

Remote Computer Terminal

C. J. Stephenson

IBM CONFIDENTIAL

WORK-AT-HOME SUBGROUP REPORT
RESEARCH ENERGY TASK FORCE

David Reich
Sam Smart
Merlin Smith
Chris Stephenson

SUMMARY

The Work-at-Home group has concluded that the net energy savings for working at home are small compared to the total energy expended, and small compared to alternate energy saving measures, if significant data processing facilities are used to enhance the effectiveness of working at home. Such facilities are also quite expensive. Working at home as an alternative to building new facilities, for example, time-sharing office facilities, saves more energy than other work-at-home variations considered. Perhaps as data processing costs are reduced, it may eventually become attractive economically, particularly in considering Research (801-type) building costs.

Curtailing the work week for the entire Research Center, to 3-day or 4-day weeks, is also quite limited due to the extensive power used in non-working hours. The estimates are 15% savings for a 3-day week and 7% savings for a 4-day week.

It is technologically possible to increase the work-at-home population, through a wide variety of communications, remote control, and data processing (and data) facilities--particularly if we alter our work habits and types of research projects. The availability of these technologies as broad-based commercial products may be a long time coming, especially if strong economic or energy conservation pressures (not yet obvious) don't exist. Most to the point here: We don't see large energy savings possible without dramatic changes in our way of life.

The study showed that Research employees live an average distance of 14 miles from the Research Center. The average number of employees per car is 1.23. Considering energies for transportation; extended car life; heating, lighting and cooling costs at work and at home; manufacturing costs for cars, terminals and computers; and other operational energies, the study shows the following savings and losses for each person working at home, in kwh/person/day:

Transportation	46 kwh
Research Center	110
Add. Comp. Ctr. Fac.	(-) 60
Home	(-) 50
Terminals	(-) 5
Net	41 kwh/person/day

Applying this (with some variations) to an example of 270 persons (working a split work week to time-share facilities at work):

Transportation	1340	kwh/yr
Research Center	3500	"
Comp./Comm. Fac.	(-) 1900	"
Home	(-) 840	"
Terminals	(-) 650	"
Net	1.6 M kwh/yr	

With more effective heating/cooling systems at work (or heating the new modules by oil instead of electricity), this difference would be reduced to about 0.2 M kwh/yr. Eliminating the computing facilities (and terminals) would increase the savings to about 5 M kwh/year. Comparing these to other energy expenditures and savings, the numbers look as follows:

	Oil Equiv. M kwh/yr
Research Center 1972	168
Estimated 1974	134
Saving (against 1974 proj.)	
3-day week - Res. Center	22
- Driving	7
4-day week - Res. Center	10
- Driving	3.5
Work-at-Home Illustration	0.2 - 5

Working at home for significant periods is not as effective for most people, particularly with the facilities immediately available today. We estimate that a fair (only) terminal for programmers is about 3 times as expensive as the better facilities at work. Better facilities are not yet available to the home because of bandwidth limitations--and such facilities would cost significantly more.

There may be circumstances in which gasoline, in particular, is in extremely short supply, so some suggestions are made for improving communication and selecting terminal facilities. Some ideas are also advanced as variations on the work-at-home theme. At least two projects in the Computer Sciences Department, Digital Switching and Speech Filing, could be relevant to such needs.

INTRODUCTION

The Work-at-Home group has examined the major energy consuming items in a work-at-home situation. Included are determinations of average commuting distances and car pooling habits for Research Center employees. A simple model is given for evaluating the net savings (or losses), which includes the various energies of transportation, equipment operation and manufacture and heating, cooling, and air-conditioning, both for home and offices. An illustration of saving for 270 people working part time at work is shown, and comparisons are made with total energies expended and alternate energy conservation measures.

Suggestions for improving both communication and terminal facilities are made. Some variations in the work-at-home context are also presented. Finally, an estimate for energy savings for 3-day and 4-day work weeks are shown.

COMMUTING STATISTICS

In order to determine the transportation energy saved by working at home, some quantitative information about the commuting behavior of Research Center employees was required. Little such information was available at the start of the study, and some simple statistical surveys were carried out to provide reasonable estimates of the quantities needed.

An approximate distribution of commuting distances was obtained from a computer printout of 1260 addresses provided by John Riddick. This list included addresses of about 1160 permanent Research Center personnel, with the remainder being made up of post-doctoral, part-time, and SPD employees. In the first stage of the survey each employee was assumed to have a commuting distance equal to the road distance from the Research Center to his post office. This approximation appeared to work well for longer distances but gave some obviously artificial peaks and valleys in the distribution for distances under 15 miles. These irregularities were smoothed by breaking the three largest groups (Yorktown Heights, Peekskill, and Mahopac) into two or three subgroups and assigning these subgroups driving distances suggested by a corresponding subdivision of the post office delivery area. The results are shown in Table 1. The mean one-way commuting distance for the 1260 people was found to be 13.9 miles.

TABLE 1

Distribution of One-Way Commuting Distance for Research Center Employees

Range (mi.)	Number	Range (mi.)	Number
0-4	75	28-32	44
4-8	357	32-36	41
8-12	337	36-40	40
12-16	180	40-44	23
16-20	69	44-48	6
20-24	37	>48	14
24-28	36		

The energy used in transportation depends not only on the commuting distance but on the extent of car pooling. To get some information on this point, the cars entering the back road of the parking lot were surveyed between 7:45 and 8:45 a.m. on January 7 and between 8:45 and 9:10 on January 17. Of the total of 391 cars observed, 320, 57, 10, and 4 carried one, two, three, and four persons, respectively. The average number of persons per car was 1.23. On two days during this period, counts of the cars in the employees' parking lot in the middle of the afternoon showed about 865 cars both times. At 1.23 persons per car, this accounts for about 1060 people. If we assume that a total of about 60 persons walked, bicycled, or were driven to work, then 140, or 11 per cent, were absent because of vacation, illness, personal business or travel. These last figures are only educated guesses, but they seem plausible and we shall use them because there is apparently no easy way to get firm information about them. The results of our survey and estimates are summarized in Table 2. It should be noted that the table is compiled for the hypothetical

TABLE 2

Commuting Transportation for Research Center Employees

Method	Number of Cars	Number of Persons	Percent of Persons
Car (1 person)	794	794	63.0
Car (2 persons)	143	286	22.7
Car (3 persons)	25	75	6.0
Car (4 persons)	10	40	3.2
Car (driven by someone else)	55*	55	4.4
Walking, bicycling	0	10	0.8

*Not parked here

day when all 1260 persons report to work. On the average, only 89 per cent of each group will be at the Research Center on any given day.

WORK-AT-HOME MODEL

This section describes a simple model for calculating the energy trade-offs involved in a work-at-home regime. This model is, of course, intended to apply specifically to the Research Center but we have tried to make it sufficiently general so that it could be applied to other installations (IBM or otherwise) in areas without mass transportation.

Consider an establishment with N employees, each of whom comes to work by one of the six methods listed in Table 2. Then

$$N = n_1 + 2n_2 + 3n_3 + 4n_4 + n_d + n_o$$

where n_k is the number of cars carrying k persons, n_d is the number of people who are driven by someone else, and n_o is the number who do not require a car. We assume that a fraction f_1 of these employees are assigned to work at home D days per year.

Transportation. In estimating the transportation energy saved, we must first recognize that most of the savings will come from the reduction in number of trips made by people who normally drive to work by themselves. If a person in a car pool is assigned to work at home, there will be no saving in trips unless the remnant of his car pool can recombine with someone else. For $f_1 < 1/2$, such recombinations seem rather unlikely, especially for conditions similar to those now existing at the Research Center. Moreover, the person assigned to work at home will still have to make some trips to the Research Center. Presumably most of the people who are driven to work represent two round trips per day but they probably live much closer than the average commuting distance of 14 miles. In addition, we may generally expect this group to be small in number. We estimate that transportation energy savings can be almost entirely accounted for by the $n_1 f_1$ fewer trips each day made by one-person cars.

An employee who lives d miles from work and gets μ miles per gallon will then require $2d/\mu$ gallons of gasoline for each day's driving to work. To estimate the total saving, we need the mean value of d/μ for the whole group but since that information is not available, we assume that it can be approximated satisfactorily by $\bar{d}/\bar{\mu}$. The total average saving per day is then

$$E_g = \frac{2\bar{d}}{\bar{\mu}} n_1 f_1 f_2 \text{ gal/day} = 73.2 \frac{\bar{d}}{\bar{\mu}} n_1 f_1 f_2 \text{ kwh/day}$$

The fraction $f_2 < 1$ is introduced to account for vacation, sick leave, etc. That is, if the employee would not be coming to the Research Center under the existing arrangement, nothing is saved by his not coming under the work-at-home plan. The combustion energy of a gallon of gasoline is taken as 125,000 Btu = 36.6 kwh.

The reduction in mileage also means an increased lifetime for the automobiles used, so that we also consider a possible saving in energy required for manufacturing. Suppose that under our present operating conditions, an employee's car lasts y_1 years. Then the group of $n_1 f_1$ persons purchase on the average $n_1 f_1 / y_1$ new cars per year. Under the work-at-home plan, cars will last for a somewhat longer period, $y_2(D)$ years, where y_2 is an increasing function of D. Then the energy saving in auto manufacturing is

$$E_c = \frac{37{,}000}{D} n_1 f_1 \left(\frac{1}{y_1} - \frac{1}{y_2(D)} \right) \text{ kwh/day}$$

The figure of 37,000 kwh manufacturing energy for a car was taken from Berry and Fels (1973). The values of y_1 and y_2 can only be estimated as rough averages over the population of car owners involved, and depend on the kinds of cars purchased, uses other than commuting, etc. Some people may respond to the work-at-home plan by reducing the number of cars in the family and driving the remaining cars for longer distances in the same time period. This contribution is even harder to determine accurately than the first one, but rather crude estimates suggest that it would be considerably smaller, and we have neglected it.

The divisor D appears in the equation for E_c because our general procedure is to express the energy changes as average savings (or losses) per day. Then values for longer periods can be obtained simply by multiplying by the appropriate factors, i.e., D for a year, D/50 for a week, etc.

Research Center. The energy saved because employees spend less time at the Research Center can be expressed simply as

$$E_R = N\, f_1 f_2\, [E_{Rl} + E_{Re} + E_{Rh} - E_{Rc}] \text{ kwh/day}$$

where E_{Rl}, E_{Re}, and E_{Rh} are respectively the savings per person per day for lighting, equipment, and heating/air conditioning, and E_{Rc} is a loss term introduced to account for increased computer usage. Power consumption in electrical kilowatt hours (lighting and equipment, in this case) should be multiplied by 10/3 to give the fossil fuel equivalent.

Home. The increased energy usage in the home can also be expressed as a sum of terms,

$$E_h = N\, f_1 f_2\, [E_{hl} + E_{he} + E_{ha} + E_{hh}] \text{ kwh/day}$$

where the heating and air conditioning contributions have been separated to allow for the fact that the power sources may be separate.

Terminals. Working at home will necessarily require some increase in electronic equipment, particularly terminals. We try here to estimate the energy required to manufacture this extra equipment. If we use the Berry-Fels figure for a 3400 pound auto as a starting point, assume that a terminal weighs 100 pounds and is composed of materials which require four times as much energy per pound as those in the car, the result is 4400 kwh per terminal, a figure which can probably be regarded as an upper limit. If we further assume that each terminal is replaced every five years, the energy loss equation becomes

$$E_t = \frac{880\, N_t}{D} \text{ kwh/day}$$

Here N_t is the net increase in number of terminals required. N_t, of course, increases with the number of people working at home but not necessarily in any simple fashion and is best estimated specifically for each case.

The net energy saved per day is then given by

$$\Delta E = E_g + E_c + E_R - E_h - E_t$$

NUMERICAL ESTIMATES

This section gives some numerical estimates of the change in energy usage that might be expected in shifting from the present mode of operation at the Research Center into a partial work-at-home regime. The appropriate values of the parameters appearing in the energy equations are then

$$N = 1260,\quad n_1 = 794,\quad f_2 = 0.89,\quad \bar{d} = 14 \text{ mi.}$$

Also, we assume $\bar{\mu}$ = 14 mi/gal.

In order to establish the magnitude of the savings (or losses) expected, we give some typical results for the various energy terms as obtained from sample calculations carried out with the following ranges for the other parameters:

- D : 100-200 days/year (2-4 days/week)
- y_1: 5-8 years
- y_2: 7-10 years
- E_R: 40-80 kwh/person/day
- E_h: 30-70 kwh/person/day
- N_t: (0.7-1.0) Nf_1

The considerations that led to the selection of the above ranges are discussed in the next section.

All five energy terms appearing in ΔE may be expected to be approximately linear in f_1 for $f_1 < 0.5$. With this assumption, estimates of the energy changes per person per day can be obtained simply by dividing all terms by Nf_1. Typical values are shown in Table 3.

The left hand column of Table 3 corresponds to the current situation with $n_1/N = 0.63$. The other two columns show how the transportation savings would diminish with increased car pooling.

TABLE 3

Typical Values for Energy Saved by Working at Home (kwh/person/day)

	n_1N		
	0.63	0.50	0.60
Transportation			
Gasoline	41	33	26
Manufacturing	5	4	3
Research Center			
Heating, Cooling, Air-cond.	110	110	110
Computer use	-60	-60	-60
Home			
Power	-50	-50	-50
Manufacturing (terminals)	- 5	- 5	- 5
Net	41	32	24
Estimated Range	20-80		

The figures for the Research Center and home are considerably more uncertain than those for transportation. By taking reasonable best and worst case conditions, we estimate that the actual savings under present conditions would lie in the range 20-80 kwh/person/day.

The results of Table 3 can be strictly accepted only if all forms of energy are equally available (or equally scarce). If, as is likely to happen, this is not the case, then some weighting factors must be introduced. In this connection, it should be noted that gasoline energy is always saved, while the net changes in electricity and fuel oil usage might be either plus or minus, depending on the exact balance between home and Research Center consumption.

Work-At-Home Illustration

An illustration is chosen based upon an assumed work-at-home population of 270 people out of the approximately 1,250 people at the Research Center. These 270 people work two days at home and three days at the Research Center. Two principal cases were considered. In one case the 270 persons work Monday, Tuesday and Wednesday at the Research Center, and the offices portions of the building which they occupy are collected together and sealed off (70% energy-wise) from Wednesday evening until Monday morning. The second case presumes two staggered, but overlapping working periods at the Research Center where 135 persons work Monday through Wednesday and 135 people work Wednesday through Friday. (The overlap day is mainly for meetings, library use, etc. to reduce the need for individual office space.) Such a time sharing of offices reduces the size of the installation to be operated, or the necessity for additional office-type extensions. The choice of 135 (and 270) permits a more direct comparison with the energy anticipated in the planned additional modules which also are expected to house about 135 persons.

The two cases differ mainly in the central computing facility and in the heating, lighting, and air conditioning "at work." The calculation shown below is for the staggered working hours case. The heating/cooling/lighting saved is due to saving the additional construction area for 135 people. Note that no laboratory operations are considered, and the energy wastes due to the fume hood exhausts have been removed from the considerations.

