Inspection Stop #2

Jack Harper
revised, 10/4/73
(Entire)

CLEAN ENERGY

INTRODUCTION

With the formation of NASA 15 years ago, the Lewis Research Center was assigned the responsibility to develop electric power systems for space. Since that time the needs of aerospace have kept us at the frontiers of technology in both electric power generation and propulsion. Now in the face of an impending energy crisis we find that our advanced technology is of considerable interest to other agencies which are charged with finding solutions to our energy problems. There has been so much discussion of the energy crisis that we will not belabor the point here. But we would like to remind you of the situation as it is understood today.

(SLIDE 1 ON) We currently obtain about 97% of our nation's energy from the fossil fuels: coal, gas, and oil. The remainder comes from wood, nuclear energy, and hydroelectric plants. At the presently projected consumption rate, our reserves of gas and oil are expected to be exhausted in 30 to 50 years. On the other hand our coal reserves are somewhat larger. At the presently projected consumption rate of coal, it should last several hundred years. Therefore we have some obvious alternatives in the near term: switch from using natural gas and oil to using coal and synthesize gas and oil from coal. We might also increase our use of nuclear energy which today supplies somewhat less than 1% of our total energy.

(SLIDE 1 OFF)

In all cases, we convert these fuels into heat. Sometimes we use the heat directly, as to heat our homes. But more often we further convert the heat into other useful forms of energy, such as electricity or mechanical power for transportation. This conversion process of fuel into heat into other energy forms can and must be accomplished more efficiently.

Today we wish to emphasize two approaches to solving our energy problems: first, how we can use and convert the fuel we have more efficiently and, second, how we might use the Sun as an alternate energy source that is clean, abundant, and inexhaustible.

Over the past 15 years, we have been engaged in extensive space power research on a variety of methods of converting heat into electricity. (SLIDE 2 ON) Some of these methods are: Rankine systems using liquid metals such as mercury and potassium as working fluids (to carry the heat through the system), Brayton systems using inert gases or air as working fluids, thermionic and thermoelectric systems, and MHD or magnetohydrodynamics. Today we will discuss only the Rankine and Brayton systems, even though all but the thermoelectric systems are now being considered for near or long term application to ground power needs. (SLIDE 2 OFF)

Let's first look at a schematic diagram of a modern steam power plant to see how a Rankine system works (SLIDE 3 ON) Within the boiler, fired primarily by coal or natural gas, steam is produced and heated to 1050° F where it exerts a pressure of 2500 psi. This pressurized steam is expanded through a series of turbines that drive generators to produce electricity. Now for every 100 MW of power put into the system by burning fuel, we only get out 40 MW of electrical power. We must throw away 60 MW of power as waste heat into the environment. Of course, dumping this waste heat into the water and air sometimes has adverse effects.

The most effective and direct way to increase the system efficiency and therefore reduce the amount of waste heat rejected to the environment, and thus save energy is to increase the peak operating temperature of the (SLIDE 3 OFF) (SLIDE 4 ON) system. This figure shows the relationship of peak operating temperature to projected system efficiency. On the figure we have listed three classes of conversion systems that the U.S. is considering for electric power generation. The first is Rankine systems, examples of which are our modern steam plants. But the best of the modern steam plants can only operate up to 1050° F and until now it has not been economical to operate at higher temperature. In fact to go to higher temperatures we may have to use a liquid metal (such as potassium) as the working fluid. Another alternative would be to use Brayton systems which are gas turbines using air or an inert gas such as helium as the working fluid. To reach still higher temperatures we might use MHD or magnetohydrodynamics.

Now let us consider the rewards of increasing the operating temperature and hence system efficiency. Two scales have been added to (SLIDE 4 OFF) (Slide 5 On) the previous figure. They show the fuel that could be saved and the reduction in thermal pollution that could be achieved if the system efficiency could be increased from what it is now. As an example, if we could achieve an efficiency of 50%, our fuel consumption for electrical power generation would be reduced by 20%. This would also reduce the thermal pollution by one-third. (Slide 5 off)

But if Rankine system plants are to operate at higher temperatures, and hence higher efficiency, then we must consider a working fluid other than water. One which is being studied now is potassium. (SLIDE 6 ON) This is a schematic of a steam plant with what is called a potassium topper. In this case the fuel is burned and used to heat potassium vapor to about 1450° F. The potassium vapor is expanded through a turbine which in turn drives a generator. But the waste heat from the potassium system, instead of being dumped into a river or the air, is still hot enough to be used to produce steam in a conventional steam plant.

With this topper system, we believe an efficiency of 50% could be achieved resulting in fuel savings of 20% and a waste heat reduction of one-third (mentioned earlier as an example). If this fuel savings could be applied to all electric generating plants in the U.S., the equivalent savings would be about one million barrels of oil each day. This is one-half of what the Trans-Alaska pipeline is expected to carry at its capacity. The cost of power using the potassium topper system is predicted to be no more than from current systems and perhaps less.

The potassium topper system is presently being evaluated by one of our contractors as a result of a joint effort between the Office of Coal Research of the Department of the Interior and NASA.

In our space power research, our experience with potassium shows a number of significant achievements. (SLIDE ~~6~~ 7 ON) We have successfully run two turbines on potassium vapor at 1500° F for 7 months apiece. And a complete 200 KW system consisting of turbine, boiler, boiler feed pump, and condenser has been run for 14 months. (SLIDE ~~6~~ 7 OFF)

BRAYTON

But the upper temperature to which even a potassium Rankine system can operate is limited - by corrosion. A Brayton system, on the other hand, because it uses air or an inert gas as a working fluid is not so limited. (SLIDE ~~7~~ 8 ON) This example is a closed-cycle Brayton space power system. The "closed-cycle" just means that the working fluid, such as helium, stays permanently within the system. A part of this system is shown here on the stage in its hardware form.

(LIGHT UP BRU ON STAGE)

This is a compressor, turbine, and electrical generator all on one shaft. You can see that it fits together with the other components to make a compact space power conversion system. This system would operate at 1600° F, which is 300° F hotter than similar systems used for ground power in Europe. Here in the U.S. closed-cycle Brayton systems are being considered for several applications. One of particular interest is its use with a high-temperature, gas-cooled nuclear reactor (at about 1500° F). This emphasizes an attractive feature of these energy conversion systems - they can be used in either fossil or nuclear fueled power plants.

However, this high temperature space power system is very small. It produces only 15 KW of electric power, but it does demonstrate the technology. We have operated these systems at LeRC for a total time of over 28 months. One system has operated more than 17 months. During 90% of that time the engine was run by a computer with no personnel present. (SLIDE 8 OFF)

This concludes my part of the presentation on our efforts to apply our electric power generation technology to stationary power plants. I would now like to introduce Mr.   who will tell you about our efforts to apply aerospace propulsion technology to ground transportation and also how we might use the Sun as an alternate energy source.

CONSERVATION OF ENERGY IN TRANSPORTATION

First, let's take a look at our efforts to use aerospace technology to assist in developing clean, energy conserving, power plants for ground transportation. We have provided some assistance to both the Department of Transportation and the Environmental Protection Agency in this area. I think most people will agree that we must significantly reduce auto exhaust emissions, but as we move toward the 1977 Federal Emission Standards, we are paying a penalty in fuel economy. (SLIDE ~~8~~ 9 ON) You can see the emissions of cars prior to emission controls, 1973 cars, and the 1977 standards. While the total emissions of today's piston engine have been reduced by a factor of five, they must be still further reduced by a factor of six to achieve the 1977 standards. You can also see the trends in piston engine fuel economy: it has decreased from 12 MPG to 10 MPG to day, and is expected to fall to 9 MPG by 1977, as a result of emission control. To meet federal emission standards we have sacrificed fuel economy.

This adverse trend has raised the question: (SLIDE ~~8~~ 9 OFF) Are there other engines which have low exhaust emissions and good fuel economy? The answer is "yes"; a wide variety of such engines are being considered by industry, some with government support. Typical of these are the Rankine engines, which include the steam engines, gas turbine engines, and Stirling engines.

