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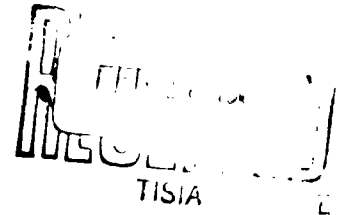
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ELECTROCHEMICAL FUEL CELLS: AN ANNOTATED BIBLIOGRAPHY



SPECIAL BIBLIOGRAPHY
SB-62-51

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ELECTROCHEMICAL FUEL CELLS: AN ANNOTATED BIBLIOGRAPHY

Compiled by:
SCOTT J. BUGINAS

**SPECIAL BIBLIOGRAPHY
SB-62-51**

DECEMBER 1962

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA

ABSTRACT
ELECTROCHEMICAL FUEL CELLS: AN ANNOTATED BIBLIOGRAPHY

This bibliography consists mostly of references dated late 1961 and the first 9 months of 1962. It is a supplement to the following LMSC Electrochemical Fuel Cell bibliographies:

SRB-60-5 (AD-251 660) Nov 1960

SRB-60-5 (AD-253 809) Feb 1961

SRB-62-2 Mar 1962

Search completed October 1962.

Availability notices and procurement instructions following the citations are direct quotations of such instructions appearing in the source material announcing that report. The compiler is well aware that many of these agencies' names, addresses and office codes will have changed; however, no attempt has been made to update each of these notices individually.

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LOW TEMPERATURE FUEL CELLS

Primary

1. Austin, L. G.
 REDOX FUEL CELLS. Pennsylvania State U.
 Mineral Industries Experiment Station,
 University Park. Quarterly progress rept. no. 6,
 1 Jun - 1 Sep 1961. 1 Sep 1961, 4p. (Contract
 DA 49-186-502-ORD-917). ASTIA AD-266 103

An analytical procedure was developed for determining Sn (++) , but it has not been possible to determine Sn(4+) ion in the presence of Sn (++) , or to quantitatively reduce Sn (4+) to Sn (++) by means of the Jones reductor. At temperatures below the normal boiling point, no reduction of Sn (4+) to Sn (++) is obtained with 11C110 as the reducing agent, in concentrated 11C1 solutions. At 200 C, a high pressure build-up occurs in the reaction tubes; on breaking the tubes, the pressure release is so violent that it is difficult to collect the sample. Although this may be invalidating the results, no reduction of Sn (4+) to Sn (++) was observed.

2. Bacon, F. T.
 OXYGEN-HYDROGEN FUEL CELLS. Assigned
 to National Research Development Corp., U. S.
 Patent No. 3,002,039. Appl. 7 Apr 1960.

A hydrogen circulation system is described which controls the flow of hydrogen as a function of the H₂O buildup in the cell. When the H₂O in the condenser reduces the hydrogen pressure, a valve discharges the H₂O. The control of the valve is governed by the differential pressure between the electrolyte and the hydrogen.

3. Blackmer, R. H.
 FUEL-CELL SYSTEM WITH MEANS FOR PRE-
 VENTION OF DAMAGE BY DIFFERENTIAL GAS
 PRESSURES. Assigned to General Electric Company.
 U. S. Patent No. 3,014,976. Appl. 29 Feb 1960.

A solid ion-exchange electrolyte membrane may be ruptured by differential gas pressures. Methods for maintaining equilibrium pressures on the membrane are

illustrated. Each method uses a liquid or gaseous inert fluid to flood the appropriate electrode chamber, terminate the cell reaction, and maintain equilibrium pressures on the membrane.

4. California Research Corp., Richmond, Calif.
INVESTIGATIVE STUDY RELATING TO FUEL
CELL. Quarterly progress repts. 1, 3.
Jul 1960, Mar 1961. (Contract DA 49-186-502-ORD-
929). ASTIA AD-243 550, ASTIA AD-254 512

An investigation is being undertaken of the detailed chemical reaction mechanisms and kinetics of fuel half cell electrodes. The study will include: (1) development of chemical intermediates in an operating fuel cell by representative hydrocarbon-type fuels such as methylcyclohexane, cyclohexane, decalin, n-heptane, isooctane, hexene-1, a cyclopentane, and an aromatic; (2) the extent of the effects of electrolyte pH on the intermediates (3) the polarization characteristics of an operating cell or fuel half cell and (4) the details of the reaction between fuels and typical catalytic surfaces, such as Ni, Pd, and Pt with emphasis of the determination of the number of labile H atoms on the catalyst surface.

5. California Research Corp., Richmond, Calif.
INVESTIGATIVE STUDY RELATING TO FUEL
CELLS. Quarterly progress rept. no. 5,
26 Apr - 25 Aug 1961. 27 Oct 1961, 47p.
(Contract DA 49-186-502-ORD-929). ASTIA
AD-267 073.

Studies of hydrocarbon oxidations at fuel cell anodes were extended. Erratic behavior resulted from poisoning by air and materials leached slowly from ion exchange membrane separators. The ratio of reactivities of H and hydrocarbons differed with different electrodes. Cyclohexane and n-hexane gave low orders of reactivity on platinized porous carbon anodes in 5N H₂SO₄ at 88 C. Gaseous hydrocarbons were more reactive, with C₂H₆, C₃H₈, C₄H₁₀ and 1-butene showing similar reactivities. When current is kept below a certain threshold value, prolonged operation is possible with very gradual polarization; when this threshold is exceeded, a rapid loss of activity occurs. Present temperature-effect data indicate some fuel cell activity with C₃H₈ at 30 to 40 C, increasing as the temperature is increased to 80 to 90 C. Calculations indicate the rates of diffusion of CO₂ from, and hydrocarbon to, the reaction zone in porous electrodes are rapid enough to support practical current densities. On replacing silica by graphite as the support, the available Ni surface was found to be markedly lower.

6. California Research Corp., Richmond, Calif.
INVESTIGATIVE STUDY RELATING TO FUEL
CELLS. Quarterly progress rept. no. 6,
26 Aug - 31 Dec 1961. 20 Feb 1962, 28p.
(Contract DA 49-186-ORD-929). ASTIA
AD-273 427.

Product studies with n-butane using platinized porous carbon electrodes and 5 N H₂SO₄ electrolyte at 80 C gave 106.6 to 108.2% of the theoretical amount of CO₂ compared with 99.0 to 100.5% for propane. Gross comparisons of time-voltage curves at constant current for butane and propane show somewhat better over-all performance for propane. Evidence for the presence of appreciable amounts of reactive intermediates is seen in the shapes of the voltage-time curves. Observations of the effects of varying intervals of operation at open circuit on the performance of butane-oxygen fuel cells are reported. Further data on the effect of temperature on a propane-oxygen fuel cell show evidence of pre-electrochemical electrode reactions. Propane-oxygen fuel cell currents at constant voltage were found to change with time in much the same way as voltages at constant current. The anodic oxidation of propane and butane on platinized Pt was studied. Other studies included the anodic oxidation of methanol and the chemisorption of fuels on electrocatalytic surfaces.

7. Campa, A. B., et al.
BASIC STUDIES ON FUEL CELL SYSTEMS.
Lockheed Aircraft Corp., Sunnyvale, Calif.
Quarterly rept. no. 3, 3 Nov 1961 - 12 Feb 1962.
Rept. no. 2-99-62-1. 12 Feb 1962, 43p.
(Contract NOW 60-0738-d). ASTIA AD-273 702

The alkaline, aqueous N₂H₄, NH₃ and CH₂O anodes, and the intermediate NH₃-O fuel cell system were evaluated. Preliminary results were obtained with alkaline O and air cathodes. The most feasible systems were the aqueous N₂H₄ and the aqueous NH₃-O or air fuel cells. Evidence that N₂H₄ is anodically oxidized through H as an intermediate in alkaline electrolyte was obtained. Reduction of the surface area of the N₂H₄ black Pt anode catalyst was investigated for possible optimization with respect to N₂H₄ decomposition rate and anode polarization. N₂H₄ anode gases were analyzed at closed and open circuits. N₂H₄ was consumed at the cathode in multiple-cell fuel cells. The molten caustic NH₃ anode oxidized NH₃ to nitrate and nitrite at 150 C. The black Pt CH₂O anode had poor life in alkaline electrolyte.

8. Chu, Ju Chin and Salzarulo, L. M.
FUEL CELL AND ITS RELATED TECHNOLOGY.
III. CORRELATION BETWEEN SURFACE CONDUCTIVITY AND CATALYTIC ACTIVITY OF ELECTRODE. Polytechnic Inst. of Brooklyn, N. Y. Final rept., 16 Jul 1960-15 Jul 1961. 15 Jul 1962, 42p. (Contract DA 44-009-eng-4586). ASTIA AD-270 571.

The correlation between surface conductivity and Hall effect and catalytic activity of fuel cell electrodes was investigated. Equations for the Hall voltage are presented for both cylindrical and rectangular shapes of a sample. For the measurement of Hall effect during chemisorption, a complete setup was designed. For simplicity in depositing the catalytic film, the cell was cylindrical. The catalyst metal was deposited on the cylindrical surface by vacuum vaporization. The various types of polarization which occur in a fuel cell are discussed and quantitative expressions are developed for them. Included are activation polarization, mass transport polarization, gas transport polarization and electrolyte concentration polarization. Two fuel cells were designed and fabricated. The first one was made of PVC and the second of Teflon. The change of activation polarization with different catalyst on the electrode was evaluated.

9. Chu, Ju Chin and Yu, W. S.
FUEL CELL AND ITS RELATED TECHNOLOGY.
II. CORRELATION BETWEEN INFRARED SPECTRUM AND CATALYTIC ACTIVITY OF ELECTRODE. Polytechnic Inst. of Brooklyn, N. Y. Final rept., 16 Jul 1960 - 15 Jul 1961. 15 Jul 1961, 21p. (Contract DA-009-eng-4586). ASTIA AD-269 998.

