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Workshop on Materials Science and Physics of Non-Conventional Energy Sources

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"Fuel Cells R&D and Applications: World Programmes"

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These are preliminary lecture notes, intended only for distribution to participants.

A. Ascoli* - Seminar on:

Fuel Cell R&D and applications: world programmes.

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Summary

We examine the state-of-the-art throughout the world and briefly outline the European (and particularly the Italian) R&D programs in this field. The application prospects of this technology are also briefly reviewed.

SHORT AND MEDIUM-TERM PROSPECTS

The development of new SOFC geometries and new SPEFC polymeric membranes are followed with considerable attention. Possible changes in the relative rate of development of the different technologies may determine aim corrections in R&D programming.

The analysis of the integrated energy distribution in the territory should take into consideration the advantages offered by these devices for the direct conversion of energy distributed by a fluid fossile vector (natural gas) or recovery energy (agricultural or catabolic biogas).

The Japanese NEDO has recently organized a symposium in which over 350 specialists from all over the world have compared the fuel cell R&D state of the art in their respective countries. Shortly afterwards IEA (International Energy Agency) has held a restricted Workshop (which, by the way, was chaired by the speaker) whose object was the establishment of international collaboration channels on MCFC, SOFC and SPFC R&D. These initiatives clearly show the willingness of Japan to share the world leadership in this field with the United States as well as the efforts made by IEA to spread this new technology beyond the Japanese and American borders.

A recent financing granted by the American Department of Energy (DOE) to an important American industry for the development of cheaper PAFC manufacturing techniques and the ECC Cost Reduction program also referring to PACFs show a general tendency to revalue this "tried and tested" technology with respect to other more suggestive but "futurable" systems which still require further

MCFC

theoretical and experimental investigation of the elementary mechanisms which control material degradation. This does not seem to apply to the less developed SOFCs, seeing that Westinghouse has announced that a SOFC pilot factory started production in August 1988. It Italy, the opportuneness of R&D support measures in this field is under consideration.

As can be seen, the competition between the different fuel cell concepts is still very fluid. There is no doubt however that we are confronted with a new means of achieving a substantial energy saving and a considerable decrease in the environmental impact.

ITALIAN FUEL CELL R&D PROGRAMS

Research on fuel cells in Italy started in the seventies within the framework of the first national energy project (PFE I) of the National Council for Scientific Research (CNR). This preliminary attempt gave no results because it was impaired by a major underestimate of the size of the necessary efforts and resources.

The National Board for Electric Power (ENEL) set up the first Italian fuel cell know-how nucleus and entrusted CISE Tecnologie Innovative S.p.A. (a research and technological transfer company of Segrate, near Milan) with the task of implementing (from 1973 to 1981) a critical survey program with yearly updating on the world-wide state of the art of fuel cell technologies. ENEL subsequently commissioned an experimental program extending over the 1981-1983 period which enabled CISE to set up a laboratory for tests and inspections and maintenance of FC stacks and the training of skilled personnel. This laboratory was equipped with a 2.5 kW PAFC stack complete with a methyl alcohol reformer and dc-to-ac inverter.

At about the same time Ansaldo set up with an ENEA grant two small laboratories for the study of PAFC and MCFC components. In 1983 the CNR/TAE Institute of Messina, founded for the purpose of studying energy conversion and storage techniques and chemical processes, worked out with CISE's assistance an experimental program on fuel cells. In only a few years it obtained substantial results on the lineup and analysis of PAFC catalysts and components and on MCFC materials.

This initial stock of know-how was the foundation of the work carried out by the "Volta Project" Research Group consisting of a score of different organizations (industries, research centres, potential users, universities, etc.). This Research Group was chaired and coordinated by ENEA (the Italian National Nuclear and Alternative Energy Authority). The project proposed by the Research Group to ENEA in March 1984 consisted of three different activities: a demonstration program for PAFC generators, a development program of small portable PAFC generator units based on techniques specially devised for this purpose and an agreement with a foreign partner for the acquisition of the MCFC technology. The project contained proposals for the activities and role distribution in the first five-year period and a development forecast for the next two five-year periods. Agreements for the financing of the project and the distribution of financial charges connected with the first five-year period activities were drawn up in 1987. ENEA accepted liability for most of the financial charges involved.

In the meantime CISE, Ansaldo and CNR/TAE carried on other R&D activities with small grants provided by CNR and ENEA within the framework of the second national energy project PFE II and with their own financial resources. ENEA entrusted TESI s.r.l. with the task of carrying out a market research for the purpose of assessing the prospects of fuel cells entering the Italian market. The results of this market research were used for providing a guideline for the "Volta Project" options.

The main results of above activities were the production of PAFC components and laboratory monocells (Ansaldo and CNR/TAE), the design and construction of a methyl alcohol reformer (OTB Partecipazioni, now Tecnars of the Marelli-Acqua Holding Group), a feasibility study (ENEA and Ansaldo) for a 1 MW PAFC power station to be installed in the Milan Municipal Electric Power Corporation (AEM) Bovisa works. Fig. 6 shows the diagram[8] of this natural gas-fuelled water-cooled cogenerating unit scheduled to produce up to 1350 kW(e) and over 130 Mcal/h, with a net conversion efficiency of 41.1%.

AEM is responsible for the civil engineering, the connections to the natural gas network and the mains and the testing, management and electrical characterization of the station. Ansaldo, as chief contractor, is responsible for design and system engineering. IFC (International Fuel Cell Corporation) supplied two PAFC stacks of 675 kW each. ENEA is in charge of coordination, and provided most of the financing as well as the laboratory tests backing up the testing of the electrochemical section.

Photoelectron spectroscopy analysis techniques were set up by CISE Tecnologie Innovative S.p.A. and used for the characterization of new PAFC catalysts produced partly by CNR/TAE and partly by CISE.

Ansaldo and CISE have carried out a joint program for the survey of the operating features of CISE's 2.5 kW PAFC unit for the purpose of automating the control of small (1-5 kW) field generators which Ansaldo is making for the Ministry of Defence.

The same 2.5 kW PAFC unit belonging to CISE was fed with a gas mixture simulating the reformed biogas composition in order to show that PAFC stacks may be used as stand-alone generators for the supply of electric power to remote villages. The fact alone that 220,000 Indian villages are too far away from the national supply mains for a connection, at a reasonable cost gives a rough idea of the enormous market potential of this product, even if in Italy it cannot as yet compete with such traditional means as the gas turbine generator (which however produces much NO_x).

Satisfactory results were also obtained in the study on MCFC materials and components. CISE researchers investigated the dissolution processes which shorten the life of nickel oxide cathodes in contact with molten carbonates (usually a lithium and potassium carbonate eutectic). Vapor-phase deposition processes were studied with the view of devising new materials able to obviate this drawback and a half-cell was set up for the comparison of these materials under actual operating conditions. CNR/TAE performed endurance tests on an MCFC laboratory prototype and analyzed the gradual impairment of its performance under different fuelling and utilization conditions. An accurate (and very instructive) postmortem analysis was then performed on the MCFC materials and components.