The unique feature common to all of these alternative engines is that they operate with continuous low pressure combustion, which is inherently cleaner burning than the intermittent combustion which occurs at high temperatures within the cylinders of piston engines. Another advantage of these engines is that they can burn low-grade fuels such as kerosene rather than the high octane gasolines. The EPA, with the assistance of this laboratory, is investigating these and still other engines.

In fact at the request of EPA, NASA is participating in a joint program to demonstrate by 1975 a gas-turbine-powered automobile which meets the 1977 emission standards with both good fuel economy and drivability. (LIGHT UP TURBINE CAR) We have on display a Chrysler gas turbine-powered car which will be used in NASA's joint program with EPA. We'll start it to give you a feel for how quickly it starts and how quietly it runs. (Slide 10 on) This car (POINT to G.T. DISPLAY CAR) has a total emissions level of about 1/4th that of the 1973 piston-engine cars, and is not too far above the 1977 standards.

You have heard, or will hear, at another stop about our work in combustor technology for aircraft gas turbines. This technology, as you might expect, will be put to good use on the automotive problem and is predicted to lower emissions. Also recently in our automotive program preliminary tests were run on a new type of burner, called the catalytic combustor. (Slide 10 off) (POINT TO COMBUSTOR DISPLAY) This is not to be confused with the catalytic reactors intended for piston-engine exhaust cleanup. (SLIDE ~~9~~ 11 ON)

This sketch of the catalytic combustor shows a lean fuel-air mixture entering the ceramic honeycomb which contains imbedded catalyst particles. A chemical reaction between fuel and oxygen molecules occurs on the surface of the catalyst - in a clean flameless combustion process at relatively low temperatures. The catalytic action greatly reduces emissions.

Although preliminary data indicate that this combustor has much lower emissions than the 1977 standards (Chart "D") further development work is needed to confirm performance with a variety of fuels and engine operating conditions. (SLIDE 11 ~~9~~ OFF)

It looks like we can make the gas turbine meet the exhaust emission standards, but what about fuel economy?

At its present state of development it does not have good fuel economy over the federal driving cycle. (SLIDE 12 ~~10~~ ON) (POINT TO CHRYSLER GAS TURBINE CAR) It gets 7.7 miles per gallon compared to 10 miles per gallon for the 1973 automobile. The EPA goal is to demonstrate a 20 percent improvement in fuel economy over present cars with a redesigned engine in a 1975 automobile. It is our role in working with EPA not only to assist in reducing exhaust emissions but also to apply the most advanced aerospace technology to improving fuel economy. (~~SLIDE 10 OF~~F) (POINT TO G. T. HARDWARE)

A few of the major areas where EPA with our assistance will seek to improve gas turbine efficiency include the application of advanced designs to the compressor and turbines, higher turbine temperatures with compatible materials, an integrated control system, and water injection.

NASA and industry studies on still further advanced technology engines suggest that fuel economics of as high as 15 MPG under city driving conditions may be achieved. (Slide 12 off) These high temperature engines would use either ceramic or cooled metal turbine technology. You will hear about ceramic materials like this (HOLD UP CERAMIC VANE) at our materials presentation.

This turbine rotor was developed by Lewis for aircraft jet engines. It has hollow blades to allow a forced draft of cooling air to pass through them thus maintaining the metal temperature well below gas temperature. In this way we can use lower-cost conventional materials at higher temperatures.

SOLAR ENERGY

Let us now turn from the automotive problem to the problems of providing clean, electrical and thermal power from an alternate source - the Sun. (SLIDE ~~12~~ 13 ON)

Here we see a picture of Skylab which uses large solar cell arrays that directly convert the energy of the sun to electricity. In fact most of the electrical energy we now use in space comes from sunlight converted to electricity by solar cells. (SLIDE ~~12~~ 13 OFF)

In his energy message of 1971, the President asked NASA and the National Science Foundation to reexamine our efforts in solar energy research with a view towards utilization of the Sun's energy to produce energy needed on Earth. NASA and NSF assembled experts to conduct a study. A report on the results was published last year.

(SLIDE ~~12~~ 14 ON) The first observation is a rather obvious one. The energy from our Sun is abundant and inexhaustible as a good energy source should be, but it is diffuse and of course is only available during the daylight hours. However, over a year the total solar energy falling on the Earth is about 1000 times greater than the amount of energy we now consume from all forms of fuels. If we could convert sunlight to more useful forms of energy at an efficiency of only 5% it would take about 2% of our land area to supply all our needs. (SLIDE ~~12~~ 14 OFF) Since the Sun doesn't shine all the time, we must during the day collect the energy and store it for use at night. (SLIDE ~~13~~ 15 ON)

As I'll show by some examples, the Sun can provide energy in all forms we need: electricity, heating and cooling. We can even provide clean renewable fuels by growing crops and burning them directly or by converting them through chemical processing to gas and oil.

We can use several methods to generate electricity. Solar cells convert sunlight directly into electricity. The problem is that solar cells are much too expensive for widespread use today. We must cut their cost by a factor of several hundred before their widespread Earth use is economical. Until then they will be used only for special applications where other power is not available. (LIGHT WEATHER STATION) For example, this is a model of a solar cell powered weather station that we have installed on the shores of Lake Erie where power was not conveniently available. It is a demonstration project and part of a joint program with the City of Cleveland.

Other methods of generating power from the Sun include (1) use of a system we call "solar thermodynamics" where solar heat is used to run a heat engine which drives a generator, (2) use of the temperature difference of 45° F between the surface and lower regions of the gulf stream to run a heat engine, and (3) use of the energy from the wind which is, of course, derived from the Sun. (SLIDE ~~13~~ 15 OFF) Let's look briefly at utilization of wind power.

(SLIDE ~~14~~ 16 ON) Although we often think of windmills as useful for pumping water on farms, wind driven electric generators have been built in the past 20 years as indicated by this 200 KW machine. The problem has been that wind energy machines were not cost effective when we had plentiful supplies of low cost fuel. (Slide 16 off)

NSF has asked us to assist them in the creation and project management of their wind energy program. As a first step we are applying modern technology to the design of a wind energy system to provide up to 150 KW of electricity to the island of Culebra in Puerto Rico at the request of that government. The winds are relatively steady there at nearly 20 miles per hour and providing of other fuels is expensive and inconvenient.

(Slide 17 on) Large systems present some difficult technological problems in achieving good performance at low cost. On this wind machine we have called out some of that technology. For a 150 KW machine the blades are large, about 65 feet long with a width of about 8 feet, approximately the size of an aircraft wing. Actually this commercial blade uses a

NACA airfoil that evolved in early NACA aerodynamics research. Major problems are instability and flutter resulting from highly variable wind gusts and from the interruption of the airflow as the blade passes the tower. In our design for Puerto Rico, we will apply our new computer techniques and the latest technology in lightweight, high-strength composite materials evolving from our aerospace programs for improved structures. (Slide 17 off)

(Helicopter rotor section)

We will also use our battery technology for storage of the electrical energy for use during those periods when the wind does not blow. We have here at Lewis perhaps the largest contract and in-house program in advanced battery and fuel cell research within the U. S. Government.

To use the Sun's thermal energy for heating and cooling buildings we can collect the heat in a fluid such as water. Efficient collectors with space technology coatings (SHOW SOLAR FLAT PLATE COLLECTORS, ETC.) such as these we have built can heat water to over 200° F, even on a cold winter day. This hot fluid can be used directly to heat buildings or to cool buildings it can be used in absorption refigeration systems, similar to today's gas refrigeration systems. The heat of the day, however, must be stored for use at night.

(~~SLIDE 15 ON~~) Another approach to producing electricity uses the Sun's energy to run a heat engine. These systems would use focusing collectors to concentrate the solar radiation. You know from your childhood experience that a magnifying glass can focus enough of the

Sun's heat to burn wood. We built a 20' diameter mirror for use in a space electric power system several years ago. That mirror can produce temperatures over 1500° F. A segment of that mirror is shown here.