The application of IR to the catalytic study of the fuel cell electrode is reviewed with emphasis upon chemisorption. Transmission and reflection methods are well known techniques in obtaining an IR spectrum; the latter is extremely expensive and impractical. Several techniques were considered for obtaining IR spectrum by transmission. One method involved the impregnation Cab-o-sil with a metal nitrate to form a thin disc whereupon the nitrate was reduced to the metal. The use of an evaporated metal film involved a nickel film of 100 angstroms thickness; the area of the film is relatively small and the amount of chemisorption by propane can be negligible.

10. Clifford, J. E., McCallum, J., and Semones, D. E.
ACID PRIMARY CELLS. Assigned to Remington
Arms Co., Inc. U. S. Patent No. 2, 992, 143.
Appl. 14 Oct 1958.

Primary cells containing H_3PO_4 electrolytes and Ti-alloy anodes show improved performance over alkaline cells with similar anodes. Optimum electrolytes contain 30-85 wt. % H_3PO_4 which can be supplied by any equivalent combination of P acids or oxides. These electrolytes are 0.05-0.2M in F^- , and the F^- is not consumed electrochemically during discharge of the cell. The alloy anodes contain a minimum of 50 at. % Ti. A cell containing an anode composed of Mo 27, Al 10, and Ti 63 wt. % will furnish a high discharge rate where extended cell life is of less interest. In the same electrolyte, but with a Ti-alloy anode containing 10 wt. % Nb in place of the same amount of Al, a long cell life is obtained where a high discharge rate is of less significance.

11. Dieberg, R.
GAS-DIFFUSION ELECTRODES FOR FUEL CELLS.
Assigned to Accumulatoren-Gabrik A.-G. Ger.
Patent No. 1,116,287. Appl. 31 Dec 1959. (In
German)

An electrode for combustible gases for fuel cells is prepared by mixing Ni powder and very fine C powder ($< 60 \mu$), sintering, and then impregnating colloidal forms of a catalyst. The C content can be $\approx 30\%$. Best catalysts are Pt, Pd, and Rh. Suitable pressures are 0.25-2 atm., and the operating temperatures are 20-65°. The c.ds. are 100-50 ma./sq.cm.

12. Eyraud, C., Lenoir, J., and Gery, M.
Fuel cells utilizing the electrochemical
properties of adsorbants. COMPT. REND.
252(11): 1599-1600, Mar 1961. (In French)

The three basic factors limiting the development of fuel cells are: the energy output, the specific power and the working temperature. With regard to the specific power, considerable advances may be achieved by, on the one hand, replacing the liquid electrolyte with a mobile adsorbed phase and, on the other hand, by passing a microporous cell element through the gaseous mixture of combutant and fuel.

13. Fuel cells to have first operational use in GEMINI.
THE SPACE LETTER., No. S-182, p. 4-5,
15 Aug 1962.

GE's ion-exchange membrane fuel cell will be used. A pint of pure drinking water is produced as a byproduct of each kilowatt hour of operation. This could be used for drinking, cooling or other life support processes. Peak load delivery will approach 2KW of dc electricity. 60% thermal efficiency is achieved under normal load.

14. Garner, P. J. and Williams, K. R.
GASEOUS FUEL CELLS. British Patent
844,584. 17 Aug 1960.

A gaseous fuel cell with a pair of C electrode plates having a 2-compartment electrolyte space, which is separated by an ion-permeable membrane, has an open-circuit voltage of 1.05 v. and delivers a current of 1 amp. at 0.6 v. of 2.2 amp. at 0.16 v. The hydrogen electrode in H_2SO_4 is coated with Pt. When the oxygen electrode in HNO_2 is coated with manganese, and the ion-exchange membrane is of ceramic tile coated with collodion, the cell has an open-circuit voltage of 1.15 v. and delivers a current of 32 ma. at 0.62 v.

15. General Electric Co., West Lynn, Mass.
RESEARCH ON LOW TEMPERATURE FUEL
CELL SYSTEMS. Progress rept. no. 17,
15 May - 15 Aug 1961. 15 Aug 1961, 98p.
(Contract DA 44-009-eng-3771). ASTIA
AD-265 763.

The polarization behavior of the oxygen electrode or hydrogen-oxygen cells on open circuit and in the non-linear region is shown to depend, among other factors, on (a) type of electrode material (b) surface treatment (c) pH (d) presence of foreign ions and their concentrations (e) stirring or agitation (f) cell design parameters and the technique of single electrode potential measurement. Most significant experimental observations concerning the open circuit behavior include (a) transient open circuit voltages greater than the thermodynamically reversible potential of 1.23 volts under certain conditions, (b) experimentally observed effect of higher temperature on the open circuit voltage of the oxygen electrode is in a direction opposite to thermodynamic predictions. Experimental evidence is presented to show that the hydrogen and oxygen electrodes operating in the same bulk electrolyte under steady-state current flow conditions are always associated with significant pH changes at each electrode.

16. General Electric Co., West Lynn, Mass.
RESEARCH ON LOW TEMPERATURE FUEL
CELL SYSTEMS. Special technical progress
rept. no. 18, 1 Jun - 30 Sep 1961. 30 Sep
1961, 41p. (Contract DA 44-009-eng-3771).
ASTIA AD-268 235.

Comparative reactivities of a group of saturated hydrocarbons were determined in Pt anode fuel cells containing both strongly acidic and strongly basic electrolytes at 25 to 65 C. Rough values of activation energy for the over-all oxidation processes were calculated for high reactivities. Measurements with the series CH₄, C₂H₆, C₃H₈, isobutane, neopentane show that the tertiary 11 in isobutane does not produce any noticeable enhancement in the anodic reactivity of this molecule. Galvanostatic studies of CH₄, C₂H₆, C₃H₈, isobutane, ethylene and cyclopropane indicate that the rate of adsorption of saturated hydrocarbons on Pt black electrodes is markedly dependent upon the electrolyte. Slow adsorption occurs in the presence of bicarbonate and caustic. Ethylene and cyclopropane are more readily adsorbed than the saturated hydrocarbons, and both gases adsorb readily in the presence of acidic caustic and bicarbonate electrolytes. Steps attributable to adsorbed H appear on the saturated hydrocarbon galvanostatic oxidation curves. The adsorbed carbonaceous species from the hydrocarbons require high overvoltages for their oxidation.

17. General Electric Co., Lynn, Mass.
RESEARCH ON LOW TEMPERATURE FUEL
CELL SYSTEMS. Technical summary progress
rept. no. 19, 1 Nov 1959 - 30 Nov 1961. 30 Nov 1961,
117p. (Contract DA 44-009-eng-3771). ASTIA
AD-269 227.

Fuel electrode studies resulted in the following: Development of two electrode structures for carrying out fuel and electrocatalyst investigations in matrix-type fuel cells, and cell structures including one with reference electrodes; A survey of chemical elements for electrocatalytic activity with H, hydrocarbons, and other fuels, C base electrocatalysts for activity with H, hydrocarbons, and O, and a number of mechanical mixtures and compounds and a few alloys for electrocatalytic activity in fuel cells; identification of Pt as the most active simple catalyst for anodic oxidation of hydrocarbons in fuel cells; Discovery that saturated hydrocarbons are more rapidly oxidized in acidic electrolyte cells as compared with basic electrolyte cells and that with olefins the electrolyte effect is smaller and in favor of the basic electrolyte; and identification of strong effects of electrolyte upon adsorption rates of hydrocarbon fuels which correlates with the observations of the preceding item.

18. General Electric Co., West Lynn, Mass.
**VOLTAGE REGULATION AND POWER STABILITY
 IN UNCONVENTIONAL ELECTRICAL GENERATOR
 SYSTEMS.** Quarterly progress rept. no. 6, 30 Sep -
 31 Dec 1961. 31 Dec 1961, 219p. (Contract
 NOw 60-0824-c). ASTIA AD-273 869.

Research continued on the study of voltage regulation and power stability in Unconventional Electrical Generator systems. Test results are presented which illustrate the control of fuel cell output voltage by varying the velocity of mixtures of inert gas and reactant gas past the appropriate electrode. Information is included showing typical dynamic characteristics of thermoelectric and thermionic power sources. Design data giving weight, volume, and efficiency of series regulating switching circuits and dc-dc and dc-ac power transistor voltage converter circuits are presented. Weight versus efficiency characteristics of various combinations of source voltage control and external voltage converters are included. Weight data on minimum weight complete systems incorporating voltage regulation and conversion are presented. A laboratory model system consisting of a fuel cell and a dc-dc voltage converter-regulator is described. Performance test results for this laboratory model system are presented.

19. Gentile, R. G. et al.
FUEL CELLS. Monsanto Chemical Co., Everett,
 Mass. Final rept., 1 Oct 1959-1 Dec 1960.
 27 Dec 1960, 211p. (Contract DA 44-009-eng-
 4154; Proj. 8-18-13-420). ASTIA AD-272 352.

Contents: Apparatus and procedure; Interpretation of data. Fuels: mass transfer; fuels containing H and N; fuels containing C, H, and O; hydrocarbon fuels; fuels containing C, H, and O and N; Product analysis; Catalysts; Long-term operation of fuel cell electrodes; Temperature; Electrolyte; Influence of O on the fuel electrode; Measurement of O electrode potential; Future study; Calculation of diffusion-layer parameters in a fuel cell; Methods of catalyst preparation; Literature survey; Summary of electrode potentials.

20. Gray, T. J. and Bridgeo, W. A.
HYDROGEN-OXYGEN ELECTRODE STUDY
IN HYDROX FUEL CELLS. New York State
Coll. of Ceramics, Alfred U. Quarterly tech-
nical progress rept. no. 1. 15 Mar 1962, 9p.
(Contract AF 33(657)7564). ASTIA AD-274 614.

Study has centered on a standardization technique to provide reproducible electrodes of accurately known characteristics. Although graphite was selected as a suitable starting point, C, porous metal and composite electrodes will be included. Electrodes were examined before and after use by surface area measurements, optical and electron microscopy and by spectrographic analysis. This work will give the degree of reproducibility necessary to ensure the validity of detailed measurements of electrode performance.