Manufacturing and evaluation techniques of the different MCFC components (electrolyte, electrodes, separators, distributors and collectors) were also studied by Ansaldo, where a prototype fuel cell for testing components was set up. Ansaldo also investigated the operating conditions of an integrated coal gasifier-MCFC system. The purpose of the studies carried out by Ansaldo and ENEA was to build up a suitable stock of know-how in view of the intended acquisition of a consolidated MCFC technology.

Solid polymeric electrolyte fuel cells (SPEFC) have recently had a significant development chiefly due to the advance of membrane technology. In addition, the Italian electrochemical group DE NORA is in possession of advanced membrane cell techniques and know-how. This set of circumstances favoured the launching of a project whose medium-term objective is the development, in Italy, of a competitive SPEFC technology in terms of both performance and costs.

This project, which started off at the beginning of 1988, brought up the construction and testing of a 10 kW demonstration module with a power density of about 10 kW/m^3 and an estimated production cost of about 150,000 lire/kW. It also provides for a market research with a view of assessing the market potential of this technology, particularly as regards electric traction.

Main objectives are the procurement of high ionic-conductance membranes, the optimization of the noble-metal (now platinum, later its cheaper alloys) catalyst loading, improvement of the application technique of catalytic powders onto the membrane and tests on pilot fuel cells and stacks.

The results of the studies on catalysts and fuel cell engineering may have a favourable effect on the future development of phosphoric acid and molten carbonate fuel cells.

EUROPEAN FUEL CELL R&D PROGRAMS

The above Italian activities certainly had a share in arising the interest of the European Community Commission (ECC). First the ECC General Management for Research (DG XII) then the General Management for Energy (DG XVII) started to organize conferences, meetings and technical visits and launched a European fuel cell research, development and demonstration program within the framework of the ECC nonnuclear power R&D projects.

The main participants in this project which includes the development of a European MCFC technology, the European back-up of the Italian 1 MW demonstrative PAFC plant and the means of reducing PAFC manufacturing costs, are CISE, Ansaldo, CNR/TAE and AEM in Italy, ECN, Hogovens/ESTS and TNO in Holland, Johnson Matthey in the U.K. The European and Italian programs partly overlap each other: in many cases financing is provided jointly by ECC and ENEA (e.g. CISE's research on dissolution processes of MCFC cathodes). Sometimes ECC succeeded in preceding ENEA in providing financing thereby ensuring the survival of the know-how and the advantage of sharing options. The main benefit of this collaboration is the fact that decision making moves from a domestic to a European level. This may help to bridge the technological gap between European industries on one side and American and Japanese industries, on the other.

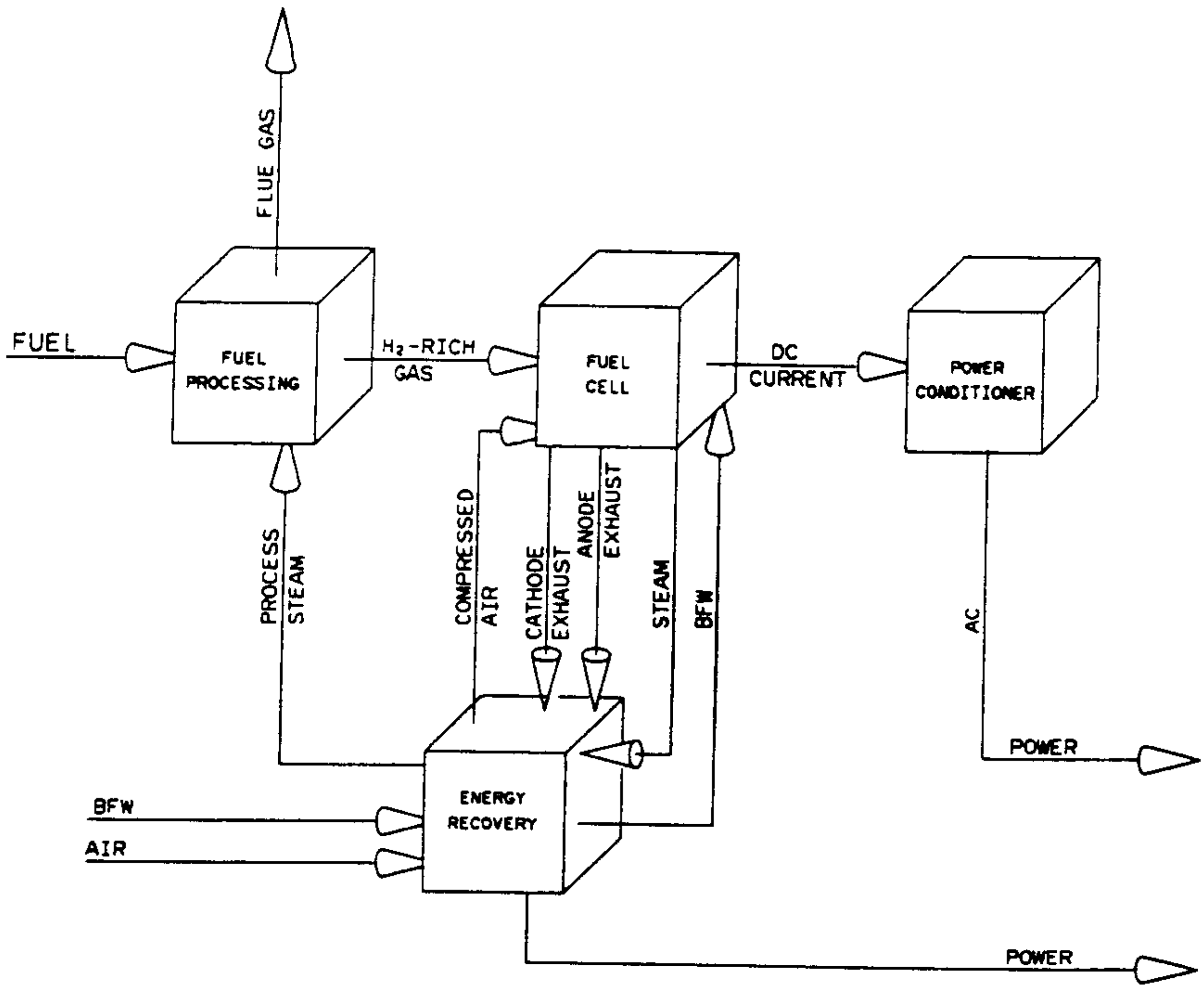
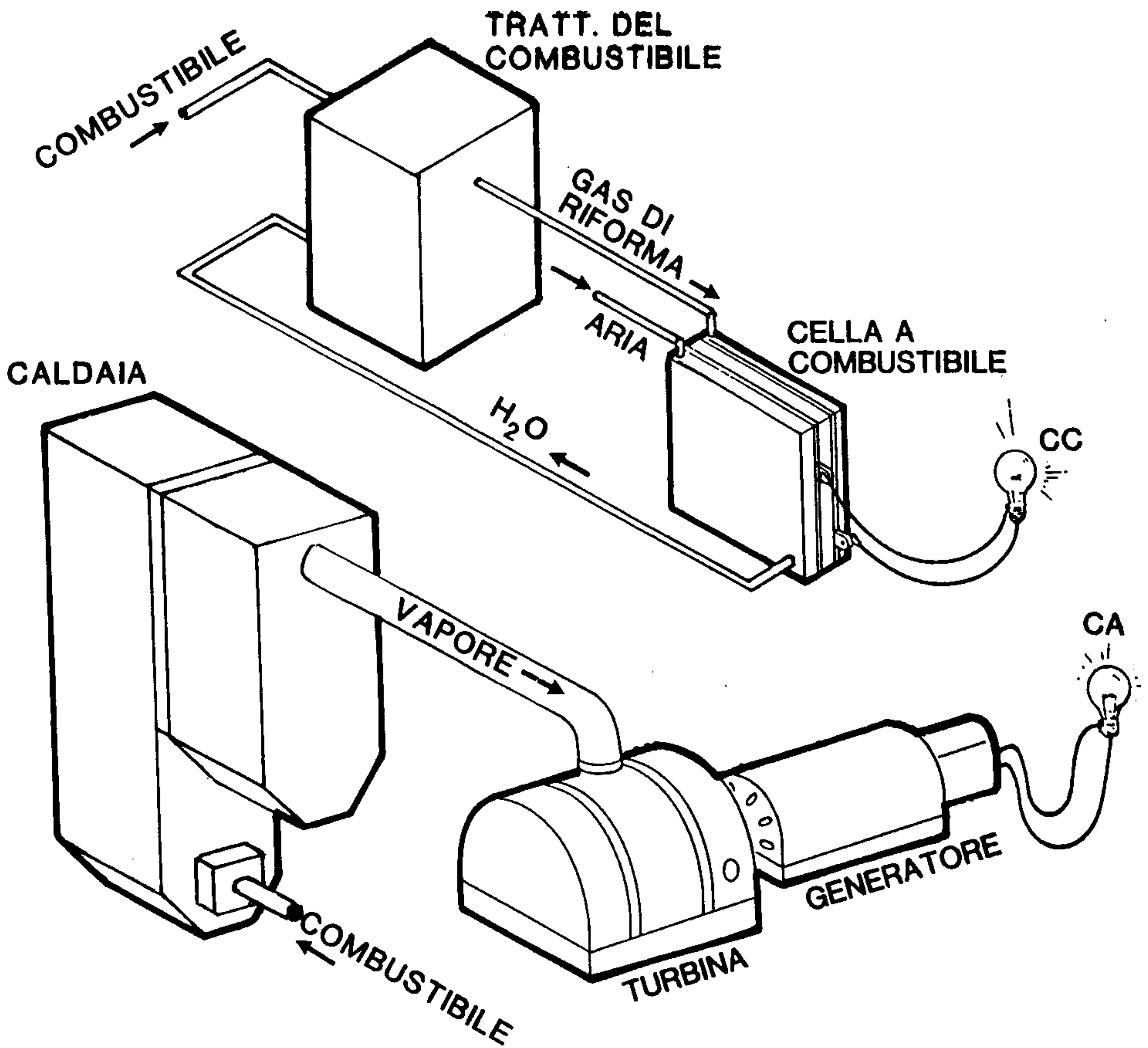


