TECHNOLOGY OF EFFICIENT ENERGY UTILIZATION

REPORT OF A
NATO SCIENCE COMMITTEE CONFERENCE

Technology of efficient energy utilization

The Report of a
NATO Science Committee Conference
held at
Les Arcs, France
8th-12th October, 1973

Editor:
Eugene G. Kovach

SCIENTIFIC AFFAIRS DIVISION
NORTH ATLANTIC TREATY ORGANIZATION
BRUSSELS, BELGIUM

Table of Contents

Participants

Mr. E. R. Ambrose,
780 North Baker Street,
Mount Dora,
Florida 32767, USA.

Dr. A. J. Appleby,
Laboratoires de Marcoussis,
Centre de Recherches de la CGE,
Route de Nozay,
91 – Marcoussis, France.

Dr. R. Avenhaus,
International Institute for
Applied Systems Analysis,
Traungasse 12,
A-1030 Vienna, Austria.

Prof. J. G. Ball,
Department of Metallurgy,
Royal School of Mines,
Prince Consort Road,
London SW7 2BP, England.

Dr. R. Bleekrode,
Philips Research Laboratories,
Eindhoven, Netherlands.

Prof. J. O'M. Bockris,
The Flinders University of
South Australia,
Bedford Park,
South Australia 5042.

Dr. H. Brown,
Associate Director,
Center for Urban Research and
Environmental Studies,
Drexel University,
Philadelphia, Pa. 19104, USA.

Dr. G. W. Brundrett,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES,
England.

Dr. U. Businaro,
FIAT, Direction Centrale
Recherche et Développement,
Service Planification et Promotion,
Corso Agnelli 200,
10135 Turin, Italy.

Dr. A.T. Churchman (*Co-Chairman*),
Director,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES, England.

Dr. J. B. Comly,
Manager – Thermal Branch,
Research & Development Center,
PO Box 45,
Schenectady, NY 12345, USA.

Dr. R. A. Dugdale,
Materials Development Division, 552,
Atomic Energy Research Establishment,
Harwell, Berks OX11 ORA, England.

Dr. H. Düker,
Director of Central Research,
Robert Bosch GmbH,
7000 Stuttgart,
PO Box 50, Germany.

Dr. R. J. Eden,
Cavendish Laboratory,
Free School Lane,
Cambridge University,
Cambridge, England.

Prof. D. E. Elliott,
Department of Mechanical Engineering,
University of Aston in Birmingham,
Gosta Green,
Birmingham B4 7ET, England.

Prof. P. O. Fanger,
Technical University of Denmark,
Laboratory of Heating and
Air Conditioning,
Building 402,
2800 Lyngby, Denmark.

Dr. P. Fedi,
Via Andrea Baldi 6,
00136 Rome, Italy.

Prof. N. J. Felici,
Laboratoire d'Électrostatique,
B.P. 166, Centre de Tri,
38042 Grenoble Cedex, France.

Prof. D. Gabor, CBE, FRS,
Department of Electrical Engineering,
Imperial College of Science and
Technology,
City and Guilds College,
Exhibition Road,
London SW7 2BT, England.

Dr. L. Gillain,
EBES,
Mechelsesteenweg 271,
2000 Antwerpen, Belgium.

Dr. J. E. Goldman,
Senior Vice-President,
Research and Development,
Xerox Corporation,
Stamford, Connecticut 06904, USA.

Dr. D. O. Hall,
Department of Botany,
King's College,
68 Half Moon Lane,
London SE 24, England.

Dr. B. Hamel,
Center for Urban Research,
Drexel University,
Philadelphia, Pa. 19104, USA.

Dr. A. L. Hammond,
Research News Editor 'SCIENCE',
American Association for the
Advancement of Science,
1515 Massachusetts Ave., N.W.,
Washington, D.C. 20005, USA.

Dr. R. P. Hammond,
Oak Ridge National Laboratory,
Oak Ridge,
Tennessee 37830, USA.

Dr. D. G. Harvey,
Director,
Energy and Environment Systems,
Hittman Associates, Inc.,
9190 Red Branch Road,
Columbia, Maryland 21045, USA.

Dr. D. R. Jenkins,
Thornton Research Centre,
PO Box 1,
Chester, CH1 3SH, England.

Dr. R. H. Johnson,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES, England.

Dr. E. Kauer,
Director,
Philips Forschungslaboratorium,
D-51 Aachen,
Weisshausstr., Germany.

Prof. M. Kersten,
Knappstrasse 8,
33 Braunschweig, Germany.

Prof. N. G. Koumoutsos,
Faculty of Chemical Engineering,
National Technical University of Athens,
42, 28th October Street,
Athens (147), Greece.

Prof. N. Kurti, CBE, FRS,
University of Oxford,
Clarendon Laboratory,
Oxford OX1 3PU, England.

Dr. J. Lawton,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES, England.

Dr. E. A. Lisle,
Director, CREDOC,
45 Bd. de la Gare,
Paris-13e, France.

Dr. E. Massar,
Siemens AG – Abtl. E WT –
8520 Erlangen,
Werner-von-Siemens-Str., 50, Germany.

Dr. R. J. Meijer,
N.V. Philips,
Eindhoven, Netherlands.

Dr. H. Michel,
Chef de la Division « Études Générales »,
Dépt. Applications de l'Électricité EDF,
Direction des Études et Recherches,
Les Renardières,
77250 Moret sur Loing, France.

Dr. D. N. Morris,
RAND Corporation,
1700 Main Street,
Santa Monica, California 90406, USA.

Dr. J. C. Moyers,
Oak Ridge National Laboratory,
Oak Ridge,
Tennessee 37830, USA.

Dipl. Ing. W. Münch,
OSRAM GmbH,
8000 Munchen 90,
Postfach 900620, Germany.

Prof. W. Murgatroyd,
Mechanical Engineering Department,
Imperial College,
Exhibition Road,
London SW7 2BX, England.

Ir. F. Oostvogels,
Development Department,
Philips ICM, NV,
Gierlesteenweg,
2300 Turnhout, Belgium.

Dr. K. G. A. Pankhurst,
Deputy Director of Laboratories,
Railway Technical Centre,
London Road,
Derby, England.

Mr. M. Penel,
Attaché au Directeur des Études
et Recherches d'EDF,
2 rue Louis Murat,
75008 Paris, France.

Dr. C. Roscoe,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES, England.

Dr. M. D. Rubin,
Raytheon Company,
Equipment Development Laboratories
Boston Post Road,
Wayland, Mass. 01776, USA.

Dr. J. H. K. Shannahan,
President,
Electric Energy Association,
90 Park Avenue,
New York, NY 10016, USA.

Ir. A. C. Sjoerdsma,
Director,
Future Shape of Technology Foundation,
Prinsessegracht 23,
The Hague, Netherlands.

Dr. W. E. Shoupp,
Vice-President – Research,
Westinghouse Electric Corporation,
Pittsburgh, Pa. 15235, USA.

Dr. C. B. Smith,
Applied Nucleonics, Inc.,
PO Box 24313,
Village Station,
Los Angeles, California 90024, USA.

Prof. Chauncey Starr (*Co-Chairman*),
President,
Electric Power Research Institute,
3412 Hillview Avenue,
Palo Alto, California 94304, USA.

Dr. H. Tannenberger,
Battelle – Geneva Research Centre,
7 route de Drize,
1227 Carouge – Genève, Switzerland.

Dr. J. M. Taub,
Los Alamos Scientific Laboratory,
Los Alamos,
New Mexico 87544, USA.

Dr. L. Thörnqvist,
Division of Heat and Power Engineering,
Lund Institute of Technology,
PO Box 725,
S-220 07 Lund, Sweden.

Dr. A. Vellard,
Directeur des Centrales Électriques à la Générale des Houillères du bassin du Nord et du Pas-de-Calais,
20 rue des Minimes,
BP 75, 59505 Douai, France.

Dr. H. J. Vink,
Director,
Philips Research Laboratories,
Eindhoven, Netherlands.

Dr. G. Walter,
Head, Electro-Chemistry Division,
Battelle Institut eV,
6000 Frankfurt/Main 90,
Postfach 900160, Germany.

Prof. F. J. Weinberg,
Department of Chemical Engineering and Chemical Technology,
Imperial College,
Prince Consort Road,
London SW7 2AZ, England.

Prof. J. J. Went,
N.V. KEMA,
Utrechtseweg 310,
Arnhem, Netherlands.

Dr. A. H. Willoughby,
Director of Research and Engineering,
Thorn Lighting Ltd.,
Research and Engineering Laboratories,
Gt. Cambridge Road,
Enfield, Middlesex, England.

Dr. J. G. Wistreich,
Head of Corporate Engineering Laboratory,
British Steel Corporation,
140 Battersea Park Road,
London SW11 4LZ, England.

Observer

Dr. H-E. von Scholz,
Kommission der Europäischen Gemeinschaften,
Generaldirektion Energie – Dir. A,
200 rue de la Loi,
B-1040 Bruxelles, Belgium.

***

Dr. E. G. Kovach,
Deputy Assistant Secretary General for Scientific Affairs,
NATO,
1110 Bruxelles, Belgium.

Miss E. I. Austin,
Scientific Affairs Division,
NATO,
1110 Bruxelles, Belgium.

Mrs. A. Owen,
Electricity Council Research Centre,
Capenhurst, Chester CH1 6ES, England.

Preface

The Conference on the Technology of Efficient Energy Utilization was held under the auspices of the NATO Science Committee as part of its continuing effort to promote the useful progress of science through international cooperation.

Science Committee Conferences are deliberately designed to focus attention on unsolved problems, with invited participants providing a variety of complementary expertise. Through intensive group discussion they seek a consensus on assessments and recommendations for future research, which will hopefully be of value to the scientific community. The subjects treated have been as disparate as science itself—e.g. computer software, chemical catalysis, oceanography, and materials research.

In the present instance the Organizing Committee deliberately chose a small part of the spectrum of problems evoked by the term "energy crisis", but one which seemed to have escaped critical attention so far—namely the contributions which science and technology could make to maintaining current processes at lower energy cost. Attention was to be centered only on the *end-uses* of energy, without consideration of its original source, its transmission, or even its form. While recognizing full well that major social, political or economic decisions would be determining factors in the long run, it felt that the R & D community nevertheless had a role to play, and indeed a responsibility to fulfil, in identifying the contributions which it alone could make in energy conservation.

The Organizing Committee was successful in assembling expertise from the academic, industrial and governmental sectors of many countries to focus on these purely technical aspects. All participants gave generously and enthusiastically of their wisdom and knowledge during the week of the meeting, and we extend to them our deep gratitude.

Special thanks go to Dr. Trevor Churchman and Prof. Chauncey Starr for their diligent efforts as Co-Chairmen of the meeting, to their colleagues on the Organizing Committee, Prof. R.P. Hammond, Prof. N. Kurti, Dr. J.J. Went, Dr. M. Kersten and Dr. E.A. Lisle, for their wise counsel and guidance, and to the leaders and recorders of the working groups, as listed, for their indispensable dedication.

Eugene G. Kovach
Deputy Assistant Secretary General
for Scientific Affairs

NATO
Brussels, Belgium

Introduction

The developing, multifaceted constraint on the availability of energy needed to meet a growing world demand has become a matter of growing international concern. The reasons for the increasing mismatch between supply and demand are the subject of many continuing studies. The growth of world demand appears to be the inevitable result of both an increasing population and growing expectations of an improved life-style. One consequence is an exponential increase in the rate of depletion of the natural store of fossil fuels. Combined with wide-spread pressures to reduce undesirable environmental impacts of their use, this leads to a limitation of supply.

The net result is that the world will be hardpressed to supply the energy to meet an unrestricted demand. As a consequence, several courses of action must be undertaken simultaneously, particularly in the industrial, energy-intensive nations. First, Society must begin to accommodate its life-styles and expectations from energy-abundant (and cheap) conditions to energy-constrained (and costly) conditions. Second, intensive development of additional energy sources must be undertaken—developments that extend the utility of our present depletable sources, exploit new, long-term sources such as fission, fusion, solar and geothermal, and do so in an acceptable environmental manner. Third, the efficiency with which resources are used to accomplish end-purposes must be improved, so that we can obtain more output for less input. As the energy available will be resource-limited, what Society can practically achieve will depend on how it *uses* the energy.

Technology plays a significant rôle in all aspects of this problem, and is particularly critical in its contributions to the resource and efficiency issues. It is the hope of scientists and engineers concerned with these matters that the technological options which may result from their efforts will permit Society to avoid serious consequences of "energy malnutrition", even though accommodation to a carefully managed and restricted energy diet may be a permanent part of the planning of this and future generations.

The recent public awareness of the tight budget on energy resources has resulted in much attention and discussion. Almost weekly new professional meetings and new analytical studies address the questions of increasing and managing our energy supply. The parallel issue of energy conservation—while often mentioned—has had almost no organised attention from technical bodies. For this reason, the NATO Science Committee believed it would be fruitful to bring together a carefully selected group of scientists and engineers, whose special experience and expertise would highlight the technological opportunities in, and barriers to, the more efficient use of the energy available. It was recognised that this point of view would allow only modest contributions to overall amelioration of our energy problems when compared with the introduction of completely new energy sources, or decisions in the market place or in legislatures which might drastically alter life-styles. Nevertheless it seems eminently justified to examine critically the procedures and processes developed over many years when energy availability was a spur rather than a constraint.

Sixty individuals from 13 countries, each highly qualified in a relevant discipline and together representing a broad spectrum of expertise, met for a week at Les Arcs, France. They accepted with grace the severe constraints imposed by the Organising Committee—attention was to be focussed on the efficiency of energetic processes at the point of use, with exclusion of consideration of sources and supplies, and generation and transmission. Furthermore, emphasis was to be given to the scientific and technical aspects—first examined individually and subsequently as they might interact in integrated systems. The focus throughout was on identification of technical opportunities deserving further study. Prof. Nicholas Kurti admirably summed up the goals of the meeting by likening them to Robert Hooke's description of the business and design of the Royal Society:

> "To improve the knowledge of naturall things, and all useful Arts, Manufactures, Mechanik practises, Engynes and Inventions by Experiments—(not meddling with Divinity, Metaphysics, Moralls, Politicks, Grammar, Rhetorick, or Logick)."

Following brief plenary sessions—one in which Prof. Denis Gabor outlined the principal energy sinks in today's society and estimated the areas likely to yield to technical improvements, and one in which Prof. Philip Hammond described the ways in which integrated energy systems might operate with an efficiency superior to the sum of their parts—the participants divided into small Working Groups. Initial topics for consideration were the end-use requirements of Heat, Light, Motion (both Transport and the Shaping of Materials), and Electrolytic and Electronic Processes. Subsequently, Residential/Commercial, Industrial and Urban systems were examined. Intensive discussion in these small groups led to conclusions and recommendations which were further refined by exposure to the entire meeting. Emerging principles are summarised in the following section, and then the reports of the separate Working Groups are presented in full. In the interest of preserving the flavor of the discussions no effort has been made to reduce these reports to a completely uniform format, or to correct imbalance or overlap. Instances of repetition (e.g. the several references to the desirability of expanded heat pump usage) should rather be viewed as reinforcement of emphasis.

The constraints placed on the groups' considerations—particularly those which barred examination of social, economic and political aspects—and the short time which precluded any serious attempt at thorough quantitative analysis underline the preliminary and limited nature of the conclusions reached. Nevertheless the discussions stimulated several creative insights and suggestions, and there is no doubt that light has been shed on possible new approaches to energy conservation. It was evident that the participants developed increased perception of the issues and would transmit this appreciation to their colleagues and organizations, thus contributing to continuing efforts in energy conservation research. It is in the hope of further stimulating others to such investigations that this report is published.

The Organizing Committee

Summary

Principles of Energy Conservation

Prof. Chauncey Starr

The discussions of the Working Groups revealed that the basic approaches to energy conservation fell into three general categories; (1) the development of manufacturing processes to reduce their energy requirements and to reduce wastage of energy intensive materials; (2) the optimal choice and development of materials in relation to their end use; and (3) the design and management of systems, subsystems, and components, so as to reduce the total integrated energy consumed to accomplish specific end purposes. Although these objectives are almost self-evident, the criterion of energy resource conservation, as contrasted to our historical monetary cost criterion, leads to different technological research and development paths and performance goals. Many of these R & D directions are discussed in the following individual reports.

Several broad principles of energy conservation came out of the discussions of the Working Groups. These common threads were (1) the removal of inbuilt obsolescence, (2) the sequential use of energy forms and energy-intensive material, starting at their highest performance level, and (3) the integration and aggregation of processes, industries and energy consuming activities.

Regarding inbuilt obsolescence, for example, the energy input required to rustproof motor cars by appropriate coatings must be very small compared to the total energy input to the vehicle. Obviously, if a long life of energy-intensive products can be achieved at low additional energy cost (or perhaps by better design only), there appears to be no question that it should be done.

Further, anticipated *technological* obsolescence may place an upper limit on the lifetime objective of a complicated technical device. For example, a house may properly be designed for a forty-year lifetime, but it is doubtful that a telephone should be. The criterion here should be the minimum average annual energy use projected for the performance required, taking into account the initial energy resource investment, maintenance, change in performance expectations, and end-of-life recycle or disposal options.