21. Gray, T. J. and Eiss, R.
Silver/silver oxide electrodes for fuel cells.
NATURE. 194:469-70 (1962).

The significance of the solubility of Ag_2O in aqueous alkali to the operation of O cathodes is emphasized. The solubility of Ag_2O at 25° as a function of KOH concentration is presented.

22. Gregor, H. P., Danziger, R. M., and Tejeda, A.
FUEL CELL MATERIALS. Polytechnic Inst.
of Brooklyn, N. Y. Quarterly progress rept.
no. 3, 1 Mar-31 May 1961. 31 May 1961,
20p. (Contract DA 36-039-sc-85384). ASTIA
AD-272 863.

An improved cell for measuring the ohmic resistance of fuel cell electrolytes was constructed. A number of new homogeneous anion-permeable membranes of low ohmic resistance were prepared. Pt-black catalyst was incorporated into certain of these cells.

23. Gregor, H. P., Danziger, R. M., and Tejeda, A.
FUEL CELL MATERIALS. Polytechnic Inst. of
Brooklyn, N. Y. Quarterly progress rept. no. 4,
1 Jun - 31 Aug 1961. 31 Aug 1961, 21p. (Contract
DA 36-039-sc-85384). ASTIA AD-272 865.

The series of anion-exchange interpolymer membranes presented show that membranes of increased conductance, improved mechanical properties and therefore higher ion transport properties were prepared. The presence of a small amount of water in the casting solutions had little effect on the conductance of the final films. The addition of a small amount of cross-linking agent increased the resistance. The failure of solutions of individual components to yield a homogeneous casting solution was attributed to a type of salting-out effect where the non-polar polyelectrolyte was forced out of solution by the more polar polyelectrolyte. Concentration potentials obtained with the poly-N-vinyl-n-butylimidazolium iodide (BPVI) membranes in every instance more closely approached the theoretical maximum values than those achieved with corresponding poly-N-methylvinylimidazolium iodine (MPVI) films.

24. Gregor, H. P., and Danziger, R. M.
FUEL CELL MATERIALS. Polytechnic Inst. of
Brooklyn, N. Y. Quarterly progress rept. no. 5,
1 Sep - 30 Nov 1961. 30 Nov 1961, 25p. (Contract
DA 36-039-sc-85384). ASTIA AD-272 864.

The measurement of the functional behavior of catalyst impregnated ion-exchange membrane electrolytes with H and O fuels was made in a modified cell. Known membranes were catalyst impregnated with an imprinting technique, and tested in this cell. Additional new membrane electrolytes were prepared.

25. Grubb, W. T. Jr.
ION-EXCHANGE-RESIN MEMBRANES AS THE
ELECTROLYTE FOR GALVANIC FUEL CELLS.
Assigned to General Electric Company. German
Patent 1,036,345. 14 Aug 1958.

Membranes, preferably 0.05-0.75 mm. thick, made from ion-exchange resins permeable to either anions or cations, are used as the electrolyte. Ten examples are given which use various electrodes, electrolyte foils, and fuels. A suitable resin is prepared by polymerizing 92% styrene and 8% by wt. divinylbenzene, pulverizing the

product, heating it with 1.75 times as much chlorosulfonic acid for 3 min. at 152°, and then leaving it for 50 hrs. at room temperature. After treating it with H₂O, this resin contains 3.1 meq. labile H/g. Two parts resin and 1 part polyethylene are mixed and pressed to foil which is soaked in H₂O before use. This foil absorbs 45% H₂O. The resin is treated with aqueous KOH to give a foil with transportable OH ions.

26. Grubb, W. T.
ON THE REACTIONS OF PROPANE AT THE
SURFACE OF A WORKING FUEL CELL ANODE.
General Electric Co., Lynn, Mass. Interim
rept. no. 1 on Saturated Hydrocarbon Fuel
Cell Program (ERDL). 15 Mar 1962, 16p.
(Contract DA 44-009-eng-4909; Proj. 8X99-25-
001-40; In cooperation with General Electric Co.,
Schenectady, N. Y.) ASTIA AD-274 734L.
27. Grueneberg, G. Kubisch, J. and Spengler, H.
PRODUCING ELECTRICITY FROM CARBON
MONOXIDE IN FUEL CELLS WITH ALKALINE
ELECTROLYTES. Assigned to Ruhrchemie Akt.
Ges. and Steinkohlen-Elektrizitäts Akt.-Ges.
German Patent 1,065,489, 17 Sep 1959, (In
German).

Quantitative utilization of CO is accomplished by absorption in a lye solution either within or separated from a fuel cell. The resulting HCOO⁻ is catalytically dehydrogenated and the free H electrochemically converted.

28. Grueneberg, G. et al.
REGENERATION OF FUEL-CELL ELECTRODES.
Assigned to Ruhrchemie A.-G. and Steinkohlen-
Elektrizität A.-G. German Patent 1,115,322,
6 Jun 1957. (In German)

Poisoned electrodes are regenerated by dipping in a strong base at elevated temperatures, then in strong acid, and then passing an a.c. through them while in an acid bath.

29. Hills, G. J., Jacobs, P. W. M., and
Lakshminarayanaiah, N.
Membrane Potentials. PROC. ROY. SOC.
SER. A. 262(1309): 246-70, 4 Jul 1961.

Theory of electromotive force of cells containing ion exchange membranes; principal theories of membrane potential reformulated and compared; application of theory of irreversible thermodynamics; measurement of emf of cells containing cation-exchange membrane, cross linked polymethacrylic acid; measurements of membrane potentials, ionic transport numbers, solvent transport numbers, membrane composition and intramembrane activity coefficients.

30. Hunger, H. F. and Wynn, J. E.
FUEL CELL WITH CATION-EXCHANGE RESIN
MEMBRANE AS ELECTROLYTE. Assigned to
U. S. Dept. of the Army. U. S. Patent
No. 3,013,098. Appl. 3 Oct 1960.

A solvated cation-exchange resin can be used as an electrolyte for liquid fuels if the fuel is mixed with a mineral or simple organic acid, i. e. a mixture of 1 part MeOH to 1 part by vol. of an 50% H_2SO_4 soln. The acid increases the conduction of the layer between the catalyst on the surface of the electrodes and the cation-exchange resin.

31. Jochim, E. and Vielstich, W.
Experiments on the development of membrane
element fuel cells. ELECTROCHIM. ACTA 3:
244-52 (1960). (In German)

H-O fuel cells with solid ion-exchange membranes as electrolyte were constructed by selecting suitable catalysts. These cells operate at room temperature and require gas pressures slightly above atm. pressure. The most efficient type has an open-circuit voltage of 1.03v., and at 0.65v. a current of 10 ma./sq.cm. can be drawn. At lower c.d. (up to 2 ma./sq.cm.) the cell life can be several months.

32. Justi, E.
The economic generation and storage
of electricity by use of fuel cells. ETZ.
ELECTROTECH. Z. 13B: 377-386,
10 Jul 1961. (In German)

Fuel cells are galvanic cells which convert the chemical energy from the oxidation of commercial fuels directly into electrical energy at high efficiency. The idea of avoiding in this manner the detour via the heat engine, which in accordance with the second law of thermodynamics involves unavoidable losses, was put forward as early as 1894 by Wilhelm Ostwald, but in spite of efforts spread over many years by such famous workers as Nernst and Haber, no success was achieved. Recently this work has again been taken up, and considerable initial success has been achieved by using suitable gaseous or liquid fuels, in particular hydrogen and alcohols. Cells fed with H_2 and O_2 give efficiencies up to about 90% at low current densities; the loading per square centimetre of electrode surface, which is over 500 mA/cm^2 , exceeds that of all other known batteries, and then an efficiency of over 50% can still be obtained. For engineering purposes the high energy density per unit volume and unit weight is particularly important. These cells can also be used with advantage for the reverse process of the electrolytic decomposition of water.

33. Justi, E., et al.
High-drain hydrogen-diffusion-electrodes
operating at ambient temperature and low
pressure. Research Information Service,
New York, N. Y., (Trans. no. E-541 and
T-769, 1960, 1 v. Translation of AKADEMIE
der WISSENSCHAFTEN und der LITERATURE,
MAINZ. ABHANDLUNGEN der MATHEMATISCH-
NATURWISSENSCHAFTLICHEN KLASSE, no. 8,
1959). ASTIA AD-248 215.

34. Keppel, R. A.
FEASIBILITY STUDY OF REDOX FUEL CELL
WITHOUT SEPARATOR. Florida U. Engineering
and Industrial Experiment Station, Gainesville.
Summary rept. no. 4 on Fuel Cells, 31 Jan 1962,
38p. (Contract DAI 49-186-502-ORD (P)-860).
ASTIA AD-272 262.

A theoretical study of the redox fuel cell suggests that it is not feasible to design such a cell without a separator between the anolyte and catholyte compartments. One of the main obstacles to the attainment of high power densities from redox fuel cells is the problem of reducing the ohmic losses by bringing electrodes very close to each other while at the same time working toward a design which presents very large reactive surfaces to the action of the anolyte and catholyte. Calculations indicate that any useful cell must be designed with minimum distance between electrodes because of ohmic losses at high current densities. The significance of roughness factor provides justification for efforts in seeking improved electrode materials.

35. Lockheed Aircraft Corp. , Sunnyvale, Calif.
BASIC RESEARCH IN FUEL CELLS: AMMONIA,
ETHYLENE GLYCOL, AND UREA SYSTEMS. Final
rept. 1 Jul 1960 - 31 Aug 1961. Nov 1961, 41p.
(Contract DA 44-177-tc-634). (TCREC TR 61-135).
ASTIA AD-273 049.

Research work was conducted on electrochemical fuel cells operating with NH₃, ethylene glycol, or urea fuel. This work was primarily with aqueous, low temperature systems in K₂CO₃ or KOH electrolytes. The program included an electrode preparations and electrochemical evaluations study, the use of gas adsorption techniques and other methods in catalyst evaluation, and preliminary engineering and design studies on fuel cell batteries. Experiments showed that one of the basic systems did not. The acid glycol and the acid urea systems were not promising. Oxidation of the NH₃ to N and water was 100% complete. A typical NH₃ anode potential (2.2M NH₃, 30% KOH, 50 C, current density equals 1.0 ma/sq. cm) is 0.5 v.