Energy Reductions	kwh/yr (oil equiv.)	
Driving -	Gas Savings	1110 k
-	Reduced Car Wear	230 k
-	10% fewer second cars	< 100 k
Terminals at work		
-	20 fewer	< 40 k
-	power saved	52 k
Reduced Heating/Cooling/Lighting at work, 150 sq ft/person, 135 people		3450 k
170 kwh/sq ft/yr oil equiv. (more efficient structures would require about 100 kwh/sq ft/yr oil equiv.)		
	TOTAL SAVED	5 M kwh

Energy Increases	kwh/yr (oil equiv.)		
Terminals at home			
–	270 terminals	<	280 k
–	operating		370 k
Lighting Increment			160 k
Heating/Cooling Increment			680 k
25% require extra 100 sq. ft. 25% require extra energy 50% no change			
Increased Comm. Equip. (incl. oper.) at work (modems +)			300 k
Increased Computer Facilities at work, extra space		<	1600 k
1/5 of a 168, operation + mtg (no heat recovery)			
	TOTAL LOST		3.4 M kwh

Yearly Net Savings

Reductions	5 M kwh	
Increases	3.4 M kwh	
	1.6 M kwh	(oil equiv.)

This energy saving would be substantially less if a more efficient, even typical office structure was considered, or if the added modules were heated with oil instead of electricity. This is also comparable to the case where 270 people work at home simultaneously. The net saving would then be about 0.2 M kwh. On the other hand, an additional savings of up to 0.8 M kwh of computer heat could be recovered.

Comparing these savings with the 1972 energy consumed by the Research Center,

150 M kwh (oil equiv.)

the savings are of the order of 1 percent. Clearly, many alternatives and conservation measures are saving or could save comparable or larger amounts of energy.

We should note that if we work at home <u>without</u> terminals, probably less effectively, we would save not only the above facilities but possibly some existing computer facilities. Under these circumstances we would have

Reductions	4.5-6 kwh
Increases	< 1 kwh
Net Savings	3.5-5 kwh (oil equiv.)

Work-At-Home Illustration - Supplementary Information

Plausibility of 270 working at home - Some sampling and certain intuitions suggest the plausibility of these numbers of people working at home 2 days a week:

Computer Sciences	178 x 70%	=	120 people
Math Sciences	60 x 90%	=	50
Applied Research	273 x 20%	=	50
Computing Systems	98 x 30%	=	30
General Sciences	25 x 40%	=	10
Physical Sciences	184 x 20%	=	40
			300 people

Administrative groups were not estimated. We have not attempted to make a serious evaluation of the effectiveness of this population working at home. However, some people believe the numbers could be much higher and others feel this number would seriously handicap the performance of the Research operation. (Paul Green's input was valuable here.)

The selection of 270 people clearly places a rather low upper limit on the total savings possible. However, even at 540 the savings would be small, 2 to 4% of the 1972 energy.

Plausibility of working two days per week at home - A small sampling of opinions ranged from those who felt they couldn't work effectively at home to those who felt they could work effectively at home up to four days per week. No serious study was made of this and the choice of two days per week with one day overlap appealed to the committee members performing the study.

Research Center Office Requirements

Estimates are that 3/4 of the oil and electric energies are supporting laboratory requirements, including the large fume hood exhaust waste. Deducting these laboratory requirements, including normal laboratory heating and lighting, the remaining energy required for offices is approximately

170 kwh/sq.ft/yr (oil equiv.)

Energy conservation measures reduce this, but the accuracy of this estimate is not certain, and it is believed that the basic inefficiency of the Research system and the high structural losses support this relatively high energy level.

Estimates provided by Frank Daria for the new temporary building modules are

Lights and Receptacles	240,000 kwh/yr
Air Conditioning	99,000
Heat	923,000
	1.262M kwh/yr

Since the new modules are electrically heated, the oil equivalent energies per square foot are

$$\frac{1.262\text{M} \times 3.3^{+}}{25{,}000} \approx 170 \text{ kwh/sq.ft/yr (oil equiv.)}$$

(This assumes the source of electricity is oil and accounts for the inefficiency of conversion and transmission.)

Note, however, that if the modules were heated directly with oil, the energy would be less:

Electrical	$.239$ M kwh $\times$ 3.3^{+}	$\equiv$	1.1 M kwh
Heat	$.923$ M kwh $\div$ 8	$\equiv$	1.2 M kwh
			2.3 M kwh

or 93 kwh/sq.ft/yr (oil equiv.)

This would be comparable with other IBM installations, as per Ken Ellis,

Armonk $\equiv$ 110 kwh/sq.ft/yr (oil equiv.) and
Rye Ridge $\equiv$ 85 kwh/sq.ft/yr (oil equiv.) - 30% energy savings assumed over 1972 usage.

The average office space per person used in the calculations was 150 square feet.

Heating/Cooling at home

On a per square foot basis, heating and cooling at home is comparable to heating and cooling in typical office structures. However, the rationale used is that people would use less space at home. We have assumed that only 25% would add to their home and only 50% would require additional energy.

The net effect of our assumptions is that the additional space required at home is one-sixth of that occupied by the same population at work and the combination of heat, airconditioning, and light added at home is about one-fourth of the amount used at work.

Computing facilities

We have assumed that all people working at home should have a terminal, if for no other reason, to increase communications. We would expect their use to become significant with the generation of useful data bases. The same 270 people now have less than one terminal for three people. Thus, we would need the same number of terminals at work in one case and forty fewer terminals at the Research Center for the staggered work week case (the one shown), since there could be additional sharing at the Research Center.

The central facility would have to be larger for both cases, but smaller for the staggered work week, i.e., 135 of 270 terminals potentially operable as opposed to 270 out of 270 for the case where all 270 work at home at the same time.

The energy expenditures for a 370/168, and its associated hardware and cooling facility, can exceed 800,000 kwh per year--large when compared to our total energy savings.

Our calculation allows one-fifth of a 168 configuration for the added home load. We estimate that this is equivalent to about 10 relatively simple interactions per second, considerably fewer complex interactions. Note that these are incremental facilities. That is, a heavy programming user is presumed to already have the major computer service required under normal circumstances, and would only require the incremental facilities to aid in working remotely. For some programmers, who want frequent listings, for example, this could be extensive.

Some Facilities for Improving Communications

Some people could work at home with enhanced communications and secretarial functions facilities like those suggested below:

Typing from dictation or written material

1. User to transcriber

   a. Portable recorder played over telephone to remote automatic receiver.
   b. Central recorder controlled by telephone buttons.
   c. Facsimile transmission for written notes.

2. Transcriber to user

   a. Typewriter and US mail.
   b. Typewriter and facsimile transmission.
   c. Computer entry, editing and formatting. User initiated retrieval.

Telephone answering and message routing

1. Automatic answering and message recording

   a. Existing commercial devices.
   b. Central multi-user configuration.

2. Person locator

   a. Virtual telephone number with central office mapping.
   b. Automatic beeper.

Voice memos (See 'Speech Filing' project, Dept. 440)

1. Recording

   a. Normal voice recording.
   b. Digitized voice recording.

2. Routing

   a. Telephone buttons or automatic dialer card.
   b. Broadcast and mailing list classes.

Communication Lines

Questions arise as to the load a large number of terminals place upon local telephone exchanges. Rita Hickey has provided us a list of employee telephone exchanges, which is broken down below.

Area Code	Exchange	Number	
201		10	New Jersey (north)
203		29	Connecticut
212		56	New York City
516		6	Long Island
609		2	New Jersey (south)
914	245	106	
	LA8	95	
	MA8	81	
	PE9	81	
	YO2	74	
	WI1	67	
	PE7	64	
	MO6	33	
	RO2	31	
	CR1	28	
	86 others	378	
TOTAL		1,141	

An active terminal user can look like 5 to 20 subscribers in terms of blocking a telephone exchange. Without knowing how close to full capacity these exchanges are, it is possible that the 6 or 7 exchanges with the largest number of Research employees connected could experience service difficulties if a large number of these people became terminal users--a public relations problem, at least.

Remote Terminals for Programming

For some people, working at home could be more effective with a good computer terminal. There is already a fair amount of experience with portable typewriter-terminals which use a telephone. In many cases, however, this is inadequate, in the sense that it seriously reduces the effectiveness of a person's time compared with working at the laboratory, where video displays and high-speed printers are available. We therefore examined what could be done to provide better remote terminals.

By way of a disclaimer, it should however be stated that it is not at all clear whether the installation of terminals would be an effective or economically viable way of saving energy, compared with the alternative steps available. Nevertheless, an advanced terminal configuration is possible, something which we at IBM Research ought to be looking at independent of the energy shortage.

In the long run, cable television may provide means for transmitting images from computing centers to remote video devices at very high speed. It is, however, instructive to see what can be done in the immediate future for an alphanumeric terminal connected by telephone line, where the transmission rate is (for practical purposes) limited to 4,800 bits/second.

Two basic configurations have been considered; (a) a keyboard for input and a large video display for output, and (b) a keyboard for input and both a small video display and a medium-speed printer for output. At first sight configuration (a) seems the more attractive; however, we have tentatively rejected it for three reasons: (1) a large video display, adequate to show clearly the listing of a moderately large program loop, is not readily available; (2) a large video display (of say 7,000 characters) would take too long to refresh over a telephone line; and (3) it is not at all certain that programmers can manage without at least the occasional paper listing. On the other hand, configuration (b) turns out to be just about possible with present equipment, by dint of using Huffman encoding to reduce the number of characters actually transmitted. It is then possible to refresh a small video display (of 1,000 to 2,000 characters) in about 1 second, and to have a data rate which is more than adequate for a remote personal printer. The device characteristics for such a configuration are as follows; for more details see the Appendix.

Possible Terminal

Input keyboard	Include some 'function' keys $30/month
Video display	10-24 lines of 80 chars screen refresh in ~ 1 sec. $170/month
Printer	132 chars wide 3 lines/sec $350/month
Modems	4,800 bits/sec $220/month
Additional gear for Huffman codes and local multiplexing	$150/month (est.)
Telephone (14 miles)	$74/month
Total price:	$994/month

ADDITIONAL COST CONSIDERATIONS

Terminal systems as a means to save building costs are not very attractive.

Some Basic Rentals

Mod 168 configuration	$100,000/mo	
Terminals	$40 - $1,000	
Modems	$10 - $120	
Phones	$10.60	
Lines - with Telpak	$.68/mile/mo	
- conditioning	$20/mo (both ends)	
- N.Y. Tel. rental	$5.37/mile/mo	
Office space	$.40 to $1.00/sq ft/mo	(typically)
New building - prefab	$26/sq ft	(purchase)
- Res. Center ≈	$70/sq ft	"

Hardware and Communications Costs for Work-at-Home Illustration

1/5 of Mod 168 configuration	$20,000/mo	
230 additional terminals	86,000	
460 additional modems	24,000	
270 phones	3,000	
270 lines (14 miles average)	20,000	
	$153,000/mo	(full rental costs)

Space for 135 people, 150 sq. ft/person

Research Center (801-type) Construction	$1,418,000	(purchase)
Prefab Construction	526,000	"
Shopping Center space (typically)	12,000/mo	

There are also additional operational, maintenance and insurance costs not included in both of the totals above.

If working at home is used as an alternative to new construction, or to renting space, this space for 135 people could cost considerably less than the hardware and communication rental. We believe that the net operational costs could bring the comparisons closer but at current costs it is not particularly attractive to work remotely generally, if sophisticated computing facilities are to be provided. This suggests that one must look for justification beyond cost and energy savings to areas of time savings and convenience, or wait until computer costs are significantly lower. Perhaps this bears watching in the future, particularly as an alternative to expensive construction.

VARIATIONS ON THE THEME

Complementing Working at Home

Several suggestions relating to working away from an employee's normal work site have been made to complement and serve as alternatives to the work-at-home scheme illustrated.

1. Remotely located multiplexing stations to afford wider band services.

2. Communications through CATV networks.

3. IBM employees reporting to nearest IBM location (part-time).

4. Shopping Center Work/Communications Centers.

   a. As a supplement to item 3 above.
   b. As a multicompany or general business opportunity.

Each of the above concepts saves travel energy; however, items 3 and 4 could actually result in a net energy increase if permitted to significantly increase the total work space per employee.

If facilities were adequately shared, each of these suggestions could increase energy savings by enhancing the numbers and efficiencies of people working off their normal working sites. Still, savings would probably not be large. However, since most of these ideas are already practiced to a limited extent, it is reasonable to consider them beyond the context of energy savings.

Saving Gasoline

Obviously, gasoline savings comparable to those illustrated can be obtained in several ways. To give some feeling for some of these savings, we give some equivalences. In terms of the Research community, 10% working at home full time,

= 20% car pooling
= 50% working a 4-day week
= 15% working in "local" centers
= 60% avoiding one business trip per year
= 100% reducing non-business travel 5%.

Shorter Work Weeks

Data measured on weekends has been used in a crude model to estimate the savings in energy if Research employees worked 3-day or 4-day weeks. (Very little data is available at this time, particularly in the electrical energy consumed.) What data we do have suggests that there is approximately 25% less fuel and 25% less electricity consumed on a weekend day as compared with the average weekday. Based upon our projections that 1974 electric and oil use (as metered) will be 23M kwh and 73 M kwh, respectively, we calculate that our energy savings will be reduced as follows:

Three-day week	≈	15%	(max. 30%)
Four-day week	≈	7%	(max. 20%)

This is based upon present conservation procedures. However, we suspect that before we resort to a 3- or 4-day week many other major conservation measures would be instituted during working days, and this could mean that the percent savings would be even less.

IBM CONFIDENTIAL

IBM RESEARCH
ENERGY TASK FORCE
'WORK-AT-HOME' SUBCOMMITTEE

APPENDIX

Remote computer terminal

1. Introduction

These notes present some design considerations for a remote computer terminal for programmers and other computer users. Such a terminal could be used from his home if it was necessary or desirable for a computer user (a) not to travel to his normal place of work, or simply (b) to have the freedom to work at home. It might also be of social or economic value to certain people who do not at present make any direct use of computers, but who could do so if they had an adequate terminal in their office or home.

By way of a disclaimer, it should be stated that, in the case of IBM Research, it is not clear that the installation of remote terminals in people's homes is likely to save much energy (compared with the alternative steps available), or is likely to be attractive economically or from the point of view of work-habits. The energy-balance for working at home is presented elsewhere. The immediate economic picture looks hopeless. What kind of computer terminal can be rented and used for the cost of two gallons of gasoline a day? Perhaps, if it was necessary to reduce the number of journeys made between work at home, it would be more sensible to do at home that work which does not need a computer: even programmers spend a fair proportion of their time reading, designing and writing.

Nevertheless, an adequate terminal for using a computer remotely is something which we at IBM Research ought to be looking at independent of the energy shortage. Then, if we had a terminal 'in house', we should be in a better position to consider its installation, at least on a limited scale, in the event of a severe gasoline shortage, or simply in order to improve the facilities in a way which, even if it does not save much energy, is at least not a heavy consumer.

2. Present situation

Most users of the computers at the Research Center fall in the following two broad groups:

(A) those who are predominantly writing or modifying programs, and running them; and

(B) those who are predominantly using the computers to store and process English text.

The latter group includes some users of the interactive text editors, users of the experimental printer, and a number of secretaries.

In both groups the trend of the past few years has been towards the use of:

(a) a terminal consisting of

(i) a typewriter for both input and output, and

(ii) a video display for additional output;

together with

(b) a fast centrally-located printer for large amounts of output.

The present sizes, speeds and prices of these devices are as follows.

Typewriter	130 characters wide 10-15 characters/second Rent $114/month
Modem	$25/month
Video display	12-24 lines of 80 characters each Complete screen refresh in 0.1-1.0 second Rent $170/month (including share of control unit) (Device is used in 'local' mode, with coaxial cable between device and computer.)
Printer	132-151 characters wide 10-40 lines/second Rent $15/month/user
Total rent	$324/month

The video display is used mainly as a 'window' into the user's data, such as into a file being edited. It can provide immediate feedback for editing and can (in the same mode) be used to browse through files.