Figure 2-1. Schematic of Fuel Cell Power Plant System

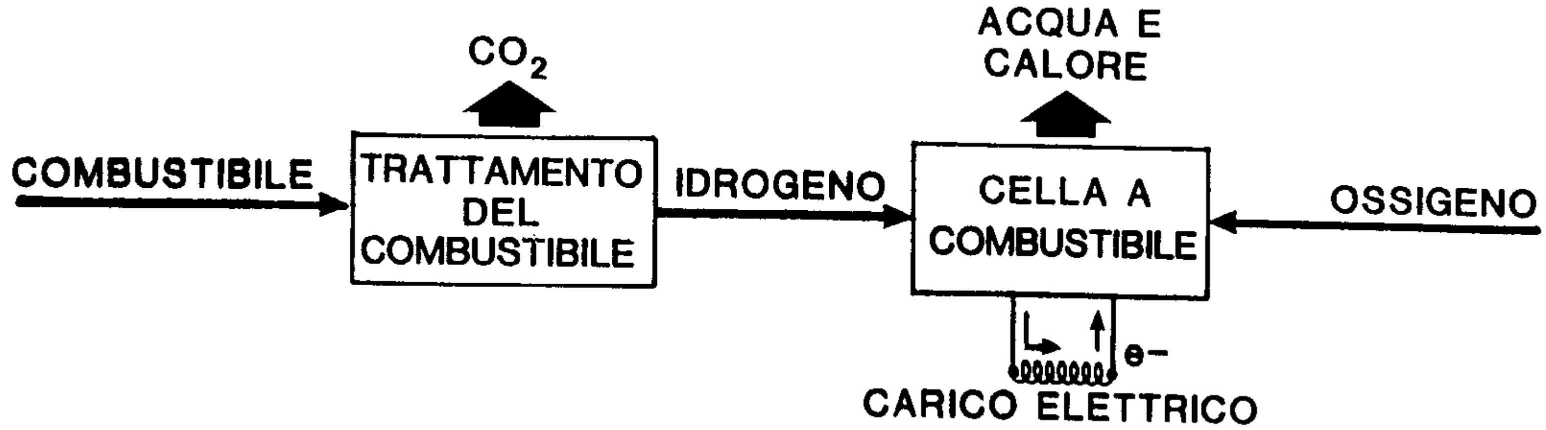


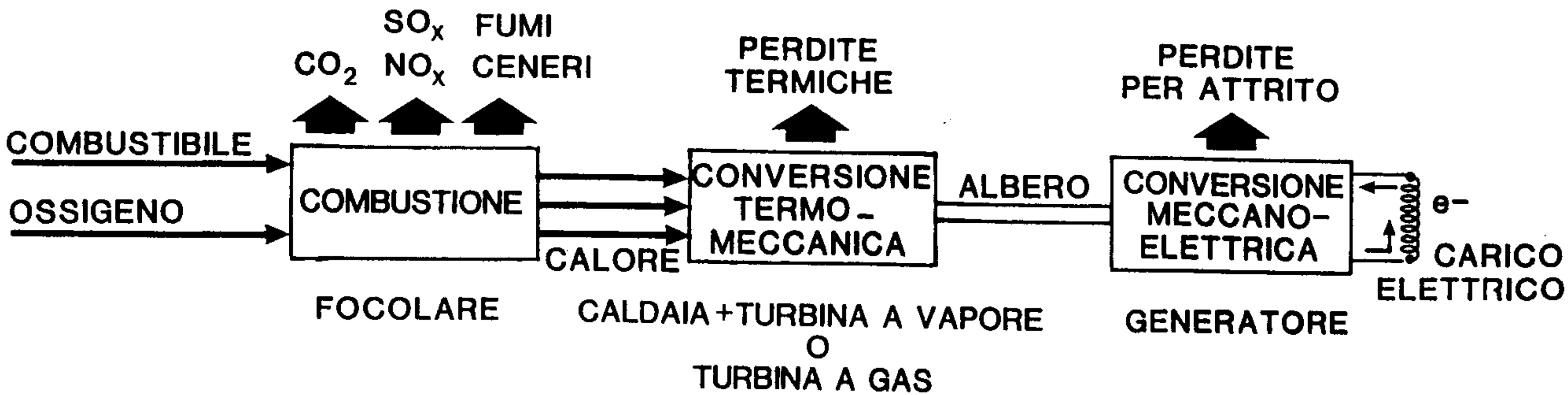
TRATT. DEL COMBUSTIBILE
COMBUSTIBILE
GAS DI RIFORMA
ARIA
CELLA A COMBUSTIBILE
CC
H_2O
CALDAIA
VAPORE
CA
GENERATORE
TURBINA
COMBUSTIBILE