36. Lurie, R. M., Shuman, R. J., and Viklund, H. I.
STUDY OF ION EXCHANGE MEMBRANE FUEL
CELL COMPONENTS. Ionics, Inc., Cambridge,
Mass., Final Rept. 30 Oct 1961, 19p. (Contract
DA 44-009-eng-4554). ASTIA AD-266 036.

The results are presented of work on the development of improved hydrogen-oxygen ion exchange membrane fuel cells. Studies included catalysts electrode structure, membrane composition and thickness, cell design, and structure. This work demonstrated the advantages of the concept of a dual membrane cell. Major features include safety, ease of humidification in air-breathing cells, ease of cooling and water removal in oxygen cells, and high allowable current densities (lower cell weight). Over 6 weeks of continuous operation at 16 amps/sq. ft. at room temperature and atmospheric pressure with no change in performance indicates the advance in the state of the art of membrane fuel cells that was obtained.

37. Mailen, J. C.
HYDROCARBON REGENERATION OF THE
ANOLYTE IN A REDOX FUEL CELL SYSTEM:
n-HEXANE, n-HEXANOL. Florida U. Engi-
neering and Industrial Experiment Station,
Gainesville. Summary rept. no. 3 on Fuel
Cells. 26 Apr 1962, 16p. (Contract DAI 49-
186-502-ORD(P)-860). ASTIA AD-275 013.

The anodic regeneration step in redox fuel cells and the nature or extent of the reactions involved were studied. Calculations of the free energy of reaction of CH_4 and C_2H_6 with the stannous-stannic system were made. The standard free energy of both reactions was found to be positive at atmospheric pressure and approximately room temperature. Thermodynamic methods were used to estimate the free energy involved in the oxidation of hexane to hexanol in an effort to estimate the relative difficulty of this reaction as a possible first step in the oxidation of the hydrocarbon to H_2O and CO_2 . For the reaction $\text{H}_2\text{O} + \text{Sn}(+4) + \text{C}_6\text{H}_{14}(\text{aq}) = \text{Sn}(+2) + \text{C}_6\text{H}_{13}\text{OH}(\text{aq}) + 2\text{H}(+)$ at 113.6mm and 16 C, it was estimated that the over-all free energy of reaction is +10,660 cal/g mole C_6H_{14} .

38. Massachusetts Inst. of Tech., School of Engineering.
RESEARCH ON MATERIALS, PROCESSES, AND DEVICES RELATED TO ENERGY CONVERSION.
Semiannual Technical Summary Report No. 2.,
30 Mar 1962, 165p. (Contract Nonr-1841(78);
ARPA Order 214-61).

CONTENTS: I. HIGH TEMPERATURE MATERIALS RESEARCH ON THERMO-ELECTRIC AND THERMIONIC MATERIALS; A. Phase Diagram Investigations. B. Deformation and Fracture of Thermoelectric Materials. C. Preparation and Evaluation of MoThO_2 Thermionic Emitter Materials. II. THERMAL ELECTRIC ENERGY CONVERSION RESEARCH: A. Thermal-Photo-Voltaic Energy Converter. B. Development of a Radiation Source for the Thermal-Photo-Voltaic Energy Conversion System. C. Graded-Gap Converter. D. Investigation of the Lead-Telluride Tin-Telluride Solid Solution System. III. THERMIONIC ENERGY CONVERSION RESEARCH: A. Thermionic Energy Conversion Research. B. Experimental Program. IV. SUPERCONDUCTING MATERIALS RESEARCH: A. Development of a Ductile, High Field, High Current Ternary Superconducting Alloy. B. Micro-structure Superconductivity and Mechanical Properties of Sintered Nb-Sn Compacts. V. SUPERCONDUCTING SYSTEMS RESEARCH: A. Large Volume Superconducting Solenoid. VI. ELECTROCHEMICAL ENERGY CONVERSION RESEARCH: A. Cathode Studies in Aqueous Systems. B. Oxidation of Formic Acid.

39. McKee, D. W.
THE KINETICS OF PROPANE CRACKING ON NICKEL. General Electric Co., Lynn, Mass.
Interim rept. no. 2, on Hydrocarbon Fuel Cell Research. 20 Mar 1962, 27p. (Contract DA 44-009-eng-4853). ASTIA AD-274 932L.

40. Miller, K. D.
Sodium fuel cell goes operational. CHEM. ENG. PROG. 57: 140, 142, Feb 1961.

Full-scale chemical power plant under development for U. S. Navy will use sodium amalgam-oxygen combination.

41. A new battery: The fuel cell: Will it have an impact on mining? ENG. & MINING J. 159: 89-91, May 1958.

Description of National Carbon Co. (Union Carbide Co.) fuel cell. Notes are given on fuel gas (with unspecified catalyst) and direct fuel cell (both illustrated). Short description of Redox fuel cell. Catalysts which will improve performance of air-H₂ cell are Pd impregnated on H₂-electrode, and Ag-Ag oxide on O₂ electrode.

42. New fuel cell promises high voltages. ENG. 191: 268, 17 Feb 1961.

An improved fuel cell, which makes use of the electrical properties of the element sodium, has been developed. Its voltage output is double that of the hydrogen-oxygen cell.

43. Oster, E. A.
ION EXCHANGE FUEL CELL. General Electric Co., West Lynn, Mass. Semi-annual technical summary rept. no. 1, Oct-Dec 31 1961 on Ion Exchange Membrane Fuel Cells. 31 Dec 1961, 31p. (Contract DA 36-039-sc-89140). ASTIA AD-273 107.

It appears feasible to investigate ion exchange membrane fuel-cell electrodes using modifications of standard electrochemical techniques and apparatus. The main problem is associated with a proper reference-electrode design and placement. The cationic-membrane fuel-cell operates essentially at a 100% current efficiency based on the formation of water as the main power-producing reaction. A 4-electron change per O molecule occurs at the cathode and a 2-electron change per H molecule occurs at the anode. Essentially these reactions operate in reverse during electrolysis with this fuel-cell. Many commonly used sulfonic cationic-exchange membrane materials have only about a 50% dissociation of the hydrated hydrogen ions at each ionized sulfonic site. If polymer structures can be found that increase this dissociation, higher ionic conductivity can be realized in membranes. Such an increase would improve fuel-cell power output by lowering internal resistance.

44. Parker, W. E., et al.
 DEVELOPMENT OF ELECTRODE MATERIALS
 FOR FUEL CELLS. Speer Carbon Co., Research Laboratory, Niagara Falls, N. Y.
 Quarterly repts. 2, 3, Dec 1960 - Mar 1961.
 (Contract DA 36-039-sc-85356) ASTIA
 AD-254 459, ASTIA AD-260 120.

Samples have been prepared from a variety of raw materials and also a variety of fabricating conditions. A filler made from coconut shells has shown considerable promise. Activated carbons are also being tested. A study of the effect of process variables on the physical properties of carbons has been intensified.

45. Rose, A., et al.
 Exploratory research on demineralization. AD-
 VANCES IN CHEM. SER. (27): 50-5 (1960).

Several ideas are advanced concerning the use of ion-retardation resins, algae, salt precipitation, recompressive freezing, and electrolysis with the use of a fuel cell. The last two ideas apparently have little chance of success.

46. Seagoing fuel-cell power at prototype design
 stage. INDUS. SCI. & ENG., 8: 26-27, Jan
 1961.

One of the first major applications of the fuel cell principle to specific power and service requirements is represented in a \$764,000 contract awarded by the Navy Bureau of Ships to the M. W. Kellogg Company. Based on the success of two earlier research programs by the firm, the new development project calls for the design and testing of a complete chemical power plant, a prototype of a Naval version for use by that service.

47. Shamsul Huq, A. K. M.
RESEARCH RELATING TO FUEL CELLS.
Tyco, Inc., Waltham, Mass. Quarterly rept.
no. 1, 20 Sep-31 Dec 1961. 5 Jan 1962, 6p.
(Contract DA 49-186-ORD-982). ASTIA
AD-270 302.

The object of the present program is the theoretical and experimental investigation of the cathodic reduction of oxygen in acidic solutions. The relevant electrode properties are determined by 2 principle factors, the solution parameters, and the electro-chemical properties of the electrode. A scientific approach to the oxygen electrode requires, first, the elucidation of the mechanism or mechanisms which are operative for a given electrode material under various solution conditions. These studies must be extended to ascertain how the reaction mechanisms respond to changes in the electronic and physico-chemical properties of the electrode material. This knowledge is necessary for the scientific pursuit of improved electrode materials.

48. Sodium reaction powers new fuel cell. OIL &
GAS J. 58(52): 84, 26 Dec 1960.

By using mercury amalgam of sodium, explosive effects in cell are prevented; energy from reaction is converted directly to electrical energy instead of being released as heat; sodium amalgam-oxygen fuel cell develops twice voltage of hydrogen-oxygen cell; storage requirements are considerably less; 75 kw experimental power plant will be about 15 times lighter than standard electric batteries.

49. Spengler, H. and Grueneberg, G.
Low-temperature fuel cells. DECHEMA
MONOGRAPH. 38(579-599): 249-75 (1960).

A general review is given of the technology of low-temperature fuel cells, including patent literature. Performance data are given for a cell with Raney-Ni electrodes, KOH electrolyte, and glycol fuel.

50. Stevens, B.
EFFECT OF FUEL CELL POWER PLANT ON
FUTURE AUTOMOBILE DESIGN, SAE Paper
no. 303A for a meeting held 9-13 Jan 1961,
7p. [Abstracted in SAE J. 69(3):28-31 (1961).]

Discusses the feasibility of a fuel cell powered automobile by 1970. The compact power plant will be located in the skin of the vehicle.