It is planned, in the near future, to remove the typewriter-terminals from a number of rooms in the Research Center, leaving the people involved with a video display for output and a keyboard for input. It will be instructive to find out how this changes their method of working, their reliance on the fast printers, and their requirements from the other hardware and software.

There are a few people who have typewriter-terminals at home, and others who take one home for an occasional evening. Mostly these terminals seem to be used for fairly small jobs, such as writing small APL programs, or rerunning a given program with different data.

3. Overall design considerations

3.1 Human engineering. Detailed design of equipment which is to be used over long periods directly by human beings needs careful testing and experimentation, and is unlikely to be done successfully on paper alone. It is important not seriously to reduce the effectiveness of people's time and effort.

3.2 Feasibility of dedicated mini-computers. The replacement of a share of a large computer by a dedicated small computer at home might be feasible for typists who are copying or updating documents: the material which they prepare could be transferred over a telephone line in a burst, or brought in on tape and read from there into the central data-base. For most programmers, however, dedicated mini-computers would not be realistic. Many users need frequent access to public or other people's files, and the trend is probably for this to increase. Dedicated mini-computers will not be considered any further.

3.3 Outline of terminal. We shall consider the overall characteristics and limitations of an alphanumeric terminal with:

(1) a typewriter-like keyboard for input, and

(2) some means of producing output.

It could in addition have a 'function' keyboard, and a light-pen or a 'mouse', without affecting most of the points which follow.

3.4 Local intelligence. In what follows, the devices are assumed to have that logic capability (wholly in hardware or partly in software) which is necessary to operate the device physically and to handle its communication protocol. High-level 'local intelligence' (such as editing) will not be considered. Its desirability is controversial. Its advocates claim savings (on average) in communication costs: its critics claim that its presence tends prematurely to constrain the use to which a device is put; and to require duplication of function (centrally and locally), with resulting problems in compatibility, documentation and overall complexity.

4. Specific design considerations

4.1 Input keyboard. The input keyboard does not present any particular difficulty. There are many keyboards available, with and without 'function' keys.

4.2 Output devices. The choice of output devices is more difficult. For programs, the writer is unconvinced that video displays are an adequate substitute for paper listings. They are too small and cannot be scribbled on. The same holds true to some extent for purely textual material, especially if the screen cannot display a full 8.5 x 11-inch page (and this is true of all available computer displays). Yet there is no doubt that a fast video display with only 10 or 20 lines of 80 characters each speeds interactive work greatly. This forces us to consider a combination of video display and hard-copy for output, i.e. to consider a terminal which is at least qualitatively similar to what is already in use at the Research Center. The main difference is in the speed required of the hard-copy device; for it is (according to this proposal) required for printing program listings and not just trivial amounts of diagnostic and debugging information (which is the main use of the existing typewriter-terminals). We then need the following speeds:

Video display:	10-20 lines of 80 characters (minimum), total screen refresh within 1 second.
Hard-copy output:	121 characters wide (minimum), 5 lines/second.

(The importance of fast response on a video display can be appreciated from the following. It takes just under 1 second completely to rewrite the screen of the 2260, and therefore about 0.5 second to reach the middle of the screen when writing from the top. It turns out that, when the user's attention is directed to the middle of the screen, and only the middle (or the middle and the bottom) is to be changed, a significant improvement in human factors can be obtained if the top of the screen is skipped and writing starts in the middle. This shows that an delay of 0.5 second is noticeable and can be annoying.)

5. Communications

Modems are available for standard telephone lines which operate at 4,800 bits/second. Assuming a code which occupies an average of 8 bits/character transmitted, this would give a transfer rate of 600 characters/second. Huffman encoding of source programs yields a compression factor of between 2 and 3.5 approximately, giving an effective transfer rate of (say) 1,500 characters/second. In what follows, we shall assume that Huffman encoding is done, even though it requires additional equipment at each end of the line.

5.1 Keyboard. The data transfer rate between the input keyboard and the computer is low compared with those of the output devices.

5.2 Video display. A data rate of 1,500 characters/second would be adequate for a small video display of 1,000-2,000 characters, such as are already in use, but would probably not be adequate for a screen containing more than about 2,000 characters.

5.3 Hard-copy device. A data rate of 1,500 characters/second corresponds to about 12 lines/second, which is more than adequate for a personal high-speed printer.

6. A configuration

The following are the main components of a possible experimantal programmer's terminal.

6.1 Keyboard. A possible keyboard is the one which can be obtained with the IBM 3275 display, which rents for about $20-$35/month (depending on options).

6.2 Video display. The IBM video displays number 2260 and 3277 are in widespread use at the Research Center, and rent for about $170/month. Each has a sister-version which can be used over a telephone line (numbers 2265 and 3275), which could with minor modification be hooked up in this configuration.

6.3 Printer. The IBM 'Lynx' series of printers is representative. Models are available which print 80 or 132 characters per line at 2 to 3 lines per second (64-character set). This is roughly ten times the speed of a typewriter-terminal, and one-tenth the speed of a high-speed printer. It would print a 100-page listing in 40 minutes, which seems barely adequate; however a speed improvement by a factor of 2 is likely within a year. In the case of 'Lynx', the characters are on a flexible band which spins around in a horizontal plane (in roughly the same geometric configuartion as a chain in a chain-printer). The band can be changed in about 2 minutes. The devices are reasonably compact, and the rentals are in the range $260-$450/month.

6.4 Telephone. An additional telephone is required, since (apart from personal considerations) it is often necessary for a computer user to make or receive telephone calls while he is connected to the computer. The cost of this depends crucially on whether the computer is within the local dialling area of the user:

Within local dialling area:
$6/month approx.

Outside local dialling area:
$5.37/mile/month for dedicated line

6.5 Modem. Modems for 4,800 bits/second cost $110/month each, plus $100 for installation. These figures need to be doubled since a modem is required at each end of the line.

6.6 Huffman encoding and decoding. Equipment must be developed for Huffman encoding and decoding of output data, and for multiplexing the three devices of the terminal (so that the keyboard and the display are not locked out during the printing of a listing). Estimated cost is $150/month.

6.7 Total cost of proposed configuration.

Keyboard	$ 30
Video display	170
Printer	350
Telephone (14 miles)	74
Modems (excl. installation)	220
Local multiplexer	150
	$994/month

7. Alternative proposal

An alternative configuration eliminates the printer (which is an expensive item) and contains a larger video display. As already stated (in section 4.2) the writer is not convinced of the desirability of this. Let us however examine the principal consequences of it.

In this case the screen must show nearly a page of listing or English text -- at least enough to contain a reasonable program loop. Such computer displays are not at present available (see Datamation, November 1973). (They could however be developed, and probably are being developed. 1000-line high-resolution television is capable of displaying easily 80 lines of 120 characters each.) Such a display would, however, hold about 7,000 characters, which would take at least 4-5 seconds to refesh over a telephone line. This is certainly too slow for comfort, and it would therefore be desirable (in this scheme) to use either (a) cable TV for transmission, or (b) local 'intelligence' to try to minimize the data transmitted.

8. Suggestions on design

These notes conclude with a few suggestions for someone who might pursue a terminal design of the kind outlined here.

8.1 The host computer should have absolute program authority over all parts of the terminal (once it has been connected). Examples are locking of keyboard (if wanted), erasing of screen, setting of tabs.

8.2 With the configuration suggested here, the video display would need to be capable of presenting the characters which are typed in at the keyboard as they are typed in. In the case of a keyboard-display combination (such as the IBM 3275) this is automatic. In the case of a separate keyboard, attention would have to be given to the way in which this was done, e.g. by having the two devices hooked up locally, or by gaining access to the line buffer in the control unit at the computer.

8.3 The local store associated with the video display should ideally be capable of holding any character which is storable in the main computer, so that it is possible to write an arbitrary line from the main computer and then read it back without loss of data. (Unfortunately the 3277 does not have this property.)

C.J. Stephenson.

Yorktown Heights,
30 January 1974.

IBM CONFIDENTIAL

SECTION VIII

PROPOSAL FOR A RESEARCH PROJECT IN MODELING THE ENERGY SYSTEM: A REPORT OF THE RESEARCH DIVISION ENERGY TASK FORCE

Kai-Ching Chu
George J. Fan
P. Dean Gerber
James F. Ziegler

January 30, 1974

1. INTRODUCTION

The Research Division Energy Task Force (ETF) was convened by Richard Garwin on December 21, 1973 and met until January 30, 1974. The mission of the ETF was to

1. Investigate problems posed to our normal operation by the energy crisis.

2. Investigate opportunities for Research Division technical work in areas made important by the energy crisis.

3. Seek an understanding of new Corporate problems posed by the crisis, so that the Research Division can provide the necessary support and leadership to IBM efforts in this field.

The output of the ETF is a series of reports from the specialized working subgroups into which it divided. This is the report of the Energy Systems Modelling Group, consisting of K. Chu, G. Fan, D. Gerber, and J. Ziegler; chaired by D. Gerber.

2. OVERVIEW

The primary conclusions and recommendations of the Energy Systems Modelling Group are the following:

. Our entire way of life, both personal and economic, rests on the character of the energy sector, and this sector has not appreciably changed until rather recently.

. The character of the energy sector is currently undergoing large discontinuous changes, leading to a radically different economic environment.

. Dealing with this new environment will require an enormous increase in the use of computers for controlling, monitoring, analyzing and understanding the behavior of large complicated systems. There will be a great need for models of the energy sector and its various components.

. This new demand for a systems modelling technology should be supported by basic research in modelling techniques and methodology and their specific application.

. The Research Division should initiate this research by attempting to develop a large scale model of the energy system.

3. THE CHANGING CHARACTER OF THE ENERGY SECTOR

For the greater part of the last two hundred years, the essential character of the energy sector in the United States economy has remained unchanged. The fundamental features of this sector have been

1. Exponential (in fact, hyper-exponential) growth of demand
2. Unlimited supply
3. Low and slowly declining (in constant dollars) price
4. Great stability of price, supply and demand.

For example, the annual increment in energy use per capita was 1.2% from 1880 to 1930, 2% from 1931 to 1960, 2.7% from 1961-1970, and 4.9% in the last five years. We see from this that even the per capita demand for energy is growing at a hyper-exponential rate! This and other data confirming the above features may be found in [ ].

Figure 1 demonstrates that total commercial energy consumption and per capita G.N.P. are roughly proportional. It would seem obvious that the energy sector is the very base on which our highly industrialized and technological economy is founded, and the above result confirms this. It follows that our entire way of life, featuring rapid growth, stability and increasing productivity and real income, rests heavily on the four fundamental characteristics of the energy sector.

The net effect of this historic behavior of the energy system has been to place the United States in an energy utopia. Associated with living in this energy utopia are certain policies and attitudes which are extremely relevant to understanding our current dilemma:

. Governmental Neglect. Agriculture, food processing and food distribution account for about 10% of the nation's economic activity. To support the agricultural sector there is a cabinet-level department of government, extensive federally supported research and extensive federal subsidy, development, and emergency aid. To support the energy sector, which is the base of the economy and also represents about 10% of the nation's economic activity, the government does essentially nothing.

. Calculated Waste. For years the oil industry regarded natural gas as a waste product and burned it off at the well-head. More recently, the government has priced natural gas artifically low. The net effect of this has been to encourage demand and discourage development of supply. The misuse of a vital resource is thus encouraged by an intentional policy.

. Distorted Price Structure. The true cost to the economy of energy is not reflected in its price. Much of this excess cost is absorbed by the government via its tax policy and various leasing programs. The notorious oil depletion allowance is a good example of this. The balance of the excess is in the form of damage to the environment. The costs of this damage are to some extent absorbed by other sectors, for example, the health care sector, but until recently they have been mainly deferred to the future.

. Energy Efficiency Unimportant. Because energy has been so cheap,' its efficient utilization has been relatively unimportant in many sectors of the economy. This is particularly noticeable in the auto industry, where operational efficiency has steadily declined, and in the housing industry, where relatively simple changes in construction can lead to energy use reductions of 30 to 40%.

. Ignorance of Energy System Behavior. The most glaring example of this is the current controversy over whether there is or is not an energy crisis. Does daylight savings time really help? Why did energy use per G.N.P. suddenly begin to increase in 1966? (See figure 1.) In the midst of a fuel crisis, the Government is unable to say just how much fuel there really is. This is but a small sample of the questions and issues which show our complete lack of understanding of the energy sector.

Having summarized the past character of the energy sector and the consequences of that character, we must now consider the present and future. It is widely recognized that there are definite limits to the growth of energy use. One obvious reason is that the supply is finite, but there are other, more important factors. One is that increased energy use causes increased pollution and this is becoming intolerable. Governmental antipollution regulation is already interfering with the growth of energy production, and this trend is likely to continue.

Another important limit is the instability that occurs in a highly interconnected system which is operating at or near peak capacity. The failure of a single system element can have a severe effect on the whole system. There is no better example of this than the current fuel crisis, largely due to the failure (intentional) of the Mid-Eastern oil component. Another example is the current economic crisis in Britain, brought on by a labor dispute in the coal industry.

For any exponentially growing activity, there is a time period - the "doubling time" - during which the activity doubles in size. Exponential growth toward an ultimate limit results in a surprising social phenomena, which we term the "doubling discontinuity." In essence, such a system doubles in size during each doubling period, and this goes on for many years without notice. Eventually the system is halfway or more to one of its limits, at which time it cannot double again. Thus the exponential growth must stop, and this takes place in a single time period! This change of circumstances occurs so quickly that it appears discontinuous.

There is little doubt that the energy sector is entering a period of doubling discontinuity. The large number of local energy crises now occurring are the clearest evidence of this. Two additional examples concern the electric and oil sectors.

In recent years, the doubling time for electric demand has been less than eight years. To continue this growth rate for the next twenty years would require the siting and construction of 300 generating stations of 3000 Mw capacity. This would also require 7 million new acres of land for transmission, and about 5×10^{14} gallons per year of cooling water - without the use of cooling towers and assuming an average temperature increase of 10°. This is approximately the annual run-off of the United States!

. National oil demand has recently grown at a rate of 10%. In 1972, the supply was short by 2% and by 15% in 1973. The supply picture cannot change appreciably for three to five years, so during this period demand must stay constant.

The foregoing arguments and facts demonstrate that the fundamental character of the energy sector is radically changing. Where we have in the past had exponential growth, unlimited supply, low cost and great stability we will in the future have some mixture of flattened growth, shortages, high costs and great instability. These are in fact extremely conservative conclusions but of great significance if true. They imply that our entire economic way of life will be radically changed.

4. THE IMPORTANCE OF ENERGY SYSTEMS MODELLING

The likely consequences to the economy of the changes in the energy sector are:

- Extensive Governmental Intervention. This will occur not only in the energy sector but in energy intensive sectors also, e.g., transportation, building operation, etc.

- Rapid Shifts in Price Structure. Changes in energy price will have a multiplier effect throughout the economy. Governmental price regulations are likely to change.

- Large Penalties for Energy Use Inefficiency. Shortages and increased energy costs will create great pressures for increased efficiency. The auto, electric, and building heating industries are already under heavy pressure.

Successful handling of these problems will require extensive development of models of the energy system and many of it components.

- The government and industry will need large models of the entire energy sector in order to predict the future and to simulate the effect of policy decisions.

- As concern over energy mounts, large amounts of data and information on the energy sector will have to be collected, organized and made readily accessible.

- Manufacturers will need new device models that take energy consumption into account. For example, the design of an energy efficient building could be greatly aided by a computer simulation of the energy flow in the building.

. New pollution and energy efficiency standards will have to be developed. This cannot be done without careful modelling of the effect on the total system. For example, air pollution regulation has led to decreased use of high sulphur fuels. But the increased demand for low sulphur fuels has depleted their reserves and severe shortages now exist. Good modelling could have avoided some of this difficulty.

