The Australian National University

Department of Engineering Physics

Institute of Advanced Studies
Research School of Physical Sciences
Post Office Box 4, Canberra ACT 2600
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Prof. J.H. Carver,
Director,
R.S.Phys.S.

July 10, 1985.

Dear Professor Carver,

Ventures involving Power Kinetics Inc. (PKI) Troy, N.Y., U.S.A.

As you know there have been negotiations and discussions with PKI over the past year following their approach to us expressing interest in the White Cliffs Engine Development and in our Thermochemical Research. This interest culminated in S. Kaneff, P. Carden and R. Whelan visiting Troy NY (May 21-27) at PKI expense for more detailed discussions.

The following developments are noted:

(1) PKI have ordered a sample engine from us for testing and demonstration, with a view to using this in modular solar/dish systems for electricity generation and mechanical work production and in Third World rural electrification systems (using crop wastes and/or fuel crops to generate steam).

(2) We and PKI have signed a Confidential Disclosure agreement allowing more frank discussions between us (See enclosed copy Attachment 1).

(3) Recognising the advantages of the ANU engine / for example as listed in the enclosed paper "Some Advantages of the ANU Steam Engine", (Attachment 2) PKI propose to commercialise this development and seek an appropriate licence to do so. A letter of intent has been signed by the President of PKI - see enclosed copy of letter of intent, together with some information about the solar activities and a corporate overview of PKI (Attachments 3, 4).

They (and we) believe that this kind of engine is currently the only practical unit so far available. This situation will continue until the new generation engines (Stirling, Brayton and Sodium Heat Engines) now being developed, achieve cost effective reliable operation - a situation some years off. Consequently the period over which the ANU engine holds priority seems limited and must be exploited in timely manner. (There are grounds for expecting that over a longer term the ANU engine may still be preferable in some applications because of its simplicity of maintenance and spare parts availability).

The likely volume of engine sales is quite unknown. PKI have tendered to the US Department of Energy for the Molokai (Hawaiian) Solar Power Station: if they win this tender, 6 engines will be required later this year. They are also carrying on a venture in China to supply solar equipment. The levels of funding and licence fees take market uncertainties into account.

The Energy Authority of N.S.W., in the terms of the ANU/ANUTECH/EA NSW agreement on White Cliffs, has an interest in this matter, and a copy of the PKI information and developments has been sent to them for comment. Formal ANU comment is of course sought, especially on how any agreement with PKI may be handled and on the terms of any such agreement. PKI are aware of the EA of NSW interests in the matter.

(4) In the second half of 1984, in conjunction with PKI, we arrived at a draft programme of R and D for the Thermochemical Research (which has been ongoing in the Department since 1972) to be carried to the stage of gaining data from an experimental system adequate to commence design of a $10MW_e$ power plant or similar.

There is a current awakening of interest in USA in thermochemical systems for a number of purposes, including solar applications, but also for more exotic systems, for example the transport and utilisation of heat from the Earth's magma. The US Department of Energy is now funding thermochemichal systems (via Sandia National Laboratories, Albuquerque, NM) based on SO_3 and on CO_2/CH_4, and the impression previously given was of a lack of interest in ammonia. But as a result of the recent US visit, we now know that this was not a correct assessment of Sandia's interest, which has in fact regarded ammonia as an important candidate system. This interest has now become more intense since Sandia's awareness of the recent Carden developments which permit direct work output from the synthesiser, thereby adding some 50% more useful output from an ammonia system.

We have been advised, both directly and indirectly by personnel in Sandia that, given an appropriate submission, we are likely in due course to succeed in gaining funds for the ammonia research programme. An appropriate submission would involve PKI, an ammonium plant manufacturer and Sandia (US Dept. of Energy).

Acting on the above basis PKI have proposed a licence intent agreement, the broad terms of which are indicated in Attachment 5. The details need to be worked out and the ANU is requested to advise on this matter. Point B(3) in the draft intention (Attachment 5) concerns our programme as identified in Attachments 6, 7 and updated and overviewed in Attachment 8. Essentially a sum of $A492,000 is involved over a period of 2½ years, which would enable much of the first 3 steps (of the 5 identified in the first page of Attachment 8), to be carried out.

All 5 steps of Attachment 8 are taken seriously, as commercial involvement requires an at least potentially viable product to be demonstrated. We would expect to play an active and mainly leading role in steps 1-4, and a consultative role in step 5. It is PKI's task to obtain and organise the necessary support.

Comments and advice on how to proceed in these matters are requested.

Yours sincerely,

S. KANEFF
PROFESSOR AND HEAD.

c.c. Dr. E.K. Inall
Dr. P.O. Carden
Mr. R.E. Whelan

Attachment 1

CONFIDENTIAL DISCLOSURE AGREEMENT

between
Professor Stephen Kaneff
Dr. Peter O'Neill Carden
Mr. Robert Edgar Whelan,
all of the Department of Engineering Physics,
Research School of Physical Sciences,
The Australian National University (ANU),
and
Power Kinetics Inc.

Power Kinetics Inc. ("PKI") is an organization which, among other activities, carries out research and development and produces products in the area of solar energy utilization, in energy conversion and in control systems.

Professor Kaneff, Dr. Carden, and Mr. Whelan ("The Researchers") have conducted and are conducting research and development in the areas of solar energy utilization, energy conversion and control systems and especially in thermochemical energy conversion, transport, storage and utilization; in high performance steam engines; and in systems using high performance steam engines powered from solar energy and from other heat sources.

PKI and the researchers wish to meet to discuss work in these areas. The proposal is that the meeting is to take place over the period 21 May to 27 May 1985 inclusive and may be followed by subsequent meetings and/or other means for contact. It will be necessary for PKI and the researchers to disclose to each other information ("the information") which is considered to be confidential. The parties agree to disclose the information to each other on the following terms.

1. It is agreed that the disclosing party will disclose the information to the recipient party upon the following conditions:
   (a) that the disclosure of the information will be received and held in confidence by the recipient party;

(b) that the recipient party will take such steps as may be reasonably necessary to prevent the disclosure of the information to others; and

(c) that the recipient party will not commercially utilize the information without first having obtained the written consent of the disclosing party to such utilization.

2. The recipient party will receive a disclosure of the information on the condition that the commitments set forth in 1(a) through 1(c) above shall not extend to any portion of the information:

(a) which is presently known to the recipient party, except for that information which has already been nominated by either party as confidential, specifically details of solar receiver configurations and performance as disclosed by the researchers to PKI, information on thermo-chemical systems disclosed by the researchers to PKI and details of the ANU high performance steam engine to be supplied to PKI by the researchers; or in the case of the steam engine, the confidential information shall be deemed to include that which is necessary to allow the engine to be constructed so that it functions effectively, whether such information has been specifically disclosed or not and includes that information which resides in the engine hardware itself, or,

(b) which is information generally available to the public; or

(c) which, hereafter, through no act on the part of the recipient party, becomes information generally available to the public; or

(d) which corresponds in substance to information furnished to the recipient party on a non-confidential basis by any third party having a lawful and unrestricted right to do so; or

(e) which corresponds to information furnished by the disclosing party to any third party on a non-confidential basis, except as incident to limited consumer testing.

3. This agreement shall promptly and automatically terminate in its entirety upon the lapse of a period of five (5) years commencing on the date of PKI and the researchers' signed acceptance hereof. Following termination of the commitments set forth in 1(a) through 1(c) above with respect to the whole of the information, or upon termination thereof in connection with specific portions of the information by operation of any of items 2(a) through 2(d) above, the recipient party shall be completely free of any express or implied obligations restricting disclosure and use of the information or portions of the information, respectively, subject to the disclosing party's patent rights.

4. Correspondence with respect to this agreement shall be sent as follows:

ACCEPTED :

PROFESSOR STEPHEN KANEFF

By ____________ ____________

DR. PETER O'NEILL CARDEN

By ____________ ____________

MR. ROBERT EDGAR WHELAN

By ____________ ____________

POWER KINETICS, INC.

By ____________

Date May 22, 1985

Attachment 2

SOME ADVANTAGES OF THE ANU STEAM ENGINE
(Steam Expander, Heat-to-Mech-Work Converter)

- Robust, reliable, uses a high proportion of standard commercially available parts. Essentially only new cylinder heads required and piston modifications.

- With simplification and relatively small production run, ($\approx$100) engines could be produced for $\approx$ $US0.20/watt in sizes of a few kw to a megawatt.

- Reliability and attention required are better than small diesel engines (i.e, less frequent oil changes, more trouble free).

- Currently recommended head inspection every 1000 hours. Experience over much longer periods is expected to improve this further.

- Can be maintained by those with automotive engine experience only.

- Removing the head and re-assembling, $\sim$3 man hours; dismantling completely and re-assembly, $\approx$7 man hours.