10

(3)

Confronto fra generatori a celle a combustibile e generatori termoelettrici tradizionali





1.2. SISTEMATICA DELLE FILIERE DI PAC DI INTERESSE INDUSTRIALE: FILIERE A BASSA TEMPERATURA (t.a. - 200 °C)

Tipo	Elettrolita	T (°C)	Ione trasportatore di carica	Princip. combust. utilizz.	Comburente	Vantaggi	Limitazioni	Disponibilità commerciale
polimerico (PEFC)	membrana polimerica contenente un acido	t.a.-80	H^+	H_2 anche se diluito in CO_2	ossigeno o aria	robustezza; lunga autonomia di manutenzione; tollera CO_2, perciò può usare aria come comburente	non tollera tracce di CO, perciò deve usare H_2 puro come combustibile, o voluminosi purificatori	1,5-18 kW a catalogo
alcalino (AFC)	KOH in soluzione acquosa	t.a.-90	OH^-	H_2 puro	O_2 puro	robustezza; lungamente provata	non tollera tracce nè di CO nè di CO_2, perciò deve usare H_2 puro come combustibile e O_2 puro come comburente	3 kW a catalogo, altre taglie su misura
acido (PAFC)	H_3PO_4 concentrato	185-200	H^+	metanolo, idrocarburi leggeri, biogas	aria	lungamente provata; grande tolleranza al CO e alla CO_2, perciò grande versatilità nell'uso di combustibili commerciali (con stadio di riforma) e di aria come comburente	costo (in piccole taglie); relativa delicatezza meccanica; relativa sensibilità alle variazioni di umidità relativa; relative esigenze di manutenzione periodica	7 kW e 25 kW a catalogo, 1,3 e 5 kW su misura

1.2. **SISTEMATICA DELLE FILIERE DI PAC DI INTERESSE INDUSTRIALE (segue): FILIERE AD ALTA TEMPERATURA (600 - 1050 °C)**

Tipo	Elettrolita	T (°C)	Ione trasportatore di carica	Princip. combust. utilizz.	Comburente	Vantaggi	Limitazioni	Disponibilità commerciale
carbonati fusi (MCFC)	eutettico $(Li,K)CO_3$	600-650	CO_3^{--}	gas di carbone, metano	aria	grandissima tolleranza a tutte le principali impurezze, perciò enorme versatilità nella scelta di combustibili anche di basso costo, con stadi di riforma ridotti, e di aria con qualsiasi grado di umidità come comburente; alto rendimento; calore di scarto "pregiato"	breve durata (provate solo per 5000 ore); instabilità dei materiali (a lungo andare, i catodi tendono a sciogliersi nell'elettrolita)	prototipi di laboratorio da 1 kW, già collaudati; prototipi di laboratorio da 10 kW in corso di collaudo
ossidi solidi (SOFC)	ZrO_2 stabilizzata col 10% in peso di Y_2O_3 o col 15% in peso di CaO	850-1050	O^{--}	gas di carbone, metano	aria	versatilità nella scelta di combustibile; buon rendimento; calore di scarto molto pregiato; economicità (limitata però alla prospettiva di impianti di grossa taglia)	scarsa esperienza di collaudo; fragilità agli shock termici	prototipi commerciali da 3 kW collaudati però con alimentazione a idrogeno puro

PAFC

METHODES DE REFRIGERATION

AIR (ERC, Ⓦ, Sanyo)

EAU (UTC → IFC, Fuji, Mitsubishi)

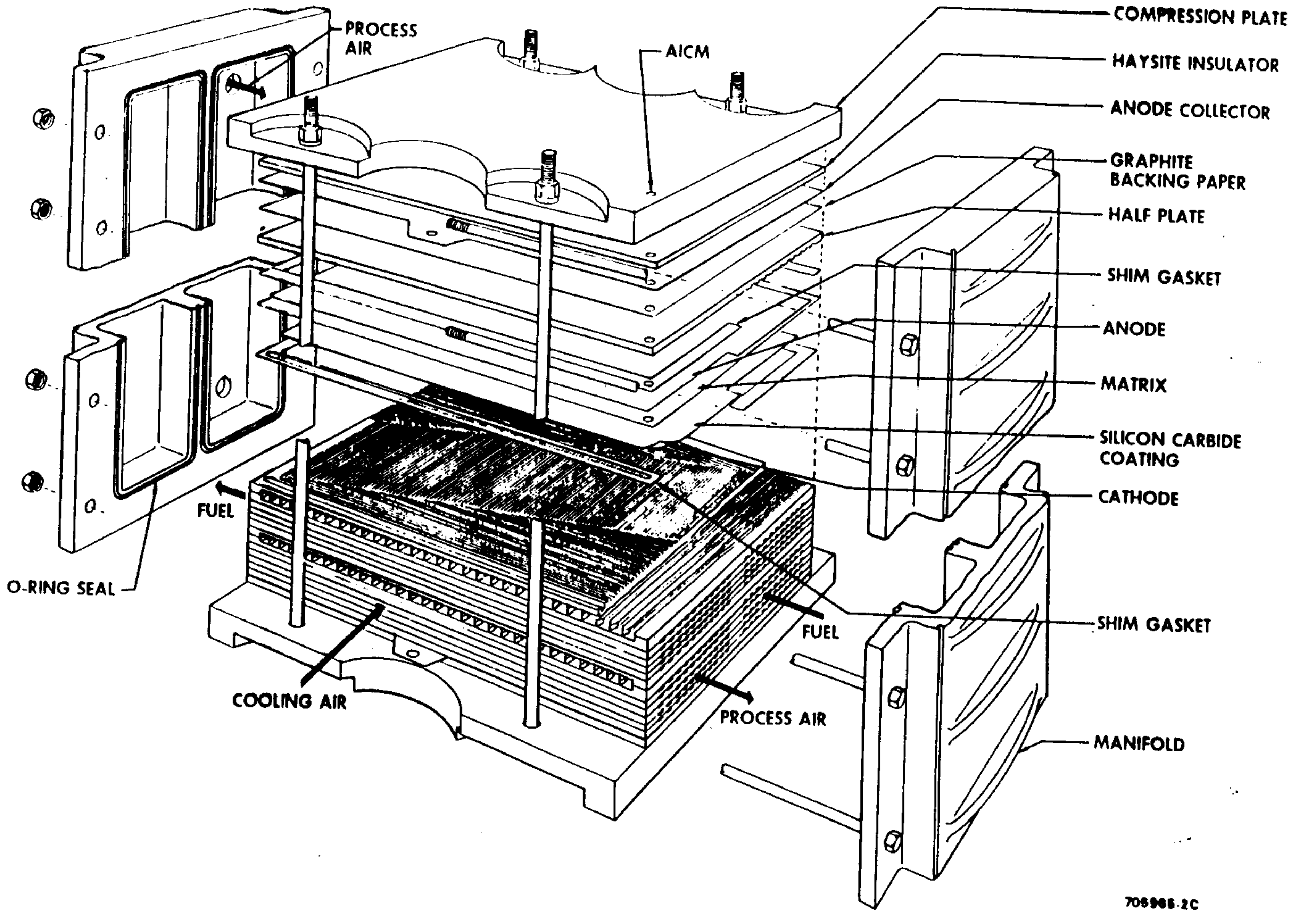
Huile diatermane (Engelhard, Fuji)