The sequential use of energy forms and energy intensive materials starting at their highest performance level is perhaps a more subtle concept. It involves minimising the degradation of use after each level of performance is completed. For example, in an ideal energy economy, wood should first be used as a structural material to take full advantage of the free solar energy and nature's cementing of its individual fibres. Next, it could be used for manufactured fibre-board or synthetic cloth, and finally, as a basic material for paper pulp.

The idealised sequence does not end here. Waste paper may be recycled, as feed stock for the chemical industry, or in a final step, as a source of heat energy.

This idealised sequence may not be fully applicable with our present forestry practices where much of the growth is not suitable for construction lumber and is therefore converted directly to paper pulp. Nevertheless, an energy conservation goal would suggest a re-examination of forest managerial options, as well as an evaluation of long-term planning implications and the energy requirements of substitute construction materials and paper fibres.

Coal is similar in this respect to wood. It contains many complicated hydrocarbons in addition to pure carbon, and therefore a portion of its content is energetically significant as a starting point for valuable petrochemical manufacturing processes. The direct combustion of coal prior to removal of its useful hydrocarbons represents an unnecessary resource degradation if energy conservation is the primary criterion.

The energy investment in alternative materials for specific applications is a field of study that is just beginning. As examples of such alternatives, we have synthetic versus natural fibres for cloth, steel beams versus laminated wood, plastic versus metal sheet, aluminum versus steel cans and plastic versus glass containers. The list is long, but our quantitative knowledge of the energy investment in these alternatives is too limited now for significant conclusions.

The recycle of materials, although a popular subject, was not discussed extensively by the Working Groups. It was clearly recognized that, for energy conservation, recycling would have to be examined on a case-by-case basis. The energy investment in collecting waste material, separating it into components, and then upgrading it into a reconstituted form, is not obviously less than the energy required to start from initial resources. Mineral resource conservation may not always be compatible with energy conservation, although clearly both are socially and environmentally desirable.

The design and management of systems, subsystems, and components, so as to reduce the total integrated energy consumed to accomplish specific end purposes, is a most complex issue. The basic difficulties arise from the separation, both in space and time, of the various components and processes that sequentially interact with each other before any end purpose is achieved.

In the manufacturing process industries the physical separation of individual steps and the storage in inventory between steps, tend to disaggregate the energy investment and induce substantial energy waste. In the delivery of products and services to end users, the physical separation of activities, suppliers, and consumers result in a similar energy waste in transportation and service requirements. And finally, our socially common life style separates our industrial complexes from our residential, and these from our recreational and leisure activities.

The basic point is that energy conservation is best achieved by aggregating sequential and interacting activities both in space and time so that energy systems may supply requirements in a continuous manner from the highest temperature level in small steps to the lowest temperature heat sink. Disaggregation (i.e. separation in space or time) tends to force large temperature changes and consequent energy wastage, as well as energy consumption for transportation and handling, which are not fundamentally essential to the system.

Some typical examples raised by the Industry Working Group are (1) the upgrading of unnecessarily impure ores, with rejection of impurities with high energy content; (2) wasteful process heat management during separate stages each requiring high temperatures; and (3) the scrapping of material, with its invested energy, during cold working manufacturing processes. Many similar system examples can be found in the individual Working Group reports.

To achieve the benefits of aggregation, several Working Groups suggested industrial complexes to concentrate processes and permit continuous temperature sequences for process purposes.

Similarly, the Working Groups concerned with residential and commercial environmental conditioning placed great emphasis on the energy advantages of building complexes which would permit the use of integrated utility systems, sewage systems, heat pumps and a variety of common heat sources and sinks. The creation of such complexes for residential, commercial and industrial purposes would appear to raise new problems of transportation and associated energy demands which certainly would require further study.

In an energy constrained society these concepts lead to re-examination of the rationale for our present life style criteria, which encourage individual dwellings, separation of work and industrial activities, and deurbanization of our high density population centers.

If one assumes that visual amenities, privacy and avoidance of cross-pollution are the basic motivations for such separation, then an extreme solution such as underground cities with all services integrated might provide an environmentally and energetically acceptable solution. The surface would be wholly devoted to parks, food production, leisure facilities and natural scenery. The underground would provide a stable heat reservoir with a very long time constant for a heat pump system, and privacy would now be compatible with a concentration of energy using functions. Transport requirements would be drastically reduced, and made compatible with increased accessibility to leisure and recreational activities. The question remains as to whether such underground cities require less total integrated energy for their construction and operation than that required by our present apparently inefficient surface cities.

We recognize that the suggestion of a compact underground city, with completely integrated and aggregated activities, represents a wide departure from presently accepted life style concepts. Nevertheless, this extreme scenario illustrates most of the concepts which are a consequence of optimising energy and resource conservation. It deserves serious thought as the end point limit of the spectrum of options between the present energy abundant life styles and the most energy constrained system.

A more homely example of these principles of aggregation is the Working Group-suggested concept of a single intense light source, of the highest efficiency, located in a house energy center. The light would be distributed by "light pipes" to the many points of use. Such a concept could be engineered today and would use roughly one-fourth the energy now needed to produce the same light. The unavoidable waste heat, being concentrated, can easily be converted to an end use such as hot water supply.

These concepts illustrate the relationship between the scientific and engineering aspects of energy conservation and the problems of urban planning and residential design. The interaction between relevant fields such as architecture and sociology and the technology of energy resource conservation was raised in many of the Working Group studies. It is very evident that the architectural and other relevant professions must participate in the technological developments related to energy conservation.

Continuation of the present practices in urban planning and building design are not compatible with an energy resource constrained society.

For Society thoroughly to assess the many real options for systems which meet energy and resource constraints, the present data base and analytical models are inadequate. The time elements of social costs and social benefits, long-term and short-term, are not adequately understood. Economic models and technological systems models need to be integrated more fully and with greater insight to the key parameters. To achieve a balance between man, machines, money, environment and social objectives, we require a more complete and quantitative analysis of the complex interactions of future societies in our ecosystem.

These insights to the societal problems of energy conservation, which evolved from the discussions of the meeting, may be as significant as the specific R & D suggestions which follow.

Working Group Reports

WORKING GROUP A

HEAT

SUB-GROUP

INDUSTRIAL HEAT

J. Lawton — Group Leader
D.E. Elliott — Recorder

J.B. Comly
B. Hamel
A.L. Hammond
N.G. Koumoutsos
W.E. Shoupp
A. Vellard
F.J. Weinberg

General Considerations

It became clear that very great improvements could be made in the efficiency of energy utilization of industrial heating systems without any research or development at all, i.e. by good maintenance of equipment, use of automatic control and good initial design. These approaches not only reduce operational energy requirements but also reduce the amount of rejected material produced.

There is a wide diversity both of industrial heating techniques and of the processes to which each technique needs to be adapted. For this reason significant improvements in energy utilization efficiency on the overall industrial scene can be achieved by new scientific and technological developments only if there is an attack over a wide front. From this point of view, more closely itemised data on the current utilization pattern of available techniques would assist greatly in establishing priorities.

For convenience, opportunities for improvements in industrial energy utilization efficiency were considered under the following four headings:

I. Change of Basic Process.
II. Heat Recovery and Loss Suppression.
III. Novel Techniques and Improvements to Existing Techniques.
IV. Use of Substitute Materials.

Specific Opportunities for Better Heat Utilization

I. Change of Basic Process

The philosophy behind this approach is to eliminate certain energy intensive steps in the manufacture of a product by a complete reconsideration of the whole process. Four industries were selected for special treatment because of their large energy requirements: Metals, Paper, Food, and Stoving of Paints and Varnishes.

A. Metals

1. *Iron* is extremely energy intensive, both in its production and in its conversion into steels and subsequent processing; in the U.S.A. it consumes about 8% of the total energy. In the present route to steel, ores beneficiated to about 93% Fe_2O_3 are fed to a blast furnace which, in best practice, yields about 2 tonnes of iron per tonne of coke. (In the blast furnace itself 1 tonne of Fe, in best practice, requires ca. 2.3 Gcal as against a theoretical value of ca. 1.64 Gcal.)

The principal ways in which energy must be supplied in excess of the thermodynamic minimum to reduce Fe_2O_3 are as follows:

a. Loss of heat when the coke is quenched on emergence from the oven (ca. 4% of energy requirement).
b. Heat supplied during sintering prior to charging.
c. Beneficiation of the ore.
d. Carry-over of carbon in the molten iron product (ca. 4 wt % of C, i.e. 8% of energy requirement).
e. Sensible heat of the slag and molten iron (ca. 13% of energy requirement).
f. Loss of charge on oxygen lancing in steel converter (ca. 7% of Fe, i.e. 7% energy loss).
g. Loss of heat between charges in the steelmaking process.

In the present route to steel (d), (e) and (f) cannot be considered as losses because alloying is carried out in the molten state and heat is needed to melt additions of scrap and alloying materials.

There are alternative reduction techniques available which, if technically feasible, could by-pass most of the energy consuming steps (ore beneficiation would still be needed, of course). The use of hydrogen reduction of iron chloride, produced by leaching the ore (or dissolving the scrap) with hydrochloric acid followed by fractional crystallization, could be employed at either low or high temperature to yield either a pure iron powder or a pure iron melt (i.e. no slag, and no carbon carry over). In the case of powder production it might be possible to proceed directly to steel by a powder technology route (no need to melt, no product loss on lancing). In the case of molten iron production the process could be made continuous because there would be no need to ensure uniformity by bulk batch treatment (savings on energy between charges, no product loss on lancing). The use of hydrogen as the reducing agent has additional long term advantages in view of the predicted scarcity of coking coal.

This whole area of technology presents problems associated with scale-up of pilot plant, the financial risk, and strategic planning on a grand scale. However, in view of the potential of such developments in terms of energy conservation (perhaps up to 40%) and the steel industry's acknowledged interest in more direct routes to steel for reasons somewhat unconnected with the immediate question of energy efficiency (e.g. direct use of nuclear power), this could be an important area for long term development.

Some areas where further knowledge could open up new energy saving routes to steel are:

- Systems studies relating iron and steelmaking techniques (conventional and non-conventional) to the types of ore and reducing agents available now and in future.

- Powder metallurgy routes to steel.
- Plasma and low temperature reactors for oxide and chloride reduction: performance, materials and design.
- Development of powerful hydrogen plasma sources (ca. 2000 MW).
- Development of very large scale, fractional crystallisers.

2. *Titanium* is generally produced from $TiCl_4$ by sodium reduction, and the existing processes could be improved. By carrying out the primary reduction process above the melting point of titanium (e.g. at about 1900 °K) all the impurities could be removed in the gas phase, the metal being produced as a pure, continuously cast ingot in one step. Since the reduction process itself raises the temperature to only about 1600 °K, an arc would be required to raise the temperature to the required level. This involves arc heater and reactor developments—typically the arc heater would need to provide about 5 MW for a plant producing 2000 tonnes a year. Very great further savings in energy would accrue in the final product if a flexible casting system (tube, rod, plate) could be attached to the reactor—the cost of titanium strip is about twice that of the ingot because of the immense amount of rolling necessary to form it. This is a long to medium term development. Similar arguments with regard to flexible continuous casting also apply to steel shaping.

B. Paper

The present technique for making paper involves the formation of a pulp slurry, the water content of which is reduced from 99.5% to a final, ideal value of 7%. The water is removed mechanically down to about 70%; from then on the removal is by evaporation at low efficiency because in current practice this is done without heat recycling. Even ideally, the current drying operation requires a minimum of 1.5 MWh/tonne of paper, but in practice at least three times this energy is consumed. Alternative, non-wet methods are required. Although these would involve drying the pulp in order to produce a fibre feedstock, they could be carried out at very low power requirements using a heat pump (e.g. with 10% of the energy currently used). Electrostatic laying of dry fibre has been attempted and has been found technically feasible at low production rates. Other adhesive techniques may be possible.

This is an area requiring a good deal of technological research. However, in view of the fact that the paper industry consumes a not negligible fraction of the total energy (1.5% in the U.S.A.) this effort is justified. Capital investment as well as technical considerations make this a medium to long term project.

C. Food

One of the most energy intensive aspects of the food industry is the cooking of food prior to and/or after canning. This amounts to about 50% of the heating requirements in a cannery. Apart from providing "convenience" food which needs only reheating, the main object of cooking is to ensure its sterility. Other sterilizing techniques are available and should be exploited. The use of ionizing radiation is well known. However, recently it has been reported that bacteria can be killed by the application of intense, high frequency fields. If this can be carried out at frequencies which do not heat the material appreciably, this could lead to very important savings and is well worth considering as a fundamental scientific study. If this technique or others like it were found feasible the appropriate plant modifications could be made quite quickly.

D. Paint/Varnish Stoving

In many applications it is necessary to raise paints and varnishes to about 200-300 °C in order to produce a firm and lasting polymeric coating. This is a major operation in the motor car industry, for example. In the conventional methods it is necessary to raise the whole assembly (i.e. metal substrate plus coating) to the required temperature. The use of non-thermal methods based upon radiation-induced polymerisation could reduce energy requirements by an order of magnitude. Efforts have already been made in this area using hard vacuum electron beams and ultra violet light. The hard vacuum beam technique is geometrically inflexible because of its dependence on a metal window or a differentially pumped orifice/slot through which the beam passes. UV sources are available and recent work on glow discharge electron beams shows promise. Further work should be carried out both on paint formulation (with regard to UV and electron beam polymerisation) and on the physics and engineering of large glow discharge electron beam devices. This is a medium term development problem.

II. Heat Recovery and Loss Suppression

A. Heat Pumps and Energy Transport

Several examples were discussed where large heat pumps, in the range from 100 KW to 2 MW could be applied to industrial processes, and to large district heating systems. With coefficients of performance (COP's) of 5-7, clear cut savings could be made of factors of 5-7 in electrical energy or of factors of 2-3 in input fuel, assuming 40% efficiency of conversion from fuel to electricity, a realistic goal for the year 2000. In the case of conversion from directly used natural gas or distillage oil to electrically driven heat pumps an added benefit is realised, since the electricity will be generated primarily by a mix of less scarce fuels: coal, uranium, hydro, and some residual oil.

Examples of possible applications include:

1. Heat recovery and upgrading for industrial drying, for instance, in paper mills where plants might require up to 4 MW of thermal energy at ca. 140 °C (284 °F), upgraded from ca. 80 °C (176 °F).
2. Circulation of cooling water from central steam power stations to community-level heat pump stations where it is upgraded to temperatures for space heating in residential, commercial and industrial buildings. Large communities (over 1000 large houses) might require over 10 MW of thermal energy upgraded from piped water from power plants at 38 °C (100 °F) to space heating temperatures, on the heat pump side of air heat exchangers, of 65 °C (150 °F).

Several research areas must be pursued to remove the present-day technical barriers to these applications, including:

- New working fluids capable of withstanding the peak cycle temperature likely to be reached in the industrial applications (ca. 400 °C) and fluids with higher density and sound velocity than freons to allow design of such high throughput compressors. Some possible candidates are biphenyls, terphenyls, hydrocarbons, water.
- Compressor designs for high throughput, high temperatures and new working fluids.
- Heat exchanger designs for optimum heat transfer on the heat pump side including boiling and condensing of new fluids.
- Investigations of new cycles using single phase gases instead of two phase systems.
- Schemes to modulate capacity over a range of throughputs as needed, with little degradation of efficiency, for example, by speed change in the compressor.
- The reversed Stirling engine functioning as a heat pump should be considered in this context because of its potentially high thermodynamic efficiency.

With the exception of the Stirling engine based system, the technical problems in making the heat pumps required are medium term.

A further development of pressure exchangers in the field of refrigeration could be worth considering. This type of thermodynamic engine uses a fuel input either to produce compressed air directly or to upgrade low temperature heat to a higher level without the production or input of mechanical energy. Realization of this technique will need to await more basic studies.

B. Heat Exchangers

Heat exchange is a fundamental process in all heat recovery systems. Research to improve gas/liquid heat transfer either by better gas convective systems or by use of the shallow, low pressure drop, fluidised bed, heat exchanger (see: Elliott, Institute of Fuel Total Heat Conference, Brighton, 1971) would be worthwhile pursuing. The latter is already showing promise, its heat transfer coefficients being about 5-10 times greater than convective hot gas exchangers under similar conditions. In this context heat pipes developed with a view to heat recovery are worth assessing. New heat exchanger design poses short to medium term problems. In many industrial processes waste heat recovery from a gas above 100 °C is made impractical by the presence of solids in the exhaust gases, indicating the need for a high temperature filter, e.g. the experimental, pulsed sand bed filter for which 99.9% efficiencies are claimed (work at City College, New York). This is another medium term problem that requires investigation.

C. Thermal Storage

Centrally distributed power, both gas and electric, poses the problem of how to fill in load troughs which usually occur at night. Thermal energy storage at the point of utilisation is a well-established solution to this problem. Also in many industrial applications heat or cold is used periodically or is available for recovery periodically, e.g., in metal casting, heat treatment of metal gears, batch drying and cooling of food. These difficulties can be alleviated by high capacity, low volume stores. Storage techniques are already available and in use. However, further research in several areas could provide new options for lower volumes, easier and more efficient access to the stored energy and larger thermal storage capacity; for example:

- Fluidized bed heat storage and heat exchange.
- Molten salt materials and heat exchanger.
- Low temperature hydrated salts—problems with non-congruent freezing and heat exchange design.
- Organic materials with low freezing temperatures (preferably extending over a temperature range) around −20 °C (−2 °F).