- Heat to mechanical work conversion efficiency is 23% at steam temp 460°C, pressure 800-900 psi. Higher efficiency is possible with use of high temp materials and higher steam temperatures ($\approx$27-28%)

- The engine will run effectively on wet steam and can cope with intermittent energy supply, i.e, stopping and starting (automatically) as frequently as necessary. Operation is satisfactory for steam temperatures $\approx$160-460°C at pressures 100-1100 psi.

- The engine may be coupled to drive any mechanical load, i.e, for electricity, but also has significant applications where electricity need not be the first output.

  For example: The direct pumping of water; direct coupling to drive a reverse osmosis water purification plant; multi purpose applications.

- The engine can readily and effectively be used in a cogeneration module at a reasonable price for waste heat utilization (diesel exhaust heat, etc.)

- When supplied with steam from a simple combustion system, the engine can run from crop wastes, waste products and from any fuel, including wood. Rural electricity generation systems in third world countries appear an attractive market.

Engine Advantages (continued)

- As a dish/engine system, overall efficiencies of 18% are possible. With engine components designed for higher quality heat, this efficiency might be raised to 22%.

- The engine may be supplied from several alternative sources of steam, including hybrid combinations.

- Waste heat from the steam engine may be used to desalinate water, for space heating, for ground heating in glass houses, etc.

Attachment 3

Power Kinetics, Inc.

SOLAR PRODUCT DESIGN • R & D • AUTOMATION

1223 PEOPLES AVE. TROY, NEW YORK 12180 (518) 271-7743

MAY 26, 1985

Prof. Stephen Kaneff
Australian National University
Head, Dept. of Engineering Physics
Research School of Physics
GPO 4
Canberra City ACT 2601
AUSTRALIA

Dear Stephen:

Power Kinetics, Inc. (PKI) intends to obtain a sole worldwide license for the diesel block based steam engine technology of the Department of Engineering Physics of the Australian National University (ANU). In consideration for this worldwide license PKI will pay, contingent upon a suitable agreement which protects the interests of Power Kinetics, a prepayment of $A100,000, which is to be paid upon the sale of the first sixteen (16) units according to the attached Schedule I.

Power Kinetics will also pay a 2% royalty on all sales for a period of six years, following the date of the signing of an agreement, on sales of units above the first sixteen units.

It is understood and agreed that Australia will be excluded from the domain of this license. It is also understood and agreed that the value of this steam engine technology lies primarily in the nature of trade secrets which ANU must guard to protect PKI's interests.

Both parties to this agreement recognize that this steam engine technology may have a window of opportunity for commercialization. A good working relationship between the parties is essential for the successful diffusion of this technology.

A listing of some advantages of the ANU steam engine is attached.

Sincerely,

POWER KINETICS, INC.

Robert Rogers

Robert J. Rogers
President

Schedule I (\$Australian)

Years 1 - 2

Payment(s) \$10000/engine for the first 6 engines, then \$4000/engine for the next 10 engines.

Year 1 - 6

Payment(s) 2% royalty on all sales above 16 engines.

SOME ADVANTAGES OF THE ANU STEAM ENGINE
(Steam Expander, Heat-to-Mech-Work Converter)

- Robust, reliable, uses a high proportion of standard commercially available parts. Essentially only new cylinder heads required and piston modifications.

- With simplification and relatively small production run, ($\approx$100) engines could be produced for $\approx$ $US0.20/watt in sizes of a few kw to a megawatt.

- Reliability and attention required are better than small diesel engines (i.e, less frequent oil changes, more trouble free).

- Currently recommended head inspection every 1000 hours. Experience over much longer periods is expected to improve this further.

- Can be maintained by those with automotive engine experience only.

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  For example: The direct pumping of water; direct coupling to drive a reverse osmosis water purification plant; multi purpose applications.

- The engine can readily and effectively be used in a cogeneration module at a reasonable price for waste heat utilization (diesel exhaust heat, etc.)

- When supplied with steam from a simple combustion system, the engine can run from crop wastes, waste products and from any fuel, including wood. Rural electricity generation systems in third world countries appear an attractive market.

Engine Advantages (continued)

- As a dish/engine system, overall efficiencies of 18% are possible. With engine components designed for higher quality heat, this efficiency might be raised to 22%.

- The engine may be supplied from several alternative sources of steam, including hybrid combinations.

- Waste heat from the steam engine may be used to desalinate water, for space heating, for ground heating in glass houses, etc.

PKI SQUARE DISH SOLAR COLLECTOR SYSTEM

SYSTEM DESCRIPTION

LOW COST: Innovative flat mirror design and modular construction keep costs down.

HIGH PERFORMANCE: 75% clear day efficiency.

LOW OPERATING AND MAINTENANCE COSTS: Fully automated microprocessor control minimizes need for operator attention.

AUTOMATIC MIRROR POSITIONING: When the sun is not out, mirrors turn upside down to prevent accumulation of dirt and snow.

SELF-PROTECTION DESIGN: Mirrors automatically feather during high winds, preventing damage to the collector.

The concentrator is comprised of 108 [144*] identical mirror assemblies that incorporate eight inexpensive flat glass mirrors per assembly. Elevation tracking is achieved by pivoting mirror assemblies on their centers of gravity. The entire concentrator structure rides on an inverted track, and rotates from east to west to provide azimuthal tracking. The concentrator is supported by a space-frame structure that distributes all wind and gravity loads to the base supports.

An efficient cavity receiver is mounted at the concentrator's focal area. Concentrated solar energy is transferred to a fluid circulated through the receiver.

Automatic two-axis tracking and operational control is provided by a microprocessor. Active tracking is accomplished through concentrator-mounted shadow band sensors. A software program continues azimuthal tracking during cloudy periods.

Through eight generations of design, an integrated system has been developed that is optimized for cost/performance trade-offs, durability, ease of assembly, operation and maintenance and safety.

SYSTEM SPECIFICATIONS

DESIGN: Point-focusing faceted Fresnel concentrator.

NET APERTURE AREA: $80 m^2$ ($864 ft^2$) [106.6 (1152)*] concentrator mirror area.

CONCENTRATOR RATIO: 350 (to 500) :1 (estimated).

ABSORBER: Cavity receiver painted with Pyromark 2400.

REFLECTIVE SURFACE: Second surface, silvered glass mirrors.

SUPPORT STRUCTURE: Thin wall steel tubing, steel plate joints, box beam track.

STRUCTURAL STABILITY: The collector can withstand 100 mph winds in stowed position, 40 mph winds in focused configuration.

HEAT TRANSFER FLUIDS: Water, Syltherm.

APPLICATIONS: Industrial process heat, electrical or mechanical power via steam engine or turbine, space heating or cooling, and hot water.

PRODUCT: Steam or other heat transfer fluid from 120°C (250°F) to 400°C (750°F).

PERFORMANCE: 75% when isolation = 1 kw/m^2 and output is 120°C steam (includes line losses to center pier). Under these conditions thermal output will be 60 kw or 180 lbs of steam per hour.

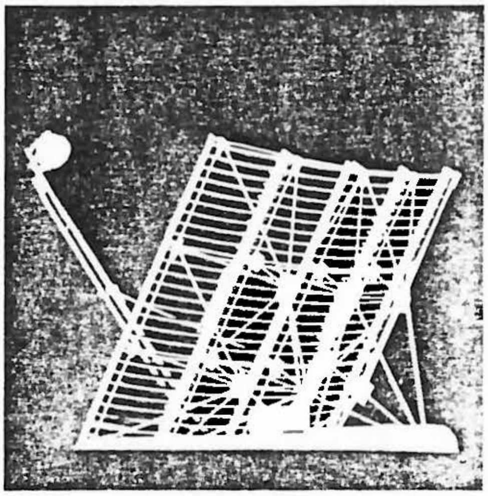
ELEVATION DRIVE: Dual hydraulic, using 1/3 hp pump motors.

AZIMUTH DRIVE: Sprocket/roller chain, using 1/4 hp motor and 3600:1 gear reduction unit.

CONTROLLER: 6502-based microprocessor (Super Kim).

* enhanced version

POWER KINETICS, INC.
1223 Peoples Avenue, Troy, New York 12180
(518) 271-7743



P O W E R   K I N E T I C S,   I N C.

1223 Peoples Ave., Troy, NY 12180, (518) 271-7743

8. INTEGRATED DESIGN: Because each collector is an entire system in itself, each unit can be postioned according to the layout of land and buildings. For the growing energy user, collector units can be added to an existing array of units to handle additional energy loads required by manufacturing processes or space heating and cooling.