SCHEMAS DE REFRIGERATION

EAU : plaques refroidissantes intercalées aux plaques bipolaires, amènant des tuyots d'eau deionisée (en circuit fermé) tension!

AIR : voir transparences suivantes

WESTINGHOUSE PAFC STACK Z-BI-POLAR & TREE COOLING PLATES



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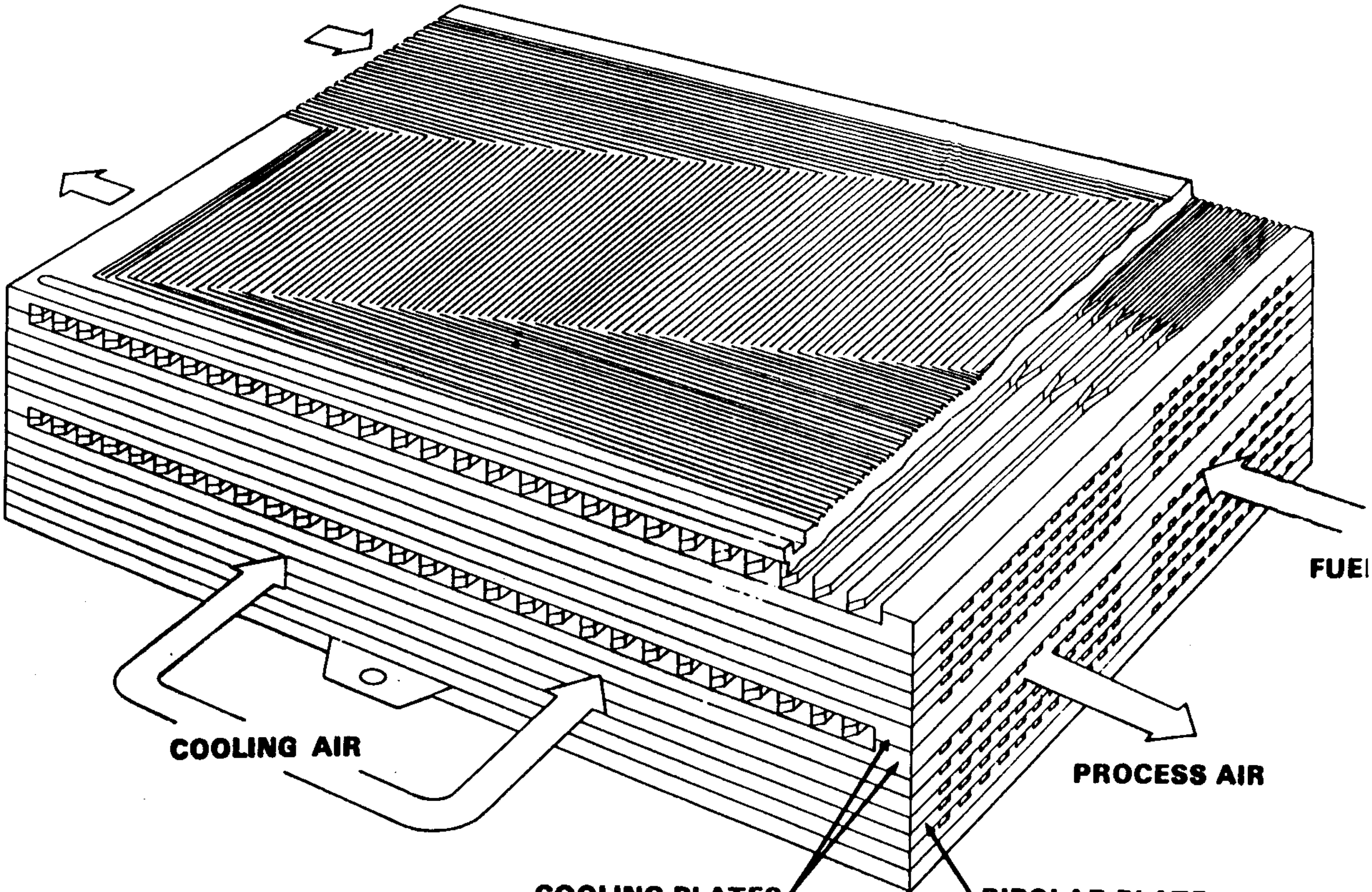
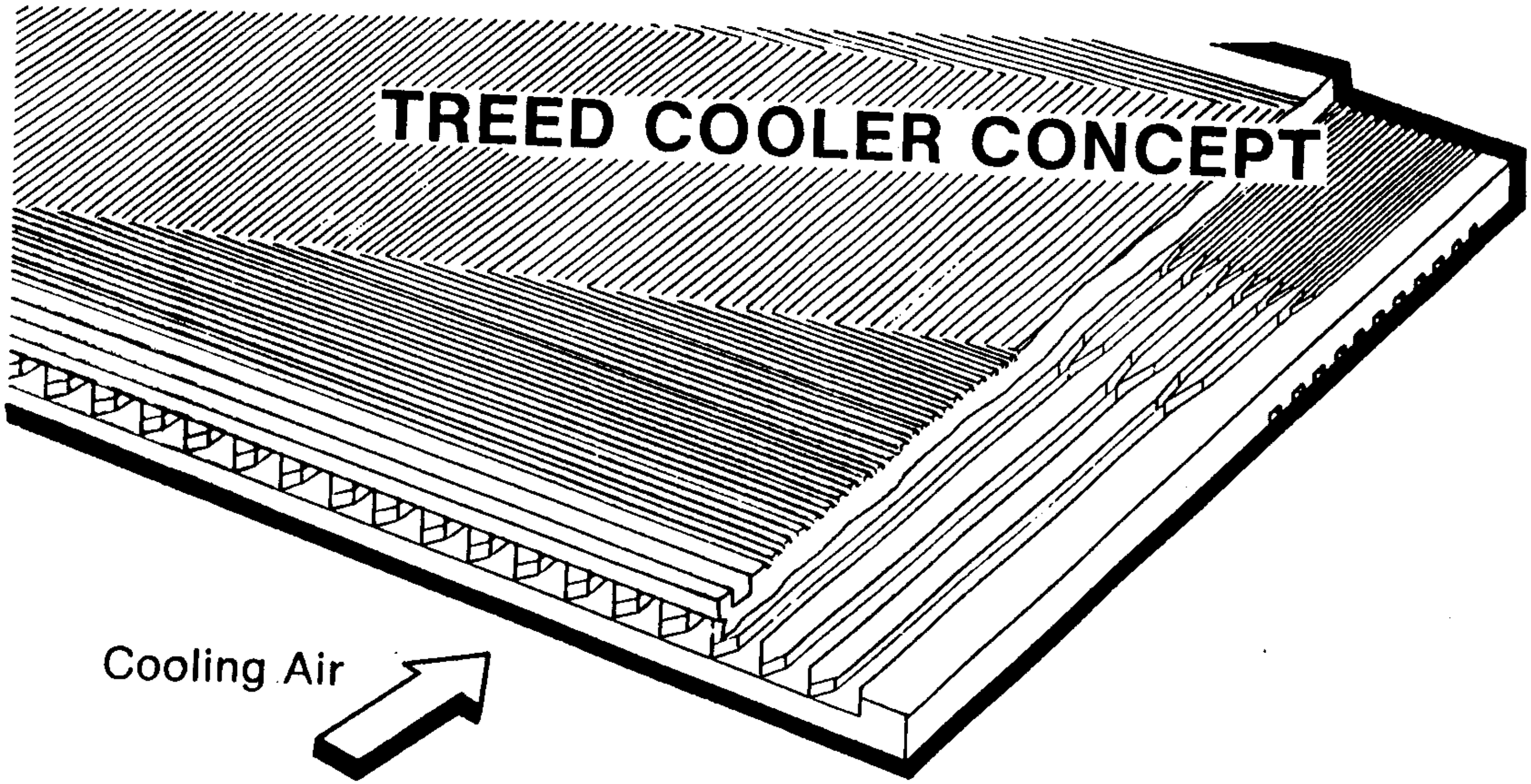
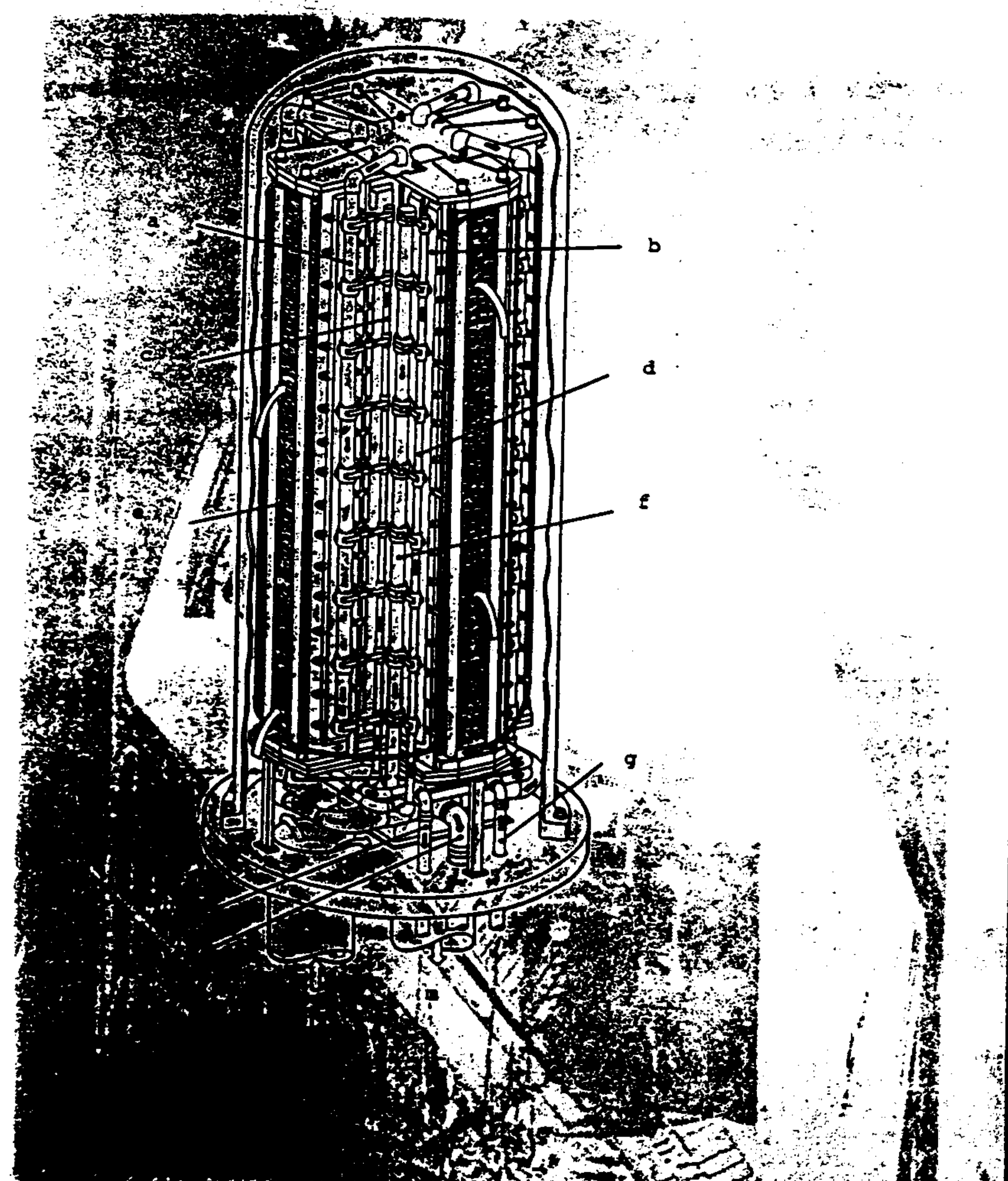
BASELINE FUEL CELL STACK



TREED COOLER CONCEPT



- Increase surface area as cooling gas temperature rises
- Variable pitch
  — Compensates for changes in current density



[illegible] PAFC Westinghouse da 375 kW autotrasportabile [illegible] aria di processo (comburente); b) distributore; [illegible] (d) immissione combustibile; e) pile di [illegible] ritorno dell'aria di processo (comburente) [illegible] ritorno del combustibile; [illegible] di processo (comburente); [illegible] immissione aria refri- [illegible]

