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## FOREWORD

The Alternative Energy Systems Seminar was held on March 30, 1978 at the Jet Propulsion Laboratory. Sponsored jointly by the Southwest District Office of the U.S. Department of Energy and JPL, the seminar was an experiment in information exchange. The aim of the seminar was to present, in a single day, status and prospects for a number of advanced energy systems to a diverse, largely non-technical audience, and to solicit post-seminar responses from that audience as to the seminar's usefulness.

Presented herein is a lightly edited transcript of the talks given at the seminar, along with the visuals used by each speaker.

Comments or questions regarding this material or the seminar itself may be forwarded to:

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## INTRODUCTION - M. E. ALPER

MR. ALPER: This promises to be a long and productive day and I would like to get it started.

I would like to first introduce General Charles Terhune, the Deputy Director of the Jet Propulsion Laboratory. General Terhune.

## WELCOME - GENERAL CHARLES H. TERHUNE

GENERAL TERHUNE: This I think is going to be a very exciting day. I hear it quite often and it is exciting every time I hear it and I think you will agree after you participate in the program today.

I want to welcome you to JPL. We are very honored and pleased to be asked by the Department of Energy to help in the hosting of this particular gathering.

I looked over the Attendance List and I am really impressed because there must be about 25 or 30 different agencies represented here in forms of different offices, different organizations, different companies, to say nothing of City, County, State, and the Air Force. I don't know whether the other services are represented or not. But, anyway, we have a very large group of people from many, many different places and we want to welcome you all.

We perform a great deal of civil systems work here. It started about ten years ago or a little bit longer perhaps. It started under the name of "Technology Transfer." What it amounts to is taking anything that we learn in the planetary program and trying to apply it to the problems of the civil sector. So we came up with the name "Civil Systems."

We cover many, many areas, one of which is energy, and since energy is receiving such a tremendous amount of attention now, it is slowly evolving into the most active area that we have.

We found that the U.S. is going through a major educational period right now. I think that the solutions to the energy problem, the ones that are successful and economic enough to follow; are not going to be as much in competition with each other as they are going to be needed for the various applications around the country -- all of them -- because I find there are literally hundreds and thousands of unique requirements, and there are many, many, many, tens and hundreds of probably unique solutions. Some of these will certainly be covered today, inasmuch as we are working in certain of these specialty areas.

Now, I would just like to put in a plug since I have a captive audience of DOE people here, that while we are looking for the most efficient and the most cost-effective and the most immediate of all of these good things wrapped up into one solution, we feel we in addition must get started, we the country. So we encourage action in the areas in which we are working and hopefully we will have a few places where we can take some immediate action.

So, without stealing anybody else's speeches, I would like to introduce Mr. Ember, who is really the organizer of this meeting and the one who has asked us to participate, for which we are very thankful. He represents the Southwest District Office of the DOE.

#### REMARKS - GEORGE EMBER

Southwest District Office, DOE

MR. EMBER: You said something about not stealing speeches? So, I ought to throw this away.

I have already been introduced as with the Southwest District Office. Let me take a second to introduce my direct supervisor, the Director of the Southwest District Office, Mr. Douglas Campbell. I wonder if Doug would mind standing up so that the audience can see you.

You might be asking a question: What prompted this seminar? Let me answer that by saying that during the last ten weeks there have been a considerable number of inquiries to our office from various members of this audience. These inquiries were based on the fact -- and I might as well say it -- that military bases were concerned about near-term requirements for alternate energy systems at their sites. These inquiries indicated to our office that there was a need for a seminar that would provide a basic understanding of the various alternate energy systems, their application and their availability. So that is the basic reason why we tried to establish this seminar--

To help both JPL and DOE determine the success of this seminar, we would appreciate hearing with correspondence from all of you, basically, your opinion of the seminar and any suggestions or changes in the topics, degree of presentation and the like.

We would also appreciate, on a voluntary basis, receiving responses to a questionnaire that will be handed to you at the end of the seminar.

With this, let me introduce the next speaker, Dr. Alper of JPL.

#### INTRODUCTION - M. F. ALPER

MR. ALPER: Thank you, George. I will only take a few minutes since we are a bit behind the schedule we are trying to keep.

One housekeeping detail. The luncheon tour has been arranged this afternoon, and what we would like to do is split the audience up. We will be very arbitrary about it. We have gotten the cafeteria roped off, a section of it, so that we don't have to worry about a place to sit, and you can eat with all the rest of us.

I think you will find that the institutional meal is about as good as any institutional meal, better than some and not worse than any

others.

The tour will take you up to the area where our photovoltaic work is going on. There will be some busses.

I would like to introduce Bob Rose. Bob, will you stand up?

Bob has been coordinating the activities associated with this seminar and will be keeping us on schedule during the day and taking care of us through lunch. So if there are any questions that come up, please check with Bob.

Also, if any questions come up with respect to reservations, or if you need any help, would you please touch base with Bob at coffee break time. We will have somebody up here to take care of your problems and needs.

We have asked each speaker to touch on the question of what kind of resources these alternative energy sources have, what some of the characteristics are that you need to be aware of in order to use them effectively, what kind of appropriate applications seem to make sense, what seem to be current costs and technology capabilities and where these technologies appear to be going.

We recognize that few, if any, of them today are cost-effective. There is no huge market for them. I recognize also, as I am sure each of you do, that each of them have to compete against a wide variety of other energy sources.

We will try to give you a perspective about where these things are and where we expect them to be going.

Before we start into that, though, I might just comment about the Laboratory's energy program. As General Terhune said, it began when we looked at civil systems activities some ten years ago and found it focused on four major areas: coal, which we won't touch on today; geothermal, a major area because we are in Southern California and there is such a potential major resource down here; and solar energy.

The solar energy activity has focused in three main areas: photovoltaics, as an outfall from the space activities where we have been using photovoltaic power systems for many years; solar thermal conversion to electricity, concentrating collectors of one sort or another which can create fairly high temperatures, about 2,000 degrees, very easily; and the more common building applications.

In addition, we also worried about the fourth area, and that was utility systems. How do these alternative energy sources interrelate within existing kinds of utilities? How do they become effectively integrated? What are the problems of integration? What are some of their advantages and what are some of their disadvantages?

That gives you a background of the kind of work we have been doing. The activities of the Laboratory in each of these areas have varied in

size. They are all now reasonably large. We have been contracting with industry, doing systems studies, systems applications studies, and a limited amount of in-house research activity to support them.

The people we have brought together to talk to you today are the project managers of these activities. So we hope that you will find that the background made available to you is useful for your purposes, and we hope that you will take as much advantage of it as time will permit.

I will see you again later in the day. Right now, I will turn the meeting over to our first speaker, Mr. Robert Forney, who is the manager of the low-cost solar photovoltaic project here at the Laboratory.

## SOLAR PHOTOVOLTAIC SYSTEMS - R. G. FORNEY

MR. FORNEY: Good morning, ladies and gentlemen. It is a pleasure to have this opportunity to describe to you, this morning, the Department of Energy's photovoltaic program that the Laboratory has been given the responsibility for. During the course of the presentation I will try first to describe the program itself and how it is mapped out.

Secondly, we will then go into a discussion briefly of where we are today in the current status of the technology as well as the progress and system activity. Finally, then, address the subject of the broader and eventual application of the variety of systems that are being considered and will be evolving over the next ten years to fulfill the many applications that are possible with photovoltaic energy.

I might say first that it is a reality that indeed photovoltaic does exist. I have in front of me -- and you will see more of these on the tour, a typical photovoltaic module that is in production today and is being used throughout the country on small and emerging applications. We will go into more detail on this during the morning, but you will see many of the varieties of configurations and different materials being used as you do make your tour during the lunchtime.

First, I would like to show you briefly some of the outlining and planning that has gone into the program itself under the Department of Energy.

Could I have the first viewgraph, please.

(See Fig. 1)

The program was initiated in 1975 under the then ERDA, Energy Research and Development Administration. Starting in 1975, it was initiated with a broad approach to the photovoltaic technology and how to develop it into the lower cost needs that would make the technology viable in future energy applications.

After the program was launched within ERDA it eventually, of course, was transferred over to the recently organized Department of Energy and JPL subsequently continued to work under that program.

The originally-stated goals in 1975 remain today, and those that we are directing our efforts to, as well as the total program, are in fact set up to administer and accomplish those goals.

At the top you will see the statement of the DOE program objectives. Of course, the main intent is to develop low-cost reliable terrestrial photovoltaic systems. That includes the stimulation of a viable industry that can commercially produce these and dispense them throughout the country.

Finally, of course to foster widespread use of the systems in the many applications that do exist and provide potential energy sources in the future including residential, industrial and commercial applications.

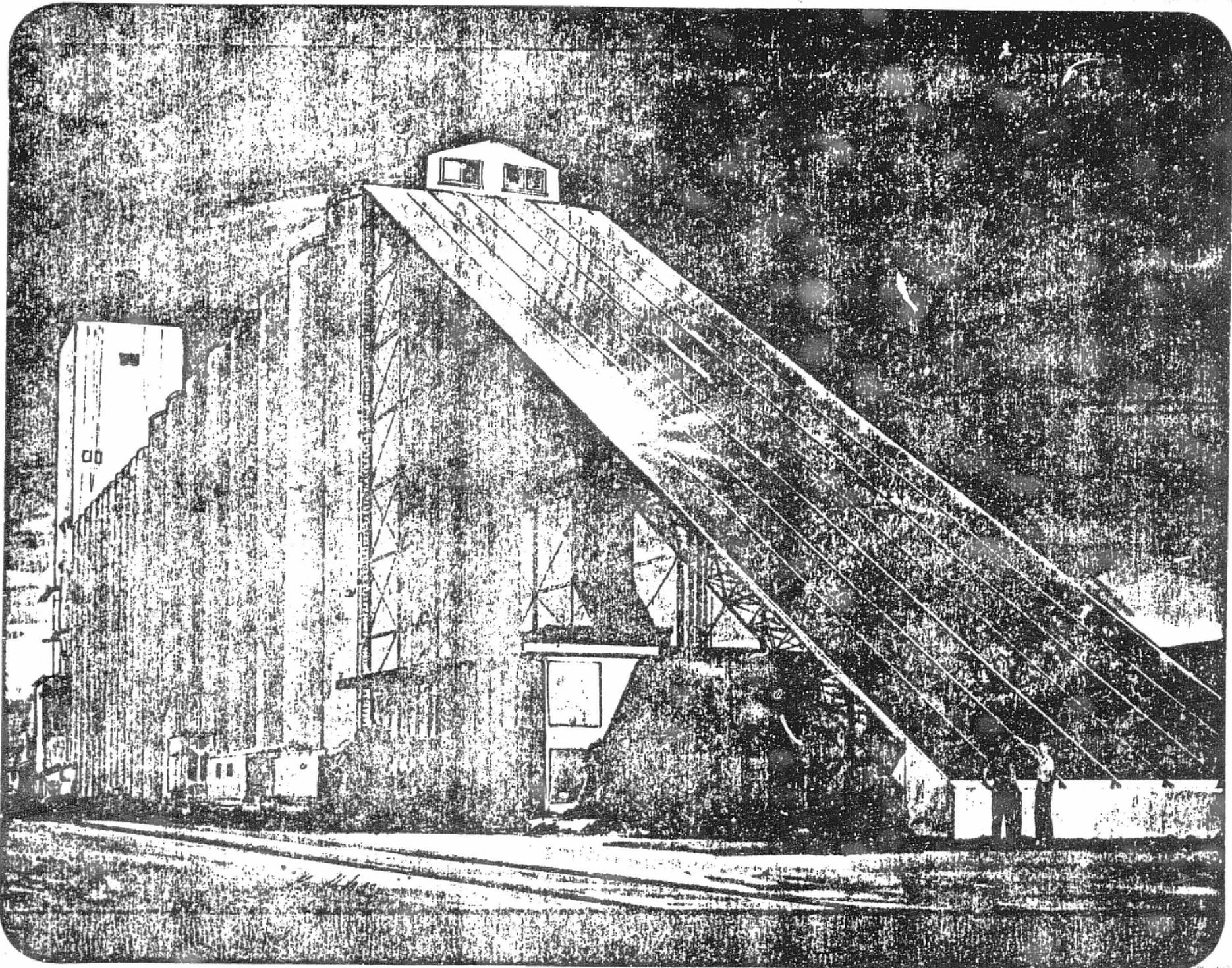


Figure 17.

The Laboratory's role which was initiated in 1975 and continues today includes: (1) That we would develop Silicon solar array technology, all of which is directed towards lowering the cost of the end product to the user.

Secondly, to stimulate the industrial production of these low-cost arrays, which means as the technology begins to emerge and become successful, that the continuing growth and expansion of the industry is also needed in order to reach the ultimate goals that have been set for the program.

Finally, to encourage in any way that we can the support of the market expansion so that, number one, it does reach a quick and broad dispersal throughout the nation, and, secondly, if you will, that the rapid expansion of the market will, in fact, entice and encourage industry, on the supply side in particular, to invest their capital and begin to expand their program, their own company base, in the production capabilities that would exist for these large objectives that we have.

Now, the specific details of the goals for 1986 are noted here. First, that the array price -- and this constitutes an array -- I may use the term "module" as well. Nevertheless, the module that is produced, the price objective that we are trying to achieve by 1986 is \$500 per kilowatt. I may also use the term 50 cents a watt as a simpler explanation of this price objective. That number is quoted in 1975 dollars to remove the confusion that may exist in predicting the normal inflationary trends that exist. So all of these will be referenced to the 1975 dollars.

Secondly, the production capability as we approach and reach the 1986 goal of 50 cents would also include then that the industry capacity be able to produce modules that have a capacity of 500 megawatts per year.

Included in the array price, and very important to the future users, will be two other parameters that we also are steering for here -- or two other goals: first, is the array lifetime which is set for greater than 20 years. In reality today, many of the utility applications depend on a 30-year lifetime for the components that they use. So, in fact, we will be steering for that, but right now the goal does exist for a 20-year lifetime. Once installed in the field, these arrays, along with their support systems, would have that lifetime capability.

Finally, to make this economically viable, we also must reach a performance capability of the modules, that they will have a conversion efficiency in the field of greater than 10 percent. Again, we will see more detail of this later.

Can I have the next slide, please.

(See Fig. 2)

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# LOW-COST SILICON SOLAR ARRAY PROJECT APPROACH AND INTERFACES

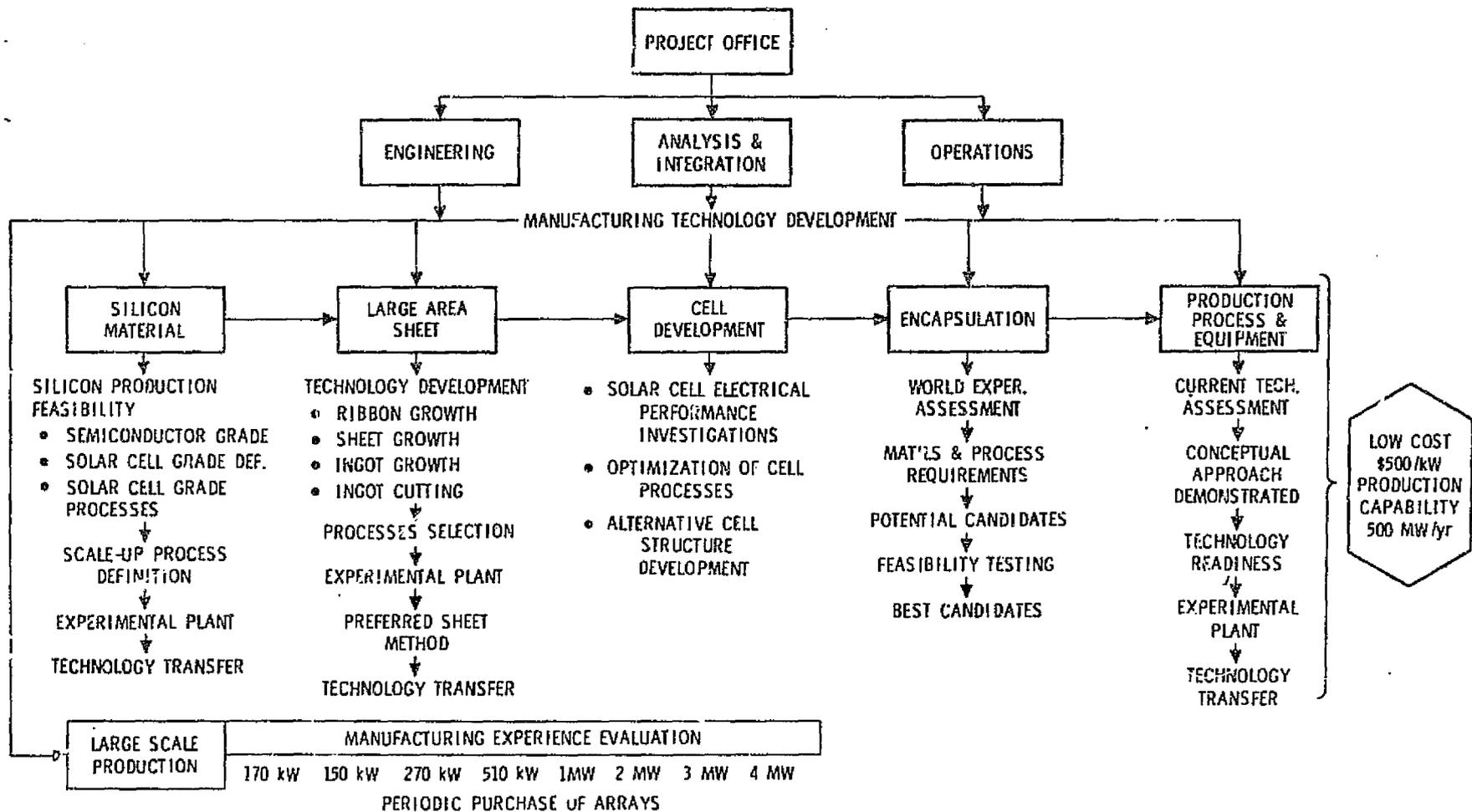


Figure 2.

Now, just quickly to look at the project structure here at the Laboratory and how we have approached this problem of accomplishing the cost reduction for silicon solar arrays. We have set up an organization that includes five major cost drivers that are included in the manufacturing of the arrays. So we are trying to single out in the project structure those high-cost areas, which, incidentally, are also high-technology areas in each case. We then undertake specific cost-reduction efforts in each of those areas. Quickly, I will read across the page if you can't see those from the back.

First is the silicon material, the basic material that goes into the photovoltaic process of converting the sunlight directly into electrical energy. It depends, in this case, heavily on silicon material.

Silicon today is the largest and highest cost part of the array that we have. So silicon material is undergoing special technology development trying to extract from the research laboratories and from the industries throughout the country the best of the ideas that can be moved forward into the development.

The second area is then taking the silicon material and processing that into large, flat sheets that will then prepare for the conversion of that material into solar cells. We have a high technology area there, the conversion of this silicon into the thin sheet configuration. Again the development is on sheet. It is another unique technology within the process of manufacturing the arrays. As a consequence, a great deal of effort is going into that, again soliciting from the industry -- and this, incidentally, comes a great deal from the existing semiconductor industry -- that ability to process molten silicon into thin sheets.

The next step in the general processing and manufacture has to do with converting those sheets into solar cells. It requires special processing and again a high degree of technology. A considerable amount of special equipment is employed, and also automation in order to gain high yields and high production rates on a yearly basis. So here we have special technology in silicon development, the cell processing.

Again, much of this stems from and is associated with the semiconductor industry that is in existence today. However, there are unique features that require it to be adapted to the terrestrial solar cell manufacturing process.

The next step in the manufacturing includes the processes as well as the materials that are used to seal the cells against the environment in preparation for their being placed in the fields for long periods of time. So the encapsulation materials and processes is a fourth area focused on from a technology standpoint.

Finally, the overall production of the modules calls for special processes, special equipment, and eventually, to reach the ultimate goals, it will require high-speed automated processing equipment. So we have a major technology effort delegated to that as well.

All of these are moved forward towards the main and overall objectives in yellow on the right again, quoting there the 50 cents a watt, and noting in particular that a high production capability is an objective that has been set by the Department to be achieved in 1986, namely, the production of 500 megawatts per year of the modules.

Supporting this overall effort, we have also been conducting large-scale procurements of the modules on an increasing annual basis for the Department for three major reasons: First, it would supply the Department with the current technology that can be deployed by the Department into demonstrations and large tests and applications projects. Second, we use it as a means of measuring the existing and improving technology as we go through the next several years and, thus, be able to measure the benefit of the ongoing technology development that is incorporated by them into the current production. So we use it then as testing that technology improvement.

Third, and very important, of course, is the measurement of the parameter of cost; what is happening to the cost as we go through the years incorporating the new technology and increased production and government buys as well as supporting the increasing open market. What are the cost benefits being incurred? Are they meeting our objective or are they falling short and where can we make improvements?

We use then the large-scale production for that.

I might mention for some of you who have been a party to some of the recent activities with the Department and some of the proposals that have been submitted to them, there is a transition at the present time now, since we have gone through our third year and third generation of buys, to have the department begin to make these buys through what is called the PRDAs which is establishing a large number of individual procurements. Not for just the modules that you see here, but also for the systems that will be using those modules. Those procurements are being made through the Department, and the most recent one was a concentrated procurement that was issued out of the Albuquerque office. We will address this in more detail, but it was completed and the contracts were recently awarded to 17 winners, who are now launched on a design of the systems. Thus, the transition from buying specifically modules into buying systems and having the systems contractors go to the manufacturing industry is now a process that is taking place.

Now, the next slide, please.

(See Fig. 3)

We might take a quick look at some very general information that I thought might be of interest to you in looking at the overall program and what in fact is the status of it.

First of all, the current production estimated today in the world has been something on the order of 750 kilowatts to a full megawatt. Now, these are relatively small numbers for those of you who are

# SOLAR PHOTOVOLTAIC CONVERSION PROGRAM

## GENERAL INFORMATION

CURRENT PRODUCTION (1978)	1 MW
FUTURE GOAL (1986-87)	* 2000 - 4000 MW
PRESENT MANUFACTURERS	8 - 10
CALIFORNIA MANUFACTURERS	5 - 6
PRESENT DEVELOPMENT CONTRACTS	80
FY-78 JPL BUDGET	\$27M

PHOTOVOLTAICS: NON-POLLUTANT -- NON-DEPLETABLE -- NON-DEGRADING

\* MC CORMACK BILL HR 10830

Figure 3.

dealing with utilities, or are from utilities, and deal with very, very large amounts of power. But in the emergent industry of photovoltaics, which, incidentally, is still termed a cottage industry because it is very small, one megawatt production is a sizable production at this time in the new industry.

Future goals -- and I am referring now to a recent number that is projected from the McCormack Bill, H.R. 10830, which is still not completely approved but is indicative of the kinds of numbers that the Government and particularly the Congress is pressing for -- the future goal then would be in that Bill that would be issued to the DOE as a program plan then, would be something in the order of 2,000 to 4,000 megawatts or a scale up from where we are today of about 3,000, if you will.

Present manufacturers in the industry are ranging from eight, to twelve. It depends a little bit upon the state of the individual companies and how they presently see themselves, producing and marketing these products. But for the moment we quote roughly eight to ten, of wh'ch in California there are five or six of these that are active and are some of the major producers today.

Under contract to us in supplying this year's buy we have five major contractors. Included in that is Motorola of Phoenix. We have ARCO, which is a newcomer, ARCO Oil Company who has bought up a small manufacturing company in the Valley and has taken over its scaling operation and production.

In addition to ARCO, we have Sensor Technology, again in the Valley, and Spectrolab also there which is an affiliate of Hughes.

In the East we have two. Solar Power, which is owned by Exxon, and also Solarex, a small private business firm.

There has been, in the last year or so, an increase of approximately five to six producers who are directly manufacturing these modules. There are many, many suppliers of other materials that I will refer to later.

Present development contracts that have been issued by the Laboratory to industry now total 80 covering those five major blocks that I showed you in the original viewgraph of the high technology areas. Those contracts were issued mostly under competition and have gone to the major suppliers, major contractors of the various materials, processes and equipment that are used in the normal production of these modules.

I will take, as an example, the case of silicon. Silicon material is a chemical industry production commodity and there are four major producers: Dow -- Dow Chemical, Motorola, Westinghouse, Union Carbide, Monsanto, and one other one is Battell Memorial. All are doing significant work in trying to develop new technology that will emerge in the late 1980's to provide and contribute significantly to the lower cost.

I just will mention one number here. The silicon material that is used today costs, on the open market, \$65 a kilogram. Now, this is semiconductor grade, highly purified silicon derived from sand or quartz.

When we achieve our 50 cent goal in 1986, contributing to that we will need to have this price of silicon down to \$10 a kilogram. Consequently, it is demanding of new technology to be developed by these companies and to place on line for achieving that goal of \$10 in the quantities also that will be needed at that time.

The JPL budget for FY '78 is \$27 million. Next year's budget is in question as to how big it will be because it is greatly a function of what Congress will finally wind up with in awarding to the Department of Energy, their yearly budget. But our present budget is \$27 million in support of the DOE contracts I mentioned.

I would like to call your attention now to three major points and it is very important. Sometimes they are treated glibly, but I think in the evolving situation that we face as a nation photovoltaic has three major attributes that I think are very important and will be brought more to the fore in their consideration for the systems applications in the future.

First of all, the use of photovoltaics is non-pollutant. There are no residual materials, be they gases or otherwise, that come from the use of it.

Secondly, the use and generation of photovoltaic technology does not employ materials that are depletable. In other words, we do not continue to use and burn, as in the case of other fuels, any of the materials. The silicon is available in abundance on the earth's surface. Furthermore, in its use it is not destroyed or depleted.

Finally, the use of the photovoltaic, you might call it a static system. It does not wear out with time. We do have a problem of making sure that it is well protected but there is not a wear-out process taking place. If the material is well protected against the environment it can survive a long, long time.

Our goals, of course, have to do with not only the silicon material but mostly the encapsule material in regard to the lifetime that we quoted of 20 years or greater.

The next slide, please.

(See Fig. 4)

Now, the cost goals that have been set forth in 1975 remain to be guiding the program in general and the project specifically. These price goals that I show here are dedicated towards the total program objective. However, we use them in guiding the project itself.

The main objective, as I noted earlier, is the 50 cents a watt to the far right to be achieved in 1986.

# LOW-COST SOLAR ARRAY PROJECT TERRESTRIAL SOLAR MODULE PRICE HISTORY & GOALS

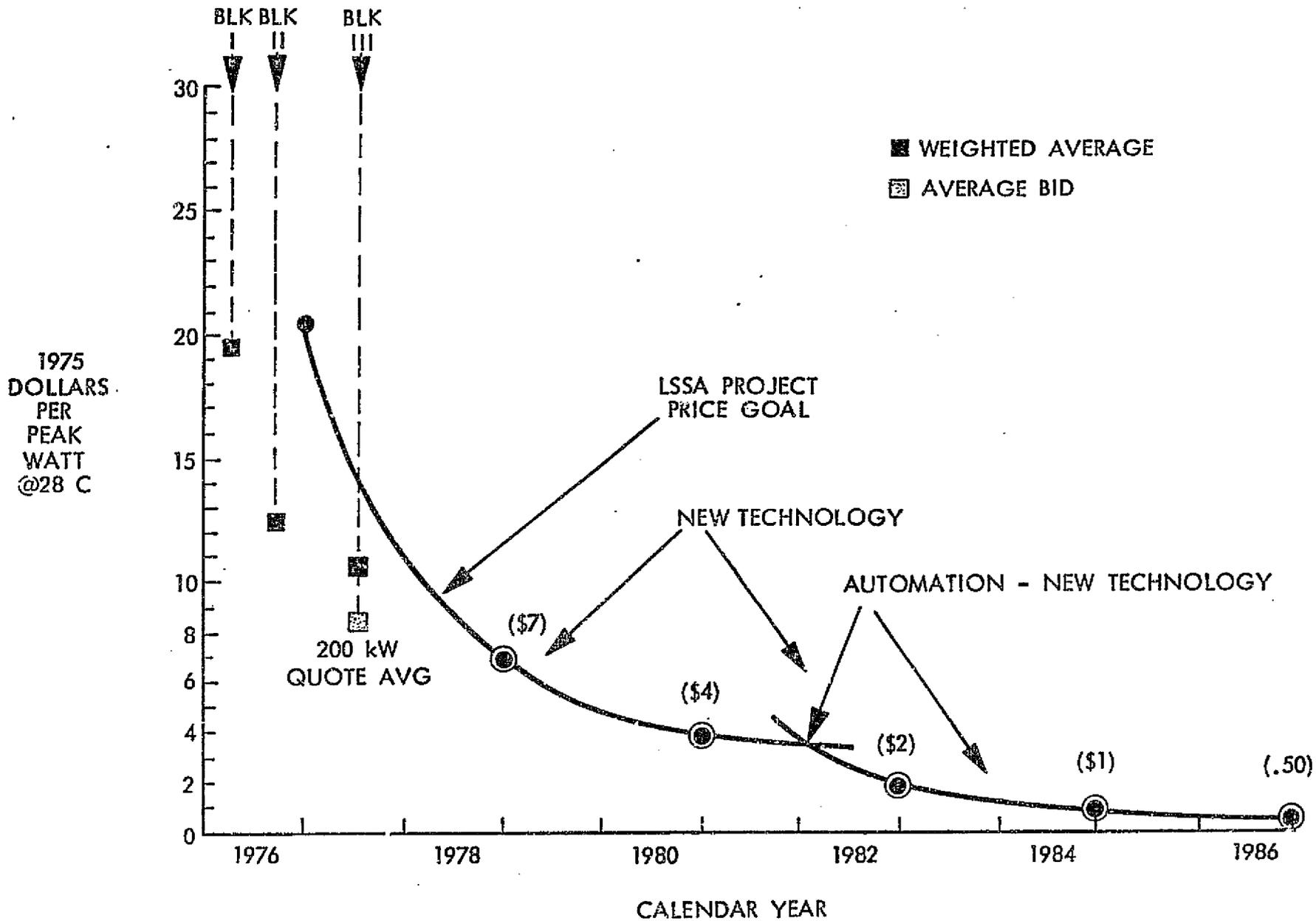


Figure 4.

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These heavy black lines with intermediate check points are what we have set for our goals to guide us in administering to the project and trying to bring forth these as rapidly as we can so that we can continue to assure ourselves that we are on the right course to achieve the 50 cents by 1986.

Also, the square blocks on here are numbers that are resulting from our past procurements of the modules that I mentioned that have been used to supply the demonstration program with equipment that could be fielded for tests and applications.

The first buy was made in 1975, 45 kilowatts worth. We call that Block 1, and the average price turned out at that time to be almost \$20.

Now, there was a range from about somewhere in the \$17 range all the way up to about \$30 or \$35 per watt at that time, but the average price turned out to be \$20.

The second buy that we made in 1976-77 was for 130 kilowatts. The average price for that buy was at a value of about \$12.50 per watt.

Finally, our most recent buy of what we call Block 3, was for 200 kilowatts. The average price there is just at \$10, or slightly over.

The extra square that I note here is that we asked the industry to also bid on -- each of them -- for 200 kilowatts. Their budgetary estimate that came in showed that they could or would produce a 200-kilowatt order for about \$8 a watt.

These again are quoted in 1975 dollars. In other words, we normalize them back to the original chart and the original buys for keeping the inflation variables out of the consideration here.

In the near term then, 1978 and 1979, if we are on course with the project, we will see \$70 or so beginning to come out of the current industry.

However, it is interesting and important to note that from here on, in this period, we must begin to see new technology, and to further aid that price reduction. We have been achieving this mostly by standardization, large buys, allowing the industry to spread them over a variety of months for most optimum for low costs and production benefits to them directly. But from here on in we must begin to see results from our technology work in the industry and having them introduce that to begin to realize the \$7 down to the \$2 objective.

As we pick up the period of 1980 to 1981 we must also, at that time, begin to see results from our automation activities where the new technology and related automation would begin to show up at this time and be introduced into the industry so that they can continue down to this 50 cents.

When we hit 50 cents there will be three major methods or results that are going to accomplish that: First is the new

technology. Secondly, is that fact that we do automate heavily within the industry. And, thirdly, the new and best materials that are available will be introduced for that.

This is not the end of the program. As far as the Department of Energy, their program goes and continues. The 50 cents is the hard goal that we have at the moment. Beyond that, and most important to the utilities, there is a need to achieve something on the order of 20 to 30 cents to really make the use of photovoltaics, in a comparison with ongoing utility prices, make them viable. So from 50 cents on down to 30 is where new materials will be introduced and some of the new technology, of course, will be matched with that. But for the moment, and very important for the whole program, is the fact that the 50 cents is met.

Now, for consideration of system prices, if 50 cents is accomplished in 1986, and with the ongoing development for the rest of the system components, it is deemed that it would be successful at that time, we would be able to provide a system that will deliver energy at the price of something between 60 mills and 100 mills. Now, the mills are roughly 5 to 10 cents per kilowatt hour, typical of the current prices of energy. If this is accomplished and the system costs match the reduction that is shown here, it then says that we will be in the ball park of a competitive energy price at that time.

I might add that the Laboratory, since this view graph and some of the others were made, has been assigned the task by the Department to extend its work from silicon to all other materials as well, including cad sulphide, gallium arsenide and the other photovoltaic conversion materials that are potentially viable. The new role that is being assigned is to apply the same processes that we have been conducting here on the other materials. Namely, to extract from the research activities that are going on the materials that are showing most promise and are reaching the point when they need to enter and be brought into the development stage for application in the system. So this is a new role recently assigned and will begin to take place in 1979.

Could I have the next slide, please.

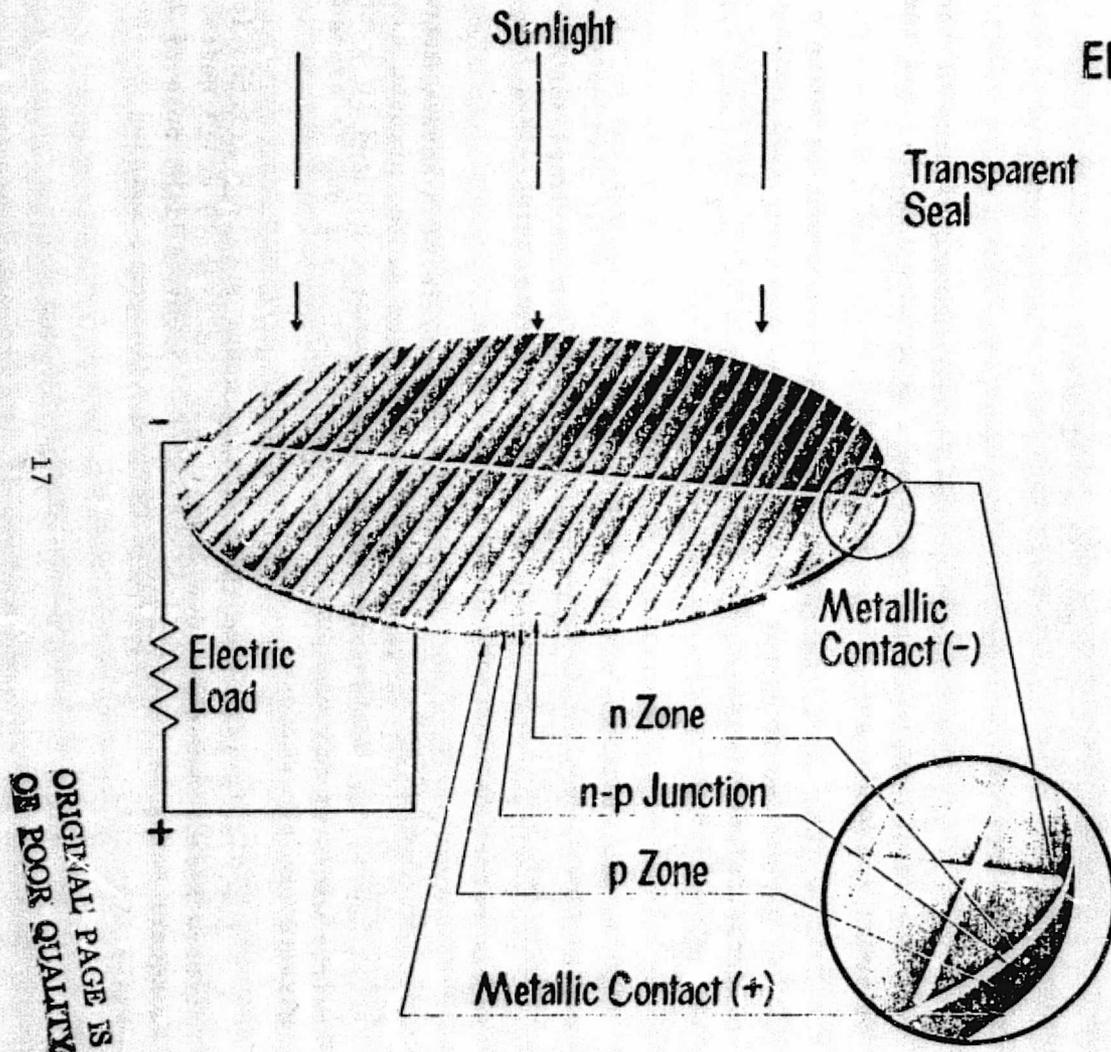
(See Fig. 5)

Just quickly, the technology, or the physical phenomenon that occurs in the solar cell I thought might be of some interest to you so that you will understand a little bit about what is happening as we talk about the cell.

The silicon material offers a photosensitive material which when properly processed with other materials, can provide the conversion from the solar energy impinging on the surface to an electrical energy output. This takes place first on the basis that we are using high-purity silicon that is derived from quartz or sand. That is processed into a very pure condition and prepared in a form that will accept the other materials which are called semi-conductor materials or -- well, other materials that have the N and P characteristics within them that provide an excess

# SOLAR CELL

## *How Sunlight is Converted into Electricity*



### ELECTRICITY IS A FLOW OF ELECTRONS

- High purity silicon from quartz
- Semiconductor material converted into "n and p" zones by "doping"
- Junction of "n and p" forms an electrical field
- Light falling on cell absorbed, releases some silicon electrons creating "holes"
- Internal electric field separates electrons and "holes"
- Cell metallic contacts connected to external load, permit flow of electrons
- Electricity supplied as long as light illuminates cell

Figure 5.

of electrons within this material. Those materials that are segregated on the silicon are then exposed to the sunlight, and as a result of the photon energy within the sunlight, they impinge themselves on the materials within the silicon and discharge or detach the electrons from the various materials freeing them up so that they are able to move about within the material. Due to the fields that exist at the junction between these two materials, the electrons then are in a position to be moved to the outside of the cell and carried to a load. This is done on a very small basis. This might be representative here of a three-inch solar cell, and there is a connection across the top of connecting materials -- let's call it for the moment a wire -- that collects the energy from the topside, delivers it out to the electrical load and then is returned back to the lower side of the cell so that there is a continuous flow of current around and through the load therefore providing the energy from the cell. Again, the impact of the solar photons on the surface create and free-up the electrons that are allowed to flow and circulate through the load.

Now, this is done on a very small scale here, but if you multiply these up in modules of this kind you can then connect these in the form that you would a battery and begin to add those up in whatever manner you wish for the uniqueness of the load so that you can series and parallel them until eventually you have a very large source of energy.

If we can have the next slide, please.

(See Fig. 6)

We can see here, briefly, some of the characteristics of the areas involved if you employ these cells as I described earlier, and the kinds of power you would get out of a particular size module.

Typically, we refer to a standard of measurement as being a square meter, and if you expose that to sunlight, the full sunlight directly perpendicular to the surface, then there is essentially a thousand watts available of equivalent electrical energy being imposed on the surface.

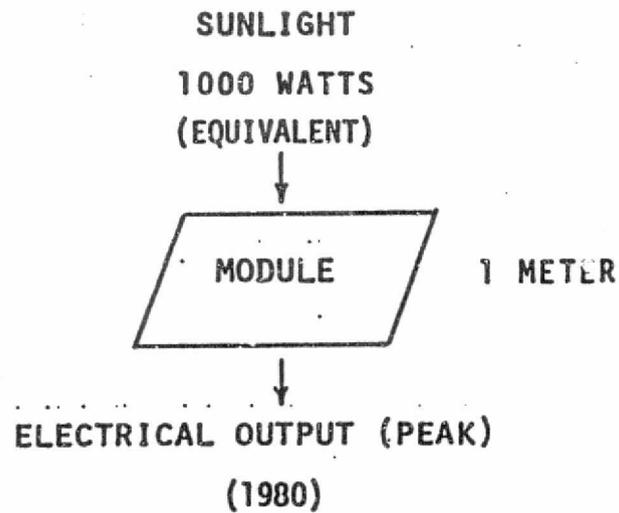
As you go through the process of the cell conversion to electrical energy there is an efficiency term there that begins, obviously, to reduce this considerably and, therefore, the output drops significantly. But, nevertheless, the output will result in something like, for a square meter, between 100 to 130 watts out.

In other words, the efficiency of a module of a square meter of solar cell material is around 10 to 13 percent at the present time. Consequently, we would gain from a square meter a hundred to a hundred thirty watts at any one point in time providing the sun is exposed directly to the surface.

Now, let's just jump through some other strictly arithmetic numbers here. A square foot can provide you from 10 to 13 Watts. Or, a square meter is required to, of course, light a light bulb of 100 watts intensity. A square mile will provide you something on the order

# SOLAR PHOTOVOLTAIC CONVERSION PROGRAM

## POWER AVAILABILITY



19

- ° 1 SQUARE FOOT = 10 - 13 WATTS
- ° 1 SQUARE METER = 100 - 130 WATTS
- ° 1 SQUARE MILE = 215 - 280 MW
- ° 4 SQUARE MILES ≈ 1000 MW
- ° FOOTBALL FIELD = 450 - 585 KW
- ° 76 x 76 MILE ≈ 1223 GW

ASSUME: 10 - 13% EFFICIENCY 1979-80  
14 - 16% EFFICIENCY 1985-86

Figure 6.

of 280 megawatts, and that begins to approach the capacity of some of the smaller utility plants.

We can go further than that and say that a four-square-mile area would provide a thousand megawatts, or the equivalent of typically what is being developed today by the nuclear power plant.

Another point of interest might be that a football field, if you had it covered with photovoltaic cells, could provide you with something between 450 and 585 kilowatts, or this could supply something between 20 and 40 residences that are typical of the power that they demand throughout the day.

Finally, I am extracting a number here from Al Canada of Canada West who went to the extreme and said what it would take to provide the national electrical energy load if you went totally to photovoltaic. His current number is that you need 75 miles square to provide the total electrical energy that is anticipated as the nation's demand in the near future.

So that these numbers are not quoted so rigidly that they become gospel -- there are so many assumptions in the numbers -- but, first of all, I am assuming here currently we have under test arrays of this kind that are showing efficiencies between 10 and 13 percent. This is the module that is seen here when exposed to full sunlight. We anticipate in the not-too-distant future to see 14 to 16 percent, and these numbers will be carried forward to the 1985-86 goal.

Can we have the next slide, please.

(See Fig. 7)

This is typical of some of the current production, one of which you see here. But these others are the ones that have been purchased in the last year for the Department of Energy and are being deployed throughout the country in many test programs.

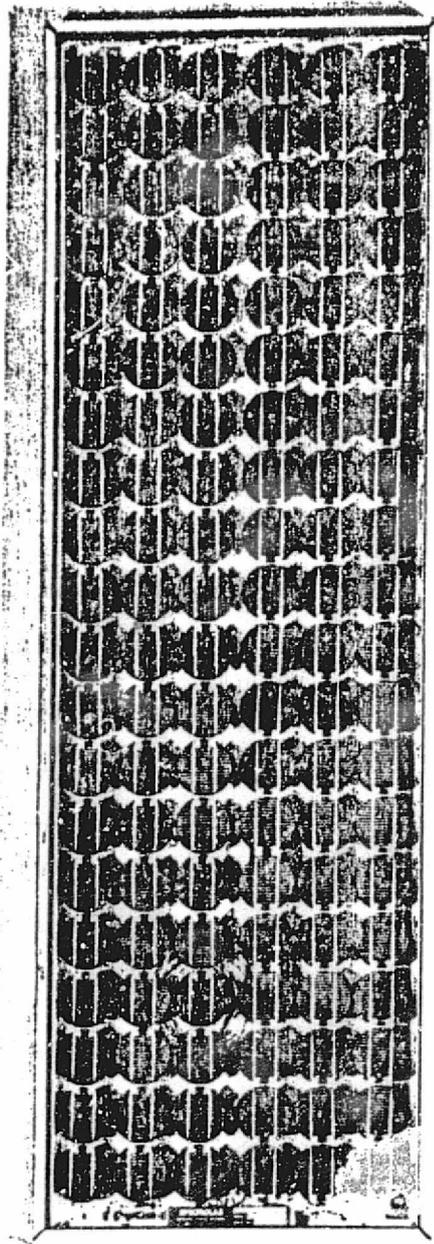
The diversity is because the individual manufacturers have their own techniques and technology that they have developed or are developing within their company and we have not wanted to control or dictate a particular technology to them. So what we have done is to standardize, on configurations and connections so that it can be most versatile to them and be useful to them in their own marketing as well as at the same time being used for many of the Department of Energy programs. So, primarily we have outlined or defined the outlines and the interconnects, but the technology internally in each of these is up to the company's own innovative planning and development.

