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PHOTOVOLTAIC REFRIGERATION APPLICATION: ASSESSMENT OF THE NEAR-TERM MARKET

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E-9476

SUMMARY

A preliminary assessment of the near-term market for photovoltaic refrigeration applications (both foreign and domestic) is presented. This assessment was performed as part of the Tests and Applications Project being conducted by NASA-LeRC as part of the Department of Energy's (DOE) National Photovoltaic Program. One of the objectives of that Program is to stimulate the demand for photovoltaic power systems so that appropriate markets will be developed in concert with the increasing photovoltaic production capacity also being supported by DOE. The refrigeration application represents a possible market for photovolatics; hence a brief survey of potential applications was conducted. Both refrigerators and refrigeration systems are considered in the assessment although the primary emphasis is on refrigerators of 9 cu ft or less. Three user sectors are examined: (1) government, (2) commercial/institutional, and (3) general public. The two areas identified with greatest market potential are refrigerators for (1) recreational vehicles in the United States and (2) for preservation of perishable medicines and food stuffs in remote areas, both foreign and domestic.

INTRODUCTION

A major goal of the Department of Energy (DOE) National Photovoltaic Program is to raise solar cell array production from the present 700 kW/year to 500 MW/year by 1986; a corollary goal is to

stimulate the demand of potential users to absorb this production rate. In order to achieve these near-term goals, various markets for which photovoltaics can provide a viable power source need to be penetrated. For the most part, however, these markets are latent. Many potential users are unaware or unsure of the benefits and the readiness of solar cell power for their applications. Unless such users, and the manufacturers serving such users, are fully cognizant of the solar electric option, their entry into the solar cell market may be greatly delayed.

Due to the complexity of getting photovoltaic systems into the marketplace, the government has an important role to fill. This is to share the risk of new venture development and to facilitate the transfer of technology to the users and manufacturers. In this endeavor it is a major objective of the Tests and Applications Project, managed by the NASA, Lewis Research Center (LeRC) for the DOE National Photovoltaic Program, to identify and cooperatively test, with selected users, applications judged to be cost-effective in the near-term. These near-term applications experiments are structured to engage the active participation and interest of the private sector; they are intended to lead to commercial development and marketing of photovoltaic-powered products. It is also expected that these experiments will provide a flow of application-related information to the technical community, especially the DOE Photovoltaic Program participants and contractors.

This report provides a preliminary market assessment of the photovoltaic refrigeration application category. The refrigeration category was originally identified because (1) photovoltaics appeared cost-effective relative to alternative sources for near-term refrigeration applications in remote areas, (2) users have indicated interest in cost-sharing experiments, and (3) refrigeration experiments could assist in promoting a general awareness of photovoltaics as a power source for other potential applications.

DEFINITIONS AND TERMINOLOGY

Refrigeration Processes

The three types of cooling processes that are currently used are vapor-compression, absorption, and Peltier (or thermoelectric).

The vapor-compression and Peltier-type refrigerators require electrical power for their operation. Absorption refrigerators require heat power, supplied by burning propane or natural gas or by electrical resistance heating. The coefficient of performance (COP), defined as the ratio of the heat energy extracted to the work (electrical or thermal) supplied to operate the cycle is used by refrigeration engineers to measure the efficiency of the cooling process. The COP of vapor-compression-type refrigerators is about 2 compared to about 0.5 for Peltier and for absorption-type refrigerators. In addition, the performance of Peltier-type units often degrades due to changes in thermoelectric material properties with time. As a result, vapor-compression refrigeration, because of its higher cooling efficiency, requires only about one-fourth the size of photovolatic power system to provide comparable refrigeration relative to the other two types.

Refrigerators

Refrigerators are defined to be single integrated units which provide low-temperature storage for medicines, foodstuffs, or other perishable items.

Refrigeration Systems

Refrigeration systems are systems which provide cooling for commercial applications such as mobile milk coolers, reefer cars and trucks, field chilling of harvested crops, and trout farming.

User Sectors And Applications

Three user sectors have been identified for consideration: (1) government, (2) commercial/institutional, and (3) general public. Within the government sector, possible user agencies are the Department of the Interior (Bureau of Indian Affairs, National Park Service), Department of Agriculture (National Forest Service) and the Department of Health, Education and Welfare (Indian Health Service and Public Health Service). Within the commercial/institutional sector would be reefer cars, remote hunting and fishing lodges and camps, and medical field services. Within the public sector would be camping and recreational vehicle (RV) refrigerators and remote or cabin household refrigerators.