Clearly this new demand for modelling technology should be supported by basic research and development in modelling techniques, methodology and applications. Some examples of areas greatly needing models follow.

. Environmental Dispatch in the Power Industry. This refers to the problem of distributing the loads of generating stations to produce minimal environmental disturbance.

. Transmission Line Routing. The problem is the balance of the effects of power loss and social costs in the routing of power lines.

. Energy Flow in Buildings. What is required here is a simulation of the entire energy flow of a building (dynamic). This tool is essential to investigating such questions as to the use of a small computer to run a building and to evaluation of the many new suggestions for energy systems in buildings.

5. TECHNIQUES AND PROBLEMS IN MODELLING THE ENERGY SYSTEM

By one estimate, more than 700 models of energy systems have been developed in the past decade. For reasons which will appear below, we were unable to make any valid comparisons in the time available. The principal groups of investigators are listed in Appendix A and the principal sources of energy data in Appendix B.

The principal approaches to modelling the energy system are

- Input-output Models. These are linear models of a static nature and are effective for very short range predictions.
- Control and Game Theory Approach. Mostly concerned with optimizing or controlling some aspect. This approach has an extremely well developed and effective mathematical backing.
- Mathematical (Linear) Programming Models. Again the attempt is to optimize something, but this approach has highly effective theoretical and computational techniques for dealing with constraints.
- Statistical Approach. Uses regression analysis, decision theory and estimation techniques for effective short term predictions. Has developed extremely good techniques for handling real data, testing hypotheses, and comparing projections with real data.
- Dynamic Feedback Models. These models consist of systems of difference-differential and algebraic equations. They predict the dynamic behavior of the system, but no firm conclusion as to their effectiveness can yet be made. They have great promise.
- Network Flow Approach. Well founded in graph theory, this method seeks to analyze that behavior which does not depend on the detailed interrelation of system components. It often provides surprising and vital information.

. Data Base Models. These models consist of collections of energy system data and supporting retrieval software. These are extremely important, yet virtually non-existent.

. Stochastic Models. This approach is based on probability theory and has been extremely successful in a variety of related areas. It does not seem to have been applied to any extent to energy systems.

. Dynamic Programming. This is a large collection of computational and mathematical techniques for optimizing dynamic systems. There are many valuable tools in this subject.

There are a number of models of the entire U.S. economy which are widely known and respected. This is not the situation in energy modelling for the following reasons:

. Generally the models do not interface with a large base of real data. Consequently, calibration of the models is difficult, and there is little testing of model behavior versus real data.

. Modelling groups tend to use only one or two of the above techniques instead of picking the best technique from each.

. The approaches do not make effective use of modern computing capability.

. Current capabilities in data base construction and management have not been used.

. The computer simulations are not backed up with mathematical, stability, and sensitivity analysis, and there is little comparing of results with other models.

6. CONCLUSIONS AND RECOMMENDATIONS

This committee makes the following conclusions and recommendations:

- The basic character of the energy sector has changed radically from its historic pattern. The essentials of the current energy crisis will be with us for a long time.

- There will be a great demand for modelling capabilities in the energy sector. IBM will need energy system models both for its own operation and that of its customers.

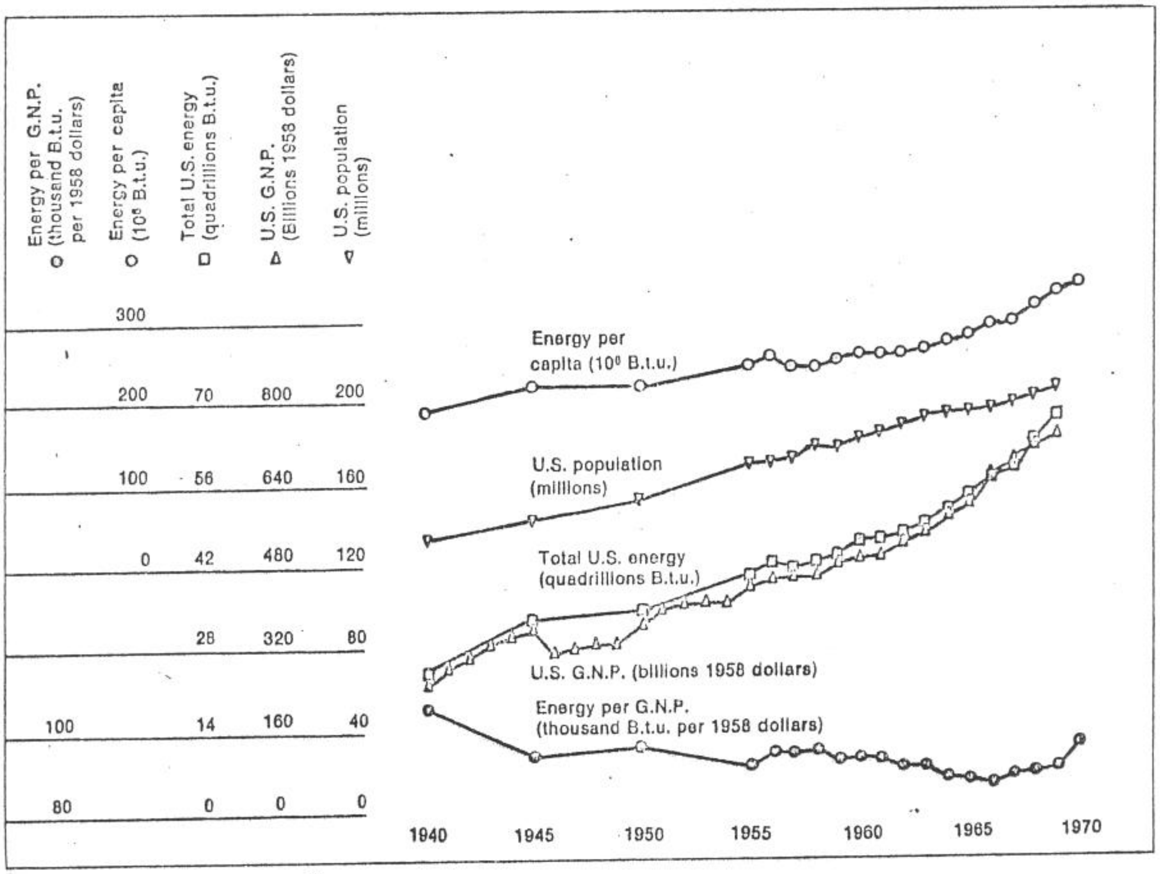
- There is a good prospect for an effective energy system model if it combines the best techniques mentioned in section 5 and interfaces with an advanced data base of real data. The Armonk econometric model, one of the best available, is preeminent precisely because it combines the best techniques of econometrics and data base management. This has not been done in the energy field, and looks promising.

- The Research Division should explore the possibilities of this approach in greater depth. Specifically, we propose an investigation into modelling the physical energy system of the United States. By avoiding the jungle of economic and social issues the true technical scope of the problem can be revealed. Also, this approach can utilize existing personnel and expertise.

Here is a program to better understand – and perhaps thereby begin to resolve – the complex dilemmas which even with our present primitive insight we begin to observe in our demand for ever-increasing amounts of energy.

IBM CONFIDENTIAL

FIGURE 1



Since 1850 the U.S. energy industry has maintained a 3-per-cent average annual growth rate. But in the last half of the twentieth century the curve has been steepening—4.2 per cent in the 1960's, 5.1 per cent in 1969. Even the energy consumption per unit of gross national product has advanced sharply in the last years of the 1960's. The web of issues which determine these trends remain little understood.

IBM CONFIDENTIAL

APPENDIX A LISTING OF INSTITUTIONS ACTIVE IN RESEARCH OF ENERGY SYSTEM MODELLING

Institution	Person to Contact	Subjects
Brookhaven Laboratory	P.F. Palmedo	National System Model (Linear Programming), Future Energy Options for N.Y.C.
Calif. Institute of Technology, Environmental Quality Laboratory	Lester Lees	Environmental Implications Energy Demand
Drexel Institute of Technology	C.C. Mosher	Utilization Analysis of Energy Systems
Hudson Institute	Kahn Herman	Systems Command and Control, Communication Service Facilities
University of Illinois - Urbana, Ill.	B.M. Hannon	Environmental Aspects of Conversion and Consumption, Energy Costs, Regulation Effects
Mitre Corporation -McLean Va.	J.E. Just	Information Source Survey, Energy Data Needs and Resources
M.I.T.	David C. White	Dynamics of Energy Systems, Demand and Conservation, Regulatory and Institutional Problems, Impact of New Technology
Bureau of Mines Dept. of Interior	W.E. Morrison	Prediction and Planning

New York University	Dick Netzer	Electrcal Energy Supply in New York Area
Oak Ridge National Laboratory	Alvin Weinberg	Demand, Conservation and the Environment, Directory of Current Energy Research
Queen Mary College Univ. of London, Energy Research Unit	R. J. Deam	World Oil Supply Modelling (Linear Programming)
RAND Corporation	D. N. Morris	Demand Projection, Conservation Mearsure Evaluation
Resources for the Future, Inc.	J. L. Fisher	Social Science Aspects of Energy Systems, Energy Research Needs
Westinghouse Electric Corp.	P. F. Schweizer	Impact of New Policies and Technologies (Linear Programming)

Institutions which Collect Energy Data:

AMERICAN CHEMICAL SOCIETY

CHEMICAL ABSTRACTS SERVICE
The Ohio State University
Columbus, OH 43210

614/421-6940

Dale B. Baker, Director

AMERICAN METEOROLOGICAL SOCIETY

45 Beacon St
Boston, MA 02108

617/227-2425

Kenneth C. Spengler
Executive Director

AMERICAN PETROLEUM INSTITUTE

CENTRAL ABSTRACTING & INDEXING SERVICE
275 Madison Ave
New York, NY 10016

212/685-6250

Everett H. Brenner, Manager
I. Zarember, Asst Manager

AMERICAN SOCIETY OF MECHANICAL ENGINEERS

APPLIED MECHANICS REVIEWS
Southwest Research Institute
P O Box 28510
San Antonio, TX 78284

512/684-2000, ext 315

Dr. Stephen Juhasz, Editor

BATTELLE MEMORIAL INSTITUTE
BATTELLE ENERGY PROGRAM

ENERGY INFORMATION CENTER
505 King Avenue
Columbus, OH 43201

614/299-3151, ext 3711

David M. Liston, Jr.
Manager

BORD NA MONA

Scientific Office
Droichead Nua
Co. Kildare, Ireland

BRITISH COKE RESEARCH ASSOCIATION

Chesterfield
Derbyshire S42 6JS
England

Information Officer

CCM INFORMATION CORPORATION

866 Third Ave
New York, NY 10022

212/935-4296

Bill J. Funderburk
Director, Consulting Services

ENGINEERING INDEX, INC

345 East 47th St
New York, NY 10017

212/752-6800

John E. Creps, Jr.
Executive Director

ENVIRONMENTAL INFORMATION CENTER, INC

Index distributed by
Johnson Associates
175 5th Ave
New York, NY 10010

212/677-5250

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR QUALITY PLANNING & STANDARDS

AIR POLLUTION TECHNICAL INFORMATION CENTER (APTIC)
Research Triangle Park, NC 27709

919/549-8411, ext 2131

Peter Halpin, Chief

GEOLOGICAL SOCIETY OF AMERICA
and
AMERICAN GEOLOGICAL INSTITUTE

GSA BIBLIOGRAPHY PROJECT
2201 M Street NW
Washington, DC 20037

202/296-7950

Dr. Linn Hoover

Bruce Adkins or
Phil Johnson (Tape info)

ILLINOIS INSTITUTE OF TECHNOLOGY

INSTITUTE OF GAS TECHNOLOGY
Technical Information Services
3424 South State St
Chicago, IL 60616

312/225-9600

Harold Mensch, Manager

INSTITUTE OF PETROLEUM

61 New Cavendish St
London W1M 8AR, England

Abstracts published by
Applied Science Publishers Ltd
Ripple Road, Barking,
Essex, England

INSTITUTE FOR SCIENTIFIC INFORMATION

325 Chestnut Street
Philadelphia, PA 19106

215/923-3300

Eugene Garfield, President

Melvin Weinstock

INSTITUTE OF FUEL

18 Devonshire St
Portland Place
London W1N 2AU, England

INSTITUTION OF ELECTRICAL ENGINEERS

INSPEC - INTERNATIONAL INFORMATION SERVICES FOR THE PHYSICS AND ENGINEERING COMMUNITIES
Savoy Place
London WC2R OBL, England

01-240-1871

Ms B. Rosenberg

INSTITUTION OF ELECTRICAL ENGINEERS and
INSTITUTION OF MECHANICAL ENGINEERS

ISMEC - INFORMATION SERVICE IN MECHANICAL ENGINEERING
Savoy Place
London WC2R OBL, England

INSTITUTION OF MINING AND METALLURGY
44 Portland Place
London W1N 4BR, England

INTERAGENCY ADVANCED POWER GROUP
UNIVERSITY OF PENNSYLVANIA
INSTITUTE OF COOPERATIVE RESEARCH
POWER INFORMATION CENTER
3401 Market St, Rm 2210
Philadelphia, PA 19104
215/382-8683, 8674
Paul S. Balas, Director

INTERNATIONAL ATOMIC ENERGY AGENCY
INIS
INTERNATIONAL NUCLEAR INFORMATION SYSTEM
Kärtner Ring 11
P O Box 590, A-1011
Vienna, Austria

LIBRARY OF CONGRESS
SCIENCE AND TECHNOLOGY DIVISION
NATIONAL REFERRAL CENTER
2nd and Independence Ave, SE
Washington, DC 20540
Marvin W. McFarland, Chief
202/426-5687:
John F. Price, Head
Reference and Referral
202/426-5670,71,72,73:
John A. Feulner, Referral
202/426-5580,81,82,83:
Constance Carter, Reference

NATIONAL AERONAUTICS & SPACE ADMINISTRATION
SCIENTIFIC & TECHNICAL INFORMATION OFFICE
300 7th St, SW
Washington, DC 20546
202/755-3464
Dr. Harold E. Pryor, Director
Paul S. Feinstein, Chief
Information Services Div

NEW YORK TIMES INFORMATION BANK
229 West 43rd St
New York, NY 10036
212/556-1234
Dr. John Rothman, Director
Library and Information Services

PUBLIC AFFAIRS INFORMATION SERVICE, INC
11 West 40th St
New York, NY 10018
212/736-6629

SMITHSONIAN INSTITUTION
SCIENCE INFORMATION EXCHANGE
1730 M Street NW Room 300
Washington, DC 20036
202/381-5511
Dr. David F. Hersey, Director

UNIVERSITY OF TULSA
INFORMATION SERVICES DEPARTMENT
1133 North Lewis Ave
Tulsa, OK 74110
918/939-6351, ext 296
Dr. Harry O. McLeod, Jr.
Director
John A. Bailey
Asst Director

U.S. ATOMIC ENERGY COMMISSION
DIVISION OF TECHNICAL INFORMATION EXTENSION
P.O. Box 62
Oak Ridge, TN 37830
615/483-4611
John W. Norris, Chief
Sci & Technol Branch

U.S. ATOMIC ENERGY COMMISSION
OAK RIDGE NATIONAL LABORATORY
ENVIRONMENTAL INFORMATION SYSTEM OFFICE
ENERGY INFORMATION CENTER
P.O. Box X
Oak Ridge, TN 37830
615/483-8611, ext 3-1289
Miriam P. Guthrie, Director