Next slide, please.

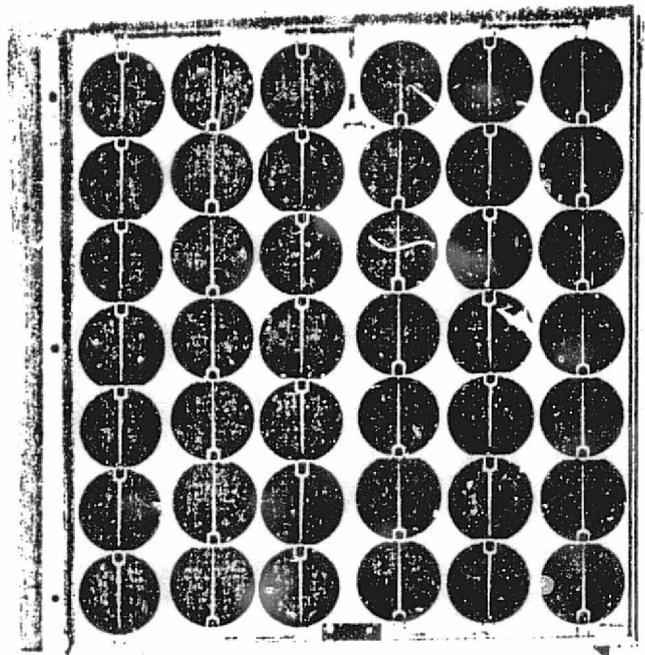
(See Fig. 8)

Some of the new work in what we call the next generation is shown here. In particular, I will call your attention to the two that have

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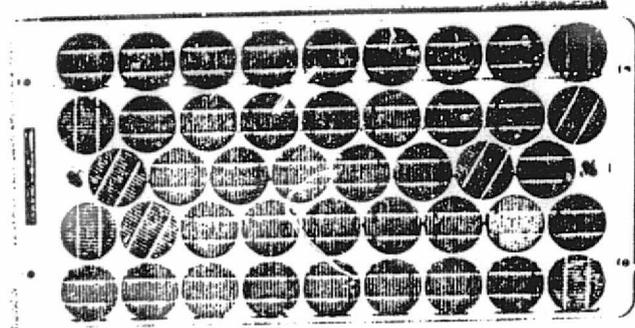


SPECTROLAB 23.3 WATTS

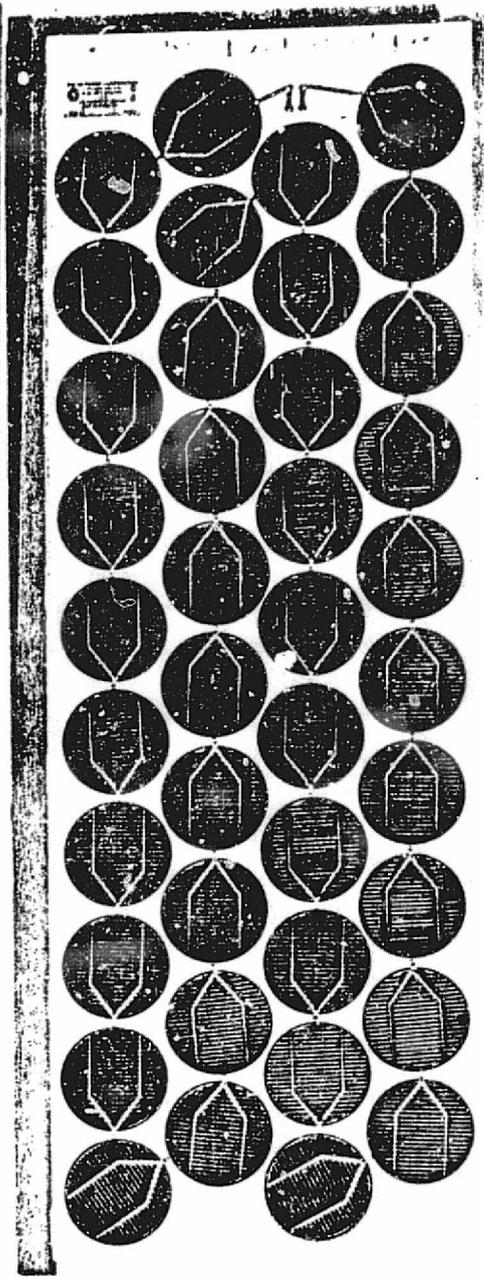


SOLAREX 18.6 WATTS

12 INCHES



SENSOR TECHNOLOGY 9.7 WATTS



SOLAR POWER 28.7 WATTS

DOE BLOCK II SILICON SOLAR CELL MODULES  
MODULE PEAK POWER AT 60 C AND 15.8 VOLTS

Figure 7.

# LOW-COST SILICON SOLAR ARRAY PROJECT ADVANCED DEVELOPMENT MODULES

22

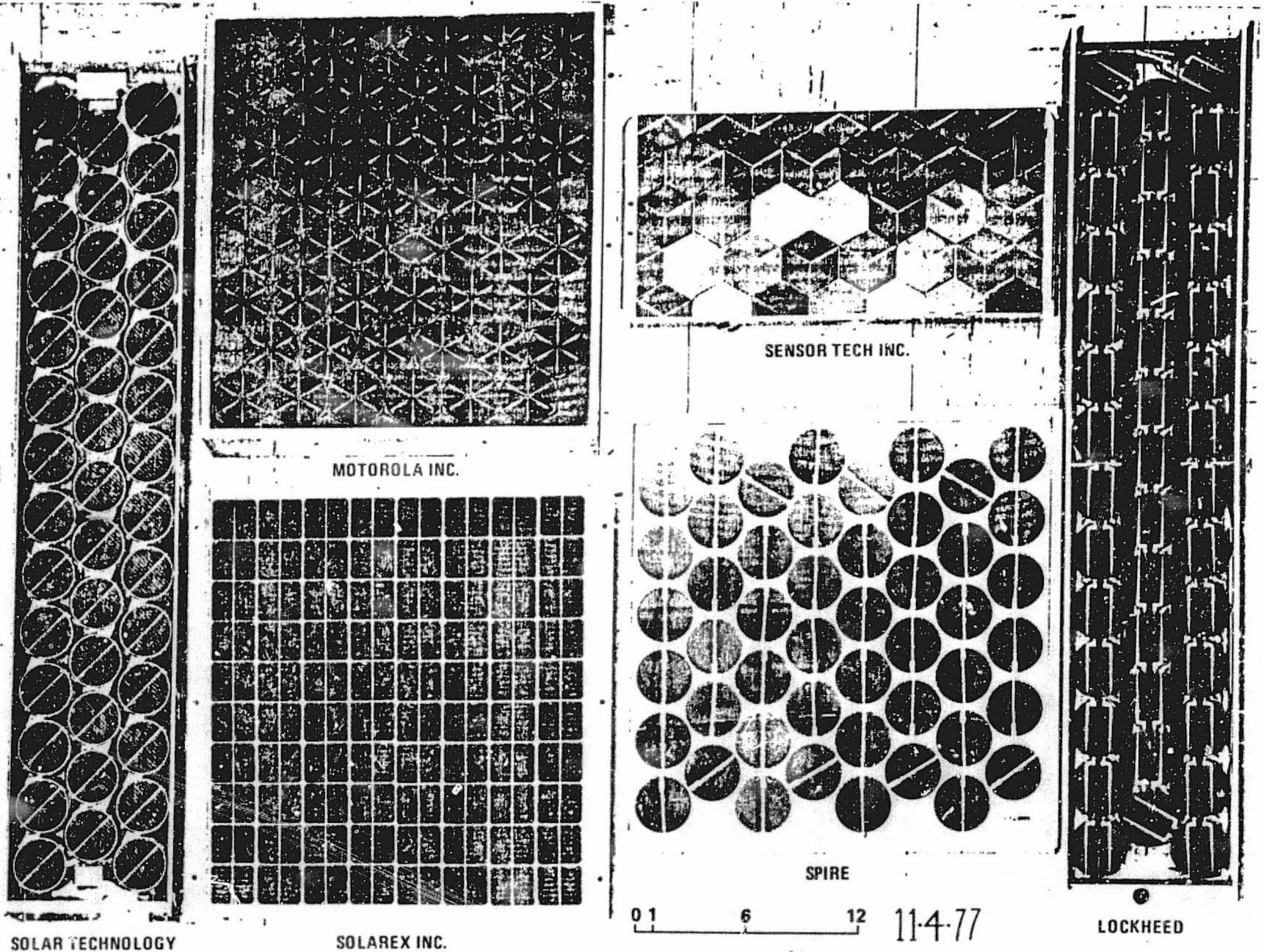


Figure 8.

square cells as opposed to the round ones here. That is because we are trying to increase the density of the module, increasing its output because of the higher packing density, or, therefore, the efficiency of the total module. These are where we are beginning to see results carrying up to about 13 percent efficient due to the high packing density and the use of cells that run in the vicinity of perhaps 12 percent efficient. Some of them are a little higher and some of them are a little lower, but generally this is the new technology that is being looked at and will be available for procurement in the next year.

Next slide, please.

(See Fig. 9)

Shifting over now a little bit from the -- well, perhaps before I leave the subject of the project activity and its current technology, let me explain briefly how the program is organized so that as we go forward into the system work you will hear some names and can understand a little bit better how the Department has organized it.

Within the photovoltaic conversion program there is a main thrust first of all in research and that is set aside separately to be administered out of the program and out into the field of universities and industrial firms. There is some research also going on in the various government laboratories.

In addition to the research, there is also the silicon development project that I have described and which JPL is supporting. As I mentioned, that has been broadened now from silicon to consider all of the other materials as well.

Next comes in the organization a system effort conducted by Sandia for the Department, and they are responsible for the development and consideration of system analysis and development such that all applications, the variety of applications that exist, are being considered and the optimum system development is being undertaken by them to assure that the broader array of applications are going to be met in the near term.

Finally, there are three agencies that are being called upon for the development and the execution of tests and demonstration programs. These include the NASA Lewis Research Center, which is responsible for small remote applications; the MIT Lincoln Laboratories, responsible for the larger disperse applications including residential; and the Department of Defense, which has undertaken specific or special applications of a variety of demonstrations to show the wide range of photovoltaic systems that they can deploy. They are presently under way on this wide variety including a 60-kilowatt installation that I will mention in a few minutes.

So that is the program map-out, and these individual projects are interacting continuously to make sure that there is total coordination through there regarding the technology development and how they are dispensed to demonstrations and how they are considered for future

# POWER SYSTEM (PHOTOVOLTAIC)

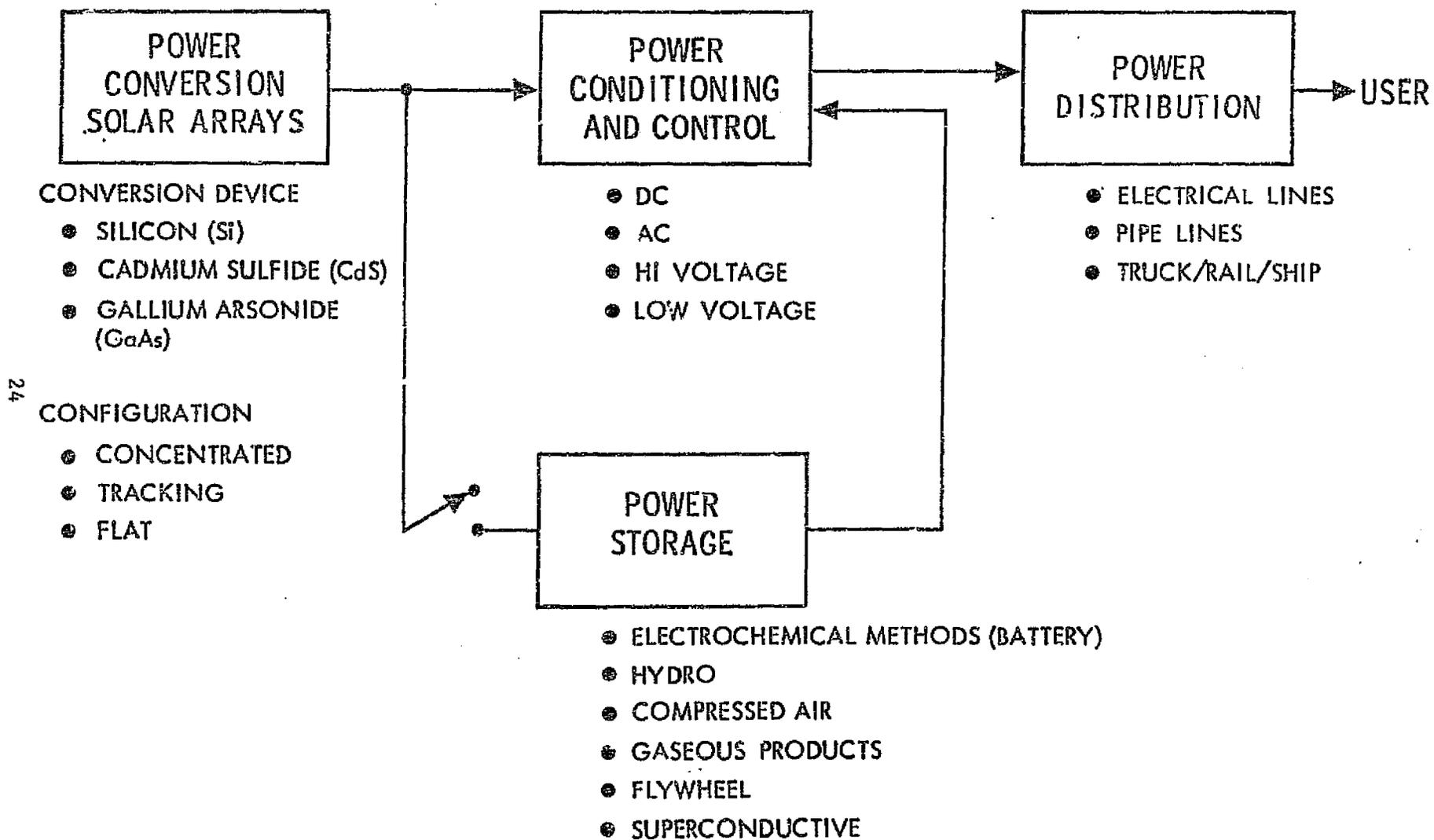


Figure 9.

applications and the many system configurations that are potentially available.

In the case of a power system now it will be made up of the ingredients or the substances that are noted here. First of all, in the front, if you will, of the system comes the power conversion device. In this case, we have addressed this morning, the photovoltaic conversion and there are two technologies that are being considered here. First, in the case of the one that we talked mostly about and you have seen the pictures of, flat plate photovoltaic conversion has been discussed mostly. This is where the material is spread in thin sheets that you have seen and collect the solar energy, converting it to electrical by nothing more than just having the sunlight exposed to the surface.

A second technique can be where you concentrate the sunlight onto the conversion material and with higher concentrations you can then reduce considerably the expensive use of, or the use of expensive materials, in the case of silicon, or cad sulfide, or, more importantly, in the case of gallium arsenide types of material. The concentration then reduces the amount of converting material that you need that presently is very expensive and one of the high-cost drivers that exist.

Now, a third configuration would be if you concentrate but you also track those concentrators with the sunlight so that as the sun comes up over the horizon in the morning the device is pointed directly at the sun and tracks the sun through the complete traverse throughout the day. That develops more electrical energy output and, therefore, you have a great deal more of energy than if you stay with the flat plate.

Now, there are many pros and cons on this technology. For the moment, these are totally under development and continue moving forward quite successfully. Eventually, the use of these can be considered in that any one of them may have an optimum application. In other words, what I am trying to say is, I don't think that we will see that you throw out all the others in favor of one, but, in fact, there may be many uses where one is more optimum than another. So this then, I think, represents a major thrust of the total program.

As I mentioned earlier, within the materials that are used are silicon and a variety of other compounds including cad sulfide, gallium arsenide, and so forth, that are being developed and emerging from the laboratories. In the next ten years you could see a great number becoming successful and moving into the development phase.

The rest of the system then usually requires the following subsystems to work.

First, the power conditioning. The power coming out of the module here, or the array, is DC power, direct current. The configuration that is wanted by the customer varies considerably. First of all, they may want AC power; they may even want different frequencies, and certainly different voltages, and so forth. So, as a result of power conditioning that acts on the resulting energy here the power is then modified in the

conditioning equipment and the control equipment to be processed and then moved on to the distribution system.

Supporting that, and sometimes used to optimize the full extent of the solar energy, is power storage. You may need, as an example on a simple basis, if it was a residential power application, as the sun goes down you still need electrical power, you would like then of course to have it available throughout the night. There are several ways to do that. One is through storage such as batteries, which is, of course, the present most common one, and where the solar energy could be stored in here and at the same time you could be using some of the solar energy but be storing the excess and then using this during the nighttime or in the periods when solar energy is not available.

Finally, there are distribution systems and those range all the way, of course, from the simple and most common electrical lines themselves to disperse the energy to the user in whatever form he wishes it. In addition to that, though, you could convert from the solar energy through electrical conditioning various other forms of energy such as the generation of hydrogen that could be piped to the other sources or stored and transported by rail.

The power storage also has a variety of technologies. In addition to the electrochemical method, such as batteries, it could include the storage of water, compressed gases, gaseous products, flywheel, or even superconductive storage techniques, all of which are being developed, but generally today, of course, most of it focuses on the use of batteries.

This is the general system then that must be considered and you, of course, have to configure the system and develop it for the particular applications. In many cases there may not be need for storage. For instance, again using residential as an example, if you had solar arrays on the house, the sun comes up, gives you electrical energy throughout the day, and you don't wish to or cannot afford to -- or it is considered at least most optimum not to use storage -- as the sun goes down you would pick up the load from the existing utility lines and use that through the night; and again as the sun comes up the next day you can go back to the solar energy.

But in the applications must be considered the economics and so forth as to whether you use storage, how much storage you need. Also, the same thing applies to the amount of power conditioning and the type of conditioning and the type of control. This has to do with the complexity of the application and ranges over from very simple things to battery chargers all the way up to a very complex energy-demanding system.

Next slide, please.

(See Fig. 10)

I think I will speed through this and only say that the applications that are under consideration today are categorized in a way to deal with

# SOLAR PHOTOVOLTAIC CONVERSION PROGRAM

## APPLICATIONS

- **SMALL, REMOTE**                      **UP TO 5 KW**  
    **UNATTENDED, RADIO RELAY**
- **RESIDENTIAL**                      **5 - 25 KW**  
    **HOMES, SMALL BUSINESS**
- **DISBURSED**                      **250 KW - 50 MW**  
    **LOAD SITES, INDUSTRIAL COMPLEXES**
- **CENTRAL POWER**                      **250 - 1000 MW**  
    **UTILITIES**

Figure 10.

the specific technologies within it and range all the way from small, remote applications all the way from nothing more than a remote battery charger driving radio relays and so forth in remote areas on up to residential, which is under development both as a stand-alone or a residence that would have both the ability to use solar energy directly during the day and have storage ability during the night independent of utility connections, or it could be in conjunction with utilities, small businesses, other kinds of small 5 to 25 kilowatt kinds of applications.

A third category is the disperse system and that ranges over a considerable size all the way from very small things again, perhaps nothing more than 25 kilowatts, but generally it is larger than that running from 250 on up to 50 megawatts. So again these numbers are not rigorous. It is just kind of putting a ball-park number in front of you of the variety of applications and their categorizations.

Finally, the central power kinds of operations where there is a utility-type large central power-generating plant ranging from 250 megawatts all the way up to 1,000 megawatts, typical again of the nuclear installation.

The next slide, please.

(See Fig. 11)

Present demonstrations. Also, we will go quickly over these to just show you what is available in case you have the opportunity of seeing them or wanting more information on them.

There currently is in operation, since last July, a 28 kilowatt installation at the University of Nebraska in Meade which is set up and designed to do irrigation during the summertime and crop drying during the wintertime. This has been in operation and has been highly successful and continues to be monitored and evaluated in its continuing operation.

The next installation coming on is a 60 kilowatt Department of Defense power station that is being used for the Air Force as radar installation. This is located or will be located in the Laguna Mountains in San Diego. It was recently awarded a contract to a firm in Orange County and they will be assembling this and then installing it for the Air Force in the mountains and will be operational in July of next year.

The next one is now in the design process, a hundred kilowatt installation, which is being done for the National Park Service. The MIT Lincoln Laboratories have the prime responsibility to design and install this, and they are calling for many subcontractors to help them. This will be installed at the Natural Bridges, National Park Service in Utah. Again, it will be operational in the middle of next year.

# SOLAR PHOTOVOLTAIC CONVERSION PROGRAM

## PRESENT DEMONSTRATIONS

- 28KW UNIVERSITY OF NEBRASKA  
IRRIGATION - CROP DRYING
- 60KW DEPARTMENT OF DEFENSE  
AIR FORCE RADAR - LAGUNA MOUNTAINS
- 100KW NATIONAL PARK SERVICE  
NATURAL BRIDGES - UTAH
- \* 250KW MISSISSIPPI COUNTY COMMUNITY COLLEGE  
ARKANSAS
- \* 17 CONCENTRATOR SYSTEM DEVELOPMENTS  
DESIGN PHASE
  - FLAT PLATE
  - \* CONCENTRATOR SYSTEMS

Figure 11.

A larger system now is already under way in installing the equipment. This is at the Mississippi County Community College in Arkansas. It is a 250 kilowatt system minimum. I believe its maximum capability will be something like 330 or so kilowatts. It is using concentrator systems and is a collaborative effort with the university and other industrial groups.

Finally, and most recently, there were 17 concentrator system development contracts awarded by the Department. They are presently in a fixed alignment design phase which afterwards there will be selection of many of those to go into actual construction and operation of the variety of systems. Their sizes range from as low as 25 kilowatts all the way up to 500 kilowatts in power capacity.

Note that the upper ones are in flat plate technology. The last group here is in concentrators. And, incidentally, there will be another procurement much like this one for flat plates coming out from the department in the next few months.

Next slide, please.

(See Fig. 12)

Now, just quickly looking at some of the current technology. This is one that is commercially being developed and installed in Kern County. It is for the Sheriff's relay department. It is for the Sheriff's radio relay requirements in the county. It is rated at 3.3 kilowatts and it is a stand-alone system unattended. It is placed there and it is very economically viable because they could mount diesel or gasoline-driven generators. So, as a result, the photovoltaics here is proving to be very cost-effective.

Next slide, please.

(See Fig. 13)

This is the Nebraska irrigation project that I mentioned. It is 28 kilowatts. The arrays are shown here continuing down across the picture. This is the irrigation reservoir where the water is drained from the field, brought into the reservoir and then recycled through the pumps that are operated from these photovoltaics and back to the field for further irrigation use.

One of these arrays was made by Solarex on the East Coast, and one by Sensor Tech here in the San Fernando Valley.

The experiment also includes the fact that they are using DC motors and also using AC motors driving the pump and there is battery storage which we will see in the next slide, please.

(See Fig. 14)

This is the battery storage system that is used to operate the pump or the corn driers during the wintertime. It permits them five days'

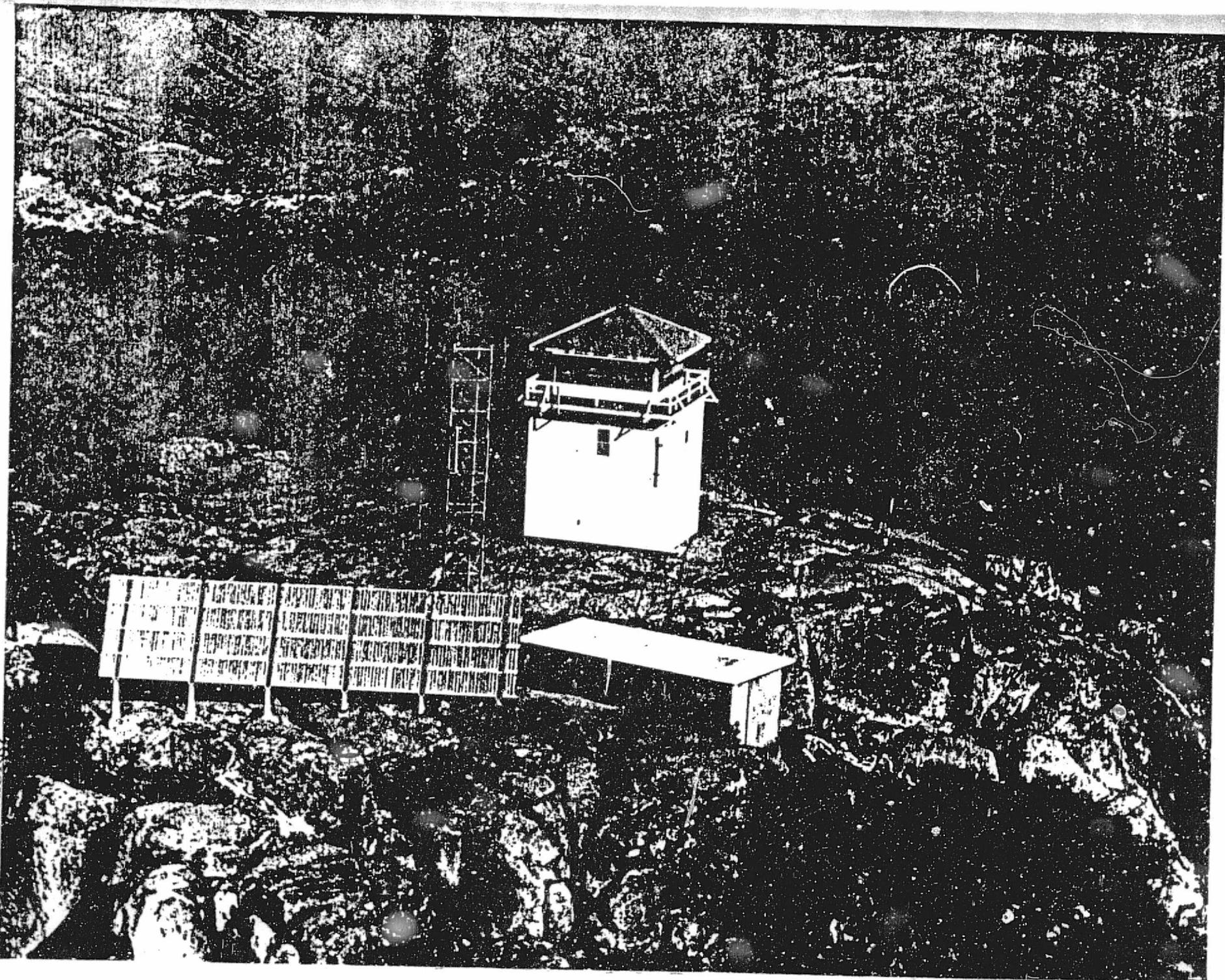


Figure 12.

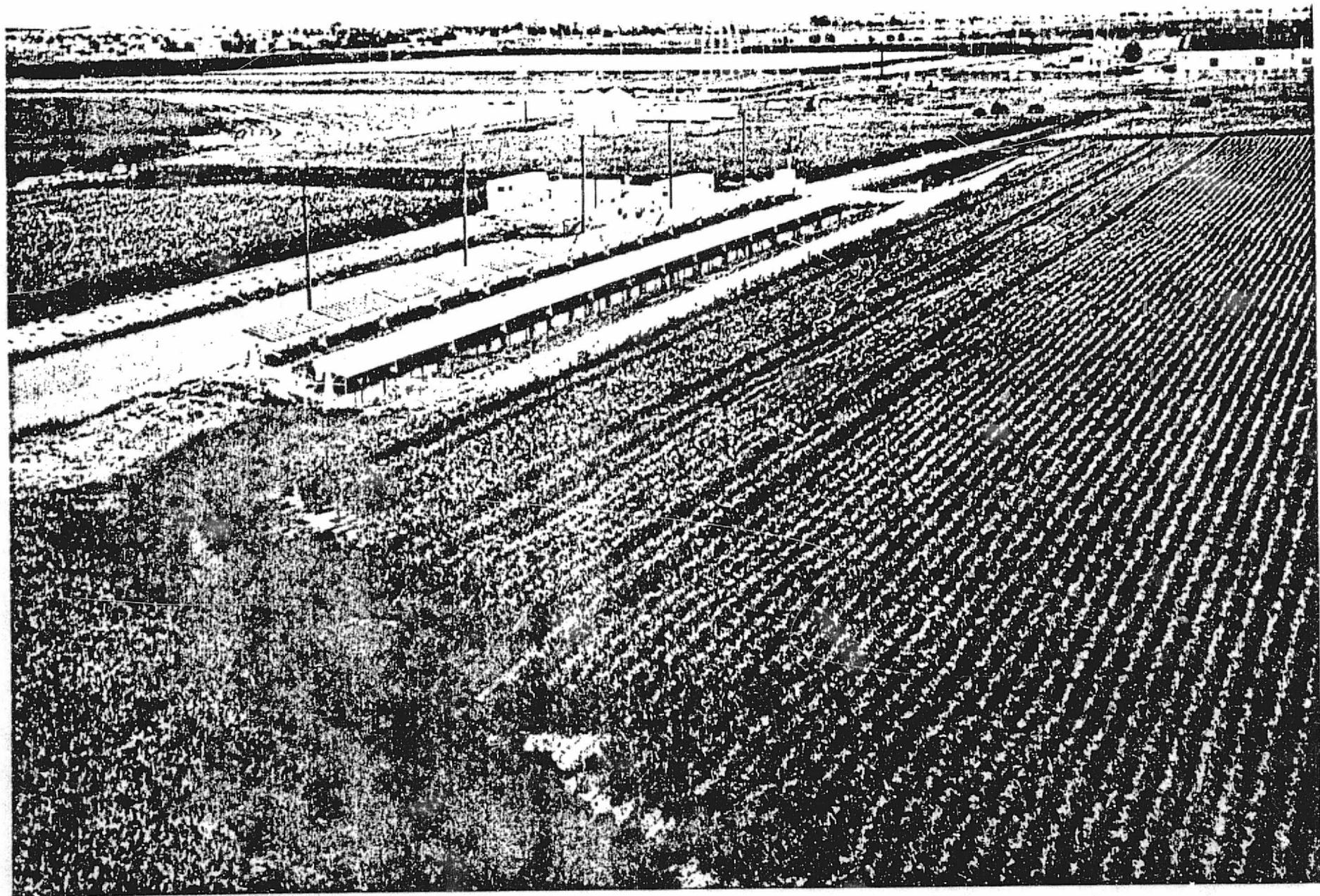


Figure 13.



Figure 14.

operation without sunlight in case they have heavy overcast.

Next slide, please.

(See Figs. 15 and 16)

This is a residential application, strictly showing -- and there are developments under way for house-top photovoltaic panels in two forms. One is in flat panels as shown here, and in the next slide we will see panels that are configured much like shingles. In either case they offer two benefits: one, of course, to serve as a rooftop serving to, of course, hold off rain and snow and wind and other things as well as insulate the rooftop, as well as provide electrical power. Both of these are under development at the present time.

The next slide, please.

(See Fig. 17)

A larger and what might be called an isolated or sole site installation would be something of this configuration. These panels could be either electrical or could be heating panels. In this case the configuration was studied just to say typically then you could install onsite enough photovoltaic panels to operate some of the plant as well as the drying system that would be required for this.

Next slide, please.

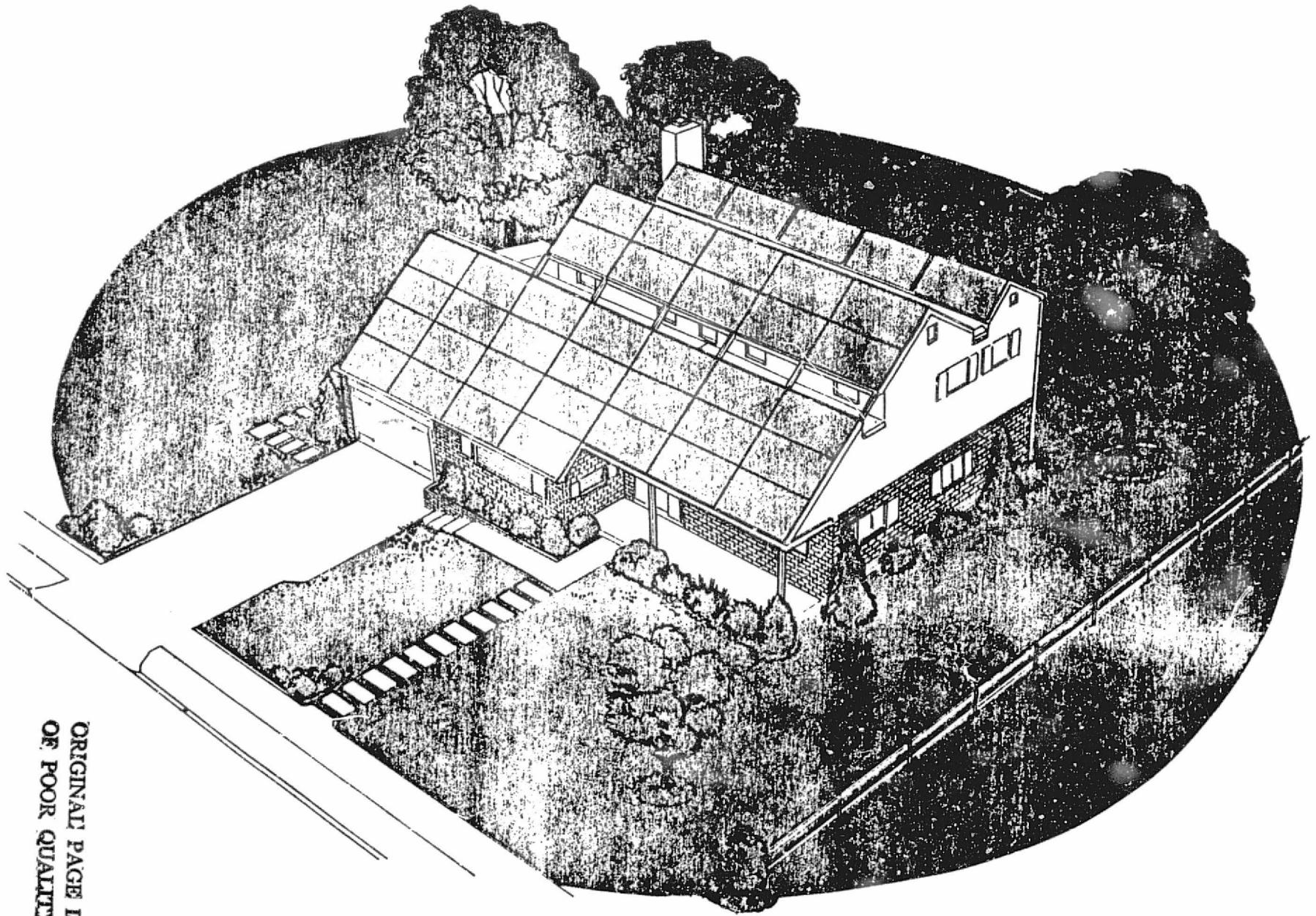
(See Fig. 18)

Finally, the large central power station configuration would be something of this kind where you would have large areas of panels installed in remote areas so that your land usage and costs would be as low as possible, at the same time covering a large central installation that could then feed the electrical grid with the output of it and, of course, transmit the electrical energy to wherever it is needed in the area.

I think this completes then what I would like to say regarding the photovoltaic program. Could I invite any questions at the present time?

MR. EMBER: Robert, I just wonder if you would do two things: one, the audience here, half of the audience does not have a technical background. I wonder if you could tell them what you mean by the efficiencies and so forth, the efficiency of 13 percent. The second thing is that some of the audience here are interested in knowing what can be done today or by 1980 relative to the installation of photovoltaics at their sites basically. I wonder if you could give us some comments on that.

MR. FORNEY: First of all, in regard to efficiency, I used two efficiency numbers. One is the cell efficiency. That is the efficiency numbers. One is the cell efficiency. That is the efficiency of taking



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Figure 15.

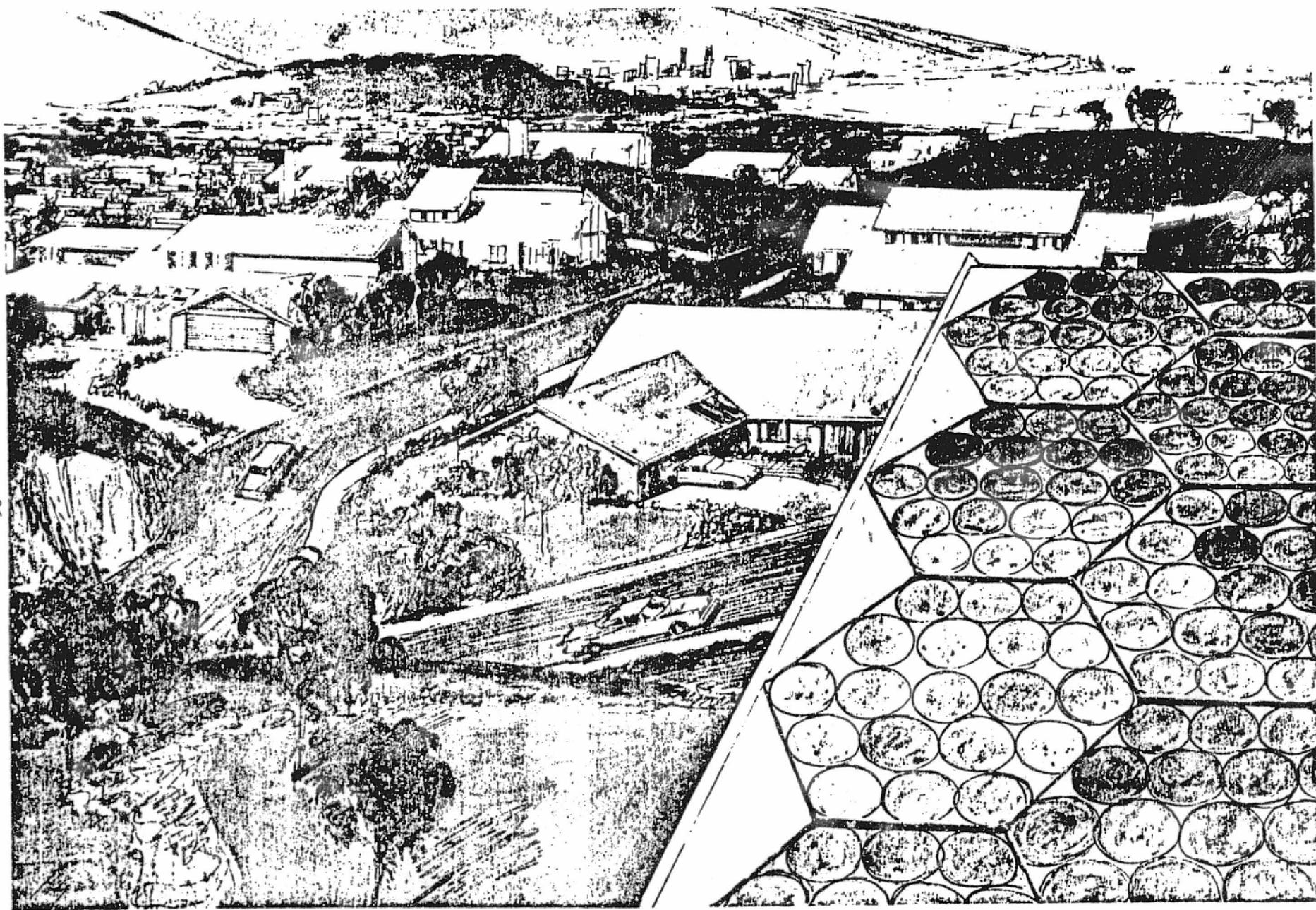


Figure 16.

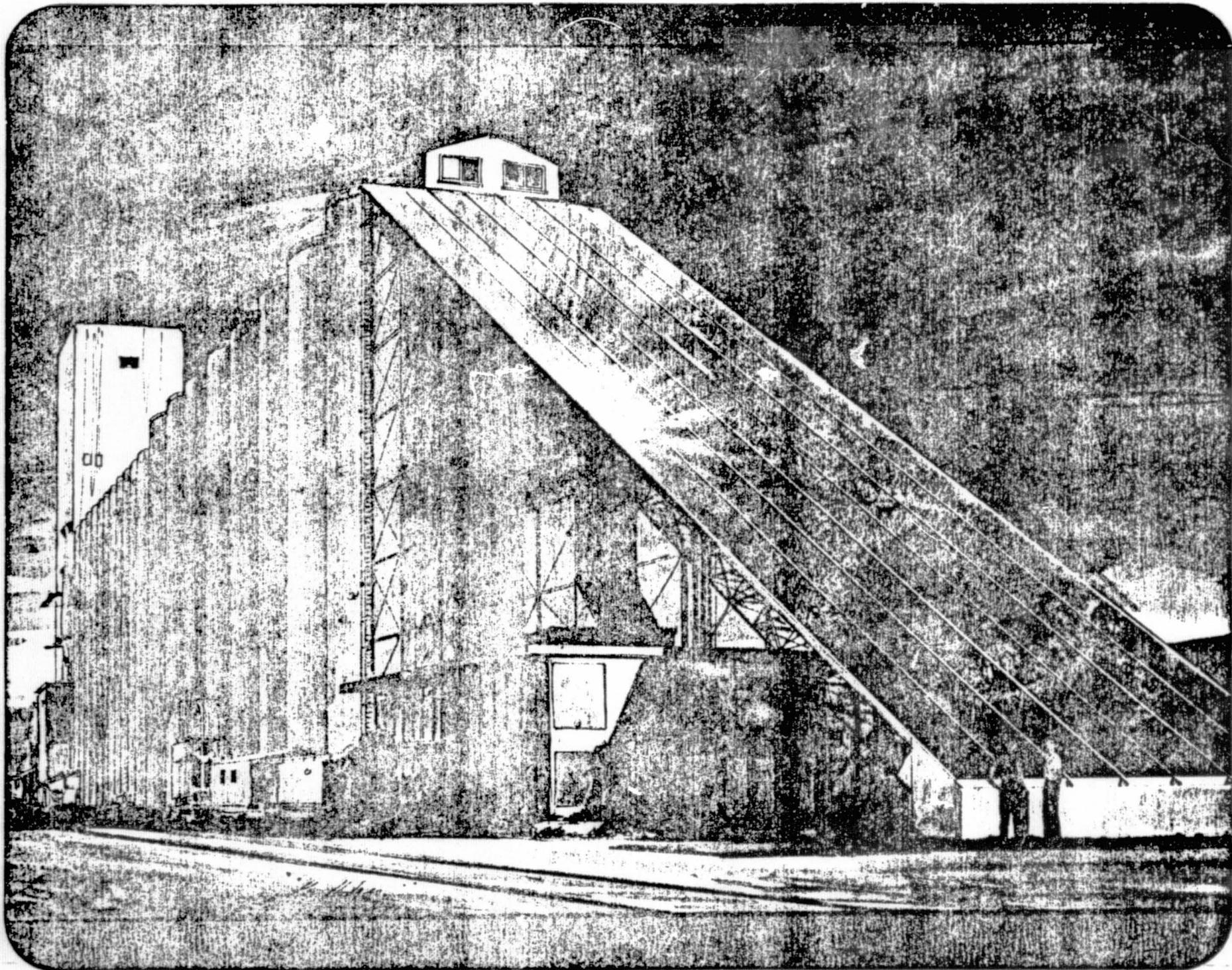


Figure 17.