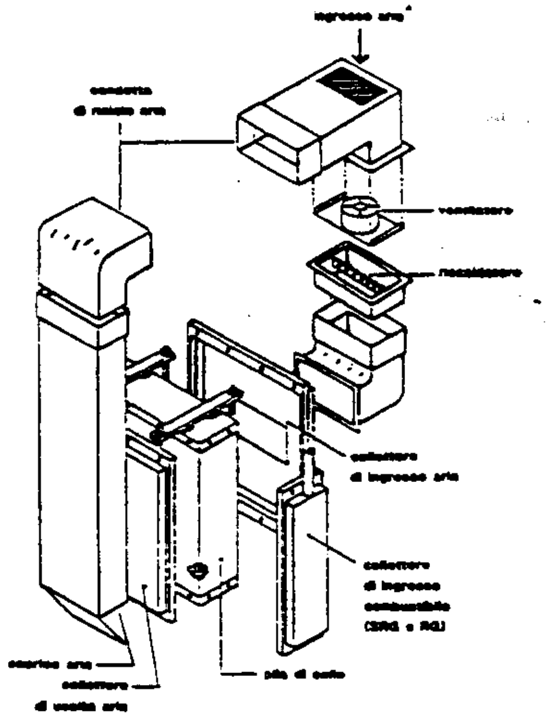
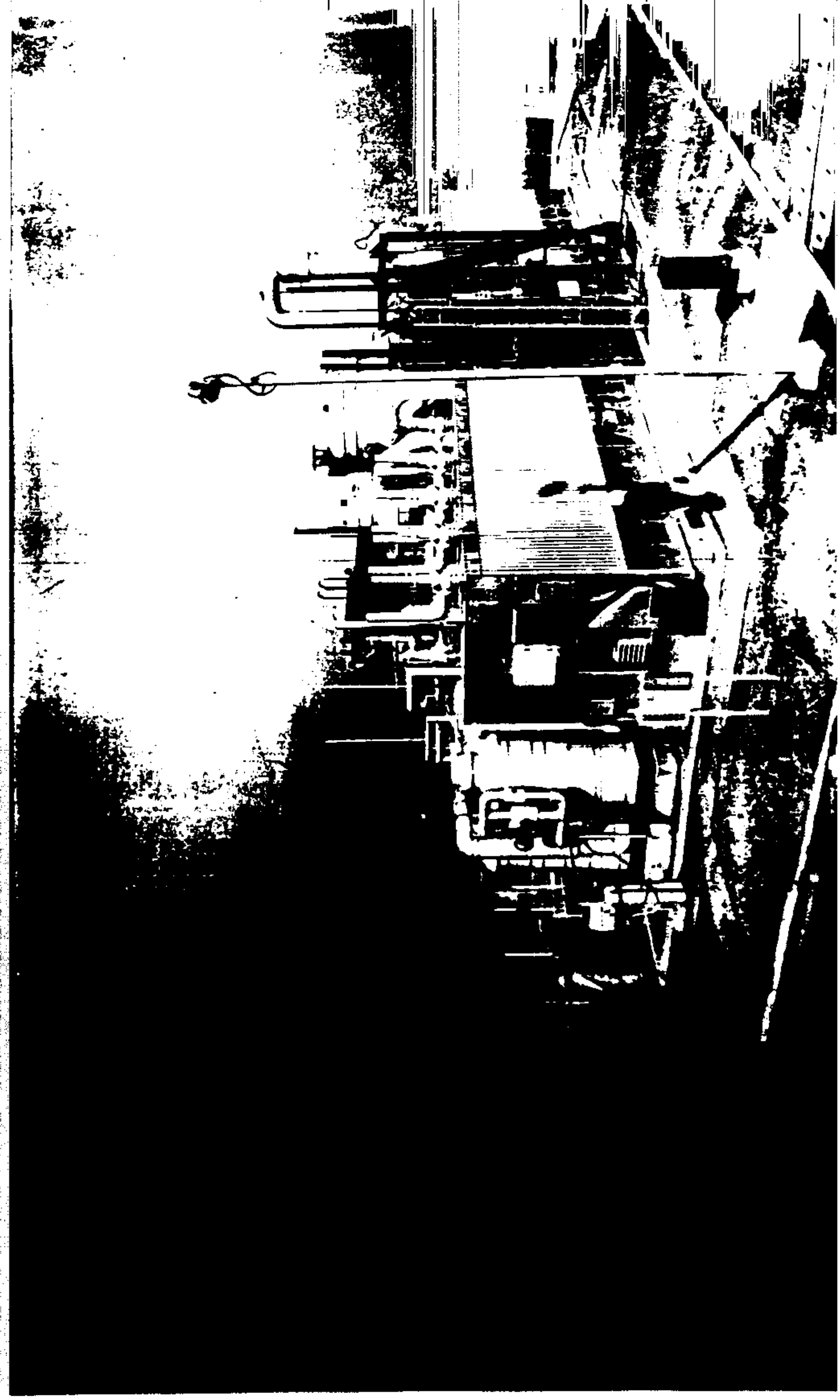
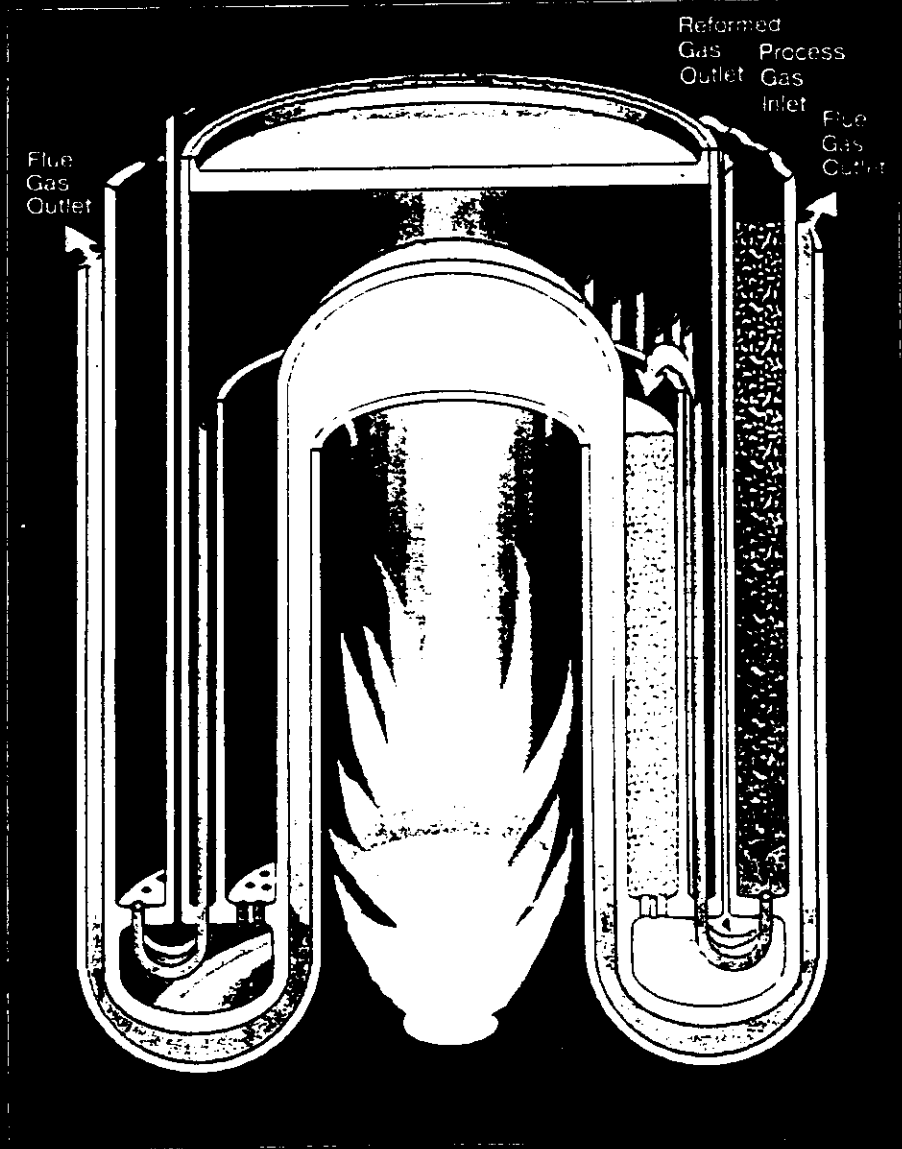
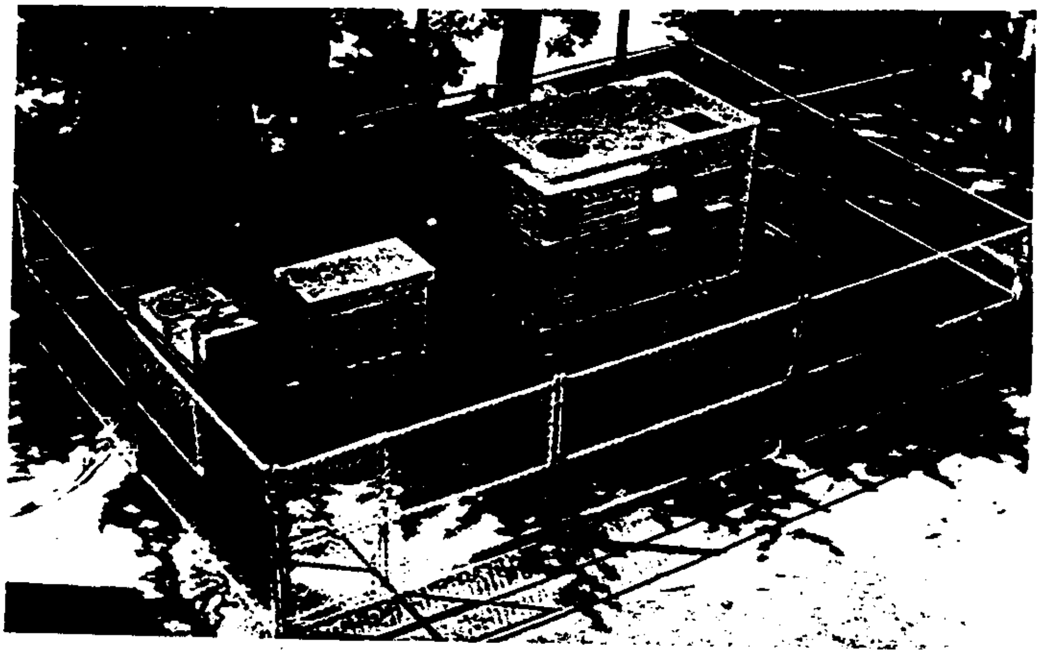