U.S. ATOMIC ENERGY COMMISSION
OAK RIDGE NATIONAL LABORATORY
ENVIRONMENTAL INFORMATION SYSTEM OFFICE
ENERGY RESEARCH AND DEVELOPMENT INVENTORY
P. O. Box X
Oak Ridge, TN 37830
615/483-8611, ext 3-1322
Gloria M. Caton, Director

U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
P. O. Box 1553
Springfield, VA 22151
703/321-8574
William T. Knox, Director

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
COMPUTERIZED RESOURCES INFORMATION BANK (CRIB)
Washington, DC 20244
202/282-7268
Dr. James A. Calkins

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
GEOLOGICAL SURVEY LIBRARY
General Services Admin Bldg
18th & F Streets NW
Washington, DC 20242
202/343-3863
George H. Goodwin, Jr.
Librarian

U.S. DEPARTMENT OF THE INTERIOR
NATURAL RESOURCES LIBRARY
18th & C Streets NW
Washington, DC 20240
202/343-5821:
Mrs. Mary Huffer, Director
Office of Library Services
202/343-5815:
Mrs. Signe Larson
General Reference Service

U.S. DEPARTMENT OF THE INTERIOR
OFFICE OF WATER RESOURCES RESEARCH
WRSIC
WATER RESOURCES SCIENTIFIC INFORMATION CENTER
Washington, DC 20240
202/343-8435
Raymond A. Jensen, Manager

U.S. FEDERAL POWER COMMISSION
FEDERAL POWER COMMISSION LIBRARY
825 North Capitol St, NE
Room 8502
Washington, DC 20426
202/386-5191
Mrs. Mildred L. Henderson, Librarian
Mrs. Rita Mayer, Reference

```
∇SOURCES∧IBM[⎕]∇
```

IBM CONFIDENTIAL

```
∇ SOURCES∧IBM
  ENERGY MODELLING DATA SOURCES
  ⍝
  PUBLICATIONS FREQUENTLY CITED IN ENERGY MODELLING PAPERS.
  ⍝
  AVAILABLE AT IBM-RESEARCH:
  ⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕
  AMER.INST.CHEM.ENG.JOURNAL
  AMERICAN SCIENTIST
  APPLIED SCIENCE AND TECHNOLOGY INDEX
  ASHRAE JOURNAL
  ASME JOURNAL-J.OF ENG.FOR POWER
  CHEMICAL TITLES
  CHEMICAL ENG.
  CHEM.ENG.PROGRESS
  CURRENT PAPERS IN E.AND E ENG.
  CONFERENCE BOARD RECORD
  DIRECTORY OF INFOR.RESOURCES IN THE US[PHYSICAL SCIENCES]
  E.AND E.ABSTRACTS
  ENG.INDEX ANNAL
  ENG.INDEX MONTHLY
  EE TRANSACTIONS
  ENERGY CONVERSION
  ENG.INDEX
  ENG.NEWS RECORD
  ENVIRONMENT
  ENVIRONMENTAL SC.AND TECH.
  FACTORY
  HYDROCARBON PROCESSING
  IEEE SPECTRUM
  IEEE TRANS.ON INDUSTRIAL APPL.
  IEEE TRANS.ON NUCLEAR SCIENCE
  IEEE TRANS.ON POWER APPARATUS AND SYSTEMS
  J.CHEMICAL AND ENG.DATA
  J.OF ENVIRONMENTAL SCIENCES
  J.OF NUCLEAR ENERGY
  J.OF PETROLEUM TECH.
  NUCLEAR SCIENCE ABSTRACTS
∇
```

∇NONAIBM[⎕]∇
NONAIBM
ENERGY MODELLING DATA SOURCES

IBM CONFIDENTIAL

A
PUBLICATIONS FREQUENTLY CITED IN ENERGY MODELLING PAPERS.
A
NOT AVAILABLE AT IBM-RESEARCH
⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕⎕
AIR POLLUTION ABSTRACTS
API ABSTRACTS OF REFINING LITERATURE
API ABSTRACTS OF REFINING PATENTS
API PATENT ALERT ABSTRACTS
APPLIED MECHANICS REVIEWS
ATOMINDEX
AMER.SOC.FOR SAFETY ENG.JOURNAL
AMER.SOC.C.ENG.:J.OF POWER DIVISION
ANNALS OF ASSOC.OF AMER.GEOGRAPHERS
BIBLIOGRAPHY AND INDEX OF GEOLOGY
BIBLIOGRAPHY OF KENTUCKY COAL
BIBLIOGRAPHY OF THESES
CANADIAN MINING AND METALL.BULL.
CANADIAN MINING JOURNAL
CHARTERED MECH.ENG.
CARBON
COAL AGE
COKE REVIEW
COAL,GOLD,AND BASE MINERALS OF S.AFRICA
COLLIERY GUARDIAN
COL.SCHOOL OF MINES-MINERALS IND.BULL.
COL.SCHOOL OF MINES-QUARTERLY
COMBUSTION
COMBUSTION AND FLAME
COMBUSTION SCIENCE AND TECH.
CONSULTING ENGINEER
ELECTRICAL LIGHT AND POWER:ENERGY GENERATION MANAGEMENT
ELECTRICAL LIGHT AND POWER:ENERGY TRANSMISSION MANAGEMENT
ELECTRICAL WORLD
ENERGY DIGEST
ENERGY INTERNATIONAL
EARTH SCIENCES RESEARCH CATALOG
ENG.AND MINING J.
ENVORONMENTAL AWARENESS READING LIST
ENVIRONMENTAL SCIENCE CITATION INDEX
FUEL
FUEL ABSTRACTS
FUEL AND OIL HEAT
FUEL SOCIETY OF JAPAN
GAS
GAS ABSTRACTS
GAS TURBINE INTERNATIONAL
GEOTHERMICS
HEAT ENG.
HPAC J.
INTER.PETROLEUM ABSTRACTS
INVENTORY OF ENERGY RESEARCH
INST.OF GAS ENGINEERS J.
INST.OF MINING AND METALL.TRANS./SECT.A AND C
INTERMET BULL.
INTER.J.OF MINING SCIENCES
INTER.MINING EQUIPT.
J.OF AIR POLLUTION CONTROL
J.OF ENVIRONMENTAL SYSTEMS
J.OF INST.OF FUEL
J.INST.OF PETROLEUM
J.S.AFRICAN INST.OF MINING AND METALL.

LIGHT AND LIGHTING
MARINE TECH.SOC.OF JAPAN
MINE AND QUARRY
MINERALS SCIENCE AND ENG.
THE MINES MAG.
METEOROLOGICAL AND GEOASTROPHYSICAL ABSTRACTS
NSF-RANN ENERGY ABSTRACTS
NATL.PETROLEUM NEWS
NATIONAL SAFETY NEWS
NLPGA TIMES
NUCLEAR ENG.INTER.
NUCLEAR INDUSTRY
NUCLEAR NEWS
NUCLEAR SAFETY
NUCLEAR TECHNOLOGY
OFFSHORE
OFFSHORE SERVICES
OIL DAILY
OIL AND GAS J.
ONTARIO HYDRO RESEARCH QUART.
PEAT ABSTRACTS
PETROLEUM ABSTRACTS
PETROLEUM ENG INTER.
PETROLEUM AAND PETROCHEMICAL INTER.
PETROLEUM REVIEW
PIPELING AND GAS J.
PIPELINE INDUSTRY
PIPELINE NEWS
PIT AND QUARRRY
PLANT ENG.
POWER
POWER ENG.
PROCESS ENG.
PROCESS TECH.INTER.
PROFESSIONAL ENG.
SOC.OF PETROLEUM ENG.J.
S.AFRICAN MINING AND ENG.J.
TRANS OF SOC.OF MINING ENG.
TRANSMISSION AND DISTRIBUTION
TRANSPORTATION
TRANSPORTATION J.
TRANSPORTATION AND DIST.MANAGEMENT
UNDERWATER RESOURCES
U.S.NAVAL INST.PROC.
WATER RESOURCES RESEARCH CATALOG
WEEKLY GOVT.ABSTRACTS:ENERGY
WORLD OIL

SECTION IX

ENERGY CONSERVING AND COMPUTER DEPENDENT PRIVATE CAR (with OUTLINE AND NOTES ON POSSIBLE DEVELOPMENTS IN ENERGY CONSERVATION AND COMPUTER CONTROL FOR PRIVATE CARS)

Work Done By

J. Cocke
J. B. Ian Gunn
R. A. Toupin

Distributed by: R. L. Garwin
IBM Thomas J. Watson Research Center
Post Office Box 218
Yorktown Heights, NY 10598
(914) 945-2555

January 31, 1974

013174..JC

Energy Conserving and Computer Dependent Private Car
01/31/74

Ideas for the utilization of a built-in computer to the control of a private car have been floating around, both inside and outside IBM, for some years. The advent of the current "energy crisis" makes some of these ideas a great deal more timely, especially if they can be combined with available (but currently unexploited) mechanical technology for energy conservation. Although it is not likely that the manufacture of private cars, or even of the relevant electronics, will provide acceptable business opportunities for IBM, it does appear that we can perform a socially useful function by research and development in this area. In order to have a useful impact, work of this sort must lead to a working, driveable demonstration car, and this should be the goal of the project.

To make quantitative estimates of the energy savings available from various approaches will need more study than has been possible during the life of the task force, and probably some experimentation as well. However, it is believed that the biggest single step which can be made is the addition of regenerative braking, which will permit recovery of some or most of the energy now wasted in the frequent decelerations of urban driving. If implemented in the right way, it can be integrated with several other improvements. The basic necessity for such a scheme is a means of transmitting power to and from the wheels, in a readily storable form, and with high efficiency. Only two media seem to merit serious consideration: electricity and high pressure oil. Electric transmissions are less desirable, because the weights and sizes of electric motors and generators are greater than those of corresponding high-pressure hydraulic pumps and motors, and batteries capable of accepting energy at the required rate are not well developed.

Consequently we envisage a system which, in the fully developed form, would have the following characteristics: an internal combustion engine would drive a pump to maintain a pressure of the order of 5000 psi in a hydraulic system, which would feed a variable displacement hydraulic motor at each wheel. The displacement of the motors would be varied, under the control of the accelerator pedal, to produce the desired driving torque. On deceleration, the displacement would be reversed, thus producing a braking torque, and delivering energy to the system as pressurized oil. This energy would be stored for re-use, either by compressing gas in a hydraulic accumulator or, more desirably but less certainly, as kinetic energy in a flywheel* driven by a high speed hydraulic pump/motor. Anti-skid braking is easily incorporated by sensing wheel locking in conventional ways, and controlling motor displacement accordingly. Because the engine now serves only to maintain hydraulic pressure, it can be designed and computer-controlled with much greater emphasis on fuel economy and emissions than presently. Its peak power output can be reduced also leading to further fuel economy, because substantial extra horsepower will be available for short periods from the hydraulic accumulator. The engine need run only when actually required because it can be restarted frequently, reliably, and smoothly using its hydraulic pump as a motor, and the accumulator as the source of starting energy. In this way, it may be possible to achieve thermal efficiency from a spark-ignition engine comparable with a diesel; alternatively, it may be possible to achieve a higher power-to-weight ratio from a diesel. Certainly, idling can be eliminated, and with it the problem

* We believe it may be possible safely to store in a flywheel the relatively small amount of energy required for regenerative braking. To store all the energy required for a trip implies unacceptable consequences of even a minor accident.

of the diesel's noisy running at idle.

There are additional possibilities for energy conservation in exploiting waste heat from the engine, either in the coolant or the exhaust gas. Apart from the possibility of "bottoming" cycles, where the waste heat is used to provide additional motive power, it may be feasible to drive some by the accessories in this way. An immediate possibility is an absorption refrigerator for air-conditioning.

The presence of both a computer and a high-pressure hydraulic system will make it easy to add further functions, if desired, such as adaptive or active suspension. The computer can also be used for such things as better instrumentation, safety monitoring (including detection of a sleepy or drunken driver), and maintenance monitoring, as well as providing additional useful functions such as headlamp control. Accessories, both in the engine and body of the car, can be better controlled by a single-wire bus carrying both 12V d.c. and p.c.m. control signals than by a conventional wiring harness.

Opportunities exist to exploit the computer also to improve engine performance and fuel economy. An interesting possibility with a gasoline engine is inverted fuel metering, in which rate of fuel injection is taken as the independent variable, and air intake is adjusted by a metering system. If the air metering system includes a feedback loop to maximise torque output, the mixture is always adjusted to give maximum economy. This is not possible if air flow is taken as the independent variable, as in all conventional metering systems.

Because of the lack of necessary data, as mentioned in the second paragraph above, any serious attempt to design a regenerative braking system would probably require an initial effort to collect a statistically significant quantity of data on driving patterns. Fortunately, the significant variables - longitudinal acceleration, including any component due to gravity, and vehicle speed - are easily measured, and could be measured for many different cars and drivers by a quickly installed instrument package. Various hydraulic systems and control algorithms would then be evaluated against these data by computer simulation, and design could begin.

Any serious work along the lines proposed would require facilities which do not now exist at Yorktown. Apart from an appreciable investment in instrumentation, there is also needed a place to do the work. High-pressure hydraulic development work is very messy, and requires a lab adapted to handle large quantities of spilled oil. Work on an actual car requires a lab with garage doors, or something similar permitting driving in and out.

The following is a (very) rough estimate of manpower requirements for such a project:

Phase 1 Instrumentation and data gathering

- 1 P Instrumentation
- 1 T Electromechanical

Phase 2 Data analysis and simulation

- 1 P Hydraulics
- 1 P Simulation
- 1 T Coding, analysis, simulation

Phase 3 Design

- 1 P Hydraulics
- 1 P Control system and algorithms
- 1 T Draftsman

5.