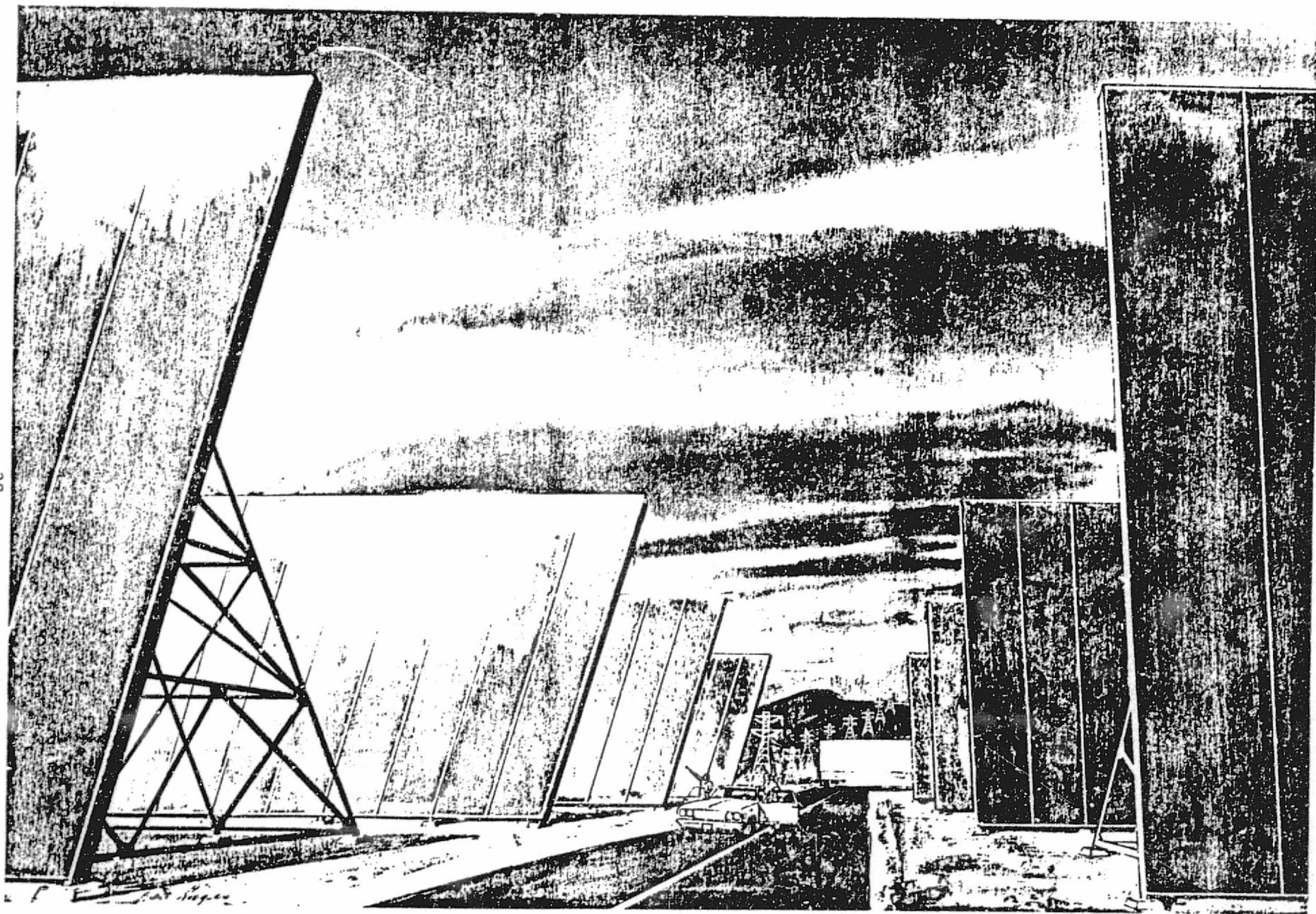


Figure 18.

the solar energy impinged on the surface of the cell and comparing it to the electrical output gained from the cell. I used the term earlier a thousand watts per square meter of equivalent electrical energy available from sunlight at the surface. That would be if I had a square meter of sunlight on the surface I should be able to get a thousand watts electrical energy out of it. Actually, we can only get a hundred watts out of it from a square meter. Therefore, the efficiency of the conversion is 10 percent.

So first we must develop a cell with reasonable efficiency and then we must package that cell into an area such as this with as high a density of packing as possible so that the maximum usable surface is available for the sunlight to impinge on and take the maximum, therefore, energy out.

That conversion efficiency is what we call the module area efficiency. Today, we are typically, when we buy, in the ballpark of 5 to 7 percent efficient. The numbers I used were 10 to 13 because as I said, the new generation of modules that we have in tests now are achieving from 10 to 13 percent efficiency due primarily to the high packing density. So, as a consequence of that, the efficiency of the cell runs presently from 11 to 13 percent. When you pack those together in an area like this the efficiency of the total module then becomes something in the order of between 10 and 13 percent.

So that is the efficiency. And then the important thing is how much does it cost you to install this kind of a device over a period of time compared to the amount of energy you get out of it, and then you would compare that to the cost of other energy.

In regard to the second question, what can you do now or in the near term for your facilities or your installation, the examples you saw here are in fact operating and operating quite well. The reliability is holding very reasonably. I don't say that reliability is still super, but it is well up in the objectives that we were trying to accomplish and it is going higher.

The installations that you see are primarily prohibitive to most on the basis of their high cost because of the photovoltaics and the rest of the system as well. If I can set the cost aside for the moment, though, today with what you saw here and the demonstrations that are being designed and implemented, there are power systems then that could be brought together that would range anywhere from the small few watts on up to hundreds of kilowatts, and these are being deployed or will be deployed in reasonable good form.

I know there are many, many smaller applications today. For instance, I believe Edison is installing locally a 3 kilowatt system to drive air conditioning pumps for their building -- their headquarters building.

That is common throughout the country in limited cases. But again it shows it can be done, and it is primarily one of what would be considered cost-competitive and/or if there is an absolute need to

detach yourself from a particular source of energy, to go to complete solar, I think the technology is there and the industry is being prepared. It is not yet a fully developed industry by any stretch of the imagination, but I think that our technologies are ready to be moved in and begin to be applied. But it certainly would have to be considered on a selective basis and one in which there would need to be a continuing management effort on it to optimize its operation and to maintain it before the reliability would be expected.

Any other points?

ATTENDEE: In regard to I think more applicable to concentrators than flat panels, what is the consideration total energy application to where you can actually utilize heat as well as the energy conversion?

MR. FORNEY: The concentrator system, first of all, two things. They do depend upon cooling because of the high concentration of solar energy on the small cells. So there is a high intensity temperature developed there which must be carried away. However, on the other hand, carrying it away makes that high temperature available for other uses, and generally it is cooled primarily, through liquid cooling devices, although air cooling could be used and could be a means of carrying the heat away from the concentrator. So there is heat available as well as electrical energy available of reasonably high temperatures from concentrators.

In the case of flat plates, there is also under development what is called a hybrid system, flat plate photovoltaic modules that do employ either water or air cooling and draw away from the cells within the collectors the heat that is also transferred for other uses as well. But there is higher heat available from the concentrators.

ATTENDEE: For systems on the order of about 200 kilowatts and for the storage power like batteries, in terms of size and in terms of cost, I notice that you are planning to reduce the cost for the cell itself. But what about the batteries themselves?

MR. FORNEY: Yes. In the Department of Energy, in conservation and another area of the organization, battery development is under way as well as other storage techniques that I showed, flywheels, compressed gases and so forth. But battery technology is also being sponsored, or development is being sponsored.

ATTENDEE: Your seven or eight manufacturers, are they all using that same silicon?

MR. FORNEY: Yes. Silicon is the material for the semiconductor process. All of those are presently used. There is no other use of

material today available on the open market. The next one to emerge probably will be cad sulfide. There are two companies presently developing products that eventually, in the near term, should be available on the open market. One of those is Shell Cil along with the University of Delaware in developing cad sulfide panels, and a new one in El Paso called Photon, Incorporated, which is a subsidiary of a European oil combine, which is also gearing up for production. But neither of those, as yet, has delivered a product.

ATTENDEE: RCA has got some allegedly low-cost material. Have you heard about that?

MR. FORNEY: Yes. That is also being sponsored. That is another form of silicon and is capable of being applied in thin film characteristics which has a benefit because it can be spread easily and effectively over quite wide areas. But that is also being sponsored for development now.

ATTENDEE: You mentioned, I think, five to six firms participating in your project, and maybe I misunderstood. You said, I think, one small company.

MR. FORNEY: Yes.

ATTENDEE: Why would the ratio be such?

MR. FORNEY: Well, I will tell you primarily why. We had four small companies involved at the beginning of the program and two of those sold out to oil companies. One of those most recently was Arco who bought up Solar Technology in the San Fernando Valley. So, therefore, it is now a big company. The second one was the same way. A third one did drop out of production.

So we have lost three, two because of buyouts by large companies. That leaves presently in the mainstream of our work, at least for manufacturing of these arrays, one small business, Solarex of Baltimore.

ATTENDEE: I wanted to ask what existing centralized storage systems like pump storage, sump power systems do we have; what significance they might have in the economics of photovoltaics.

MR. FORNEY: Well, I think the easy answer is primarily because of the size. I believe today Los Angeles Metropolitan Water District or Los Angeles Bureau of power -- you know, Water and Light, use the system of pumping water at nighttime when they have excess capacity and then deploying the water back through turbines in the daytime. The benefit of that is primarily that huge quantities of water can be stored and shifted and applied as compared to batteries which are very, very costly to have large storage capabilities right now.

Also, the problem with the batteries compared to water pumping is that the battery is DC power and you may have large quantities of AC power needed, of which water provides you with AC power very readily through the turbine-drive system using alternators.

But it is primarily a form of economics right now. Batteries are costly if you go to huge installations.

ATTENDEE: So the pump storage would be preferable?

MR. FORNEY: Yes.

Now, this installation of 250 kilowatts in the Mississippi Community College installation, I believe that they are going to run something on the order of -- I am not sure of the exact number of batteries for storage -- they are developing, though, a very advanced technology, iron redox battery technology. Now, it is risky, but if proven successful it will be a real step forward from a technology standpoint and an economics standpoint as well.

If that doesn't materialize in the next few months then they will shift over to lead acid batteries to accommodate the system.

ATTENDEE: I just wanted to check to see if I understood. You mentioned the three kilowatt air conditioning installation that Edison has.

MR. FORNEY: Yes.

ATTENDEE: In the context of it being cost-competitive? Is that what you said?

MR. FORNEY: No. I meant that it was being set up and operated as a demonstration. I didn't mean to make the statement that it was cost competitive at the present time. It is just that it was beginning to be operated for results by the industry.

Any other questions? All right. Thank you.

(Applause.)

MR. ROBERT ROSE: Thank you, Robert.

The next speaker is Mr. Casey Mohl who will talk to you about geothermal systems.

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## GEOHERMAL SYSTEMS - C. F. MOHL

MR. MOHL: Well, the first thing I should really make clear is that unlike the solar array process discussion that preceded this one, there is no major JPL project involving geothermal efforts, rather, we have a program that consists of several specific tasks unrelated to a particular project.

Our present funded effort consists of specific tasks in study work in which we support DOE, Department of Geothermal Energy, and particularly SAN, and also the Energy Commission in doing some of their study efforts, technical support and their study efforts in helping in their decision-making.

One of the outputs of such a study is a recently published "Analysis of Requirements for Accelerating the Development of Geothermal Energy Resources in California." Unfortunately, I can only wave it at you because our contract didn't supply sufficient funds to publish 500 of these things. Hopefully DOE will make them available for further distribution. I think it is an interesting document. Most of the work was put into it by Chuck Fredrickson and I think it is a very good analysis for the requirements for acceleration of the geothermal energy in California.

Another task that is on our program has been a small research and development task, in the area of elastomeric materials. A lot of you undoubtedly know, one of the problems with geothermal wells is that the environment for downhole instrumentation is considerably more hostile than the environment for downhole instrumentation for oil wells. So we have a task here where we are trying to develop materials that can be used for O-rings and other material applications in downhole instrumentation that can survive in this hostile atmosphere with more success than present equipment.

A further task that we have had is an engineering and economics task where we are really in the unusual position of being a subcontractor to Desert Hot Springs. Desert Hot Springs has been trying to determine how they can more effectively utilize the underlying low temperature resource at their disposal out there. This is one of a family of engineering and economic studies that was funded by DOE, a year or so ago, where they wanted to look at specific reservoirs and specific applications.

Now, a further task that we have been involved in, and probably our major task, -- undoubtedly our major task -- is the procurement and test and evaluations of a helical screw device. Now, a helical screw device, which I will talk about later, is essentially a wellhead unit which would probably be the maximum size of five megawatts, but we are not sure of that. The present one we are building is a one megawatt size. This is a device that can work off a wellhead. It is tolerant to brine, containing a high percentage of the salt solids and is also

tolerant to an input of steam that has a high percentage of water. It is not sensitive to -- the normal turbine in a power plant situation requires nice, dry steam. High-temperature dry steam is what I would like to see. In this particular case, it would be nice if we could have a turbine work off a wellhead that was relatively insensitive for that.

As for the reasons for a wellhead device, in an oil well situation, once you get a well drilled and oil starts to flow you can put it in barrels and sell it and start getting a return on capital in a reasonable length of time. Now, with a steam well, once you find it you still have a liability on your hands. You can't do anything with it, you can't sell it to the utilities until you prove up the whole field. It would be nice if you had a device that you could put on a wellhead and start using it to generate electricity for housekeeping purposes or driving machinery that you have in the field; some immediate return on capital. So, essentially, that was our thrust in being involved in this particular program and we worked with HPC, Hydrothermal Power Company, on that project.

Unlike the speaker ahead of me, our budget isn't \$27 million, it isn't \$10 million; it is more close to \$1 million, and most of that is pass-through money that goes to the developer of the helical screw. So that helps to put you in perspective as to the magnitude of our program. I think it is small, but our interest in geothermal is completely opposite that and JPL's interest in geothermal is very large.

Now the rest of the talk will be generic in a sense. I will discuss the present status, the future potential of geothermal energy, use for electrical generation and for direct use. That is, instead of using energy to generate electricity, to put it to work in heating applications, cooling applications and whatever anyone can think of to make this low-temperature resource a useful item.

Could I have slide 1, please.

(See Fig. 1)

For those unfamiliar with the geothermal -- the derivation of geothermal in general, I put up this generalized geothermal reservoir slide which shows basically the heat being derived from the magma which is located considerably underneath the surface of the earth; conduction then lets the heat rise. On the left, you will see a steam filled -- well, first, on the right-hand side, is a representation of a water-filled reservoir, hot water trapped in the rock overlying heater rock that is referred to as a vapor-dominated field where you have entrapped water and above it fractures above the water line capable of being filled with steam. In other words, a steam dome essentially in the vapor-dominated field. When you drill down into the steam dome rather than drilling all the way down into the water reservoir, what comes out of the well is steam, and as in the case of The Geysers it is relatively high-quality steam and it is led directly into the turbine in a normal power plant operation.

Unfortunately, there are not too many vapor-dominated fields in

# GENERALIZED HYDROTHERMAL RESERVOIR

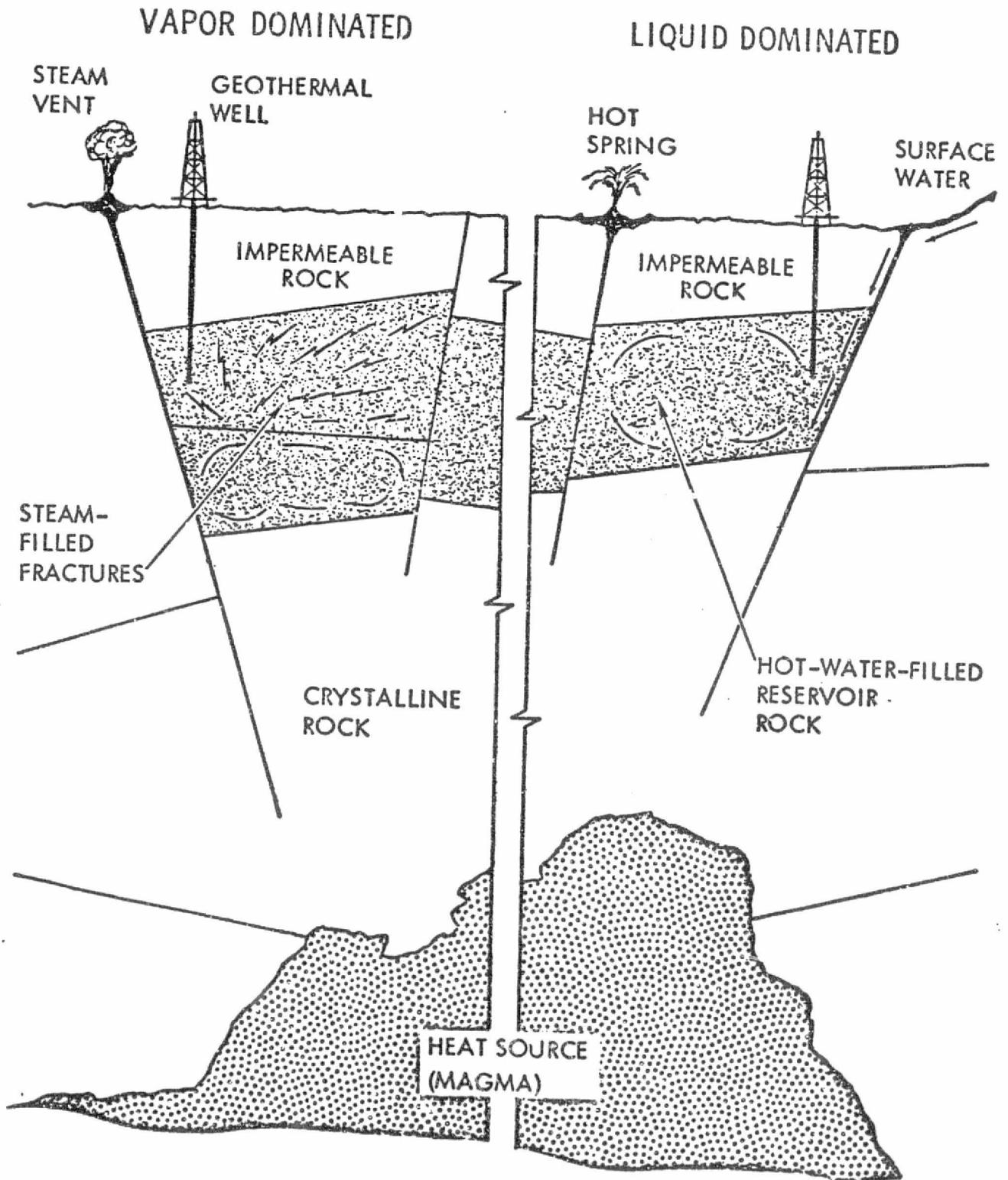


Figure 1.

the world. The field at The Geysers is one of the few currently in production and producing over 500 megawatts on-line right now.

On the other side it shows a separate case where the entrapped water has no steam vents, there are no fractures capable of being filled up with steam, and when you drill down into the reservoir you tap into a water region and what comes out of the well is a mixture -- is really hot water, and when it is hot enough, depending upon its temperature, you could let it flash and lead the flash steam to a turbine in the normal way. Then you have to dispose of the rest of the water in some way. You could dispose of it or make it useful; you could use it for heating and cooling, if you had a market for it.

Unfortunately, in some places there is not a market for it. For example, in New Zealand, at the more active field, they produce about 145 megawatts of electricity from a liquid-dominated field, but after they separate the steam from the water they just throw the water away and don't make any use of it. The power plant is out in a relatively remote area and there are no heating needs or applications for it at that particular site.

On the other hand, in another locale they have a wood-processing plant, a lumber plant, and that plant uses the equivalent of over 85 megawatts of electrical energy, for direct processing, for wood drying, and for the various processes in the wood plant. This is a very effective way of using it.

In any case, these are two separate schemes for geothermal power plant generation, the vapor-dominated and the liquid-dominated fields.

Now, if there is no water, then we have what is called a hot rock situation. You have the heat, but you don't have the water for transporting the heat to where you can effectively use it. There are experiments going on at Los Alamos where they drill down into what they consider the hot rock situation, fracture the rock and introduce water; they import water and introduce it down into the fracture, and are experimenting with how to obtain power, how to obtain hot water back at the surface after introducing their own water.

Next slide, please.

(See Fig. 2)

Now, this slide shows where the known geothermal sources are in California. The most important field is The Geysers, as I mentioned before, which is north of San Francisco. That is a vapor-dominated field, as I explained in the prior slide, and it is currently under production producing over 500 megawatts on-line. The field is estimated to be capable of carrying 2,000 megawatts, with full development. Of major importance to future growth in geothermal use for electric generation is a field under production verification in Imperial County. It is a liquid-dominated field. So there are difficulties in bringing it on-line as compared to The Geysers. The costs are relatively uncertain.



There are four major areas. They include the Salton Sea, Brawley, Heber and the East Mesa areas. These reservoirs have slightly different characteristics. Brawley and Salton Sea are relatively hot. They run around 600 degrees Fahrenheit which is a nice temperature for use for the production of electricity. However, there is a bad side. The bad side is that the total dissolved solids that they contain are very high. So you have a problem relative to how to use those economically and how much it will cost considering that the handling of the dissolved solids will cause downtime and other economic problems.

Now, as for the other two sites, Heber and East Mesa, the resource there is relatively clean. But the problem with the East Mesa site is that the temperature is much lower. It is in the 300-degree Fahrenheit range, which is at the lower range of where you would expect to produce electricity. Now, on the Mexican side of the border there is a 75 megawatt plant on-line already. I guess you have to ask; given the Mexican plant, in the same general reservoir area, why is Mexico on-line and the United States, with its superior technology, not on-line? Well, consider that the Mexican plant was built with government capital. That is one impediment removed. In addition, the Mexican plant did not worry about reinjection and did not worry about other environmental considerations. They just dump their effluent out on the ground and pond it and they just don't worry about it or haven't worried about those things up to now.

A third factor I believe in bringing the Mexican plant in ahead of the United States is the fact that their particular effluent approached the heat content of the Brawley and Salton Sea fields and approached the Heber and East Mesa sites relative to being a clean source. So they were hotter and cleaner than the sites that seem to be available in the Imperial County.

Now, if you broaden our scope to the Western United States you can see in that map over against the wall many geothermal sites available for exploitation.

Just recently in Ocean City on the East Coast they drilled a 7,000-foot well and found a considerable hot water resource at that level which opens up speculation that there might be an underlying pool of geothermal resources all along the East Coast. My understanding is there is a drilling program in mind to investigate whether that exists or not. Now, this would be of considerable advantage to geothermal in general because if the East Coast had a geothermal resource, at least to my perception, we would have a national commitment rather than a regional commitment, and if national support and recognition were given to geothermal then the funding for it would hopefully increase.

When you think of the funding that JPL has on the solar program, it has been a considerable fraction of what the Department in geothermal energy has had for the total nation-wide program. It hasn't had the national commitment for its development that the other forms of energy have had up to now.

Next slide.

(See Fig. 3)

Now, this is a rather difficult slide. It is essentially based on a United States Geological Survey estimate of the total heat content available to California, and that is without regard to whether it is recoverable or not. The units in this case are given in quads, where a quad, as it states in the lower left part of the chart, can be equated to 170 million barrels of oil. So the potential for geothermal energy is great.

Now, while all that is showing there is great potential, we are really only in a position to recover with our present technology, resources that are in the hydrothermal domain, the vapor dominated (steam) and liquid-dominated (hot water). For electric generating purposes, we are really only interested in those temperatures that exceed 150 degrees centigrade, over 300 degrees Fahrenheit. That doesn't mean that the intermediate temperature resources are not of interest. Those resources are of great interest and the development of those resources should be accelerated to help the country in its energy program.

Now, the hot rock potential is also very high, but as of the present there is only experimental work being done at Los Alamos and it really isn't in a position yet to come on-line.

Could I have the next slide, please.

(See Fig. 4)

In considering the use of geothermal energy for electric generation it is instructive to look at a particular time line. The time line starts with the initiation of land acquisition, and this is when you are going toward your first plant, the first opening-up of a new field. Your first concern is to acquire the land and at this point in time you don't know exactly where you are going to site the plant. So you have to acquire a sufficiency of land to allow for your exploration process, and you are concerned with obtaining the legal rights to obtain the underlying resources. Fortunately, in California that right has now been defined as the mineral rights that you are concerned with obtaining. It has been fairly cloudy up until recently, but recent decisions have clarified it in California as a mineral, so at least you know you want the mineral rights.

Then you go into a period where you are acquiring the land and have to be concerned with environmental planning. The requirements and complexity of the environmental planning diverges radically, depending upon what sites you are in. Every site has its own problems.

Subsequent to that, you must characterize your resource and determine whether the quantity available is sufficient for your purpose. Now, in a power plant situation you are concerned with whether the quantity available and the quality available would justify the decision

**HEAT CONTENT OF CALIFORNIA'S  
GEOHERMAL RESOURCE BASE  
(HEAT IN GROUND ABOVE 15° C  
WITHOUT REGARD TO RECOVERABILITY)**

RESOURCE TYPE	ENERGY CONTENT IN QUADS*	
	IDENTIFIED	UNDISCOVERED
HYDROTHERMAL		
VAPOR-DOMINATED (STEAM)	75	75
LIQUID-DOMINATED (HOT WATER)		
• HIGH TEMPERATURE (> 150°C)	650	2000
• INTERMEDIATE TEMPERATURE (90-150°C)	30	120
HOT-IGNEOUS	14,700	55,000
CONDUCTION-DOMINATED		
• NEAR NORMAL GRADIENT	> 635,000	0
• GEOPRESSURED	UNKNOWN	UNKNOWN

\*1 QUAD = 10<sup>15</sup> BTU's AND IS EQUIVALENT TO APPROXIMATELY 170 MILLION BARRELS OF OIL OR 50 MILLION SHORT TONS OF COAL

Figure 3.

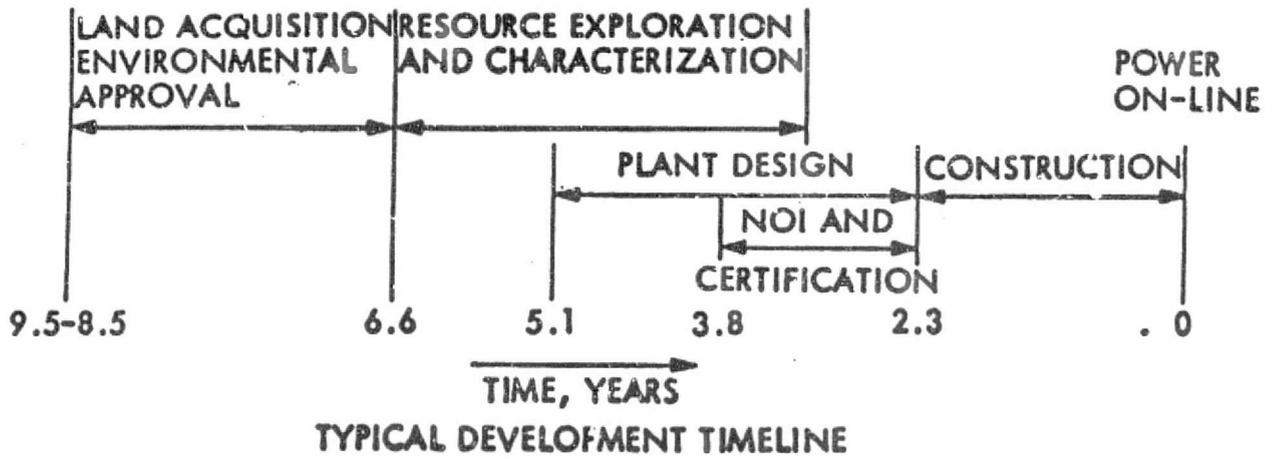


Figure 4.

to make the capital investment necessary to put a power plant on the site and be assured that it will be capable of producing electricity for the next 30 years so that you can write off your investment. That is a considerable concern to the utility people who are naturally conservative in nature -- required to be conservative in nature.

This is basically generated for electrical power plant siting, however, the users of direct energy have a similar problem. For example, if Sunkist Orange Company decided they couldn't get enough gas or oil to process their plant -- and they are an intensive energy user organization, they have to evaporate a lot of liquid -- if they decided they are not going to be able to obtain enough fuel to do their work, for them to consider redesigning their process to use geothermal energy, they would have to go through a set of similar logic. They would have to determine if the cost of redesigning their process, and moving their plant to the geothermal site (probably away from the market and probably away from where they get their oranges) was an investment that they could afford and whether they could be assured of getting a return on their capital. So, no matter whether it is electric or direct use, there is a timeline and the timeline is very important.

Let's consider the case where the resource that we are counting on doesn't really exist. If it doesn't really exist then we are not going to bring it on-line no matter what. But if we consider the case where the energy is there, we are not going to bring it on-line when we need it if we don't start taking the necessary steps in a sufficiency of time so that we can accomplish all these steps and it can be brought on in a timely manner. Even if it is there we are not going to be able to use it if we don't start the process early enough.

Let's have the next slide, please.

(See Fig. 5)

Now, this slide is based on work from Stanford Research Institute and if you stand on your heads I am sure you can read it. It tries to estimate the cost of geothermal energy from the various reservoirs. To calibrate this slide I will direct your attention to The Geysers steam field. It is believed that that field can be developed to 2,000 megawatts over a reasonable period of time. And as the plants that are now on-line are very competitive relative to price versus the price of conventional fuel -- in fact, they can undersell them -- the Geysers steam field will continue to be able to undersell conventional fuels which is the price band that is indicated in that area, 29 to 33 mills per kilowatt hour. And that is one of the reasons for confidence in The Geysers region attaining its full fuel capacity in a reasonable length of time. It is economically very competitive. We have plants on-line and it is understood. But when you consider Salton Sea and Brawley, as I said before, that is a nice hot resource. If it were clean there wouldn't be much question whether it could produce competitive electricity. But it is not clean and you have technical problems in determining how to live with the dissolved solids without undue plant shutdowns. So you have a band of uncertainties.

# ESTIMATED CURRENT COST OF GEOTHERMAL POWER

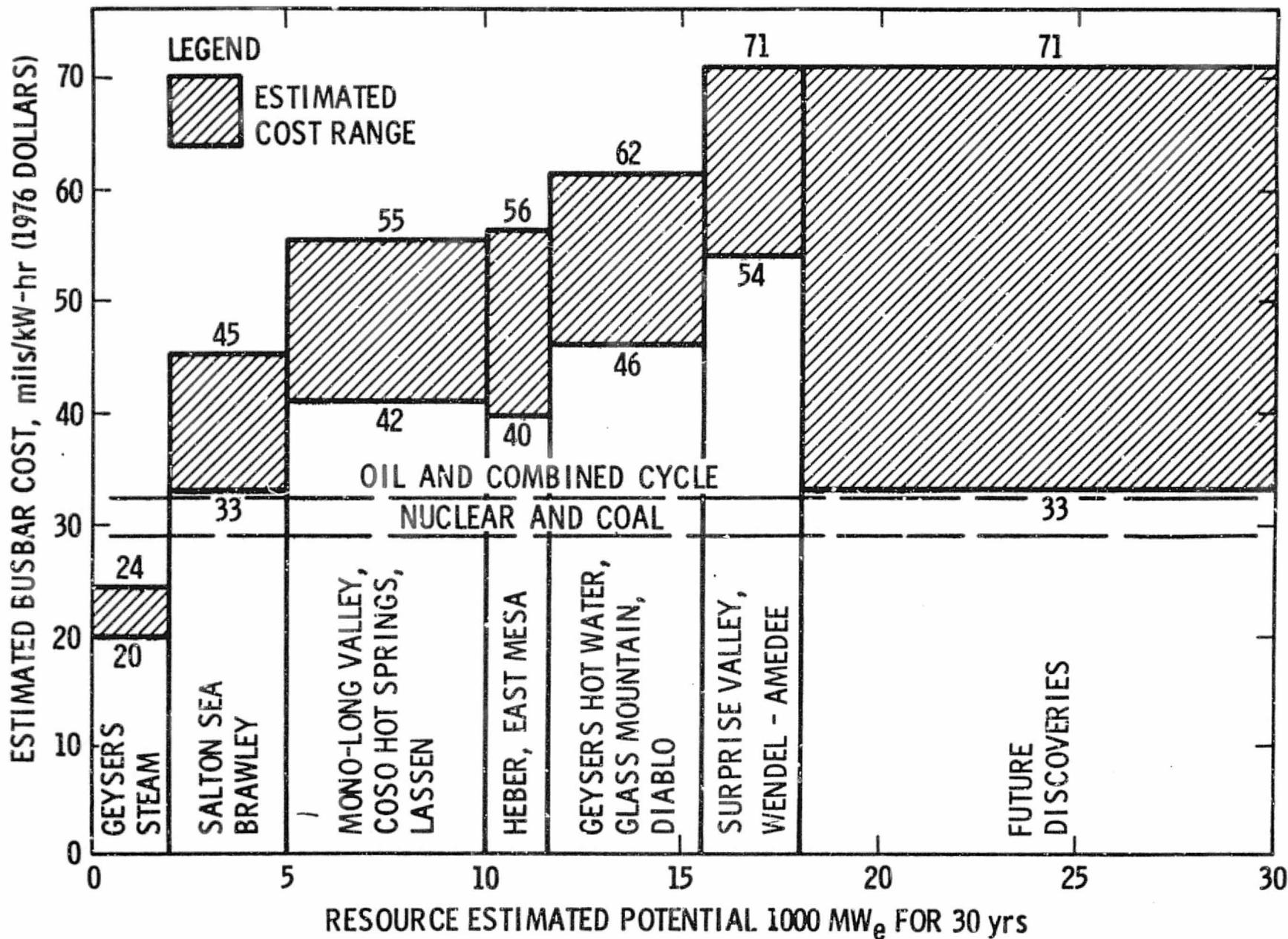


Figure 5.

Now, at the Salton Sea there is a test loop and that test loop merely takes the brine and passes it through and they are trying to learn what their problems are in living with this heat exchanger and with the composition of the geothermal resource at that site. That eventually will be expanded into a pilot plant and there will be cost numbers and eventually, beyond certainty, it will increase and if the price of alternative fuels increases that will be a competitive situation.

Now, in Heber, as I mentioned, we have a nice, clean resource but the economic uncertainty there is whether you can produce electrical energy in a competitive manner with heat content as low as what we find in Heber. Now, there is a competition going on for a government-shared funding of a demonstration plant that would help answer that question. But whether that demonstration plant would go in Heber or not is still open to speculation. There is more than one competitor for that support.

Now, all the rest of the reservoirs have their problems as to the uncertainty of cost of producing electricity from each one of those.

Could I have the next slide, please.

(See Fig. 6)

This slide sums up the present status. In this particular column, as I said before, the sum is very easy. It is 502 megawatts on-line.

Looking down at all the other reservoirs that I mentioned which are under production verification in the Imperial Valley, there is nothing on-line. There is drilling at Coso Hot Springs but that reservoir is still in the exploratory stage.

So using the timeline that we showed you earlier and using information that we obtained from industry, the utilities and the exploration companies, what has been laid out here is an expectation chart of how power plants could come on-line as a function of time.

In 1978 we are relatively certain of the 161 because that represents two plants at The Geysers presently under construction.

As to the rest, the dependency of those plants coming in relates to the timeline and starting your activities at a proper time. If you don't start them at a proper time they move back down the line.

So, to the best of our perception at this time, if an aggressive program is pursued, by 1990 you can have 7,000 megawatts on-line in California.

The message in this slide is if we ultimately confirm the existence of the resources we can have that power on-line. Naturally, as I said before, if our fielding doesn't confirm the existence of a resource it doesn't matter anyhow. The answer in a geothermal program is the drilling and finding of the resource. Until you really find it,

# CALIFORNIA NEAR TERM SCENARIOS (POWER ON-LINE MW<sub>e</sub>)

RESERVOIR	CALENDAR YEAR													
	TO 1978	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
GEYSERS "STEAM"	502	161	245	-	220	220	220	220	110	110				
RESERVOIRS UNDER PRODUCTION VERIFICAT'N														
SALTON SEA			10(F)			50		50	50	50	100	100	100	100
HEBER					50(D)			50		50	50	100	100	100
BRAWLEY							50		50	50	50	100	100	100
EAST MESA		10(P)				50			50	50	50	50	50	50
RESERVOIRS UNDER EXPLORATORY DRILLING														
GEYSERS "HOT WATER"							50		100	100	100	100	100	100
LONG VALLEY									50		100	100	100	100
COSO									50	50	100	100	150	150
SURPRISE VALLEY							50			50		50	50	100
POTENTIALLY HIGH HEAT CONTENT														
GLASS MTN											50		50	100
LASSEN											50		50	100
WENDEL-AMEDEE												50		
DIABLO														50
POTENTIAL FUTURE RESOURCES:														
1980 - 85 (6000)										50	100	150	200	200
1988 - 90 (6000)														50
ON-LINE MW <sub>e</sub> PER YEAR	502	171	255	-	270	320	370	320	460	510	650	850	950	1300
CUMULATIVE MW <sub>e</sub> (TO NEAREST 100 MW <sub>e</sub> )	500	700	900	900	1200	1500	1900	2200	2700	3200	3800	4700	5600	7000

Figure 6.

there is a degree of speculation in everything you talk about.

Next slide, please.

(See Fig. 7)

In addition to conventional utility generation of electricity, the probability of using wellhead generators in 5-megawatt range exists. This slide is JPL's prototype of a helical screw expander which I talked to you about before. Here we see the expander portion of it which is essentially two rotors. A mixture of steam and water comes in the entry port and as the rotors turn the entrapped quantity of resource is allowed to expand and we have a constant, continuous flashing process that could be very efficient. Furthermore, as I said before, the rotor itself is not unlike a turbine; it is insensitive to whether the input resource is high-grade steam or a mixture of water and steam, and it is relatively insensitive to the total dissolved solids.

This particular unit is now at Roosevelt Hot Springs undergoing evaluation tests. It turned over last week for the first time in Utah and it has been running only at a percentage of its capacity up to now.

Now, some of the advantages of any wellhead unit, and of this unit in particular, is that it can be used in remote locations. It could be used in a field that has not yet been fully developed, and it could be used in a field that is incapable of supporting a major power plant. You could still exploit that resource.

Next slide.

(See Fig. 8)

This is an artist's conception of what the installation of our helical screw will look like at the Utah site. As of yesterday, we got some nice pictures in showing how it really looks, but I haven't reduced them to slides yet. Pretend you don't notice the NASA logo. It is really a DOE effort. It is a NASA trailer.

Could I have the next slide?

(See Fig. 9)

Now, in trying to think about the cost of wellhead devices for generating electricity we didn't have any direct experience. We knew that Roger's Engineering in San Francisco had built some 5-megawatt units and shipped them abroad to different countries. In talking to them we got this generalized version of what the cost of a wellhead unit is, and this one was generated without including the cost of the steam. You can see that it doesn't compete with the cost of the power you can get from a standard, conventional utility. So only in exceptional circumstances would you want to use a wellhead generator, and you wouldn't use it in direct competition with the utility.

This is a generalized set of cost curves. It is pretty obvious

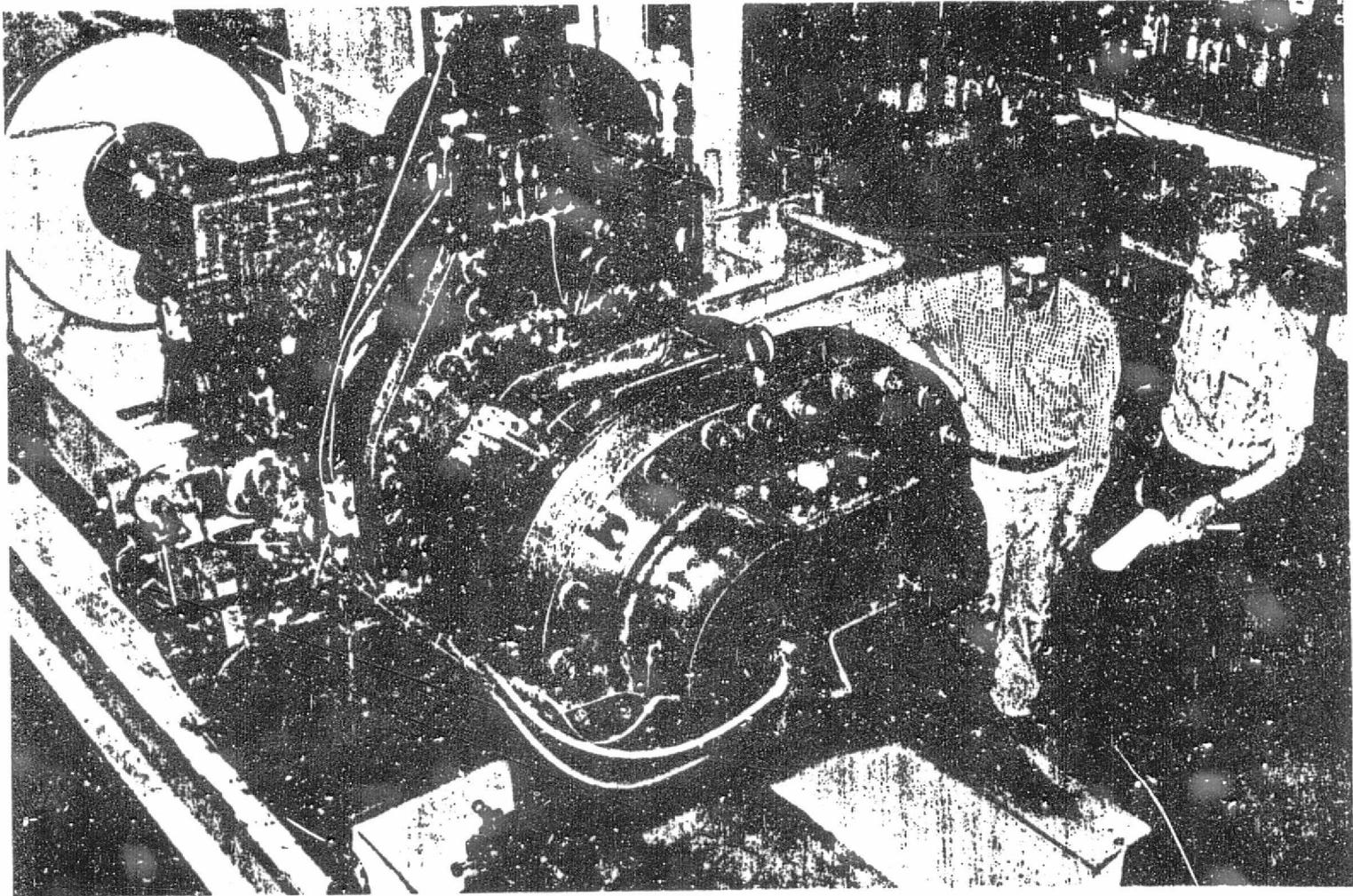


Figure 7.