MARKET ASSESSMENT

Preliminary Market Information

A brief market survey was made to obtain preliminary estimates of markets and the potential of photovoltaic refrigeration applications. The basic refrigeration market is quite broad, ranging from 0.2 cu ft refrigerators to large commercial refrigeration systems. Because it is likely that the first cost-effective application will involve small refrigerators in remote areas, the preliminary market assessment concentrated on refrigerators of 9 cu ft and less. Nevertheless, some potential near-term applications also exist for larger size refrigerators and refrigeration systems based on the limited information obtained during this survey.

Present Market Size

For small, that is, 9 cu ft and less, vapor-compression and absorption refrigerators, it was found that the total world-wide market in 1976 was approximately 10 million units. The breakdown for domestic United States and for foreign sales is:

	Vapor-compression	Absorption	Totals
United States	1.5×10^5	$4.5\text{-}5.0\times10^5$	$6\text{-}6.5\times10^5$
Foreign	9×10^6	$0.4\text{-}0.5\times10^6$	$9.4\text{-}9.5\times10^6$
Totals	9.15×10^6	$0.85\text{-}1.0\times10^6$	$10.0\text{-}10.2\times10^6$

The vast majority of the refrigerators were manufactured overseas.

In the domestic market, the majority of the vapor-compression refrigerators were used as supplemental refrigerator units in residences (e.g., home bars), or in college dormitories and the like. The average size was 4-5 cu ft. With respect to absorption refrigerators, about 90 percent of the units sold in the United States in 1976 were for use in recreational vehicles (RVs); the remaining 10 percent were for houseboats, camping and recreational sites, and so on. The size distribution of the absorption refrigerators sold was:

Size (cu ft)	Percent of market
7 and 9	35
6	40
4	10
3	10
2	5

The 6-9 cu ft sizes comprise 75 percent of the market, and are the most commonly used in the RV industry.

No market size data could be obtained during this preliminary assessment for thermoelectric coolers. The size of the units in use range from 0.2 to 2 cu ft.

User/Manufacturer Contacts

A number of telephone contacts were made with federal and international agencies, manufacturers, trade associations and trade journals to delineate possible user categories and potential refrigera-

tion applications. A list of these contacts is presented in Appendix A. As was indicated earlier, both U.S. and foreign markets exist. Within these broad categories, there are three general user sectors: government, commercial/institutional and general public. Government contacts were at the federal level; commercial/institutional contacts included refrigeration manufacturers, RV manufacturers and trade associations. Another user sector, not cited as such, is agricultural. This sector overlaps both commercial/institutional and a portion of the general public.

In addition to the telephone contacts, 74 inquiries were received as a result of press releases (June-December 1976) on the three photovoltaic refrigerator experiments initiated by LeRC as part of the DOE Tests and Applications Project. Appendix B presents a summary of the types of requests received and their geographical distribution. This information suggests that a considerable interest exists for a marketable solar-powered refrigerator, particularly in foreign countries.

Potential Domestic Markets

Government. - A number of potential user agencies within the government sector were contacted regarding the possible need for small photovoltaic-powered refrigerators. For some agencies, such as the National Park Service, Forest Service and Indian Health Service, a multiplicity of contacts (i.e., individual states, parks, tribes, etc.) were required to obtain the needed information on market potential. Many representatives exhibited substantial interest and enthusiasm when informed of the photovoltaic option. These sources felt that photovoltaic refrigeration would be especially attractive when the projected lower costs, expected in the early to mid-80s, are realized. A variety of refrigeration applications were identified in the government sector.

One such application is to provide refrigeration for medicines at remote locations. A photovoltaic-powered refrigerator experiment

of this type has been in operation since July 1978 at the Papago Indian Village of Sil Nakya as part of the DOE/LeRC Tests and Applications Project (see fig. 1). This system, installed by NASA-LeRC personnel, uses a 330-watt (peak) array with storage batteries to power a 4 cu ft RV type refrigerator. Sil Nakya, 60 miles northwest of Tucson, is home to about 25 people and does not have electrical service. Although the traditional Papago diet does not depend on foods needing refrigeration, several of the residents of Sil Nakya require medicines which must be kept at or below room temperature to preserve effectiveness. Until now these people had to travel 64 miles to and from the Public Health Service Hospital at Sells, Arizona for their medications. The photovoltaic powered refrigerator will not only provide for better medical services, but will also allow perishable foods to be kept on hand thereby improving the diet of the whole village.