Phase 4 Construction

1 P Hydraulics

1 P Control

2 T Mechanical

Phase 5 Testing

Same 2 P 2 T

Phase 6 Engine development

1 P Internal combustion engineer

1 T Mechanical

1 T Draftsman

Phase 7 Full exploitation of computer control

1 P Interfaces, transducers

1 P Software

1 T Electro-mechanical

Notes: a) Manager could be one of the professionals

b) Phases 5, 6, and 7 could be appreciably overlapped

OUTLINE AND NOTES ON

POSSIBLE DEVELOPMENTS IN ENERGY CONSERVATION AND

COMPUTER CONTROL FOR PRIVATE CARS

1 Total system changes

1.1 Car-train combinations

1.2 Mini-rentals

1.3 Hands-off highway guidance

1.4 Power from or in highway (LIM, trolley wire)

1.5 Selective pollution regulations

2 External changes

2.1 Advanced traffic control

1.1 Bunching

1.2 Individual route allocation

2.2 Advanced information systems

2.1 Road conditions

2.2 Individual route guidance

2.3 New fuels or additives

3.1 Hydrogen

3.2 Liquified hydrocarbon gases

3.3 Alcohols

3 Vehicle changes compatible with existing highway & support systems

3.1 Complete re-designs

1.1 Urban cars

1.2 Expandable cars

1.3 New Power sources

3.1 Steam (vapour)

3.2 Electric

3.3 Stirling

3.4 Flywheel

3.2 Modifications

2.1 Internal combustion engines of improved efficiency

1.1 Diesel

1.1 Supercharging for improved power/weight

1.2 Glow-plug or high-cetane no. fuel for decreased pressure

1.3 Idling eliminated

1.2 Spark ignition

2.1 Thermal efficiency

1.1 Increased expansion ratio

1.1 Early inlet valve closing

1.2 Variable clearance volume

1.3 Servo throttle

1.4 Ignition retard

1.2 Decreased heat losses

2.1 Low cycle temperatures

1.1 Very lean mixture

1.1 Stratified charge

1.2 Injection against continuous ignition source

1.2 Exhaust gas recirculation

1.3 Conventional (inlet) water injection

2.2 High coolant temperature

2.1 Non-aqueous liquid coolant

2.2 Air cooling

2.3 Evaporative cooling

3.1 Boiling liquid

3.2 Heat pipe

2.2 Mechanical efficiency

2.1 Ball & roller bearings

2.2 Piston design

2.3 Compound engines (bottoming cycles)

3.1 Exhaust turbine

1.1 Power

1.2 Accessories

3.2 Exhaust boiler + steam engine

2.1 Power

2.2 Accessories

3.2.1.2.3.4 Direct use of waste heat for absorption air-conditioning

4.1 Exhaust

4.2 Coolant

3.5 Cylinder water injection

5.1 6-stroke (additional cycle)

5.2 4-stroke (boosted power stroke)

2.4 Control

4.1 Fuel metering

1.1 Carburation

1.2 Fuel injection

2.1 Open-loop digital

2.2 Closed-loop with exhaust sensor

2.3 Inverted metering, closed-loop with torque sensor

4.2 Fuel distribution

2.1 Atomization

2.2 Vaporization

2.3 Supercharging

4.3 Ignition timing

4.4 Valve motion

4.1 Exhaust gas recirculation

4.2 Compression pressure

4.3 Torque optimization

4.4 Emissions optimization

4.5 Clearance volume ("compression ratio")

5.1 High expansion ratio at part load

5.2 High compression pressure for regenerative braking

4.6 Engine accessories

6.1 Fan

6.2 Variable air-conditioning

6.3 Single-wire control with p.c.m.

4.7 Idling & overrunning

7.1 Start-on-demand, no idling

7.2 Reduced number of cylinders for idling

7.3 Dead-engine overrun

3.2.1.2.4.8 Starting

8.1 Improved efficiency (non-electric)

8.2 Minimized rich-mixture operation

4.9 Impedance matching (engine/load)

9.1 Transmission to optimize fuel consumption

1.1 Close-ratio, multi-speed mechanical

1.2 Infinitesimally variable

2.1 Hydrostatic

2.2 Electric

2.3 Compressed air

2.4 Mechanical

4.1 Variator

4.2 Belt

9.2 Different engine configurations for acceleration/cruise

2.1 Two engines

2.2 Cut out cylinders mechanically

2.3 Clutched-in supercharger

2.2 Improved energy utilization

2.1 Regenerative braking

1.1 Electric

1.1 Battery storage

1.2 Flywheel storage

1.2 Hydraulic

2.1 Accumulator storage

2.2 Flywheel storage

1.3 Compressed air, reservoir storage

3.1 Engine used as compressor and motor

3.2 Separate compressor and motor

1.4 Thermal

4.1 Hot gas (Stirling)

4.2 Steam

3.2.2.2 Transmission efficiency

2.1 Oil-pump instead of splash lubrication of gearbox.

2.2 High-efficiency bevel gear final drive

2.3 Chains instead of gears

3.1 Gearbox

3.2 Final drive

2.3 Rolling resistance

3.1 Wheel bearings

3.2 High-pressure tires

2.1 Active suspension

3.3 Non-drag disc brakes

2.4 Suspension losses

2.5 Aerodynamics

2.6 Reduced vehicle mass

2.3 Improved vehicle utilization & control

3.1 Non-skid braking

3.2 Collision avoidance

3.3 Active suspension

3.1 Minimum power

3.2 Maximum adhesion

3.3 Levelling

3.4 Adaptive power steering

3.5 Instrumentation

5.1 Engine performance

5.2 Engine efficiency

5.3 Fuel consumption

3.1 Available range by extrapolation

5.4 Speed

4.1 Instantaneous

4.2 Average

4.3 Pre-set warning

5.5 Distance

5.1 Cumulative

5.2 Miles-to-go

5.3 E.T.A.

3.2.3.6 General accessories

6.1 Single-wire bus

6.2 Modulation

3.7 Lighting

7.1 Automatic high beam

7.2 Ambient light control of signal lights

3.8 Monitoring

8.1 Safety

1.1 Brakes

1.2 Steering

1.3 Lighting

8.2 Maintenance

2.1 Temperatures

2.2 Pressures

2.3 Fluid levels

8.3 Driver

3.1 Drunk

3.2 Asleep

Notes

1. Total System Changes

Obviously, the best opportunities for improving the convenience and energy economy of systems for surface personal transportation would arise from freedom to re-design the whole system (right-of-way, vehicles, support services, controls), rather than limited segments of it. However, the size and complexity of any such project, from the point of view of hardware, social, and legislative development, would seem to put it beyond the reach of any reasonable effort at IBM Research.

2. External Changes

The same difficulties (1, above) apply to a lesser extent to attempts to change the nonvehicle components of the system. Some work along these lines (e.g., traffic control) has been done at Research in past years, and it would be more reasonable to expand that than to start a new effort.

New fuels represent a borderline case. Some external changes (e.g. up to about 10% methanol in gasoline) could be accommodated with minimum vehicle modification. Others, such as a changeover to hydrogen or liquified hydrocarbon gases, would require revision of the vehicle and the whole support system. A limited degree of hydrogen injection, which has been proposed as a means to permit burning a very lean gasoline/air mixture, might be achieved by an on-board reformer, converting gasoline into $Co_2 + H_2$, with no change in support system.

3. Vehicle Changes

3.1 Complete re-designs

Changes restricted to the vehicle alone do not require the social and legislative development which are required by changes in the total system, and it is possible to envision the development of novel forms of car, such as small, low-powered, sideways-parking boxes for urban use, or expandable cars to which extra sections can be added when more capacity is needed; these again appear to be beyond the reach of a limited IBM effort. This applies to a lesser extent to the development of alternative propulsion systems such as steam, Stirling cycle, flywheel or electric. However, there is some possibility that rechargeable-electrolyte batteries might ultimately be developed to competitive levels of energy density, and so existing work on these devices might be continued with an eye to this possibility. Steam, Stirling, and flywheel systems seem to be under sufficiently intensive development elsewhere, although their significance is not yet clear.

3.2 Vehicle modification

Changes which can be developed as modifications to existing vehicle designs have the advantage that they can be developed with much more limited effort, and yet some of them, if successful, could be incorporated in complete re-designs of the vehicle.

3.2.1 Engines of improved efficiency

In the present environment, improved utilization of scarce petroleum fuels is probably the most visible need.

3.2.1.1. Diesel engines

Existing engines operating on the Diesel cycle have thermal efficiencies exceeding those of spark-ignition engines, especially at part-load. These result from a) increased expansion ratios, available for the high geometrical "compression ratio" needed to provide compression ignition, and b) high charge density, and hence reduced peak and mean cycle temperatures and heat losses, resulting from the absence of throttling at part load. However, the very high compression and peak pressures demand substantially stronger and heavier moving parts. This causes a Diesel engine to be heavier than a spark-ignition engine of the same displacement, and to be limited to lower rotational speed, so that its power output per unit weight is much lower. In addition, the rough and noisy running of present-day Diesels, especially at idle, hinders their acceptance for private car use. The power-to-weight problem might be alleviated by supercharging, which gives more power from the same displacement, or by some form of hot surface (glow plug?) ignition, or the use of a high cetane-number fuel, either of which might require less mixture compression, and hence less engine weight. It is not clear whether such a modified Diesel would retain the desired thermal efficiency. The problem of rough idle would be eliminated if idling were prevented (3.2.1.2.4.7.1)

3.2.1.2 Spark ignition engines

2.1 Thermal efficiency

The thermal efficiency of spark ignition engines can probably be improved, but at a cost which will have to be balanced against the advantages. The expansion ratio can only be improved by increasing the ratio of displacement to clearance (compression) volume, but means would have to be found to limit compression pressures, which are already as high as conventional fuels can use (alcohols can go higher, however). This means that a larger cylinder volume is needed to handle the same amount of fuel, and hence that the power output per unit volume and per unit weight will decrease somewhat, despite the increased efficiency. Means to control the compression pressure would include early inlet valve closing, variable clearance volume (small at high speeds or small throttle openings, where charge mass is small, large at full load, with sacrifice of efficiency) or servo control of throttle to maintain safe conditions. Variable clearance volume entails mechanical complication, but is feasible; servo throttle control has other advantages if combined with a novel system of mixture control (3.2.1.2.4.1.1.3). Delayed inlet closing is easily and cheaply implemented. A reduced clearance volume would have advantages with one scheme for regenerative braking (3.2.2.1.3.1) Another way to obtain a virtual increase in clearance volume would be to retard the spark sufficiently at full load, so that the combustion chamber has expanded to a safe volume before combustion reaches the detonation - prone stage. This would be the easiest of all schemes to implement, but would entail some loss of energy due to heat losses to the cylinder head from the charge before it is ignited.

Heat losses to coolant (as opposed to exhaust, which are controlled by expansion ratio) can be reduced only by decreasing the difference between the mean cycle temperature and that of the cylinder walls. The cycle temperatures can be reduced without other sacrifices only by increasing the heat capacity of the charge for a fixed fuel content. Probably the most attractive method is to increase charge mass by increasing the amount of air (i.e., use very lean mixtures), since this also reduces CO + HC emissions. However, additional means are needed to ensure ignition of weak mixtures; the most promising of these is the use of a stratified charge, but existing designs (e.g., Honda) probably do not go to weak enough mixtures to give much improvement in efficiency. A lot of work has been done on stratified charge systems in the past, and it is not clear whether a small effort could contribute anything useful. Another possibility is cylinder injection of gasoline against a quasi-continuous ignition source (spark or perhaps a laser discharge). In this case the distinction from the Diesel cycel becomes a bit blurred. Charge mass can also be increased by heavy recirculation of exhaust gas, but ignition problems are likely to be even worse in this case. The charge temperature can be decreased also by an increase of effective specific heat at some point between the atmosphere and the point of ignition, by the injection of a liquid (e.g., water) with a high latent heat of vaporization. (See 3.2.1.3.3 for other water injection possibilities)

Heat losses to coolant can also be decreased by raising the coolant temperature. Air cooling is the easiest solution, but the complications needed to extract heat from the confined environment of the cylinder heads of an enclosed, multi-cylinder engine exact a heavy price in bulk and power consumption for the blower. Possibly a better scheme is to go to liquid cooling at temperatures over 100°C, using a liquid other than water (aircraft engines have used pure ethylene glycol for years), or some form of evaporative cooling. Heat-pipe techniques have not yet been exploited for engine cooling, but would be especially attractive if a sprayed wick could be developed, to be applied to the jacket surfaces of cylinder heads and liners. This would have the additional advantage of more uniform temperature distribution through the engine. A heat pipe can only be used with a pure liquid, however. Any rise in coolant temperature, but especially one involving a vapor, would make it easier to exploit waste heat (See 3.2.1.3.3 and 4)

3.2.1.2.2 Mechanical efficiency

Present designs of piston engine have quite high values of mechanical efficiency; some improvement can be made by the use of properly designed ball and roller bearings, instead of plain journal bearings for crank- and camshafts, but at substantial expense. A better return might result from reduction in piston friction by the use of narrower rings, radical slipper skirts, and roller or teflon thrust guides.

3.2.1.3 Compound engines

Because about 70% of the heat content of the fuel is rejected to the atmosphere by a spark-ignition engine, considerable improvement in efficiency would result if some of this heat could be pub to work. Because this would be done after the primary expansion, this would be equivalent to the addition of a bottoming cycle. Topping cycles do not appear to be practical because of the very high temperatures involved. Exhaust turbines are now highly developed, but because of their very high speed, are inconvenient as a source of additional primary motive power. Alternatively, a steam or other vapor engine can be driven from a boiler heated by exhaust or coolant, or even more conveniently from a boiling coolant. In all these cases, the expense of coupling the secondary engine to the drive train can be avoided if it is used, instead, to drive accessories, such as supercharger (already a well-developed application), alternator, or air conditioner. The simplest scheme of all would be to use exhaust or coolant heat to drive an absorption refrigerator directly.

Some forms of secondary engine might be adaptable to regenerative braking (3.2.2.1)

An interesting scheme which has recently been proposed is to utilize the waste heat, which would normally be rejected to the coolant, to vaporize water injected directly into the cylinder during an additional power stroke. Additional power is developed in this way, with the claimed result that the thermal efficiency is raised by about 10%. The heat is extracted directly from the surfaces of the combustion chamber, which requires no other cooling. It is not clear whether the heat transfer rates available from a solid surface to an impinging stream of water are sufficient to make this a practical proposition. Since an additional exhaust stroke is needed to dispose of the steam before the internal combustion cycle can be repeated, this has been described as a 6-stroke cycle.

It might be possible to use a similar scheme with a conventional 4-stroke cycle in which water would be injected on the power stroke shortly after combustion is complete. In this case, heat would be extracted from the hot gases, as well as from the chamber surfaces, and so the heat transfer problem would be eased. Also, the power for a given displacement would be increased, since the steam simply raises the b.m.e.p. The disadvantage would be the increased pressure needed to inject the water against full combustion pressure.

In both cases, there would be a weight penalty in the water tank needed.

3.2.1.2.4 Improved engine control

4.1 Fuel metering

All existing mixture control schemes allow engine speed and throttle opening to determine air flow, and attempt to meter fuel flow proportionately. The disadvantages of carburation seem to be so great that the limited improvements in metering which might be made are not worth while. Fuel injection, on the other hand, offers many advantages. Injection into individual inlet ports or cylinders eliminates mixture distribution problems, and is readily adaptable to electronic control. Existing systems generally make some compromises, such as shared injectors, and use analogue electronics. All operate as open loops - that is, the fuel requirements are calculated by dead reckoning from variables such as manifold pressure, temperature, and engine speed. Further improvement will result if the calculation is done digitally (e.g., by table look-up), as it can take better account of more variables, and this has already been proposed, though not marketed. A much better scheme is to sense the oxygen potential of the exhaust gases by means of a semiconducting sensor, and to correct any error by closed-loop feedback to the injectors. This scheme is not yet fully practical, owing to the limited life of the sensors. A possible compromise is to up-date the data of an open-loop system by intermittently closing the loop through an exhaust sensor.

There is an alternative scheme which does not seem to have been explored, and which offers what look like substantial advantages. In this scheme, the functions of the accelerator pedal and the metering system would be reversed, with the pedal controlling fuel flow and the metering system operating a servo-controlled throttle to provide the correct air flow. Then, if the loop is closed by sensing b.m.e.p. (torque), and controlling the air flow for a maximum of this variable, the system automatically operates at the most efficient conditions of weak mixture. No delicate exhaust sensor is needed, and it becomes easy to use a reduced clearance volume to improve the expansion ratio, since a simple limit on fuel flow will cause the servo automatically to limit the air flow to a safe value. There may also be a psychological advantage to such a control system, since fuel consumption will be much more closely related to accelerator pedal position than is the case with a conventional throttle, where engine speed is equally important.

4.2 Fuel distribution

As we have said, port or cylinder fuel injection eliminates mixture distribution as a problem, so there is little point in pursuing fuel atomization or vaporization schemes (by ultrasonics, heat pipes, etc.) which are advantageous with carburettor systems. Also, supercharging loses its advantage of improving distribution.

4.3 Ignition timing

Existing ignition systems vary ignition timing by inaccurate mechanical means according to a crude algorithm related to engine speed and inlet manifold pressure. Digital electronics would permit a great improvement in accuracy, but, since most engines are not very sensitive to ignition timing, the value of this is not clear.