51. Union Carbide Consumer Products Co.,
Cleveland, Ohio.
EXPERIMENTAL PROPERTIES OF CARBON
ELECTRODE FUEL CELL. Final rept., pt. 1,
May 1960 - Jun 1961. Dec 1961, 57p.
(Contract AF 33(616)7256; Proj. 3145-06). (ASD
TR 6-1-342.) ASTIA AD-271 971.

Design and assembly of a 560-watt experimental fuel cell system is described. This fuel cell was a low temperature, low pressure, C electrode system which operates on a continuous feed of H and O (or air), and converts the potential chemical energy directly to electrical energy. The results of experimental testing are reported, covering both electrical characteristics and operating procedures over a broad range of conditions. Application of the knowledge obtained was directed toward the design of a fuel cell system suitable for operation in space.

52. Vielstich, W.
The decomposition voltage of hydrogen in the
electrolysis of aqueous solutions with Raney-
metal electrodes. CHEM.-INGR.-TECH.
33: 75-9 (1961). (In German)

The use of double-skeleton Raney Ni catalyst electrodes permits operation with extremely low overvoltage with alkaline solutions. In a 27% KOH solution at 80° and 1500 amp./sq. m., the deviation from the reversible H voltage was only 30 mv. Practical cell voltages are 1.4-1.6 v. When an electrolytic cell is coupled with a H-O fuel cell the over-all electrochemical energy conversion can reach an efficiency > 60%. Also discussed are C1-alkali electrolysis, amalgam-H cells, and D enrichment.

53. Vielstich, W., Grueneberg, G. and Spengler, H.
FUEL CELL FOR PRODUCING ELECTRICAL
ENERGY BY DIRECT REACTION OF GASEOUS
FUELS WITH OXIDIZING GASES. Assigned to
Ruhrchemie Akt.-Ges. and Steinkohlen-
Elektrizitat Akt.-Ges. German Patent No.
1,086,768, 11 Aug 1960. (In German)

Describes a fuel cell which uses electrodes for both the fuel gas and oxidizing gas layers of granular or powdered catalyst confined by an electric conducting screen provided with a power supply.

LOW TEMPERATURE FUEL CELLS

Regenerative

54. Young, G. J. and Rozelle, R. B.
 FUEL-CELL ELECTRODE PROCESSES.
 I. CATALYSIS AND CHEMISORPTION.
 Alfred Univ., Alfred, N. Y. Rept. no.
 PB 150 515, 1962, 33p.

Studies on low-temperature fuel cells were concerned with various aspects of chemisorption and catalysis as they apply to the electrode processes. Dissociative chemisorption of H on a metal oxide can proceed by 2 different mechanisms; an irreversible process where H is adsorbed on the oxide ions and desorbed as H_2O , and a reversible adsorption, presumably on the metal ions, with the H being desorbed as H_2 . Both of these processes may operate simultaneously, although the reversible process is favored at lower temperatures. The influence of either surface or bulk-defect structure on the chemisorption of H is over-shadowed by a general correlation with the electronic configuration of the lattice cations. This result should not be construed to imply a direct relation between the ground-state configuration of the gaseous cation and adsorption but is presumably a crude approximation of the actual energy levels resulting from the asymmetrical crystal field of the surface. The catalyst surface can play a dual role in fuel-cell reactions. First, it can enhance the rate of reaction if chemical kinetics are the rate-controlling factor, thus playing its usual role as a catalyst. Secondly, it can influence the potential of the cell by minimizing the free-energy loss due to chemisorption.

55. Conway, C. G.
 FUEL CELLS. Assigned to National Research
 Development Corp., British Patent No. 877,410.
 Appl. 5 Oct 1956.

The fuel electrode, or at least that part which is brought into contact with the electrolyte, is composed of an oxide which has an excess of the electronegative constituent. For example, the fuel electrode may be sintered from NiO powder or from Ni powder. Then, a firmly adherent layer of black Ni_2O_3 prepared from $Ni(NO_3)_2$, is applied throughout the porous mass of the electrode. For the oxygen electrode, a nonstoichiometric material having an excess of its electropositive constituent is selected. For example, ZnO and CaO which have an excess metal constituent owing to interstitial cations are especially suitable for accepting oxygen and transporting it as ions to the electrolyte.

56. Eisenberg, M. and Silverman, H. P.
Photoelectrochemical cells. ELECTROCHEM.
ACTA 5:1-12 (1961). (In English)

Presents new method for utilization of light energy through photochemical reactions in combination with electrochemical processes. Operation of the system involves the utilization of many electrochemical oxidation-reduction couples, one of which must be photochemically sensitive. The theoretical background of the photoelectrochemical process is discussed and a possible power scheme is presented, together with some experimental results on single electrodes and on complete cells.

57. Gandel, M. G.
SOLAR REGENERATIVE CHEMICAL SYSTEM.
Lockheed Missiles and Space Co., Sunnyvale,
Calif. Fifth semiannual rept., Jul 1961-
31 Dec 1961. Rept. 2-52-61-2, 1962, 119p.
(Contract DA 36-039-SC-85245; Proj. 3A99-09-
001). (ARPA Order Nos. 80-59 and 80-61).

A study of photochemical and thermochemical approaches to convert solar to electrical energy is reported. The photochemical work is finalized; a power conversion efficiency of greater than 0.2 percent was achieved for a closed regenerative system, employing Victoria Blue B, an insoluble dye deposited on the electrode surface. A regenerative-type fuel cell based on thermal dissociation of cadmium iodide or stannous iodide is shown to be unfeasible. Experiments are described and theories presented, for thermocell and double thermogalvanic cell thermal regenerative systems.

58. Ludwig, F. A.
EVALUATION OF REGENERATIVE FUEL CELL.
Electro-Optical Systems, Inc., Pasadena, Calif.,
Rept. no. EOS 1584-I-R-I, 31 Mar 1961, 33p.

Laboratory experimental testing of an optimum fuel cell design, based on various design parameters, gave initially poor results. At least a 60 percent current efficiency was guaranteed by a careful setting of two variables, a set value for the compression of asbestos packing and a set value for the amount of KOH electrolyte solution added to the cell. Current efficiencies of 100 percent could be obtained on short cycles; however on long cycles (for example, 65 minute charge, 35 minute discharge cycle run at deep discharge for seventy cycles), performance deteriorated with cycle life. Tests performed showed that current efficiency could be upped from

60 percent to 100 percent by applying a light coat of lithium oxide to the nickel electrode used as the hydrogen electrode. This coating was sufficient to stop an undesirable $\text{Ni}_2\text{Ni}(\text{OH})_2$ electrochemical reaction and yet not hinder other reactions such as hydrogen absorption into the nickel. Apparently, on long cycles, the hydrogen electrode had to be made more inert to obtain the desired chemical reaction and prevent the nickel itself from reacting.

59. McKee, W. E., et al.
A NITROSYL CHLORIDE SOLAR REGENERATIVE
FUEL CELL SYSTEM. Sunstrand Aviation-
Denver, Paicoma, Calif., Final rept., Jul
1961, 122p. (Contract AF 33(616)6585;
Proj. 3145). (WADD TR 60-821, pt. 2). ASTIA
AD-267 060.

Regeneration is accomplished utilizing solar energy to dissociate NOCl into No and Cl . Product separation is accomplished by using solvent extraction techniques. The separated dissociation products are used as fuels in a C electrode, ambient temperature fuel cell. A breadboard model photoregeneration system was designed and built. Data are given relating to the model fabrication, preliminary system tests, separation of regenerated fuels, and the development of the No-Cl fuel cell. Encouraging progress was made in the performance of the non-regenerated NO-Cl fuel cell. Current densities up to 8.5 amp/sq ft at about 75% of the theoretical cell voltage (0.21 v) were achieved. In preliminary system tests, solar energy was converted into electricity for the first time by a photochemically regenerated fuel cell system employing product separation. Although conversion efficiencies in these few tests were very low, the photochemical process for storing and converting solar energy has thus been demonstrated.

60. Rowlette, J. J.
INVESTIGATION OF NEW SOLAR REGENERATIVE
FUEL CELL SYSTEMS. Electro-Optical Systems,
Inc., Pasadena, Calif. Semiannual rept. no. 1,
14 Mar-30 Jun 1961. EOS rept. no. 1720-2A-1,
10 Jul 1961, 33p. (Contract DA 36-039-sc-87425).

A re-investigation has confirmed that the maximum efficiency of a thermally regenerative fuel cell is equal to $\Delta F/\Delta H$ at the low temperature side. A qualitative and semi-quantitative comparison between thermally regenerative fuel cells and other thermal converters shows that the former have the potential to compare very favorably with the latter. A quantitative comparison with thermionic converters indicates that one thermally regenerative cell, the H₂SO₄ concentration cell, should eventually compete very favorably with them. A preliminary comparison between thermally regenerative fuel cells and photochemical converters indicates that the latter will probably be several years behind the former in development. However, for conversion of sunlight there are many reasons to believe that the photochemical converters, or other devices operating by a quantum process, may eventually prove to be best.

61. Rowlette, J. J.
INVESTIGATION OF NEW SOLAR REGENERATIVE
FUEL CELL SYSTEMS. Electro-Optical Systems,
Inc., Pasadena, Calif. Semi-annual rept. no. 2,
1 Jul-31 Dec 1961. EOS rept. no. 7120-2Q-2,
10 Jan 1962, 61p. (Contract DA 36-039-sc-87425).
ASTIA AD-274 387.

Solar energy conversion by fuel cells regenerated either photochemically or thermally was evaluated. For the photochemical systems, it was concluded that only a very small number of known reactions could ever form the basis of a practical solar energy converter by virtue of their having threshold wavelengths which are too short. Of the ones which meet this qualification, most are unattractive either because of thermal degradation reactions or because measured quantum efficiencies were too low. A system based on I might be feasible since it meets the criteria. Conclusions about the thermal systems are less definite at present mostly because the relative importance of the criteria is less understood. The tentative conclusions are that most systems considered would not be feasible for one or more of several reasons. Melting points of some components are often too high, or the rate of change of potential with temperature is too low to allow an acceptable cell emf within a reasonable temperature interval.