POSITION OF THE POINT FOCUSING TECHNOLOGY TODAY

In the solar thermal energy field there are two key considerations governing practical utilization of solar heat, quality of energy (i.e. temperature level) produced, and cost per unit of energy. In addition, load requirements can play a role in technology selection. Flat plate collectors only see application in low temperature regimes (less than 200 degrees F.) Because of the large receiving (and heat loss) surface area, flat plate collectors suffer from greater heat loss and are much less efficient than concentrating collectors. Moreover performance is affected significantly by ambient temperatures. Concentrating collectors are required for medium temperature (up to 500 degrees F) process heat applications, although flat plate evacuated tube collectors can be used at the low end of this regime. The PKI collector has operated to date primarily in this regime and has demonstrated a capability to compete well with troughs on a cost per Btu basis.

In the solar thermal area, PKI is competing primarily against troughs and other dishes. For cogeneration of electricity using an efficient steam turbine, the Company competes only with dishes, since troughs do not produce the temperatures needed to drive such equipment cost effectively. Industry predictions indicate comparable long term installed capital costs of approximately $25/square foot, when and if mass production is reached.

The Square Dish can be installed for $32 per square foot today which translates to $1.32 per installed peak watt of cogenerated energy in a sunny location. This compares well with Frost and Sullivans 1983 review of the worldwide solar electric generation market which indicates a $9.66 per peak watt price today for the $156 million market. An engineering analysis by the Company which incorporates a steam turbine with the Square Dish achieves a $3.63 per peak electrical watt. Without considering the large quantities of thermal energy byproduct.

The PKI collector has a substantial advantage in system performance. Predicted performance for troughs is in the 40% to 60% range for system thermal efficiency. In contrast actual trough performance in the D.O.E. Industrial Process Heat program is considerably below predictions. Though trough manufacturers have enjoyed a lead in entering the commercialization process through D.O.E. funding, they have not fully resolved design and operational problems necessary for convincing the financial community to back the costs of industrial projects.

MANUFACTURING CAPABILITIES

One of PKI's primary concerns has been preparing the collector design and the company personnel for commercial production. To that end as many components as possible of the collector have been designed to be off the shelf or readily manufactured by existing suppliers. These suppliers locally allow the production of 300 units/year,or approximately ten megawatts of electrical generation capacity at $30 million, without the necessity for long lead time production facility expansion. At a foreign location or distant U.S. location, the same capability can be set up with a six month lead time after initial contacts are made in that area.

In the initial phases of production, development of quality control systems for ensuring satisfactory performance of sub-contracted manufacturing took top priority along with continuing to identify the best component suppliers. Only the most critical components are reserved for in-house manufacture. As the possibility of substantial cost savings warrant or quality control requires, additional manufacturing functions will be developed in-house.

APPENDIX A

THE SQUARE DISH

1. DESIGN ELEMENTS

The PKI collector has three primary subsystems: the Square Dish Concentrator, the Receiver/Fluid Loop, and the Controls. These subsystems are described below:

A. THE SQUARE DISH CONCENTRATOR

The Square Dish provides the point-focusing function of the PKI system. It consists of 864 flat, one-foot-square, second-surface, silvered glass mirrors. The mirrors are affixed to rows of identical curved supports positioned in a faceted Fresnel design of the 80 m^2 for the current product.

Each mirror assembly within the dish rotates through its center of gravity to provide elevation tracking. Two draglinks each serve to interconnect half of the mirror assemblies. Each draglink is moved by a hydraulic actuator.

The dish is supported by a lightweight spaceframe structure composed of steel tubing members and steel plate joints. This design distributes all wind and gravity loads to the base supports. This spaceframe is made up of similar parts so that a $27m^2$ version of the product was made readily for one design contract, while another proposed design allows the product to be expanded to $133m^2$, or with more engineering, to be expanded to $160m^2$. These enhancements are possible becouse wind loads are distributed throughout the structure unlike the competing dishes, which direct all wind loads through a single large joint. Since windloads, which can exert ten tons of force on a dish, are directed evenly through so many members and joints in the Company's Square Dish, parts can remain light and inexpensive. This aids in site installation, packaging, and shipping of parts as well.

The base of the structure is a circular track, inverted to eliminate problems of dirt and ice build-up. The track rides on wheels mounted on concrete piers and is motor-driven by a simple, reliable sprocket/roller chain assembly. The rotation of the entire collector on its base provides azimuthal tracking. The size of the concentrator can be increased 66% with only minor design changes, making it viable for applications which cannot be easily addressed by competing products.

Initially the point focusing programs of DOE attempted to focus energy into a small hole to obtain the highest temperatures possible. Such temperatures were difficult to contain so government programs have deemphasized the need for such precise equipment, which were priced out of reach of any short term markets for the equipment.

B. THE RECEIVER/FLUID LOOP

A well-insulated steel receiver is mounted on a boom at the focal point area of the square dish concentrator. A variety of receivers appropriate for specific applications have been tested, including monotube and parallel tube configurations. Recent designs by the Company address the short term market needs of reliability and low cost.

C. THE CONTROLS

A microprocessor-based package provides automatic two-axis tracking and operational control. Shadowbands mounted on the dish are the basis for active tracking during sunny periods. A software program provides azimuthal tracking during cloudy periods so that collection can begin immediately upon reappearance of the sun.

This feature permits the system to begin collection of energy after an extended cloudy period within 10 minutes of detection of a threshold insolation level. An added advantage is the reduction in parasitic losses, since a large motor is not required in order to "catch up" to the sun position.

The control package also includes a real time clock, digital display, and an integral digital voltmeter.

The Company has superior controls compared to the competition. This superiority has allowed the Company to compete well on government projects where additional requirements are placed on the computer capability built into each product. In mass production, the Company's controls will be reduced to a simple "black box" which serves all site specific needs, but is packaged for easy replacement and rugged handling.

2. AUTOMATION AND SAFETY FEATURES

The PKI collector is able to operate in an unattended mode because of the safety features built into drives, the microprocessor controls, and structural design of the equipment itself. The collector is protected against damage from any system malfunction or environmental conditions such as high winds, snow and ice buildup, or hail. Automatic shut-down conditions include boiler overheating, low feedwater pressure, high winds, user-initiated manual stow, controller failure, AC power loss, and activation of the low limit switch on the elevation drive.

Although all control functions are automatic and do not require a human operator, periodic checks are still required for maintenance at this date.

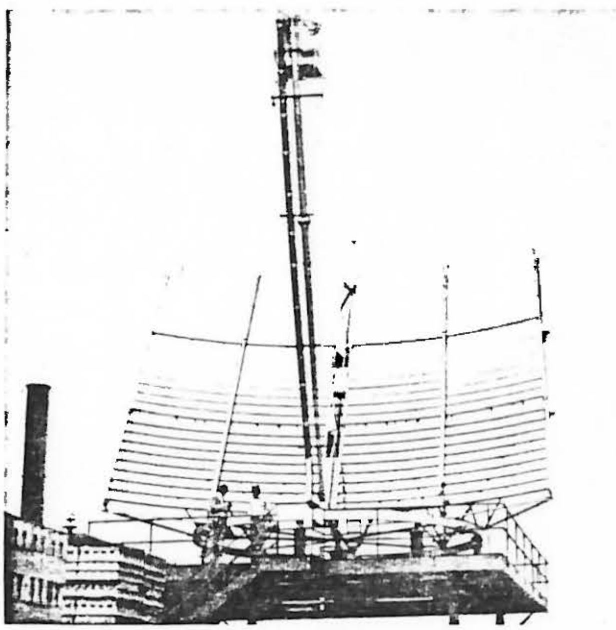
3. RELIABILITY AND EASE OF INSTALLATION

Reliability has been enhanced through recent design modifications to drives, controls, and to other active parts in the product. Platforms can be incorporated into the spaceframe supporting structure to allow safe and easy installation of mirror assemblies and the elevation drive package. The draglink assemblies are located behind the face of the collector, allowing ready access from the working platforms. An electric winch is incorporated into the design to permit easy raising and lowering of the boom for servicing the receiver.

The products of the competitors in most cases require special equipment for installation and maintenance. Power Kinetics designed its equipment for installation at remote sites and by the Company's own work force. This orientation serves the product well in small projects and in the first years of product deployment.

The Company's equipment has had several thousand hours of operation time and has been tested in two government projects to date and is currently being tested by an independent laboratory for a six month period through a Midwest Research Institute program.

THE SHAPE OF TOMORROW



POWER KINETICS, INC.

THE PKI SQUARE DISH COLLECTOR – a stellar performer.

It started out in 1974 as a bright idea in the imagination of a university researcher. A new way to collect the sun's light and turn it into usable energy.

The researcher was Bill Rogers.

The university, Rensselaer Polytechnic Institute.

◄ The 80-square-meter reflective dish of PKI's collector consists of more than 800 inexpensive second-surface silvered flat mirrors. The use of a faceted design is the key to the collector's low cost and high efficiency.

The idea: a high-performance point-focusing, computerized solar collector made with inexpensive flat mirrors.

From the start the idea made sense. Combine high technology with low-cost materials and construction. The idea, turned into a working model, won the Most Innovative Design award in an international competition on relevant engineering.