Based on the Sil Nakya results, the Indian Health Service indicates that on-site refrigeration of medicines at remote villages may be preferable to both patient and doctor and more cost-effective compared to the existing method of transporting individuals from the villages to medical centers for medication.

A number of other Indian reservations have situations similar to the Sil Nakya village. For example, there are about 150,000 Navahos that are sparsely located on approximately 24 million acres. Of these, about 40,000 are in areas where there is no utility power available. In addition, there are about 5,000 Hopi Indians without electricity. The full extent of this potential market is yet to be determined.

Another application is to provide refrigeration for foodstuffs at remote backcountry camps and fire lookout towers for the Forest Service and National Park Service. For example, Region 1 (Montana, northern Idaho, and part of North Dakota) of the Forest Service has 114 lookout towers of which few have commercial power. Two such applications currently being sponsored by the DOE/NASA-LeRC Tests and Applications Project are shown in figure 2. For this application, 300 watt (peak) photovoltaic arrays were architecturally integrated into two newly designed U.S. Forest Service forest lookout towers

located on Antelope Peak in the Lassen National Forest and Pilot Peak in the Plumas National Forest (both in northern California). The photovoltaic array provides power for a refrigerator, lights, water pump and Forest Service two-way radio. This system not only makes living conditions more pleasant for lookout personnel, but also saves the Forest Service the considerable time, trouble and expense of procuring, storing and transporting fuels to these remote locations for other types of electrical generators. There are several wilderness stations as well. At some of these sites, fuel must be flown in for refrigeration and other purposes. The Forest Service is estimated to have a total of 1500 towers, camps, etc. nationwide. A similar situation exists for the National Park Service. For example, the North Atlantic Region, covering eight states, has 163 fire towers. Of these, 92 are without utility power. The total number of Forest Service and Park Service remote towers and camps that may be suitable for photovoltaic-powered refrigerators is not known. Further study is needed to define the market in this area. It should be noted that the Director of the National Park Service has issued a position paper which calls for the serious consideration of solar power for all new installations. A photovoltaic-powered refrigerator experiment, shown in figure 3, was conducted in 1976 at Isle Royale National Park, Michigan as part of the DOE/NASA-LeRC Tests and Applications Project. For this application, a 200 watt array was used to power a portable refrigerator at a trail construction camp. Isle Royale National Park is a wilderness island in northern Lake Superior. Electrical power, generated on site, is available only at the Park Headquarters, the visitor center, and the lodge area. Each year the island is visited by many thousands of visitors, 90 percent of whom hike and camp in the back country. Wilderness trails are constructed and maintained by trail crews working out of camps like the one where the refrigerator was located. The remoteness of the camps allows for food resupply only once a week. With refrigeration, the crew was able to enjoy a more varied and nutritious diet, including perishable foods.

Commercial/Institutional. - Contacts with elements of this sector indicate a number of potential refrigeration applications which warrant further investigation. As was pointed out earlier, a large market exists at present for small refrigerators for RVs. Refrigerator manufacturers, RV manufacturers, trade magazines and trade associations surveyed indicated considerable interest in photovoltaic-powered refrigerators.

The upper end of the market for RVs, that is, RVs costing more than $30,000, is inelastic in that purchasers readily spend money for various high-dollar options. Additionally, the psychology of the RV buyers seems to be such that they are interested in energy conservation-oriented options due to the poor fuel economy of the vehicle itself.

In relation to the lower priced RVs one source contacted felt that a photovoltaic array cost of $1-2/watt is needed for competitiveness with existing systems. This price range is within the DOE goals for the near-term (early 1980s). Hence, a good possibility exists for photovolatic-powered vapor-compression units to penetrate the absorption refrigerator market in RVs.

A potential market for 1-10 kW peak photovoltaic-powered refrigeration systems may also exist for applications such as foodstuff refrigeration at remote fishing and hunting lodges, field chilling of harvested crops and trout farming. Further investigation is needed to adequately assess these applications.