These are probably short to medium term technological problems.

D. Insulation and Radiation Shielding

There is a continued need for proper and adequate insulation on furnaces, steam pipes, and heat storage and heat treating vessels. Appropriate insulation systems are well known and are available commercially.

Research could be pursued profitably on new insulation schemes for new applications. For example, efficient, light-weight, reflectively coated radiation shields for heat cycling furnaces (>1000 °C) could save substantially in heat losses attributable to the thermal mass of the furnace.

III. New Heating Techniques and Improvements in Established Techniques

A. Lasers and Electron Beams for Welding

The use of lasers and electron beams for welding offers, thanks to the narrowness of the heated zone, the opportunity for much lower energy utilization and higher quality than obtained with electric welding (i.e. clean welding). Lasers pose problems of light conversion efficiency, reliability at high continuous power operation and power loss due to reflection at the weld surface. Electron beam welders of high power have been produced but require further development if they are to be used for atmospheric welding (e.g. X-ray screening, cathode life, life of differentially pumped electron beam orifice, orifice fluid dynamics). In view of the large amount of electric power consumed in welding this is a worthwhile area for long term further development. Ultimate energy savings of 40% were thought possible.

B. Hot isostatic pressing

Hot isostatic pressing of materials in powder form permits a low temperature and low mechanical work route to shaped articles for materials such as refractory metals and oxides—thus avoiding the high energy demands of melting and high temperature sintering. Alloys and fibre reinforced materials can be formed into complex structures in this way—further research and development are required in this area to obtain the desired material properties.

C. Plasma Jets for Cutting

Although much development has gone into plasma jet devices for cutting, there is still room for further energy economies (ca. 50%) by producing very constricted discharges. These improvements are made necessary by the rapidly increasing use of these devices, and can be introduced by short term development.

D. Radiofrequency and Microwave Devices

Radiofrequency power has many applications, e.g. in plastic welding and the drying of wet materials. Present net efficiencies are of the order of 50% of mains power. There is a great advantage to be gained by improving the R.F. generation stage (currently ca. 70%). Solid state devices, if developed, would be a great scientific advance; a target of 85% would be reasonable.

Microwave ovens when used in the home and industry save a considerable amount of the energy normally used in cooking (ca. 50%). Moreover, they are likely to be used for a wide range of heating applications in industry. The magnetron operates at high efficiency but because of the mismatch between the load and the capacity the net energy utilization can be low (ca. 50%). Adjustable systems can give very high efficiencies indeed, e.g. 95%. However, these need the development of cheap power circulators to protect the magnetron whilst working at maximum efficiency.

E. Induction Heaters and Melters

The efficiency of induction heating is limited by the resistance of the primary winding and by the gap between the coil and the charge (the filling factor). To improve the latter, which seems to be the principal limitation, requires development of new materials to provide adequate strength, durability and electrical and thermal insulation in thin sections. In this way the electrical efficiency of induction heating could be raised from the currently quoted values of about 70-80% to near the ideal value of 100%. From a product point of view there is also the need to take the shape, size and frequency of the inductor into account when designing the whole production line.

F. New Combustion Techniques

In the future it is almost certain that a large number of virtually hitherto disregarded, potentially useful fuels will become economic sources of combustion energy, e.g. upcast gases from coal seams and mines, exhaust gases from a variety of industrial plants, lean methane/air mixtures from fermenting wastes and dried sewage. To burn these materials efficiently with the minimum degree of pollution and with the maximum utilization of their energy—even though they may be below the limits of flammability at normal temperature and pressure and have a low calorific value—several new techniques are being investigated which, with sufficient short and medium term research effort, promise to offer practically viable solutions. These are based on increasing combustion rates by recirculating heat between reactants and products using heat exchangers (see Weinberg, *Nature*, *233*, 239, 1971), fluid bed combustors (see International Conference on Fluid Bed Combustors, E.P.A. 1972) and by injecting radicals from small plasma jets—i.e. using electrically augmented flames (see Harrison & Weinberg, *Proc. Roy. Soc.*, *A321*, 95, 1971). The use of properly developed fluid bed combustors in, for example, metal hardening and annealing processes, could, because of their high heat transfer coefficients, result in worthwhile energy savings over the use of conventionally fired gas and oil systems.

The use of hydrogen as a fuel (as in the Hydrogen Economy suggestion) would also demand more elaborate combustion techniques. Burning in stoichiometric proportions could give rise to unacceptable detonation hazards as well as to excessive NO formation (unless O_2 as well as H_2 is to be piped in which case NO will not be formed). For initially separate undiluted reactants burning always occurs at a stoichiometric contour. Hence burning of diluted reactants might become important here also. Unlike the case with conventional fuels, the method of combustion would depend very much on the purpose and location of the burner, and research into such devices appears desirable.

IV. Use of Substitute Materials

There seem to be two principal areas where substitution of materials could save a significant amount of energy. Both involve lightening of the structure. On the one hand, low density concrete blocks could be widely used in building construction and provide favourable insulation properties. Foaming techniques are available to produce the low density mix and savings of 50% in the amount of material used are possible. Research and development is required to produce the maximum strength at the lowest possible density, e.g. by using fibre reinforcement. Another possibility is to use light (e.g. carbon fibre) reinforced materials instead of steel. For the same structural duty a much smaller mass of such materials is needed than of either concrete or steel, hence a saving in energy in their manufacture. The cost of manufacture, vulnerability to ultraviolet light and mechanical surface damage are the main problems at which research needs to be directed.

Quite apart from the above particular "solutions" proposed, the whole general area of new materials is a very important one because of the vast amount of energy intensive materials, (requiring transport as well), used in the construction industry (e.g. steel, bricks, tiles, cement and concrete).

WORKING GROUP A

HEAT

SUB-GROUP
RESIDENTIAL AND COMMERCIAL HEAT

P.O. Fanger — Group Leader
J.H.K. Shannahan — Recorder

E.R. Ambrose — D.N. Morris
H. Brown — J.C. Moyers
M. Kersten — M. Penel
N. Kurti — L. Thornqvist

Introduction

Most of the energy consumed in residential and commercial buildings is used for space heating, space cooling and air conditioning. Since this accounts for approximately 20% of the total energy consumption in the U.S. and considerably more in several European countries, it is obvious that even moderate improvements in energy utilization in this field could influence the total energy consumption significantly.

The Working Group quickly realized the necessity of focussing its discussions on areas of greatest potential energy savings because of the limited time and the vast scope of the subject. It was agreed to discuss, in this order:

I. Human Comfort.
II. Building Structure and Outdoor Climate.
III. Heating and Cooling Technology.
IV. Energy Utilization Data Banks.

The findings may be summarized as follows:

The most significant opportunities for energy conservation in the area under discussion (Heat—Residential and Commercial) would be in more effective insulating practices and in further use and development of the heat pump and its applications, including waste heat reclamation and solar energy. Investigation of the factors determining human comfort could lead to the development of methods for a better matching of those needs. The desirability of an international data bank to cover all aspects of energy utilization was also emphasized.

I. Human Comfort

The main factors determining human comfort were identified since it was felt that a better understanding of the relations between these factors could ultimately lead to more efficient utilization of energy in satisfying demands for comfort:

- Environmental Factors:
  Air temperature,
  Mean radiant temperature,
  Humidity,
  Air motion.
- Personal Factors:
  Clothing,
  Activity level.

In spite of considerable research efforts during recent years to establish comfort conditions, there are still several important questions which have not been investigated and even the established relationships between the above factors should be examined in the light of the current energy problems. Of special interest are the effects of non-uniform heating or cooling of the body. Information on this subject could influence the relationship between the energy consumption of different types of space heating or cooling. Present technology is largely focussed on conditioning whole areas with little attention to localized or 'spot' heating and cooling. More research is also needed on the non-thermal effect of humidity on man and on development of new and acceptable types of textiles with good thermal characteristics.

The following recommendations were developed:

- Establishment of comfort limits for non-uniform heating or cooling of the body (draughts, asymmetric radiant fields, cold or warm floors, vertical air temperature gradients). This could influence the differences in energy consumption of different types of space heating or cooling systems (radiant ceilings, floor heating, air heating or cooling, radiators, etc.).
- Investigations, especially of non-thermal effects, of air humidity on human beings. It is important to study to what extent humidification and dehumidification of air spaces can be justified since these processes are quite energy consuming.
- Investigations of the acceptability of local cooling or heating at work places. For instance, in industry this could be much cheaper than to heat or cool the entire space.
- Influence of thermal environment on man's mental performance and on sleep quality. Detailed knowledge is needed in order to avoid unnecessary overheating or cooling of working places and bedrooms.
- Development of a "comfortstat" to replace the traditional thermostat could eliminate overheating. The sensor of the ideal comfortstat should integrate the four classical thermal comfort parameters (air temperature, mean radiant temperature, air velocity and humidity) in a space in the same way as does the human body.
- Development of possible new types of textiles for clothing with better insulation properties at lower weights. Technical possibilities for changing the existing trend towards clothing with low thermal resistance should be studied.

II. Building Structure and Outdoor Climate

General

In considering the various effects of the building structure and outdoor climate upon the efficient utilization of energy it became immediately apparent that by far the most important single factor was the thermal insulation of the structure. Insulating materials and installation techniques were discussed for both new and existing structures. It was generally concluded that more attention needs to be given to techniques of improving the thermal characteristics of existing structures, and that thermal insulation standards for new building should be made more rigorous.

After thermal insulation, the next most important structural factor is the fenestration, both as to quantity and type of windows including the use of double glazing or storm sash. This is the major source of infiltration and hence very important in controlling heat losses.

Many other factors were considered and are listed below (no attempt has been made to list according to importance or possible contribution to energy conservation):

- Orientation of structure; on surface, below surface.
- Geometric configuration of structure — optimal shapes.
- Interior configuration.
- Exterior shading — structural, environmental.
- Infiltration — normal leakage, air needed for combustion.
- Exterior colour and materials.
- Entrance design — air locks.
- Thermal inertia of structure.
- Population density — single family versus multi-family structures.

All factors identified merit consideration in the design of future structures and modification of existing ones. There is also need for an improvement in the exchange of information regarding practices in different countries and climates. This desire for constant exchange of information pervaded all the discussions of this Working Group.

The following recommendations were developed:

- Development of new types of high efficiency insulation materials and of application techniques to existing buildings.
- Study and development of efficient methods of sealing buildings in order to decrease air infiltration.
- Further development of glass types with high reflectivity in the near infrared and low emissivity in the far infrared.
- Study of the needs for windows in buildings and the psychological effects of different window sizes, shapes, etc. It is important to analyse whether the present use of large window areas can be justified.
- Study of the effects of the microclimate around buildings on their thermal performance (including the effect of terrain, landscaping, orientation, shape, etc.). Conservation of energy seems possible by modifying the microclimate around a building.
- Development and refinement of models describing the thermal performance of buildings, including their energy consumption. Optimisation techniques should be

used to establish optimal comfort conditions at minimum energy consumption. Large scale field studies of characteristic types of real buildings should be carried out and compared with the models. Thermal measurements including energy consumption, types of heat losses, temperature distributions, etc., should be carried out over a period of several years.

- Studies should be made to reduce ventilation requirements by developing new methods of air filtration to remove odours and by selection of building materials with low generation of odours.

III. Heating and Cooling Technology

A. Comparison of the Efficiencies of Various Heating System s

The discussion of heating and cooling technology in existing structures brought out the differences in practice in the European countries and the United States. In Europe most residential central heating systems are based on hot water radiators. In the USA heating is done mainly by hot air circulation systems which are cheaper in prime cost and are readily adaptable to central air cooling. The following figures based on the 1970 US Census shows the distribution between the various types of domestic heating systems:

Central hot water systems	20%
Central hot air systems	42%
Other, non-central systems	38%

No comparable data are available for Europe.

There seemed to be differences in operating efficiencies of the hot air and hot water systems, the latter apparently having a slight edge.

This difference between the US and European practice was startling and further discussion revealed unexpected differences in efficiencies experienced in actual usage, not only between water and air systems but also between electric and fossil fuel systems.

The following data on relative efficiencies were mainly derived from metering of energy input at the house by utility companies in US and Europe:

	Design Efficiency	*Actual Efficiency*
Electrical Resistance	100%	100%
Gas, Oil hot air	65-80%	35-70%
Gas, Oil hot water	75-80%	50-75%
Coal		50-60%
Heat Pump		230-280%

It should be noted that these figures do not take into account the thermodynamic losses in the power plant cycle, nor the much smaller losses in the electric or gas transmission/distribution systems. The former would bring the Electric Resistance and Heat Pump efficiencies down to 35-40% and 80-110%, respectively.

The principal reasons for the loss of efficiency in actual use were thought to be the following: frequent cycling (especially of the air systems), poor maintenance, inadequate control, infiltration of combustion air. It was felt that quite substantial energy savings could be had by remedying these shortcomings.

Work on oxygen enrichment in combustion chambers and on improving the operating efficiencies of furnaces is recommended.

B. The Heat Pump

Most of the discussion on heating/cooling technology was centred upon the Heat Pump because of its obvious efficiency advantages. Further, the heat pump provides an effective method for utilizing waste heat from other processes and also solar energy.

The following topics are recommended for further research and development:

- Multispeed compressors for 25-100% capacity modulation to improve the efficiency during the considerable periods of light loads and rotary compressors which permit full capacity modulation.
- Improvement of heat transfer rates coupled with more favourable operating conditions.
- Design of heat pumps for heating only in countries where cooling is generally not used.
- Adding a heat exchanger to a heat-pump cycle to pre-heat hot water would improve the overall efficiency of the two independent systems during the heating cycle and would permit the full utilization of the condenser heat during the summer cycle which is now wasted to the atmosphere.
- Variable volume air flow can be used with advantage to raise the efficiency when the cooling and heating loads are light.
- Application of Stirling Engine to heat pump drive.

C. Technology of Waste Energy Reclamation

Significant amounts of energy are at present wastefully discharged within residential units, commercial establishments and industries which works against good energy utilization. In a residential unit the waste energy which could be reclaimed may represent as much as 15% of the heating needs. If such is the case, then there is a need for research in the following:

- Define sources of waste energy and how much is available for use.
- Develop hardware, components and systems for the collection of this energy, particularly from municipal sewage plants and individual septic tanks.
- Develop optimal use for this reclaimed energy whether it be for specific purposes such as pre-heat water or as source for heat pump. A hardware system must be developed which couples collection with utilization.
- Each source of energy must be examined relative to cost and energy effectiveness.

D. Control Technology for Heating/Cooling Systems

Development of control technology is an important facet of efficient energy utilization. The complexity of the heating/cooling system dictates the level of sophistication of control. The following research areas should be explored:

- Development of control technology for complex, integrated energy systems which include reclaimed energy and multipurpose heat pumps.
- Development of automatic local control for heating/cooling systems which operate on demand. Such system criteria should include "human comfort" and minimum energy consumption. Energy waste could also be avoided by further development of local thermostatic devices for hot water supply.

E. Solar Technology

Development of low cost solar collectors in various configurations and heat storage facilities for the following purposes:

- To serve as heat sink for heat pump applications.
- Solar collectors without storage to supplement heating/cooling and hot water requirements.
- Solar collectors with storage to supplement energy requirements and for "peak-shaving".
- Solar collectors with storage for specific applications (e.g. pre-heating, drying, etc.).

IV. Energy Utilization Data Banks

There is a strong need for the compilation and exchange of data and other information on present practices and energy use patterns in the various countries. Because of climate and tradition there is wide diversity among the countries both in the needs and the manner of achieving those needs. Both sectoral and functional distributions of energy use should be determined. The distribution of the energy by source should also be determined.

Methods for utilizing basic energy to achieve desired effects of comfort control differ from country to country. For example, hot air heating predominates in fossil-fueled systems in the United States while hot water systems are used mostly in Europe. The relative performance of these systems, from an energy utilization efficiency standpoint, should be compared to determine whether one has a clear superiority over the other. Another example is the widespread use of air conditioning in the United States and its more limited use in Europe. This may cause U.S. experience with heat pumps to be not directly applicable in Europe. Fitting older houses with thermal insulation in the vertical walls is a developed practice in Europe but is seldom done in the U.S. A systematic exchange of information on these and other items would be beneficial.

WORKING GROUP B

LIGHT

R. Bleekrode — Group Leader
F. Oostvogels — Recorder

G.W. Brundrett, P. Fedi, L. Gillain, D.O. Hall, D.G. Harvey, E. Kauer, H. Michel, W. Münch, H.J. Vink, A.H. Willoughby

General Considerations

In the industrialised countries a considerable portion of the electrical energy is used in lighting. In the USA for instance lighting is estimated to account for up to 25% of all electrical energy. Taking into account the conversion efficiency from primary energy sources to electrical energy this portion corresponds to about 3% of the total energy budget. This portion is expected to increase—even further because of the expansion in street lighting and the demand for higher light levels in other fields. In the USA the lighting consumption tripled from 1960 to 1970, corresponding to an annual growth rate of about 12%. Given this growth rate and taking into account the poor overall conversion efficiency of present light sources one may ask the following questions:

(i) What are the fundamental limits of the different methods of light generation?
(ii) What is the present state of the art and can the theoretical limits be attained by future technologies.
(iii) What are the criteria one has adopted for light sources in general?