Today this marvelous energy machine, known simply as The Square Dish Solar Collector, has proven itself to be a reliable performer. In field tests from Troy, N.Y. to Topeka, Kan., and from Salt Lake City to Albuquerque, The Square Dish Solar Collector has demonstrated itself to be a product ready for the marketplace.

THE SQUARE DISH: A SENSIBLE SOLUTION

People who see The Square Dish Solar Collector for the first time are captivated by its elegant space-frame structure, and the images of clouds and blue sky reflected from the silvered mirrors.

Yet the collector's aesthetic appeal is not what led the Jet Propulsion Laboratories to select the Square Dish Solar Collector over all other competitors for its first industry proposed heat experiment using a dish collector.

The Square Dish Solar Collector has a number of features that make it the most sensible industrial solar product on the market.

LOW COST: *Cost savings is, of course, the bottom line of any energy investment, and the PKI Square Dish Solar Collector was designed with economy in mind.*

The Square Dish is the first solar collector of its kind to be mass-producible, consisting primarily of off-the-shelf components. Unlike competitive products that rely on expensive curved dish mirrors, PKI's Square Dish is composed of 864 inexpensive flat mirrors.

The savings are broadened when you consider the ease with which The Square Dish Solar Collector can be installed. Most of its component parts are small enough to be handled by one person. No special machinery is needed for installation.

The Square Dish was designed to keep operating costs at a mimium, so that the benefits of using free energy from the sun are not diminished.

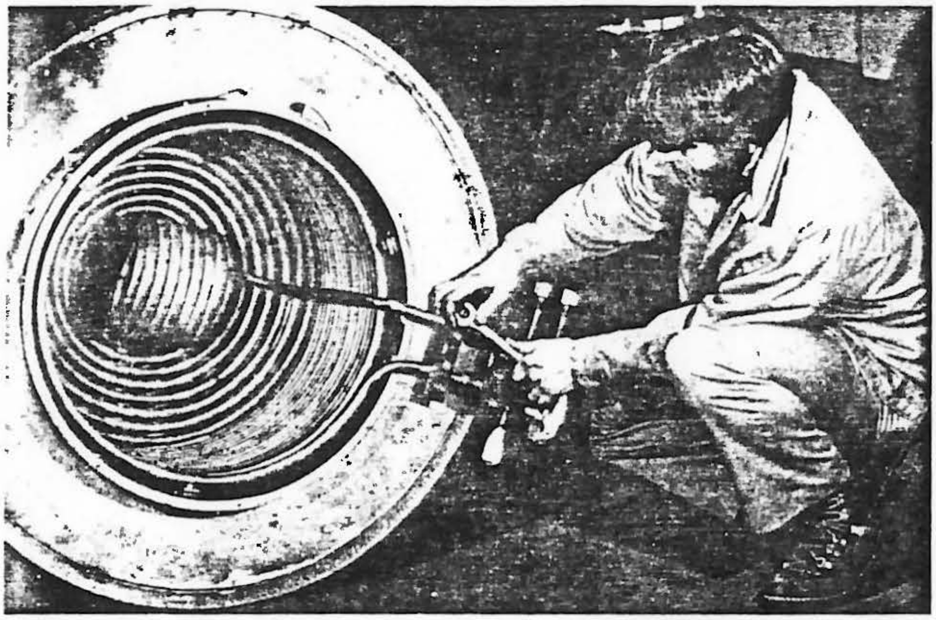
PERFORMANCE: *High performance is an essential ingredient in this collector's success story. On a clear day, The Square Dish Solar Collector converts more than 80% of the sunlight received into usable heat energy – an efficiency rating far better than comparably priced solar collectors.*

The high quality output has been used to generate steam for industrial process heat applications, and to heat oil used to drive a water desalination process. Other potential applications include space heating, air conditioning, enhanced oil recovery and electrical power production.

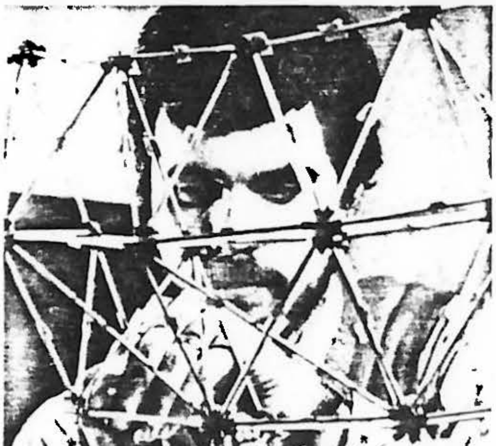
INNOVATION: *Seven generations of working prototypes have resulted in a product loaded with technological innovations – features responsible for the collector's high performance at low cost. In fact, The Square Dish Solar Collector is so advanced, it is on the leading edge of the solar technology field. Consider some of the system's innovations:*

* FULLY AUTOMATED: A sophisticated microprocessor design eliminates the need for operating personnel and minimizes maintenance costs of the system.
* MIRROR POSITIONING: The mirrors automatically turn upside down when the sun is not out, preventing dirt, ice or snow from accumulating. The mirror assemblies even have a special rain-wash position for self-cleaning.
* CAVITY RECEIVER: A well-insulated stainless steel housing incorporates heat exchanger technology at the collector's point of focus. Temperatures in excess of 1000 degrees F can be generated.
* TWO-AXIS TRACKING: Individual banks of mirrors rotate about their centers of gravity, as does the entire collector, eliminating the need for large motors.
* SAFETY: During periods of high winds, the mirror assemblies feather like venetian blinds, allowing the air to blow right through the Square Dish, even winds up to 100 mph.

The Square Dish Solar Collector also includes electrical and mechanical features that prevent the collector from focusing the sun's energy anywhere except the boiler.

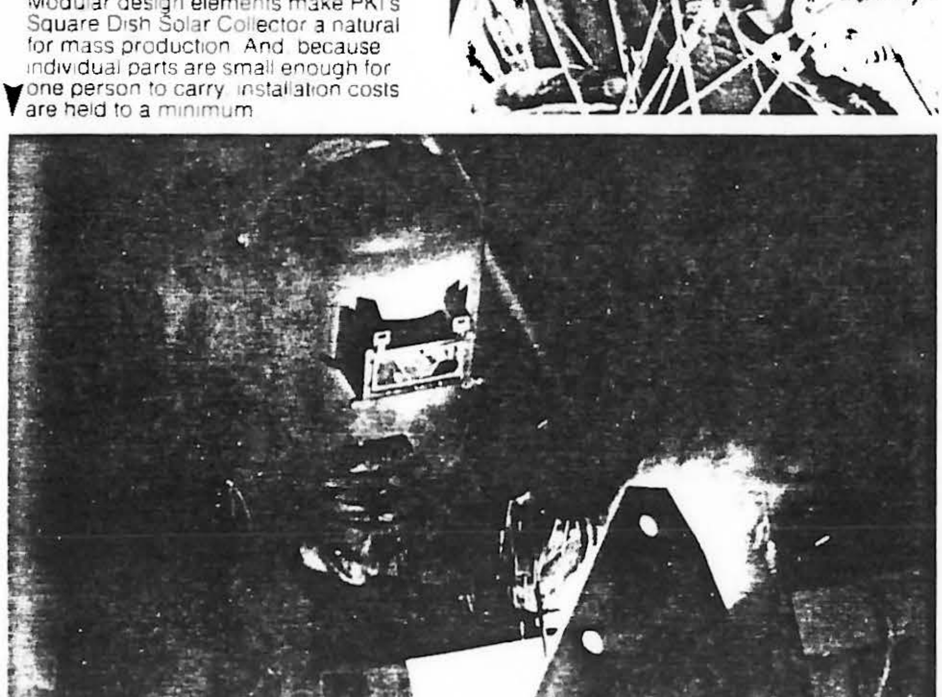


▲ The cavity receiver is a self-contained unit that relies on proven, low-cost basket-coil technology. This receiver can handle temperatures exceeding 1000 degrees F. and consists of stainless steel tubing, high temperature insulation materials and a stainless steel housing.



► The Square Dish Solar Collector has evolved through eight generations of prototypes, each of which was conceived on paper, expressed in models and developed into working systems. As a result of this testing, today's Square Dish Solar Collector has the most extensive track-record of any collector in its class.

Modular design elements make PKI's Square Dish Solar Collector a natural for mass production. And, because individual parts are small enough for one person to carry, installation costs are held to a minimum. ▼



PKI: THE COMPANY WITH A FLAIR FOR SOLAR

Power Kinetics Inc. is no ordinary high tech company. In fact, from its very beginnings PKI has had some very special assets — assets uncommon among small start-up firms.

PKI was one of the first companies to join RPI's Incubator Space Project, a program designed to foster the development of new high technology companies.

The benefits for PKI were immediate, and continue today. PKI has a direct terminal link to the university's IBM 3033 computer, access to the university's top technical and management consultants, and a virtual limitless pool of potential technical employees.