We have a demonstration (TURN ON SUNLIGHT) of a simple focusing collector that uses those automobile headlights to simulate the Sun. The collector focuses the light on the liquid in the tube. The liquid boils and the vapor drives a simple turbine.

In our system - for more rapid startup we are using a low-boiling Freon. In a power system the fluid would probably be water and of course the turbine would drive an electric generator. These are the elements of the Rankine cycle described earlier except now we are using the Sun's energy instead of fossil or nuclear fuel (SLIDE ~~15~~ 18 ON).

Such a thermal system then is made up of a collector, a method of storage of day heat for use at night, a method of transferring the heat to the turbine, and a generator. Key technology problems are: the development of low cost collectors with high efficiency coatings, good heat transfer devices such as heat pipes, and efficient energy storage.

Such a thermal system (SLIDE ~~17~~ 19 ON) with a collector area of no more than 6 miles by 6 miles could produce about 3-1/2 million KW of electric power. That's enough electricity to meet the present needs of the city of Los Angeles - with no pollution or fuel consumption. (Slide 19 off)

We've described some of the technology and shown you some of the actual hardware for using our present fuels more efficiently and for topping our clean, everlasting energy source - the Sun.

Much yet remains to be done. Devices and machines must be scaled-up to plant size and of course economic feasibility must be demonstrated.

However, we do believe that among the technologies presented here today are solutions to some of our Earth energy problems.

STOP 6   LOU REVNYAK 2158

CS 67699 1) SOURCES OF ENERGY TODAY IN U. S. AND THEIR RESERVES

CS 67700 2) SYSTEMS FOR CONVERSION OF HEAT TO ELECTRICITY INVESTIGATED

CS 67701 3) TYPICAL MODERN STEAM PLANT EFFICIENCY 40%

CS 67702 4) HIGHER CYCLE TEMPERATURES
YIELD: INCREASED EFFICIENCY

CS 67703 5) HIGHER CYCLE TEMPERATURES
YIELD: INCREASED EFFICIENCY FUEL ENERGY SAVINGS
LESS THERMAL POLLUTION

CS 67704 6) STEAM PLANT WITH "POTASSIUM TOPPER" EFFICIENCY 50%

CS 67705 7) THREE STAGE POTASSIUM TURBINE AFTER 7-MONTHS OPERATION

CS 67706 8) CLOSED CYCLE BRAYTON SPACE POWER SYSTEM

CS 67707 9) AUTOMOTIVE PISTON ENGINE EXHAUST EMISSIONS

CS 67708 10) AUTOMOTIVE GAS TURBINE EXHAUST EMISSIONS

CS 67709 11) AUTOMOTIVE CATALYTIC COMBUSTOR

CS 67710 12) AUTOMOTIVE ENGINE FUEL ECONOMY

13) SKYLAB (CS-59852)

CS 67711 14) SOLAR ENERGY IS DIFFUSE BUT ABUNDUNT

CS 67712 15) SOLAR ENERGY CAN PROVIDE ALL ENERGY FORMS

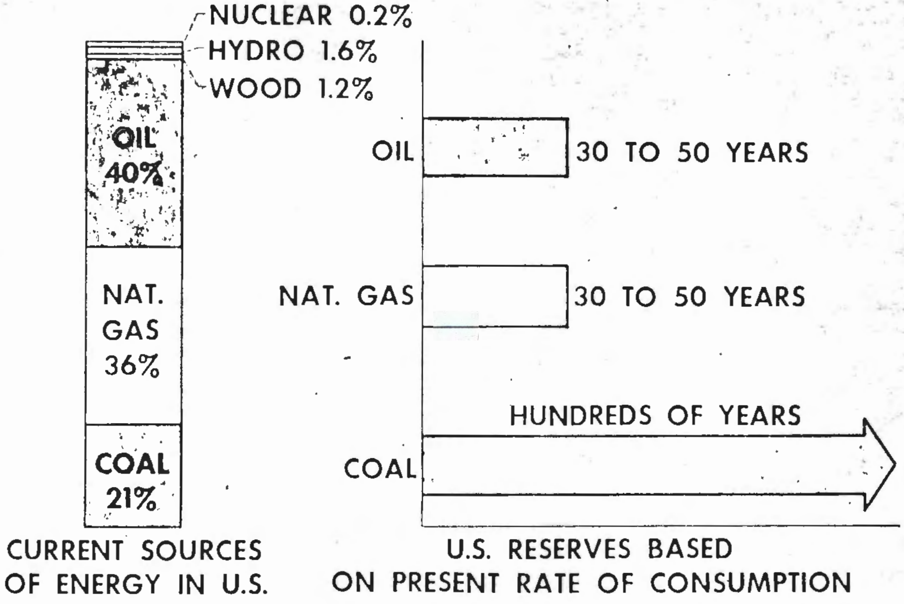
CS 67713 16) DENMARK 1957   200 KW

CS 67714 17) WIND MACHINE (COMPOSITE)

CS 67715 18) ELECTRICITY FROM SOLAR THERMO-DYNAMIC SYSTEM

CS 67716 19) ELECTRIC POWER FROM SOLAR THERMAL ENERGY (FARM)

SOURCES OF ENERGY TODAY IN U.S. & THEIR RESERVES



SLIDE 1

~~CS-677~~
CS-67699

SYSTEMS FOR CONVERSION OF HEAT TO ELECTRICITY INVESTIGATED IN OUR AEROSPACE PROGRAMS

RANKINE:

- TURBINE SYSTEMS WITH LIQUID METALS (POTASSIUM OR MERCURY)

BRAYTON:

- TURBINE SYSTEMS WITH INERT GASES OR AIR

THERMIONIC EMISSION

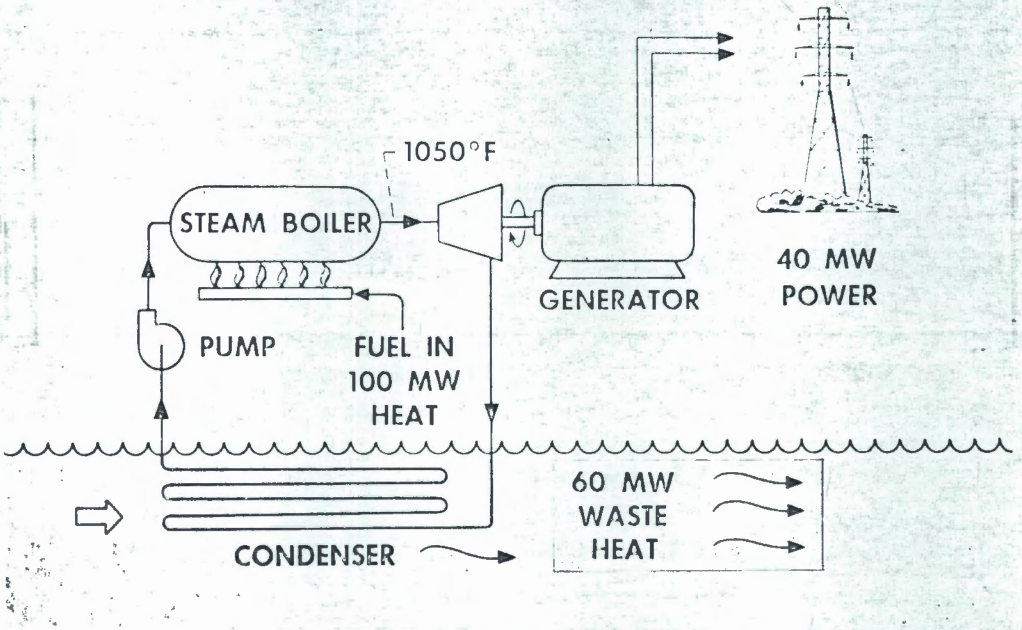
THERMOELECTRICS

MAGNETOHYDRODYNAMICS

SLIDE 2

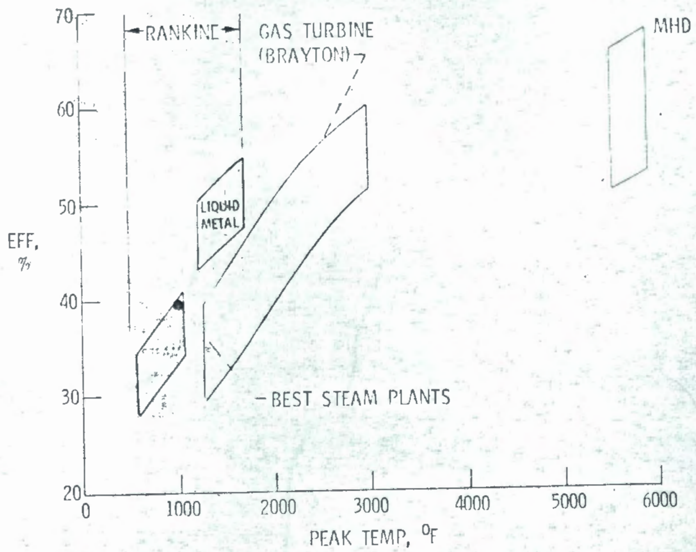
CS-67700

TYPICAL MODERN STEAM PLANT EFFICIENCY 40%



SLIDE 3 CS-67701

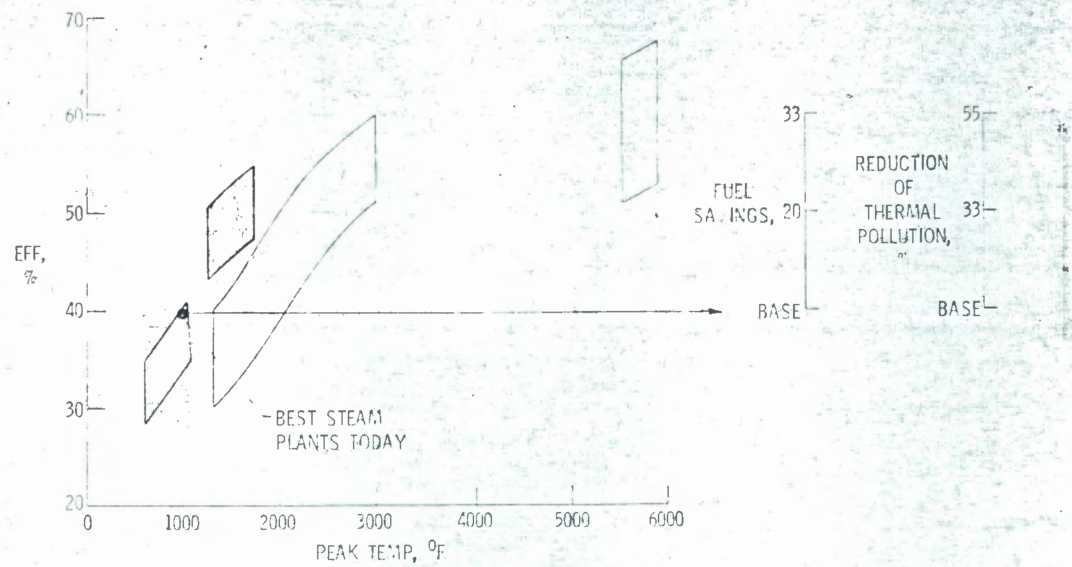
HIGHER CYCLE TEMPERATURES YIELD:
INCREASED EFFICIENCY



SLIDE 4 CS-67702

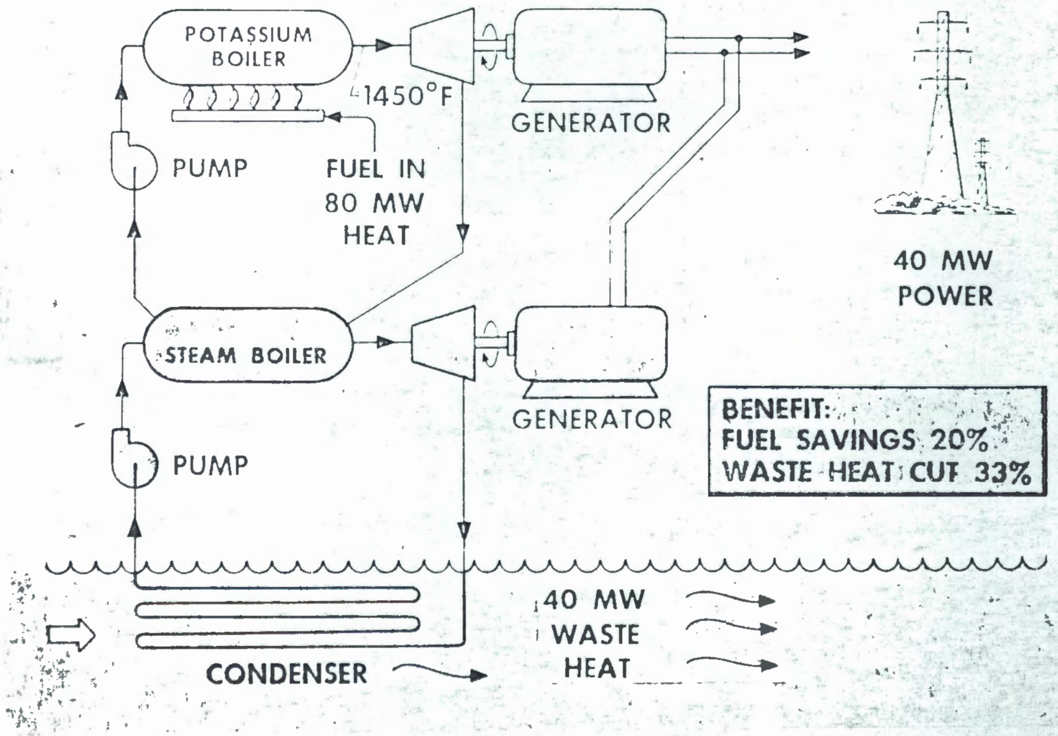
HIGHER CYCLE TEMPERATURES YIELD:

- INCREASED EFFICIENCY
- FUEL ENERGY SAVINGS
- LESS THERMAL POLLUTION



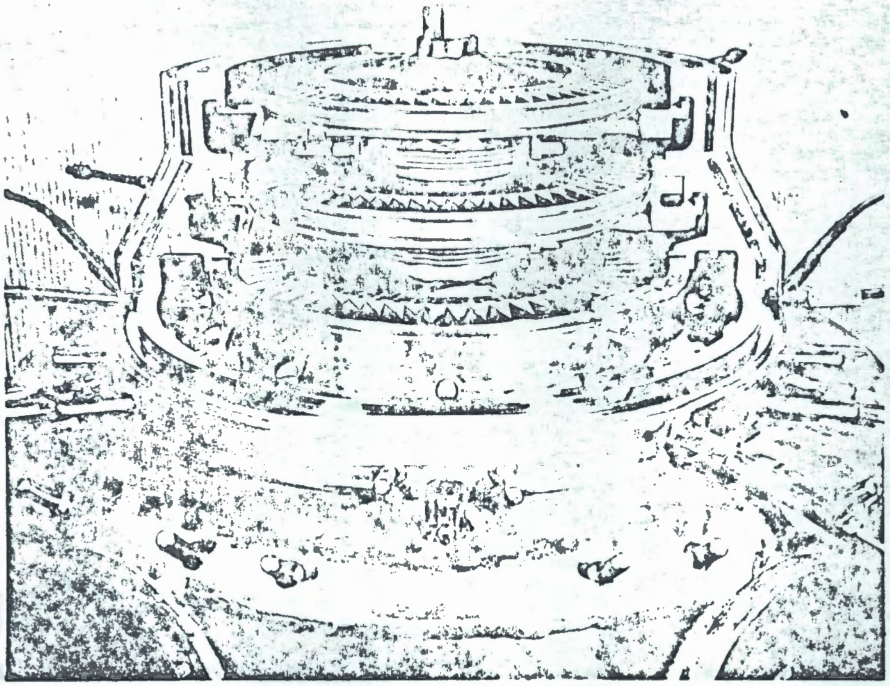
SLIDE 5 CS-67703

STEAM PLANT WITH "POTASSIUM TOPPER" EFFICIENCY 50%

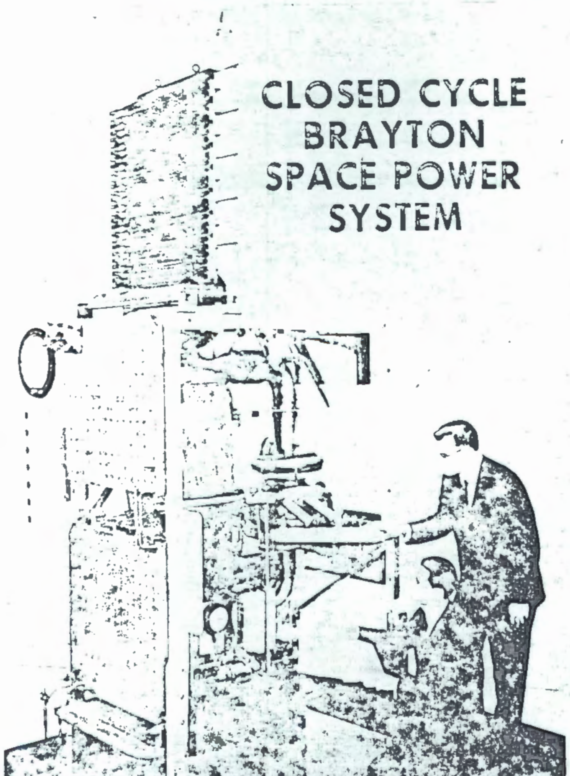


SLIDE 6 CS-67704

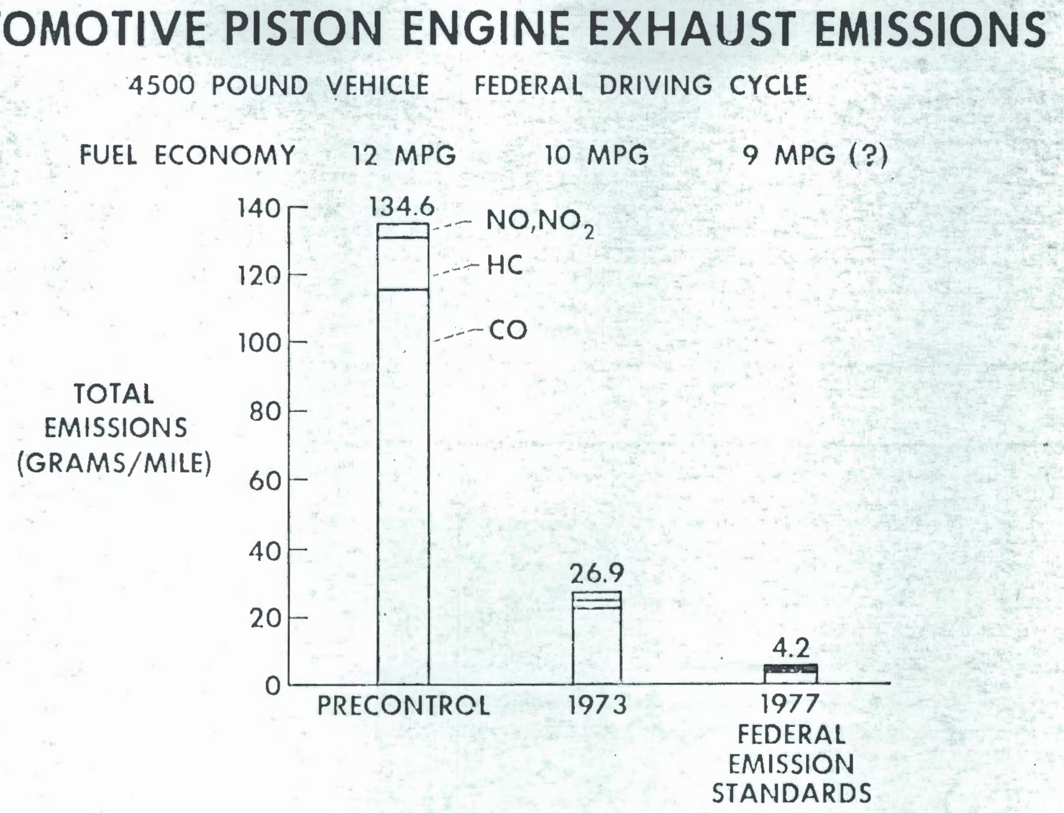
THREE STAGE POTASSIUM TURBINE AFTER 7-MONTHS OPERATION



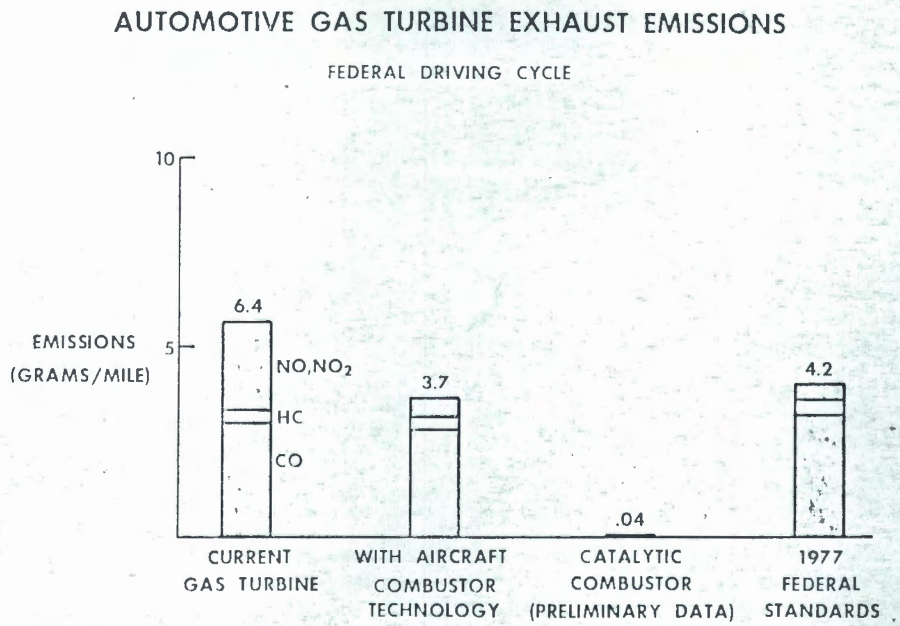
SLIDE 7 CS-67705