A fairly complete introduction to these questions can be found elsewhere 1) 2). With regard to these questions the Group concluded that:

(i) there are no fundamental theoretical reasons why a 100% conversion efficiency could not be reached;
(ii) the fact that the best light sources known at present have efficiencies of the order of 30% indicate that further improvements can be obtained. Table I collects energy data on a variety of lamps.
(iii) the criteria for user-acceptance of light sources are related to properties such as colour rendering properties and appearance; light output; size and shape; electrical and optical characteristics under operational conditions (*cf* especially reference 3)).

The deliberations of the Working Group were centered around the three questions mentioned above. It was recognised, however, that the science, technology and art of lighting has already developed to the extent where drastic improvements in efficiency are not to be expected in the near future.

TABLE I

Energy distribution (percentage) for various lamps

Lamp type	*Incandescent*	*Incandescent halogen*	*Fluorescent*	*Sodium low pressure*	*Sodium high pressure*	*Mercury*	*Metal-halide*
Power (W)	100	100	40	180	400	400	400
Electrode losses	—	—	15	10	6	8	9
Arc power	—	—	85	90	94	92	91
Non-radiative loss	34	16	25 (63)*	59	44	44 (63)*	40
Radiative	66	84	60 (22)*	31	50	48 (29)*	51
UV	0	0	58	0	1	18 (2)*	4
Visible	5	13	2 (22)*	27	29	15 (15)*	23
Infrared	61	71	0	4	20	15 (12)*	24
lm/W	15	30	80	180	120	57	80
$(\mathrm{lm/W})_{max}$	260	310	(330)	530	(390)	250	(325)

* Energy conversion fluorescent layer included.

TABLE II

Properties of incandescent and electrical discharge systems for illuminating purposes

Lamp type	*Power* (W)	*Lamp efficiency* lm/W	*Lamp efficiency* %	*Ballast power* (W)	*Ballast + lamp efficiency* lm/W	*Ballast + lamp efficiency* %	*Fitting loss* %	*Overall efficiency* lm/W	*Overall efficiency* %
Incandescent	100	15	5	—	—	—	10-50 (indoor)	7-13	2.5-4.5
Incandescent halogen	100	30	13	—	—	—		15-27	6.5-12
Fluorescent	40	80	22	13.5	60	16.5		30-54	8.5-15
	65	85	—	11	73	—		36-66	—
Low-pressure Sodium	90	140	—	35	100	—	20-45 (outdoor)	55-80	—
	180	180	27	30	155	23		85-125	13-18.5
High-pressure Sodium	250	100	—	33	—	—		60-86	—
	400	120	29	39	108	24		72-103	14-20
High-pressure mercury	80	44	—	8.5	39	—		22-31	—
	250	54	—	18.5	50	—		28-40	—
	400	57	15	26	53.5	14		30-43	8-11
High-pressure metal-halide	400	85	23	26	75	21.5	30-40 (flood light)	45-52	13-15
	1000	90	—	43	86	—		51-60	—
	2000	100	—	68	97	—		58-68	—

Light sources can be divided into classes according to the various ways the energy is supplied to generate the light. A list of these classes is given below.

Energy Conversion Modes for the Production of Light

	Energy	*Phenomenon*
I.	Electrical	— incandescence
		— gas discharge
		— electroluminescence
		— p-n luminescence
		— phosphorescence/fluorescence
II.	Chemical	— flame
		— flame + selective radiator
		— chemiluminescence
		— candoluminescence
III.	Radiative	— photoluminescence

It proves useful to base a discussion on efficiency improvement of a light source on the following relation:

$$E \propto \varnothing \times h \times (\eta_l \times \eta_b \times \eta_f)^{-1}$$

between the total energy (E) consumed by the light source and the product of its luminous output ($\varnothing$), operation time (h) and the inverse of the product of lamp efficiency (η_l), ballast efficiency (η_b), and fixture efficiency (η_f).

For a number of well-known lamps data of these quantities are given in Table II.

The possibilities to improve energy utilization for lighting purposes have been discussed on the basis of the above list. Lamp efficiency improvement was central in these discussions. In addition a number of other topics have been treated in varying degrees of detail. The conclusions and recommendations of these will also be given.

I. Electrical Energy

A. Incandescent Lamps

Looking at the criteria for acceptance, the incandescent lamp has many advantages. It is because of its low efficiency that it has been replaced by other light sources in many applications. In theory, and neglecting losses, a considerable improvement could be obtained if it would be possible to satisfy the following conditions for the temperature dependent spectral emissivity $E(\lambda)$ of the electrically heated radiator

$E \simeq 1$ for $\lambda < 0.7\ \mu m$, $T = 0$, $R = 0$

$E \simeq 0$ for $\lambda > 0.7\ \mu m$, $T = 1$ *or* $R \simeq 1$

T = transmission, R = reflection

It is also possible to increase the efficiency of incandescent lamps by the application of heat filters. Maximum efficacy of approximately 250 lm/W for white light could theoretically be obtained with a filter that transmits only radiation of a wavelength from 0.4 μm to 0.7 μm and reflects all other radiation back to the radiator. Alternatively a maximum efficacy of 673 lm/W could be obtained with a narrow pass filter centered on 0.555 μm (maximum of eye-sensitivity), the light source then emitting monochromatic green light.

Incandescent lamp efficiency can also be improved beyond that at present achieved by tungsten halogen incandescent lamps, by increasing the temperature of the thermal reactor. It is believed that this can be achieved through a regenerative cycle using fluorine compounds.

It is recommended therefore that research be aimed at:

- improved optical filters,
- selective radiators,
- fluorine chemistry.

The possibilities of using multiphoton phosphors to improve the efficiency of the incandescent lamp should be investigated more closely.

The development of halogen-tungsten lamps of lower wattage for residential lighting should be stimulated.

B. Gas Discharge Lamps

1. Fluorescent lamps

In general the size and shape of the fluorescent lamp is considered to have hindered its application in residential lighting. Because its efficiency is higher than that of the incandescent lamp (Table II) such use would be desirable.

Research and development should be carried out:

- to improve the efficiency at acceptable values of the colour temperature,
- to reduce the size without loss of efficiency.

It is known that the operation of fluorescent lamps at higher frequencies (1-3 kHz) improves the lamp efficiency (10-15%) and reduces ballast losses (about 50%).

It is recommended that, especially in large scale applications, higher frequency operation be introduced in the near future.

Improvement in the efficiency of the supply units (inverters) should be developed.

As a general recommendation further investigations for better and new phosphors should continue to be given attention.

2. High-pressure lamps (general)

A variety of so-called high-pressure lamps are known to have good efficiencies (Tables I & II) and in particular cases combine these with good colour and good colour rendering properties. In principle the relatively small physical size of these lamps make them suitable for indoor lighting.

It is recommended that further R & D be aimed at the development of these light sources for many lighting applications (industrial, commercial and residential) by:

- adoption of the properties to the specific applications;
- studying in greater detail the power/efficiency relationships.

3. High-pressure sodium lamps

The high-pressure sodium lamp has a *very good* overall efficiency (Tables I and II), but is not suited to street lighting.

Recommendation: Botanical side effects which have been attributed to emission in the red part of the spectrum (around 680 nm) should be investigated in more detail.

4. Low-pressure sodium lamps

The low-pressure sodium lamp is the *most efficient* light source known to date. The light is monochromatic (about 590 nm) and this makes it suitable only for outdoor lighting.

C. Electroluminescence

Despite the great effort that has been devoted over the past twenty-five years to the Destriau-effect, relatively little progress has been achieved. The prospects for further improvement are not rated high. On the other hand there has been a rapid development in the field of p-n or injection luminescence with a variety of materials. High quantum efficiencies have been obtained in the red and infrared. Injection diodes for general lighting purposes would, however, require much larger radiating areas.

The extremely high theoretical internal conversion efficiency (>100%) warrants further investigations of semiconductor materials with regard to:

- spectral output,
- technology of large-size devices.

The field of p-n luminescence is considered to be of great interest for long-term development of high-efficiency "cold light" radiation sources.

II. Chemical Energy

It is likely that there is only a limited application for direct chemical energy conversion into light. The main reason being that high inversion efficiency is rarely obtained. It may be noted, however, that examples are known where efficiencies of the order of 10% can be achieved (e.g. flash lamp). It has also to be remembered that only about half a century ago artificial light was produced predominantly by direct conversion of chemical (free) energy (gas, candle, petroleum lamp).

In developing countries or in gas/H_2 economies a potential for the flame/selective radiator (e.g. Auer-mantle) is recognised.

We recommend therefore, reconsideration of the problems related to the properties of refractory materials at high temperatures and in chemically reactive atmospheres. Special attention should be given to vapour pressures, absorbing centres and chemical and mechanical stability.

Another possibility, namely production of selective radiation by seeding flames with small particles, should also be investigated.

Bioluminescence is a special case of chemiluminescence, and might be useful in specialised circumstances, such as camping and blackouts. The phenomenon is not considered as energy saving in general.

General Conclusions

It goes without saying that improvement of efficiency of ballasts for gas discharge light sources by using solid state devices or other components should be aimed at.

The recommendations should be brought to the attention of international bodies. In particular the *Commission Internationale de l'Eclairage* should give these the proper attention.

The possibilities of developing self-cleaning of light source/fixture combinations must be investigated.

Schemes which create a wide variability in electrical usage increase energy losses in the generation part of the system. The optimisation of lighting systems should take the effects related to this into account.

For the purpose of including lasers into our discussion, "light" was defined to cover the range of electromagnetic radiation between 10^2 and 10^4 nm. Recent developments in thermonuclear fusion research emphasize the importance of the efficient production of radiation in wavelength regions shorter and longer than that of "visible light" (400-700 nm). Furthermore, there is a tendency to increase the application of "light" in industrial processes. Research and development for these and many other purposes most probably are of importance for the further development and improvement of light sources and hence should be given the proper attention.

Lasers are considered as devices with a high potential as efficient light sources, either alone or in specific applications such as:

- high harmonic generation,
- stimulated anti-stokes,
- multiphoton phosphors.

Primary energy sources for lasers can be: electrical, optical, chemical, thermal, or combinations of these.

It is recognised that all aspects of lighting including the resulting heat load are to be taken into account in design consideration of buildings and houses. As a consequence the optimal requirements for outdoor lighting can be entirely different from those to be met in indoor lighting applications.

Investigations should be initiated to explore the potential for "central lighting" systems in which a central light source is used in conjunction with a light distribution system.

In view of this general recommendation, the application possibilities of lasers and light pipes should be considered in detail.

Research should also be carried out to adapt the properties of the "central lighting" systems to an integrated sunlight/artificial system.

Furthermore, the integration of lighting into the energy flow through buildings, particularly commercial buildings, must be given full attention.

References

Introductory papers to the subjects treated by the Working Group were presented at the meeting by Dr. Kauer and Dr. Willoughby. The presented material was based on papers that were published elsewhere.

1. E. Kauer, Generating light with selective thermal radiators, *Philips Technical Review, 26*, 33 (1965).
2. R. Groth and E. Kauer, Thermal insulation of sodium lamps, *Philips Technical Review, 26*, 105 (1965).
3. A.H. Willoughby, New lamps—their suitability for interior lighting, *Lighting Research and Technology, 6*, No. 1, to be published.

WORKING GROUP C

MOTION

J.G. Wistreich Group Leader
R.H. Johnson Recorder

J.G. Ball
U. Businaro
H. Düker
R. Eden
N.J. Felici
J.E. Goldman
E.A. Lisle
E. Massar
R.J. Meijer
W. Murgatroyd
K.G.A. Pankhurst
M.D. Rubin
J.M. Taub

General Considerations

The Group was given to understand that its assignment comprised transport of goods and people and the shaping of materials (e.g. forming, joining, cutting). Since, however, its subject title was Motion, consideration was also given to those aspects of industrial processes in which movement was being imparted to the materials being processed.

Energy utilization statistics were available mainly for US transport (e.g. E. Hirst and J.C. Moyers, "Science", *179/1299* and R.Q. Rice, International Automotive Engineering Congress, January 1973, S.A.E. 730066), but there was a paucity of data on European transport and on the industrial processes. The Group enters a plea for an extensive energy utilisation data base for the field under examination as an essential ingredient of the drive for energy economy.

I. Transport

Since between $\frac{1}{4}$ and $\frac{1}{3}$ of the total energy budget in the US is absorbed by transport (the figure is about $\frac{1}{6}$ for the countries of the European Economic Community), and this sector exhibits the fastest growth rate, all measures to reverse or at least to arrest this trend are desirable. Whilst the Group could see many opportunities for this being achieved through technical improvements, it is convinced that, besides the use of smaller cars, better organization and management of transport and traffic offer the most immediate and probably most cost-effective possibilities. The Group also wishes to draw attention to the desirability of fostering developments in communication technology to help eliminate some of the present demand for travel.

The energy consumed in the manufacture of transport equipment probably amounts to 10% of the energy expended in transportation (based on average car lifetime in conditions typical of the U.S.A.) and efforts to make the equipment more durable seem distinctly worthwhile. Dr. Massar calculates, for example, that (in conditions more typical for Europe) a 20% increase in the life of cars could save up to 5% of the total transport energy requirements. A similar effect would result from a decrease in the size of cars and a simplification of car equipment.

Air transport consumes by far the largest amount of energy per passenger (or freight ton) mile, followed by car and lorry, and railways, pipelines and public transport buses (at a stipulated average passenger occupancy) are the most economic means of passenger travel and freight transport. Everything should therefore be done to shift the present distribution of use of the different modes of transport towards the more energy efficient ones. For example, Dr. Massar estimates that transferring 50% of the transport of freight by road to goods trains saves 17% of the total energy consumption attributable to transport. Accordingly, the Group examined what part technological developments could play in bringing about this shift in the distribution of the use of different modes of transport, and so reversing the historical trend. Its conclusions are stated below.

A. Road to Rail

The main virtue of road transport springs from the flexibility and comfort of car and lorry. Accordingly, development is called for in the following areas:

in regard to urban passenger transport —
- provide far more frequent trains and buses with more stopping places and greater passenger comfort;
- develop moving walkways, perhaps aerial rope chair lifts in order to link up homes and ships with subway and overground commuter trains;

in regard to urban freight transport —
- further development of over or underground pipelines to link up rail depots with local pick-up and delivery points;

in regard to inter-city transport —
- improve roll-on and off of cars from car ferry trains;
- develop dual purpose freight vehicles to run on either road or track;
- develop an extra low-cost car, taking advantage of the fact that it would spend much of its time riding on trains.

B. Air transport will continue to be the preferred mode for intercontinental and trans-maritime journeys, (it is many times more energy efficient than seagoing passenger transport). Although reduction of air speeds would be the most powerful means of improving energy utilization, the flight time will continue to dominate passenger choice. Research into more economical engines is the only feasible recommendation (e.g. plasma jet with leaner mixtures in gas turbines).

For short and middeldistance overland passenger travel, the new fast trains already have the edge on airplanes. For the longer distances magnetic levitation with linear motor propulsion, whilst comparable with STOL (short take-off and landing) aircraft in terms of energy efficiency, has the advantage of greater capacity and more convenient terminal points. Its development should therefore be fostered, especially for very high speed applications in partially evacuated tunnels, further enhancing its overall efficiency.

C. Ships are a relatively efficient means of trans-maritime freight transport, but improvements may be worth obtaining by developing freighter submarines or even airships, on account of their lower resistance to motion. All three are also suitable for nuclear propulsion.

D. Prime Movers

The engines of transport vehicles, especially of short distance rail transport and generally of cars, operate a great deal of the time well below their peak efficiency, and a substantial proportion of the total energy consumption of transport is due to this. Undoubtedly, in the case of urban car transport a great deal of this could be avoided through the improvement of traffic flow, partly by better segregation of the various traffic streams (freight, buses, cars), and partly by more sophisticated electronic traffic control, and further research in the latter field is to be encouraged.

When all this is done, however, there still exists much scope for further saving of energy lost in the transmission system and in braking, and this not only in road but equally in rail transport. The Group commends the following directions for further R & D in this respect:

- more efficient and flexible automatic transmission systems for cars, probably via electronics rather than hydraulics;
- more efficient and compact regenerative braking systems, whether by flywheel or perhaps elastic hysteresis of suitable materials, or via energy storage batteries;
- more sophisticated control of the combined engine, transmission and regenerative braking system, e.g. by computer optimisation.

It was also noted that hybrid rail drive systems combining a diesel engine operating at constant speed with a sodium-sulphur storage battery providing peak power are possible and further developments in this direction are to be encouraged. As regards electric traction railways, the Group noted that the problems of using regenerative breaking in AC systems have yet to be solved satisfactorily. Light-weight storage batteries could also be used in combination with conventional electric traction systems.

However efficient the prime mover, the greater part of the input is wasted, and so, systems in which the waste-heat is small or recovered in a useful form and which are acceptable in transport vehicles need to be developed.