General public. - Potential applications in this sector have already been cited earlier in the commercial/institutional sector. For example, individuals owning remote cabins or recreation sites are expected to be interested in photovolatic-powered refrigerators for foodstuffs. Interest in photovoltaic-powered refrigerators on the part of RV manufacturers is, of course, dependent on their estimate of the buying public's interest in such an option. A market may also exist to replace existing absorption units in RVs with photovoltaic-powered vapor-compression units. Due to the ready availability of utility power at most residences, no market potential is seen for photovoltaic refrigerators as a primary or secondary home refrig-

eration unit in the United States. There is probably a market for home refrigerators in remote villages, for example, Indian reservations.

Potential Foreign (Non-U.S.) Markets

Contacts were made with various individuals in international organizations, such as the United Nations and the World Health Organization, and elsewhere regarding possible photovoltaic refrigeration applications outside the United States. Additionally, as a result of press releases (June-December 1976) on the three refrigerator experiments initiated by LeRC as part of the DOE Tests and Application Project 56 inquiries were received from individuals and companies outside the U.S. Inquires were for information, for commercial availability and price, and for distribution and manufacturing rights. Strong interest was expressed in the potential for refrigeration applications. Additional effort is needed to quantify the market size for the foreign sector.

As a result of these contacts, a significant market is thought to exist for refrigeration of medicines and vaccines (rabies, snakebite, etc.) at remote medical and veterinary posts in developing countries and elsewhere. Hospitals and schools are also thought to be a potential market.

Another large potential market is in the preservation of foodstuffs, that is, in providing primary food refrigeration in dwellings where no utility power is readily available. One example cited is the Sultanate of Oman, where the staple diet is meat and milk. It is felt that a market would exist in Oman if there were a cost reduction of 3 or 4 in the current photovoltaic array price. Community refrigerated "warehouses" in remote agricultural areas are another possibility, as are portable refrigerated trailers for use in cooling milk in the field.

CONCLUDING REMARKS

On the basis of the survey performed, the two areas with greatest market potential appear to be refrigerators for RVs in the United States and for preservation of perishable medicines and foodstuffs in areas of the world where utility power is not available and/or alternate power sources cannot compete with photovoltaics on a cost-effectiveness basis.

These conclusions are based on limited information. Further in-depth investigation is necessary in order to quantify the photovoltaic refrigeration application potential.

APPENDIX A

A LISTING OF GOVERNMENT AND COMMERCIAL CONTACTS MADE

Government

Baker, J. O.
Aviation & Fire Service
National Forest Service
Roselyn, VA

Bosken, Sam
U.S. AID
Department of State
Washington, DC 20523

Bowman, Chuck
Office of Environmental Health
HEW/Indian Health Service
Albuquerque, NM

Mr. Burbank
Fire Management Engineering
USDA/Forest Service
Roselyn, VA

Mr. Cregger
Ass't Executive Director
C.A.R.E.
New York, NY

Esquivel, George
Office of Environmental Health
HEW/Indian Health Service
Tucson, AZ

Harges, Howard
Chief, Professional Support Division
DOI/National Park Service
Denver Service Center
Denver, CO

Howlett, Mike
Director of Engineering
USDA/Forest Service
Roselyn, VA

King, John
Isle Royale National Park
DOI/National Park Service
Houghton, MI

King, Bill
DOI/Bureau of Indian Affairs
Washington, DC

Lovejoy, Derrick
United Nations Development Program
New York, NY

Meyers, Don
Office of Environmental Health
HEW/Indian Health Services
Phoenix, AZ

Morton, William
Engineering
USDA/Forest Service
Washington, DC

Pewitt, Bruce
Region 1 Forest Engineer
USDA/Forest Service
Grangeville, ID

Reiss, Richard
Contacting & Property Management
DOI/National Park Service
Washington, DC

Reyer, Eldon
Legislation
DOI/National Park Service
Washington, DC

Dr. Stillis
Vector Biology and Control
World Health Organization
Geneva, Switzerland

Thomson, Paul
Agricultural Research Service, USDA
Beltsville, MD

Worthington, Richard
Office of Director of National Forest Mgmt.
USDA/Forest Service
Washington, DC