INTERMEDIATE TEMPERATURE FUEL CELLS

62. Austin, L. G.
 REDOX FUEL CELLS. Pennsylvania State U.
 Mineral Industries Experiment Station, University
 Park. Quarterly progress rept. no. 7, 1 Sep -
 1 Dec 1961. 1 Dec 1961, 4p. (Contract
 DA 49-186-502-ORD-917). ASTIA AD-271 005.

A high pressure build-up occurred when stannic in HCl solutions were heated with formaldehyde at 200C. A mass-spectrographic analysis of this gas was performed. The principal products were CO₂ and CH₄. No H was found in the gas, although appreciable amounts of CO were found. Further titrations have not given any evidence for appreciable reduction of stannic to stannous Sn.

63. Elmore, G. V. and Tanner, H. A.
 Intermediate temperature fuel cells.
 ELECTROCHEM. SOC. J. 108(7): 669-71,
 7 Jul 1961.

Experimental cells which can be operated above 100 C at atmospheric pressure, retaining enough water for good electrolytic activity and losing excess product water as vapor; electrolyte contains solid phase which reduces creep, and electrodes are made nonwetting by use of Teflon; current densities of 50-100 ma/sq cm have been realized.

64. Universal Winding Co.
 FUEL-CELL CONTROL SYSTEMS. British
 Patent No. 857,368. 29 Dec 1960.

Means of establishing and maintaining an interface between the electrolyte and both the fuel supplied to the cell and its oxidizing agent are provided. A cell provided with porous Ni diffusion electrodes is shown.

HIGH TEMPERATURE FUEL CELLS

Primary

65. Broers, G. H. J.
High-temperature fuel cells. DECHEMA
MONOGRAPH 38:579-599, 277-303 (1960).

The thermodynamics of processes of high-temperature fuel cells with H, CO, C, CH₄, and C₂H₆ as fuels and the effect of pressure are reviewed. Factors influencing reactivity and polarization, coupling of high-temperature cells to increase overall efficiency, and practical aspects of high-temperature cells are discussed. Experimental data were obtained with a cell having a 40% porous MgO matrix containing a carbonate electrolyte paste at 550-770°. This cell is shown schematically, and results are given in detail for CO and H as fuels with Ag cathodes and Pt anodes. Polarization curves for CH₄-H₂O mixtures with Ni powder electrodes at 770°, and CO-CO₂ mixtures with an Fe-Ni-Cu anode are also shown. For the CO electrode the anode materials are arranged in the following activity series: Pt > platinized Fe > Fe > Ni = Co > Cu.

66. Chambers, H. H.
Fuel cells. N. E. COAST INST. ENGRS.
& SHIPBDRS. TRANS. 77, part 6; 379-388.
Apr 1961. (disc. pt. 8, Jul, p. D. 79-82).

Very considerable effort which is being devoted to fuel cells, especially in the United States, is expected to lead to commercial exploitation within the next five years. Unless there is a major breakthrough in the near future, the first cells for operation on commercial hydrocarbon fuels will be high-temperature cells running above 400° C, and, as they will not be capable of rapid start-up, they are unlikely to be used for such things as powering motor cars. They will be quite suitable for any use where the power demand is steady or intermittent but without long idle periods. The first commercial batteries are likely to replace small motor generator sets of up to 20 kW output. Larger units may be developed fairly soon after the first appearance of small units. The future for large central power-station generation is uncertain. It is too early to predict capital costs, but in view of the high operating efficiency and versatility, it is likely that fuel batteries will begin to become competitive before the capital cost approaches that of diesel

generators. Parallel development of other types of cells, including low-temperature cells, is probable, and such cells will be used for special purposes where the relatively high cost of specialized fuels can be tolerated.

67. Chambers, H. H. and Tantram, A. D. S.
ELECTROLYTES FOR FUEL CELLS. Assigned
to National Research Development Corp. German
Patent No. 1,051,350, 26 Feb 1959. (In German)

Fusible eutectic mixtures of fluorides and a metal oxide are better than molten carbonates for producing oxygen ions to function as electrolytes in fuel cells. Oxides of Al, Be, Ca, Sr, or Ba, but preferably Mg oxide, are used. Suitable mixtures are NaF 39 11.5, KF 42, and LiF 46.5 (m. 454°), LiF 53 and MgF₂ 47 (m. 718°), NaF 40, and KF 60 (m. 710°), LiF 61 and NaF 39 (m. 652°), LiF 50 and KF 50 (m. 492°), NaF 6.5, LiF 46.5, and RbF 47 (m. 426°), MgF₂ 6.5, NaF 34.5, and KF 59 (m. 685°), and MgF₂ 10, NaF 43, and LiF 47 mole % (m. 630°). To complete the electrolyte, e.g., 2.5% by wt. MgO is added to the first mixture or 10% to the second. Other suitable electrolytes contain MgO 10, NaF 36, and KF 54 mole % or Al₂O₃ 3, LiF 16, NaF 38, and AlF₃ 43% by wt. At 580°, the electrolyte containing 2.5% MgO develops 1.15 v. with H and air with ZnO electrodes. A linear voltage-current relation is observed up to 97 ma./sq.cm. A maximum power (at 575 mv. and 54 ma./sq.cm.) can be maintained for long running times without altering the electrolyte.

68. Chambers, H. H. and Tantram, A. D. S.
FUEL CELLS. Assigned to National
Research Development Corp. British Patent
846,039, 24 Aug 1960.

Electricity is generated by oxidizing a fuel gas at the fuel electrode of a fuel cell and simultaneously reducing oxygen at the oxygen electrode. The electrolyte consists of a mixture of at least two alkali metal carbonates which exist in a pasty state over the working temperature of the cell. The pasty state is defined as a solid matrix carrying a liquid in its interstices. Since the electrolyte is solid, the electrodes may be imbedded in and supported by the electrolyte.

69. Degobert, P.
Les piles a combustibles a electrolytes fondus.
INST. FRANCAIS du PETROLE et ANNALES
des COMBUSTIBLES LIQUIDES. Rev. 16(6):
747-73, Jun 1961. (In French)

Fuel cells with molten electrolyte; difficulties encountered with use of hydrocarbons in fuel cell; chemical nature and electric conductivity of molten electrolytes.

70. Florescu, A.
Some recent forms of direct transformation of
thermal, chemical and nuclear energy into
electric power. ENERGETICA (Roumania).
9(6): 237-41, Jun 1961. (In Roumanian).

A survey is of industrial methods for producing electric power. Devices described are the solar-, atomic-, thermoelectric- and gaseous-combustion batteries and plasma-operated thermocouples.

71. Horsley, G. W.
SOME EXPERIMENTS ON GALVANIC CELLS
USING SOLID ELECTROLYTES. Great Britian.
Atomic Energy Research Establishment, Harwell.
Rept. R-3427, Jan 1961, 24p.

Variation of the emf with temperature of a number of solid electrolyte galvanic cells were measured.

72. Natural-gas fuel cells may supply home power.
OIL & GAS J. 59(15):74, 10 Apr 1961.

In high temperature cell methane is converted to hydrogen by steam reforming; current is generated by electrochemical oxidation of hydrogen; oxygen source is either carbonate or solid oxide; in power pack for home installation, steam would be added to natural gas.

73. Shultz, E. B., Jr., et al.
From fuel cell, power for homes? AM.
GAS. ASSOC. MON. 43:11-12, 31-32,
May 1961.

Current progress of an Institute of Gas Technology project is reviewed as well as that on related engineering economic studies, which are directed primarily toward the development of fuel cell power packs for dwellings, to supply all or most of the home needs for electricity.

HIGH TEMPERATURE FUEL CELLS
Regenerative

74. Ciarlariello, T. A., McDonough, J. B., and
Shearer, R. E.
STUDY OF ENERGY CONVERSION DEVICES.
MSA Research Corp., Callery, Pa. Final
rept. no. 7, Jul 1959-May 1961. Rept. no.
MSAR 61-99, 14 Sep 1961, 69p. (Contract
DA 36-039-sc-78955). ASTIA AD-270 212.

Prior experiments showed the feasibility of alkali and alkaline earth metal/molten salt electrolyte/hydrogen gas electrochemical cells. These cells produce metal hydride, heat and electric power. Batch regeneration of a calcium-hydrogen cell was demonstrated. Regenerative cells were tested. The major difficulties noted were the plugging of the circulating salt lines, the low dissociation pressure of LiH in dilute solutions, and an electric cell-shorting effect arising after long operation. Various molten salt electrolytes were tested. Low melting point eutectic salts containing Na, Rb, Cs, K, and Li were found. Fluorides, bromides, and chlorides were found to be the best electrolytes. Borohydrides and iodides were not satisfactory. Various hydrogen electrodes materials were tested. The best electrodes consisted of mesh electrodes or sintered porous discs. The dissociation of LiH over molten salts was determined, and the LiH content of various cell electrolytes was measured. The feasibility of the electrochemical cell, and of the hydride dissociation was demonstrated. However, the complete regenerative system has not been reduced to practice.

75. Crouthamel, C. E., et al.
ENERGY CONVERSION. Argonne National
Lab., Lemont, Ill., Chemical Engineering
Div., Summary rept. for Mar 1962. p. 204 -
216.

Operation of a regenerative lithium hydride fuel cell system for converting nuclear energy to electricity is being studied. This thermally regenerative emf cell system is one in which heat is used to disassociate lithium hydride, which is then reformed in an electrochemical cell with the production of electric power. The hydrogen diffusion rates through pure iron diaphragms were found to be about two percent of those desired for cell operation. The hydrogen gas electrode efficiency under a typical load was found to be 90 percent. However, this decreased sharply under lighter load conditions. Characteristics were estimated for a lithium hydride cell utilizing pure iron throughout. The gas diaphragm area was maximized to compensate for the slow diffusion of hydrogen through pure iron. Preliminary experimental work on the lithium-tin cell has been completed and a current density of 470 ma/sq cm was obtained at 0.3 volt. Research in thermoelectricity methods for direct conversion of nuclear heat energy into electrical power was continued. Absolute Seebeck coefficients were measured for the indium-antimony liquid system at 360°C. A point of inflection was observed at a composition corresponding to InSb.