4.4 Valve motion

In current engine designs, valve motion is intended to remain fixed. With belt- or chain-driven double overhead camshafts, it is relatively easy to vary the camshaft timing relative to the crankshaft, if necessary under some form of real-time control, but it would be much harder to vary the duration of valve lift. Probably some advantage in fuel consumption (or equivalently, b.m.e.p. for a given fuel flow) could be obtained by controlling the overlap events (inlet opening and exhaust closing), with fixed durations, and exhaust gas recirculation could be controlled similarly. To use inlet closing to vary air flow (perhaps advantageous with increased expansion ratio) would require a variable duration, however.

4.5 Clearance volume control

Variation of the clearance (combustion chamber) volume is mechanically awkward (because the mechanism must handle full piston thrust and combustion temperatures, and possibly piston velocities as well) but is perfectly feasible, even Diesel engines having been built this way. It offers an attractive means of combining high expansion ratios for part-load economy with the availability of full power (at reduced expansion ratio) when needed. The ability to reduce the clearance volume to a small size would permit very high compression pressures (of air without fuel) to be used for regenerative braking (3.2.2.1.3.1)

4.6 Engine accessories

Engine accessories (fan, alternator, and pumps for water, lubricating oil, power steering, exhaust air, air conditioner refrigerant) now consume a significant fraction of gross engine output. Of these, one of the worst is the fan, but the recent development of thermally controlled clutches and electric drives has mitigated this. Nonetheless, considerable power could probably be saved by more sophisticated control of all the accessories, if indeed it is not practical to drive them from otherwise wasted heat energy (3.2.1.2.3).

4.7 Idling & overrunning

In long distance driving on limited access highways, only light-load, high (road) speed fuel economy is important. Under urban conditions, the whole cycle of starting, accelerating,cruising, braking, and idling becomes important. The simplest way to improve fuel consumption in traffic jams is to switch the engine off, instead of letting it idle, but to make this acceptable, re-starting must be simplified, e.g., by control through the accelerator pedal. One of the Japanese manufacturers is already offering this, presumably with the Tokyo market in mind. Present electrical starting systems are not sufficiently efficient or durable to be the best solution to this problem; some forms of regenerative braking would be ideally suited (3.2.2.1)

Another remote possibility is a reduction in the number of active cylinders during idling, but this would require that the inactive cylinders be mechanically uncoupled to eliminate their losses.

Overrunning (car driving engine during deceleration) wastes energy in the mechanical losses of the engine. Only some of this energy would be recovered if the engine were disconnected and switched off on overrun (because in many cases the brakes would be used instead) unless regenerative braking were used as well. However, some fuel would be saved with present carburettor systems, which actually open the throttle slightly on over run to comply with emission requirements. Any sensible fuel injection scheme would switch the fuel off altogether on overrun, and then there would be little savings in disconnecting the engine without regenerative braking.

4.8 Starting

If idling is eliminated, the actual efficiency of conversion of stored energy into engine rotation may become important, as mentioned above. Another consideration is more sophisticated control of cold starting. Existing automatic choke systems try to fit all combinations of weather conditions and load with a single response, which results in excessive idling speed and mixture enrichment under average conditions. More sensitive control could minimize the amount of fuel used.

4.9 Impedance matching

The very variable mechanical impedance presented by a car which changes between acceleration, hill-climbing, and cruising, results in the engine often operating under conditions which are far from the optimum for fuel consumption. This is especially true with manual transmissions, given the extreme reluctance of the average driver to change gear. Conventional automatic (hydrokinetic) transmissions are mechanically inefficient. Multi-speed mechanical transmissions would become more acceptable if manual gear changing were eased or eliminated by automatic control, and the latter could be arranged to optimize the fuel consumption given the prevailing road conditions. Some form of overdrive would be essential for economical cruising, and gear changing could be done through multiple mechanical or electrical clutches (as in the Wilson pre-selector or Cotal electric gearboxes) or even through a conventional single clutch with computer control of clutch and throttle opening. More and closer gear-ratios than the normal 4-speed box might be needed.

An alternative approach would be the use of an infinitesimally (not infinitely!) variable transmission of hydrostatic, electrical, or mechanical type: The first two offer an easy way to incorporate regenerative braking, but electrical rotating mechinery is at a disadvantage from the point of view of bulk and weight, and appropriate batteries are not yet available. Hydrostatic transmission, using variable displacement pumps and motors, is very compact and can be very efficient, but tends to be expensive, because of the close tolerances required in the moving parts. Mechanical types exist, using rollers or belts connecting wheels of variable effective diameter, but they are not very well developed for the power levels required. Compressed air could also be used in principle, but is undeveloped.

Another way to match engine and load is to change the engine configuration as needed, for example by using a small engine and a large one which runs only when needed, or by switching off and mechanically disconnecting un-needed cylinders of a multi-cylinder engine. In these cases, the mechanical complication may outweight the advantages. A further scheme which has been used in the past is to provide a supercharger which is used only when needed, but in this case the range of "impedances" available is limited. One could view a turbo-blower as a device of this class.

3.2.2 Improved energy utilization

Equally as important as extracting the maximum mechanical energy from a limited amount of fuel, is husbanding this energy when produced. In urban driving, a large amount of energy is wasted in braking, and some of this could usefully be recovered. In highway driving, smaller amounts of energy are wasted in losses which are not strictly necessary. The major highway losses, tire rolling and air resistance, are probably difficult to reduce.

3.2.2.1 Regenerative braking

Any system which will allow some of the kinetic energy of the vehicle to be recovered on deceleration will improve urban fuel consumption. Since driving an internal combustion engine backwards does not cause fuel to flow out of it, some more reversible mechanism must be added. Although it does not need to cope with heavy braking (which occurs rarely and would be handled by conventional brakes), a regenerative brake should recover energy at a peak rate comparable with the power output of engine.

In addition, the energy stored in a regenerative system could even be used to boost the output of an abnormally small and economical engine to provide high peak powers, as for acceleration into fast-moving traffic. In this case, one might want to extract energy from the engine itself during periods of light load.

As mentioned before, D.C. electrical systems are probably ruled out on grounds of bulk and weight of the machinery, and because batteries which can be efficiently charged at the needed rates are not yet developed. High-frequency machines, and flywheel storage, would be more compact, but flywheel technology is still in its infancy.

Hydraulic regenerative braking, in which energy would be stored as fluid under pressure in an accumulator, is easily integrated with a hydrostatic transmission. In this case, only the accumulator and controls need be added.

Compressed air represents an energy storage medium which could perhaps be exploited with minimum additional equipment. The conventional piston engine, with minimum changes, could serve, if fuel were cut off, both as a compressor for braking and as an air motor for propulsion, but it would not serve simultaneously as a prime mover without more extensive alterations. In any case, additional valves, or variable timing for the normal ones, would be needed. One difficulty with storing compressed air in a pressure vessel, and indeed, with a hydraulic accumulator of the gas-energized type, is that much of the heat of compression may be lost, even if the reservoir is insulated, so that some of the energy absorbed is lost. Other difficulties with compressed air are that the reservoir would be excessively bulky at reasonable working pressures of 300 psi, and that even these pressures would require reduced clearance volume if the engine were to be used as the compressor.

An air compressor and motor separate from the engine probably offers no advantages over an equivalent hydraulic system.

A possible storage medium is a hot body, with which some heat engine, other than an internal combustion one, would exchange energy. This would be an especially attractive scheme if a Stirling engine were the prime mover, since limited amounts of heat could be stored in the engine itself. Similar schemes could be used with steam.

3.2.2.2 Transmission efficiency

As explained above, present hydrokinetic transmissions are unacceptably inefficient, and probably inherently so. Conventional mechanical gearboxes are much better, but still have losses, which are not unavoidable, due to oil churning. These could be eliminated by a drop in the oil level, with a metering pump replacing splash as the oil transport mechanism. The same thing applies to conventional hypoid bevel final drives, but in addition, these contain two more sources of avoidable friction. The first of these is the axial sliding which occurs in the meshing of hypoid bevels, but not of old-fashioned straight or spiral bevels which have intersecting axes. The latter may be more expensive to produce, and require a higher drive shaft location, which complicates body design in conventional front-engine, rear-drive cars. The second source of friction is in taper-roller bearings, where axial thrust causes friction between the roller ends and the abutting face of the inner race. Since the bearings are necessarily subjected to an axial preload, it might be worth replacing the taper-roller bearings by a more complex design using balls and cylindrical rollers.

A further improvement in friction losses could be made if all gears in the drive train were replaced by chain-and-sprocket drives, using either roller or inverted-tooth (Morse) chains. Chain drives are the most efficient known means of coupling shafts at different speeds, and are cheap to produce and reliable if properly lubricated. They do require wide shaft centers, so they often take more space then equivalent gears. They cannot couple shafts at an angle, so a pair of bevels would still be needed except in transverse-engined designs.

3.2.2.3 Rolling resistance

Rolling resistance (i.e., all non-aerodynamic energy losses beyond the drive train) contains three components: wheel bearings, tires, and brake drag. Taper-roller wheel bearings, if preloaded, have the same losses as in final drives, and can easily be replaced by ball bearings. Tire losses are related to pressure and cross section, and probably cannot be substantially reduced, with conventional suspension, without compromising road-holding and ride comfort. However, small improvements might be made (not by IBM!) by detail tire design changes, if rolling resistance became an important tire design parameter. Better opportunities might be provided by the development of a servo-controlled suspension, which would simulate an unsprung assembly (wheel, tire, and brake) of reduced or zero mass, at least over some frequency range. An ideal active suspension of this sort would reduce the effective mass to zero, which would permit infinitely stiff (and thus loss-free) tires to follow road irregularities. This is obviously unachievable, but a practical scheme might permit worthwhile improvement. It remains to be seen whether the savings in rolling resistance would outweight the energy used by the servo (though the latter could, in principle, be made regenerative in addition). (See below, and 3.2.3.3)

Modern disc brakes have some drag even when not applied, which could be eliminated by detailed re-design.

3.2.2.4 Suspension losses

Energy absorption by the necessary damping of suspension movements plays a negligible part except on very rough roads. If it were important, it might perhaps be reduced by a regenerative active suspension.

3.2.2.5 & 5 Aerodynamics and vehicle mass

Vehicle mass is probably the single most important determinant of fuel consumption, but it is probably difficult to get much below 2500 lbs. without unacceptably expensive construction, too much austerity for the market, or failure to meet the safety regulations.

To make an appreciable improvement in aerodynamics probably requires a complete re-design, rather than modification, and will be of real importance only at speeds higher than those common in the U.S.

3.2.2 Improved vehicle utilization and control

3.1 Non-Skid braking

Systems which limit the deceleration of an individual wheel, to prevent the brake from locking up, are now well developed, but would be more acceptable if the price could be lowered through the use of shared logic.

3.2 Collision avoidance

Various active, passive, and harmonic radar systems have been proposed, all of which would benefit from cheap on-board logic, but the present problems relate more to the overall system than to detailed implementation.

3.3 Active suspension

The concept of an active suspension has been discussed above (3.2.2.3) in connection with the use of low rolling resistance tires, and the reduction of suspension losses, but its applications are not so limited. By optimizing the response of the servo to maintain best contact between the tire and road surface, handling and road-holding could probably be improved. This would probably require a sophisticated adaptive servo, which would benefit from computer control. An additional function easily incorporated with an active suspension is levelling, to keep the mean vehicle altitude constant in the face of load changes.

3.4 Adaptive power steering

For large vehicles, power steering may be a real necessity. In that case, a variable servo is well worth while, to alter the steering response and feel as a function of road speed, as has already been done. This is another function which could benefit from on-board logic.

3.5 Instrumentation

The titles under this heading seem to be self-explanatory.

3.6 Accessories

Digital control can achieve an enormous simplification in the control of electrical and electromechanical accessories, which represent a majority of those used in modern cars, and an even greater proportion of the unreliability and service problems. The improvement would result from replacing the present monstrous wiring system by a single bus carrying both 12 V d.c. and time multiplexed p.c.m. control information. Each accessory would have a decoder, with a unique address, which would permit control either by manually operated switches (each with an encoder), or by a central computer. Such schemes are already in use in controlling the passenger compartment lighting of the Boeing 747, and have been announced (but not sold) for automotive use in Britain.

An additional improvement in accessory systems which would be desirable is to provide for continuously variable, rather than on-off, control, especially in such energy-consuming areas as air-conditioning.

3.7 Lighting

Very little technical progress can be made at present in the design of lighting units themselves, because the existing regulations constrain structure, as well as limiting performance. However, lighting control is not so inhibited, and the presence of an on-board computer could permit advances in this direction, such as automatic high-low beam control, modulation of signal lights according to ambient light levels, and so on.

3.8. Monitoring

One of the most useful groups of functions achievable by an on-board computer is the collection of data to warn of or prevent unsafe conditions. Such things as brake performance and lining thickness, steering play, and lighting failures could be diagnosed in real time, and fluid levels, pressures, and temperatures could be measured to reduce the amount of routine preventive maintenance required. In addition, driver behaviour patterns (chiefly small steering movements) could be analyzed to detect a driver who is drunk or in danger of falling asleep.

IBM CONFIDENTIAL

SECTION X

MEMORANDA TO EFT FROM THE CHAIRMAN

R. L. Garwin

Name Internal Zip City & State

To: Energy Task Force ("ETF")

IBM

Date: January 2, 1974
Name & Tie/Ext.: R. L. Garwin
Title/Dept. Name: 465
Zip/City, State: 7-045
U.S. mail address: Yorktown Heights, N.Y.

IBM CONFIDENTIAL

Subject: Scope and Organization of the ETF

Reference:

By January 30, 1974, the date of its reporting and dissolution, the ETF will have:

1. Explored the promise of certain opportunities in sufficient depth to have them initiated as new research division ("RD") programs,

2. Reviewed the entire field of energy production, consumption, management, and trade-offs in sufficient depth so that its report, although it is impossible to make it complete, can serve as an example of the kind of review which must be continued within the departments and the staff to guide new research programs in energy-related areas, and

3. Answer certain specific questions, e.g. as to present prospects for and the ultimate promise of silicon or other photo-voltaic cells.

Logically, the work at the ETF (and most energy-related work) can be categorized as:

I. Energy Production
II. Energy Consumption
III. Energy-Related Regulation, Modelling, Planning, Legislation and Enforcement.

Since neither the ETF nor IBM has within its power to make all trade-offs among various aspects of production or of consumption, we shall not have sub task forces corresponding to the major categories, but shall partition the substantive efforts under these categories as correspond to our needs, our talents, and the opportunities. Thus we may consider the following sub-items, presented here as a list, and in expansion of which there will then appear (unequal) paragraphs of text to serve as a beginning for sub-group efforts. As individuals, we shall be judged every bit as much on our ability to ask the right questions as to answer them during January.

I. ENERGY PRODUCTION

A. Silicon and other solar cells.
B. Other solar power, e.g.
   1. Solar-thermal power plants (Meinel, Physics Today, February, 1972, pp.44ff)
   2. Bacterial or other production of hydrogen gas from sunlight.
   3. Systems for growing plants from sunlight, which plants will serve to make methane.
   4. One-or-more-stage fluorescent concentrators of diffuse sunlight (R. L. Garwin, Rev. Sci. Instr.31,1010-1011, Sept.1960. W.A. Shurcliff
C. Energy Storage Schemes for Solar Power Plants
D. Improved solar heat and light of buildings
E. Improved coal mining techniques (e.g. anoxic mining)
F. Coal gasification prospects for producing low BTU process-gas and high BTU pipeline-gas.
G. Coal liquefaction techniques for producing synthetic crude.
H. In-situ retorting of shale oil.
I. Explore feasibility and economics of a total energy package involving a nuclear reactor for a large office building, apartment development, and possibly its neighborhood. Also benefits of an IBM-owned standard 1000 MWE power reactor feeding the electrical grid, with rights of withdrawal from that grid.