The energy consumption of a vehicle is directly related to its tare weight and the Group noted that the three-wheeler car with a two-stroke engine achieves typically 60 mpg (miles per US gallon) compared with the 10-12 mpg of the average US car (and, say 20-30 mpg in Europe). The development of a car combining light weight with adequate safety is urgently recommended.

Over and above all the foregoing measures, there is much scope for the raising of the thermal efficiency of vehicle prime movers, not only at their peak value but also over a wider range of operating conditions. Much effort has been already expended, but the energy crisis adds a new incentive to further activity in this direction. Most obviously, the replacement of the conventional IC (internal combustion with spark ignition) engine by the diesel engine with its 25-28% efficiency, can produce substantial economies most quickly. In London the substitution of diesel engines in taxi-cabs has produced a 50% fuel saving. Applied to the world energy picture, this figure implies a 6% net improvement. R & D is required to overcome the present disadvantages of the diesel engine in terms of noise, lower power density, higher capital cost at given power, lower acceleration and dirtier, smellier, though less noxious exhaust.

Further, the Group noted the substantial progress made in recent years in the development of a practical automatic Stirling engine, which in addition to an efficiency similar to that of the diesel, claims low-noise level, very low emission, flat efficiency/load curve, dispensation with lubricating oil and ability to operate on a wide range of low grade fuels. Its further development should be encouraged, and to this end R & D on the heater, preheater and high temperature materials of construction is required, as well as work on the engineering design so as to simplify its construction.

Thirdly, with recent developments of battery systems having more attractive power and energy densities, the prospect is improving for the all-electric car. Whilst its energy conversion efficiency may not be superior to the diesel and Stirling engines, the important advantages are: flexibility as to fuel sources in electricity generation, as to a possible link-up with centralized power distribution systems under or alongside the roads and from the point of view of automatic control, and higher system efficiency, because in a central power station the waste heat could be also utilized.

Lastly the development of hybrid systems is to be encouraged; e.g. a relatively low-powered diesel could operate at all times at peak efficiency, charging an electric storage cell. Dr. Goldman estimates that overall operating efficiencies as high as 35-38% are possible, compared with the present efficiency (10% in the U.S.A., probably 20% in Europe) of the straight IC engine driven car.

In railway transport where the low weight requirements are less stringent, such hybrid systems are already in the advanced stage.

II. Shaping of Materials

A. General Considerations

The Group felt strongly that in this field important energy economies can be obtained through better organization of production, standardization of products and avoidance of over-specification of material quality, and that these can be gained without technical R & D effort.

Inasmuch as the shaping processes absorbed an appreciable portion of the total energy consumption of national economies, shaped products should be made to last longer. Life can often be prolonged with negligible extra energy outlay by improving the quality of the material, e.g. by protection against corrosion and wear.

The primary material processes for conversion of e.g. metal ores into semi-finished materials which constitute the starting point for the shaping processes consume as much and not infrequently even much more energy than the latter. Further, shaping is mostly a multi-stage operation, much of it carried out at elevated temperatures, involving repeated intermediate reheating and final heat treatments. Heating consumes several times more energy than the shaping proper. Additional energy is required in ancillary treatments, e.g. pickling and coating. These facts lead to the following general

conclusions about achieving energy economies:

- As far as practicable, replace shaping processes, having a low metal yield,—i.e. those processes whose end products contain only a small fraction of the metal used—(e.g. machining) by high yield processes, notably casting and plastic forming (e.g. extrusion, spinning). Use fabrication extensively as a means of producing complex shapes.
- Favour processes in which the final shape is achieved in the least number of intermediate stages, e.g. casting, extrusion, powder compacting.
- Favour shaping at lower temperature, even though the mechanical forces required are greater in this case. Where appropriate, electroforming should be developed further.
- Develop scrap recycling processes which by-pass the primary stage, e.g. direct compaction of turnings into reinforcing bar.

B. Specific Opportunities for Better Energy Utilization

Much energy is lost between the points of input into the machine and the point of application to the material which is being shaped. For example, in machining, a transmission or coupling efficiency of less than 50% is common. There is scope for considerable improvement of this by engineering developments of shaping machinery, and even more readily by good tribological practices of maintenance.

The utilization of shaping machinery is generally low, and energy is wasted by idling. The most obvious way of improving this state of affairs is by promoting continuous processes. Not all the technology is available, and even where it is applied there is scope for further development, e.g. in continuous casting of tubular and other slender shapes.

The potential of casting needs to be explored further with the view to achieving greater complexity of slender shapes in the more "difficult" metals, coupled with the right mechanical properties of the finished product.

Powder technology is considered to be probably the most promising of the shaping processes with reference to energy economy. It is thought however that existing research programmes are sufficient.

The conventional heating and heat treatment processes are known to be very inefficient. Processes generating heat *in situ* require further development, e.g. induction heating of conducting materials and perhaps microwave heating of non-conducting materials. The development efforts should concentrate on cheaper sources of energy for these processes (e.g. low *vs.* high frequency, chemical maser, induction coils operating in the superconducting state).

Where multistage (or even single step) operations are unavoidable, the possibility of recovery of the energy lost by cooling should be looked into (e.g. in the water atomization process of manufacture of powder).

In cutting and welding there is scope for energy economy by the use of more concentrated heat generation e.g. by electron beam and laser, but the cost is at present prohibitive, hence the incentive for R & D devoted towards cost reduction of these systems. Also in view of the low efficiency of electricity at the plug, non-electrical methods (e.g. chemical maser, thermite welding) and cold methods (gluing) should be developed.

III. Motion in Industry

Professor Murgatroyd estimates that in heavy and light engineering, where induction motors are the principal source of motion, these are essentially unsuited to the characteristics of most processes where there is a demand for low and variable speeds and frequent starting and stopping. Owing to this and the need to introduce extra transmission devices, the overall efficiency of utilization of the prime mover output over the working day averages approximately 25%.

R & D effort in this area seems therefore eminently worthwhile. One notes that the usual speed/force characteristics of the load are more readily matched by hydraulic rather than electrical power, and so, in addition to hydraulic transmission systems complete with hydraulic power drives, perhaps even centralized systems ought to be seriously looked into.

The Group notes that much of the current inefficiency is due to poor maintenance standards and shortcomings in the reliability of equipment, both of which should be remedied, even before embarking on R & D.

WORKING GROUP D

ELECTROLYTIC AND ELECTRONIC PROCESSES

J. O'M. Bockris — Group Leader
A. J. Appleby — Recorder

R. Avenhaus
R. A. Dugdale
D. R. Jenkins
C. Roscoe
A. C. Sjoerdsma
C. B. Smith
H. Tannenberger
G. Walter

I. Electrochemical Direct Energy Conversion and Storage

Great improvements in energy utilization are possible by the use of fuel cells. Fuel cells are not Carnot-limited, and are capable of efficiencies of 50-70%. Efficiency is scale-independent. Hydrogen is the best fuel choice, but hydrocarbon fuels can be oxidized at high temperatures, or used indirectly via reformers.

Direct use of fuel cells in transportation would allow approximately a doubling of the overall efficiency of the use of fuels. This could stretch the world's fossil fuel (principally coal) reserves (expected to reach maximum production 2030-2060*) out towards the 2100s, if the pollutive difficulties associated with their use could be overcome.

In a Hydrogen Economy, reverse fuel cells will produce electrolytic hydrogen and oxygen from nuclear electricity and solar power. Improvements in fuel cell technology are of the utmost importance for the success of the Hydrogen Economy.

A. Fundamental Research on Electrode Processes

Research is required in the areas of electrode processes, electrode configuration and mass transfer and electrocatalysis, especially that of the oxygen electrode.

1. Adsorption Isotherms for Organic Materials

Adsorption depends on double-layer characteristics; for most organic materials the adsorption is a maximum at or near the potential of zero charge. The isotherm changes with molecular structure. A knowledge of these effects would have a vast potential in electrosynthesis (see Section III, A). An understanding of the mechanism of electrochemical poisoning by strongly adsorbed organic molecules (e.g., CO in indirect hydrocarbon fuel cells) or by anion adsorption (H_2PO_4 or polyphosphate) is necessary.

* M.A. Elliot, N.C. Turner, American Chemical Society/Symposium on Non-Fossil Fuels, Boston (1972).

2. **Zero Charge Potentials.** Determinations to ± 0.01 volts should be aimed at.

3. **Reaction Intermediates.** Techniques for the study of reaction intermediates should be developed. This area is little developed at present.

4. **The Activation Process.** Present theories involve energy transfer either by thermal bombardment or by polarization wave propagation. Knowledge of the energy transfer mechanism and maximum possible theoretical rates is necessary.

5. **The Reaction Mechanism and Rate-Determining Step.** A knowledge of the reaction mechanism (e.g., hydrocarbon oxidation) and the free energies of intermediates is essential.

6. **Kinetics at Semiconductors.** Oxide and organic semiconductors are promising catalysts. Their surface structure and surface states need definition. Electron transfer at semiconductors is little-understood. Electron distribution in surface states (adsorption) requires study.

B. Materials Science

Lifetime of catalysts and of construction materials requires extension.

C. Ion Conduction in Solids (e.g. β alumina and doped ZrO_2)

In-depth investigation of this area (relation between crystal structure and ionic conductivity; stability and structure; impurity effects) is required. These materials are of importance in fuel-cells and batteries operating between room temperature and 400 °C.

D. Endothermic Fuel Cell Systems

Overall processes with $/\Delta G/ > /\Delta H/$ are theoretically capable of thermal efficiencies greater than 100%.

E. Configuration of the Electrode Surface

Optimization of the active surface and minimization of diffusion resistance is necessary. At present, electrode manufacture is an art. Theoretical equations for parameter optimization are required (pore size distributions, porosities, pore tortuosity and contact angle control).

F. Electrocatalysis

The hopes for successful electrocatalytic research are greatly enhanced if the mechanism of the reaction is known.

1. Electrocatalytic reactions involve compensation effects, i.e. the pre-exponential term in the Arrhenius expression is lower for high adsorption energies. Such interrelations are poorly known and should be investigated.

2. The significance of the transfer co-efficient must be known. This is mechanism and adsorption dependent (i.e. the effect of the overpotential upon the reaction rate is dependent on the transfer coefficient). Understanding may permit greatly improved reaction rates.

3. Activation by α-radiation (defect inducement), by magnetic fields and by neutrons requires investigation.

4. Synergistic effects (e.g. platinum on tungsten bronzes, platinum on carbon) are important. Ion implantation is a possible method of preparing more effective catalysts.

G. Direct Electricity Production From Fossil Fuels

The following are unclear:

1. What surface radicals are formed on adsorption?

2. Is elucidation of all reaction steps necessary to understand the electrocatalytic situation, or is only the rate determining step of value?

3. What is the precise significance of volcano plots?*

4. What is the relation between chemical structure and poisoning (including that due to anions)?

5. Noble metals may still be necessary as electrocatalysts. Can their quantities be reduced to produce acceptably priced systems?

6. Semiconductors have more potential than metals for improved electrocatalysis.

H. The Oxygen Reduction Process

This is the limiting process in both low temperature fuel cells and electrolyzers. The success of the Hydrogen Economy may be affected by oxygen electrode overpotential. Some areas that will repay investigation are:

1. Surface magnetic field and adsorption.
2. Mechanism of reduction on organic semiconductors (e.g., phthalocyanines).
3. Effect of photon activation on reaction rate?
4. Mechanism of the radioactive effect.

I. H_2 Fuel Cells

These cells, using pure H_2 are easy to engineer even using present technology and could be used at high efficiencies in the Hydrogen Economy. In dispersed, home-sized units, used according to the TOTAL ENERGY concept, they present several advantages, e.g. their heat emission can be used for domestic heating, while during the night they can be used for charging electric vehicles.

* Plots in which log reaction rate, plotted against a variable which reflects bond strength of radicals on the surface, has a maximum.

J. Fuel Cell Parameters

Best performances to date are as follows:

H_2-air*	250 °C	1 W/cm^2 100 W/kg 20 kW m^{-3}
Hydrocarbon-air*	200 °C	0.1 W/cm^2 25 W/kg 10 kW m^{-3}
Coal-air*	1,000 °C	1.0 W/cm^2 200 W/kg 20 kW m^{-3}
Hydrazine-air**	100 °C	0.1 W/cm^2 120 W/kg 40 kW m^{-3}

* With high catalyst loadings.
** This fuel has carcinogenic properties.

II. Electrochemical Energy Storage

Electrochemical storage is the only way of storing electricity whereby it may be instantly recalled.

Considerable R & D effort is needed in this area because of:

(i) The need for transportation (electric vehicles);
(ii) The need for off-peak storage of solar and nuclear energy.

The only well-known storage system namely the lead-acid (Pb–PbO_2) battery has a poor energy density and requires no further research. Many new battery systems were investigated during the '60 s; some of these, when sufficiently developed, will have up to ten times the Pb–PbO_2 energy density.

A. Research Required in Battery Development

1. **Electrode Mechanisms.** Mechanisms are imperfectly understood, e.g. electrode shape change and dendrite growth in zinc electrodes.

2. **Materials.** High temperature (300-800 °C) batteries involve materials problems, for insulators, current collectors and seals (Li–Cl_2, Na–S–β alumina).

3. **Electrode Structure.** See Section I.E.

4. **Control During Charging.** Differences in the capacities of individual cells in the batteries cause charging problems.

B. Low Temperature Systems Requiring Development

Zinc-air	Iron-air
Nickel-zinc	Nickel-Iron
Zinc-chlorine (hydrate)	Nickel-Hydrogen (compressed)
Aluminium-air	Zinc-Oxygen (compressed)
Alkali metal-air	

C. High Temperature Systems Requiring Development

Aluminium-Chlorine
Lithium (or alloys)-Chlorine with hydrate storage of chlorine
Ca-F_2 (Ca-F_2 electrolyte)
Na-S, Li-S (β-alumina solid electrolyte)

The two chlorine cells pose fewer intrinsic problems than the two sulphur based cells. The β-alumina system has thermal cycling and materials problems. The Ca-F_2 system is at present in early development. Thermally regenerative cells have high promise for the conversion of heat to electricity.

D. Hydrogen Systems

Storage based on hydrogen needs extensive development work to attain production of H_2 near the reversible potential (high temperature electrolysis of steam). Thereafter, a determined and sustained investigation of electrocatalysis of the oxygen reduction reaction must be made, to allow efficient reconversion to electricity. Many other aspects of a Hydrogen Economy must be investigated, e.g. storage, safety, pipeline engineering, etc.

E. Battery Parameters

The state of the art (and not the best) is about as follows:

	W/kg	Wh/kg
Zinc-air	100	100
Ni-H_2 (compressed)	300	80
Ni-Fe	40	50
Zn-O_2 (compressed)	300	160
Aluminium-air	150	240
Sodium-sulphur	100	100
Sodium-air	200	400
Li-Cl_2 (liquid storage)	300	500
H_2-air	100	2,000

It is reasonable to expect that in 10 years the following maximum performances will be attained:

10 W/cm^2; 100 kw m^{-3}; 75% voltage efficiency; 1 kW/kg; 1 kWh/kg

These optimal performances will not necessarily be present in the same battery; different batteries will have different applications.

III. Electrochemical Processes

Both classical and new concepts are considered here (electrosynthesis, electrowinning, electrorecycling and electrorefining). Energy gains from new methods of metal shaping (electroforming and electrochemical machining) and in other areas (e.g. corrosion) are to be expected.

A. Electrosynthesis

1. Classical Electrosynthesis

This uses electrical energy to reverse a chemical free energy gradient, and has several advantages:

In non-aqueous solvents, up to 6 eV or 140 kcal/mole (590 kJ/mole) energy is available (only 28 kcal/mole (112 kJ/mole) is normally available chemically); free energy control (controlled potential electrolysis) is possible; activation energy is often low (room temperature reactions); high yields, and a small percentage of by-products result; simpler separations and fewer reaction steps (lower energy input/Kg of product) are involved.

Future research areas:

- Porous electrodes (See Section I.E.).
- Electrical energy input is equal to $(\Delta G^\circ + \eta F)$ (ΔG° = standard free energy, η = overpotential); η can be reduced by attention to mass transfer control and electrocatalysis (see Sections I.E. and I.F.).
- Poisoning problems and electrode pulsing for reactivation (see Section I.G.).

Some current examples of organic electrosynthetic processes are adiponitrile and melamine synthesis. Electrosynthetic processes will eventually take place mostly in central nuplexes.

2. Spontaneous Electrosynthesis

This produces electrical energy along with a useful end product.

Examples:

(a) Hydrocarbon chlorination—the reversible potential for Cl_2 reduction is 1.1 V more positive than that for hydrocarbon oxidation.

$$\left.\begin{array}{l} Cl_2 + 2e^- \rightarrow 2Cl^- \\ RCH=CHR' + 2Cl^- \rightarrow RCHCl\ CHClR' + 2e^- \end{array}\right\} + \text{electricity}$$

(b) Sewage treatment (oxidation of cellulose electrochemically to CO_2 and reduction of oxygen). Pure water is produced as a by-product.