76. Friauf, J. B.
Thermodynamics of thermally regenerated
fuel cells. J. APPL. PHYS. 32: 616-620,
Apr 1961

It is shown that $d(\theta \Delta H)/dT = 0$ is a necessary condition for the attainment of Carnot cycle efficiency, $(T_1 - T_2)/T_1$, by a thermally regenerative fuel cell system in which ideal gases are reacted in a fuel cell to convert chemical to electrical energy, and are then regenerated for recycling by thermal dissociation of the product of the reaction, also assumed to be an ideal gas.

77. Hess, F. and Schieler, L.
FUEL CELL RESEARCH PROGRAM.
CHLORINE-PHOSPHORUS TRICHLORIDE
FUEL CELL INVESTIGATIONS.
Aerospace Corp., El Segundo, Calif., Semi-
annual technical rept., 1 Jan-30 Jun 1961.
Rept. no. TDR-594(1201-01)TR-1). (Con-
tract AF 04(647594). ASTIA AD-266 441.

A description is given of a fuel cell research program for space power applications. The primary objective of the program is the investigation of a regenerable fuel cell utilizing the thermal or photolytic dissociation of phosphorus pentachloride to phosphorus trichloride and chlorine as a source of chemical energy. Data reveal that thermal dissociation is feasible but photolysis techniques will need further study. Theoretical background is given for electrode reactions of the phosphorus trichloride-chlorine fuel cell and the technical progress made in this investigation during the last six months is summarized.

78. McCully, C. R.
THE CHEMICAL CONVERSION OF SOLAR
ENERGY TO ELECTRICAL ENERGY. New
York, United Nations, Paper no. E/CONF.
35/GEN/6, 16 May 1961, 17p. (Preprint of
paper prepared for United Nations Conference
on New Sources of Energy.)

Principles of the chemical conversion method are cited; the "unique" approach to the thermally regenerative galvanic cell under investigation at the Armour Research Foundation is mentioned; applications are reviewed and the conclusion reached that "in spite of their relative simplicity, conversion efficiency, and other favorable factors, thermally regenerative galvanic cells operated from solar energy do not appear to offer a promising power source for general application unless mass production is undertaken."

79. McCully, C. R.
CHEMICAL CONVERSION OF WASTE HEAT
TO ELECTRICAL ENERGY. Armour Research
Foundation, Chicago, Ill. Quarterly rept. no. 1,
30 Jun - 30 Sep 1960. 6 Oct 1960, 22p. Rept.
no. ARF 3182-1. (Contract NOw 60-0760-c).
ASTIA AD-272 067.

The research phases consisted of thermochemical and thermodynamic calculations for systems selection by the Univac 1105 computer, kinetics of regeneration reactions, and electrolyte and galvanic cell experiments. Work with the computer was limited to programming and proof runs. In the kinetic studies, both the endothermic regeneration reaction at high temperatures and the necessary low temperature regeneration of the cathodic components were considered. Equipment for experimental studies was completed for the endothermic reaction only. The low temperature regeneration is concerned initially with Ag and O. Results of a number of experiments with electrolytes are reported, and various problems in galvanic cell operation are discussed.

80. Silverman, H. P.
SOLAR REGENERATIVE CHEMICAL SYSTEM.
Lockheed Aircraft Corp., Sunnyvale, Calif.
Semiannual rept. no. 4, 1 Jan-30 Jun 1961.
Rept. no. 2-52-61-1, Jul 1961, 55p.
(Contract DA 36-039-sc-65245; Proj. 3A99-09-001).
(ARPA Order no. 80-59). ASTIA AD-268 401.

The effect of temperature, pressure, and electrolyte composition on the Cd I_2 fuel cell and reported and the thermodynamic significance discussed. A power density of 56 of anode area and 126 mw/cc of cathode area was obtained. The $\Delta E/\Delta T$ was measured and the entropy change calculated. The studies on photoregenerative chemical systems included the exploration of insoluble organic dyes and inorganic complexes as well as the more usual water-soluble dyes. The insoluble dyes proved advantageous. The rates of reaction and the magnitude of the photo-potentials are much improved. Spectra, quantum efficiencies, and the effect of wavelength, light intensity, temperature, and electrolyte composition on the photoinduced properties are reported for one of the insoluble dye systems. A 2 cell experimental regenerative system was operated for 90 days. The effect of halide salts on the quantum efficiency of photobleaching of the proflavinasorbic acid system is discussed. Photopotentials of some Werner-type complexes were measured.

81. Werner, R. C. and Shearer, R. E.
CELLS FOR THE GENERATION OF ELECTRIC
CURRENT. Assigned to Mine Safety Appliances
Co. German Patent No. 1,094,830, 15 Dec 1960.

The electrodes are made of materials reacting with each other if the current is switched off. The compound formed should be capable of regenerating at elevated temperatures. When one electrode is made of a metal, such as Ca or Li, of CuBr, or of a metal sulfide, selenide, or telluride, the other is either of H, Br, or S. A halide, water, or an alkali metal polysulfide is used as electrolyte. For example, the element is composed of a Li electrode, a H electrode, and an electrolyte of a 450° molten eutectic mixture of LiCl and LiF. The LiH obtained can be decomposed at 850°. When 1 electrode is made of Cu, the other is H. The electrolyte is a eutectic mixture of CaF₂ and CaCl₂, heated to 650°. By decomposition of CaH₂ at 1000°, the electrodes can be regenerated. If the anode is made of sulfides, selenides, or tellurides, the cathode material is S, Se, or Te. It is preferred to form the anodes from FeS, Cu₂S, PtS, CoS, NiS, InS, PdS, or MoS₂, which are all sulfides reacting with S to multivalent sulfides. The electrolyte for cells of this type is a metal polysulfide, such as NaS_x.

REVIEW, SUMMARY & GENERAL ARTICLES

82. 15th ANNUAL POWER SOURCES CONFERENCE,
Ft. Monmouth, N. J., 9-11 May, 1961. (Spon-
sored by the Power Sources Division, Electronic
Components Dept., U. S. Army Signal Research
& Development Lab.) Red Bank, N. J., PSC
Publications Committee. p. 4-58.

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Session on Primary Fuel Cell Batteries
Chairman - R. Pinnes

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| 2. Carbon electrodes | F. Rusinko, R. W. Marek, and W. E. Parker |
| 3. Catalysts | J. C. Cohn |
| Mechanism and Kinetics of reactive groups in organic fuels | L. R. Griffith, R. P. Buck, R. T. McDonald and M. J. Schlatter |
| Ion-exchange fuel cell battery | L. E. Chapman and E. A. Oster |
| Carbon electrode fuel cell battery | H. W. Holland |
| Liquid-alkaline fuel cells | P. G. Grimes, B. Fiedler, and J. Adam |

Session on Regenerative Fuel Cell Batteries
Chairman - J. J. Murphy

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| Design parameters for regenerative cells | F. Ludwig, D. H. McClelland and H. A. Frank |
| Regenerative fuel cells for energy storage | B. Argruss, E. H. Hietbrink and R. E. Henderson |
| Regenerative H ₂ O ₂ fuel cell system | R. M. Handlewich and J. M. Lee |
| Ion-Exchange regenerative fuel cells | M. P. Read, J. S. Bone, S. Gilman and L. W. Niedrach |
| Halogen alkali metal amalgam cell | J. S. Smatko |
| Photochemical regenerative fuel cell | W. R. Momyer, H. Silverman and M. Eisenberg |

83. Block-Chaude, O.
Recent developments in fuel cells. BULL.
SOC. CHIM. FRANCE. 2447-2452 (1961).

A review including 43 references.

84. Bruni, M.
Electrical generators of the future.
ELETTROTECNICA (Italy), 48(6): 367-80,
Jun 1961. (In Italian).

The review of advanced schemes of power generation includes a description of the fuel cell, thermionic, thermoelectric and magneto-hydrodynamic generators. In each case a description is given of possible practical arrangements and an account of progress made.

85. Buvet, M. R.
Contribution to the study of fuel cells. (Contribution a l'etude des piles a combustibles) SOC
FRANCAISE DES ELECTRICIENS - BULL, Ser. 8.
2(19): 405-413. (In French).

Discusses the factors limiting the electrochemical transformation of energy, viz. electrode geometry, the kinetic characteristics of oxygen reduction, etc.

86. Chambers, H. H.
Fuel cells. A review of current progress.
BEAMA J. 68:45-50, May 1961.

The present state of the art is reviewed; problems which have to be solved are outlined; advantages are indicated; and future prospects are predicted, namely that commercial units will begin to appear on the market within the next five years.

87. Cohn, E. M.
 Fuel cells direct conversion of chemical
 to electrical energy. ELECTRONIC DES.
 9: 62-67, 15 Feb 1961.

Discussion of the types, basic design, performance, and state of development of fuel cells. Fuel cells for operation at elevated temperatures are also considered. It is pointed out that efficiencies up to 80% are achievable. Infinite shelf life, high power per weight and volume, plus lack of noxious by-products are some of the features advantageous for many military, industrial, and missile applications.

88. Daniel, A. F.
 Electrochemical conversion of energy. In
 CONFERENCE ON SPACE TECHNOLOGY,
 Dallas, Tex., 11-13 Apr 1960. Papers.
 Electrical Engineering in Space Technology,
 New York, American Institute of Electrical
 Engineers, Dec 1960, p. 41-45.

Characteristics of electrochemical systems of importance to space applications are considered. They are: dry primary batteries, wet primary batteries, storage batteries, molten electrolyte batteries or thermal batteries, primary fuel cell batteries, and regenerative fuel cell batteries.

89. Fick, L. and Eisenberg, M.
 Fuel cell analysis. CHEM. ENG. PROG.
 57: 74, May 1961.

Comments on "Fuel Cells" by E. Gorin and H. L. Recht.