II. ENERGY CONSUMPTION

A. Improved economy or flexibility in stationary combustors (e.g. fluidized bed combustion of coal, with the removal of pollutants in the combustor rather than from the stack gas).
B. What are existing efficiencies of oil burners, and prospects for improvement of efficiency e.g. by burning of a 20% water-oil emulsion.
C. Reduction of energy consumption in a large facility like IBM Yorktown or IBM Armonk by rationalization of energy management, use of a total energy package, attention to regenerative heating and cooling, heat pipes, and improved insulation, etc.
D. Office-related energy consumption and its possible reduction.
E. Reduction of energy consumption in the home, especially the adaption of computer management, recycling to the greatest extent possible, etc.
F. Opportunities for energy conservation in transport, e.g. by more effective use of railroads, etc.
G. Energy conservation in private automobiles by the integration of a computer deep in the automobile design.

III. ENERGY-RELATED REGULATION, MODELLING, PLANNING, AND ENFORCEMENT

A. Energy accounting and tagging system to serve as a basis for decision by the producer, consumer, regulator, and other decision maker.
B. Modelling of world and U.S. energy production and consumption to serve as a basis for decision by government and private actors.
C. (Somewhat out of place) environmental monitoring to allow health-related environmental standards to be achieved by more flexible emission standards.

Now the promised paragraph of comments on some of the above items:

IA. Silicon and other solar cells

Everyone asks this question, including Frank Cary of Ralph Gomory. Solar cells are evidently extremely useful and even economical in providing electrical power to satellites. The economics are entirely different on the earth. However, only the top one micrometer of silicon is needed to absorb the photons -- what are the prospects for producing silicon or some amorphous material to provide solar electric power at considerably reduced costs? What then are the opportunities for powering isolated homes, buoys, safety-related road markers and telephones with economical solar energy? This question is so prevalant that the ETF should produce an interdivisional view, by involving personnel from FSD and personnel from Fishkill. Invention is demanded of us, and the amorphous bubble materials are proof of the success of invention.

IB. Other solar power sources

1. The economics of a solar-thermal power plant depend to a considerable extent on one's ability to concentrate the light by cylindrical aluminum reflectors, to minimize the radiation of thermal energy from the hot light collectors, and to produce and maintain such a system at low cost. What is our judgment of the realities and the prospects?

2. G. Corker and M. Tomkiewicz are working at Yorktown with bacterial and other systems which produce hydrogen from photons. By how many orders of magnitude does the present status depart from economical production of power for hydrogen pipelines, and what would a productive system look like?

3. Methane from plants from sunlight.
What are the best plants presently available for capturing sunlight and atmospheric carbon dioxide and converting it to materials which will then produce methane by fermentation? What are the prospects for improvement? For the use of algae or bacteria, etc.? What are the waste materials from such a plant -- how would one close the cycle; what are the economics of storage of the methane precursor versus the storage of methane, etc.?

4. Fluorescent concentrators of sunlight.

While direct sunlight may be concentrated by mirrors or lenses to produce temperatures comparable with those of the surface of the sun, diffuse sunlight can obviously not be so concentrated for transmission or use. On the other hand, the edge of a fluorescent lucite plate exposed to diffuse white light can be much brighter in the fluorescent spectrum than the incident light. In principle, the concentration factor in a single stage could exceed 100. What are the physical limitations and the economics of concentrating diffuse sunlight in this way to provide light, process heat, space heat, or electrical power?

ID. Improved solar heating and lighting

Solar energy is generally regarded as an untapped resource, but of course we do use solar energy for producing food, fiber, timber, etc. Similarly, the fossil fuels are the encapsulation of solar energy. More currently, in many buildings one can work by daylight; highways need electric lighting only at night; and the sun flooding in through a window can make a room warm even in the dead of winter. Can IBM do anything by improved design to make better use of solar heat and light in our facilities, to help our employees reduce their energy consumption in this way, and in both cases, to mediate the ill effects of solar heat in the summer?

IE. Coal mining

Strip mining is receiving considerable attention, even to the reclamation of the land. Deep mining is affected by high costs of ventilation, explosion prevention, cost for paying for black lung disease, etc. To what extent might it be possible to mine regions not currently mineable (too gassy), and to reduce costs of opening or conducting mining operations by the use of an anoxic atmosphere in which the miners are provided with breathing air through hoods or face masks or suits, and the waste air is returned to the surface or catalytically combined within the mine? TRW some years ago did some preliminary studies for the government on improving the productivity of deep coal mining.

IF. Coal Gasification

Coal gasification by the Lurgi process is being conducted by at least one modern, competitive plant in Italy. What is the status of such operations, what are the prospects for improvement by the application of science familiar to or of interest to IBM?

IG. Coal Liquefaction

The production of synthetic crude oil from coal has been achieved on a small scale. To what extent are there opportunities for improving the economics by the application of surface chemistry, surface physics, or other science? Does computer control of coal gasification or liquefaction plants help at all?

II. Nuclear Reactor

The fuel cost existing commercial reactors is less than 10% of the production cost of electricity. If a small reactor is less efficient in its use of fuel, the cost of electricity to the consumer will not be significantly increased. What are the characteristics and cost of a total energy package involving a reactor which might produce some ten megawatts of electrical power (10MWE) and provide some of its waste heat for space heating, air conditioning, etc. as contrasted with the present situation in which the utilities build 1,000 MWE reactors? Gulf General Atomic might be the place to start making inquiries.

IIA. Combustion of Coal

The efficient and environmentally acceptable combustion of coal in large utility power plants seems to be beyond the scale by the IBM Research Operations. On the other hand, a modular system providing on the order of 100,000 BTU per hour for home heating and for the production of electricity, involves the burning of only about 10 pounds of coal per hour and is something which could perfectly well fit into a normal laboratory operation. Depending on the results, one could either scale up the process by a fact of 100 to handle a building like Yorktown or use 10 modules each of 10 times the home-heating-module size.

IIB. Oil Burners

There are recurrent reports of improved combustion efficiency, a greater power output per unit size of burner, etc. from the burning of water-oil emulsions. Similarly, dispersion of the fuel by ultrasonics or by turbulence may improve the efficiency. What is the average efficiency of oil burners and to what extent can it be raised by improved design, adjustment or monitoring?

IIB'. The Hydrogen Pipeline and the Hydrogen Economy

In the long run, it may be hydrogen and not largely methane which flows through the pipeline. Hydrogen has a much wider explosive range mixed with air than does methane, but the greater explosive hazard may lead (paradoxically) to a safer system, in that one may have automatic monitoring of gas flow into the building of all combustors, etc., with automatic shut off of the flow. What are the problems of hydrogen economy? Will hydrogen be stored directly on the vehicle for use in automotive transportation, or will it be sucked a little at a time from automatic dispensing stations a few tens of miles apart?

IIC. Conservation and Facilities

What are the numbers for fuel and electricity consumption in a building like Yorktown? like Armonk? To what extent can fuel economy be realized by the use of total energy package? How much saving can be made by the use of regenerative heating and cooling (REECO Corp) and by the use of heat pipes to provide heat exchange between incoming and effluent air streams (Q-DOT Corporation)? To what extent can improved insulation help reduce the energy consumption, and how can computer monitoring of sensors and control of the building help by tailoring illumination levels, heating, ventilating, and air conditioning (HVAC) to occupancy? This category has more to do with the building as a general purpose facility than with the kind of work that goes on in it. The place to start is with numbers from Leon Cookman and comparable numbers from the IBM Energy Council.

IID. Reduction of Energy Consumption in Office

Here we need data on the energy involved in CRT or gas panel display versus paper for computer output; comparable comparison between hard-copy books and access to computer files; a good physically-based evaluation of micro image option, including micro image displays which use a little bit of technology -- e.g. automatic focus, non optical display (for instance, laser scan and laser display); electrical transmission versus the mails.

To be considered also are the eventual economics and the energy economics of time-division satellite communications; the near-term and long-term availability of voice-grade phone lines; the time required to obtain telephone lines suitable for data transmission; the availability and cost of the three dollar per month (fifteen dollar per month in New York state) data protection adapter which allows one to hardwire to telephone lines; the possibility of remote dictating; the automatic preparation of either silver halide or xerographic or other microimage material to reduce the space required for filing and weight of material to be taken home at night. Portable, convenient, high-quality microimage viewers; remote viewing of mechanically-accessed microimage materials (as installed by IBM at the New York Times) -- see FSD Graphic Systems Material, then have Charles Touchton (FSD Graphics) ---8-372-7345 come up to talk with you.

Furthermore, consider the possible saving in time and energy of having routinely available facilities for remote conferencing. Perhaps visit Port Authority prototypes with D. Gazis; (see Leon Cookman about discussions at Yorktown) determine to what extent the need for travel to the office can be eliminated by these technical innovations, and the extent to which therefore <u>no</u> permanent office space need be assigned. How in such a new world would one <u>share</u> office facilities if they were required for an individual only ten percent of the time. To what extent does this same problem of nonpermanent office space arise in discussions of three and four-day work weeks for individuals while institutions maintain a five or six-day week to their customers. In these considerations we should in <u>no way</u> be constrained by the present or planned availability of IBM equipment. We should seriously consider demonstrating in the Research Division, both in the professional and in the administrative area how the office of the future might look, even though this might require very substantial investments in non-IBM equipment, modifications of IBM equipment, etc. For instance, to what extent can our telephone operators function in entirely the same way as at present from their homes, by the addition of one or two voice-grade lines and the addition of remote indicators and switches. (Since an operator can only listen to one line at a time and can talk into one mouthpiece at a time, would not this be a feasible system?) In the larger world if one does have work-at-home -- for telephone operators, information operators, airlines reservations clerks, etc. how does one:

1) Distribute promptly to them updated hardcopy materials as are required?

2) Monitor their response to ensure adequate work habits and provide relief when required for flexible working? What are the factors involved in compensation for work-at-homes, in view of the absence of travel time and cost on the one hand, and the use of space in the home on the other?

IIE. Demonstration Home

The article "Energy Conservation by Redesign" IEEE Spectrum November 19, 1973, pages 36-43, distributed at our 12/21/73 Meeting notes two demonstration homes under construction by Westinghouse and PP and L. For the most part, these attempt to reduce energy consumption by insulation, heat recovery from various appliances, use of solar heat, storage, etc., etc. We should review what is being done to see what economies and improvements could be effected by the use of as much sensor and computing power as is necessary, in the confidence that it will all be of very low cost in the future, when replicated in millions of homes. We should look also at individual apartment buildings and apartment developments. To what extent can energy requirements be reduced by automatic control of HVAC and lighting according to occupancy. If fuel oil is truly short and is rationed or otherwise rigidly allocated, would it be useful to have accurate measurements of instantaneous consumption as well as accurate measurements of reserves left in the tank? What modification need be made to allow life to go on while large portions of the home are allowed to come to outside temperature?

To what extent do these energy conservation measures coincide with the measures needed to have efficient self-contained homes, thereby opening up for high-class occupancy areas in which there are no public utilities? One would hope to recycle water, convert septic tank wastes into methane, make use of solar heating insofar as it is efficient, store heat, have a total energy package for generating electricity and space heating, etc.

To what extent can the computer be otherwise useful in the house for monitoring, optimizing, taking and giving telephone messages, recording radio and TV broadcasts and deleting commercials; operating accurate clocks and reminders throughout the home; providing warning of fire, water, and unauthorized entry; etc., etc.? To what extent can access to the computer/control system be made as easy as access to the home electrical power system, simply by running a single data loop inside the walls with access by plugs? If some homes will have a computer terminal facility provided by the employer, what would be the <u>incremental</u> ultimate costs required to provide these home-specific capabilities?

IIF. Transport

In 1972, some 7.7 million barrels of oil per day equivalent were used for transportation, of a total of 31.6 million barrels per day equivalent. For freight, trains and ships use less than 20% as much energy per ton mile as do heavy trucks. To what extent can computer control of freight cars, automated warehousing, etc. improve the attractiveness of railroad and thereby reduce the energy consumption?

Of course one of the best ways to save energy and transportation is to reduce the amount of transportation required, e.g. not to send equivalent products from New York to Chicago and from Chicago to New York. Furthermore more durable products need to be transported less frequently, and for the most part use less energy in their manufacture as well (per unit time).

Energy can be saved in freight and passenger transportation by improved traffic control, by holding to desired speed limits, by reducing the number of stops necessary, by alerting drivers to road hazards, by enforcing rational parking regulations, etc., etc.

IIG. Car

If an automobile is designed around a computer, one could use automatic clutching with an essentially manual transmission, putting substantially less strain on the clutch, since the engine can be automatically controlled so that it engages it every time with zero slip. The computer could provide the driver with an indication of instantaneous gas mileage, with precise measurement of fuel remaining, and could be used as in the Bosch fuel injection system to provide good fuel economy, precise adjustment of fuel/air ratio in order to allow a single catalyst to meet the emission requirements, etc. Furthermore, the computer could monitor and adjust brakes; turn on the air conditioning only when it is really required; provide refill of a compressed air reservoir for safe power braking and steering; monitor safety features such as lights, battery state of charge, control the transmission of a radio signal when the car was stopped on the highway if it had suffered a serious deceleration, provide safe free wheeling, etc.

If one were to demonstrate a model car, one would have to satisfy the existing safety requirements and the existing motor vehicle emission requirements. In other respects, one seems to have a great deal of freedom. One should take advantage of the fuel economy of the diesel engine (twice as good as that of the gasoline engine car) and of the longevity of the diesel (two hundred thousand miles is typical as compared with about fifty thousand miles for a gasoline engine).

IIG. Car (continued)

Existing passenger diesels are manufactured by Mercedes, Peugot, and I believe General Motors (Europe), and the diesel can be made substantially more suitable for the passenger car by the addition of a supercharger. Although not associated with the computer, there is probably opportunity for invention in the high-pressure injection system of the diesel. A demonstration car seems to be a few-man size effort, and would seem to be an appropriate project.

IIIA. Energy Accounting and Tagging System, Energy Modelling

Battelle at Columbus is supposed to be creating an energy information center, which should be in operation about now. Battelle should be visited in regard to coal mining, coal gasification, coal liquefaction, and the EIC, as well. The energy and accounting tagging system would serve producers, consumers, and regulators, energy modelling, etc. A computer model of the world and U.S. energy production and consumption system, including coalitions, decision making, time lags, government and private actors; brokers; futures, etc., etc. would give at least some opportunity for testing proposed regulation (or lack of regulation), incentives, and for providing a better understanding of the interrelations among sectors. Two or three quite independent models would allow a properly skeptical observer to obtain an indication not only of the mean but also the standard deviation of forecasts or assessments. Such a model would be of very great value.

Improved environmental control techniques including modeling of the dispersion of plumes from smokestacks, remote sensing of the emissions, remote control of fuels, and remote reporting of actual fuel consumption could allow health-related clean air standards to be met without mandating the burning of low pollutant fuel at all times. Furthermore, a generalization of "remote meter reading", even if previously unjustifiable from the point of view of displaced cost of the meter reader, may serve a very useful function during crises.

General Comments

The product of the task force should be concise, substantive reports from the subgroups, together with a set of technical papers by task force members, or by others. It is very important to us individually that we respond well in this important and visible effort.

RLGarwin

R.L. Garwin

cc: P.S. Dauber
D.C. Gazis
P.E. Seiden
J.H. Eaton
R. P. Kelisky
S. Winograd
L.A. Cookman
T.F. Cummings
K.E. Drangeid
R.E. Comory
J.B. Little
M. Nanes
D.E. Rosenheim