(c) CO_2 reduction—CO_2 from stack gases, the atmosphere or limestone, can be electrochemically reduced to HCHO and CH_3OH. A food cycle based on this process (enzymatic formation of protein) is possible.

Other possibilities are engineered methods for use of sodium amalgam (NaCl electrolysis) and high temperature reduction of iron oxides by C.

B. Electrowinning

1. Hydrogen

The most important new process is electrolysis of water vapour (~1,000 °C) using solid doped ZrO_2 electrolyte. High current densities (~4 A/sq.cm) and low polarization are possible. Capital costs will be low. At 1,000 °C the energy necessary for water splitting is less than half that at room temperature (electrolysis at 100% efficiency possible at the higher temperatures). This has consequences for a Hydrogen Economy.

Study of hydrogen evolution processes with waste-depolarized O_2 electrodes is also needed (oxidation of SO_2 and sewage to H_2SO_4 and CO_2, with large electric power saving). Plastics disposal by this method must be considered.

2. Electrowinning of Other Materials

(a) Reduction of aluminium production voltage. Electrodes can be redesigned to reduce the voltage required.
(b) Depolarization (by hydrogen) of O_2 evolution electrodes in aluminium production (use of porous electrodes). These improvements could improve energy balance very significantly.
(c) Improvement in current density distribution, ohmic drop and mass-transport in other processes. (Electrochemical engineering design).
(d) Improvements in deuterium production (future fusion economy).

Much of the present technology of electrowinning essentially stems from the 19th century, though some new concepts exist (e.g. electrochemical reduction of metal sulfides to give pure electroformed metal and elemental sulphur). It is believed that important energy savings can be made.

C. Electrochemical Recycling

This has advantages in allowing direct separation of metals at controlled potential (potentiostat development), and in direct electroforming (direct production of sheet, foil etc.).

Processes exist or have been proposed for scrap recovery (tin cans, steel from junked cars).

Other possibilities include:

- Direct electrogalvanizing (recycled zinc);
- Direct alloy formation;
- Extraction of valuable metals from low-grade dilute wastes (Ag, Cu, Zn; metals from low-grade ore leachings; electroplating wastes, pickle liquor);

- Removal and storage of radio-active wastes as solids;
- Treatment of industrial wastes (Hg removal at high dilution, oxidation of cyanides and wood pulp wastes in fluidized bed electrodes).

D. Electroforming and Electrochemical Machining

Increased use of electroforming (complex shapes) could greatly save energy. Research on improved mass-transport (ultrasonic stirring, fluidized electrolytes) and current distribution (counter-electrode design) would be desirable.

Electrochemical machining (especially of hard metals) can be more efficient than standard grinding and cutting methods. Subjects for research are similar to those for electroforming with the addition of heat-rejection.

E. Corrosion

Corrosion (an electrochemical process) represents 1% of the GNP. About 25% of this can be saved by present technology, with up to 50-75% in the future. The biggest impact of the application of knowledge of corrosion would be in the transportation area (increased vehicle life, hence lower overall energy costs).

Research is required in:

Cathodic protection
Inhibition

An effort in education is needed,—the spread of modern knowledge in mechanistic electrochemistry to the engineer.

F. Other Electrochemical Areas

Anti-fouling treatment (chlorine evolution) can reduce ships' energy requirements.

Improvements in electroplating current efficiencies can be achieved by avoiding side reactions (e.g., hydrogen evolution in Cr deposition).

Ore separation may be achieved by flotation by electrochemical gas (e.g., hydrogen) evolution.

IV. Electronic Systems

A. Photovoltaic Cells

Areas of needed research:

- Investigation of theoretical limit of efficiency (effect of temperature).
- Cost reduction. This is improved enormously for Si cells by the edge defined growth method of crystal drawing ($200/kW for photo-voltaic Si has been predicted).
- Cheap (low efficiency) polycrystalline thin film cells.
- Development of sunlight collection and concentration systems.
- Efficient Cd-S cells (lifetime problems).
- Battery storage.

B. Thermionic Convertors

Little work is at present being conducted in this area. A new device (based on Na^+ conductivity of β alumina) has promise. It is essentially a Na (liquid)—β alumina—Na vapour concentration cell, with liquid (hot) sodium in contact with the colling loop of the reactor, the other evacuated side containing rarefied sodium vapour in contact with cold sodium metal, together with a porous current collector in contact with the solid electrolyte. Efficiencies of 50% and currents up to 0.5—1 Å/cm^2 are possible.

C. Radiofrequency Devices

These have applications for energy savings in home and industrial cooking.

D. Electroluminescence and Electrochemical Luminescence

- High efficiency devices should have applications in panel lighting, display lighting.
- Use of high efficiency lasers will save energy in welding, cutting, machining and vacuum deposition.
- Research in light-emmitting diode devices, electrochemiluminescence, light storage technology and photogalvanic cells is needed.

E. Glow Discharge

Energy gains are possible in the areas of film formation on metals and other surfaces (nitriding of steel, anodizing, sputtered films) as well as for lighting applications (high frequency).

WORKING GROUP E

RESIDENTIAL AND COMMERCIAL SYSTEMS

D.G. Harvey — Group Leader
A.L. Hammond — Recorder

E.R. Ambrose
G.W. Brundrett
J.B. Comly
R. Eden
P.O. Fanger
P. Fedi
N.J. Felici
L. Gillain
D.R. Jenkins
E. Kauer
R.J. Meijer
H. Michel
J.C. Moyers
D.N. Morris
W. Münch
M. Penel
M.D. Rubin
J.H.K. Shannahan
G. Walter

Introduction

The energy consumed in residential and commercial structures is primarily associated with the maintenance of comfortable ambient conditions and, depending on the type of structure involved, the energy consumed in specialized appliances and equipment. Residential structures may be divided into two broad categories: (a) centrally supplied heating, ventilating and air conditioning (HVAC) systems (usually for large apartment complexes) and (b) dwelling units which have individual heating and air conditioning systems (usually associated with single houses and small apartment complexes). Residential structures consume energy in space conditioning and, of course, in the many appliances and lights associated in general with the degree of affluence of the occupants.

Commercial structures cover a myriad of enterprises such as office buildings, hotels, restaurants, hospitals, theatres, laboratories, stores, gas stations, etc. Generally excluded from the commercial category are all structures which house industrial production.

It is the objective of this discussion to describe qualitatively the manner in which energy is consumed in these structures and to recommend areas in which research is required to reduce such consumption. The research items recommended are, in general, long lead items and do not reflect the many energy-conservative measures possible today at relatively low cost, e.g., storm windows, temperature set-back, etc.

Background Discussion

The diagrams in Figure 1 illustrate the typical energy gains and losses in winter and summer for any structure.

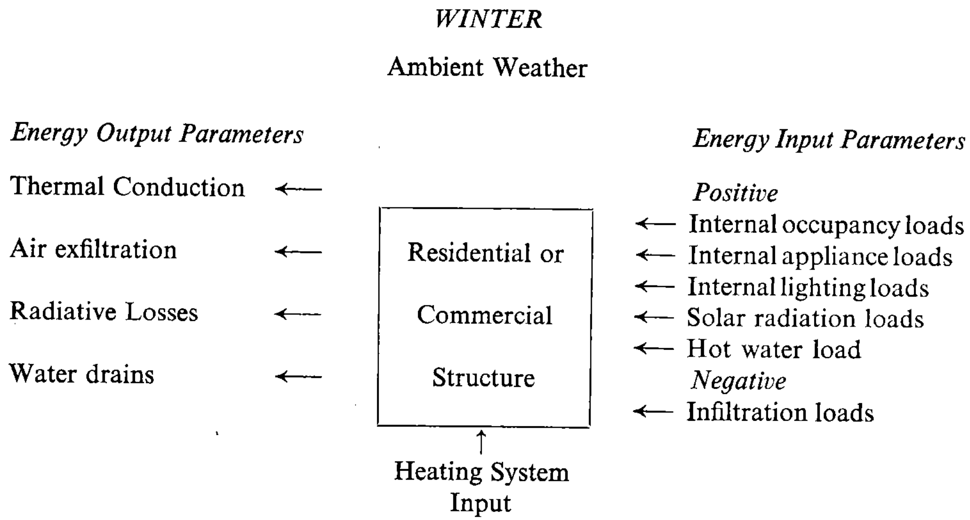

Figure 1(a)

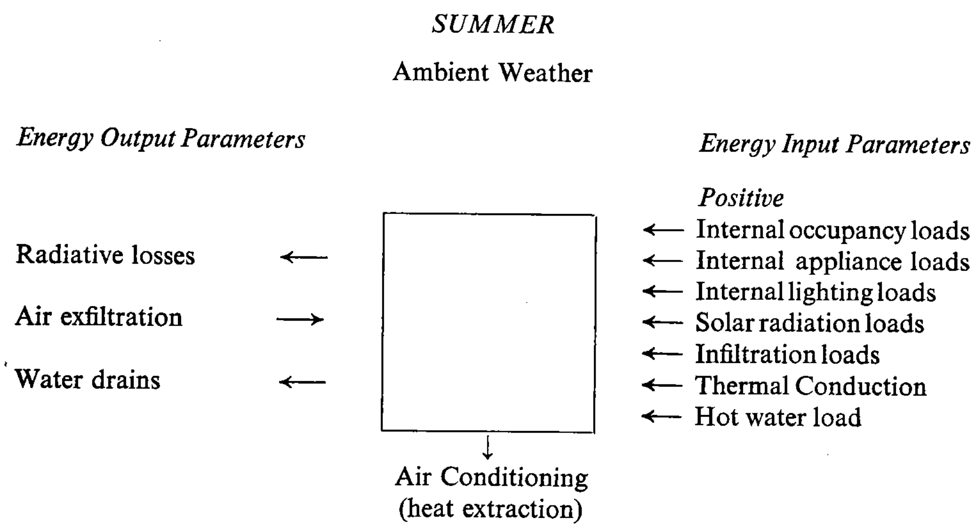

Figure 1(b)

I. Residential Structures

A. Separately supplied heating, cooling, and electricity. A breakdown of the internal energy consumption typical for such structures is shown in Table I[1] *. This consumption contributes to the heat which must be supplied during the winter but must be extracted by the air conditioner during the summer, if air conditioning is used. The heating and cooling load for this same house, which meets US Federal Housing Administration standards is shown in Table II[1]. It will be noted that the infiltration load for this house is a very substantial portion of the total system load. These values may not be typical of other countries. For example in the United Kingdom, the infiltration load is probably the same in absolute numbers, but owing to lower standards for insulation may represent only 25 percent of the total heating load[2].

TABLE I

Annual primary energy consumption for a typical residential structure in the Baltimore-Washington area

Component	*All electric house, therms**	*Minimum energy house, therms*
Hot Water Heating	480**	270(G)
Lights	218	218 (E)
Range	120	50(G)
Refrigerator/Freezer	200	200 (E)
Clothes Dryer	108	40(G)
Colour TV	54	54 (E)
Furnace Fan	0	43 (E)
Dishwasher	40	40 (E)
Clothes Washer	11	11 (E)
Iron	16	16 (E)
Coffee Maker	11	11 (E)
Outside Light	90	90 (E)
Miscellaneous	131	131 (E)
	1,487	1,174

(E) Electric
(G) Gas

* One therm = 10^5 Btu = 1.055×10^5 kJ.
** Electric power based on power plant energy consumption of 10,910 Btu/kW-hr.

* These features are for a single family house located in the Baltimore/Washington area of the United States.

[1] ANDERSON, R.W. and HARVEY, D.G., "Energy Consumption in Single Family Residences" 8th Intersociety IECEC Conference, August 1973.

[2] BRUNDRETT, G.W., "Some Effects of Thermal Insulation on Design," Aston University Conference Proceedings on Improving Thermal Comfort in New Domestic Buildings, England, April 1973.

TABLE II

Breakdown of heating and cooling loads for a typical house in the Baltimore-Washington area*

	% of Heating Load	*% of Cooling Load*
Ceiling	3.7	2.3
Floor	2.2	2.4
Total Window	13.6	4.1
Total Door	1.4	0.4
Total Wall	23.9	14.2
Infiltration Load	55.2	41.5
Internal Load	—	35.1
Total	100.0	100.0
Total Load, Therms	710	282
Total Load, kJ	750×10^5	300×10^5

* These loads are for an average house in the Baltimore-Washington area. The values presented will vary significantly for different geographic locations.

B. Centrally supplied heating, cooling and ventilation systems. The major difference in this type of structure is that the ventilation system usually pressurizes the building which results in leakage of internal air to the outside. Thus "infiltration" as such is eliminated but the much more energy-consuming practice of conditioning totally fresh air at all times is far worse.

II. Commercial Structures

The major difference between residential and commercial structures regards the internal load. Figure 2 presents the distribution of energy consumption by function for the commercial sector[3]. The internal loads in such structures are often so high that air conditioning is the primary space conditioning requirement. Figure 3 illustrates this point.

Recommendations for energy conservation

Energy may be conserved by using more efficient structures, internal loads and HVAC systems, and by integrating the function and energy consumption of these systems. Thus the recommendations for energy conservation consider these functions separately at first, and then in concert.

[3] SALTER, R.G., MORRIS, D.N., "Energy Conservation in Public and Commercial Buildings" Rand Corporation; October 1973.

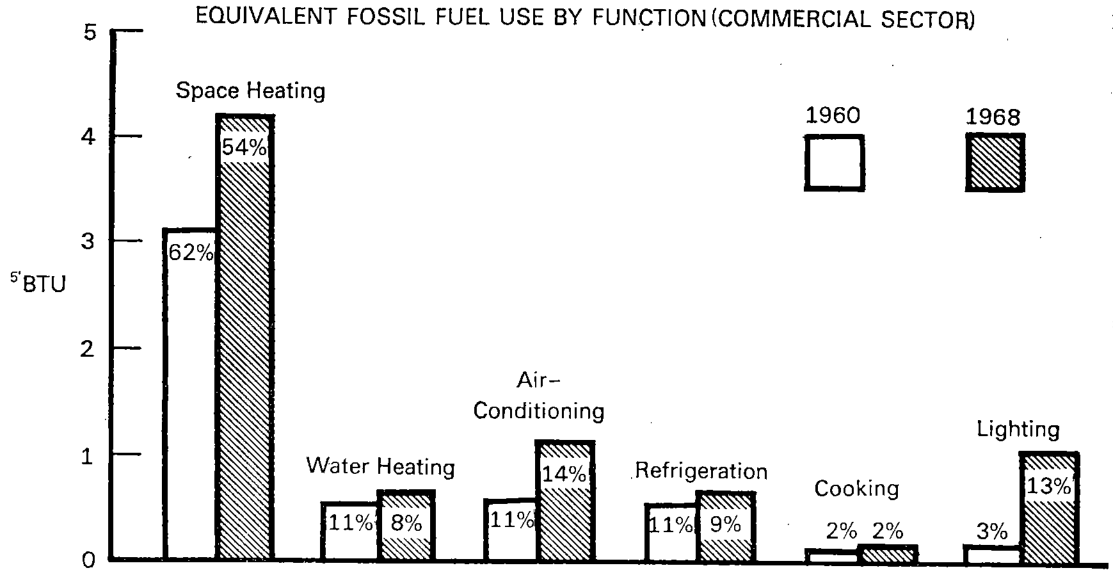

Figure 2

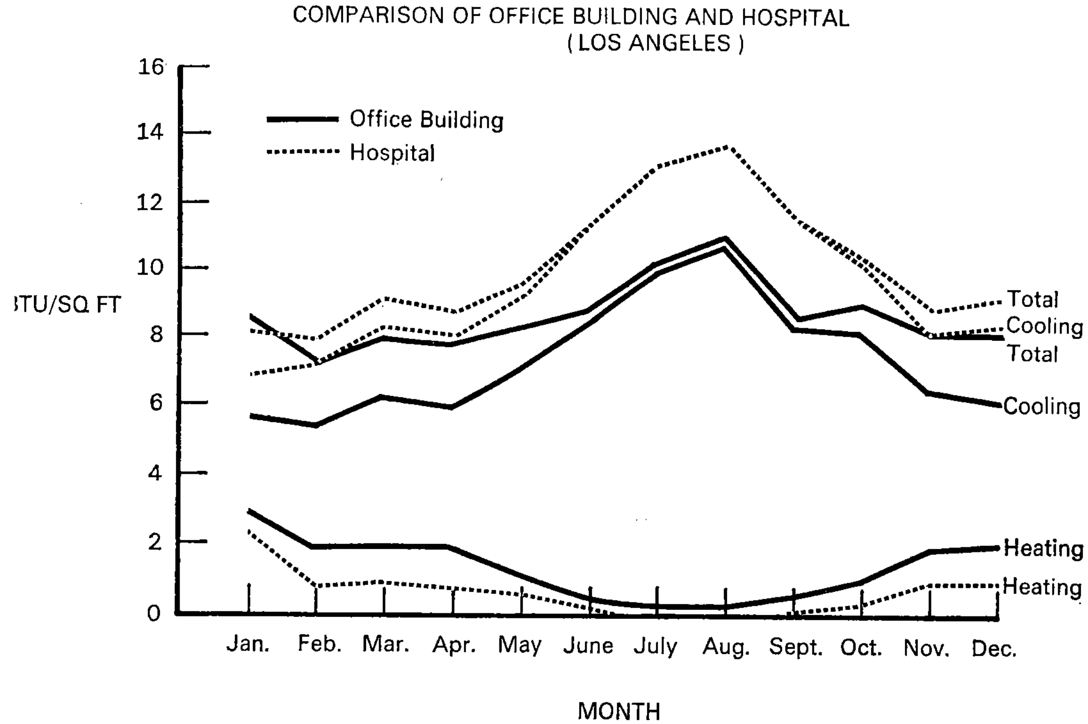

Figure 3

I. Structure

A. Improved Insulation of Existing Houses. A major loss of energy occurs in the heat transmitted through the walls of a house. In a new house, insulation of suitable thickness can be included in the initial design. Most existing houses, however, lack sufficient insulation. Therefore, research on techniques of installing insulation in existing structures must be conducted. These techniques must necessarily vary from country to country depending on building practices. It may be important to use infra-red or ultrasonics to detect beams, in order to assure accurate installation location and to examine the adequacy of installation as a quality control measure. Research is also necessary on new insulation materials which have adequate properties regarding flame retardation, stability, moisture resistance, insulating effectiveness and absence of noxious thermal degradation products.