90. Fox, H. W. and Roberts, R.
 Fuel cells. IRE TRANS. COMPON. PARTS.
 CP-8(4):162-74, Dec 1961.

A comparison is drawn between theoretical efficiencies of heat-engines and fuel-cells in the conversion of chemical to electrical energy. Electrochemical principles governing the operation of fuel-cells are discussed. Brief descriptions are given

of a few selected fuel-cell types including low, intermediate, and high temperature cells, and redox and regenerative cells. An example is given of a rough calculation of battery and fuel weight and volume for a given power level and total energy demand.

91. Genin, G.
Fuel cells. (Les piles a combustible). CHALEUR
& INDUSTRIE, 41(417-418):95-104, 145-158;
Apr, May 1960. (In French)

History since 1839. Types of cells, choice of fuel and applications are discussed.

93. Gutkin, L. V.
Fuel cells. ELEK. i TEPL. TIAGA. 5(11):47-48,
Nov 1961. (In Russian)

94. Henderson, R. E.
Nuclear fuel cells. BRIT. POWER ENNG.
4(1):50-2, Dec 1961.

A description of H_2O_2 fuel cells of the low temperature carbon and Bacon types precedes an algebraic equational summary of the theoretical possibilities of the class. The above basis is extended to include nuclear fuel and regenerative fuel cells. A survey reveals the characteristics of twenty one inorganic compounds usable in thermal regeneration. LiH has been found to provide a reversible voltage of 0.6 at about 700°K. This search leads towards renewed research into cells with low polarization losses and higher voltage. Thermal regeneration schemes not based on distillation are also being sought. Liquid metal concentration cells have recently been examined which can give high voltage, simplify reactor cooling and lower polarization. The LiH system is estimated to be capable of supplying 6.6 W/Kg in the 500 W class. Liquid metal systems in the same power range should provide 19.8W/Kg.

95. Ishino, T., Tamura, H., and Matsuda, Y.
Fuel cells. FUEL SOC. JAPAN - J.
40(407):165-76, Mar 1961.

Economical and practical prospects of fuel cells, their structures, electrode reactions, and features; fuel cells are very promising not only as mobile or independent power sources, but also as large power stations.

96. Janz, G. J.
ENERGY CONVERSION RESEARCH AT
CENTRAL ELECTRICITY RESEARCH
LABORATORIES. Office of Naval
Research, London. Technical rept.
no. ONRL-94-61. 29 Dec 1961, 9p.
97. Kangro, W.
Principles and potentialities of the fuel cell.
(Die unmittelbare gewinnung von elektrizitat aus
brennstoffen.) MOTORTECH. 22(1):11-17, Jan
1961. (In German).

Discusses problems involved in developing a practical device. Justi's high-power hydrogen-diffusion electrode used in ambient temperature and low pressure systems is studied. A review of U. S. and British work is included.

98. Kaye, J., and Co., Inc., Cambridge, Mass.
SURVEY OF LONG LIFE SYSTEMS FOR GENER-
ATION OF ELECTRICITY AT LOW POWER IN A
MARINE ENVIRONMENT. VOLUME I. Rept. no.
33, 31 Aug 1960, 1v. (Contract NObs-78711).
ASTIA AD-273 556.

A description is given of the power-system requirements, and useful sources of energy for systems producing 2 watts for 2 years and 5 watts for 2 years are discussed. Included is a description of energy-conversion methods, a discussion of the use of the system concept in considering the power systems, and the presentation and illustration of an energy-conversion matrix. A basis for selection of attractive power systems is presented, followed by the detailed analyses of the 6 most attractive systems. The power-conversion systems considered consist of an energy source such as fuel and oxidant, energy-conversion devices, necessary control system, storage tanks for the energy source, and the container to house and protect the system. Finally, the characteristics, such as weight, volume and cost of these systems are compared.

99. Kaye, J., and Co., Inc., Cambridge, Mass.
 SURVEY OF LONG LIFE SYSTEMS FOR GENER-
 ATION OF ELECTRICITY AT LOW POWER IN A
 MARINE ENVIRONMENT. VOLUME II. Rept. no.
 33, v. 2, 21 Nov 1960, 69p. (Contract NObs-78711).
 ASTIA AD-273 557.

Those systems and concepts which proved to be either completely impractical for the intended application, or which required further research or technical development, are briefly discussed. These latter systems and concepts must be examined in more detail than was permitted here before their attractiveness for future development can be determined. Batteries or galvanic devices, mechanical devices, thermo-mechanical devices, direct conversion devices, fuel cells, solid state devices, terrestrial devices, and solar devices are discussed.

100. Lozier, G. S.
 Fuel cells and batteries. RCA REV. 22(2):325-346,
 Jun 1961. (Also in ENGRS. DIG. 22(119):74-79,
 Sep 1961.)

This paper discusses the present state of development of fuel cells and batteries as energy sources and energy-storage devices. The various types discussed are evaluated from a consideration of the energy content of the reactant materials and the basic methods of handling the reactant materials in electrochemical cells. Regenerative electrochemical cells are also discussed, with emphasis on space applications.

101. Lynch, C. J.
 What use for these unconventional power
 sources? PROD. ENG. 32:57-59, 10 Jul 1961.

Eight laboratory curiosities for generating power are briefly described, among them the organic fuel cell.

102. McJones, R. W. and Bass, W. A.
 DYNAMIC ENGINES VERSUS FUEL CELLS
 FOR SPACE POWER SYSTEMS. Institute of
 the Aerospace Sciences. National Summer
 Meeting, 19-22 Jun 1962, Los Angeles, Calif.,
 Paper 62-119, 12p.

Hydrogen-based power systems using either mechanical engines or fuel cells are studied for use on medium-duration space missions. Straight hydrogen expansion uses waste heat but involves a large propellant storage volume; either electrochemical or mechanical equipment can be used. Stoichiometric hydrogen/oxygen cycles offer minimum propellant weight and volume but require radiators for heat rejection. Mechanical engines and fuel cells differ primarily in their fixed weights. Fuel-rich hydrogen/oxygen cycles eliminate radiators but require additional propellant; only mechanical engines can presently implement these cycles.

103. Menetrey, W. R. and Chrisney, J.
 ENERGY CONVERSION SYSTEMS REFERENCE
 HANDBOOK. Volume VI. CHEMICAL SYSTEMS.
 Electro-Optical Systems, Inc., Pasadena, Calif.
 Report no. WADD TR 60-600, Sep 1960, 202p.
 ASTIA AD-257 358. (PB 171 863).

Primary and secondary batteries and primary and regenerative fuel cells are discussed.

104. Micka, K.
 Progress in the development of fuel cells.
 CHEM. LISTY. 55:129-138, (1961). (In Hungarian)

A review with 13 references.

105. Mills, R.
 Fuel cells. AUSTRALIAN J. SCI.
 23:109-113, (1960).

106. Moos, A. M., Von Fredersdorff, C. G., and Schlatter, M. J.
Fuel cells. IND. ENG. CHEM. INTERN. ED. 54(1):65-68 (1962).

107. Pitts, J. N., Jr., Margerum, J. D., and McKee, W. E.
Photochemistry and space power generation. ARS J. 31:890-896, Jul 1961.

Discussion of fundamental photochemical principles and processes relative to: (1) photogalvanic solar batteries, and (2) solar regenerative cells. The necessity of intensive fundamental and applied research in these areas is indicated.

108. Rideal, E. K.
The fuel cell. ANALES REAL SOC. ESPAN. FIS. Y QUIM. (Madrid) 56B:427-32 (1960).
(In English).

A general discussion of fuel cells, with special emphasis on catalytic properties of the electrodes.

109. Ruka, R. J.
Fuel cells. POWER ENG. 65:67-71, Jan 1961.

Principles, historical background, types, and present applications are discussed.

110. Salvi, G. and Fiumara, A.
Electrical energy from fuel cells. RIV. COMBUSTIBILE 14:149-71 (1960). (In Italian)

The thermodynamics and practical aspects of fuel cells operating at low and high temperatures are reviewed at length.

111. Scientists investigate economics of fuel cells.
CHEM. & ENG. NEWS 39:86, 88, 18 Sep 1961.

112. Tantram, A. D. S.
Fuel cell progress, the last year and the future.
FUEL EFFIC. 9:50-51, Feb 1961.

A brief review is given of the rapidly rising interest now shown in fuel cells both in Great Britain and in the United States.

113. Trudeau, A. G.
Army research and development progress.
SIGNAL 15:4-6, Jul 1961.

New energy sources are mentioned and the importance of the fuel cell is stressed. A possible solution to the age-old logistics problem is forecast by the integration of the fuel cell--or groups of cells--with the nuclear reactor.

114. Watson, G. H.
Fuel cells. INDUS CHEMIST 37(431):3-10,
Jan 1961.

Review of present state of development of fuel cell; subjects include fuel cell as primary generator, fuel cell as storage system, energy losses in cell operation, concentration changes, ionic reactions, migration of ions and electrons, identification of sources of energy loss in fuel cells, technical problems and future prospects.

115. Weissbart, J.
Fuel cells-electrochemical converters of
chemical to electrical energy. J. CHEM.
ED. 38:267-272, May 1961.

Principles of operation, history of development, thermodynamic considerations kinetic considerations and types, e.g. hydrogen-oxygen (KOH), hydrogen-oxygen ion exchange membrane cells, molten salt (carbonate) cells, and solid electrolyte (ceramic oxide) fuel cells.

116. Yeager, E.
Fuel cells. SCIENCE 134(3486):1178-86,
20 Oct 1961.

Current developments in field of devices which produce more electricity per pound of fuel than any other non-nuclear method of power production; polarization problems; review of specific systems including hydrogen oxygen cells, particularly cells developed by Union Carbide, Bacon, Great Britian and Justi, Germany; General Electric ion exchange membrane cell; hydrocarbon consuming fuel cells.

117. Zachmann, H. C.
Electric power for space vehicles. AEROSPACE
ENG 21: 68-9, 78, 82-6, May 1962.

Numerous charts are presented showing values of the various parameters involved in space-vehicle electric-power systems. Characteristics are given of fuel cells, thermoelectric cells, etc.

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