All this, added to the rich collection of technical and business talent of the company's founders, makes PKI a sure bet to maintain its position as an industry leader in renewable energy products. For PKI is more than just a highly skilled R & D firm. It is a company with a knack for turning theory into practice, and turning research discoveries into new products and product improvements.

PKI scientists and engineers have worked through seven generations of collector designs — not just on paper, but in working prototypes that demonstrate results. Design development through expression in hardware. It's the key to PKI's advances in design and technology.

If you are considering the use of solar energy, it makes sense to consider the industry's front-runner, The Square Dish Solar Collector.

This advanced energy technology is available today from Power Kinetics Inc. For more information, write to our corporate headquarters in RPI's Incubator Center, 1223 Peoples Ave., Troy, NY 12180, or call (518) 271-7743.

ABSTRACT

The Osage City, Kansas Small Community Solar Experiment proposed here will produce a nominal 100 kW from four modules. These modules feature a Barber-Nichols organic Rankine engine mounted at the focal point of a Power Kinetics, Inc. (PKI) Square Dish Solar Concentrator.

The Barber-Nichols Rankine engine proposed is a slightly altered version of the unit developed under a DOE and JPL program through Ford Aerospace. At the conclusion of this program, the engine was operated for 100 hours and the results approved by a Readiness Review Board. This same hardware will complete an additional 200 hours of operation during March 1984 and will then be placed on the test bed concentrator at SNLA. The modifications proposed are for performance improvement and to slightly increase the power handling capability to match the 133 M^2 PKI concentrator.

The PKI concentrator proposed is an expanded version of the 18 units delivered to the SOLERAS desalinization program. The concentrator will be expanded from 80 M^2 to 133 M^2. Due to the modular design of the concentrator, this expansion does not involve structural changes in the basic concentrator. The added area is simply attached to the sides and top. This concentrator concept is well tested and has many thousands of hours of field operation including a unit installed at the Capital Concrete Company in Topeka, Kansas. Midwest Research Institute will be testing a unit identical to the SOLERAS units in Arizona during the early summer of 1984.

Barber-Nichols, as prime contractor, has an extensive background in project management. This was demonstrated in the recent past when Barber-Nichols designed, fabricated and operated for DOE a 500 kW geothermal plant at the East Mesa Test Facilities in California. This was a complex project lasting over several years. Barber-Nichols has well defined management techniques that are described in Section 7 of this proposal.

Barber-Nichols intends to operate a program that is cost conscious, technically sound and results oriented. We have the personnel, tools and desire to make this happen.

1.0 INTRODUCTION AND SUMMARY

Barber-Nichols Engineering Company of Arvada, Colorado proposes to provide a 100 kW solar-electric power generation system at Osage City, Kansas. This system utilizes the proven technology of the organic Rankine cycle engine (ORC) coupled with the demonstrated design of the Power Kinetics, Inc. square dish solar collector. This proposed program is technically fully responsive to the requirements of The Statement of Work of the Proposal Opportunity Notice, DE-PN04-84AL25034. The program described on the following pages is one of low cost and low technical risk. Additionally, the proposed module has the potential of commercial success due to its inherent technical superiority and low manufacturing costs.

The program specified in the PON is intended to aid the solar industry by providing a demonstration unit in Small Community Solar Thermal Power. This demonstration will provide a significant step towards commercialization of the solar-electric module. This will be the first time a point focus concentrator, focal point mounted engine field of more than one module will have been constructed. Therefore, it will provide the solar industry with the opportunity to evaluate the construction costs of this technology and the reliability and maintainability of these machines.

The program has three main goals: 1) to demonstrate the operation and performance of a module at the Sandia test site, 2) to construct the 100 kW plant and place it in service, and 3) to operate the system successfully for a period of one year. These goals can be achieved with a short schedule and at a reasonable cost due to the advanced status of the proposed hardware. Achieving the technical program goals will be ensured by complete system integration, module optimization and diligent management. The management function will include vigilant attention paid to schedule and budget.

Barber-Nichols brings to this effort an extensive background in project management along with technical expertise. This was recently demonstrated when Barber-Nichols was the prime contractor on a 0.5 mW geothermal plant built for DOE at the East Mesa test facility in California. This 4 million dollar contract was awarded to Barber-Nichols by DOE in 1978. In addition to this contract, Barber-Nichols has had numerous contracts with the government and private companies in addition to many subcontracts, most of substantial dollar magnitude. Past technical experience in solar that relates to the current proposed program would, of course, be highlighted by the recently terminated program with Ford Aerospace and Communications Corporation. This Ford program had the same goals as the currently proposed effort. Barber-Nichols, as a subcontractor, was responsible for the engine development which had been completed at the time the program stopped. The hardware from this program will be under test at the Sandia DRTF site during the period that these proposals are being considered. Other programs of related nature include a similar but small (ground-mounted) engine for a private company. That project included a solar receiver which was subsequently designed by Barber-Nichols and has operated successfully on the sun for substantially longer than 100 hours.

The major subcontractor, Power Kinetics, Inc. of Troy, New York, also brings unparalleled background experience. The PKI square dish concentrator is now in its 9th generation. The unit proposed here is an expanded version of the model recently produced in quantity (19 concentrators) for the SOLERAS desalinization plant in Saudia Arabia. As a part of this program, one of these concentrators will be under test by the Midwest Research Institute, Kansas City, Missouri at a site in Arizona during the early part of 1984. More importantly, PKI has an earlier version of the proposed concentrator at a site not far from the site of the SCSE. This unit is located at the Capital Concrete Company in Topeka, Kansas. This concentrator has been in operation since 1982. This fortunate circumstance provides invaluable information in terms of environmental factors such as wind, hail and lightning. This particular concentrator has some features that make it uniquely suited to power generation. One of the main features is the method of obtaining elevation tracking. The mirror elements tilt rather than the entire dish. Therefore, the engine attitude is relatively constant, varying only due to the azimuth drive changes. This allows significantly more freedom in the engine design. Additionally, the shadowing created by the engine on the dish is less severe due to a one-foot-wide blank slot on the center of the dish and due to the large area involved. In fact, the physical arrangement is such that an azimuth platform-mounted engine (behind the mirrors) would be a relatively simple change for future units, thereby leaving only the receiver at the focal point.

The combination of the Barber-Nichols organic Rankine engine and the PKI square dish concentrator makes it possible to have a four-module plant. This is possible as the concentrator size can easily be increased to support a 25 kWe engine. The four-module plant will have a higher reliability than a plant with more modules simply because of fewer parts. Since scheduled maintenance can be carried out in no sun conditions, the larger module will produce more power per year due to its higher availability than a field of more, small modules.

The organic Rankine engine has an inherent advantage over the Brayton engine and the Stirling engine for this alternative energy application. On a strict thermodynamic basis, the Stirling cycle has the highest potential efficiency, the Rankine cycle is close behind, with the Brayton cycle showing the lowest efficiency. This, of course, assumes that each is operating with the same source temperature and the same sink temperature. On this theoretical basis, the expanders, heat exchangers, pump/compressors and other components are assumed ideal (100% efficient). The issue can become less clear when various schemes such as regeneration, extraction, etc. is included. But, in general, the above ranking is true from this theoretical standpoint. However, when one considers the practical limitations placed on actual hardware, the Rankine cycle is second to none. The three main reasons for this is its range of temperature operation, its component efficiencies and its many years of experience. The first reason, range of temperature operation, results in great reliability. The organic Rankine engine, unlike its sister, the steam Rankine engine, is limited in temperature to the thermal decomposition of the organic which begins to take place above 800°F. Therefore, a reasonable and prudent operating temperature is 750°F. This is a very comfortable temperature for many common materials. Therefore, without going to exotic, costly materials or being concerned about high temperature creep, thermal cycle fatigue, etc., the Rankine engine can be built to last the 25 years of the plant. An additional disadvantage of high temperature operation with a solar system is the greatly decreased concentrator efficiency (alternatively more accurate and expensive) and greatly reduced receiver efficiency. "For lower receiver temperatures such as the steam Rankine application, the optimum cavity sizing is not strongly affected by optical properties."[1] On the other hand, if one did wish to make a higher temperature Rankine engine in order to increase its efficiency, there are a number of working fluids (steam, mercury, sodium, etc.) that have been used in the past. However, the higher temperatures do have the disadvantages listed above and will not be used here. The second reason, component efficiency, results in good performance at the given conditions (percent of Carnot). The Rankine engine, as envisioned here, uses turbines, centrifugal pumps, etc. that are non-rubbing, high efficiency components. The only rubbing, wearing components are small bearings, unlike the large surfaces in a piston engine. The turbine and pump can be optimized for good performance in the engine design. The third reason, experience, results in reliability and maintainability. One only needs to recall that the Watt engine was, in fact, a Rankine engine to realize that there is many years and billions of hours of operating experience with Rankine cycle engines. These are virtually all steam cycles, to be sure, but the technology is essentially 100% translatable to the organic systems. The organic systems also have a lengthy history with the main emphasis taking place since the early 1970's with the EPA clean car program. All in all, the organic Rankine engine is reasonably efficient, very reliable and has long MTBO.