fig. 4-"Vista esplosa" della pila di celle:
RG = gas di riforma, SRG = gas di riforma simulato.

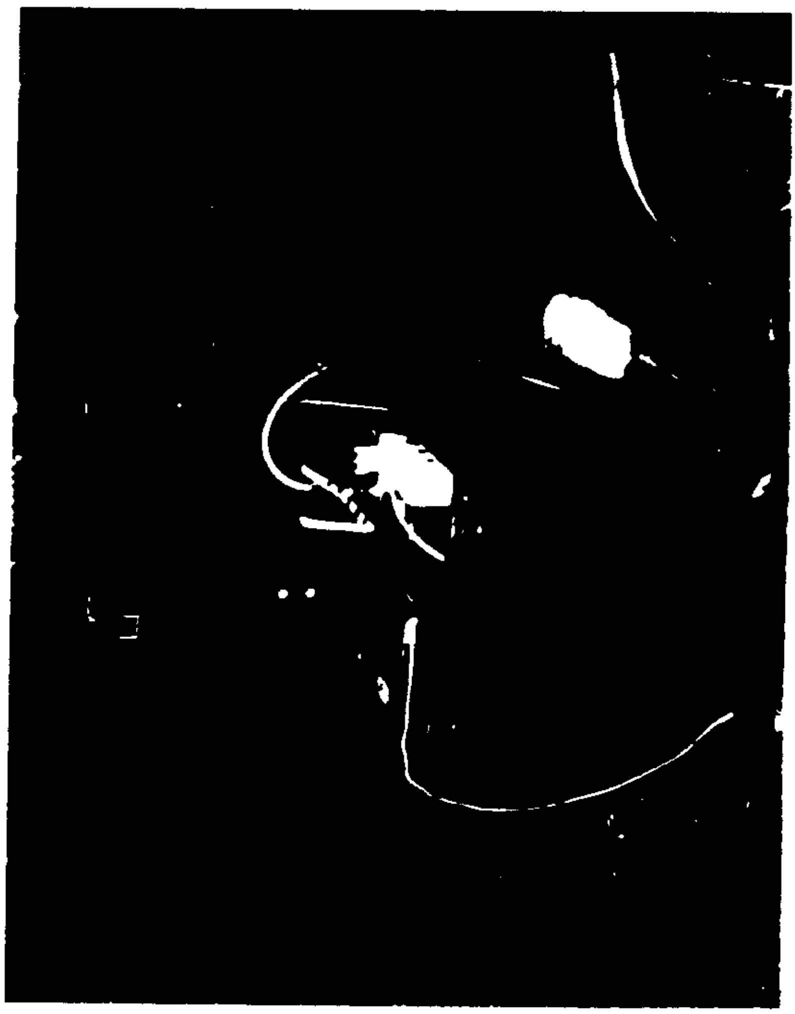


Haldor Topsoe/EPRI Heat Exchange Reforming Technology





40kW Fuel Cell Installation at Vernon, Connecticut



$$CH_4 + H_2O \rightleftharpoons CO + 3H_2 \quad \text{(endothermic)} \; , \tag{4-1}$$

$$CO + H_2O \rightleftharpoons CO_2 + H_2 \quad \text{(exothermic)} \; . \tag{4-2}$$