B. Heat Capacitance. Research into techniques of damping the diurnal thermal variations of structures could yield lower energy consumption. Increasing the thermal storage capability of a structure through the use of heavier construction materials of high heat capacitance or by a central storage facility containing special materials, e.g., high heat of fusion materials whose melting point is about 20 °C, deserves further investigation.

C. Infiltration. Infiltration is a major loss of energy in most houses. Research is required into techniques of sealing doors and windows more effectively. Some of the techniques which should be considered involve mechanical, elastomeric, and magnetic materials, such as the seals currently in practice on refrigerator doors.

D. Improved Window Insulation. A major energy loss is by conduction and radiation through windows. Conductive losses and gains are counter productive to energy-conservation in both heating and cooling seasons. Radiation gains from the sun are beneficial during the winter but detrimental during the summer. Before adapting a specific glass configuration it is necessary to evaluate the geographic location and the nature and schedule of the internal loads of the structure in question. Current practice of using double glazed windows significantly reduces both conductive and radiation losses depending on the geographical location of the structure. Research is needed to provide techniques for further reduction of such losses. An especially promising direction is the development of heat reflecting filters, e.g. indium oxide and tin oxide which transmit visible radiation with minimum losses, while reflecting up to 90 percent infra-red radiation. Of course, the transmission in the visible region of the spectrum of selective reflecting coatings will be subject to optimization taking into account acceptable loss in colour rendering looking outside the window.

It would be extremely desirable to develop such coatings which could be applied to existing single pane glass. The potential of the double pane configurations with selective reflective coatings in reducing conductive and radiation losses warrants investigation into economical production techniques. A third level of optimization could be obtained by replacing internal air with a low conductivity gas, such as Krypton.

The characteristics of a variety of potential window configurations are shown in the following table:

	Conductivity (K) in kJ per m^2 per hour per °C
Single glass	21
Double glass with air layer	11
Double glass with one coating	6.6
Double glass with one coating and Krypton	3.8
Double glass with two coatings and Krypton	3.3
Single glass with one coating	11

II. Internal Loads

Residences have an extremely diverse array of internal loads, with equally rich opportunities for energy saving through more efficient components and better system integration. The internal loads of commercial buildings, on the other hand, are predominantly lighting, people, and in specialized structures, equipment, e.g., computers, ovens in restaurants, etc.

- Minimal central heating of domestic hot water to the lowest acceptable level with local boosting for dish-washers, washing machines and similar high temperature applications, and the possibility of waste heat recovery as part of the central system should be examined.
- Systems to recover heat from hot water drains could be beneficial, especially from washing machines in laundries of large blocks of apartments. Local building codes often prevent proximity of drains to water supply pipes and in such places heat pipes might be used.
- Design of optimum lighting layouts to "light the task" for commercial buildings, flexible layouts and variable positioning of fixtures should be investigated.
- Fluorescent lamps should be improved so as to make them more acceptable to general residential use. Improvements required include lower colour temperature phosphors and simple screw bulbs adapted to current incandescent lamp fixtures.
- Inexpensive techniques for supplying a variety of forms of electricity to the consumer should be considered, for example, direct current for incandescent lighting and high frequency a/c for lighting and smaller, more efficient motor drives.
- Improved refrigerators are needed with better insulation, replacement of internal heaters, removal of condenser heat from the cabinet vicinity, and possibly, recovery of condenser heat. In this connection heat pipes should be considered.
- Reduction in energy use in cookers should be pursued along the lines of microwave and induction cooking and better matching of power to load with temperature sensors. Ventilation of ovens directly to the outside air can save energy in the summer.
- In residential structures considerable energy is consumed in the production of hot water. Fertile areas for research into reducing this consumption include: Improved insulation of the hot water heater; replacement of pilot lights with electronic ignition systems (gas systems only); energy recovery from other thermal sources in the house; energy recovery from high temperature wastewater (laundry room), and insulated one pipe distribution systems which premix the desired temperature of the water thereby minimizing the thermal losses in the distribution system.

III. Heating, Ventilating and Air Conditioning

A. Fuel Fired Heating Systems. Major improvements in the overall efficiency of fossil fuel heating systems can be obtained, for example, by design of systems that retain their efficiencies without frequent servicing, by improvements in the basic combustion processes, and by improvements in the distribution systems within the building. In the last two areas, some specific suggestions are:

- Significant improvements in efficiency are possible by use of fluidized bed furnaces. This process has been used successfully in large scale industrial systems, and should be adaptable to residential and commercial applications. Heating plant efficiencies of greater than 80 percent are possible in routine use. Recommendations for research include exploring the limits of performance (maximum and minimum heating potential), the use of liquid and solid fuels instead of gaseous fuels, and the development of consistent homogeneous ceramic plates for the beds.
- Much of the overall efficiency loss in furnaces is caused by the on/off mode of operation. This can be corrected partially by the installation of automatic dampers in the exhaust system. More promising is the development of inexpensive, reliable systems for varying the heating rate or the volume of hot air flow.
- Duct systems for hot air furnaces in residences are often poorly designed and badly insulated, the overall system efficiency being frequently as low as 30 to 35 percent from an otherwise efficient furnace. This can be improved significantly by careful attention to design in minimizing duct lengths and applying sufficient insulation. Further improvements in overall system performance can be achieved by providing individual control of room temperatures. The development of simple, reliable mechanisms for thermostatic control of the flow of warm air in individual rooms is recommended.

B. Heat Pumps and Air Conditioning Systems. A broad effort should be continued on research to increase the efficiency of heat pumps and air conditioning systems in view of their major impact on present and future energy utilization. Basic improvements in performance of heat exchangers, and research leading to application of the Stirling engine to heat pumps (primarily in large commercial systems) would improve overall efficiencies and result in energy savings.

C. Total Energy Systems. Total energy systems are already in use in a number of locations. Areas for research include:

- adaptation of the total energy concept to small scale structures such as small apartment buildings or single family homes;
- optimization of the mix of heating, electricity generation, and purchased electricity of the system;
- development of uses for the excess heat available from full on-site generation of electricity (see below, absorption Refrigeration Systems).

D. Solar Energy Systems. Solar energy systems can play an important part in reducing energy requirements for residential and commercial buildings, initially as augmentation or pre-heat for conventional heating systems (space heating, water heating), perhaps eventually as complete systems. In either case research is needed on flatplate collectors and heat storage devices to make the systems competitive economically in terms of initial investment cost and maintenance cost.

In the latter case, that of a complete system, research is recommended on:

- Concentrating collectors to provide higher temperatures and improved efficiencies;
- Simple mechanisms for accurate sun-tracking by concentrating collectors;
- Efficient heat storage systems to provide adequate heat capacity during cloudy weather.

E. Fuel Cells. Efforts to develop practical fuel cells for residential and commercial buildings should be continued vigorously. In addition, the application and systems integration of this technology to such structures should be studied and optimized.

F. Absorption Air-Conditioning System. We recommend a major research effort to effect substantial improvements in the efficiency of absorption refrigeration systems. Specific effort is required in developing refrigerant–absorbent pairs capable of operation at low hot-side and cold-side temperatures.

G. Energy Storage. Research is recommended on methods for storage of heat, including water (or other fluid) systems and those using change of phase (e.g. the latent heat of fusion). Consideration should also be given to techniques for storing cold.

With recent advancements in the storage of electrical and mechanical energy, research is needed on systems capable of "flattening" diurnal residential electric loads.

IV. Systems Integration

A. It has been shown that powerful lights of the metal halide gas discharge types exhibit a significantly higher efficiency than other indoor lighting systems. An integrated lighting system containing a large (2,000 W) gas discharge light connected by a light-pipe distribution system might be developed. Shuttered light-pipes would distribute the light throughout the structure, while a thermal recovery system distributes waste heat to the hot water supply. At first approximation, the waste heat from the lighting system could probably supply one third of the total hot water load, maybe even more.

B. It is well known that tenants who pay a lump sum for the various services (lighting, heating, hot water, etc.) use between 15 percent and 30 percent more than those who are billed individually. There is a need to develop an inexpensive individual metering capability not only for electricity and gas but also for heating and cooling. The concept of forcing the individual tenant to pay for his own energy consumption would be an effective energy-saving device. With such systems, utilities could be encouraged to sell services, not just energy, and would have incentives to install high efficiency equipment and to keep it in good repair.

C. In large structures, there are several techniques for conserving or recovering energy from refrigerators. First, a central compressor-condensor system could be used which circulates coolant to all of the individual refrigerators. A second method would be to

collect reject heat from the condensor coils in a circulating water system for use as a pre-heater for hot water.

D. The "integrated lighting system" which involves the recovery of lowgrade heat from conventional lighting systems is of marginal economy in residential structures. In commercial structures, however, the concept has far greater promise and can yield reduced internal thermal load on the building and longer life and higher efficiency for fluorescent tubes[4,5]. This concept deserves further investigation.

E. The "integrated building" commercial structure carries the concepts of integration discussed in D. well beyond energy recovery from lighting. Here energy is recovered from all internal load producing fixtures and stored in a thermal storage system. The heat is used as the thermal source for a heat pump and has been shown to be highly energy-conservative for selected structures[6–10]. These systems warrant further evaluation.

F. A "total energy" or "integrated utility" system has on-site electrical generation, heat recovery, solid waste incineration and sewage treatment all combined in the building design. Current investigations now underway in the U.S. regarding this concept should be continued.

[4] STECK, B., European practice in the integration of lighting, air conditioning and acoustics in offices Lighting, *Research and Technology*, *1* (1969) pp. 8-23.
[5] STECK, B., Beleuchtung and Klimatisierung Lux 57 (1970) pp. 217-224.
[6] WYATT, T.J., The Thermal Equilibrium Concept of Integrated Design (International Congress for HVAC, 1971).
[7] GREINER, P.C., Heat Recovery Systems (Unipede, June 1972).
[8] HARDY, A.C., Interrelationships of Thermal Design Parameters (id.).
[9] SHEPHERD, L., Integrated Buildings and their Development (UIE Conference, 1972).
[10] Integrated Design and Environmental Control (Six papers, the first of which appeared in *Electrical Times*, 7 May 1971).

WORKING GROUP F

INDUSTRIAL SYSTEMS

H. DÜKER Group Leader
C.B. SMITH Recorder

J.G. BALL
R.A. DUGDALE
D.E. ELLIOTT
R.H. JOHNSON
M. KERSTEN
J. LAWTON
E. MASSAR
W. MURGATROYD
C. ROSCOE
J.M. TAUB
F.J. WEINBERG
J.G. WISTREICH

Introduction

If we look at an industrial plant as a system (Fig. 1) we can observe on the one side the input of energy, materials and labor force, and on the other side the output of goods, waste energy and waste materials. This simple picture shows the main problem of the industrial system.

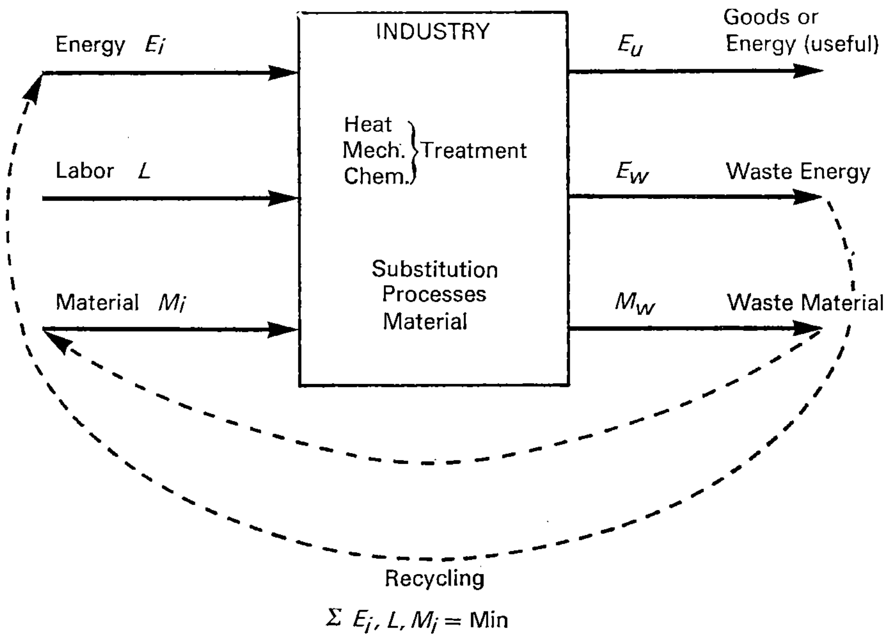

Figure 1

The objectives of the industrial managers are to keep the costs of the sum of energy + materials + labor as low as possible (see Fig. 1). In many cases the energy cost is the smallest part of the sum. In other cases the manager has no choice of the kind of energy because he can get only electricity or oil or some other form of energy. Thus, in many cases the incoming energy plays only a secondary role. With increasing energy costs this may change.

The outgoing waste energy—mostly heat—is sometimes neglected. The reason may be the lack of economic means for storing it or for transforming it to another form of energy, e.g. heat to electricity. It is more common (not in all cases) to collect waste material and to feed it back to the industrial process.

Looking into the industrial plant we find it very difficult to follow the flow of energy through the different manufacturing processes. It would be useful to investigate the energy efficiency of mechanical, chemical and heat processes. This point was the task of the first four Working Groups, and we excluded a detailed discussion of these processes. Inside industry we concentrated on substitution for widely used materials and processing.

The discussion was divided into three subgroups with the following responsibilities:

I. Recycling Industrial Materials to Conserve Energy.
II. Substituting Materials or Processes to Conserve Energy.
III. Substituting Energy Forms.

General Recommendations

Additional data are required to permit engineering, scientific, and management decisions aimed at improving industrial energy use. Three recommendations are made in this respect:

- Comparative studies of industrial energy use in similar countries should be encouraged. For example, the United Kingdom and the Federal Republic of Germany, with roughly similar populations, industry composition, and power requirements, use different amounts and forms of energy. International comparative studies, particularly within the NATO countries, will permit an identification of energy-efficient practices and a transfer of knowledge to other countries.
- Energy flow diagrams, indicating how and where energy is used in industry, should be prepared. These diagrams should show the quantity, form, source, and quality (e.g. energy content or temperature) of energy required, in order to permit identification of areas where substitution or alternative processes will permit increased efficiency.
- Tabulations of the direct energy content of various raw materials and manufactured goods should be compiled and published. Table 1 lists some representative values for common materials. However, it is felt that these values depend heavily on the process used, and such data must be correlated to specific processes to be useful.

TABLE I

Typical Energy Contents of Materials and Manufactured Products

	Energy megajoules/kg*	*Cost of energy/* Value of product*
Metals		
Steel (various forms)	25-50	0.3
Aluminum (various forms)	60-270	0.4
Copper	25-30	0.05
Magnesium	80-100	0.1
Other Products		
Glass (bottles)	30-50	0.3
Plastic	10	0.04
Paper	25	0.3
Inorganic chemicals (average value)	12	0.2
Cement	9	0.5
Lumber	4	0.1

* These are typical values. The actual value depends on the purity, form, manufacturing process and other variables.

Specific Recommendations

I. Recycling Industrial Materials to Conserve Energy

Materials are increasingly being recycled today to conserve resources. Energy can also be conserved in this way, particularly if energy expended in handling and disposing of wastes is also taken into account. In the case of metals the energy content consists of energy required for mining, extraction, processing, and fabrication (Table I). In recycling, the energy required for the first two steps is conserved.

The recommendations are:

A. Industrial surveys should be performed to determine how different industries recycle materials originating both within and without the plant, to determine if certain industries are more efficient in this sense than others, and to determine what research should be done.

B. The energy required to recycle various materials should be determined, particularly as compared to the energy required for production, manufacturing, and disposal.

C. An evaluation should be made of processes which can convert waste materials of all types into fuels or energy, suitable for use in industrial processes or for return to the grid.

D. Collection and separation are central obstacles to increased utilization of waste materials. Research should be undertaken to develop methods for handling both industrial and urban waste materials.