SLIDE 8 CS-67706

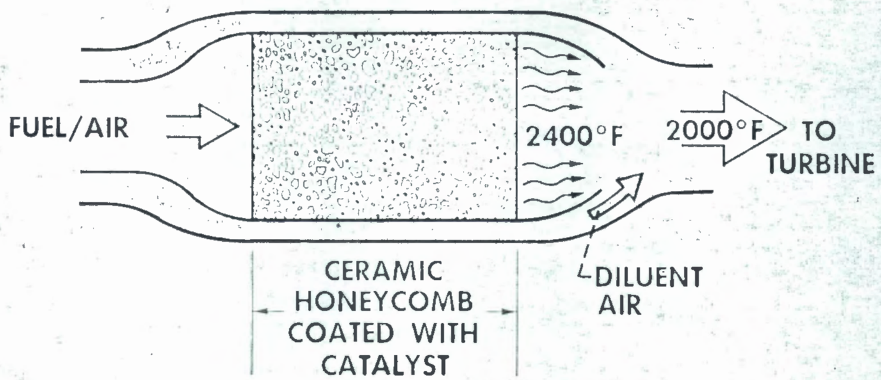


SLIDE 9 CS-67707



SLIDE 10 CS-67708

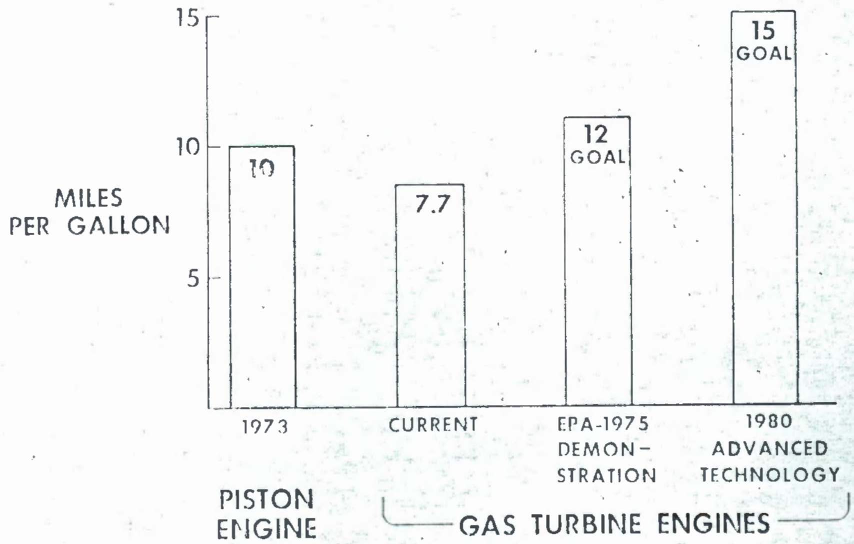
AUTOMOTIVE CATALYTIC COMBUSTOR



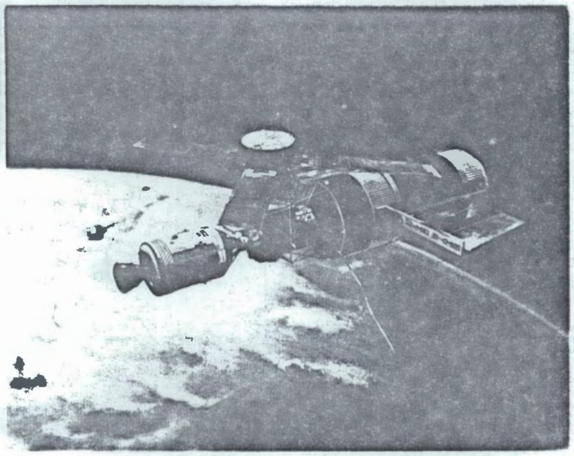
SLIDE 11 CS-67709

AUTOMOTIVE ENGINE FUEL ECONOMY

4500 POUND VEHICLE FEDERAL DRIVING CYCLE

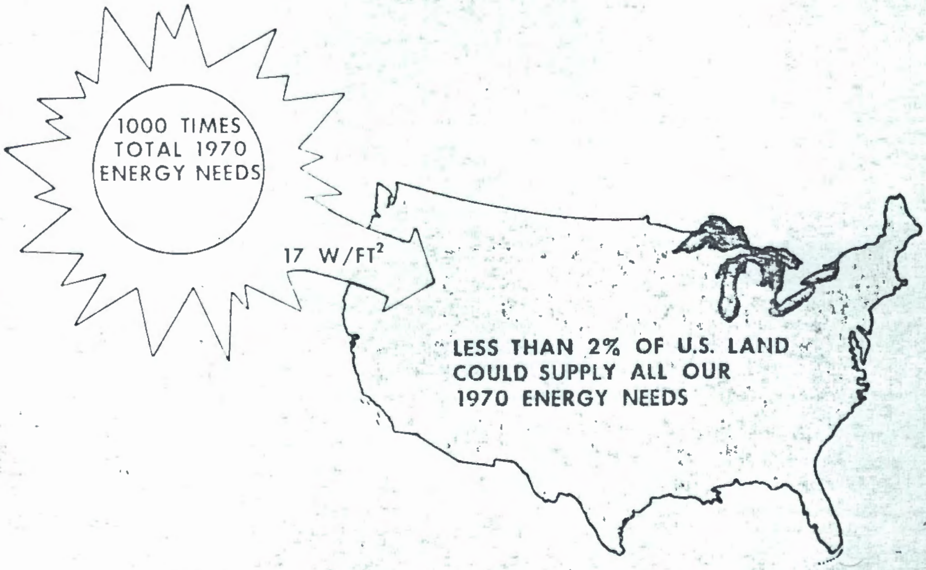


SLIDE 12 CS-67710



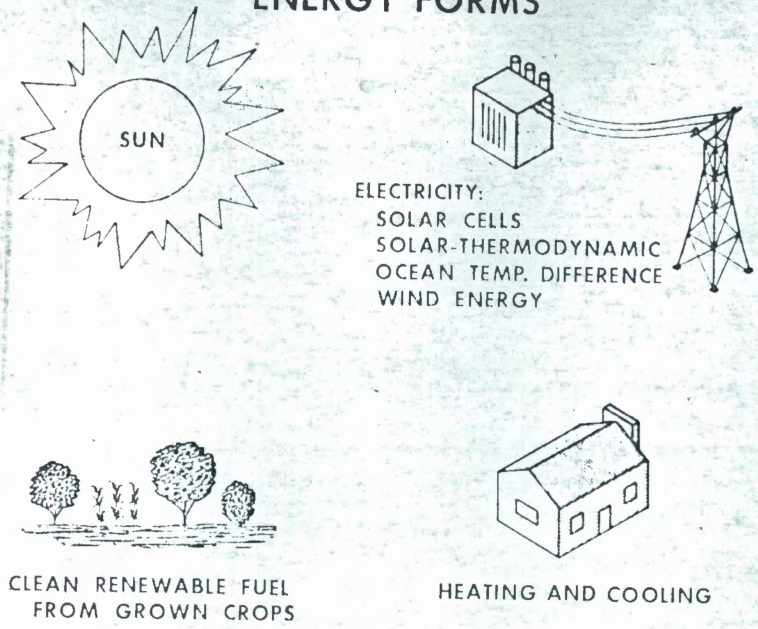