[1] L. Wen, JPL, "Effect of Optical Surface Properties on High-Temperature Solar Thermal Energy Conversion," AIAA, Journal of Energy, Vol. 3, No. 2, March 1979, P. 82.

Barber-Nichols and PKI bring to this program good technology that has a significant head start along the path to program success. The proposed four-module plant will be reliable and will have a low technical risk, low cost, short program.

POWER KINETICS, INC.

Corporate Overview

@ March 31, 1984

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COMMITMENT OF POWER KINETICS TO ADVANCE RENEWABLE ENERGIES

The incorporators began development of non-polluting, renewable energy technologies during 1974 just after the first oil embargo. Since then, many approaches to power delivery systems have been pursued including:

1. Point focusing solar collectors;
2. Wind turbines;
3. Fuel alcohol stills;
4. Photovoltaic electrical power generation.

The thrust of these efforts has been to develop systems which:

1. Are conceptually and operationally simple,
2. Use readily available materials with readily implemented production processes,
3. Utilize designs which use a minimum amount of materials and weather well for more than 25 years,
4. Implement controls and drives which run for years without attention, and are easily serviced,
5. Can be installed quickly and can be adapted to many different applications without extensive redesign.

Ten years of development and product installation have allowed the Company's Square Dish point focusing technology to develop into the commercial equipment purchased first by Jet Propulsion Laboratories in their Point Focusing Industrial Process Heat Experiment and then by the firm, Chicago Bridge and Iron, to provide heat for their Solar Desalination Project in Saudi Arabia. The low cost of the Company's equipment, its high efficiencies, and the Company's ability to respond rapidly through installation, has translated into the success of the product to date.

The U.S. Geological Survey (Open-File Report 83-728 1983) indicates that at present usage of petroleum, the world has only 36 years left of proven oil reserves and that the U.S. has only about 19 years worth of its own reserves. It is only a matter of time before a substantial market develops for oil substitutes. Coal, the most likely substitute, has significant environmental impacts especially those connected to acid rain, while nuclear power has its own share of environmental as well as economic risks. There is no question that solar equipment will become an increasingly important commodity before the end of this decade. Power Kinetics, has a demonstrated ability to develop cost-effective commercial hardware which has no equal in performance.

DESIGN ORIENTATION OF THE SQUARE DISH

In the design of its Square Dish product the Company, located in the relatively harsh and cloudy Northeast, took on the design challanges of high technology solar thermal, with the poor economics, amplified by the northern climate. Generally, adding complexity to an engineering design increases the cost of the resulting product. Without complexity, though solar energy cannot address many of the needs of the developing markets for energy alternatives. Careful control of the direction of design sophistication by the Company helped produce significant engineering gains without cost increases. Engineering development was intensly focused on the need for methods meeting the short term. This was accomplished through:

1. MASS PRODUCED PARTS: Components of the Square Dish either use off-the-shelf items or are designed to be produced in quantity using readily available manufacturing machinery.

2. QUICKLY ASSEMBLED COMPONENTS: Most of the parts in the Dish are light and can be handled by one person. Special machniery is not necessary for collector installation.

3. SIMPLE INTERCHANGEABLE ASSEMBLIES: all components of the Square Dish are relatively small and can be replaced if defective or damaged.

4. DISTRIBUTED LOADS: Spreading wind loads and the weight of the collector over many members and joints has eliminated the necessity for exotic metals and heavy, expensive assemblies.

5. FACETED MIRRORS: Mounting many small mirror tiles on a supporting curved surface has avoided the need for expensive curved or thick-glassed mirrors. Reflecting surfaces are standard mirror tiles treated for outdoor use.

6. AUTOMATIC OPERATION: A sophisticated micro-circuitry design in the product eliminates the need for expensive redesign for each application of use. As markets are identified clearly, the micro-circuitry will be packaged to allow simple installation. Automatic operation currently turns mirrors upside down when the sun is not out, to prevent dirt, ice or snow from accumulating on the reflective surface. When it rains, the mirrors are turned to the angle most appropriate for washing.

7. MIRROR POSITIONING: Extending the movement of the mirrored facets to a face-down position, allows the mirrors to be protected from the damaging effects of snow, hail, and sand. It also allows storm winds to blow through the structure by feathering, thus eliminating the need for a stronger support structure.

POSITION OF THE POINT FOCUSING TECHNOLOGY TODAY

In the solar thermal energy field there are two key considerations governing practical utilization of solar heat, quality of energy (i.e. temperature level) produced, and cost per unit of energy. In addition, load requirements can play a role in technology selection. Flat plate collectors only see application in low temperature regimes (less than 200 degrees F.) Because of the large receiving (and heat loss) surface area, flat plate collectors suffer from greater heat loss and are much less efficient than concentrating collectors. Moreover performance is affected significantly by ambient temperatures. Concentrating collectors are required for medium temperature (up to 500 degrees F) process heat applications, although flat plate evacuated tube collectors can be used at the low end of this regime. The PKI collector has operated to date primarily in this regime and has demonstrated a capability to compete well with troughs on a cost per Btu basis.

In the solar thermal area, PKI is competing primarily against troughs and other dishes. For cogeneration of electricity using an efficient steam turbine, the Company competes only with dishes, since troughs do not produce the temperatures needed to drive such equipment cost effectively. Industry predictions indicate comparable long term installed capital costs of approximately $25/square foot, when and if mass production is reached.

The Square Dish can be installed for $32 per square foot today which translates to $1.32 per installed peak watt of cogenerated energy in a sunny location. This compares well with Frost and Sullivans 1983 review of the worldwide solar electric generation market which indicates a $9.66 per peak watt price today for the $156 million market. An engineering analysis by the Company which incorporates a steam turbine with the Square Dish achieves a $3.63 per peak electrical watt. Without considering the large quantities of thermal energy byproduct.

The PKI collector has a substantial advantage in system performance. Predicted performance for troughs is in the 40% to 60% range for system thermal efficiency.

POWER KINETICS, INC.
SUMMARY OF PAST CONTRACTS
WHICH DEVELOPED USE OF RENEWABLE ENERGY

	SOURCE OF FUNDS	R&D AMOUNT	YEAR
* FIRST GENERATION DESIGN	RPI	$10,000	1974
SECOND GENERATION DESIGN	NYS ERDA	$16,000	1975
THIRD GENERATION DESIGN	NYS ERDA	$20,000	1976
FOCUSING COLLECTOR DEVELOPMENT PROJECT	NYS ERDA	$70,000	1977
FOURTH GENERATION DESIGN	NYS ERDA	$10,000	1978
FIFTH GENERATION DESIGN	US DOE	$244,000	1978
DEMONSTRATION PROJECT ON SOLAR HEATING, COOLING AND INVESTIGATION OF ELECTRICAL POWER GENERATION (USING FIFTH GENERATION DESIGN)	NYS ERDA	$100,000	1979
* THERMAL SYSTEM ENGINEERING EXPERIMENT SUPPORT (USING SIXTH GENERATION)	J.P.L.	$467,000	1981
* INTEGRATION AND TESTING OF A COGENERATING CONCENTRATING SOLAR COLLECTOR WITH ADVANCED ALCOHOL DISTILLATION EQUIPMENT	US DOE	$134,000	1982
DEMONSTRATION OF A SOLAR CONCENTRATION COLLECTOR COGERERATING SYSTEM	NYS ERDA	$25,000	1982
* VAWT WIND PROJECT	US DOE	$34,000	1982
HILL AIR FORCE BASE DEMONSTRATION (USING SEVENTH GENERATION)	USAF	$36,000	1982
REDESIGN AND REBUILD RPI'S 5TH GENERATION COLLECTOR	RPI	$5,000	1982
* SOLERAS WATER DESALINATION PROJECT (USING EIGHTH GENERATION)	CBI	$1,827,077	1983
TEST OF EIGHTH GENERATION DESIGN AT DSET LABS	MRI	$79,000	1984
TOTAL		$3,077,077	

LEGEND:

*	= WON THROUGH COMPETITIVE BID
RPI	= RENSSELAER POLYTECHNIC INSTITUTE
NYS ERDA	= NEW YORK STATE ENERGY RESEARCH & DEVELOPMENT AUTHORITY
USDOE	= UNITED STATES DEPARTMENT OF ENERGY
J.P.L.	= JET PROPULSION LABORATORIES
USAF	= UNITED STATES AIR FORCE
CBI	= CHICAGO BRIDGE & IRON
MRI	= MIDWEST RESEARCH INSTITUTE

BIOGRAPHICAL INFORMATION ON KEY MANAGEMENT

1. WILLIAM E. ROGERS, Chairman of the Board of Power Kinetics, Inc. is the chief design engineer of the firm. He is responsible for all the major aspects of mechanical design and development of PKI technologies.