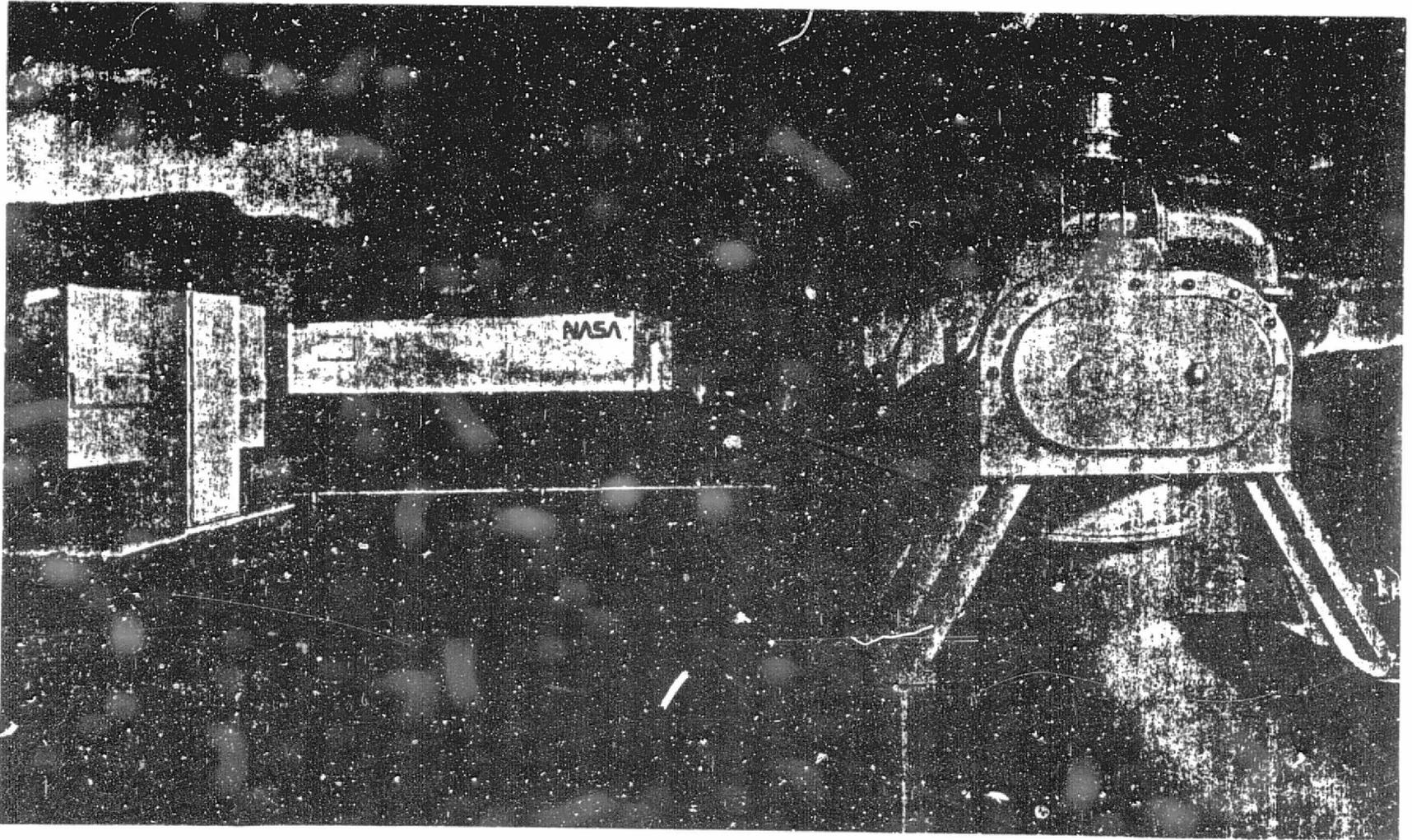


Figure 8.

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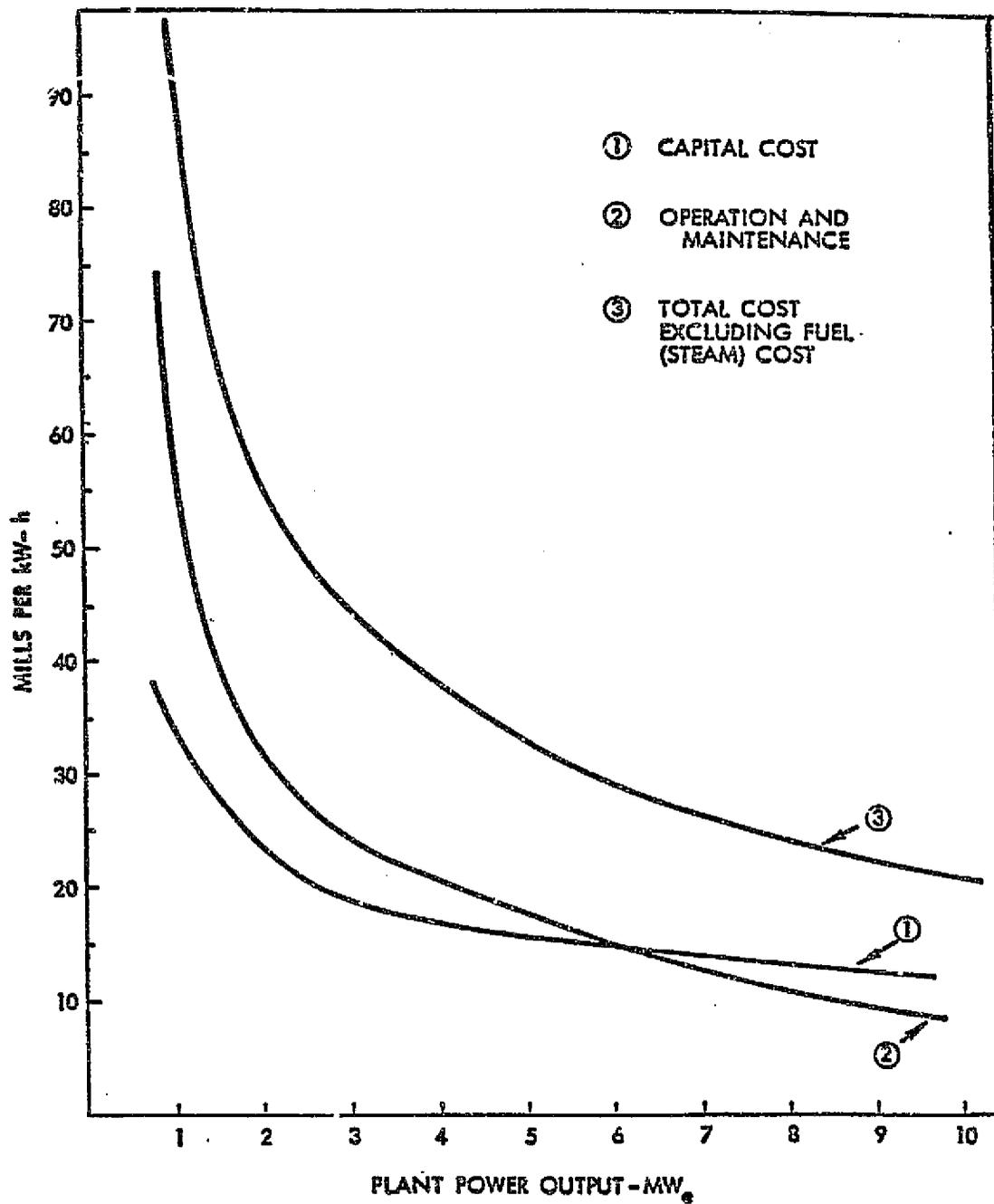


Figure 9.

that as you get in the 1-megawatt range the cost becomes prohibitive. When you go up to the higher ranges it starts to become slightly competitive with the power plants.

Now, moving on briefly to direct use of geothermal energy. The present status of it is that it is used in California for spas. For example, at Desert Hot Springs they have a resource there that has relatively low temperatures and they use it to heat their swimming pools and mineral baths, and they advertise it as having medical and therapeutic values.

This is not too inconsistent with other people. In New Zealand there is a whole hospital that solicits arthritic patients and they have a big trade. It is the Queen Elizabeth Hospital in Rotorua. They have a big trade there where people come in and go into hot baths and take massages and get at least temporary relief from their arthritic condition.

Now, the other uses for it are obviously heating, space cooling, food processing, wood drying, grain drying, and a multitude of other uses. It can be used directly without being used for the generation of electricity. In Iceland it is used for heating almost the entire city of Reykjavik. It is also used there for greenhouse applications. In New Zealand it is used to heat and cool a modern 100-room hotel.

Recently, DOE has caused many engineering and economic studies to be generated to determine applications and costs of doing specific things at specific sites. You must remember that geothermal energy is a very site-specific resource. Every site you go to, the temperature is different, the composition, the brine chemistry is different, the geography and climatic conditions are different. So really, to understand your problem, you would have to do an engineering, economic and engineering analysis of what the resources are at the site, what you want to do with those resources and whether you can do it at a reasonable and competitive cost.

Now, DOE, as I told you before, did cause many of these engineering and economic studies to be generated and that has given us some baseline to work on. We hope to follow up these studies with field experiments to improve these studies and hopefully be funded to actually do the work indicated in the engineering studies. Then we can start to develop some case histories as to what it costs and what the profits are through direct use.

Now, there is direct use in the United States. In Klamath Falls, the university there is headed with geothermal energy. Also, there are plans for expanding and heating homes and other buildings in Klamath Falls. But the United States, I believe, has been slow in trying to use that resource for obvious reasons: The past history of cheap gas and oil.

Could I have the next slide, please?

(See Fig. 10)

## COMPARISON OF GEOTHERMAL AND CONVENTIONAL HEATING

### PROBLEM --

- COULD THE GEOTHERMAL RESOURCE AT THE CITY OF DESERT HOT SPRINGS, CALIFORNIA BE EFFECTIVELY UTILIZED TO HEAT A PROPOSED MULTI-USE CENTER?

### GROUND RULES AND ASSUMPTIONS --

- SINGLE STORY BUILDING, 12,000 SQUARE FEET
- SUPPLY SPACE HEATING AND HOT WATER USE
- SITING OVER THE 150°F ISOTHERM
- 20 YEAR SYSTEM LIFE
- 15% COST OF CAPITAL
- SPENT FLUID IS REINJECTED
- COST OF SOURCE AND REINJECTION WELLS SHARED 50/50 WITH OTHER PROJECTS

Figure 10.

Now, going to Desert Hot Springs, it is a very small, specific example. I believe when you talk about direct use small is not bad because we are going to get our profit from direct use by making a multitude of small applications; heating buildings, cooling buildings, making use of the low temperature resource that exists. When you think about the way things occur in nature it is reasonable to believe that for every resource capable of supporting a power plant such as The Geysers there are going to be many more resources that don't have the temperature and quality that can do that kind of work but can still be useful for direct application.

Now, in this particular case, Desert Hot Springs had a new building in mind and they wanted to design it so that it could be heated by geothermal energy. The statistics of the building are very simple: 12,000 square feet, 20-year lifetime, and whatever wells they had to drill they considered sharing the cost 50/50 because the one well they would drill to do this -- and they also would have to drill an injection well -- would be more than ample for their particular purpose -- probably would not require more than 10 percent. You have got to remember in Desert Hot Springs their resource is less than 600 feet deep. The deepest well there is 600. They don't have to go very deep to get a well. Also, it is an alluvial plain; they don't drill into hard rock, so drilling costs are relatively inexpensive.

Next slide, please.

(See Fig. 11)

So, working with that, they found out they needed a capital investment of \$15,000 as compared with around \$2,000 if they put in a regular gas heating system. Eventually, their total cost was \$2,500 as compared to \$3,000. So it was competitive with their assumptions.

Now, the assumptions are kind of shaky on a 50/50 cost basis, and that usually is going to be the case. There is one problem with geothermal energy for direct use. There is an element of risk, as you go into it, and for a small entrepreneur this is not an easy problem to face up to. In this case, for example, if they made a decision to go to a gas unit, relative to their risk-taking problem, they know pretty well what it is going to cost to put that equipment in. They know their capital investment. Relative to their risk-taking problem on geothermal, they can't be a hundred percent sure when they drill a well they will get a live well and won't have to drill again. So there is an element of risk that underlies all decisions in direct use of geothermal energy, given that some entity hasn't drilled the wells and is ready to supply it at the curbstone and all you've got to do is hook in and pay a price for the fluid that you draw.

So we can make that number look more favorable or less favorable just by merely determining what percentage of the well is a true cost to the city.

Could I have the next one, please?

(See Fig. 12)

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## COMPARISON OF GEOTHERMAL AND CONVENTIONAL HEATING

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	GEOTHERMAL SYSTEM	GAS-FIRED SYSTEM
CAPITAL INVESTMENT	15,055*	1,806
ANNUALIZED CAP. INVEST. **	2,405	289
ENERGY COST/YEAR	123	2,803
TOTAL ANNUAL COST	2,528	3,092

\* INCLUDES 50% OF COST OF WELLS

\*\* 20 YEARS AT 15%

Figure 11.

# PARAMETRIC COOLING SYSTEM SIZE AND COST

\*ALL UNITS PROVIDE 200 TONS COOLING

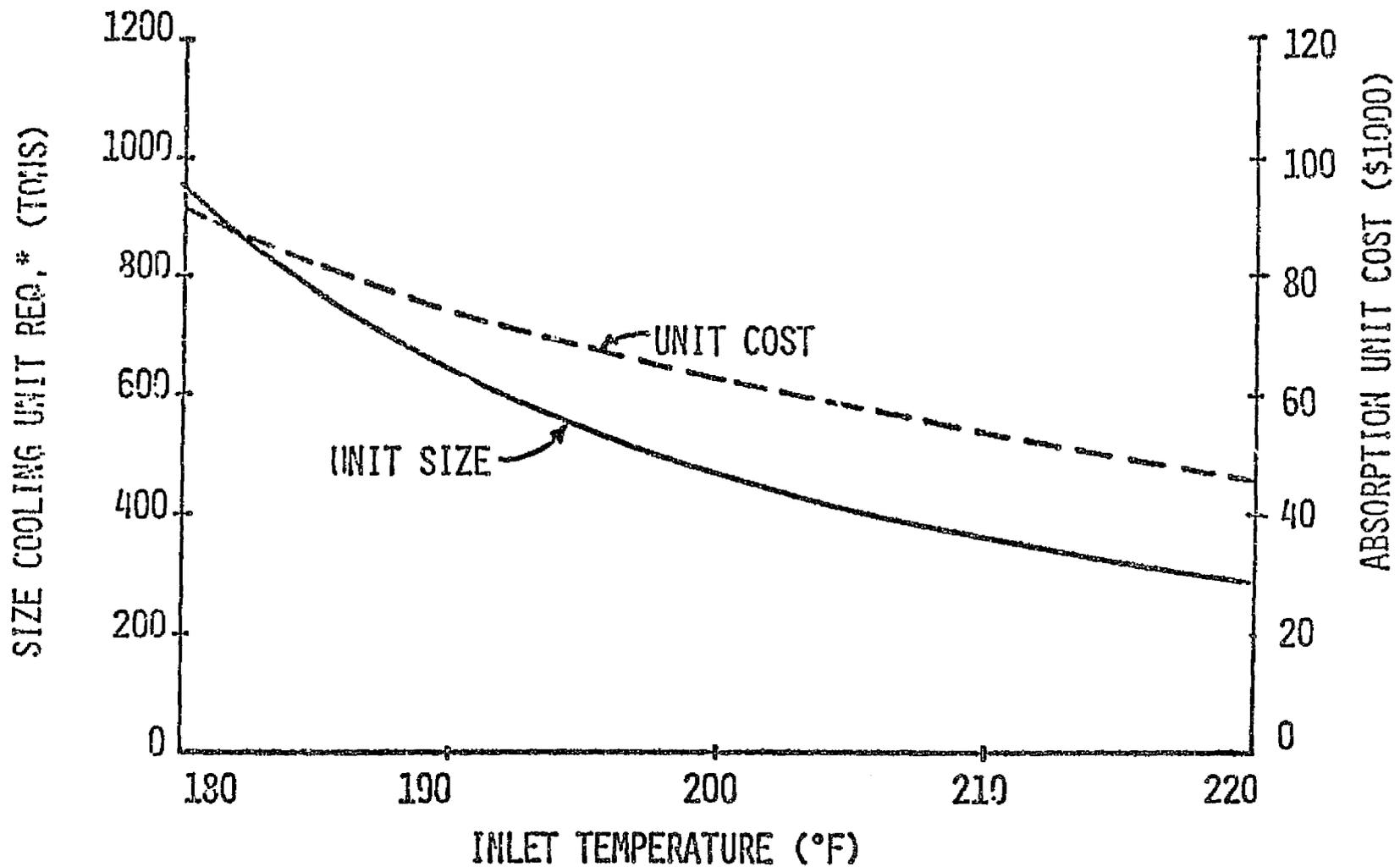


Figure 12.

Now, in cooling you have a slightly different problem. The heating is a very effective use, but in cooling you have to consider your inlet temperature much more stringently.

Now, this particular device, the requirement was for 200 tons of cooling. Remember, I talked about the one hotel in the whole world, that I know of, that is cooled by geothermal energy with a 130-ton unit, but it has an inlet temperature of over 260 degrees Fahrenheit. If you are working in 180-degree range in the cooling cycle, in order to make an absorption unit work, to get 200 tons of cooling you have to have an 800-ton unit and pay the price accordingly. It is very inefficient. So there is a cutoff point where you will not consider using geothermal resource for the cooling problem.

In Desert Hot Springs they looked at that and they were completely out of the ball game because their hottest resource is 180 and the isotherms moving out from that quickly move down to 90 degrees Fahrenheit. So for air conditioning or air space cooling there was no recommendation to Desert Hot Springs that they use it. It was just too costly.

But, as you progress up the temperature chain, the size of the absorption unit that you need starts to approach and get smaller and smaller, and finally when you get out to about 250 degrees a 200-ton unit will do 200 tons work. However, if you have a resource in the 250 degree range or even a 300-degrees temperature range that is a very effective way of using it if you can use it directly rather than paying the inefficiencies of going through a power plant, bring electricity back to an air conditioning system and pay those inefficiencies. If you can use it directly you are far ahead of the game.

Again, you have to have a need to have the place where you are using it located near the site. Site location has been a problem. The use and the site has always been a problem in geothermal direct use.

In conclusion, in the electric generation area a significant effort is under way to accelerate the growth of geothermal energy for that purpose. The state is involved, DOE is involved, the utilities are obviously interest in it, and the exploration companies are interested. So, even though you can fault it and say it is not going fast enough or not intensive enough, there is a coherent effort in trying to bring more geothermal energy to bear on the electric problem.

In direct use it is not as clear that there is a coherent effort. Yet, the direct use could be a more profitable use of our geothermal resources.

However, DOE in the past, and recent past, has funded a series of engineering and economic studies that have looked into the problem and have tried to find specific uses at specific sites, and that is leading now to a set of funded, field experiments which can actually get hardware on the line and get some reel of confidence, and confidence is a big thing. People who are spending investors' money don't like to go out on a limb and come up with dry holes or a lot of machinery that doesn't work. So, having hard-case studies, hard experiments

on-line, will do a lot to help expand the circle of influence that brings more hardware on-line.

So, the next funding effort for DOE is to do that. Hopefully that can be a promising endeavor.

Now, in final conclusion -- and I haven't talked at all in any depth about any environmental problems, subsidence problems. Geothermal energy is generally believed to be more benign and has less environmental impact than other forms of energy. That might be true, but it is not without its problems environmentally. You have subsidence, you have noise, you have water pollution, you have land use conflicts, you have reinjection problems. In liquid-dominated fields where you bring up large volumes of water along with the steam you face a problem of subsidence and the subsequent disposal of all that water without polluting overlying potable water.

So it is not a panacea, but it has a reasonable record up to date and is going good and doing reasonable work in bringing power on-line. And if we would have any kind of reasonable record in drilling successes, in other words, in a drilling program we would find a resource, geothermal energy could be a very significant contributor to our energy problems, and especially true in California.

I will take any questions that you might have now.

Yes, sir.

ATTENDEE: I wondered if you might want to elaborate on your statement about the need to move ahead and accelerate if we are going to realize this ambitious 7,000 megawatt goal by 1990. Do you mean to suggest that there is not now this drilling activity and other kinds of activities that should be going on now or planned?

MR. MOHL: Yes. I certainly would like to see more drilling going on in the Mono-Long reservoirs.

I understand there is considerable drilling going on now in Coso.

Chuck, do you have any comments on that?

(Comments by Charles Fredrickson.)

ATTENDEE: Could the gentleman in the back identify himself?

MR. MOHL: This is Chuck Fredrickson. He is the author of this document that I waved at you but refused to give to you. This is "Analysis of Requirements for Accelerating the Development of Geothermal Energy Resources in California." He is with JPL.

Any other questions?

(no response.)

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MR. MOHL: With that, I will turn you back to Bob Rose.

MR. ROSE: Thanks, Casey.

We are verging on our original schedule.

I would like to introduce Dr. Herbert Davis who is going to talk to you about cogeneration power systems.

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COCENERATION POWER SYSTEMS - H. S. DAVIS

DR. DAVIS: Good morning.

The first speaker spoke about direct conversion of sunlight to electricity. The second speaker spoke about exploiting the vast reserve of thermal energy underground and using it directly for heating or electrical generation.

Cogeneration, on the other hand, refers to the combined generation of heat and electricity.

I am also aware of the mixture in the audience of technical and non-technical people and I will try in my presentation to reach all of you most of the time, but I can't guarantee it.

The next view graph, please.

(See Fig. 1)

In order to have some basis for talking about cogeneration, I think it is important to have a definition. This definition is one that is generally agreed on, although there are others. Cogeneration has been referred to variously as in-plant generation, onsite generation, combined cycle, dual purpose generation, total energy, and MIUS, or modular integrated utility systems, and they are all saying basically the same thing. They refer to, in some cases, commercial systems, or residential systems, and sometimes industrial or utility. So really the terminology depends on where you are coming from.

I will be referring to industrial applications. So this definition, the combination of electrical generation and process heat production specifically for more efficient use of fuel, is the definition I will be using and I believe it is the accepted one.

Let's have the next slide.

(See Fig. 2)

The upper drawing indicates the use, on the left, of 2-1/4 barrels of oil to heat the kiln in some high temperature direct-fired process. What comes out of that 2-1/4 barrels of oil is 5.4 million Btus of process heat used inhouse.

At the same location, another barrel of oil is used to generate 600 kilowatt hours of electricity.

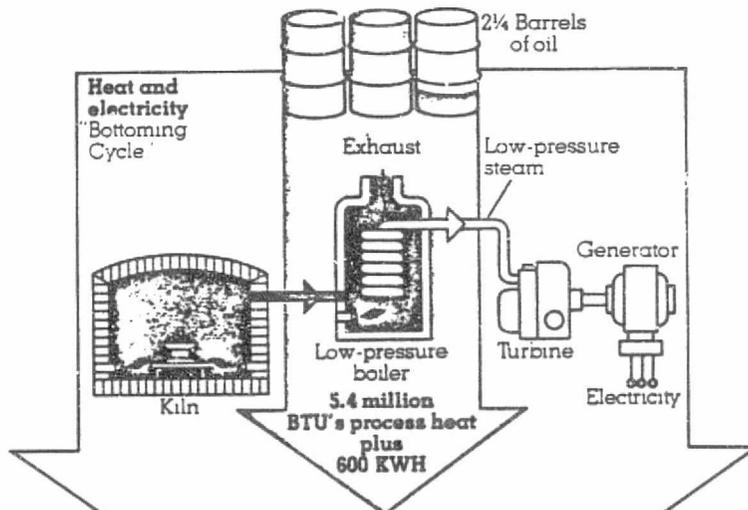
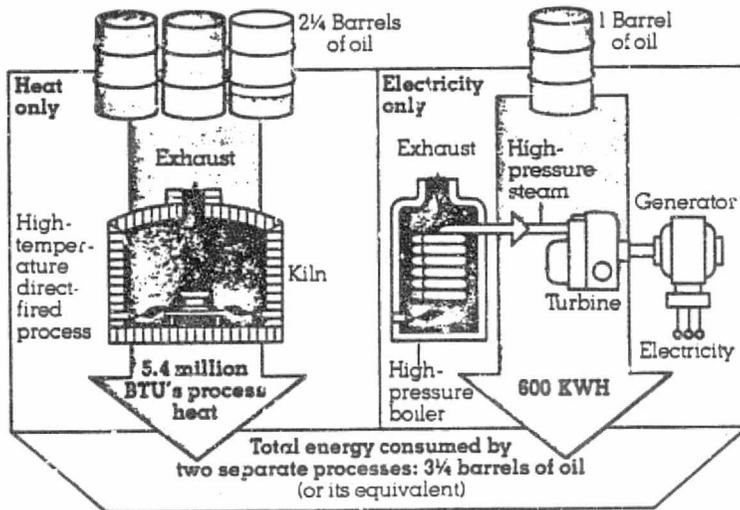
A cogeneration system, when installed, would produce the same amount of heat and electricity but use only 2-1/4 barrels of oil with a net savings, in this particular instance, of 31 percent.

This particular use is referred to as a bottoming cycle cogeneration system in that the waste heat from the industrial process is used

## COGENERATION

**DEFINITION:** THE COMBINATION OF ELECTRICAL GENERATION AND  
PROCESS HEAT PRODUCTION FOR MORE EFFICIENT USE  
OF FUEL.

Figure 1.



**Energy saving: 31%**

Figure 2.

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to generate electricity. The electricity is generated after the industrial process.

The next slide is an illustration of the topping cycle. Next slide (See Fig. 3). One barrel of oil is used to generate 600 kilowatt hours of electricity, 1-3/4 barrels of oil is used for the thermal process. In the lower diagram when a cogeneration system is installed only 2-1/4 barrels of oil are needed to develop the same energy needs. This is a topping cycle because steam is utilized to generate electricity before use in the process. The total energy savings is 19 percent.

Next slide.

(See Fig. 4)

This slide illustrates the basic principle of cogeneration. On the left-hand side where there is indicated "electricity only" in a conventional power plant, the bar on the far left is the energy required to raise the energy from the feedwater, up to point A, which is the energy level at which steam for power generation is produced.

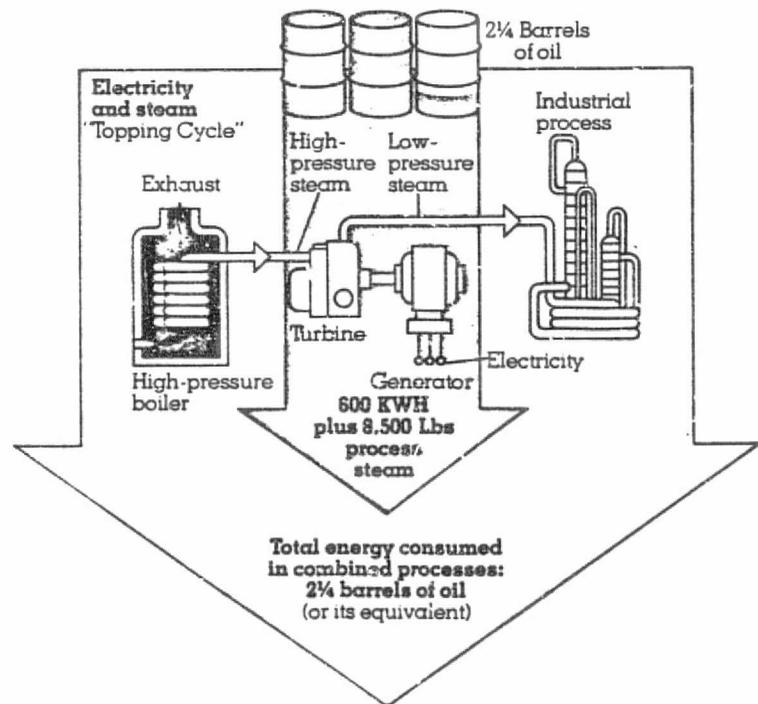
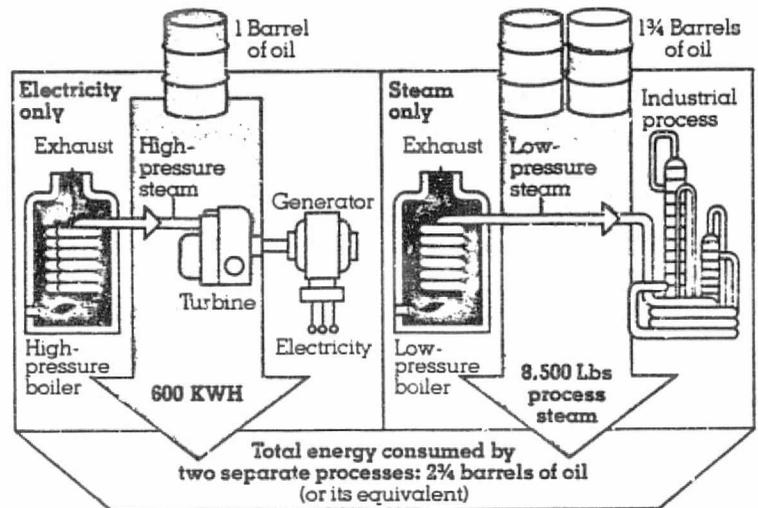
The next bar to the right indicates what you can do with all that energy at a conventional power plant.

Due to the inefficiencies in the cycle at the central power plant, the only energy available for power is from above point C, which is the steam at the boiling point, up to point A which is where the power generation is produced. Everything else, and in fact, two thirds of the energy that was originally supplied, goes up the stacks and is wasted. The efficiency is only about 35%.

The two bars on the right-hand side indicate what happens to the same amount of energy at a cogeneration plant. The energy available for power is indicated from point B, which is the energy level at which process steam is made available at that plant, up to point A. The rest of the energy is not wasted. In fact, the energy from point D to point B, from the water at boiling point up to the energy level at which process steam is made available, is available for the industrial process. Only the energy below the boiling point of water is lost. So the effective efficiency is virtually doubled. These illustrations are schematic, but the efficiency is as high or possibly higher than 75 percent equivalent efficiency.

The bottom line is that by using heat that would normally be exhausted as waste in a conventional power plant, a cogeneration plant can produce heat and electricity for 10 to 30 percent less fuel than if they were produced separately. This represents a vast potential for energy conservation. This potential is not unknown. Cogeneration is not a new concept. It has been around for many years.

At the turn of the century over half the industrial electricity used in industry was generated onsite. In 1950 this was down to about 15 percent, and in 1973 it was only about 5.



**Energy saving: 19%**

Figure 3.

**Comparison of Energy Utilization in a Conventional Electric Power Plant and a Cogeneration Plant**

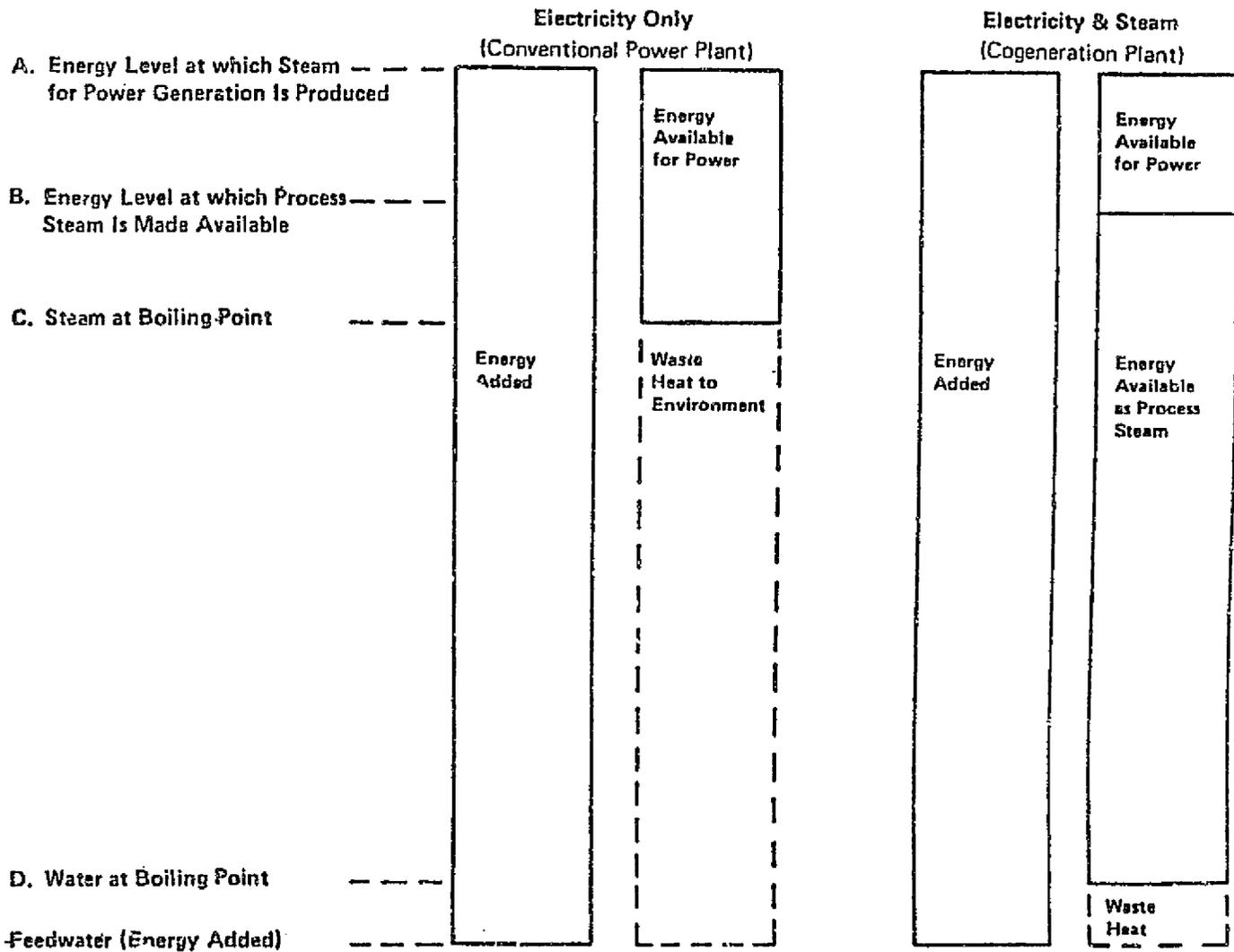


Figure 4.

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By way of contrast, industrial plants in West Germany in particular, cogenerate about 31 percent of their needs.

We have in effect in this country two separate systems for producing energy:

(See Fig. 5)

the utility system and the industrial system.

Industry uses fuel to fire the boilers to produce steam which is used in their process. Electric utilities use fuel to fire their boilers to produce steam which is fed through a turbine generator which produces the power. The waste energy, condensate, is eliminated, brought to a cooling pond or cooling tower and not used. This waste is unnecessary.

The way around this is shown in the next slide with another example of a cogeneration system.

(See Fig. 6)

On the left-hand side is the industrial side of the house which again uses fuel to fire a boiler, but this time the boiler energy is used not only to produce steam, but also to drive a turbine-generator to produce electricity. The electricity is fed to the utility grid in this particular scheme. The electricity could alternatively be used inhouse. In this particular scheme the electricity could be fed, to say, the utility grid and the company, the industrial firm, purchase electricity from the utility. But that is a separate decision.

The point here is that optimum use is made of all the energy.

The next slide shows another cogeneration scheme except in this case it is the utility that is cogenerating.

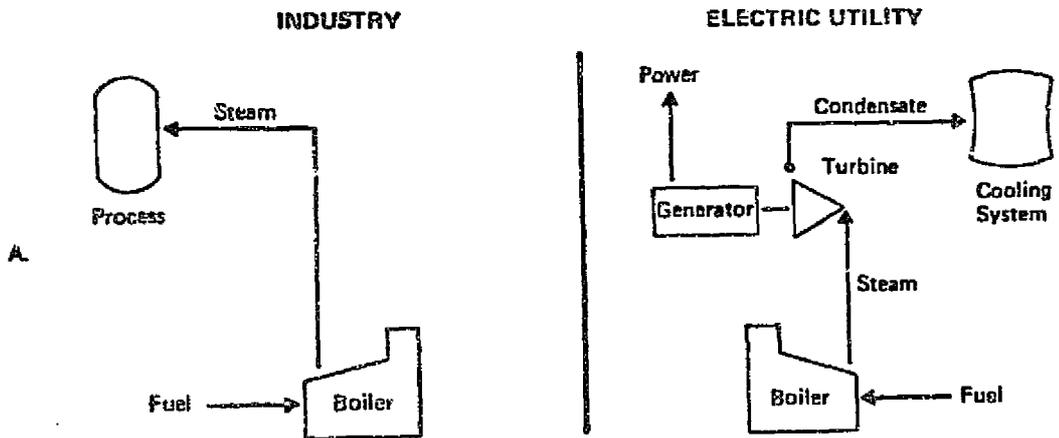
(See Fig. 7)

It is producing both steam and electricity. The steam is piped to an industrial user, somebody who can use it instead of throwing it away. This is really schematic because we can talk about questions of ownership and that can be represented by this diagram, although I didn't want to get into that discussion at this time.

The problem here is while electricity can be transported many miles, steam has stricter engineering limitations. Anything beyond five or ten miles produces problems. In an energy park where you have a large concentration of users this scheme might be practical. Somewhere else it may not be.

To give you an idea of the various cogeneration schemes that are available, we will look at the next slide.

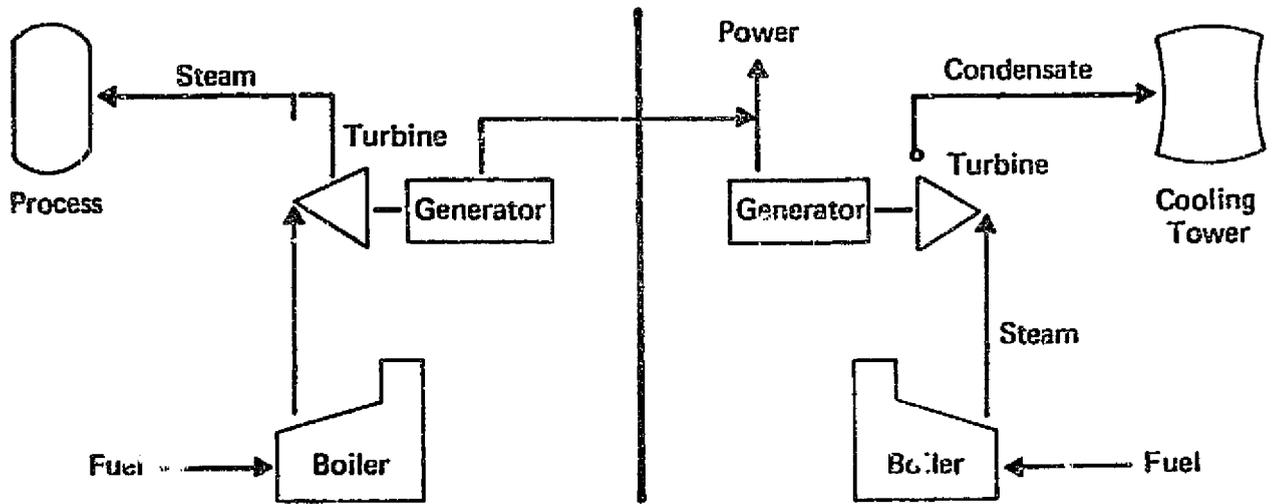
(See Fig. 8)



SEPARATE STEAM AND ELECTRIC POWER PLANTS

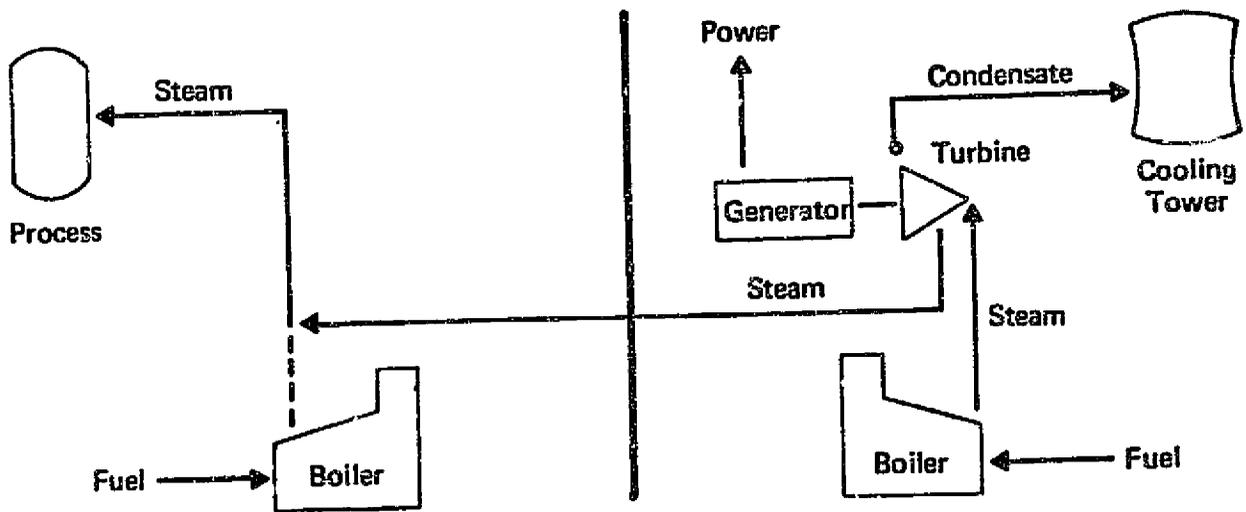
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Figure 5.



COGENERATION SYSTEM

Figure 6.



### COGENERATION SYSTEM

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Figure 7.

## CHARACTERISTICS OF VARIOUS COGENERATION SYSTEMS

System	Size (MW elect.)	Fuel	Elect Steam (KW/10 <sup>6</sup> BTU)	FCP (BTU/KWH)	Process steam press (psig)	Total Plant installed cost (\$/KW)
Gas turbine & waste heat boiler	0.5 → 75	<ul style="list-style-type: none"> <li>• Gas</li> <li>• #2 oil</li> <li>• Treated resid.</li> <li>• SNG (low BTU)</li> </ul>	200	5,500	150 - 600	\$350-400
Diesel engine & waste heat boiler	0.5 → 25	<ul style="list-style-type: none"> <li>• Gas</li> <li>• #20 oil</li> <li>• Treated resid.</li> </ul>	400	6,500	15 - 150	\$350-500
Steam boiler & turbine	> 1	<ul style="list-style-type: none"> <li>• Any oil</li> <li>• Coal</li> <li>• Wastes</li> </ul>	45 → 75	5,000	15 - 600	\$500-600
Combined cycle & waste heat boiler	1 → 150	<ul style="list-style-type: none"> <li>• Gas</li> <li>• #2 oil</li> <li>• SNG</li> </ul>	150	5,000	15 - 900	\$350-450
Steam bottoming	0.5 → 10	<ul style="list-style-type: none"> <li>• Waste heat</li> </ul>	N.A.	0	N.A.	\$400-600
Organic bottoming	0.6 → 1	<ul style="list-style-type: none"> <li>• Waste heat</li> </ul>	N.A.	0	N.A.	\$400-700

Figure 8.

This list was compiled by William Walzer, of the University of California, and presented at the Fallen Leaf Cogeneration Conference last year.

It describes the various cogeneration systems on the left-hand side, their sizes in megawatts electric, the types of fuel used, the electricity to steam ratio, which is indicative of the usefulness of the system to the plant requirements, fuel charged to power, FCP, in terms of Btus per kilowatt hour. It is a measure of efficiency. The higher the number the poorer the efficiency, the lower the number the higher the efficiency.

Process steam pressures are also indicated, and the total plant cost in dollars per kilowatt. When you compare these numbers with the cost of a central station power plant they are very low. A central station power plant, depending on who you listen to, can be anywhere from \$400 to \$2,000 per kilowatt.

The first system, the gas turbine and waste heat boiler, is a very highly reliable system and is in common use. The disadvantages is that it is restricted to petroleum-based fuels, gas, #2 oil, and so forth. It does have a high electricity-to-steam ratio and its efficiency is fairly good in terms of Btus per kilowatt hour. It does have a wide range of process steam pressures.

The next one, diesel engine and waste heat boiler, is similar to the gas turbine and waste heat boiler, but it does have a limited use. First of all, the range and power are fairly small, from half a megawatt to 25 megawatts. Again, it is restricted to what could be considered as scarce fuels. But it does have a very high electricity-to-steam ratio. The steam boiler and turbine is also highly reliable, but, as you can see, it is limited to large systems rated over 1 megawatt. It has the advantage that it does use a wide range of readily available fuels including coal and solid wastes. It also has a wide range of process steam pressures, 15 to 600 pounds per square inch. But it is expensive.

The combined cycle is one commonly used by industry, but also used by utilities to get even more electricity out of the available energy. It is similar to the gas turbine with waste heat boiler. The steam produced in the waste heat boiler drives the steam turbine. Again it uses petroleum-based fuels.

The two bottoming systems have a distinct advantage in that the fuel they need to run is free. They utilize waste heat from whatever source it is available, from the kilns of a cement plant, or whatever, but the energy is free, there is no pollution and you don't need to use any additional fuels.

The steam bottoming system is available. However, the organic bottoming system is in the prototype stage and uses relatively unproven technology. Both of them are expensive.

Next slide.

(See Fig. 9)

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## CHARACTERISTICS OF VARIOUS COGENERATION SYSTEMS (CON'T)

System	Pollution	Controls	General System Notes
Gas turbine & waste heat	NO <sub>x</sub>	•Water or steam injection	•1000°F exhaust can be used as clean hot gas
Diesel engine & waste heat boiler	•Nox •Part.'s	•Tuning •Steam inject •Baghouse	•Efficient at part load and in small sizes •High power/steam ratio
Steam boiler & turbine	SO <sub>2</sub> Part.'s NO <sub>x</sub>	•Low S fuel, scrubber •Precipitator •Design	•Efficient at part load
Combined cycle & waste heat	NO <sub>x</sub>	•Water or steam injection	•Variable power/steam ratio •Back pressure steam turbine
Steam bottoming	N.A.	N.A.	•Efficient at part load •Uses exhaust >900°F
Organic bottoming	N.A.	N.A.	•Efficient at part load •Uses exhaust >900°F •Prototypes available •Requires cooling water

Figure 9.