SLIDE 13 CS-59852

SOLAR ENERGY IS DIFFUSE BUT ABUNDANT



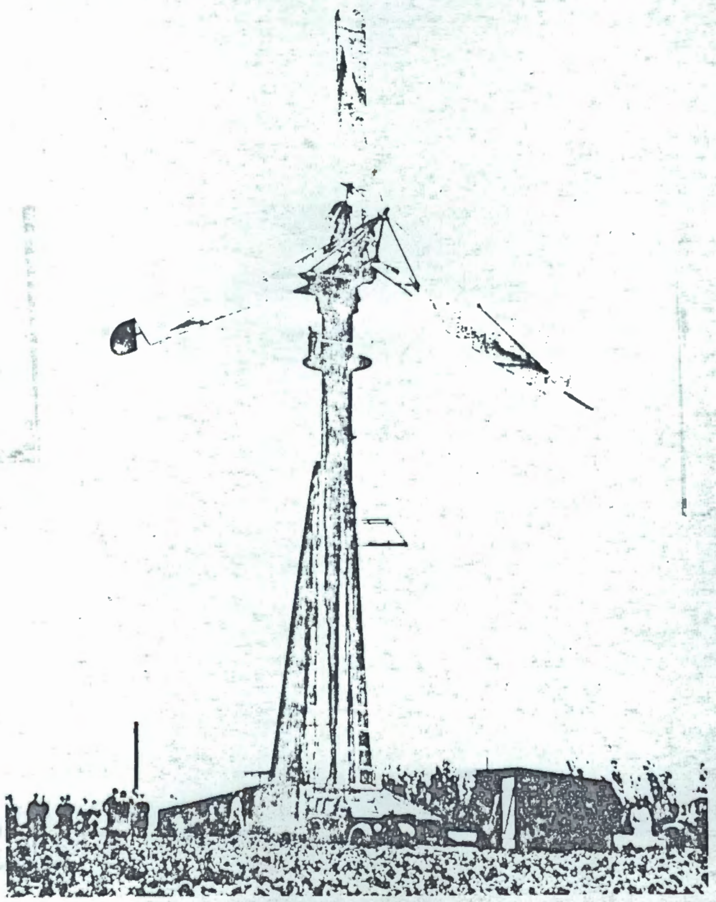
SLIDE 14 CS-67711

SOLAR ENERGY CAN PROVIDE ALL ENERGY FORMS



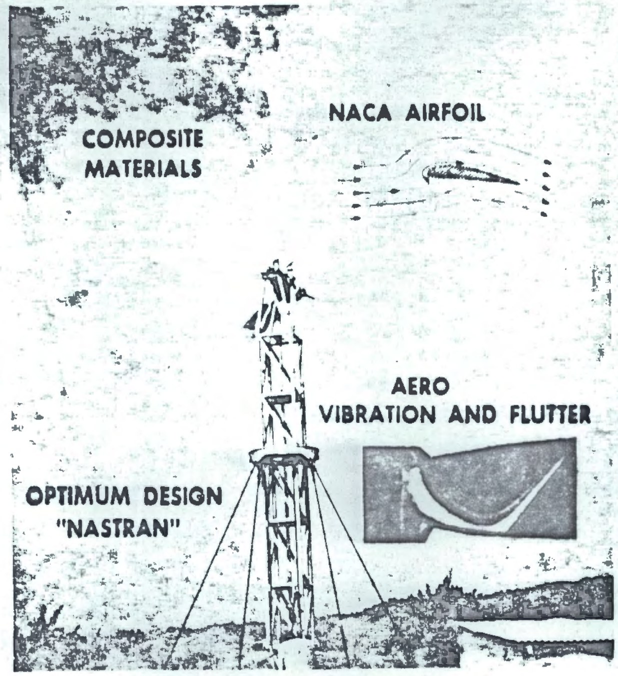
SLIDE 15 CS-67712

DENMARK 1957 200 KW



SLIDE 16 CS-67713

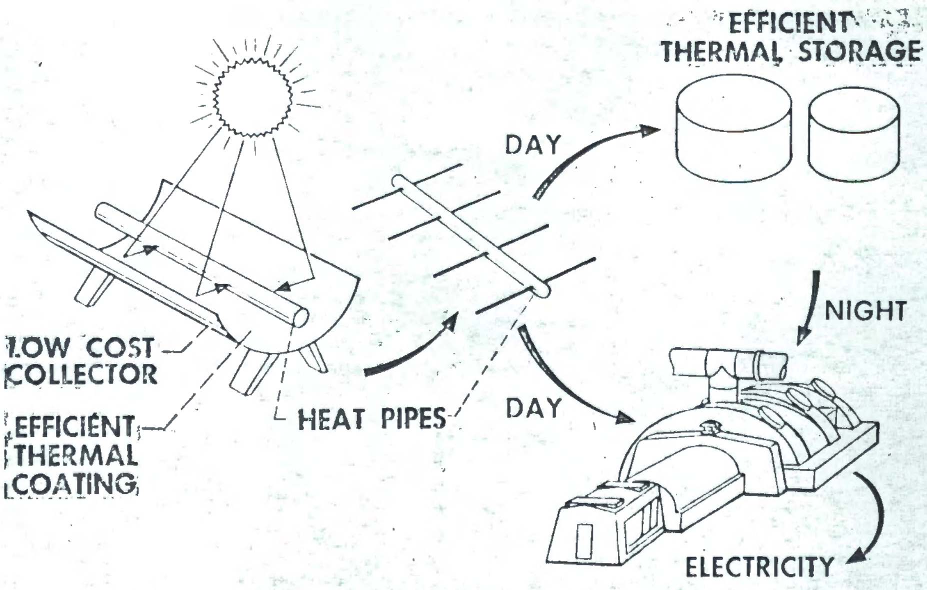
SLIDE 16 CS-67713



SLIDE 17 CS-67714

ELECTRICITY FROM SOLAR THERMO-DYNAMIC SYSTEM