E. A systematic investigation should be undertaken to find new products and uses for major industrial waste materials. Ideally these products or uses would permit energy savings through substitution for manufactured products and reduction of disposal requirements.

F. Research should be initiated to develop architectural and structural designs which permit structures to be relocated or reused rather than demolished.

G. While metals can be recycled by several methods, the same is not true of certain plastics. Research should be performed to develop methods for recycling polymers. One approach might be to develop polymers with links which can undergo scission (breaking of links) by a reversible chemical step.

H. Water is a critical industrial material, in terms of availability, quality, cost and energy content. Research aimed at increasing the recycling of industrial water should be encouraged. Methods should stress prevention of contamination as well as water treatment. Ozone may replace chlorine as an important water treatment agent. More efficient ozone production methods should be sought.

I. Synthetic fibers have replaced natural fibers for many uses. A study should be made to establish total energy requirements for clothing and other products made from both types of fibers.

II. Substituting Materials or Processes to Conserve Energy

We make these recommendations:

A. At present the use of steel, concrete, and plastics is economically determined by short-term criteria. In the future different criteria will dominate, and energy content may be important. Major constructional materials should be compared in terms of their total energy requirements relative to life cycle duration.

B. Wood, being derived from solar energy by photosynthesis, is a special case of recommendation A (above). Glueing, machining and associated techniques permit the composite nature of wood to be exploited, yielding a high specific modulus constructional material of low energy content and long useful life. Furthermore, both scrap and salvage material can serve as fuel when unsuited to further use. It is recommended that active consideration be given to increased usage of wood as a *stress bearing* constructional material.

C. Many foods contain significant amounts of non-solar energy forms in addition to their energy content. The additional energy input is derived from harvesting, processing, transporting, preserving, packaging and storing. Research should be undertaken to identify the amounts of energy so involved in major food items and to identify methods for minimizing the non-solar energy input.

D. Metal fabrication techniques are energy intensive. We recommend that comparative studies be performed to establish energy requirements for typical industrial processes. Such studies would reveal the potential benefits to be derived from new technology. For example, fabrication by powder techniques would appear to be an efficient alternative, because of the potential for avoiding machining and the ability to produce complex shapes.

E. Processes involving machining or deformation lead to solid scrap of high energy content. Alternative methods, for example the joining of simple components, could lead to energy savings, both in the product and in the scrap. Research should be performed to obtain comparative data.

F. Electric motors are an important user of energy in industry. While large motors (20 kW and larger) are already 90% efficient or better, smaller motors are inefficient. Improvements can come about in several ways: 1) designing equipment so that motors always operate at full load; 2) using variable speed drives, and 3) substitution of more efficient motors. Industrial standards or guides might be established by manufacturers to encourage the most efficient practices.

G. Substitution of different industrial processes can potentially save energy. The possibilities are so broad here no specific recommendations can be given. However, in the first working groups of the Conference (Heat, Light, Motion, and Electrical Processes) many new engineering and scientific developments having potential for conserving energy were discussed and could be reviewed in this context.

III. Substituting Energy Forms

These recommendations are made:

A. It is recommended that "Total Energy"* systems for industrial use be fostered. Research should be sponsored to develop system designs, cost and pricing policies, problems related to system interconnection with public utilities, and an assessment of potential energy savings. Furthermore, it is recommended that a macro-economic study comparing the alternatives should be undertaken from a national or even international viewpoint.

B. The efficiency and economics of total energy systems could be further improved by additional research into prime movers, heat exchangers, and control systems. This should be done.

C. Bearing in mind that in the future alternative fuels are likely to be necessary, it is recommended that research be undertaken to establish the feasibility of various options. Emphasis should be given to systems based on synthetic fuels or hydrogen.

D. As part of the concept of total energy, research into methods of matching the energy source to the work requirements rather than *vice versa*, should be investigated for improved efficiency. Potential applications might include: the use of hydraulic and pneumatic drives or systems, rather than steam or electric drives and local generation of electricity at convenient and efficient frequencies.

* "Total Energy" or "Integrated Energy" system refers to the practice of delivering a single fuel to a consuming point and using this fuel to supply all energy needs, e.g. electricity, process heat, etc.

E. In total energy systems or in normal industrial situations, the use of cooling water can be optimized to reduce thermal pollution and maximize efficiency. This can be done by using waste heat from a high temperature process to drive a lower temperature process, rather than discarding the waste heat from each process. Cooling water should flow in the reverse direction, from low temperature to high temperature processes. Work should be initiated to develop such methods and to study the savings resulting from their applications.

F. In process industries the pressure of water-steam mixtures is used as a method for temperature control. This is inefficient and wastes energy compared to direct temperature control methods. Research into improved methods is recommended.

Conclusions

The greatest possibilities for more efficient energy use in industry lie in careful management of process heat, electricity, energy intensive materials, and direct fuel consumption.

Emphasis should be placed on efforts to maintain the highest levels in both energy and material forms (e.g. enthalpy, pressure, temperature, purity) and to degrade both energy and materials gradually in as many steps as possible.

Processes involving energy intensive operations or materials should be reviewed to determine if new technology, recycling or substitution, or alternative forms of material or energy can be employed to increase efficiency.

WORKING GROUP G

URBAN SYSTEMS

E.A. LISLE	Group Leader
H. BROWN	Recorder

A.J. APPLEBY	F. OOSTVOGELS
R. AVENHAUS	K.G.A. PANKHURST
J.O'M. BOCKRIS	W.E. SHOUPP
U. BUSINARO	A.C. SJOERDSMA
J.E. GOLDMAN	H. TANNENBERGER
D.O. HALL	L. THÖRNQVIST
M. KERSTEN	H.J. VINK
N. KURTI	J.J. WENT

General Considerations

The urban utilities, transport and service system group directed its efforts to the analysis of the energy utilities, water supply, disposal of sewage and wastes and urban transport with a view toward more efficient energy utilization and energy savings. As shown in Figure 1, these support systems are provided to the major economic sectors of an urban society—*household* (residential), *business* (industrial and commercial) and *government* (including health, education and welfare services).

Both a scale effect and a population density factor must be considered; a particular service will tend to be provided differently in a 250,000 population town, in a 1,000,000 person urban area or in a 10,000,000 person conurbation. Likewise, low density urban areas, made up of a majority of single family houses ("suburbic") call for different ways of providing a given service than the high density urban areas (the "high rise" or "vertical" towns). In assessing the energy-efficiency of different systems providing a specific service it should be borne in mind that well over 50% of all dwelling units are single-family houses (50% in France; 66% in Belgium; 69% in the USA; 88% in the UK). These percentages may not diminish very significantly over the next 30 years in the countries concerned and the effect of the geographical dispersion of the population that this implies on the design of services and on the corresponding energy load must be constantly borne in mind: a suburban type urban area tends to go with private car transport and to preclude centralised or district heating systems; it may be better adapted to individualized systems (e.g. water recycling), than to the traditional urban sewage networks.

In other words, the relative potentialities of locally provided as against centrally distributed services for a specific utility should be thoroughly explored, due account being taken of town size and density.

The three utilities that the group examined are of particular importance from the point of view of energy saving, since (i) transport alone accounts for approximately one

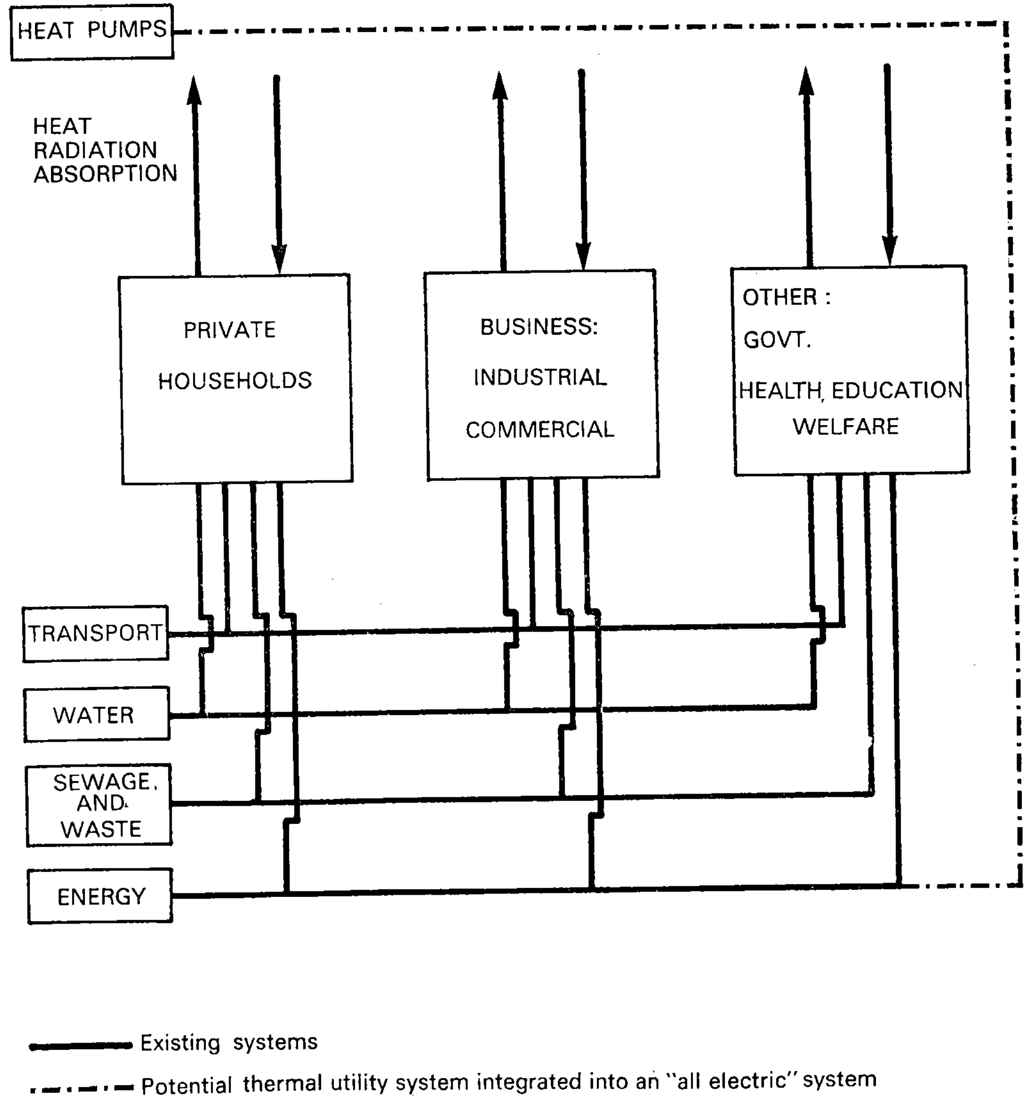

Fig. 1
Urban System Support Services

quarter of all energy consumption (about 7% of all energy used is petroleum for urban transportation)*; (ii) space heating, air conditioning (in the USA) and waste heat from industrial processes account for another 30% of the energy used. Lastly, (iii) sewage and solid waste are produced in considerable quantities which could be recycled to reclaim energy and raw materials, instead of being mostly dumped or burnt.

Energy saving in these three areas would moreover reduce environmental pollution.

* US figures; European figures are somewhat lower.

I. Urban Transport

Three broad recommendations can be made which would reduce the energy load of urban transport:

A. Substitute communications systems (videophones, cable T.V., computer networks...) for transport of people especially in the services' sector whose share in total employment is already larger than that of industry and is growing. Reducing the total time spent by the population in commuting to and from work or school (which amounts to between 1½ and 2 hours per person per day in many Western cities) would both save energy and improve the standard of living.

B. Design integrated transport systems making the best use of different modes of transport according to distance or type of urban area, viz.

- pedestrian precincts in small highly congested zones (old districts, narrow streets, shopping esplanades...) where walking is the most efficient mode of transport,
- segregated bicycle lanes along, e.g., short commuter routes,
- mass transit networks (track transport or bus traffic in separate lanes) in all high density urban areas,
- taxis and public self-drive hired vehicles in the same areas,
- privately owned vehicles in suburban and rural areas.

Between these various areas some overlap would exist with e.g. parking lots or bicycle lockers adjacent to mass transit terminals and stations.

C. Given that an integrated closely-knit urban transport system were provided which would reduce or eliminate the use of the private car in heavily built-up areas, the third recommendation is to improve the energy efficiency of the prime mover within each separate transport system. The solution here is electrification; particularly if pollution is considered as well:

- in mass transit system, the trolleybus with batteries (to ensure some freedom from overhead lines) should be substituted for the bus. (The substitution of the bus for the tram or trolley was not an improvement from the energy viewpoint);
- in the case of individual vehicles for local travel, the electric car is already technically available as a substitute for the petrol-powered vehicle. Infrastructures (electrical and mechanical recharging facilities) would have to be constructed. Pending their completion, the diesel engine (which is less polluting than the petrol engine) is a suitable interim solution providing its noise and smell are reduced. Smaller cars with reduced speed and acceleration performances would also greatly reduce fuel consumption.

It should be stressed that measures such as these would also reduce energy consumption in an indirect way, namely by slowing down urban road construction and maintenance.

II. Sewage and Waste

Recommendations in this field cover the recovery of energy rather than the saving of energy and materials.

A. Sewage: The daily output of sewage per person is about 150 kgs, but industrial effluents might raise this to about 450 kgs and this could be used as a heat source for a heat pump. If we assume the temperature of such water to be 20 °C, falling to 10 °C during heat extraction, then the daily thermal energy available would be about 5 KWH. This would represent about 7 or 8% of the daily space heating requirements under average European conditions. Clearly the gain for an individual suburban home would be relatively unimportant; main drains as heat sources could on the other hand advantageously be used in high density zones.

B. Solid waste: The daily output of solid waste of all kinds is estimated at about 2.5 kgs per person. Direct combustion of such waste would yield about 7 KWH per person day or roughly 10% of the heating requirements per person.

Other means of disposing of such waste exist however:

- conversion into methanol and/or ethanol;
- conversion into methane;
- direct conversion into electricity.

One ton of solid wastes provides about 150 kg of ethanol: the ethanol obtained from the solid waste of a 250,000 person urban town would be sufficient to run its municipal bus service.

Alternatively, solid wastes might usefully be separated, preferably before leaving the house, into i) metal and glass, ii) paper, iii) plastic and organic waste in order more easily to reclaim useful materials, as already being tried in some large US towns.

Finally, consideration should be given to the in-house treatment of water and solid wastes.

III. Heat and total energy systems

Solar energy is absorbed by structures; conversely heat is emitted into the atmosphere as a result of faulty insulation or as waste heat from industrial processes. Simultaneously, energy is expended on space heating and air conditioning. Reclaiming waste process-heat for conversion into thermal energy is often possible and should be recommended in individual buildings. The feasibility of linking such individual integrated energy systems with broader energy systems should be examined, the heat "utility" being considered on a par with e.g. the water or the electricity. Heat pumps, total energy and integrated urban energy supplies are all relevant concepts in this connection.

A. Heat pumps: In urban areas located near the sea or large lakes heat pumps could be operated against water drawn from such sources and specially circulated for this purpose. "Water" heat pumps have coefficients of performance up to four times as high as "Air" heat pumps which increase the temperature of outside air in summer and cause frost and local fog in winter. "Water" heat pumps do not have these drawbacks. Furthermore, the capital cost of "Water" heat pumps is less than that of an "Air" heat pump. It should be stressed that current technology is already available for such systems to be tried on a large scale.

B. Total energy: This is a system in which only one form of energy is brought into a building, e.g. gas is brought in and converted into heat and electricity. The reliability of such a system, as opposed to hybrid systems, should be borne in mind. Moreover, the environmental impact of such systems should be stressed whenever they entail the discharge of waste heat and/or combustion products into the atmosphere.

These criticisms do not, however, apply to the fuel cell total energy concept. In this system the fuel cell is fuelled by natural gas, methanol or by H_2. In the latter case the only combustion product would be potable water and very high efficiencies are attainable.

An advantage of the total energy system is its flexibility. It can be applied at different scales for individual buildings, neighbourhood or central systems. It can also be integrated into a utility grid system.

In any total energy system there may, however, be storage problems for the premium fuel in many areas.

C. Integrated energy supply: On a larger range than most of the foregoing recommendations are the nuplex, the all electric city and the hydrogen economy.

1. **Nuplex:** A large nuclear reactor provides both electric power and process heat with efficient consequential use of the energy. The process heat and some of the electricity is used by closely-coupled integrally planned industrial processes. The system provides the industrial base the fertiliser, can provide the water (desalting) and the energy for a contiguous agro-urban region.

2. **All-electric city:** This is a similar one-source system which deserves attention because of the possibilities it offers for reducing the urban "heat-island" effect. The system involves converting electricity into heat using heat pumps. The electricity can be provided from any primary source including, e.g., from hydrogen.

3. **Hydrogen economy:** here all the energy for a city or a region is distributed by pipelines containing gaseous hydrogen. The H_2 is converted at or near the point of use into electricity, preferably through fuel cells which can be used to drive heat pumps. It is a flexible and pollution free system with potable water as a by-product, and, like the all-electric city, will reduce the urban "heat island" effect.

Obviously, advantage may be gained from the combination of parts of any of these systems to make the most efficient use of energy and it appears that this is the direction towards which we are heading.

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