This slide summarizes the same systems as in the previous slide. It indicates some of the pollution aspects. You will notice there is none for the bottoming cycles. It indicates some of the controls that would be used for air pollution control.

Let's go to the next slide, the benefits of cogeneration.

(See Fig. 10)

There are many. This is a general list. Cogeneration does have the capability of reducing the national energy requirement through more efficient use of fuels. The estimates that have been made suggest that it has the potential of reducing the national energy requirement by as much as a million barrels of oil equivalent per day, and even as much as two million.

It does reduce the utility capital requirement, assuming industry shares the cost of equipment.

It reduces the cost of electricity to consumers. Everyone benefits.

It reduces the overall atmospheric pollution because less fuel is used overall.

Finally, it also increases the reliability and security.

That is the good news. What are the barriers to cogeneration? Let's look at the next slide.

(See Fig. 11)

This table of thermal values of steam in trillion Btu was compiled by Resource Planning Associates. They determined the potential for cogeneration in six major industries: steel, textile, petroleum refining, chemical, pulp and paper, and food.

What they learned in this nationwide study was that the available process steam in 1976 was, 4108 trillion Btus, and expected that number to grow in 1985 by about 50 percent.

But the next three lines, the numbers in parentheses, tell us that not all of that energy is available for cogeneration. The process steam unavailable due to technical constraints is, in 1985, 1681 trillion Btus.

The process steam unavailable due to institutional constraints are also sizable. In fact, 40 percent of the process steam that is unavailable is due to technical constraints and 60 percent is due to institutional and/or financial constraints.

The bottom line, literally, is that only 1/6 of the estimated total energy is available for cogeneration. So that in terms of these figures only 983 trillion Btu's are really available due to these constraints.

## BENEFITS OF COGENERATION

- REDUCES NATIONAL ENERGY REQUIREMENT
- REDUCES UTILITY CAPITAL REQUIREMENT
- REDUCES COST OF ELECTRICITY TO CONSUMERS
- REDUCES OVERALL ATMOSPHERIC POLLUTION
- INCREASES RELIABILITY AND SECURITY

Figure 10.

THERMAL VALUES OF STEAM IN TRILLION BTU

	<u>1976</u>	<u>1985</u>
AVAILABLE PROCESS STEAM	4108	5887
PROCESS STEAM UNAVAILABLE DUE TO TECHNICAL CONSTRAINTS	(1357)	(1681)
PROCESS STEAM UNAVAILABLE DUE TO INSTITUTIONAL CONSTRAINTS	(863)	(1115)
PROCESS STEAM UNAVAILABLE DUE TO FINANCIAL CONSTRAINTS	(1051)	(1376)
PROCESS STEAM SUITABLE FOR COGENERATION	837	1715
EXISTING OR PLANNED COGENERATION	(584)	(732)
TOTAL PROCESS STEAM AVAILABLE FOR GROWTH	253	983

COGENERATION GROWTH POTENTIAL

Figure 11.

What are the major technical constraints to cogeneration?

(See Fig. 12)

First, the steam available may be supplied to steam-driven mechanical auxiliaries. In other words, the steam is there, but it is already spoken for. RPA estimates the same amount of steam will be supplied to steam-driven equipment in 1985 as in 1976. There won't be any relief in that area.

Second, the present process steam is tied up or may be tied up in long-term purchase contracts. The time period for most contracts ends before 1985, but that would be too late to have a large effect on the growth of cogeneration.

Third, steam load fluctuations may be too great within a given plant. For example, the textile and food industries have very large swings in daily or seasonal loads. During off-peak or off-season it may be necessary to purchase electricity, and again we run into the economics of cogeneration. It won't pay unless the price is right.

The steam load may also be too small. PRA did not look at any systems that require less than 50,000 to 100,000 pounds per hour.

Finally, waste heat boiler steam pressures may be too low. Industry does use low pressure waste heat boilers. Besides that, new energy saving technology may eliminate even more steam or energy and make it even less available for cogeneration.

The next slide shows some of the nontechnical constraints to cogeneration.

(See Fig. 13)

The first category is institutional. One problem is the expected declines in steam demand over the lifetime of a cogeneration plant. Cogeneration plant lifetimes are on the order of 20 to 30 years or more. In some cases, longer than the plant management wants to be committed to supplying steam for cogeneration.

Also, there may be improvements in the industrial process which reduces the need for steam.

Second, the steam and electrical production may be mismatched with a corresponding excess of steam or electricity. This may not be a problem if there is a customer who is interested in purchasing the excess steam or electricity. But if not, it may not be advantageous to cogenerate.

Finally, industry fears of regulation and long-term contractual obligations are real problems. Industry doesn't want to be regulated as a public utility. Industry does not want to put its money in an area

## MAJOR TECHNICAL CONSTRAINTS TO COGENERATION

- STEAM AVAILABLE IS SUPPLIED TO STEAM-DRIVEN MECHANICAL AUXILIARIES
- PRESENT PROCESS STEAM IS TIED UP IN LONG TERM PURCHASE CONTRACTS
- STEAM LOAD FLUCTUATIONS ARE TOO GREAT
- STEAM LOAD IS TOO SMALL AT THE LOCAL FACILITY
- WASTE HEAT BOILER STEAM PRESSURE IS TOO LOW

Figure 12.

## NONTECHNICAL CONSTRAINTS TO COGENERATION

- INSTITUTIONAL
  - EXPECTED DECLINES IN STEAM DEMAND OVER LIFETIME OF COGENERATION PLANT
  - STEAM/ELECTRICAL PRODUCTION MISMATCH WITH ATTENDANT EXCESS OF STEAM OR ELECTRICITY
  - INDUSTRY FEARS OF REGULATION AND LONG-TERM CONTRACTUAL OBLIGATIONS

Figure 13.

which is not its prime business and not product oriented. This leads into the next slide, the economic constraints.

(See Fig. 14)

Generally, industry requires a higher rate of return for investments like cogeneration. Whereas 15 percent would be a reasonable rate of return for production-oriented investments, it just doesn't make it for investments like cogeneration. Industry may want something like 25 percent or even more. This attitude may change as the fuel required for the process becomes less available.

Secondly, the costs of fuel, the costs of electricity, the costs for standby power, and the amount of plant utilization are important economic factors in considering whether to implement cogeneration.

The optimum conditions would be: low fuel cost, high electricity cost and a low standby charge. Also, the plant would need to operate continuously. It is not often that all these conditions are met simultaneously.

Next slide.

(See Fig. 15)

There are several studies that JPL is currently involved in. One of these studies has performed interviews at 12 plants in California to learn about their feelings, misgivings and attitudes about cogeneration. We covered a number of industries, a variety of air pollution control districts, and fairly well covered the state. Our objective was to identify the technical, economic, institutional and environmental barriers to industrial cogeneration in California.

In the first phase, which was done for the California Energy Commission, we did some conceptual cogeneration system designs to estimate the cogeneration potential for these 12 plants.

In the second phase, which is being done for the Department of Energy, we are analyzing the economics and the environmental and institutional barriers.

Next slide.

(See Fig. 16)

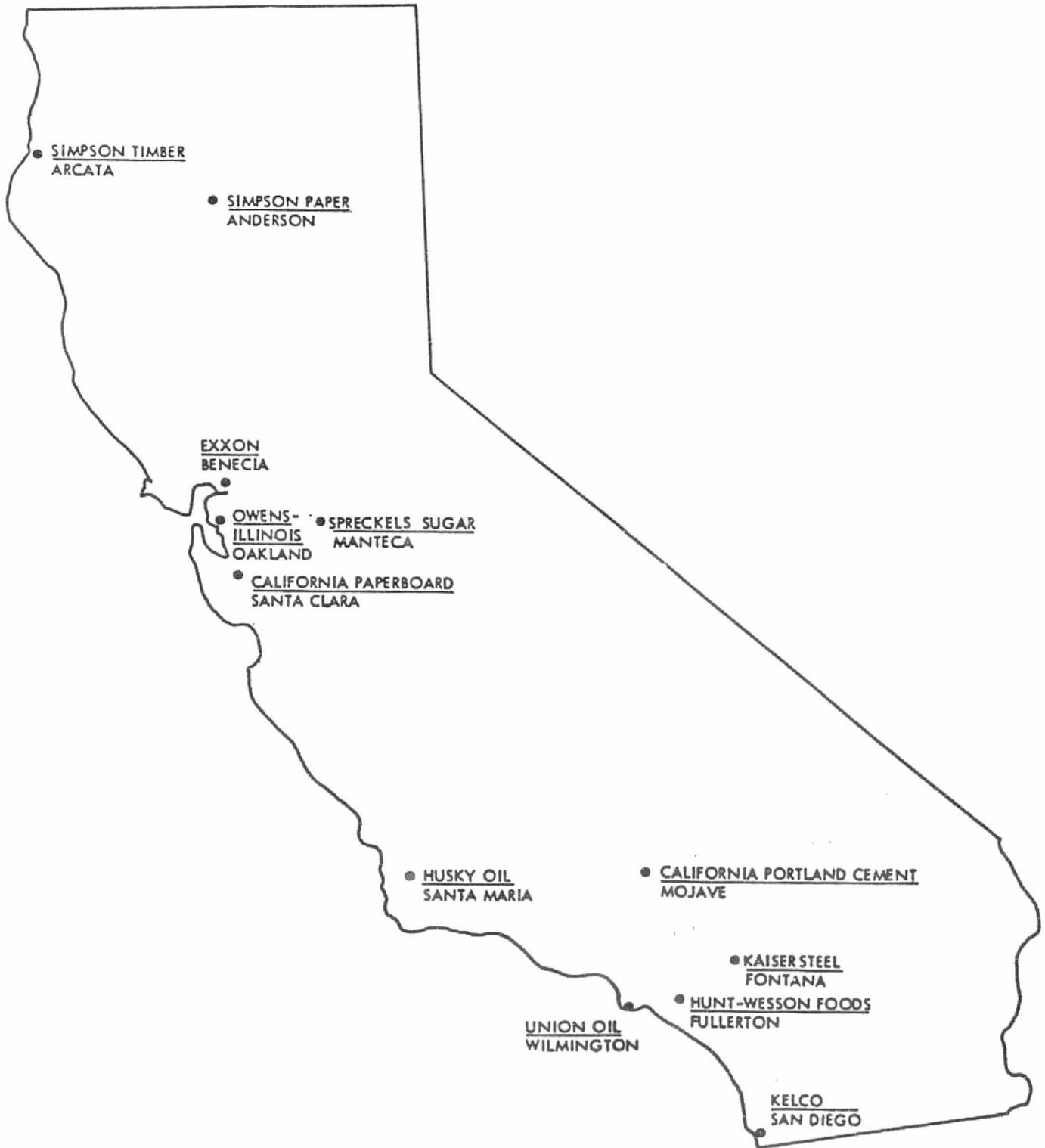
This slide gives you an idea of the variety of different plants that we investigated. Maybe among these you will be able to identify an area or plant having some of the same considerations that you might have. The industries covered include the major thermal energy users in California. The plants include a variety of topping cycles, two bottoming cycles, a number of Air Pollution Control Districts, the major utilities, PG & E, Southern California Edison, San Diego Gas & Electric and two municipals utilities.

## NONTECHNICAL CONSTRAINTS TO COGENERATION (CON'T)

- ECONOMIC
  - HIGHER RATES OF RETURN REQUIRED BY INDUSTRY FOR ANCILLARY INVESTMENTS SUCH AS COGENERATION
  - COSTS OF FUEL, ELECTRICITY, STANDBY POWER AND AMOUNT OF PLANT UTILIZATION

Figure 14.

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SELECTED COGENERATION SITE LOCATIONS IN CALIFORNIA

Figure 15.

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### Selected Cogeneration Sites in California

Plant	Industry	Location	Selection Criteria										Thermal Energy Use Rank In California	Reported Estimate of Cogeneration Capacity, MWe	
			Type Cogen. Cycle		Air Pollution Control District	Utility				Cogen. Activity					
			Topping	Bottoming		PGE	SCE	SDGE	Municipal	Existing	Future	Under Study			
California Paperboard Corp.	Paperboard Products	Santa Clara	X		Bay Area				X			X		46	10
California Portland Cement Co.	Cement Manufacturing	Mojave		X	Kern Co.		X					X		3	100
Exxon Co., U.S.A.	Petroleum Refining	Benecia	X		Bay Area	X						X		1	40
Hunt-Wesson Foods, Inc.	Food Products	Fullerton	X		South Coast		X					X		6	0.7
Husky Oil Co.	Enhanced Oil Recovery	Santa Maria	X		Santa Barbara Co.	X						X		1	300
Kaiser Steel Corp.	Steel	Fontana	X		South Coast		X					X		4	60
Kelco Co.	Organic and Inorganic Chemicals	San Diego	X		San Diego Co.			X				X		2	12
Owens-Illinois, Inc.	Glass Containers	Oakland		X	Bay Area	X						X		7	--
Simpson Paper Co.	Pulp and Paper	Anderson	X		Shasta Co.	X						X		46	19
Simpson Timber Co.	Timber	Arcata	X		Humboldt Co.	X						X		20	--
Spreckels Sugar Co.	Sugar Beet Refining	Manteca	X		San Joaquin Co.	X				X				5	4.2
Union Oil Co.	Petroleum Refining	Wilmington	X		South Coast				X			X		1	40
<b>Totals</b>			10	2	--	6	3	1	2	1	4	7	--	--	--

Figure 16.

There are other cogeneration studies ongoing at JPL. One study is looking in detail at a cogeneration system for a petroleum refinery in the San Francisco Bay Area. Another study is looking at the technological aspects of cogeneration.

Cogeneration is a proven technology with demonstrated benefits. How can it be encouraged? The next slide indicates that some of the incentives to cogeneration development can be in terms of tax credits, low-cost government loans or relaxed air pollution restrictions.

(See Fig. 17)

While air pollution is less overall with cogeneration there are problems because whoever is cogenerating will generally be using additional fuel to produce the electricity. Additional fuel, of course, produces air pollution. Overall there is less fuel used but its use is distributed differently.

Another incentive would be the removal of restrictions on the use of natural gas and oil to encourage the use of gas turbines, for example, in industrial facilities that cogenerate.

Finally, I want to mention some studies that have been done in cogeneration in addition to the ones at JPL. Next slide.

(See Figs. 18 and 19)

Dow Chemical Company in 1975 published the "Industrial Energy Center Study." This was a very comprehensive nationwide study of cogeneration. I recommend this study to anyone who is remotely interested in cogeneration.

The Resource Planning Associates' Study was completed recently, and, as I mentioned, it covers six specific industries.

Thermoelectron Corporation published "A Study in Inplant Electric Power Generation in the Chemical, Petroleum Refining, and Pulp and Paper Industries." Thermoelectron develops and manufactures products based on thermodynamic technologies.

Finally, there is a study by Robert Williams of Princeton, "The Potential for Electricity Generation as a By-Product of Industrial Steam Production in New Jersey."

That concludes my presentation. If there are any questions I will be glad to try to answer them.

ATTENDEE: Where could those copies be obtained from?

DR. DAVIS: By either writing to those organizations, or perhaps from NTIS, the National Technical Information Service.

ATTENDEE: When will the JPL study be available?

## INCENTIVES TO COGENERATION DEVELOPMENT

- TAX CREDITS
- GOVERNMENT LOANS
- RELAXED AIR POLLUTION RESTRICTIONS ON COGENERATION PLANTS
- REMOVAL OF RESTRICTION ON THE USE OF NATURAL GAS AND OIL FROM INDUSTRIAL FACILITIES THAT USE COGENERATION

Figure 17.

PARTIAL LIST OF REFERENCES

DOW CHEMICAL COMPANY, THE ENVIRONMENTAL RESEARCH INSTITUTE OF MICHIGAN, TOWNSEND GREENSPAN AND COMPANY, INC., AND CRAVETH, SEVAINE, AND MOORE, INDUSTRIAL ENERGY CENTER STUDY, A REPORT FOR THE OFFICE OF ENERGY R&D POLICY OF THE NATIONAL SCIENCE FOUNDATION, JUNE, 1975.

RESOURCE PLANNING ASSOCIATES, INC., THE POTENTIAL FOR COGENERATION DEVELOPMENT IN SIX MAJOR INDUSTRIES BY 1985, PREPARED FOR FEDERAL ENERGY ADMINISTRATION, SEPTEMBER, 1977

THERMOELECTRON CORPORATION, REPORT #TE5429-97-76: A STUDY OF INPLANT ELECTRIC POWER GENERATION IN THE CHEMICAL, PETROLEUM REFINING, AND PULP AND PAPER INDUSTRIES, PREPARED FOR THE FEDERAL ENERGY ADMINISTRATION, 1976

Figure 18.

PARTIAL LIST OF REFERENCES (CON'T)

WILLIAMS, R. H., THE POTENTIAL FOR ELECTRICITY GENERATION AS A BY-PRODUCT OF INDUSTRIAL STEAM PRODUCTION IN NEW JERSEY, CENTER FOR ENVIRONMENTAL STUDIES, PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY, REPORT #31, JUNE 21, 1976

JET PROPULSION LABORATORY, CALIFORNIA, INSTITUTE OF TECHNOLOGY, POTENTIAL FOR COGENERATION OF HEAT AND ELECTRICITY IN CALIFORNIA INDUSTRY, FINAL REPORT, TO BE PUBLISHED

Figure 19.

DR. DAVIS: The JPL study comes in two parts. The first phase should be available in May. The second phase should be out this summer.

ATTENDEE: Are you going to publish specifically the results of your interviews on the particular potential candidates?

DR. DAVIS: The interviews are included as an appendix to the first phase final report. All 12 interviews or site reports will be published.

ATTENDEE: Did you address in your study the issue of rate structuring with utility by-back cost and all the rest?

DR. DAVIS: That is addressed in the second phase, but not in excruciating detail because we look at it as site-specific and what applies to one site may not apply to another. Every cogeneration system is different. The requirements of one plant may be entirely different than another. What make economic sense for one company may not for another.

But to answer your question, yes, we do look at the economics including rates, but perhaps not to the level of detail that you may be interested.

ATTENDEE: Speaking in terms of economics, did you in your study address the possibility of extracting the CO<sub>2</sub> to be used in some other area, and did you also take a look at the extraction of the stack gases?

DR. DAVIS: Not CO<sub>2</sub>. One of the companies we looked at was Kaiser Steel, Fontana. They have CO gas that they release to the atmosphere and they were considering using this gas for fuel to generate electricity.

A study done by Kaiser Engineers on the utilization and cost-effectiveness of using those CO stack gases is estimated at about 50 megawatts.

Another organization, Husky Oil, has an enhanced oil recovery project in Santa Maria. While they were not using CO<sub>2</sub>, they were using water or steam injection.

I can't speak to CO<sub>2</sub>, but we did look at the potential for using cogeneration in conjunction with enhanced oil recovery in the recovery of oil.

Does that answer your question?

ATTENDEE: There has been some discussion about extracting CO<sub>2</sub> and going from CO<sub>2</sub> to methanol. Did you address that part of it?

DR. DAVIS: No.

ATTENDEE: In your second phase, when you get down to the potential for tax incentives and how that might affect the adoption of cogeneration are you getting down to some specific suggested changes for the tax structure or is it going to be more general?

DR. DAVIS: It is difficult for me to answer that question directly because we are not that far into our study at this time. I don't now know whether the answer is tax incentives or something else.

It may be that the most leverage is obtained with tax incentives. It is not clear that this is more important than some of the other considerations.

ATTENDEE: Your chart indicated that bottoming cycles are emission-free. Is that right?

DR. DAVIS: Yes. Bottoming cycles would be emission-free since no other fuel is used. It doesn't eliminate the emissions already there, but it doesn't need to use any additional fuels and therefore there are no additional emissions.

Thank you.

MR. ROSE: Thanks, Herb.

Gentlemen, and ladies, we come to the lunch break, and this is going to take more attention than all the proceedings.

(Instructions for luncheon and solarvoltaic tour.)

(Luncheon and tour recess from 12:15 o'clock p.m. until 1:45 o'clock p.m.)

#### AFTERNOON SESSION

(1:45 P. M.)

MR. ROSE: Gentlemen and ladies, can we get started with the afternoon session?

Our first speaker in this afternoon's session is Dr. Vince Truscello, who is going to talk to us about solar thermal systems.

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## SOLAR THERMAL SYSTEMS - V. C. TRUSCELLO

DR. TRUSCELLO: I am going to talk to you a little bit about a form of alternative energy source that I think probably is a lot closer to reality than some of the things you have seen so far today, or will see the rest of the day. I may sound like I am promoting it a little bit, and maybe I am.

The reason I think it is really close is based on this very first slide that I will show you.

(See Fig. 1)

You see, this form of energy is using machinery that is very similar to what we use in our conventional systems. Today, the way we produce much of our electrical power is through burning coal or oil or gas, or even using a reactor system, using uranium, to generate heat. Then that heat is put through a heat exchanger and a boiler and that hot gas or liquid is used to drive turbines that drive generators and produce electricity.

In using sun energy you are using the same kind of machinery and we can do exactly the same thing. The trick is to generate heat in a very inexpensive manner.

What we are doing, as a primary approach, is to just replace this portion of the system. That is, get rid of coal, oil, gas or reactor, and replace it with what we call solar collectors. The rest of the system can be almost identically the same.

My next slide shows some typical solar collector systems that have been considered or are being considered and in fact are under development by the government today.

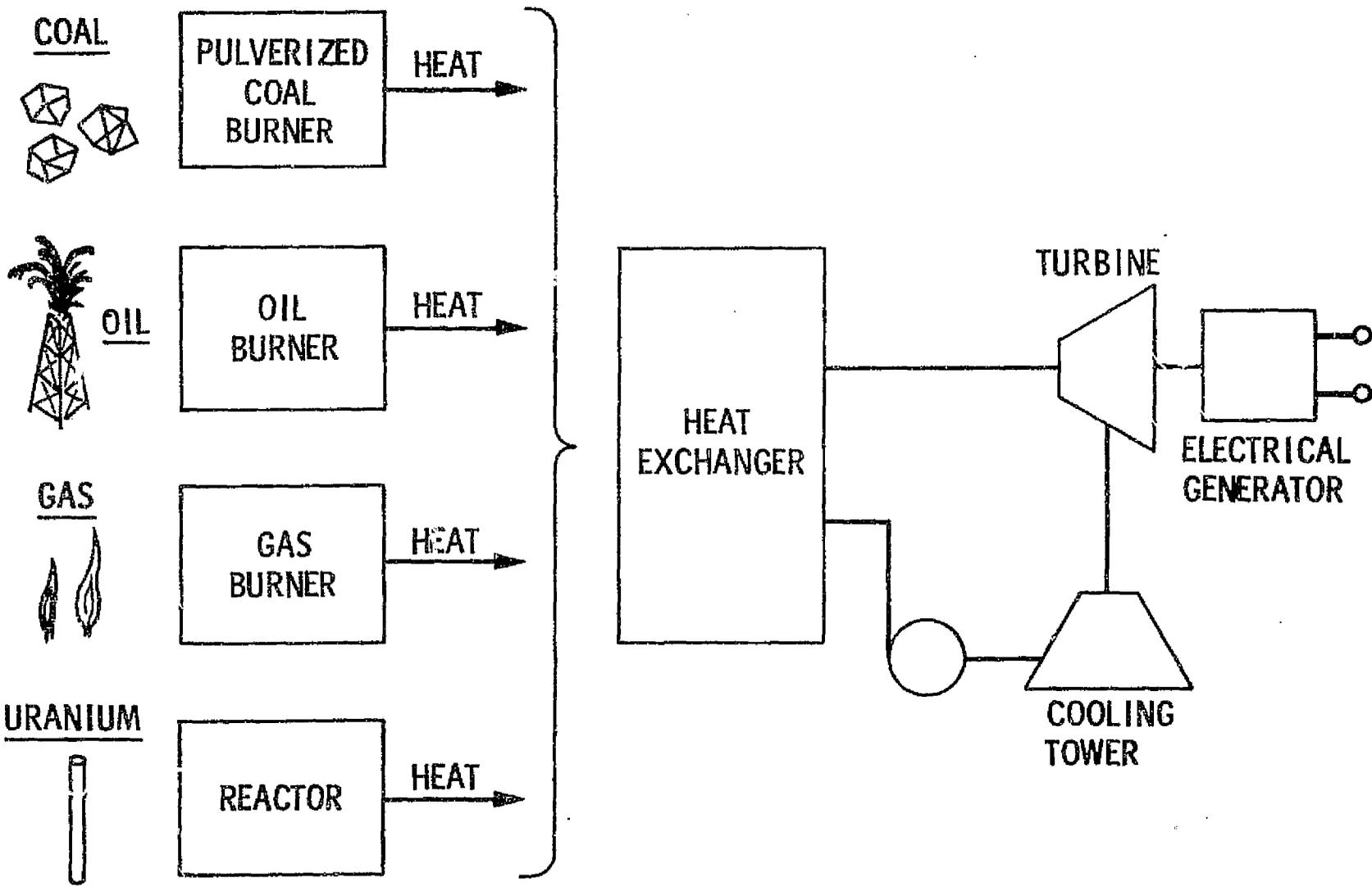
(See Fig. 2)

They do different things.

These so-called flat plate collector systems are very low temperature collectors. You will hear something of them in the next talk, but they are devices that generate very low temperature fluids and are great for heating and cooling applications for installations in homes, apartment houses, or even industrial complexes. They require very low temperatures.

If you want to get the very high temperatures you have to do something a little bit more sophisticated. I am talking about concentrating the solar energy. You can do that in several ways. I am going to use these names and introduce them now so that you will know what I am talking about. Parabolic trough, line focusing system. These are devices that concentrate the energy along a single line. They are not as effective as some of the others I will be talking about, but they can generate temperatures as high as 400 degrees centigrade, or thereabouts.

# CONVENTIONAL POWER PLANTS

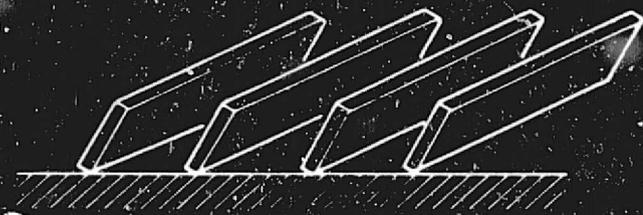


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Figure 1.

# TERRESTRIAL SOLAR PLANTS



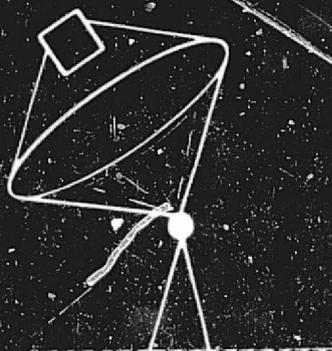
- FLAT PLATE

90 - 130°C



- PARABOLIC TROUGH

300 - 450°C



- PARABOLIC DISH

300 - 850°C



- CENTRAL RECEIVER

500°C

Figure 2

In fact, the present reactor systems that we have don't do any better than this. This is as high as we run our reactors today.

With coal systems and burning of gas we can do better and can get up to temperatures like 500 degrees centigrade. We can do that also with things called parabolic dishes or central receiver concepts. These are point focusing systems. They are collectors that can concentrate energy by a factor of a thousand to 2,000 as compared to maybe only a factor of 300 suns with linear devices and only one sun or maybe two suns with low or non-concentrating devices.

All of these type of collectors are under development by the government today at different paces and for really different types of things.

I want to walk you through some of the things the government is doing, in fact, right now to try to mature this technology so that it can be applied to a number of different applications. And I will walk you through the different types of applications they are considering. Potentially, some of these might look attractive for some of your needs.

Okay. The next slide, please.

(See Fig. 3)

The government is looking at two very broad applications: large central power stations and dispersed applications. In large power stations we are talking about systems that can compete with large nuclear power plants in the 500 to 1,000 megawatt range.

Dispersed applications include systems that would be much smaller, maybe as small as 50 or 100 kilowatts, maybe to several megawatts in size.

Now, a few years ago, the government started a rather massive program to try to develop technology for large power stations. You probably have heard that in 1980 or 1981 there will be a 10-megawatt power plant in Barstow. The technology work that is going on is known as central receivers.

We will want to come back to this slide in a second, but I will go on to the next one. It is a description of what this central receiver concept or power tower is. It has a number of different names.

(See Fig. 4)

The idea of the concept here is to have a field of mirrors, reflectors, in which the energy is concentrated to a single point. This point focusing concentrator concept produces temperatures like 1,000 degrees Fahrenheit which are the kind of temperatures that are generated by coal and oil today to drive steam turbines.

# MAJOR APPLICATIONS FOR SOLAR TECHNOLOGY

- LARGE CENTRAL POWER STATIONS

- DISPERSED APPLICATIONS

Figure 3.

# SOLAR TOWER CONCEPT

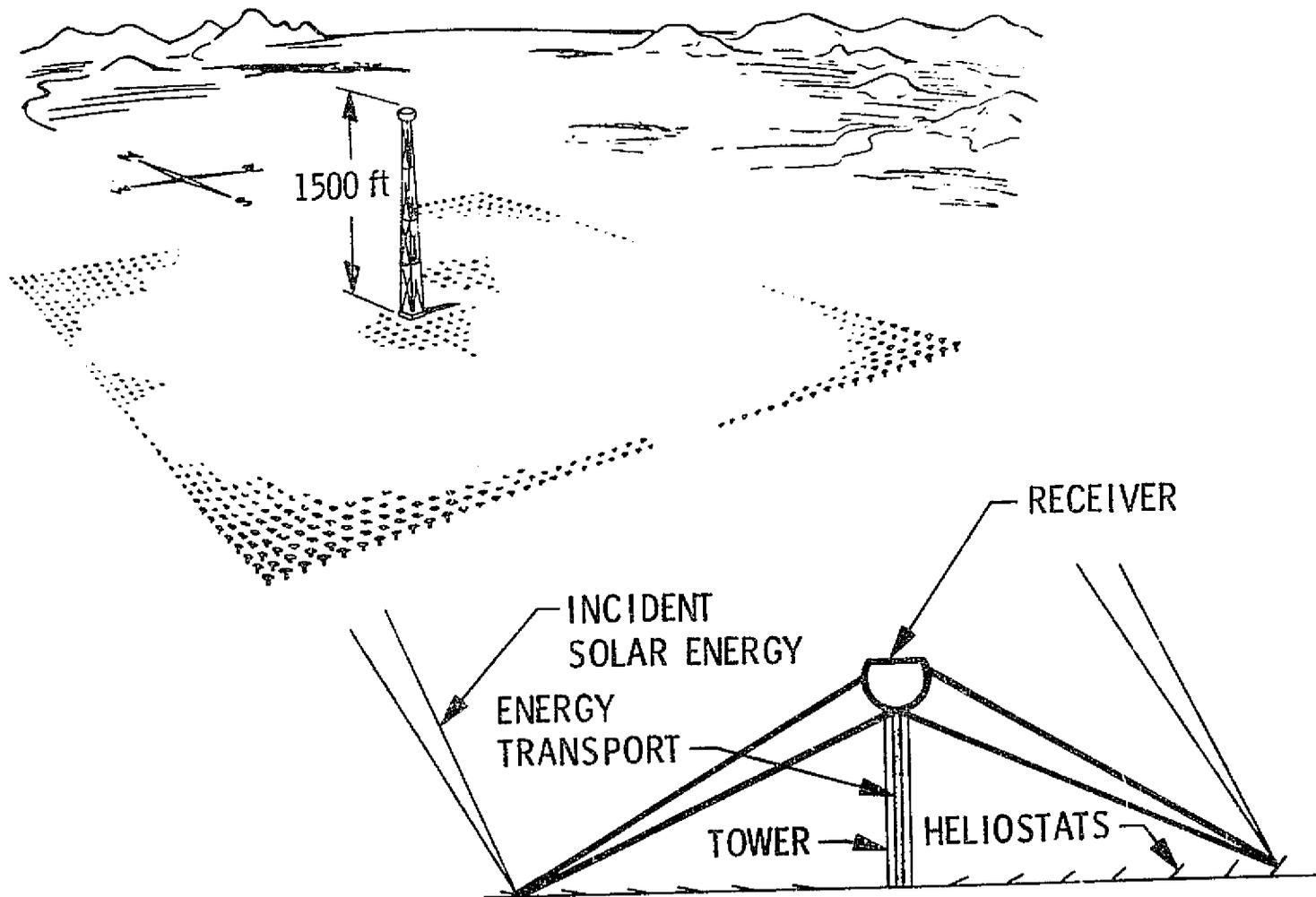


Figure 4.

So we can put conventional turbine machinery at the base of this system. Steam is generated here and we are driving standard, off-the-shelf, turbine machinery. The only part that is not off the shelf is, of course, this field of collectors. This can be rather large. For a very large system, four or five hundred megawatts in size, this might be a 1500-foot tower. For smaller systems it might only be two, three, or four hundred feet in height.

The government has a strong program. A good bit of the money in the thermal power area is aimed at trying to mature this particular technology. The first experiment for a thermal power plant that comes on-line will be around the 1980-81 time frame, it is the project in Barstow. It will produce 10 megawatts of electricity.

But the government already has a smaller plant on-line that produces about 5 megawatts thermal rather than 10 megawatts of electricity. The next slide shows the construction of that plant.

(See Fig. 5)

This is a plant being built at a test facility in New Mexico. This is the tower that you see here. These devices are the mirrors or so-called heliostats that reflect the energy to a central point at the top of the tower. This is an early picture of it. I think it is pretty much constructed right now.

So the government has a program going on to bring on-line and mature, and hopefully to make commercial in the '85-'90 time frame, large power stations that can be situated out in the desert and produce massive amounts of energy, be put into the utility network and brought to the cities.

Another approach that the government is looking at are applications that need smaller power plants. This is the dispersed power application we were talking about earlier. Back to that initial slide. I will now talk a little bit about dispersed application systems. Next slide.

(See Fig. 6)

The power range goes from a few kilowatts up to several megawatts. The government has broken it up into three categories: total energy systems, irrigation pumping, and small electric power applications. What I want to do now is walk you through a few of these applications and tell you what the government is doing in each of these areas.

Before I get to that, a little bit about dispersed power. We can design this kind of system using either so-called line focusing systems or the point focusing system. As I said earlier, line focusing is a lower temperature system, and I have a picture of that one. We will come back to this slide later.

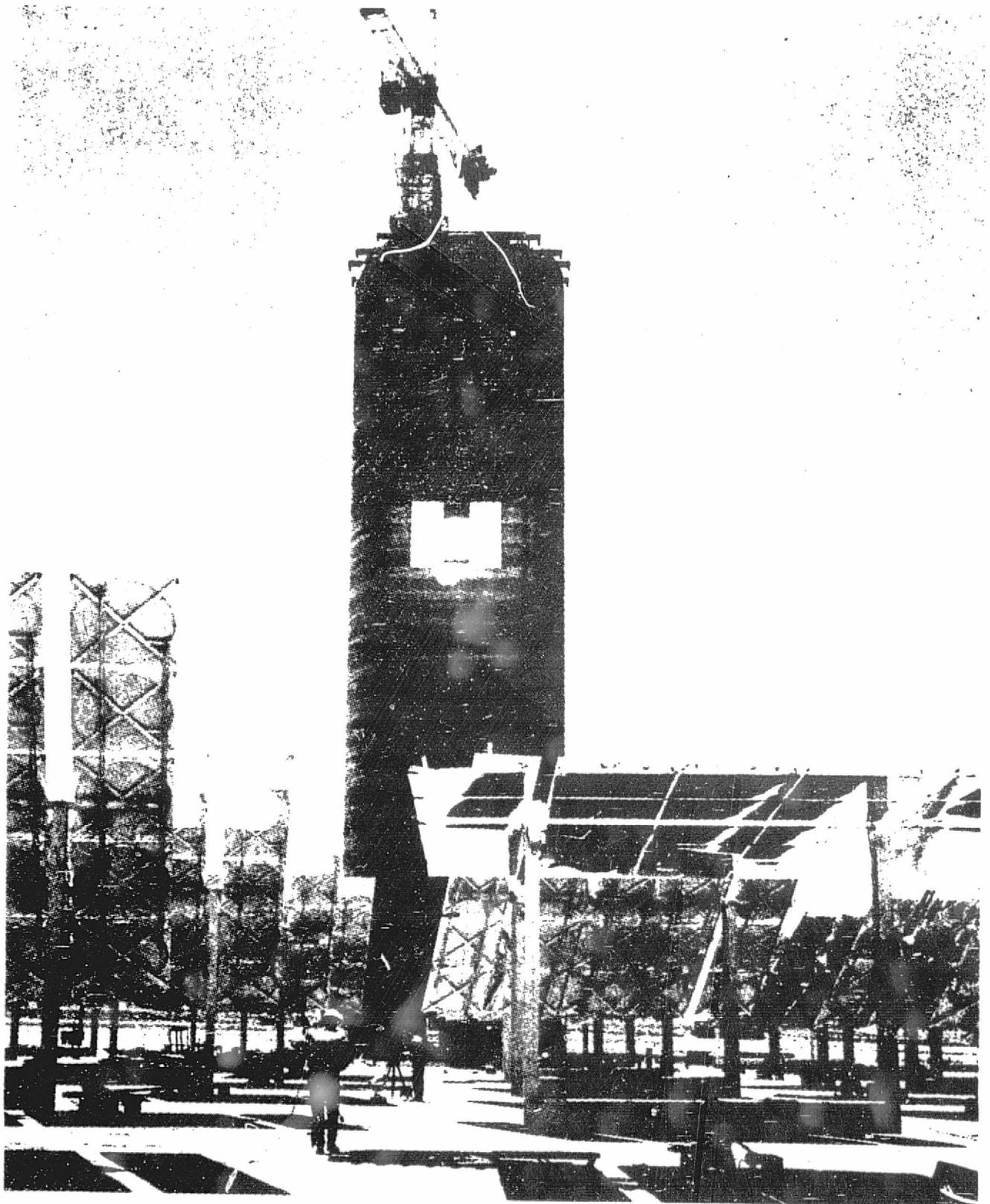


Figure 5.

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# **DISPERSED POWER**

- **POWER RANGE**

- **A FEW KILOWATTS TO SEVERAL MEGAWATTS**

- **CATEGORIES**

- **TOTAL ENERGY INSTALLATIONS**
- **IRRIGATION PUMPING/DESALINIZATION**
- **SMALL ELECTRIC POWER APPLICATIONS**

Figure 6.

Line focusing system. Here is an example of one that is being actively developed now by the government. This is the line that the energy is focused on. These are the mirrors. They are strips, elongated rectangular sections of mirror that can track, and that can articulate, so that as the sun moves during the day these mirrors are constantly pointing the energy along this line.

(See Fig. 7)

Here is a picture of what it might look like in the field. There is an array of these devices in which the energy is collected along these sites and a plumbing system or a piping system that can collect the heated fluid and transport it to a central place where again turbine machinery that is being developed can be used. It is the same kind of machinery developed under the nuclear program. The same low temperature turbine can be used by these devices to generate electricity and obtain megawatts of power. But primarily they have been aimed at the lower power level; a few kilowatts and hundreds of kilowatts.

The initial introduction of this kind of system appears to be very beneficial for the irrigation market, and I will show you that in a slide in a moment. I have one other slide that goes along with this that shows you this same kind of a system actually installed.

(See Fig. 8)

This is in Albuquerque, New Mexico again at the Sandia Laboratory in which they are testing and evaluating some of these devices. This is an aerial view of it. You can see an array of collectors which are under test. The energy from these collectors is transported to a central place where they can convert it to electricity. The next slide shows something about the applications.

(See Fig. 9)

This first one shows total energy installations that the government is considering. The idea is to integrate into either an industrial complex or a military complex, systems that can generate both electricity and thermal energy. That is why it is called total energy. It is the cogeneration type of approach that you heard about earlier today. The purpose of these installations is to have projects to test prototype systems in real life environments. The idea is not to test in Albuquerque or in a government facility, but actually out in the field where there is a real application to find out how these systems actually work when integrated into various complexes.

The government is looking at two places: Ft. Hood, which is a military housing complex, and also an industrial site, a knitwear factory in Shenandoah, Georgia, in which they are going to install one of these power plants.