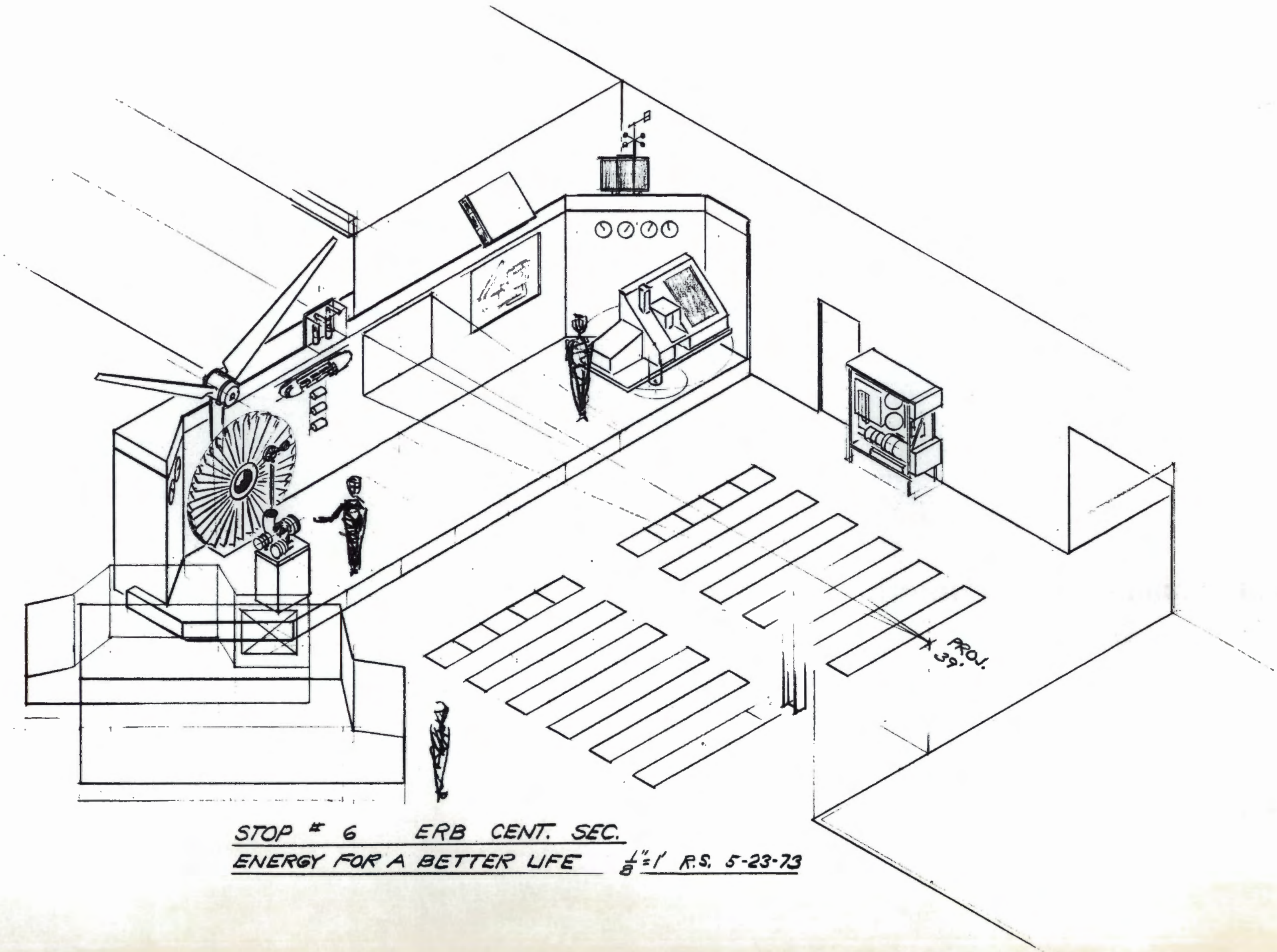
ADVANCED TECHNOLOGY NEEDS



SLIDE 18 CS-67715

ELECTRIC POWER FROM SOLAR THERMAL ENERGY

SLIDE 19 CS-67716

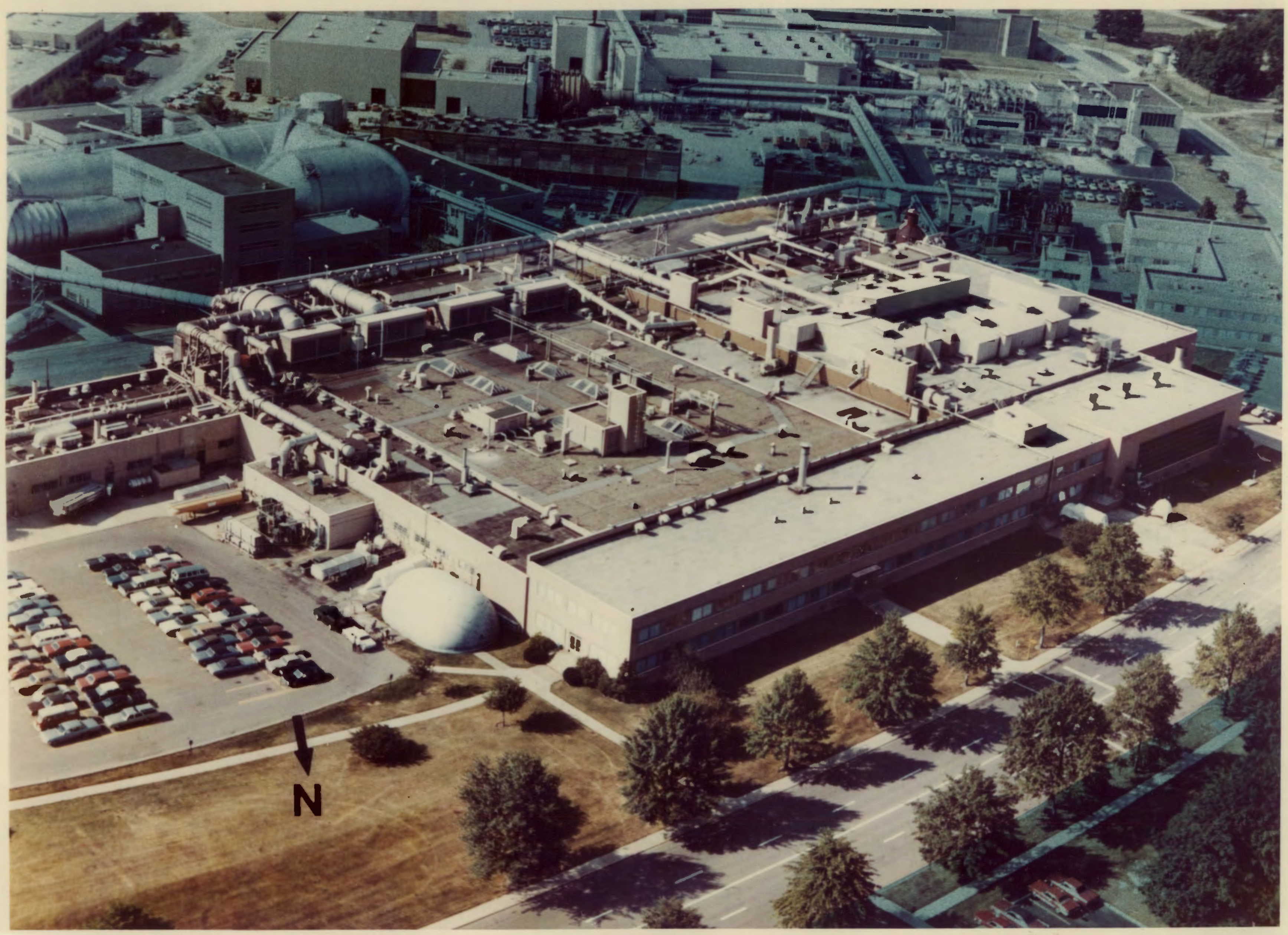


STOP # 6 ERB CENT. SEC.

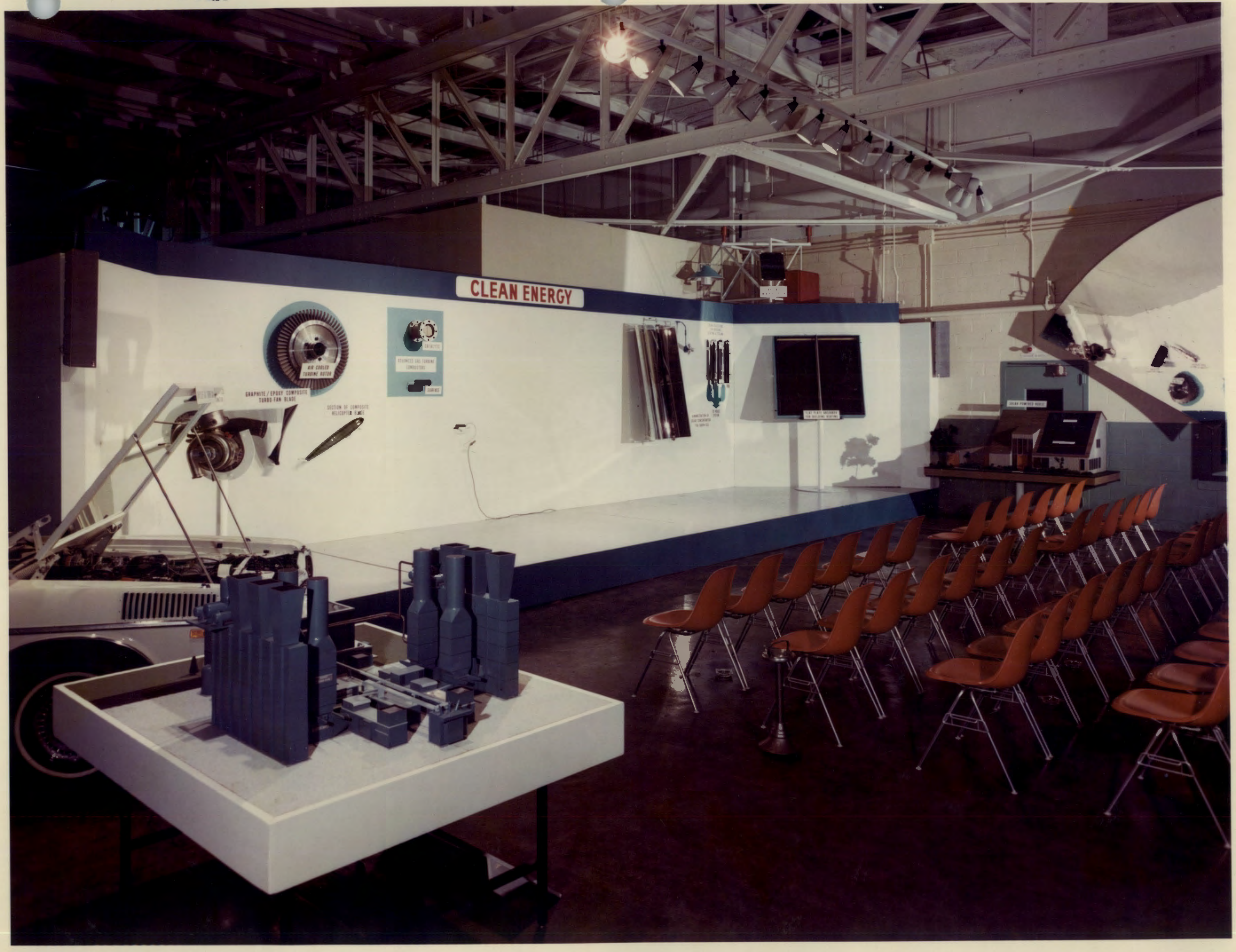
ENERGY FOR A BETTER LIFE $\frac{1}{8}'' = 1'$ R.S. 5-23-73

NASA
C-73-1524

ENGINE RESEARCH BUILDING



NASA
C-73-3418



NASA
C-73-3421