Wromble, Richard
Indian Health Service
HEW/Public Health Service
Washington, DC

Commercial

Herron, Julia
Manufactured Housing Inst.
Chantilly, VA

Ignatius, Ron
M-7 Corp.
Arlington Hts., IL

Knouff, Rolly
Research Director
Hoover Company
North Canton, OH

Langmack, Robert
Solar Engineering
Elixir Industries
Gardena, CA

Lavine, Milton
Melcor Thermoelectrics
Trenton, NJ

Lorch, Glen
Kari Kold Company
Grand Rapids, MI

McDonald, Philip
Custom Coach
Columbus, OH

Milnark, Sam
Assoc. Publisher
Air Condition & Refrigeration
Business
Cleveland, OH

Piaggi, Ezio
Piaggi International
Pacific Palisades, CA

Penho, Patrick
Norcold
Sidney, OH

Sendynsky, Chester
Glenco Refrigerator Company
and Star Metal
Philadelphia, PA

Smith, Frank
Borg Warner Thermoelectrics
Wolf and Algonquin Roads
Des Plaines, IL

Vessey, R.
Deputy Director
Disaster Services
American National Red Cross
Washington, DC

APPENDIX B

SUMMARY OF PHOTOVOLTAIC REFRIGERATOR INQUIRIES

Geographic region	Type of request			
	Information only	Commercial avail. and price	Distribution and/or manufacturing rights	Totals
Europe	22	6	1	29
Africa and Mid-East	5	3	5	13
Far-East	2	3	3	8
Australia & New Zealand	2	--	1	3
Latin America	--	--	--	--
North America	19	--	--	19
Other	1	--	1	2
Totals:	51	12	11	74

Of the above inquiries, 13 were from import/export or trading companies. Seven requests were from refrigerator or refrigerator component manufacturers.

Figure 1. - Photovoltaic powered refrigerator. At Papago Indian Village of Sil Nakya, Arizona.

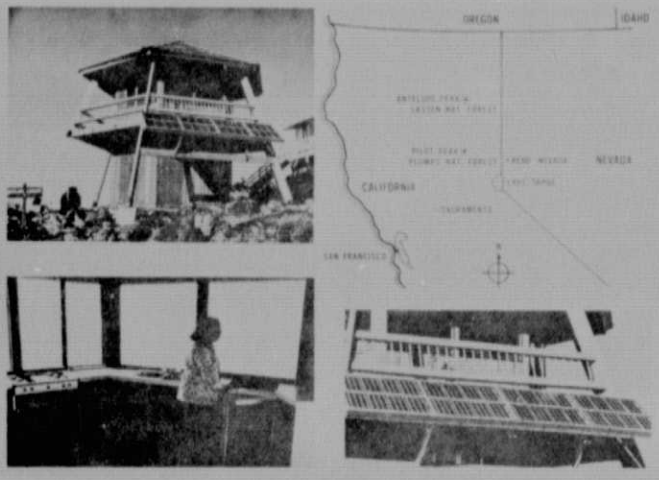

Figure 2. - Photovoltaic powered forest lookouts. Lassen and Plumas National Forests, California.

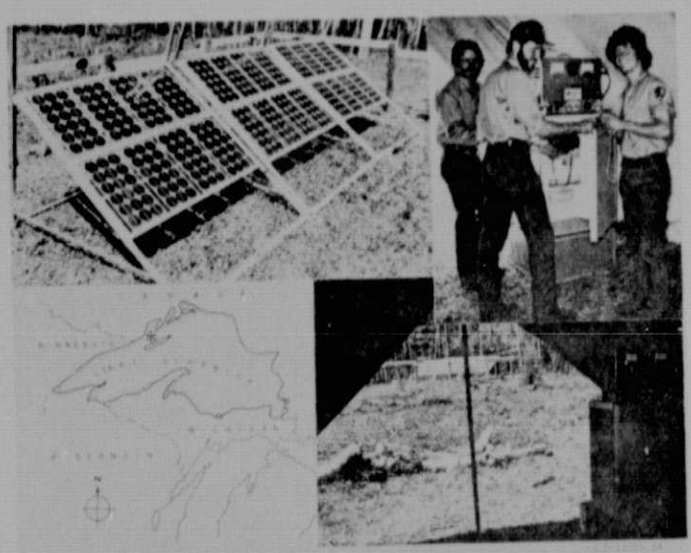

Figure 3. - Photovoltaic powered refrigerator. At Wilderness Trail Construction Camp - Isle Royale National Park, Michigan.

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