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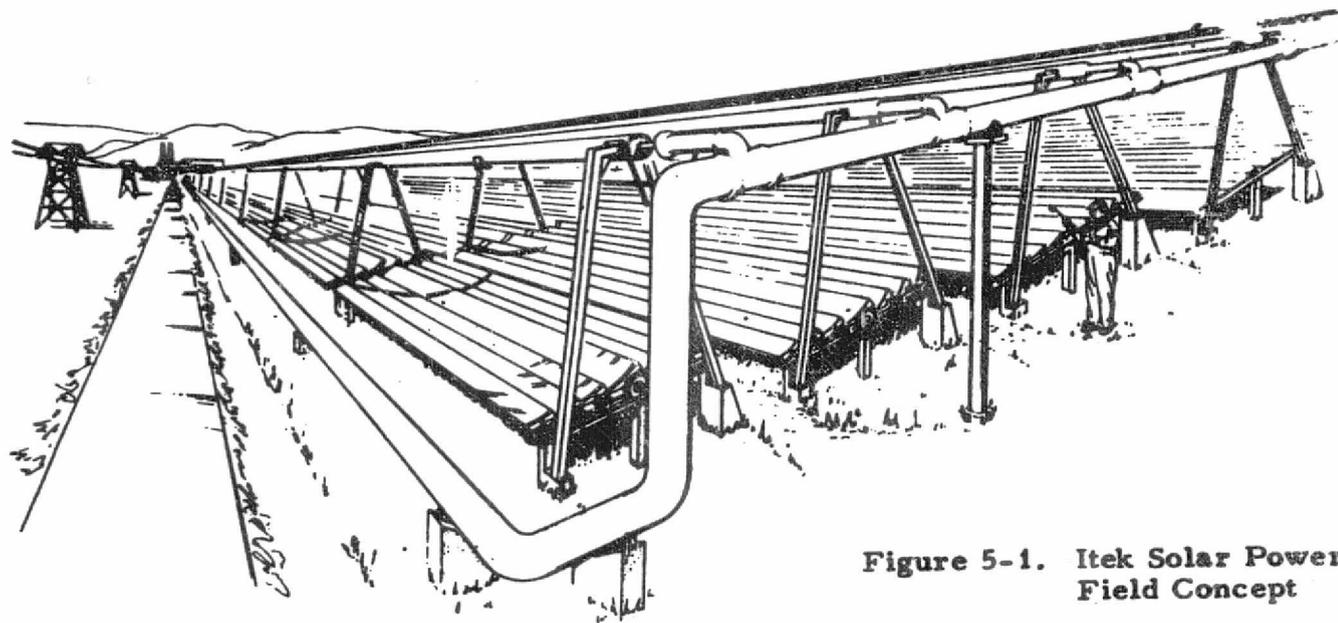


Figure 5-1. Itek Solar Power Collector Field Concept

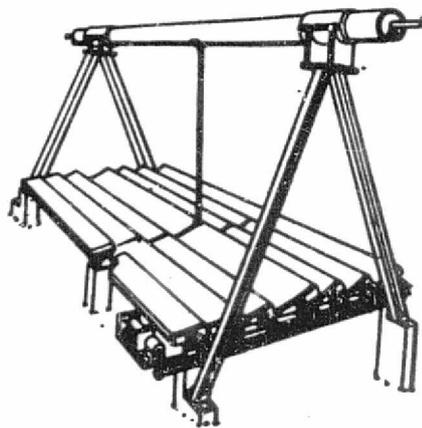


Figure 5-2. Solar Power Collector Concept

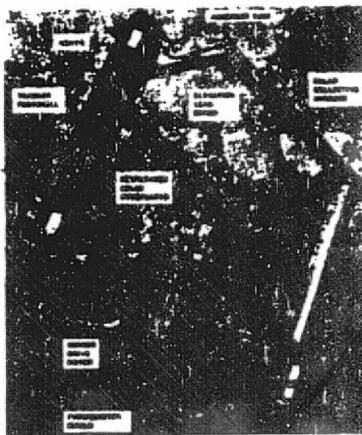


Figure 5-3. Itek Solar Power Collector Breadboard

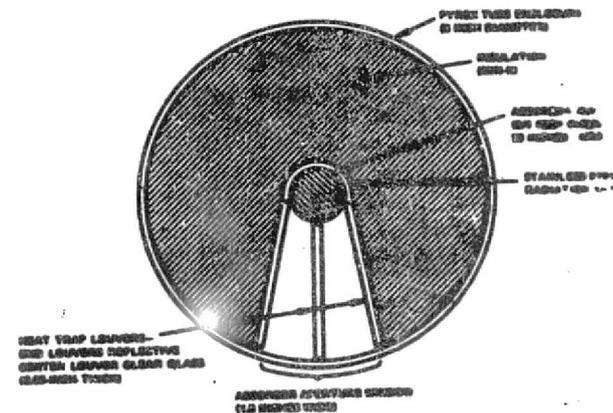


Figure 5-4. Absorber

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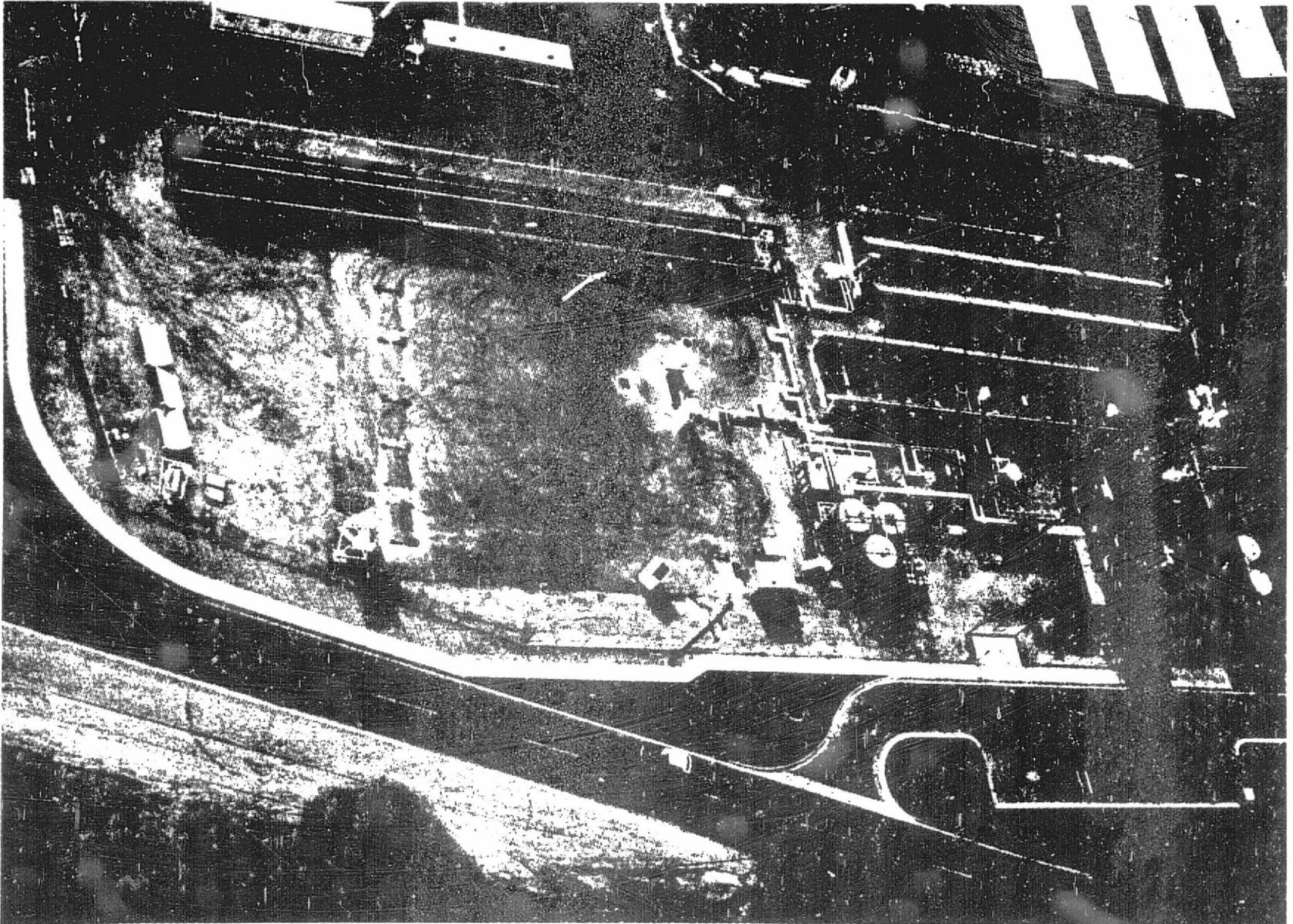


Figure 8.

# TOTAL ENERGY INSTALLATIONS

- DESCRIPTION

- SOLAR ENERGY INTEGRATED WITH A COMPLETE INDUSTRIAL OR MILITARY COMPLEX. GENERATES BOTH ELECTRICAL AND THERMAL NEEDS

- PURPOSE

- PROJECTS TO TEST PROTOTYPE SYSTEMS IN REAL-LIFE ENVIRONMENTS

- EXAMPLES

- FT. HOOD (MILITARY) HOUSING COMPLEX
- SHENANDOAH (INDUSTRIAL) KNITWEAR FACTORY
- JOINT PROJECTS WITH PRIVATE SECTOR (4 BEGINNING 1980)

Figure 9.

The government is looking for joint ventures with the private sector to install four additional systems of this type beginning roughly around 1980 and over the 1980-85 time frame, to install four more of these units.

I have got some pictures that show what these installations will look like when they are finally completed. They are now just in the design phase.

Next picture.

(See Fig. 10)

Total energy is a little bit behind some of the other application programs.

This is the Ft. Hood military complex in Texas that eventually will be serviced by this field of line-focusing collectors. It will produce temperatures around 600 or 700 degrees Fahrenheit. This will generate both electricity -- it is a total energy system -- as well as thermal energy used to heat the various buildings in this complex.

Next slide.

(See Fig. 11)

Further downstream there is the installation of a series of point-focusing systems. These are parabolic dishes that can achieve temperatures as high as 1,000 degrees or even higher. This particular installation is producing temperatures of about 700 degrees. It also will be using turbine machinery very similar to what we used with the earlier system. This is in Shenandoah, Georgia. It is a knitwear factory that will use both thermal energy and electrical energy generated by this field of dishes. It is in the design phase now. General Electric is the systems contractor in developing this system. They are supposed to have a model, one of these devices on test within a year or so, and a couple years later will have the complete power plant on-line.

Then the final one in the total energy area -- this happens to be a photovoltaic system, a concentrating system.\* This is the array out here. It collects solar energy, generates electricity directly, then the heated water that is used to keep the array cooled, is used to provide thermal energy for the complex.

So the government right now has these three very specific programs going on in the field to test out and prove out these types of systems.

Another, actually nearer term application, is irrigation.

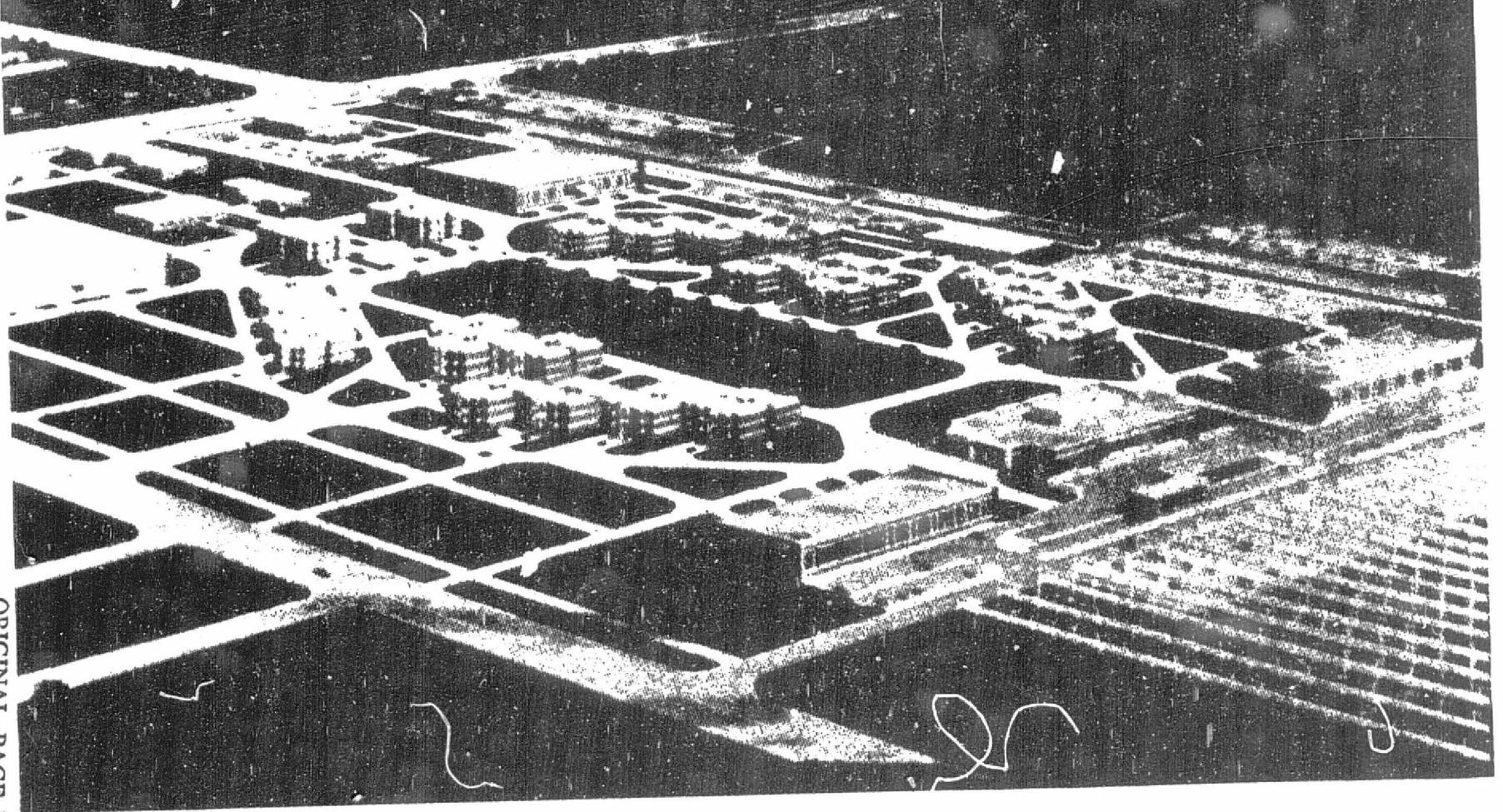
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\* Slide not available.

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# FORT HOOD TOTAL ENERGY PROJECT



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Figure 10.

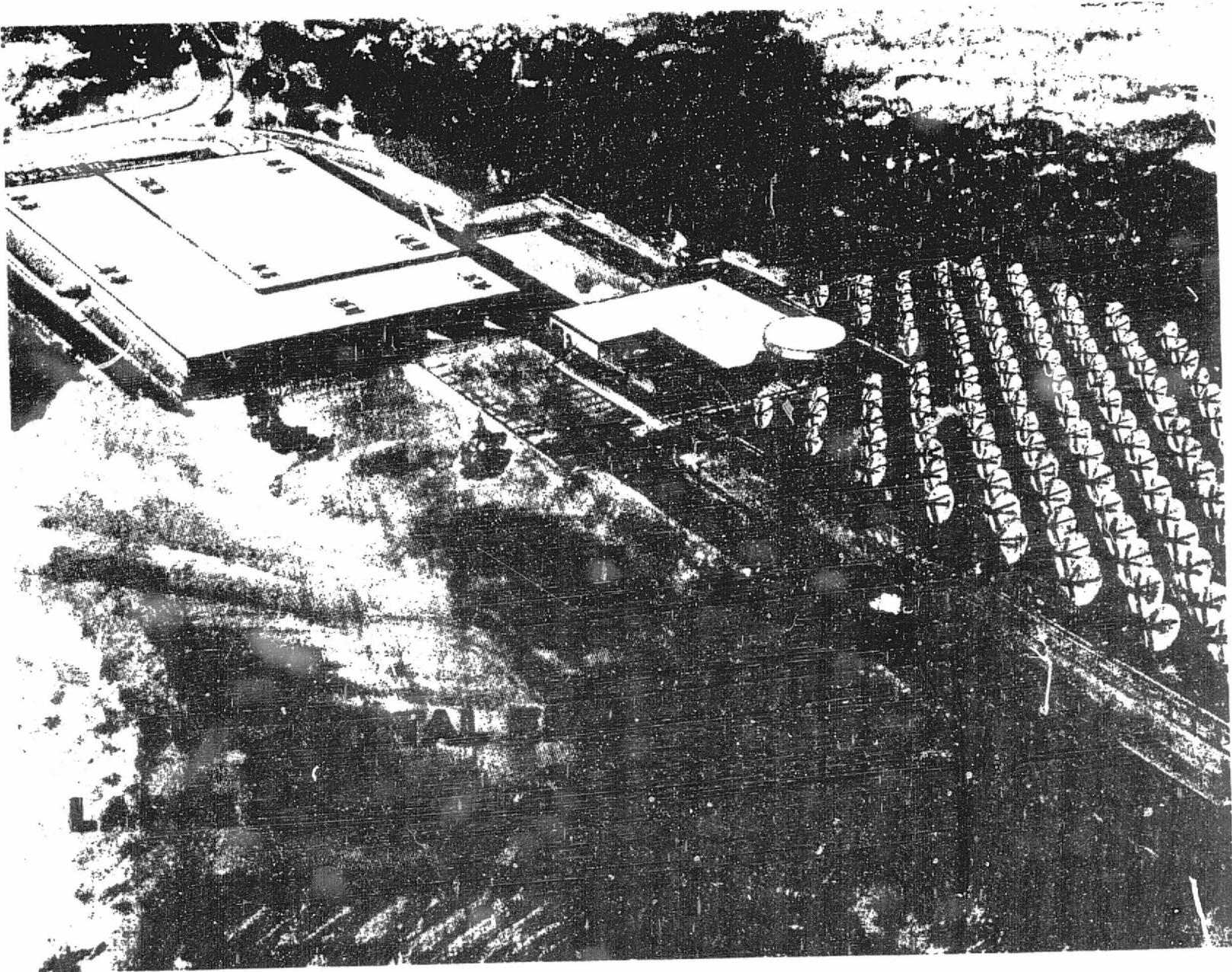


Figure 11.

(See Fig. 12)

The government has some good programs going on in this area. Again the description. Solar energy is used to produce shaft power to drive both shallow and deep irrigation pumps. The purpose is solar thermal systems in real life environment. These are some examples of programs that the government have going on in this area. There is an irrigation plant in Willard, New Mexico in operation on a farm. It is a shallow-well system. Again it uses a line-focusing system to drive a 25 horsepower engine. The system has been designed to produce pumping 23 hours a day. It has a storage capacity associated with it so that even when the sun is not available the system is still pumping water for at least 23 hours a day. It has this kind of capacity. There are 700 gallons per minute, pumping a 110-foot well, producing enough water for a hundred acres of irrigation. I have some pictures of this that I will get to in a moment.

This is a deep well irrigation plant that is planned for installation in Arizona. It is an experimental plant, but in a real life environment. This time it is a 200 horsepower engine using these line-focusing systems, and it is scheduled to be operational next year.

Then, over the next few years, the government plans to put in 17 additional shallow-well systems that are just an improvement of this version. The first two will be installed by 1982 and they are now looking around to try to find out where those installations will be.

So we will have 20 or 30 installations over the next several years to prove out these systems. Now I have some photographs. (See Fig. 13).

This is the one that has been installed in Willard, New Mexico. The line-focusing systems are here. The water is pumped out of a shallow well and stored in this area. This can act as a storage. It has an additional storage capacity with a tank that can store the hot water that is generated by these collectors so that the system can be operated by either the stored energy here or by just pumping the water out of these shallow ponds. I have another picture of the same system. (See Fig. 14).

It is an aerial view, and you can see the irrigation area that is actually serviced. So this thing is an ongoing experimental power plant that is being monitored to determine how well it is operating.

By next year the government will have another power plant on-line, shown on the next slide. It is a bigger system. This can handle a 200-horsepower pumping system, using the same line-focusing kind of an array. (See Fig. 15).

The next area is small power applications.

Next slide.

(See Fig. 16)

# IRRIGATION

## • DESCRIPTION

- SOLAR ENERGY PRODUCES SHAFT POWER TO DRIVE SHALLOW AND DEEP IRRIGATION PUMPS

## • PURPOSE

- TO TEST PROTOTYPE SYSTEMS IN REAL-LIFE ENVIRONMENTS

## • EXAMPLES

- IRRIGATION PLANT IN WILLARD, NM (SHALLOW WELL) OPERATIONAL
  - \* LINE-FOCUS COLLECTOR FIELD
  - \* 25 hp ORGANIC RANKINE ENGINE
  - \* IRRIGATION PUMP AND CONTROLS AND STORAGE (23 hr/day)
  - \* 700 gal/min FROM 110-FT WELL (100 ACRES IRRIGATED)
- IRRIGATION PLANT IN ARIZONA (DEEP-WELL)
  - \* LINE-FOCUS COLLECTOR FIELD
  - \* 200 hp
  - \* SCHEDULED OPERATIONAL IN 1979
- 17 SHALLOW-WELL SYSTEMS IN 17 WESTERN STATES
  - \* 50-hp SYSTEMS
  - \* FIRST TWO INSTALLED BY 1982
  - \* NEXT 10 BY 1983
  - \* LAST 5 BY 1984

Figure 12.

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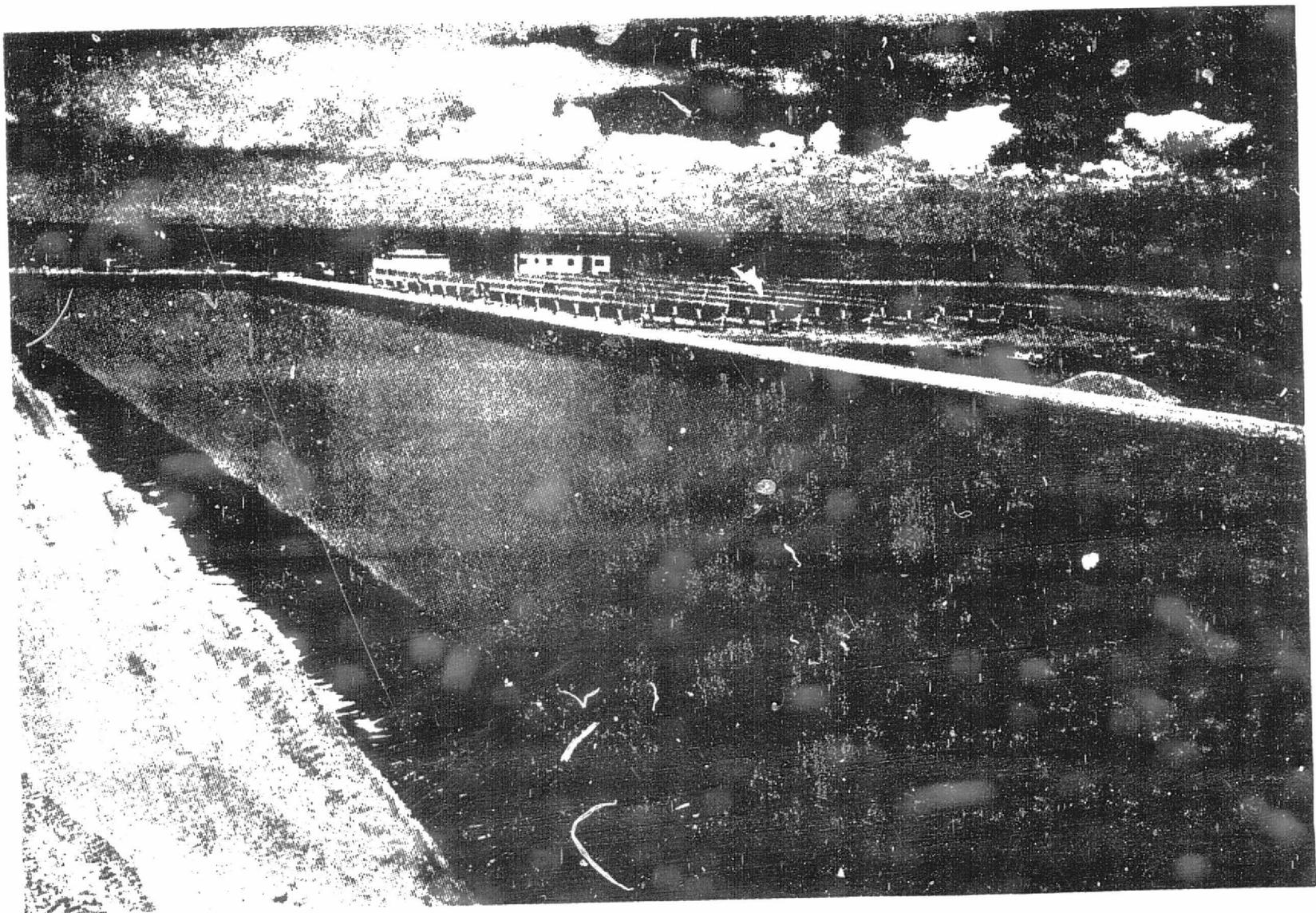


Figure 13.

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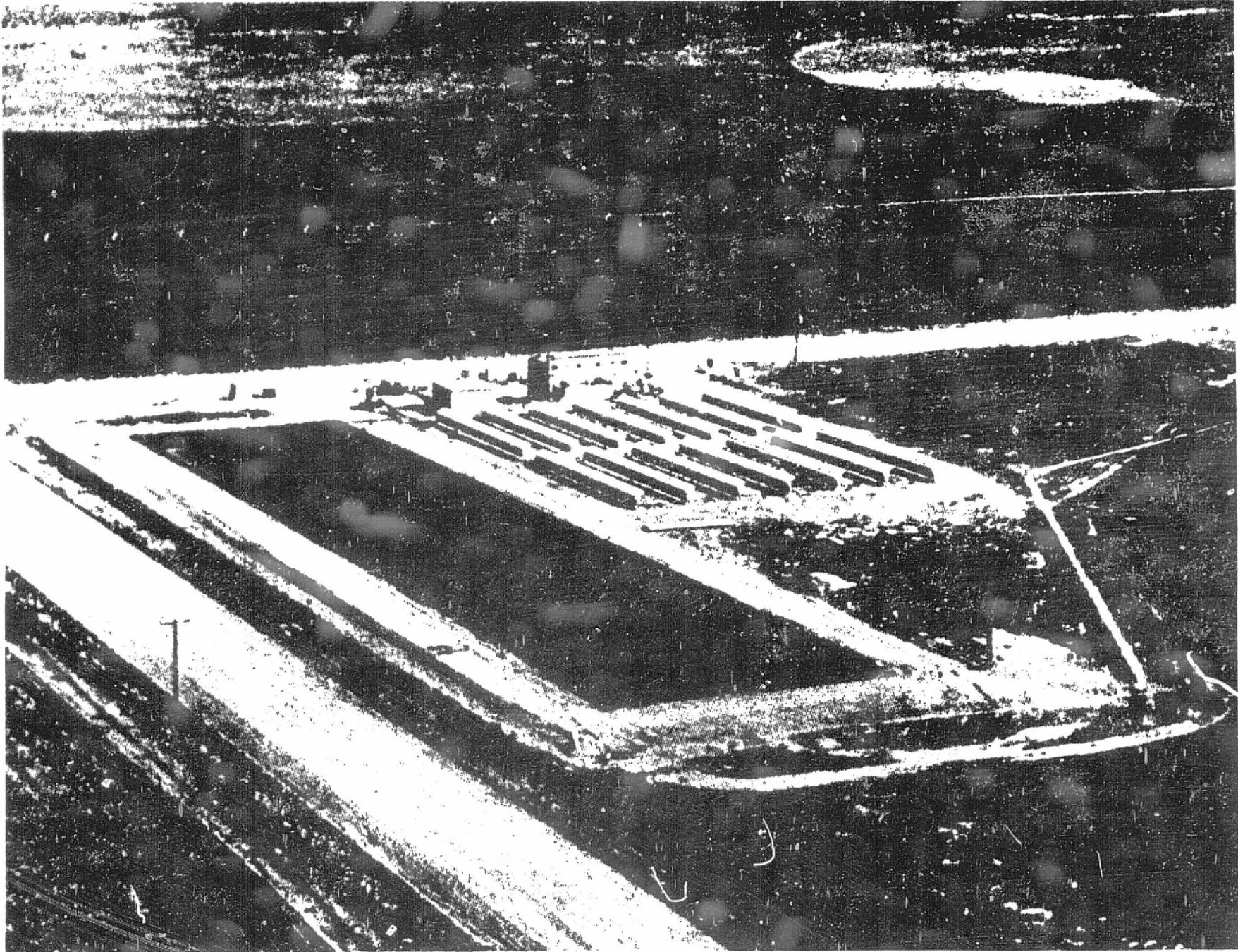


Figure 14.

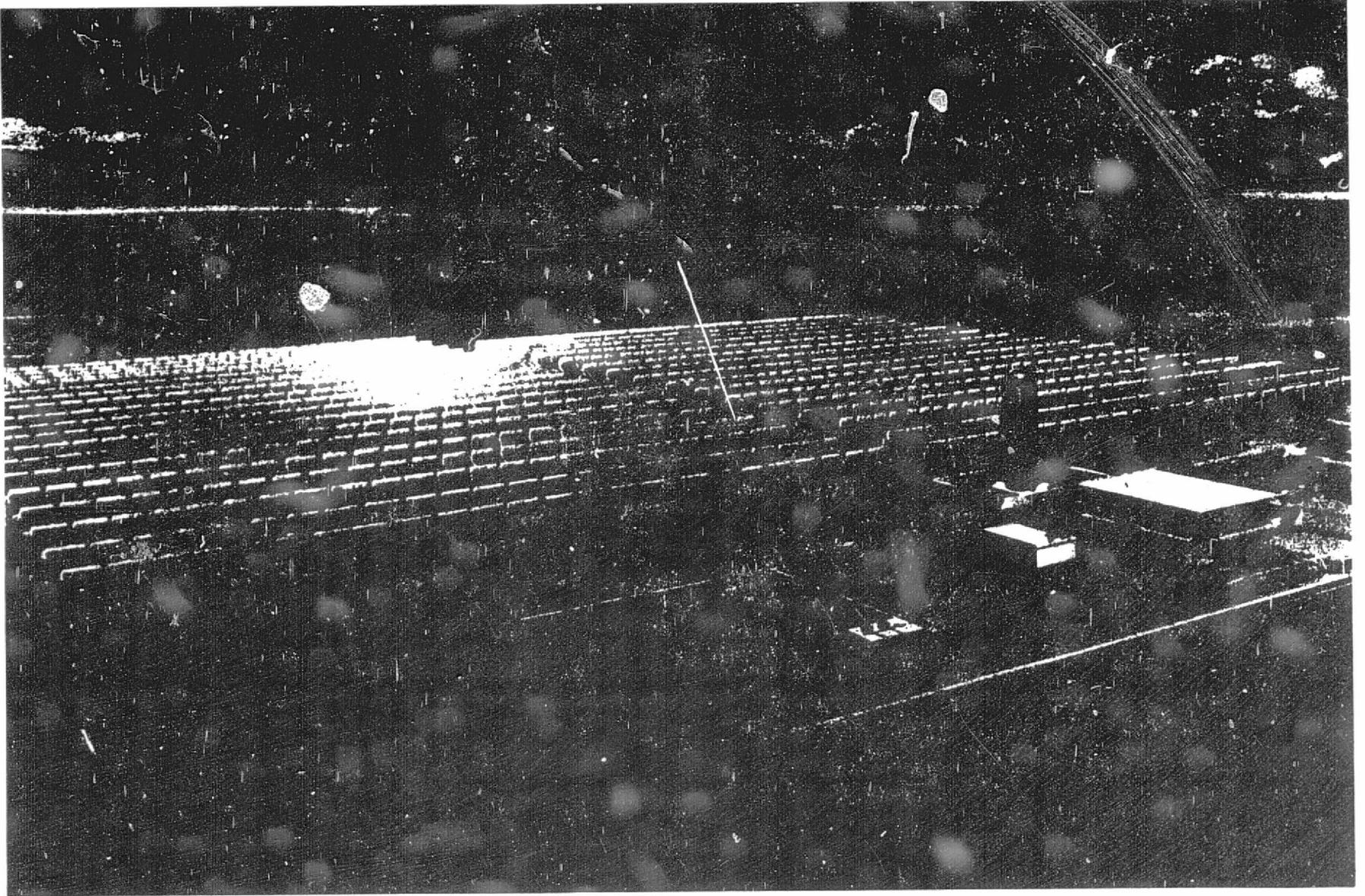


Figure 15.

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# **SMALL POWER SYSTEMS**

- **DESCRIPTION**

- **SOLAR ENERGY PRODUCES ELECTRICAL POWER**

- **EXAMPLES**

- **SMALL COMMUNITY/UTILITIES**
- **SOLAR PUMPING STATIONS**
- **OFF-SHORE ISLANDS**
- **MILITARY APPLICATIONS**

Figure 16.

Here now, instead of producing total energy, or instead of producing pump power for running an irrigation system, we are looking for a different class and set of applications. Small community utilities, or solar pumping stations that transport water from the north down to the south. These power plants could be used on offshore islands, Hawaii and Alaska and many of the isolated islands where right now we are bargaining in oil and, in fact, energy is very expensive. These might be the early markets that we can penetrate with the systems because these systems in low production will be more expensive than we hope they will be -- and I will talk about that in a moment -- in a few years when we can get an infrastructure and mass production industry going where you can produce collectors and complete power systems rather inexpensively so that this particular class of application will make more sense.

The earlier ones might be these. The military applications might be able to afford a little more in terms of the cost of energy than, let's say, our small communities can today.

I have a slide that shows a picture of a typical installation. Maybe in a small community that is serviced by a one-to-fifty megawatt alternate power plant. There are a number of different technologies that can be used, but all of these tend to be high-temperature technology. We are going that route because we think eventually we can make them less expensive than the types of systems that have been developed to date to do irrigation and total energy systems.

Next slide.

(See Fig. 17)

Now, on this small power systems program this is what we are trying to do. Basically, we are looking at the so-called point-focusing technology. Our goals are to develop low-cost, high-efficiency components in the 1983-85 time frame with collectors that cost in the range seventy to maybe a hundred dollars per square meter (seven to ten dollars per square foot). In limited production those same systems might cost \$300 to \$500 per square meter. That is part of the problem. The early market will have to be paying this kind of price. As we produce many of collectors we can get the price down. We are developing engines that have very high efficiencies.

This program has three experimental power plants very much like the irrigation program. These are bigger plants, one to five megawatts in size to produce electricity that can be integrated in some small community. The first one we hope to have installed by 1982. We hope to have at least three on-line by 1985.

The design work is beginning to be initiated already for this first one. We are, in the next few months, soliciting sites from utilities and small communities for the installation of that particular plant. We are working with the government to try to find the appropriate site in the country to be able to install that first 1 megawatt power plant.

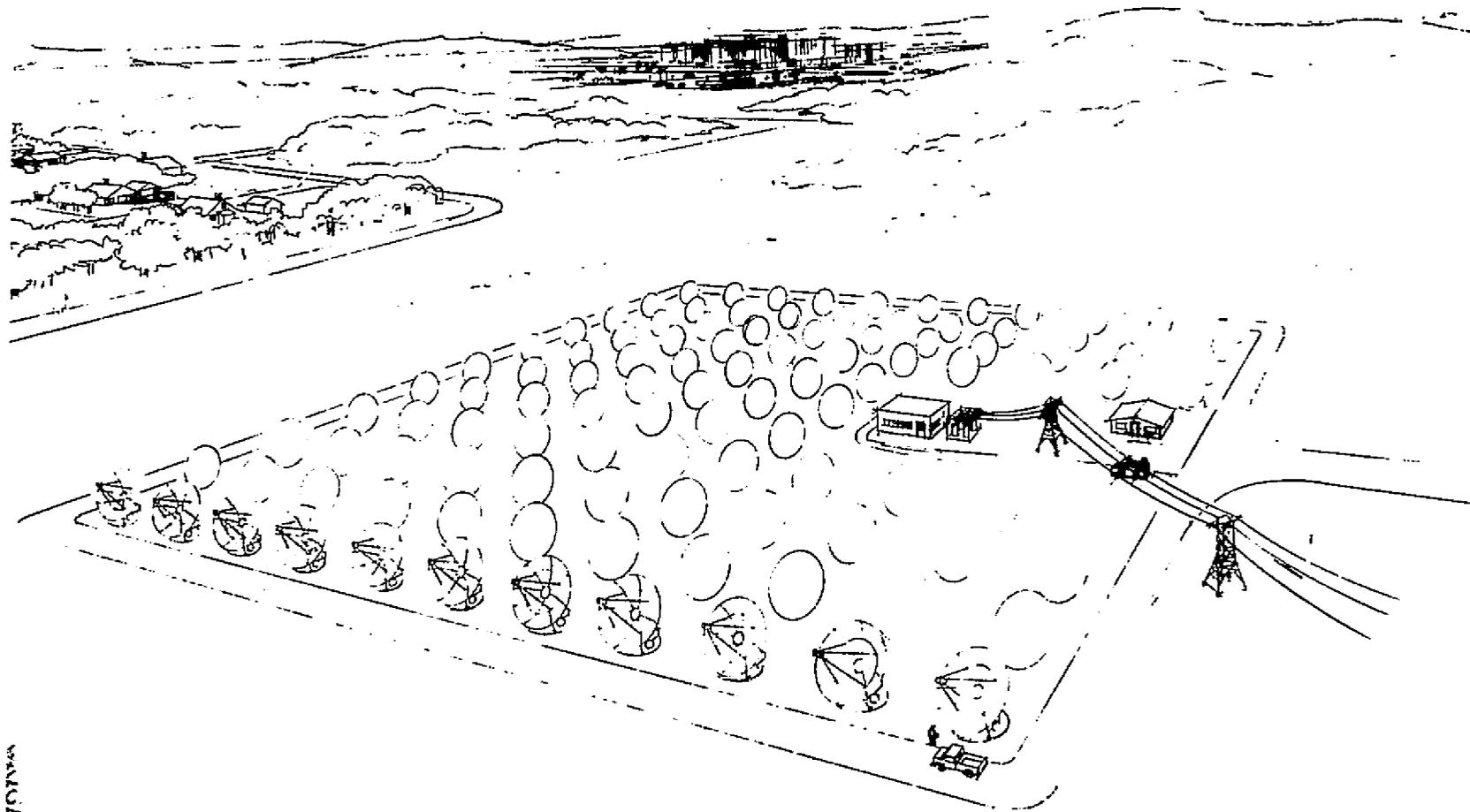


Figure 17.

In the long range where are we going? We want to be able to penetrate the small community market with these kinds of systems with energy in the range 50 to 60 mills per kilowatt hour.

In the 1990 time frame we feel that that will be a very competitive price for energy as compared to the alternatives.

Where are we in the very near term? In the 1983 time frame, '85 to '90 time frame, probably we are talking about much more expensive energy. We are probably talking about 100 to 300 mills per kilowatt hour. The early plants that come on-line will be more in those terms of expense.

My final slide addresses some of the advantages of solar thermal.

(See Fig. 18)

These systems are easily hybridized. That is, they are externally fired units so that it is possible with the same set of machinery not only to operate off the sun, but also to burn fossil fuels and operate the same turbine machinery. Early installations might be these types of plants. In other words, you might install plants that have very high reliability because not only do you operate off the sun or a storage and the sun, but, in addition, you can also have a fossil backup integrated with it so that you can assure yourself that the plant will stay on-line.

These kinds of systems, these solar thermal systems, are very efficient and we feel are going to have maybe 1/2 to 1/3 the collector area of competing types of systems. Maybe 2-1/2 square meters per peak kilowatt. Could be as much as 3 or 4 square meters per peak kilowatt. Compared with many of the present day alternatives of generation, the systems are going to be less polluting, are certainly going to be quieter and are, of course, going to be fuel savers.

I would like to stop at this point and open up to some questions.

I have some additional back-up charts if the appropriate questions are asked.

ATTENDEE: In a small thermal application, small community application, any consideration of the heat utilization again on the excess heat from that solar generation?

DR. TRUSCELLO: Well, those systems could easily also be total energy. That same technology could be used for total energy, sure.

ATTENDEE: Do you have any estimates of dollars per kilowatt hours delivered or cost per kilowatt hours delivered in that kind of system.

DR. TRUSCELLO: I did show some of those numbers.

Our long-range goal is to achieve 50 to 60 mills per kilowatt hour. You know, today you are paying from 40 to 50 mills per kilowatt hour for your electricity. That includes the distribution cost as well.

## **ADVANTAGES OF STEP**

- **EASILY HYBRIDIZED - EXTERNALLY FIRED UNITS**
- **REQUIRES 1/2 - 1/3 COLLECTION AREA OF COMPETING SOLAR CONCEPTS (2.5 m<sup>2</sup>/peak kilowatt)**
- **COMPARED WITH DIESEL GENERATORS, THEY ARE:**
  - **LESS POLLUTING**
  - **QUIETER**
  - **FUEL SAVERS**

Figure 18.

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We hope to be able to generate systems that are in the 50 to 60 mills per kilowatt hour. With distribution it might be 70 mills per kilowatt hour. We are saying by 1985-1990 -- certainly by 1990 -- these are going to be competitive with the alternative systems.

ATTENDEE: I know the figure changes rapidly, but do you have a feeling for the per-square-foot cost for a flat plate construction?

DR. TRUSCELLO: Low-temperature collectors?

ATTENDEE: Low-temperature collectors, yes.

DR. TRUSCELLO: I understand it is going to be difficult to get them lower than \$10 per square foot, as a kind of ball park number.

A part of that problem stems from the way these things are being produced in small quantities. I am sure that if you really produced them in the millions and millions of square feet like these larger applications are really aiming at, you can produce the automation, the proper tooling and so forth required to get the cost down. If the guy is doing it in his garage he is never going to get the cost down. That is part of the problem with collector systems today. Too many small businesses are generating small amount of these. To really get the cost down to what is going to be required to make these kinds of systems competitive, you are going to have to do things like General Motors does.

ATTENDEE: Have you looked at some of the solar total energy systems for urban locations like an office building or a series of office buildings?

DR. TRUSCELLO: I am sorry. Have we looked at it?

ATTENDEE: Have you looked at the economics and the feasibility?

DR. TRUSCELLO: The total energy program actually being run out of Sandia, Albuquerque, aims at looking at that kind of application. I haven't here at JPL. But I know that the government's program is looking at that as a potential application.

It suffers from the same economic problems as the rest of these applications. You have got to get the cost of the collectors down to make those systems viable.

ATTENDEE: How about the space problem in having all these collectors?

DR. TRUSCELLO: Okay. Now, clearly, applications like for irrigation systems, large central power stations, even small community installations, are likely to be found where the land will be available.

When you try to integrate these large systems into existing structures, industries, apartments and so forth, it is a more difficult problem. So you really ask yourself the question, what is the market really trying to get? The total energy people feel that they have ways of solving the problem of integrating collectors with planned, and future planned industrial sites. It may be easier to do that than trying to retrofit existing plants. I gave you examples of several: a military complex, a knitwear factory, an industrial complex that is being developed, where the necessary land area was set aside in order to make sure that it happens.

People who want to use and utilize these systems have to give that as an additional consideration in the construction of their industrial site to make sure that the land area is available. I don't think it is an insurmountable problem.

Any other questions?

ATTENDEE: You mentioned one of the problems is cost of collectors relative to a large number of small companies in production. Would it be a large number of small companies in production or not enough production in the large and smaller companies?

DR. TRUSCELLO: I think it is both. Clearly, if you have a finite production rate and you divide that finite production rate among a hundred smaller companies you are not going to be able to do the same kinds of things as if you take that same total production and did it with one company. So we have to get around that problem and it really means getting a large production requirement so that you can have a lot of companies doing it.

ATTENDEE: That is an interesting position because there are lots of people saying, you know, that we are not going to see much of a reduction and that mass production is not going to help that much. But you feel that it is.

DR. TRUSCELLO: There is no question in my mind but that mass production will help, but not the way we are attacking the problem of mass production where we produce a hundred of these units.

If you look at the industries that have done well in mass production, you see that they literally have to produce millions of something before the price comes down. By that time, they have introduced the appropriate automation techniques and tooling. It is really a material cost. Until we start approaching that kind of behavior and start doing things like that we are kidding ourselves in terms of getting the prices down on these devices.

ATTENDEE: In the total energy system, how much does the use of the waste heat help? Is that really a big factor in improving the economics?

DR. TRUSCELLO: According to the Albuquerque people, who are developing the systems, it is significant. They say that the total energy systems will reach cost competitiveness earlier than an all-electric system can because you are using the waste energy and you are making double use of that investment. A factor maybe of 50, 60, 70 percent reduction in cost because of doing that. So, yes, total energy can be a very important additive.

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SOLAR HEATING AND COOLING - R. E. BARTERA

DR. BARTERA: Vince just told you about one set of technology which is close to reality, and now I am going to talk about one which is, at least in certain phases, here already, and in other phases is not quite here.

Can I have the first slide, please.

(See Fig. 1)

Solar heating and cooling is where you want heat energy out of the sun. This slide has a picture of a domestic hot water heating system, a small-size collector on someone's roof with a storage tank and pumps and this sort of equipment.

This is close to reality. There is an industry there. There are about 200 manufacturers now making solar collectors. Most of them are small. And costs are high, as Vince just talked about. In fact, most of those manufacturers produce about 1,000 square feet a year. A few of the larger ones produce 100,000 to 200,000 square feet a year of flat plate collectors. It is not the millions that will be required to get the cost down.

The State of California, as you probably know, has a tax credit incentive for solar heating and cooling systems, and the State has just gotten a compilation of the people who claimed tax credit for last year, the first phase, which is a 10 percent tax credit, and there were 5,000 installations in the state claiming that tax credit.

I am, right now, involved in trying to locate and identify systems in Los Angeles County. We have gotten a list of people involved in solar energy, and have cross-referenced and knocked out all the duplications and we still wind up with a list of 700 individuals or companies doing solar energy business in this county. They are not all located here, but they are ones whom we know are doing business here or are likely to do business here. This includes engineers and architects as well as the manufacturers themselves. We are well into out telephone survey of those people.

The next slide, please.

(See Fig. 2)

Just to point out the differences between solar heating and cooling and fossil fuel types of applications, the operating costs with solar are quite low. The sun is there, and some people are fond of saying the sun is free. But the initial costs are high and you must amortize that over the life of the system.

Storage with solar systems is usually in the form of heat, of hot water or something like this which tends to require large volumes and

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# SOLAR HEATING AND COOLING

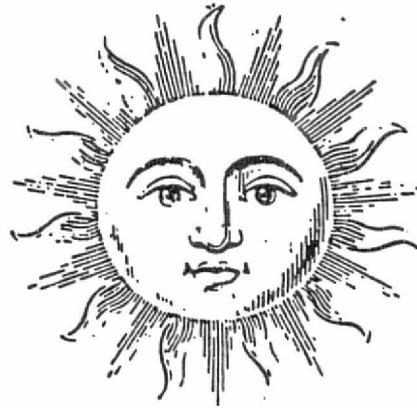
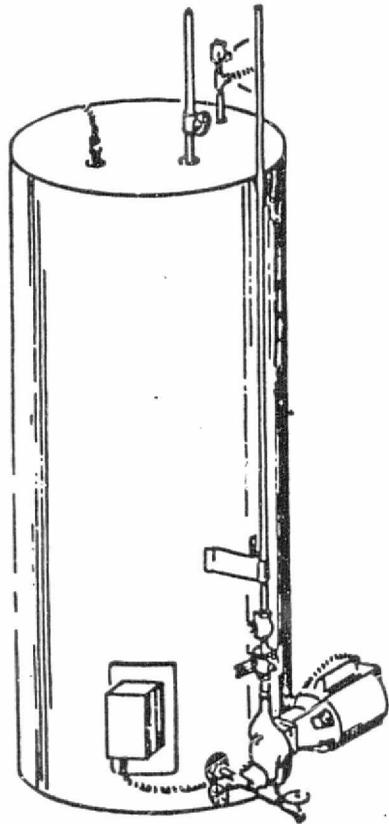


Figure 1.

	<u>SOLAR</u>	<u>FOSSIL FUEL</u>
OPERATING COSTS	LOW	HIGH
INITIAL COSTS	HIGH	LOW
STORAGE	HEAT	FUEL
BACKUP	100%	NONE

Figure 2.

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sizes, whereas the storage associated with fossil fuel type of systems is in the form of fuel, a tank of oil that contains a lot of Btu's.