Rogers is the inventor and developer of the PKI Square Dish Point-focusing Solar Collector. During the past eight years he has designed, developed and built eight generations of a Fresnel-concept, faceted-mirror, point-focusing, solar collector. He has been a Research Associate at Rensselaer Polytechnic Institute for the past six years.

Prior to founding PKI, Rogers held a number of research and development positions. He was the principal investigator for a project entitled, "Ethanol Production: An Integrated and Cyclic System Utilizing Solar and Adjunct Thermal Sources." In addition, he was the project manager for research on "Direct and Remote Coupling of Wind Turbines to Heat Pumps and other Mechanical Devices," a U.S. DOE Appropriate Technology Grant. He has also conducted research on amelioration of spills of hazardous materials on water for U.S. Coast Guard.

Rogers holds a master's degree from Rensselaer Polytechnic Institute, where he has also completed the coursework for his doctoral degree in Mechanical Engineering. He is widely published on the subject of faceted solar collectors. Foreign joint ventures. There, he served as purchasing manager.

2. DR. DAVID N. BORTON, is PKI's chief consultant for controls, sensors and system testing.

As a Research Associate at Rensselaer Polytechnic Institute, Dr. Borton assisted in the design and construction of four generations of the solar collectors leading to the PKI Square Dish Collector. Dr. Borton's special emphasis is on instrumentation, system performance testing and optimization, computer ray-trace, structural and thermal analysis, microprocessor control and data acquisition.

As a postdoctoral associate, he worked on two research contracts for the U.S. Coast Guard.

Dr. Borton holds a Ph.D. in Solid State Physics from RPI, where he also earned his master's degree. His undergraduate work was completed at Colgate University.

He has published on a number of subjects including threshold energy for atomic displacements in lead and indium; agents, methods and devices for amelioration of discharges of hazardous chemicals on water; and point-focusing solar collectors.

3. ROBERT J. ROGERS, Vice President Finance, is responsible for all accounting, marketing, and personnel functions at PKI.

His broad experience includes employment as an accountant, staff auditor, fiscal manager, and mechanical engineer. At Rensselaer County Board of Cooperative Educational Services (BOCES), Rogers designed accounting systems for the annual purchase of $10 million in goods and services, managed an annual $2.5 million investment portfolio, implemented accrual accounting techniques, and monitored the accounting operations for the organization.

At Price Waterhouse & Co. of New Jersey, he performed audit functions on clients in the drug, newspaper, instructional, flavors and fragrances, food, and manufacturing industries.

At Project Equinox, Inc., Rogers managed all activities related to budgeting and controling a half million dollars per year. At Rensselaer Polytechnic Institute, Rogers promoted the marketable design features of predecessors of PKI's Square Dish Collector.

Rogers holds an M.B.A. from the State University of New York at Albany, with concentrations in Marketing and Finance. He also holds a bachelor of science degree in Accounting from Rider College, in Trenton, N.J.

THE RPI INCUBATOR PROGRAM

PKI was one of the first companies to join Rensselaer Polytechnic Institutes (RPI) Incubator program. This program is designed to foster new high technology companies located near the campus which can participate in RPI's new Technology Center, which is modeled along the lines of that of the Stanford Research Institute's. The primary objective of the incubator program is to forge a new partnership among high technology industry, government and universities within New York State. The immediate benefit for PKI is a close cooperation with the various kinds of support from RPI, and a link through RPI with area industries and governmental agencies. PKI has a direct terminal hook-up to RPI's IBM 3081D computer.

Throughout the period of development of the PKI collector, RPI faculty have been involved on a consulting basis in such areas as concentrator spaceframe design, heat transfer analysis of receivers, and structural certification. Over 150 undergraduate and graduate students have participated in projects supervised by PKI personnel in their roles as RPI faculty members or have worked directly through production contracts. This group offers an immediate pool of potential employees, familiar with the Company and its product, from which PKI can draw in short and long term situations as the company grows. Finally, PKI has benefited from extensive consultation with RPI's administration and management school concerning business development, and is of ten mentioned by the press in articles concerning the incubator program.

BARBER-NICHOLS

ENGINEERING

PROPOSAL

BY

BARBER-NICHOLS ENGR. CO.

with

POWER KINETICS, INC.

FEB. 29, 1984

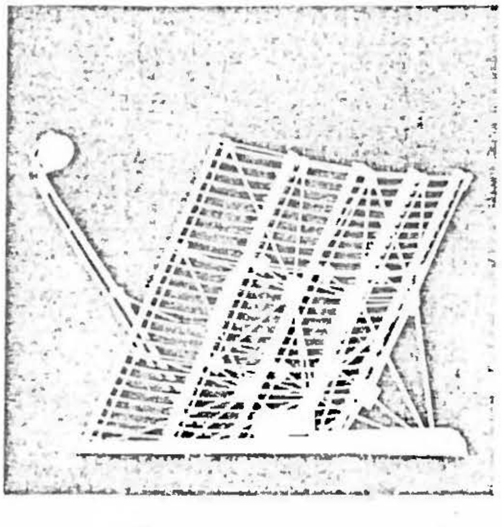
6325 West 55th Avenue, Arvada, Colorado 80002 Telephone 303-421-8111

Attachment 4

POWER KINETICS, INC.