In the case of gas or electric, which I include under fossil fuels, the storage is taken care of by utilities at some other locations.

Solar heating and cooling generally also requires a 100 percent backup. If you are willing to live in a cold house on cloudy days I guess you can get away without 100 percent backup, but I don't know many people who are willing to accept that, at least on a large-scale, commercial venture kind of operation.

The next slide, please.

(See Fig. 3)

Just to put in perspective what solar energy is, I want to emphasize the word "approximate" up there. These numbers will vary according to the climate and the temperature of operation that you want to get. But these figures will sort of put you in the right ballpark anyway, even if it won't get you into the infield, perhaps.

One square foot of solar panel produces the energy equivalent of one cubic foot of natural gas each day, on an average, for some applications. I want to keep the qualifiers in here because exactly how well you do depends on many things.

If you convert that into annual, at the bottom, three square feet of collection will get you about a million Btu's a year in fuel savings. A million Btu's sounds like a lot of energy, but if you convert that into gas it is about \$2 worth of gas or \$4 of oil or \$10 or \$12 worth of electricity.

So in order to save very much money or save very much fuel, you are going to need a very large area. You have just seen some pictures of installations that use very large areas. This is one of the drawbacks of solar energy systems, especially heating and cooling in urban areas. There are limitations on the amount of space available. If you want to do individual home water heating then there is plenty of area. You need 30, 40 or 50 square feet.

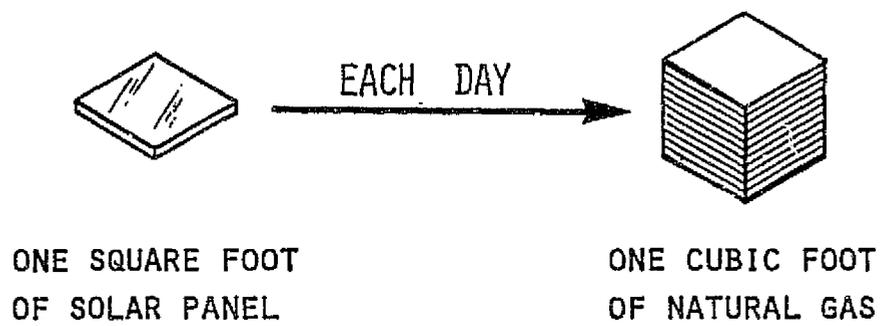
When you get into an industrial application, a great many factories use a lot of energy per square foot of factory and you are going to run into trouble there. I think the comments that Vince made in terms of setting aside space during the development and design portion of a project is going to be important.

The next slide shows one of the limitations and one of the reasons I qualified those quantity numbers in the previous slide.

(See Fig. 4)

This shows two kinds of solar collectors. The annual energy is plotted vertically and the temperature is horizontally. The flat - plate

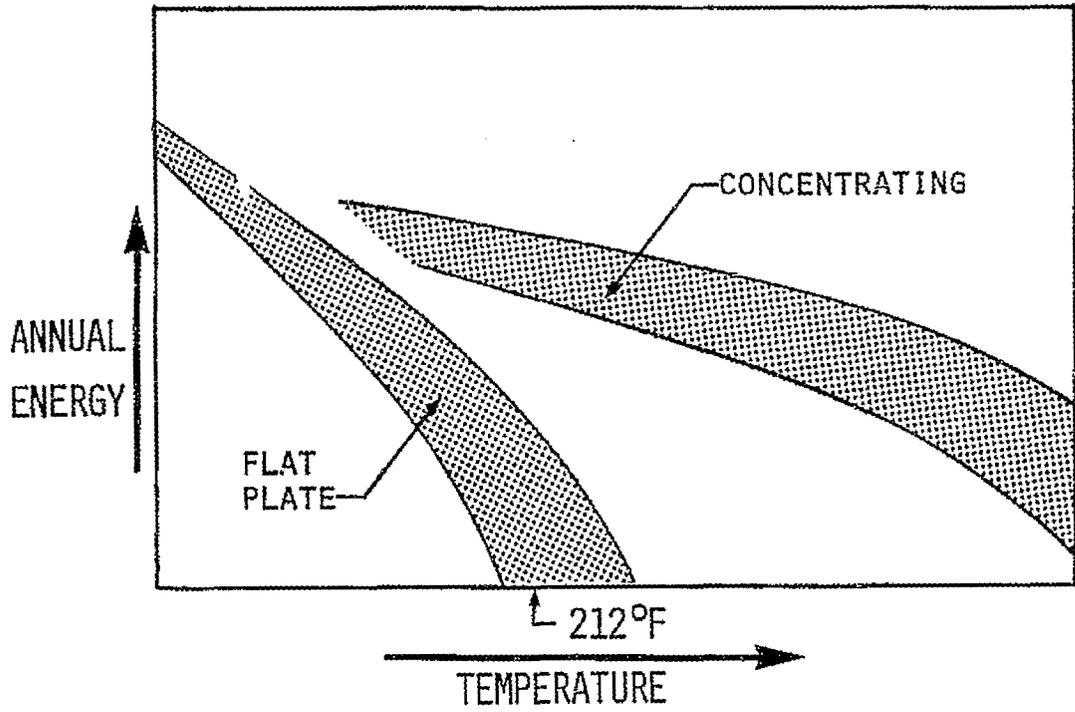
APPROXIMATE VALUES



3 SQUARE FEET	}	{	GAS	\$ 2.00
YIELD			OIL	\$ 4.00
1 MILLION BTU/YR			ELECTRIC	\$10.00

Figure 3.

# SOLAR COLLECTORS



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Figure 4.

kind of collector can be quite efficient at low, moderate temperatures, but they drop off rather quickly. Their heat losses are quite large because you have very large areas which are operating at high temperatures. I don't mean to imply that all flat plates fall in the region, that band, but this is sort of how they go. When you get up to 200 degrees or so there are very few that are going to have significant amounts of energy efficiency left. There are some which do, of course. But around that kind of temperature, 200 degrees or so, you are going to switch to a line-focusing collector or a point-focusing collector. If you need temperatures above that region they start falling off, too.

There is no scale on that temperature axis. The end isn't 500 degrees Fahrenheit, as you might imply from that 200. It might be like 1,000.

Just to give you an idea of the problems involved, as the temperature gets higher your energy collection goes down.

Could I have the next slide, please.

(See Fig. 5)

This shows another problem especially with space heating; the load is seasonal. The solid curve shows a typical space heating kind of load peaking up in January and going to zero in the summertime. The dashed line shows a particular solar energy system designed to supply that load. You see that the shaded area is actually the energy you can use. And while your three square feet might get you a million Btu's a year, if you are using it for this application you are not going to get to use all that million Btu's.

For the particular application where I got this data, there was another use which could use the energy in the summertime and it was transferred over and full benefit was obtained.

I also want to point out that the solar energy curve goes to a minimum over there in June which might look unusual, but this is one of the things which you can do, in fact, in the system design. If you do the system design correctly you can switch energy from winter to summer with certain techniques. There is more solar energy available in the summertime, yes, but this system needed the energy in the wintertime so we arranged it to collect more efficiently in the wintertime and less efficiently in the summer, primarily by making the panels very steep so that the sunlight in the summer didn't quite strike the panels. Well, it struck them, but at a very shallow angle.

Now, I am going to get into some specific applications and talk about characteristics. The first one is the next slide.

(See Fig. 6)

This is a very prosaic application like swimming pool heating. It is characterized by low temperature, 80, 90 degrees Fahrenheit, 100

# SPACE HEATING

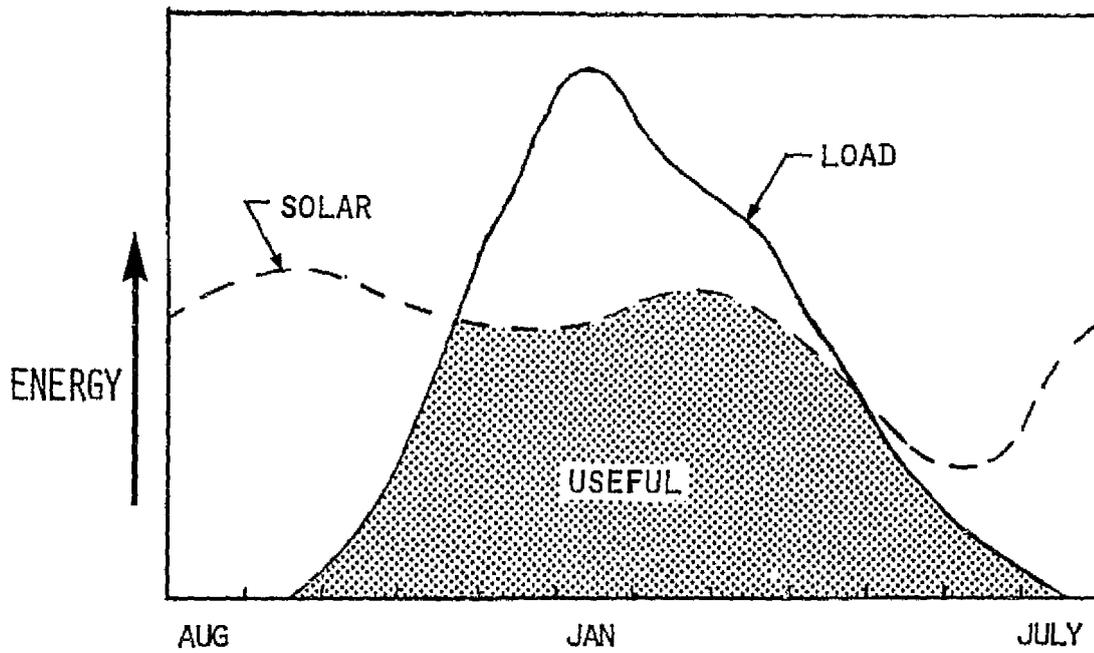


Figure 5.

## POOLS AND SPAS

- LOW TEMPERATURES
- SIMPLE SYSTEMS
- NO HEAT STORAGE
- COMPETITIVE WITH GAS
- NOW COMMERCIAL

Figure 6.

degrees perhaps for a spa.

The systems are very simple. You don't need any storage. The swimming pool or spa has all the storage you need. These systems can be installed right now and can be competitive with natural gas and, in fact, they are. I think most of those 5,000 applications for tax credit are in this category. You can very easily call up tomorrow morning and get someone to come up and install a system on your swimming pool next week, I am sure. It is here and it is going, and the industry is growing rather quickly.

So we don't deal very much with swimming pool applications. When we get calls we refer them to the Yellow Pages because that is where you get information on pools and spas.

The next slide is the next step up in terms of commercial situations.

(See Fig. 7)

Domestic hot water requires somewhat high temperatures. 140 degrees is what people usually use, although we are seeing a trend more towards 120 degrees operation, or 110 degrees, depending on who is using the hot water. If you want something to wash hands and take a shower with you certainly don't need anything more than 110 degrees, and this keeps the temperature down and the efficiencies of collection up.

It does require some storage. If you want to take a shower on cloudy days you are going to need some storage or a change of lifestyle.

It is now commercial. There are right now about, I think, a dozen companies -- at least a dozen -- offering packaged domestic hot water systems for individual homes. You can, in fact, make a telephone call tomorrow from the Yellow Pages and get somebody to come out and quote you on a hot water system to put into your house which will supply you one family's worth of hot water.

In most applications such a system would be competitive with electric heating. It is not as inexpensive as pool heating because you need higher temperatures, you need higher temperature collectors, you need some storage and some other things. But it certainly can be called competitive with electric, and certainly in the State of California with our tax credit, it is.

The next step up in applications is space heating.

(See Fig. 8)

This requires the same kind of temperatures as domestic hot water, but the load is seasonal, and if you can't find something to do with your solar energy in the summertime then the cost of the energy that you do use in the winter is obviously going to be higher.

## DOMESTIC HOT WATER

- MODERATE TEMPERATURES
- STORAGE NEEDED
- NOW COMMERCIAL
- COMPETITIVE WITH ELECTRIC

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Figure 7.

## SPACE HEATING

- MODERATE TEMPERATURES
- HEAT STORAGE (WATER OR ROCKS)
- AIR SYSTEMS
- SEASONAL LOAD

Figure 8.

You do need heat storage. You are not dealing with a comfort thing; you are dealing with a required heating in some areas of the state, or in parts of the country. You are dealing with a safety item.

In space heating there are essentially two choices. You can use a hot water system which looks like a domestic hot water system, but larger, in which you store the energy as hot water and distribute it through the house as hot water with baseboard convection coil units, or you can save a few dollars and use what is called an air system in which the collectors are designed not to carry water with all its corrosion problems, but to blow air through these collectors and then blow that air through a rock pile or a bin and heat up these rocks to store the energy. Then, when you need heat in the house, you blow the house air through that rock bed and it comes up warm, still with a back-up system.

I like that system because when I was a kid we had a coal furnace and my father switched to oil when I was about 10 years old. We had this great coal bin down in the basement, and that would be a great place to put rocks. I enjoyed hiding there, and my mother didn't seem to care that I played down there. She didn't like the idea that I played in the coal bin.

But if we could start building houses again with coal bins and fill them with rocks instead of coal this might be a very effective way to do it.

The next step up is industrial heat.

(See Fig. 9)

I qualify this by saying under 200 degrees Fahrenheit, and that is an approximate figure. When we talk about that we are talking about systems which are physically very much like the domestic hot water systems except for their size. Now you are talking about engineered systems, not having perhaps 2,000 square feet but tens of thousands of square feet or hundreds of thousands of square feet. So the systems are larger and they are going to be engineered. My experience has been that even good engineering companies have been doing engineering for a long time based on certain criteria and it is hard for them to change their attitudes, but they are learning. In these days, when we have been using fossil fuels for the past hundred years, engineers have designed systems to meet peak loading requirements and have put in enough capacity to meet the load. In fact, you put in the next size boiler just to make sure. That was because the capital costs were low and the actual cost of the heat was the fuel that you fed to the boiler. People still tend to think this way. When you go to somebody doing this as a conventional mechanical engineer he wants to know what the peak loads are and then he computes the solar array system based upon that and he says it is impractical. But people are learning that you look at the average loads. In fact, you look at the average load each month and compare that to the solar. It is a new procedure, but people are learning it.

INDUSTRIAL HEAT <200°F

- LIKE DOMESTIC HOT WATER
- ENGINEERED SYSTEMS
- LARGE AREAS NEEDED
- SOLAR PONDS CAN BE LOWER COST

Figure 9.

There is one thing here which is a potentially good application. The bottom line says "Solar Ponds can be Lower Cost." By "solar ponds" I mean just that, a very shallow, a 4-inch to 12-inch-deep pond of water setting out on your land someplace covered with perhaps a plastic film or what-have-you.

Solar ponds can be very inexpensive. You can bulldoze an area and waterproof it and put the water in with some kind of simple glazing, a plastic cover and let it sit out there all day and soak up the sun and get warm and get hot. At night you can drain it off into some insulated storage tank, if you have it, and use it for your process. These kinds of systems can be very, very inexpensive. I will use some numbers in a few minutes, but these solar ponds if your applications are right and your temperatures are moderate, can be competitive with oil. I have seen some design studies which would indicate that.

The next step up in terms of commercialization or usefulness is space cooling, and you have already studied that slide pretty well, I think.

(See Fig. 10)

Absorption chillers are the normal means of getting it, although there are other techniques. There are the desiccant techniques where you transfer the water vapor in and out of the desiccant and in the process wind up with cooler air than was put in the system by adding solar heat. Those work. They are more developmental, but there are some installations like that. Normally you use absorption chillers which are much like the old Servel refrigerators.

You saw a slide this morning which showed absorption chillers and how big a unit you need to handle a load based on the temperature that you put in. This is for geothermal projects. As you noticed there, if you are not above 200 degrees Fahrenheit you are not going to do very well. There are small home-size units now which can run down to 185 degrees Fahrenheit, but not very well. Their efficiency really falls off. You really need to get up over 200 degrees Fahrenheit, maybe 250. There are, in fact, commercial chillers which are used. These are not new items. They are used extensively where you have waste heat in a factory and you want some chilling and convert that waste heat to chilling.

But you notice that that 200-degree Fahrenheit is really unfortunate for solar energy because what that means is you can't use a flat plate collector very well. You can, but they are marginal. If you get very high performance and use expensive flat plate collectors you can make these things work, and there are several installations around the country which are doing this.

To make this really effective you need to go to a line-focusing or a point-focusing collector.

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## SPACE COOLING

- ABSORPTION CHILLERS
- NEEDS ABOUT 200°F
- 50 % CONVERSION OF HEAT
- LARGE MACHINES

Figure 10.

The other thing about space cooling is that the conversion of heat to cool, from hot to cold, is about 50 percent. In other words, to get one million Btu's of cooling out of it you need to put in two million Btu's of heat, and since in solar energy applications that heat is expensive because you are dealing with expensive collectors, this is a difficult application.

It also means that if you put in two million Btu's to get out one you have got to get rid of the other one, which means you need a cooling tower and more equipment associated with it. So these tend to be more expensive applications.

A third factor, which I have run into in a couple commercial applications that we have looked at, is the size of the absorption chillers. When a man is developing and designing a building he is very conscious of space and space allocations and space usages, and if he wants to do his air conditioning with conventional mechanical compressors run by electricity he can usually put that equipment on the roof. It is about the right size and weight. When you start talking about absorption chillers on a building they get to be very large machines compared to the other ones and very heavy and the choice usually is to put them on the ground outside the building someplace which uses up several parking spaces and he doesn't like that. So there is a size problem associated with those.

The last application I want to talk about is industrial steam.

(See Fig. 11)

350 degrees Fahrenheit is the usual temperature for industrial process work which uses steam. This, of course, is going to require concentrators to get, line or point focusing.

Steam is a very efficient means of heat transfer within a factory.

We have just recently completed a survey for the State of California in looking at industrial process heat, and what we found was that even when the process heat was 140 degrees or 120 degrees the decision was to put in a central steam boiler producing 350 degrees of steam and pipe that around the factory because steam carries a lot of heat, 800 Btu's per pound of steam. It is a very efficient means of heat transfer. Heat exchangers all have the same temperature on the hot side. You just condense the steam and the temperature stays the same.

For a solar system producing steam, storage is difficult. Factories run 24 hours a day, typically. Some run two shifts and some run one shift, but typically they have a capital investment and they want to keep the factory running. So you are going to have to run the steam and supply steam 24 hours a day which means either a fossil fuel backup to be used off-shift or a storage of steam, and that is difficult because of the heat content of the steam.

## INDUSTRIAL STEAM

- 350°F IS USUAL
- STEAM CARRIES 800 BTU/LB
- STORAGE IS DIFFICULT
- LITTLE EXPERIENCE

Figure 11.

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Many people have looked at designs in which you store the energy in other ways. You find a material which will melt at 500 degrees Fahrenheit and there is a heat of melting and heat of freezing associated with that, and you can use that for storage.

People have looked at using hot oil with hot rocks but storage is a very difficult problem. There is much research and development going on in that area.

Last, there is little experience in industrial steam produced by solar energy. There is some, to be sure, but not really enough to know even what the costs are likely to be, which is the subject of the final slide.

(See Fig. 12)

I have talked about the energy levels. Now let me talk about ranges of cost. These are initial capital investments to put in a system.

For swimming pools and spas we are talking about five to ten dollars a square foot. This assumes that you hire someone to put it in. You can go out and buy some swimming pool panels for \$3 a square foot and you can put them in yourself and reduce the cost.

The domestic hot water systems are going for about \$30 to \$50 a square foot.

Let me say now, it is very difficult to pin down these numbers. There have been lots of systems put in and the costs cover really a very wide range. But \$30 a square foot is about right for a domestic hot water system, about the minimum, and I see no reason why it should cost any more than \$50.

Space heating is \$20 to \$50. The \$20 is low because of the possibility of using air systems with rock storage. That is also a seasonal load which these numbers don't take into account. These are initial system hardware costs, not the cost of the energy coming out.

The industrial heat is like the domestic hot water except they can get more expensive because of the complexities of the system and additional problems that you might run into in interfacing with the factory.

Space cooling is more expensive, and remember you only get half of that heat as cooling.

Industrial steam is a real question mark. I really couldn't tell you what an industrial steam would cost. A guess is \$60 to \$200 a square foot.

I would like to stop here and ask for questions.

## INITIAL SYSTEM COSTS

APPLICATION	INITIAL COSTS \$/SQ. FT.
POOLS AND SPAS	5 - 10
DOMESTIC HOT WATER	30 - 50
SPACE HEAT	20 - 50 *
INDUSTRIAL HEAT ( 200 F)	30 - 80
SPACE COOLING	50 - 80 *#
INDUSTRIAL STEAM	60 - 200 ?

\* SEASONAL LOAD

# 50 % CONVERSION OF HEAT

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Figure 12.

ATTENDEE: Then when we are talking about using solar collectors and panels for the industrial customer we really almost have to stop with space heat alone; don't we? You are saying that we can go to industrial steam at sixty to two hundred or more dollars, 350 degrees steam, which would be the bottom temperature that you would want industrially.

DR. BARTERA: Yes.

ATTENDEE: When you are saying industrial are you talking about space heat only or not? Or are you talking about steam?

DR. BARTERA: No. I am talking about producing steam.

ATTENDEE: And using it for processing?

DR. BARTERA: Yes. It is essentially process steam, whatever the factory wants. If they want to put a cogeneration system in with it that is fine.

I am not trying to imply that these are costs which are going to hold. These are my estimates and what my research tells me are present day costs, and these are the ranges. They are changing quickly.

When JPL started in the solar energy program in 1973, before the oil crisis, we found it very difficult to buy collectors, to find people who had a collector on the market and were willing to sell. There were a few people. And one of the things that we decided to do was survey all the collector manufacturers to find out what they thought the market would be and where it was going and where costs would go. We started that process and then the oil crisis came along and things changed and the government put incentives on solar energy and started pushing its use and applications and development and the number of manufacturers just grew faster than we could keep up with them and costs came down.

I think what Vince said about cost being a function of mass production is true. Costs are coming down quickly, production is going up quickly, running an exponential growth curve, and we are at the very beginning. The last estimate I heard of the solar energy industry was that it was doubling every nine months now. So it is not going to take much longer before these numbers make dramatic changes downward.

ATTENDEE: I think it might have been your first slide. You indicated that solar systems require 100 percent backup.

DR. BARTERA: It is desired. I tried to qualify that.

ATTENDEE: I would take exception to that. I run a utility and I think that is totally counterproductive and that that should say that storage is required four or five or ten days, whatever, so that you really get the cost of the solar system.

What you are doing is totally ignoring the cost of providing the backup.

DR. BARTERA: What I am trying to reflect to you are the feelings which are in the community now.

ATTENDEE: That is very dangerous, though, when they wake up to reality and everyone else's power cost doubles because the power plant is out there in stand-by status; only then there is a rude awakening.

It should be planned to have that now and not wait until a lot of systems get out and the utility peaks take off like gangbusters whenever there is a cloudy day.

DR. BARTERA: I understand this.

ATTENDEE: I think people like you should be setting the record straight that a 100-percent backup is not a desired and preferred system.

DR. BARTERA: I accept that.

ATTENDEE: I will make one comment in rebuttal.

100-percent backup does not mean 100 percent utility backup. There are many forms of backup that do not require electric power lines that can be serviced on an interim basis.

DR. BARTERA: This is a subject of a whole controversy, as I am sure you're aware of. There are people who claim utilities should give reduced rates to people using solar energy because it reduces their load. As a matter of fact, it can have just the opposite effect, it can increase the peakiness of the utility's operation.

But there are also rules being suggested which say that if you use solar energy the utility may not increase your rate. So there is a lot of controversy here.

ATTENDEE: What do we mean by 100-percent backup? Does that mean 24 hours a day?

ATTENDEE: 100 percent backup, in my opinion, is if two hours a day you need it, or if two days a month you need it, you have to have a system with capacity to provide that backup.

If it is the extreme case of an electrical backup, somewhere there has to be a generator ready to provide it.

If it is a more moderate case of an oil burner on your premises and a 50-gallon oil barrel, that oil barrel has to be there and a burner big enough to run it during the time it is needed.

ATTENDEE: So presumably if the backup stays off the system peak the problem is eliminated or greatly eliminated?

ATTENDEE: That requires storage, and that is again, a moderating thing or a balancing thing. Then you get somehow dispatching that backup system and requiring it to come on only during peak.

And the next thing is the peak moves, and you go into a second generation of considerations. Somewhere in there is a preferred system.

DR. BARTERA: I was thinking this is primarily for industrial people. If a plant manager installs a solar heating system, or process heat system, he knows the sun is not going to be out but he wants his factory running because when it goes down it costs him a lot of money to stop production and operation. So he needs a backup. He won't put in a solar without it.

If that is a utility backup, then that causes problems for the utility. If it is not a utility backup then it can be solved in other ways.

ATTENDEE: The peaking situation is a problem more for a power electric utility plant.

ATTENDEE: As a gas company utility, my questions have to do with the fact that the Public Utilities Commission now requires a prospective oncoming customer to our lines to prove that he can't use solar power in his process load and in his space heating and to run his facility or certain of his equipment in his facility. And many times it is left to us to be the judge as to whether this facility can be done with solar or not.

DR. BARTERA: You are becoming a policeman then.

ATTENDEE: A little bit, and it is not a role that we relish. But some things are obvious. A man that has to heat-treat at 1500 degrees Fahrenheit, why, obviously there is no problem. But when we get down into these areas that you are talking about we certainly don't feel very expert about them. I am very interested, therefore, in what you say in this industrial area of some 150 to 350 degrees.

DR. BARTERA: There is no application here. The steam is still questionable because there hasn't been enough experience with it. But in technical terms there is no problem with it doing the other tasks that I have talked about. There are some specific design problems that will come up, but these come up with any kind of construction job or mechanical engineering job. There is nothing technically that says you can't do it. It is the economics that you must decide on.

When the Coastal Commission was first setting up operations and making rules about "thou shalt use alternate energy in the Coastal Zones" several people called me up and said, "Hey, I want to build a house and they tell me I have got to think about solar energy, would you do a study and tell me that it is not practical for my application?" So that sort of a thing will go on.

Any more questions?

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ATTENDEE: Have you done any studies of a comparative nature on solar flat plates like they were doing on photovoltaics, comparing different manufacturers?

DR. BARTERA: Yes. We did some work on that, but it has all been superseded by NBS and ASHRAE in terms of performance.

ATTENDEE: Can you recommend someone who has done more recent work in that area?

DR. BARTERA: The best way to handle it, and what I usually advise people to do, is if you are looking for collectors there is no problem in finding collector manufacturers. They will find you. If you just tell three people that you want to buy a collector, they will find you. Then when they show up on your doorstep you ask them for test performance data produced by an independent agency according to either the NBS or the ASHRAE test procedures, and that will give you your efficiency versus temperature. So you can look on that and find where your application is on that curve and see what the efficiencies are and you can compare it with a standard sort of a curve.

ATTENDEE: Has anyone compiled all these different things in one spot?

DR. BARTERA: Not recently. People started to. Lewis did a few years ago. They had a chart with all the manufacturers' collectors on one chart and all different slopes and you could look and see which was better for high temperature and which was better for low. Then their chart just became a gray area because of the number of manufacturers that had become involved. I don't know where it is and what locations.

ATTENDEE: There is a four-page brochure put out by HUD right now that summarizes where we are as far as testing certifications of collectors and also test laboratories, approved laboratories. It is something that is happening now and really not in place yet. But this brochure is a real good account of where we are and where we are going and the time frame. I have a copy in my office.

DR. BARTERA: Excuse me. For these other references which have just been mentioned, could you talk to Bob Rose and give him the information and we will put them together when we mail out the material.

Thank you.

MR. ROSE: Thank you, Ralph.

Now we have a little change of scene. We are going to hear about wind energy systems and we are very pleased to have a representative from our parent organization, the California Institute of Technology, Professor Homer Joe Stewart.

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WIND ENERGY SYSTEMS - H. J. STEWART

PROFESSOR STEWART: I am going to talk about wind energy systems and about 99 percent of what I am going to say is involved with the DOE wind energy program. Most of that will be involved with their large windmill component of the program. Large in this case means more than the 10-to 50-kilowatt size. I think the reasons for that will be apparent as we go along.

I have a few remarks of an historical nature, and then I am going to say a little bit about what the wind energy systems are, where we stand with the equipment and what remains to be done in getting to the point where the things may have a more general use.

I am sure you all know wind energy has been a significant fraction of civil economy for many centuries. It is just in this century that it has become rather small because the fossil fuel costs became so small that wind energy systems couldn't compete economically. But if you look at, say, the Clipper Ships of 1850 that were coming around to California, these were about 1-megawatt machines. If you look at the large steel sailing ships towards the end of the century up to about World War I, those were about 10 to 20 megawatts peak power output machines.

The wind is like water in that it is a naturally renewable resource. It is different from water power, though, in that it is available in much larger quantities on a potential basis. I remember when we were doing the Grandpa's Knob windmill back in Vermont in the late '30s that the studies were made at that time looking at only very good sites and I will try to specify those in more detail later. It showed that there was potentially available in the United States average power output from wind on the order of a million megawatts, which is large compared to our present electric power usage.

Another way of saying this is that since wind is quite generally available, and in many sites through the middle west the wind distribution is quite favorable, you might say why don't you use it more? You are tempted to say that the problem is purely economic; that is, they couldn't make it in competition with fossil fuels. It is a little more than that because wind energy is a different kind of energy system. You have storage problems associated with it and you have some language problems which make it difficult for conventional power system people to think logically in terms of wind energy problems. So I will try to bring some of these factors out as I go along.

This first slide is really put up to show that the situation is on the verge of being real.

(See Fig. 1)

This is the one large windmill in the United States which is actually feeding into a local power grid and supplying power under conventional commercial auspices. This is a 125-foot diameter windmill. You can see that it has two very narrow blades. The tower is about 100

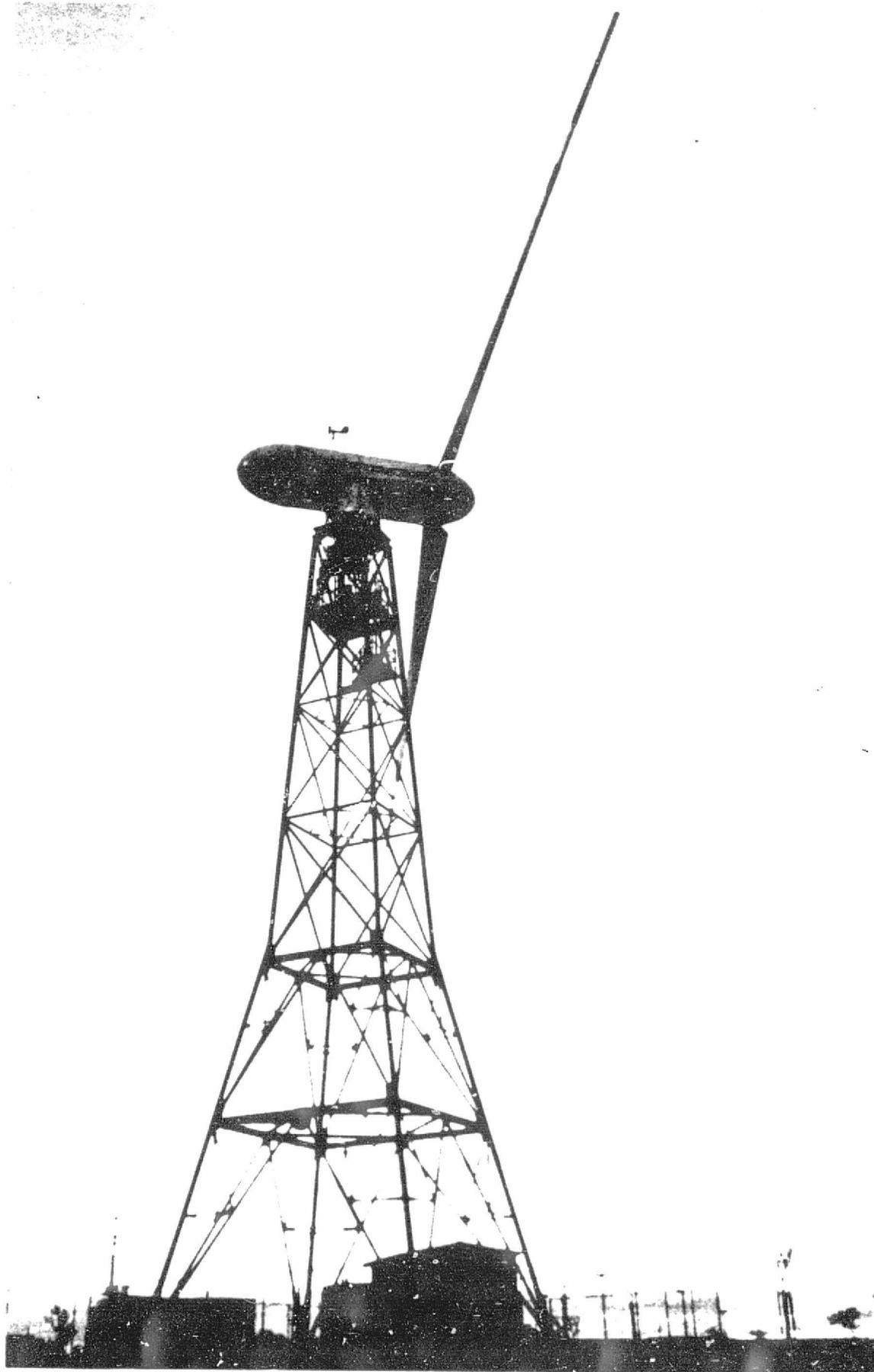


Figure 1.

feet high. It has a peak power rating of 200 kilowatts. It has been in operation since September. That is why I say "probably" when I refer to a performance number.

It probably will operate at an average load factor on the order of or perhaps a little higher than 50 percent. It doesn't supply a large fraction of the power in the little town. Clayton is a town of about 3,000 people. Obviously, an average power output of 100 kilowatts is not a large fraction of the total energy supplied. But, nevertheless, it is a significant one.

Let's have the next slide.

(See Fig. 2)

I have got to talk a little bit about some nomenclature because I want to explain some of the problems in thinking about wind energy. In the first place, the wind energy flux is clearly a kinetic energy already as it exists. The problem is you have to harvest it. You look at the wind energy flux as the energy per unit area. To locate the kinetic energy per unit mass,  $1/2 V^2$  multiplied by the mass flux, and I use  $\rho$  for the mass density and then  $\rho V$  is the mass flux. So  $1/2 \rho V^3$  is the energy flux.

Now, that is the same dimension as power. So the power that you can get out of that by some kind of a machine ought to be proportionate to that factor. To find out what that relation is, obviously, you have to use some kind of physical analysis. Now, the simplest kind of a physical analysis is the Froude Actuator Disc Analysis invented in about 1870 as a means of explaining how screw propellers work on boats. It also applies to windmills. This analysis is very simple and it has no room for losses, no friction, no swirling losses or anything. That is why we call that a "Perfect Machine," the Froude Actuator Disc. By that theory the available power per unit area is  $8/27$  of  $\rho V^3$ .

Now, if you have a site where you have wind, clearly, you can measure your velocity and see the way that varies with time. The density doesn't usually change very much and in my discussion I will treat the density as though it were a constant. As a matter of fact, if we use the metric kind of unit that we are supposed to be moving towards where you use density in kilograms per cubic meter, for standard air that is 1.2 or practically 1. Then if you use a V in meters per second the answer comes out in watter per square meter.

One way of describing the available power at a given site is to make a mean measurement of this  $8/27 \rho V^3$  and call that available power. Another one would be to just take the mean value of  $V^3$  and take the cube root and say you have got an equivalent energy speed. Obviously, since it is  $V^3$ , this is going to weigh more heavily the relatively few times when you have strong winds. That is the nature of one of the main problems you have to keep in mind when thinking about wind energy.

## WIND ENERGY PARAMETERS

### ENERGY FLUX

$$\text{Energy Flux per Unit Area} = \left(\frac{1}{2} V^2\right) (\rho V) = \frac{1}{2} \rho V^3$$

### AVAILABLE POWER

- a) Perfect Machine (Froude Actuator Disc)

$$\text{Available Power per Unit Area} = \frac{8}{27} \rho V^3$$

- b) Real Machine

$$\text{Froude Efficiency} = \eta_F$$

$$\text{Available Power per Unit Area} = \eta_F \left(\frac{8}{27} \rho V^3\right)$$

### PERFORMANCE INDEX FOR WINDMILL OF RADIUS R

$$C_P = \frac{\text{Power}}{(1/2 \rho V^3) (\pi R^2)} = \frac{27}{16} \eta_F$$

$$\text{so } C_{P_{\max}} = \frac{16}{27} = 0.593$$

### TIP SPEED RATIO (ANGULAR VELOCITY $\Omega$ )

a)  $X = \frac{\Omega R}{V}$

- b) X determines geometry of the wind and blade interaction

c)  $C_p = C_p(X)$  for a given blade geometry.

Figure 2.

So, if you want to apply this kind of an idea to a real machine, you can use that theoretical Froude power as a reference power and say then defining efficiency in terms of what your real machine puts out in terms of that theoretical one and call that a Froude efficiency factor,  $\eta_F$  there, and your available power for a real machine would be that Froude efficiency. I will give you some typical numbers for some machines a little later.

Now, the typical performance index which is used in the literature is related to these same numbers. The one that is usually used is the power coefficient,  $C_p$ , which is the power divided by this  $1/2 \rho V^3$  and the area of wind of the machine that you are working with, the  $\pi R^2$ , if you have a conventional windmill of Radius R, then this  $\pi R^2$  is the amount of air you are processing. And you will notice that is 27/16 times the Froude efficiency. So the maximum  $C_p$  is 16/27 or 0.59.

In addition, if you are dealing with a real machine, the real machines, or 99 percent of them, are rotating machines of one kind or another and have an angular velocity of  $\Omega$ . So you have a tip speed ratio that describes the geometry of the problem.  $\Omega R$  is the tip speed of the windmill and V is the wind speed. So the ratio X there describes the angle at which the wind approaches the blade or the blade approaches the wind, whichever way you want to say it. So that, in general, the power efficiency,  $C_p$ , will be a function of that tip speed ratio.

Next slide, please.

(See Fig. 3)

This shows a typical power coefficient curve. This is a theoretical calculation which should give a pretty good approximation to the Clayton windmill. You will notice it peaks in its performance at a tip speed ratio of about 10. So it is quite a fast-running windmill, as we say. The peak is at about .48 in  $C_p$  and the Froude efficiency is a little over 3/4 of the theoretical perfect machine.

Now, this is the output of the blades into the hub of the machine. You have to knock off from this the gearing losses and electrical losses in order to get the actual output of the machine.

Any kind of a wind machine will have a figure something like this. The Grandpa's Knob machine that we built back in the late '30s was a slower-turning machine. I believe it had a tip speed ratio design of about 5 instead of 10, and on the same plot it had a little higher efficiency. It would have been about .51 on this scale for peak efficiency.

You take an old-fashioned farm windmill which we have all seen; farm windmills are very slow-turning machines on this scale. A farm windmill usually peaks at about a tip speed ratio in the neighborhood of 1, and the peak  $C_p$  on a farm windmill is about .25. So it is quite low as compared to the higher angular velocity machines. But a

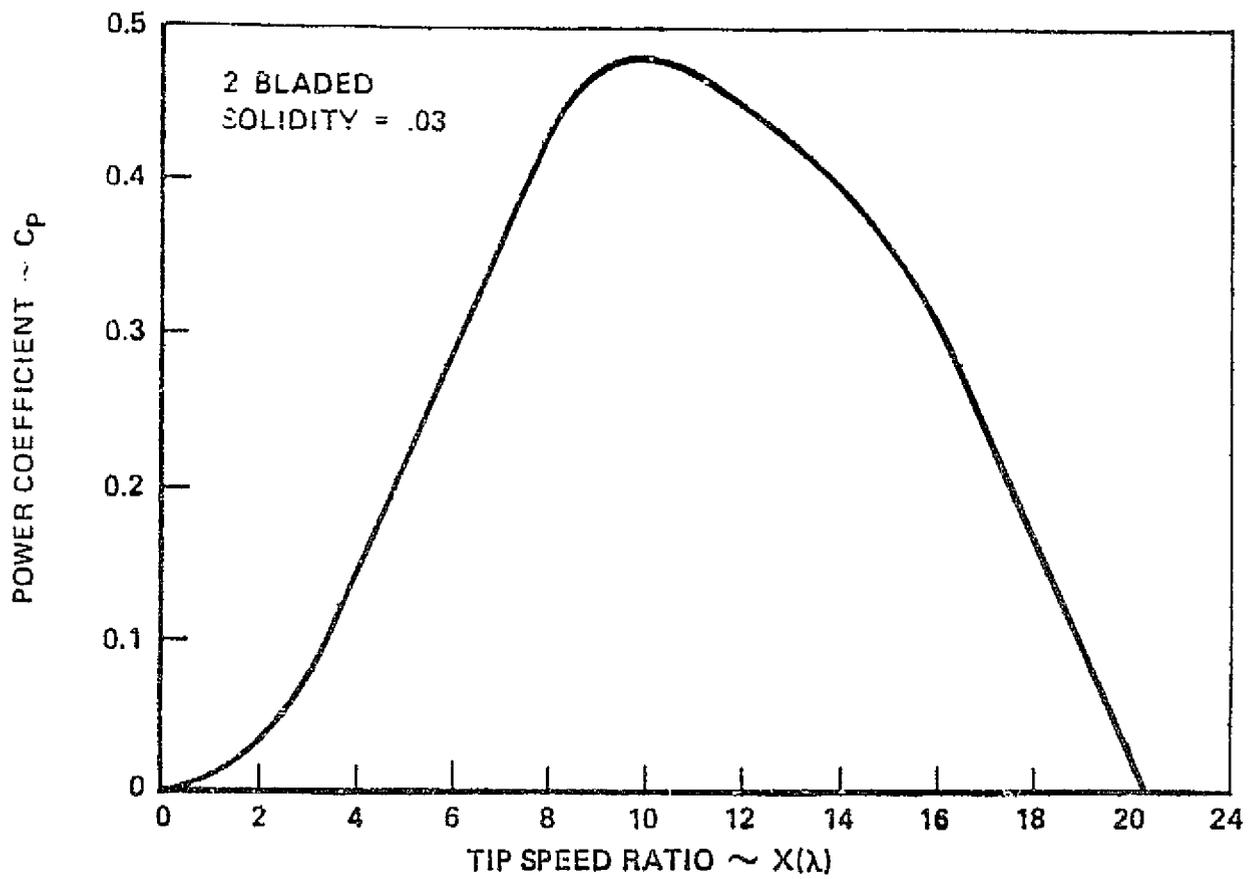


Figure 3.

farm windmill is quite a logical machine when you want it to be self-starting and operate with very little maintenance. It is quite useful and quite logically designed for its application of pumping water.

There are other types of windmills. The Sandia Corporation, as you have noticed, is working with a vertical axis machine typically referred to as an "egg beater," which has a curve quite similar to this with its peak in the neighborhood of a range of 4 and 6 in the tip speed ratio and its peak efficiency is a little lower than this Clayton machine. Its peak  $C_p$  is more like say .35 to .4.

That kind of a machine has the difficulty that at the left-hand end of the curve the  $C_p$  curve drops below the axis so that it has a negative power coefficient at low speeds and it isn't self-starting. You have got to start it one way or the other. Once it is started it will keep running.

So this is something about the nature of the machines. As I say, they can be quite efficient in comparison to the theoretical standard. We will have to see a bit about what that means.

Let's have the next slide which bears on another kind of problem that you are dealing with in wind energy.

(See Fig. 4)

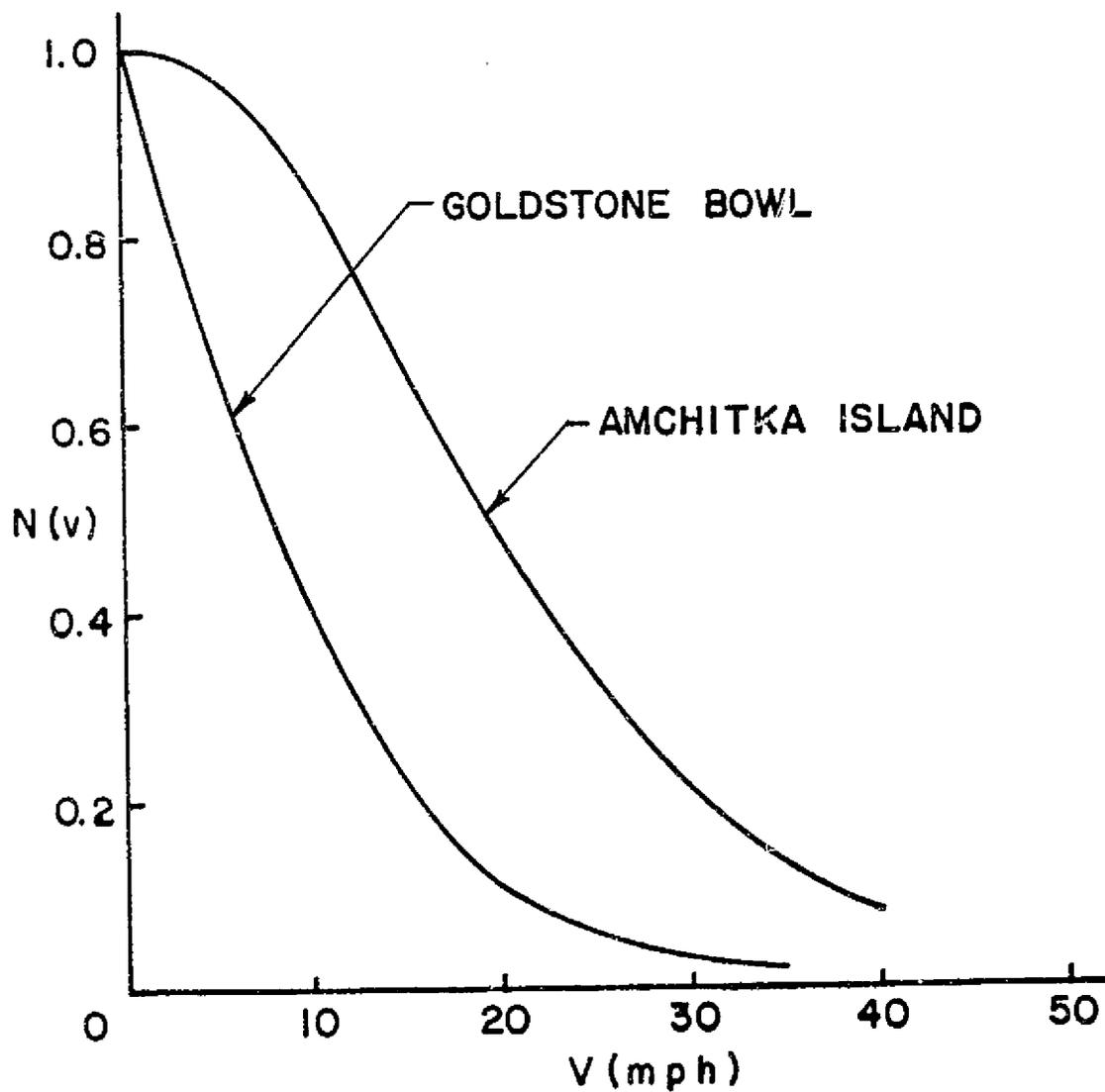
That is, that wind is of variable quantity. You can express that variability in many ways. One standard way of expressing it is in terms of the wind spectrum and is the fraction of the time the wind exceeds  $V$ . I have two wind spectra here. One is the spectrum taken at the site of the JPL large tracking antenna at Goldstone in the bowl. The other was a Navy station up on Amchitka Island. I have put these two on because they sort of illustrate the outer limits of all spectra at all sites.

The old farm rule was there was no point in talking about wind energy unless you had a 10-mile-an-hour average wind speed. Well, that is roughly the Goldstone Bowl curve. Unless you have got at least that much wind there is not much use in talking about it.

On the other hand, Amchitka Island is about as windy a site as you can find.

Now, the shapes of the curves are about as different as any I have seen here. The Goldstone Bowl has a lot of time with very low wind speed and lots of night calm. The Amchitka Island is rounded off up at the top and has relatively little light air. So these are sort of the outer limits.

Now I wanted to put these up here to illustrate one of the principal design problems which make wind energy hard to think of for conventional power plant people. I can illustrate that best by using the Goldstone Bowl curve to be specific. With any kind of a machine there is always going to be some kind of wind speed at which, if you are



$N(v)$  IS FRACTION OF TIME THE WIND EXCEEDS  $V$   
 WIND DISTRIBUTION FUNCTIONS

Figure 4.

generating electricity, your generator will be completely loaded, and if you get more wind at the point where it becomes loaded you have got to spill the extra energy somewhere or you will burn up your electrical equipment. So one of the questions is where on this curve, at what speed, should you put your design point. Suppose you were to put a design point at the mean wind speed where  $N$  is 0.5. Well, for the Goldstone one that would be a little less than 10 miles an hour. With such a machine you would come up to full load at 10 miles an hour and you would develop your full power then for half the time. You would get a little bit more power for the lower wind speed half of the time. And if you put it all together you would find that you have for such a machine a load factor of about 0.6 on an annual basis, if you use the  $N$  of 0.5 as the design point.

Let's look now at a design point that might be twice that speed, in other words, just a little less than 20 miles an hour. At that point  $N$  is about 0.1. So for a tenth of the time you would have twice as much velocity as you had at the other design point. Well, for that 10 percent of the time, though, you are developing eight times the power. Eight times a tenth is clearly more than one times a half. So that with the higher-speed design point you are clearly collecting a lot more energy per unit area. As a matter of fact, if you use that design point at a tenth your load factor will come out to be about 0.4.

Well, you might say, if you have got a point factor of 0.6 in the first one and 0.4 in the second one, why not use the first one? The reason is the second machine designed at a higher wind speed is a much cheaper machine.

Let me turn that around a little bit and talk about a given power machine. Suppose you had a given power of say a thousand kilowatts and it had a certain size at a 10-miles-an-hour design speed. Well, with the 20-mile-an-hour design speed you only need an eighth of the disc area in order to get the same power, assuming that you operate it at the same tip speed ratio with a similar design so that your efficiency would be the same. Now, with it being an eighth of the disc area, that is about a third for the radius, and if you carry the design through you find that the weight of your blade is only about a fifth as much as it was for the 10-miles-an-hour design point. So for a given power, a higher design speed makes a much cheaper machine. For a very large machine the blading is a big factor of the cost. You ultimately would get to the point where a large machine would cost an eighth as much as the smaller one and you still have two thirds as much for the load factor.

So there is a trade-off that is involved here that is very strong between low-load factor cheaper machines designed to operate at a high design point and higher load factor much more expensive machines that operate at a low wind speed design point. Now where you end up, for your design purposes, depends on what your purposes are. If you are trying to make an entirely stand-alone kind of system you have got to put in an expensive energy storage system, too, and so you tend to move to the lower wind speed as your design point in order to minimize the cost of your storage system.

If you don't have to worry about storage you move towards the higher wind speed and a lower load factor.

Now the DOE program is largely based on the system-application idea that we are going to -- and I am speaking only of the large windmill part of the DOE program -- that we are going to feed this energy into a grid so that we don't have to take care of the storage program at the point. As a matter of fact, every grid has a certain capacity to handle the relationship between energy and power and the fluctuating input in some sense is quite similar to a fluctuating load in its overall impact on the grid's stability. If the fraction of wind energy involved in the whole system is small enough then you don't need to add any special storage features at all. Now, most of the analyses that have been made indicate that up to about a 10 or 20-percent energy input into the grid the extra impact of this fluctuating input isn't such as to require specific additional storage systems. I will come back to that in a little more detail in a minute.

I want to mention that if you are dealing with that as your application, where the problem really is the most cost-effective recovery of energy and the storage problem is taken care of otherwise, then you typically end up with a design point which is like twice or perhaps even a bit more than twice the mean wind speed. This ends up with a very spikey output. You will get half of your energy in 20 percent of the time and the other half in maybe 30 and maybe none at all in half the time. So you have a fairly spikey output as a load characteristic. If you have only one windmill this would make problems. If you have a large number that are geographically dispersed they will, to some extent, smooth out, but the amount of smoothing is not very well quantified at the moment.

But, at any rate, with this kind of a system with a design point of about twice the mean, you typically end up by recovering about two thirds of the total available energy as defined in the mean value of the  $8/27 V^3$  that we talked about earlier.

Let me take the next slide here which will show us a little bit more on that.

(See Fig. 5)

Here are some local sites in this neighborhood that you may be familiar with and with these parameters, the mean speed in miles per hour, and the average available power in watts per square meter. The top line, the Goldstone, which is sort of the minimum standard, comes out in watts per square meter of about 160. That is sort of a minimum scale.

Now, if you look a little further down on the chart here at Mojave, for example, which is the airport at Mojave -- these are just data taken from the standard sites wherever the weather bureau has a measuring station -- the number is about 300. Now, that clearly looks quite a bit more interesting. Point Arguella is 342. Sandberg on the ridge up near Bakersfield, is 370, and the little off-shore site at

WIND CHARACTERISTICS AT VARIOUS LOCATIONS

LOCATION	MEAN SPEED IN MPH	ENERGY EQUIVALENT SPEED IN MPH	AVERAGE POWER IN WATTS PER SQUARE METER OF WIND DISK
GOLDSTONE	9.65	14.3	159
PALMDALE	10.63	14.4	162
MUROC	10.35	14.6	168
VICTORVILLE	11.85	15.4	196
MOJAVE	12.84	18.0	318
PT. ARGUELLA	14.45	18.5	342
SANDBERG	15.76	19.0	370
SANTA ROSA IS.	16.80	22.4	610

Figure 5.

Santa Rosa is 610. Those numbers look quite large compared to the sort of minimum farmer rule of thumb of about 160.

Now, just for a matter of comparison, I am going to show you the next slide which is a map. But about seven meters per second mean wind speed will give you about 300, and that is a quite good site indeed. Sites like that, as we will see, are available by the hundreds of thousands of square miles. When you come to looking at the especially good sites like the sites that DOE has chosen, the Clayton site, the site out in Banning Pass which has been chosen as a potential site for installation of a demonstration model, those in general are characterized by over 400 watts per square meter.

Now, let's have the next one which is the map.

(See Fig. 6)

The map is a lousy chart from the standpoint of a chart. I am using the chart really just as a mnemonic device. I know some of the numbers. The chances of your being able to read them are quite negligible. But if you look through that chart and take the rack of states from Kansas through Nebraska to North and South Dakota -- these, incidentally, are standardized at an altitude of 50 meters, so these correspond to a large windmill kind of an installation -- it you will take the rack of states from Kansas through Nebraska and North and South Dakota, there isn't a weather bureau site anywhere in any of those states that has a number smaller than 300 watts per square meter.

If you take the little California bight here where we sit below the mountains in our protected area, the numbers are all lousy. There is a 90, an 80, a 130 and a 110. Just no good at all.

As you go up the California coast you can see that Cape Mendocino is an 1100 watts per square meter site. Up along the Oregon coast is a 1500 one. We have already mentioned the 600 at Santa Rosa.

If you look out just east of the Los Angeles Area you will see a 420 there which is in the Banning Pass area. You look a little above there and in the Twenty-Nine Palms area you see a 400.

I think the point of this is that sites with seven meters with 300 or 400 are available in the hundreds of thousands. When I mentioned the number of available energy of something like five times our total current electric production in good sites I was using a 7-meters-per-second standard or 300 watts per square meter in noting the availability of such sites.

Now, this covers one aspect. Now I would like to say a few words about the storage problem because, after all, it is real. I mentioned that up to somewhere between 10 and 20 percent you probably didn't have to put any additional features into the typical utility system in order

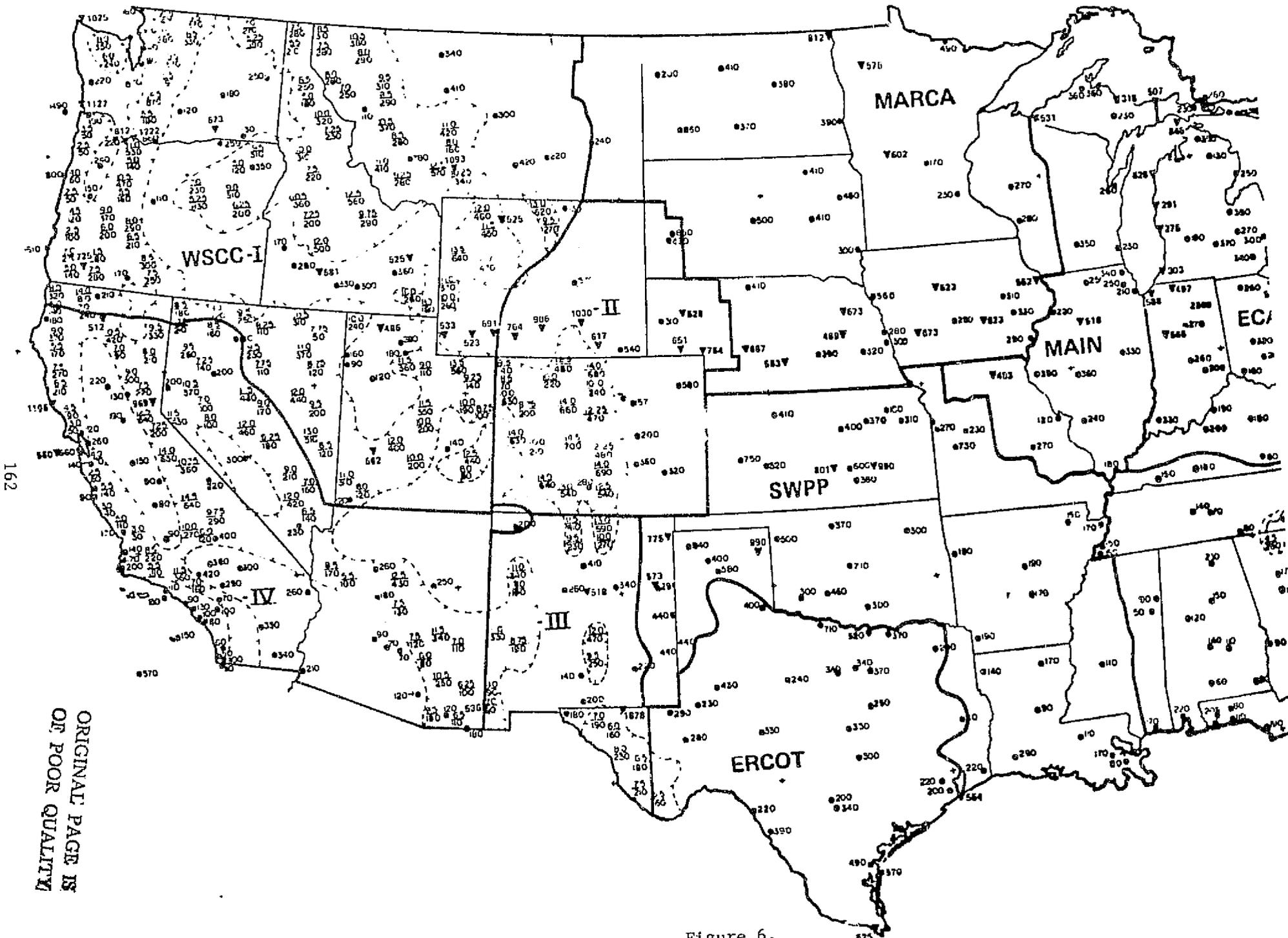


Figure 6.

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to maintain the stability of the system. That largely comes because of a synergistic relation between the fairly large water power systems that are available throughout much of the country. In the West, particularly, the water power systems have been built with storage basins which are very large because they have to operate on a strong annual cycle in the rainfall. And, in general, in these systems the number of penstocks and turbines installed are larger than the amount they can use at a steady average throughout the year and, of course, they use the excess penstocks and excess turbine capacity so that they use part of the water energy to handle peak loads at the cost of reducing the base load fraction that they can demand of the same water system.

I think it is apparent that if you have a wind energy system that is feeding energy randomly into the water system you can use that energy, conceptually, like a little extra rainfall. You can use that energy either to increase the number of hours that you will use your peak capacity or peak load problem, or you can use it to raise the base load guarantee from the combined system, or you can split it between the two. The wind energy system probably won't increase the peak capacity very much. Such things as I have seen indicate that if you have a system of wind energy -- wind generators -- distributed geographically and designed, as I mentioned, with a fairly low load factor, like 0.4, that the maximum contribution that you could count on with a statistically acceptable level for the peaking requirement, would probably be more like the 5- to 10-percent level. So they aren't very significant from that standpoint.

But they can increase the time that you can draw peak loads from water systems. The next thing it would pay you to do is to put in extra penstocks and distort your water flow of pattern with still more of your water being used for peak loads and less at the intermediate.

The corresponding interaction occurs favorably also any time you have pump storage water hydropower systems, and we, of course, have the big 1250 megawatt one out north of us here, and a quite similar problem we have of carrying water south through the California Aqueduct also permits a similar favorable interaction.

I think this describes the general characteristics of the wind problem. I would like to say a little bit now about where we are in the development. I showed you the Clayton picture.

The DOE program was started in 1974 under NSF and ERDA and now DOE. They started with the large windmill. We have a mixed program with demonstration elements being one feature and system analysis to guide the design of these demonstration elements as a second feature. Then a third one, of course, was this actual siting of places to put these things. Every year they pick out another two of three sites that would meet good demonstration capabilities. At each of these sites the equipment is integrated with the local utility so that the utility owns it and operates it in a conventionally legal, understandable sense. So it isn't just an isolated government experiment.

I mentioned that the first step was to build a hundred kilowatt (the MOD-0) design, a paper design that they bought from Germany and built an experimental windmill, 125 feet in diameter, which was installed in Sandusky, Ohio. The first started running a little over two years ago and they had their problems, but they gradually cleaned them out. Then they decided to modify that design in the direction that looked like it would make it work better and they upped it to 200 kilowatts MOD-0A design and they now call that the MOD ZERO A. The first of those is the one that was put out in Clayton. They are now installing two more like that, one in Culebra, a naval installation on a little island just east of Puerto Rico, and there is also one going on Block Island which is in the neighborhood of Long Island Sound in New York. Those should be operating in a matter of months now.

The next step of the DOE program was a series of engineering analyses that were aimed at making machines which were more apt to be more cost-effective than this first machine which was really obtained on a design-availability basis in order to get something started quickly.

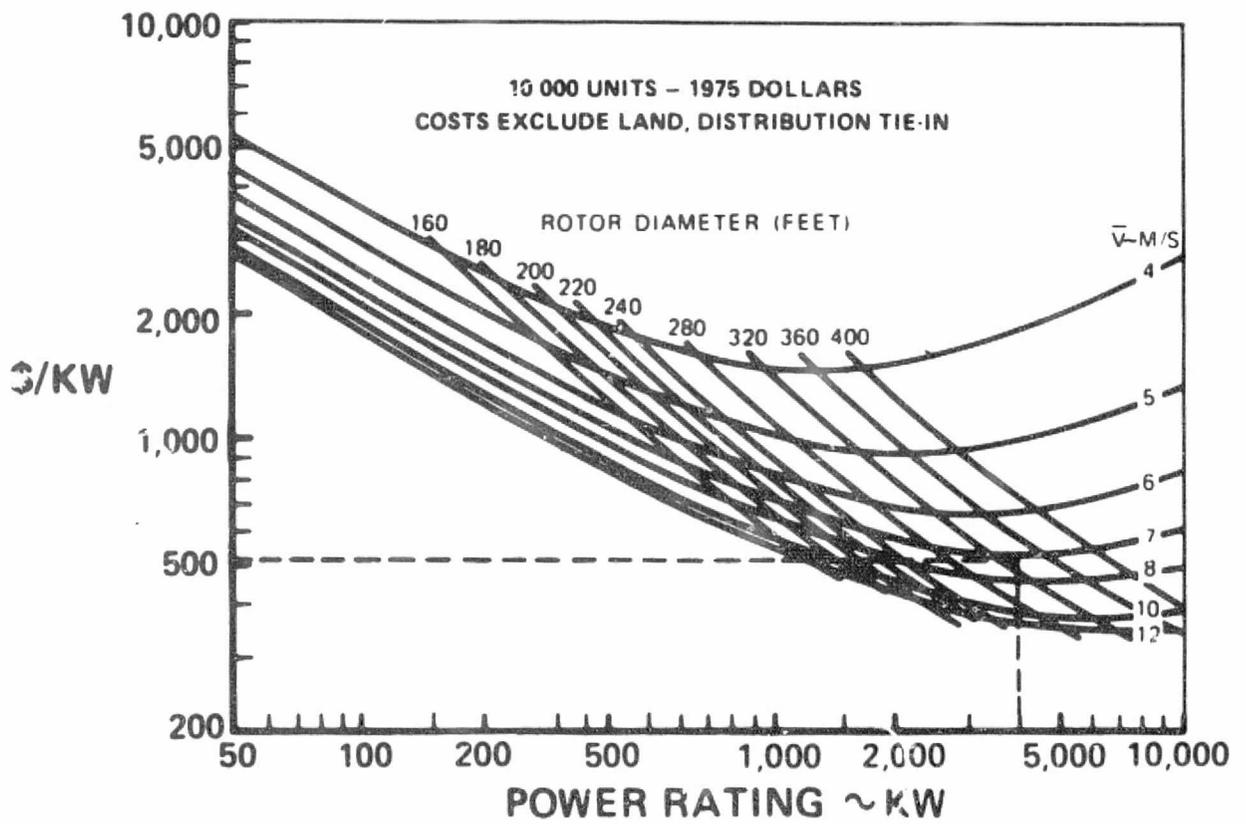
I am going to show you a few charts from some of these design studies in a moment. But the first thing that came out of these design studies was what they called the MOD-1 design which was supposed to be a design of at least the optimum sizing. The development contract for the MOD-1 design was won by GE and they expect to have the first one of these experimental models operating about a year from now. The place they are going to install it is in Boone, North Carolina. It is a 1.5 megawatt machine with a 200-foot diameter blade system. They have had some trouble making the blades. In fact, the schedule of about a year from now has slightly slipped. But, at any rate, they are going well ahead with that.

Now let me show three charts here which more or less characterize the data which has come out of these kinds of paper analyses. And, of course, the purpose of the demonstration machines, or one of the main purposes, is to get some actual equipment built so that you have a chance of calibrating whether the paper analyses are meaningful or not. It is still a bit short of real engineering data, but I will come to that in a minute.

The top chart here is one that shows the computed cost per kilowatt hour.

(See Fig. 7)

As you will notice, the main more or less horizontal parameter of curves is the wind speed curve. The seven-meters-per-second wind speed is probably a good one to take. That is the one in the middle of the block. The lighter more steeply inclined curves are diameter sizes. The dashed intersection that picks out a point there on the seven-meter-per-second wind speed line says that with this particular study the optimum power size was 4 megawatts and that at that size -- these are 1975 dollars, incidentally, standard calculations -- the expected cost should be a little over 2 cents per kilowatt hour



Investment Costs of Wind Turbine Generators

Figure 7.

including all of the capital, maintenance, et cetera and costs of the machine. These were intended to be essentially busbar costs.

Now, the corresponding capital requirements are shown in the bottom slide.

(See Fig. 8)

That same machine, the capital per installed kilowatt is about \$500. Of course, you have to remember that these are machines that characteristically operate at a low load factor, about 40 percent.

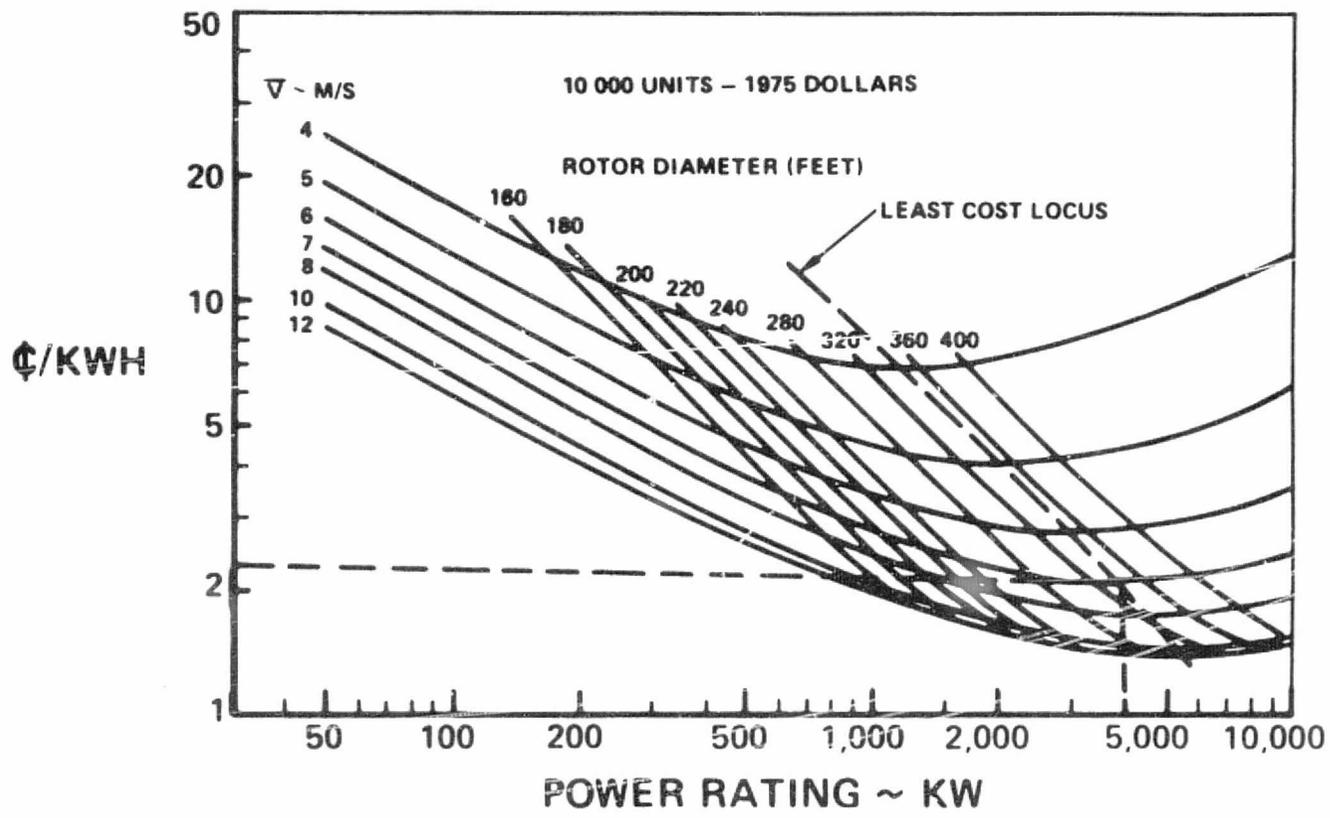
Just for comparison, we might look in this same chart at the 200 kilowatts level which is the Clayton machine. You see the Clayton machine would show an expected cost on the order of \$1500 per kilowatt according to these estimates. Now, that probably is not too bad an estimate. The Clayton machine is actually much more expensive than that. As I recall -- and I wasn't able to check this number before coming up here so I am relying on my memory at this point -- as I recall, the blades of the Clayton machines cost \$200,000, and at a 200-kilowatt rating that is \$1,000 a kilowatt just for the blades. But that is not really a significant number in the long run. It is very significant right at this moment. But, for example, those bladings have a fairly elaborate set of load measuring devices built into them, the same as they used on the experimental machine in Sandusky, and half of that \$200,000 is the experimental instrumentation. So clearly you can get the factor down by another factor of 2 from that. Also, these are one-of-a-kind construction -- well, actually not quite. They have built six of them now. But you are still not very far out in the production learning curve and your production is so small that really the tooling is almost elementary and there is almost no cost advantage from the kind of thing that you might get in any kind of a production run.

These charts (up at the top) say 10,00 units. The actual assumption was that you had about four production lines and were planning to build about 2500 of them on each one. So these costs are really representative of a production run of something like 2500 machines, and you are a long way from that with the six blades which is equivalent of three full machines that have been built to date. So that at the moment all I can say is that the data, as it is starting to accumulate, is not such that says these kinds of numbers are bad. It looks like they are reasonably compatible.

Let me show you one last chart here.

(See Fig. 9)

This is a chart which is constructed to determine what might be the national impact of wind energy systems on an overall energy base. The energy base in this case is directed toward the electric power part of it and not the total energy base. The ground rule here was that they assumed that fossil fuels were going to increase at a 7-percent



"The High Potential of Wind as an Energy Source"  
 Ugo Coty and Michael Dubey, Lockheed-California  
 Company, Burbank, California. Second Annual  
 Energy Symposium  $Q = E^3$ , Los Angeles Council  
 of Engineers and Scientists, May 19, 1976.

Figure 8.

APPLICATIONS	ENERGY FROM WIND Billion kWh/Yr	NATIONAL DEMAND Percent	INSTALLED WIND TURBINE RATING Megawatts	INVESTMENT \$ Billions	EQUIVALENT FUEL SAVED/YEAR Million Bbl Oil
<b>ELECTRIC UTILITIES</b>					
- With Hydroelectric	293	4.5	62 500	23	518
- Grid Stability Storage	835	12.9	187 000	124	1 477
- Pumped Hydro	81	1.3	17 500	11	143
<b>TOTAL</b>	1 209	18.7	267 000	158	2 138
<b>INDUSTRIES</b>	869	13.4	212 000	253	1 530
<b>FARMS</b>	40	0.6	17 000	12	71
<b>RESIDENCES</b>	135	2.0	30 000	89	239

\*Based on the assumption that fuel prices will rise 7 percent or more per year.

National Potential for Using Wind Energy  
Systems to Supplement Other Sources in 1995.

Figure 9.

per year faster than inflation. In that case they put in wind energy systems up to the level that the current available system, hydraulic or otherwise, would have a favorable intersection and end up with a generating power system which was at a lower cost than expanding the fossil fuel systems. You will notice the numbers come out quite large. This was for the nation as a whole.

If you look at the top half of this table, it shows that in the electric utility business you might reasonably develop something like 18 percent of your total national demand on an economically preferable basis by integrating wind energy to this extent. Whether it would happen that way or not is an entirely different matter because there is the assumption that you do have available commercial product lines to buy to put to these purposes and that still is something that remains to come.

The bottom half of this chart looks at some special categories of use; industrial, farm, and residential. As you see, these are much smaller in total. As a matter of fact, the industrial part largely overlaps. In fact, all of the bottom half of the chart largely overlaps the first because most of those energy sources probably would be taken care of through the electric power grid connection.

Now this is roughly where we are. These design studies don't look bad. The experiment and the data that is gradually developing is generally compatible. So what remains to be done? Well, obviously, the first step that remains to be done is to get a real machine like the MOD-1 which is sized to where you expect the most economic energy collection for these wind machines. You have to get something like that really going. With that going, then you really have a better chance of estimating the economic potential on a reasonable basis and of estimating the production costs.

The second thing that really needs to be done, that still isn't happening, is that you have to get a commercial product line established. There aren't any commercial product lines established in large windmills. There are a few experimental designs being built under government sponsorship. Now, how you are going to make the transition to commercial product line in this area is not entirely obvious to me. I should mention that these last three charts that I have shown you were taken from a paper that was done by Ugo Coty of Lockheed as a Lockheed study for ERDA. Figure 7, has a reference on it and I presume those will be given to you if you request copies of the charts. I mention that because that was taken from a paper that was presented here in Los Angeles about two years ago at a symposium somewhat of this sort. The title was the "Second Annual Energy Symposium  $Q = E^3$ , Los Angeles Council of Engineers and Scientists, May 19, 1976.

I chose that just because they had simple charts that were close to my purpose for this. A more complete study is available in DOE reports.

There is a problem where if somehow or other a commercial firm --

and there are several firms involved in the business already -- could get a potentially, and reasonably firm order for as little as 50 or 100 machines, they could probably afford to commit the capital necessary to set up a commercial product line. The problem is how we get to the point where that can happen. The DOE program has, at the moment, 17 sites chosen for putting up demonstration things of this sort and that isn't quite enough to set up a commercial product line. That is enough to support some experimental production but not a product line. That is the last problem. I will leave it with you.

## SYSTEM CONSIDERATIONS - M. E. ALPER

MR. ALPER: The hour is getting late. In talking about system considerations I feel like the guru who was asked by the tourist, "Would you please describe the meaning of life for me, but would you do it in about a minute because my bus is leaving."

We have tried to describe the DOE programs in alternative energy sources by giving you examples of where they are and where they are going. I think it is important to note that the entire program is focused on trying to make a commercial market develop, which leads us where Homer Joe left us. How that is going to happen is still a big question. I suspect that there may be a lot of people in this room who will turn out to be a primary mechanism for the early phases of making that commercial market develop. I am not sure.

Clearly, though, the activity has been aimed at not only developing technologies and involving industrial companies in the R & D, but also getting demonstrations of all of them by using people who might someday be customers, to begin to learn what these technologies are and what their applications really mean.

The discussion that ensued over the question of the role of the utility and the question of backup and the question of cost of service are clearly among the kinds of system and social considerations which are not yet understood very well. You have a segment of the population that talks about wanting solar now. And it is clear that solar energy, for example, will have much the same problems that the water shortage had in San Francisco. The reward for cutting back on the use of water was an increase in your water bill.

There are a whole host of those kinds of problems which much of the DOE program is aimed at trying to identify, and more particularly, aimed at trying to have the people who must solve the problem begin to think in terms of that problem and identify it for themselves. So a lot of these demonstration activities have that flavor.

I believe that the aim and direction of the program also results in the kinds of time scales that people have been quoting to you. You have been talked to by people who are part of that DOE program in a project management sense, and the time scales they talk about are assuming commercial markets, commercial viability, with all of the development of the appropriate infrastructure that is needed to make these things happen without massive government interference.

Clearly, if you just had the technological problem and you didn't need to make it on a commercial basis or show a profit or compete with a utility's cost of generating power, you could use the technologies faster.

Let me leave that very broad social-system problem of who does the regulating and how the regulators get together with the utilities and how the utilities get together with the private owners to use alternative energy sources as one which eventually will be

solved by the political process of the country and try to come back to the question of the systems engineering appropriate to the technologies.

If I leave out the geothermal systems for the moment, the direct solar systems and the wind systems clearly have unusual characteristics compared to nuclear power plants and coal and oil-fired plants for generating electricity, at least. They are cyclic statistical energy sources and the system that uses them must be aware of that and must accommodate to it. The statistical nature of the source depends on where you happen to have your system, and somehow your system analysis has to allow for that nature along with the nature of your load which is also in most cases cyclic and somewhat statistical. In a few fortunate cases there is a very nice match. In a few other unfortunate cases there is a very poor match. And, as was pointed out, if you happen to be tied into a utility there are cases where the poor match of solar availability and load requirements exacerbate the problem for the utility if you happen to be tied into it.

Any of these systems, then needs information about the loads and the source. In some of the work that Dr. Bartera has done it turns out that the cost of getting the information turns out not to be worth it after you have it unless somebody does it for you on a statistical basis. We have a very nice study which demonstrates that.

That, I think, is characteristic of those lower-temperature applications which are not very expensive. As you begin to talk about larger power producing systems I suspect we will all find it very, very necessary to get very site-specific about measuring resource availability data, whether it be wind speed, or solar insolation.

The sizing of the generating system, the amount of storage one allows and the amount of alternative fuel one plans to use, whether in your own oil storage tank or whether you expect your favorite utility to store it in his oil storage tank and you just draw it out of his lines when you need it, clearly goes into this system size consideration. Each of those elements has a cost associated with it at least in the applications sense, and ultimately I am sure the company will design systems which reasonably optimize cost. Unfortunately, for us today, all the information and all the understanding we need about these systems to permit us to do that job very effectively is not available.

The other thing that seems clear that will happen, is that the external world, in terms of its impact on alternative energy prices, like the price of oil or natural gas or other things, is changing rather rapidly, and how one allows for those rapid changes when one is designing a system which you hope will last for 10, 20 or 30 years, is problematical.

Again I suspect there may be people in this room who will bear the brunt of learning the hard way how to design or not to design these systems.

I think the question of costs is something that we have learned the hard way. It is not as easy to look at as we initially thought it was. The study which is on the table over there represents a first attempt at providing a means for comparing systems where one system is capital intensive and the other is not, or where one system is fuel intensive and the other is not. Systems have different lifetimes and different power factors and everything else you can think of.

Unfortunately, the document talks about those kinds of costs which are the easiest ones to handle because they are the easiest to understand and the easiest to measure. They don't permit one to very easily address how one allows for the fact that if I use this alternative energy system I avoid importing oil or I relieve a problem for a local utility or I divorce myself from a local utility, or whatever. So there are a whole bunch of external costs not easily identified, and benefits which I don't believe anybody has a very good means of addressing today except that you have to recognize that they are there.

The DOE program is a very large one and there are a large number of laboratories working in each piece of it. JPL, as you may have gathered, is only one. Sandia Laboratories, Lawrence Livermore and NASA's Lewis Research Center are among others that are also working in each of these alternative energy areas.

The question of costs and what you might expect to pay for one of these systems is one which everybody has touched on one way or the other. I think the common element to what they have said is that those of us in the program are trying to work a chicken-and-egg problem. We are looking at systems which are designed for commercial utilization except there isn't a commercial source of supply. So you have to invent what you think a system should look like based on what the commercial source of supply will look like. Then you see if you can do something to help induce that commercial supply system to come along to permit you to have what you think you want. By the time you get there you have learned enough in the process to realize that what you thought you wanted probably wasn't what you wanted at all. The result is a very difficult problem of how one compresses what our society might normally do in 20 to 30 years and have it take place between now and 1985 or 1986. I am sure you were struck by different perceptions of optimism vis-a-vis these alternative energy sources and slightly different ways of looking at what the costs are.

Homer Joe pointed out numbers which are based on having 10,000 machines a year but nobody is going to invest in a plant to build 10,000 machines a year unless he knows he has a market for 10,000 machines a year. Nobody is going to make the market unless he knows he has a reliable supply, and around and around you go.

The question of how many of these systems can bootstrap themselves into a commercial situation as a result of being useful in remote sites or special circumstances is problematical and is being looked at very hard by DOE. Whether or not there will be extraordinary government activity to help develop this market remains to be seen. One might

suspect that the Department of Defense might be enlisted in the job of trying to provide this initial market before these systems look economical in the civil sector market place.

The role of the utilities in the private sector and the way in which the regulatory bodies will treat these alternative energy sources in the future is also a problematical one. I suspect there is a great deal of information that still has to be learned, and a lot of experience on the part of state and local governments, as well as the national government, as well as utilities, before these problems will be ironed out.

So in the sense that all these kinds of issues lead to some uncertainty, let me try to reassure you of the fact that the uncertainty, I believe at least, is mostly concerned with the way in which our society will ultimately use these systems. The technology and the technical performance and the potential cost performance, when they are in fact mass produced, I think are much less uncertain. The major uncertainties are when it will happen and with what kind of social intervention.

It is very clear that you can build a good windmill today, you can build a good photovoltaic power supply today, you can build a good solar thermal power supply today. It is also very clear that there aren't more than two, three, four, five or ten of these systems around anyplace. That small a number does not make a supply industry.

I don't know if these comments are providing you with all of the information you expected. We have tried to give you some feel for the different programs, where they are going and how and why they are trying to get there and where we hope they will be. I can best summarize by saying that at least for the solar system -- I will come back to geothermal in just a minute -- at present every one of them holds both the technical and the cost promise of being a viable source of energy sometime in the next ten, fifteen or twenty years. They are a viable source of energy today, depending on what your external considerations are and how much you are willing to pay for this different source. Someplace in between their use will grow at a much more rapid rate than it has today.

I think that is the best anybody can tell you. I also think we will probably all wind up being a part of making that transition, from where we are to where we might be, occur sooner rather than later.

The geothermal sources are much more amenable to looking like a more normal source of producing electricity. They can be treated like central power plants. They do have the problem that if they are not near a transmission line you have to get a transmission line to them. The best one can say with respect to geothermal is if you are not close to one it looks like any other utility source to you. If you are close to one you might be able to develop your own.

The studies we have done in the geothermal area clearly indicate that without some kind of different intervention, the normal regulatory political process to permit you to develop a resource that you understand,

with technology that somebody understands well enough to take the risks and invest his own money in, is still a number like seven, eight or ten years unless one does something more heroic than normal.

On top of that, we have to recognize that companies like San Diego Gas & Electric and a few others have work under way. I don't know how satisfied they are that they understand those technologies yet or whether they feel about them strongly enough to make very large capital commitments at this time.

Again, the demonstration program over the next several years is designed to build plants which will give them the understanding that they can then use to decide what they will privately invest in.

The message is that left to normal devices, nine of these alternative energy sources is something you can turn on tomorrow. There is a fairly long road to travel. A lot of people are going down that road and I have no doubt that they will reach the end.

What one can do in a special situation clearly depends on how many dollars are available and what kind of mandate you are given. Given that this special situation should arise, then the system concerns, which all of us have, are that these systems are not nearly as simple as we thought they were when we started. As you look into even the very simple solar water heaters you can see some very interesting questions about how to use them, how to back them up, how much backup you need and what the costs really are.

As you get to the more capital intensive systems those problems don't get any simpler.

The methodology needed to address these questions is available or is becoming available. They are not all very widely known, they are not all very widely used, but I hope that George Ember may have something to say about that when he concludes the session.

The people in the DOE program are developing these methodologies and I think they can be made available.

With that, I will turn the chair over to George to let him wrap up from his perspective. Then the staff who are here will be glad to stay and answer any questions that you have. Suffice it to say that in any of these program areas there are more papers, systems studies, systems applications studies and charts of the kind Homer Joe showed you than you can shake a stick at. We are certainly all willing to help lead you to them, help you understand them or help you address the problem. We will be glad to stay after George finishes to cover any questions anybody has.

DISCUSSIONS - M. E. ALPER

MR. ALPER: Let's open it up for any kind of questions that you have. There are people in the back of the room who I am sure will try to tackle anything that you like. Anybody got one?

(No response.)

MR. ALPER: Okay. We either did such a good job that you know everything or we did such a shallow job that you know nothing, and there we leave it.

We can be reached either through my office or through George. If you want more detail or if there are specific program areas that you think you would like to know more about give us a call and we can arrange to get you to meet with the right people at whatever depth of technical detail you want to get into.

ATTENDEE: I have one question. When can we get copies of the proceedings?

MR. ALPER: Bob Rose told me that through his gracious efforts we hope to have these in the mail to you in two weeks.

The last time we had a meeting with the utilities we promised them in six weeks but they were two months late, but I think this one may be a little bit easier. It will not be clearly and cleanly edited, though. I will tell you that. We have asked somebody to take it down and it will be transcribed and you will get it. The intention is to get it to you sooner than prettier.

ATTENDEE: Will the view graphs --

MR. ALPER: The view graphs will be part of it. The presenters have been asked to get their view graphs to Bob so that he can get them included in it.

Bob just told me he would like the badges back when you leave. Leave them with Visitor Control.

Again I thank you all for joining us, and if there are more specific things that we can help you with, let us know.

Thank you.

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OF POOR QUALITY

CONCLUSION - GEORGE EMBER

MR. EMBER: First, let me say before you leave, be sure you get the questionnaire. We need some answers on some of these things.

Secondly, let me say that JPL graciously agreed to give this seminar. It wasn't a compulsion by the Department of Energy but it required their desire to give it. When I approached Mickey on this seminar it was only a week and a half ago, and when I approached him I asked him to give it as close as possible in a layman's language because we were going to have roughly about 25 to 30 percent of the people here who were not the technical types. I did not realize when I said that that it is impossible to give everything in the layman's language in a total energy program of this type.

Some of you in the nontechnical side might consider some of these things too technical, and some of you on the technical side may consider it nontechnical to a degree that maybe to you it is like being fed pabulum. It was very difficult to decide how much should be technical and how much shouldn't be. But all in all I have to say that it was just a week and a half ago that I requested of him for this seminar, and I say they did a darned good job in that week and a half. I want to thank Mickey and the staff of JPL for the good job that they did. I hope that the majority of you felt that it was good also.

So when you return your remarks and your letters of correspondence I hope that you will say something to that effect.

We need more of these seminars. We need them both on the technical side and the nontechnical side. We need them for the educational systems as well as the businesses and the military agencies and so forth, and I think we need more JPL seminars for this purpose.

I thank you.

(The seminar concluded at 4:20 p.m.)

REGISTERED ATTENDEES

R. J. Beeley  
Atomics International

S. D. Stewart  
U.S. Department of Energy  
Southwest District Office

Charles R. Rodgers  
U.S. Naval Weapons Center

D. L. Polino  
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Fred A. Glaski  
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Greg Rehak  
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Department of Water and Power  
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Charles A. Akins  
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