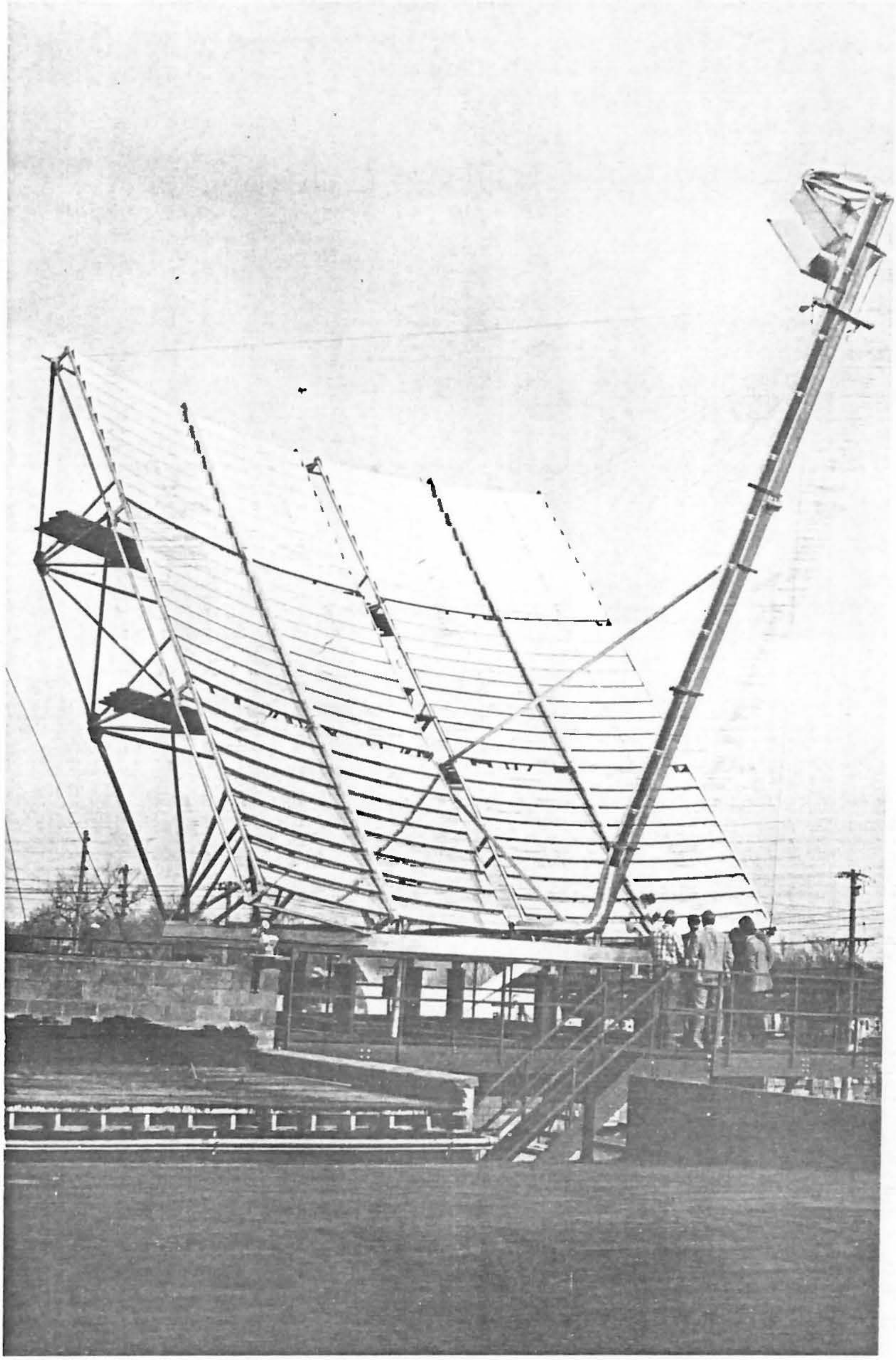
PROPOSAL TO DEPLOY

SOLAR GENERATED ELECTRICITY CAPACITY

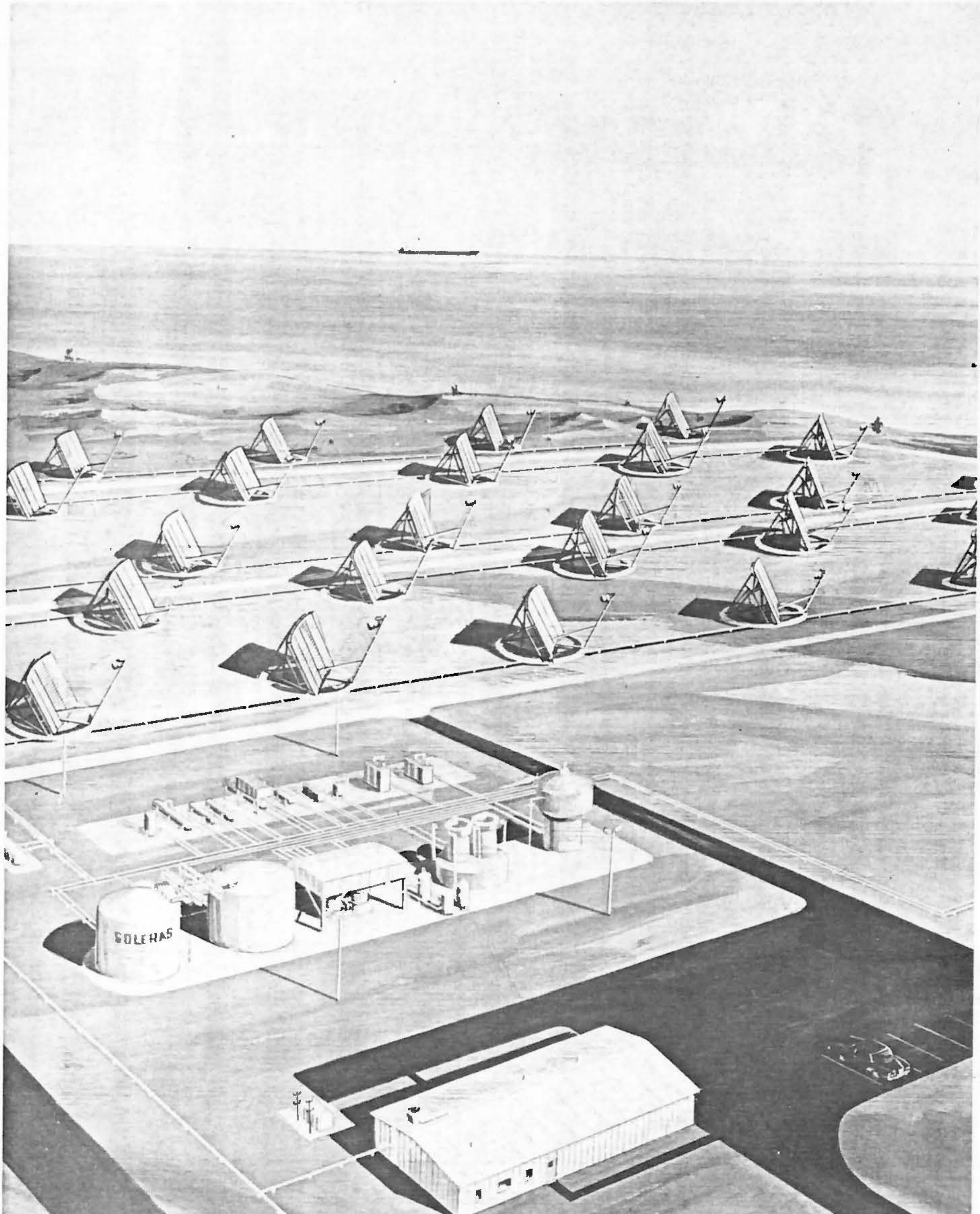


P O W E R   K I N E T I C S ,   I N C.

1223 Peoples Ave., Troy, NY 12180, (518) 271-7743



PKI 80 M_2 Square Dish Solar Collector



Proposed Soleras Water Desalination Plant using PKI Square Dish Solar Collectors

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A. Introduction

Power Kinetics has spent ten years perfecting a point focusing collector design which uses many traditional technologies including off-the-shelf materials and standard fabrication techniques. Because the engine technologies which the point focusing concept was originally meant to power will not be available for many years, the Company has located two alternatives to these engines.

The overall potential of these two alternatives may far exceed that of the engines, since high performance engines may require ten to twenty years of use to work out problems related to the high demands put on them. Already more than $300 million has gone into development of the two highest performance concepts, the Stirling and Air Brayton designs.

The alternative which Power Kinetics would propose for China long term is a thermo chemical energy transport system which eliminates costs related to heat losses for a large solar collector field. If old gas or oil wells are available which at one time contained hydrogen, these wells can serve as storage to allow 24 hours of electrical generation using only solar energy. The technologies needed to operate such a system with storage are generally well known today so only the application specific details need to be worked out. Although this process has promise for remote areas with desert sunshine and available spent gas or oil wells, working out problems related to applications may take two or three years. Therefore, in the short term we would propose a system which has operating experience already. That system would use our concentrator, storage, and organic Rankin cycle engines.

B. Conceptual Design

For an electrical solar power plant less than one megawatt, a binary engine offers several advantages. With systems larger than one megawatt a water based technology begins to offer technological economies of scale. In most cases however, risk economics drive the designs and make it more appropriate to construct modular 1/3 megawatt systems with ground mounted engines, rather than larger and larger systems with a central turbine.

For a one megawatt plant we would propose using two or three ground mounted organic Rankin cycle engines with separate solar collector field systems so that each could operate independently of the other. Organic based engines are fairly rugged and have sufficient operating experience for the purpose. Optimizing the solar field for the small engine simplifies piping requirements, since the larger piping and resulting insulation would only be required near the "hub" of the piping "spokes". Piping and insulation are a penalty of the point focusing, as well as parabolic trough designs. Using the previously mentioned chemical process would avoid these penalties, since energy could be transported at ambient temperatures.

We would propose our point focusing concentrator which has been the only design to participate in government commercialization based experiments since 1981. This demonstrates the potential for our Square Dish design to meet the short term cost requirements for this technology as well as the perceived advantage of our association with Rensselaer Polytechnic Institute, a top American engineering school.

The advantages of our solar concentrator are outlined in the accompanying material. We will be participating with Barber Nichols Engineering in the Small Community Solar Experiment in Osage City, Kansas, a Department of Energy program to test a receiver mounted, light weight organic engine to produce electrical energy for a small community. Barber Nichols recommends a ground mounted engine instead of their light weight receiver mounted engine for larger plants. The project would use the same syltherm fluid loop as we use in a Saudi Arabian desalination plant for freeze protection. We would most likely designate a firm like Chicago Bridge & Iron as the prime contractor in a large project to use their expertise in the overall project management and design.

An overview of possible system costs for a 1 MW plant and a 10 MW plant using a thermo chemical process are enclosed. The analysis of the thermo chemical process includes costs of back up systems, while only reflecting the value derived from solar energy. More work would be required to isolate the solar costs from the general system, which is designed to run 24 hours. The availability of gas well storage may eliminate substantial costs including the cost of providing fossil fuels on a continuing basis. To provide new storage through drilling would add $1 per watt to the system cost, but would incur the risks of not obtaining adequate results with each drilling. Storage in containers is not possible although storage in pipe lines may be.

C. Technical Capabilities

A summary of our past contracts is enclosed. The current work which furthers our technology is an effort with Barber Nichols to provide ~100 kw to Osage City in Kansas (Summary enclosed). This work will take place over the next two years. Our company is currently negotiating to participate in enhanced oil recovery where three solar concentrators per well inject the steam needed to cook the remaining oil for later extraction.

Our goal technically in this work is to drive economics of oil recovery by combining electrical production with steam injection. The consistency of the availability of gas at these injected wells can guarantee 15 years of steady 24 hour per day production of electricity, which in this country generates more revenues as capacity credits are given for the consistency offered.

The commitment of the company to the proposed technologies is outlined in the attached Corporate Overview. The company's relationship to a top American engineering school is also attached, as well as some other background information on the company.

D. Management Capabilities

Since the inception of the solar collector design in 1974, the company has developed both the technology and its management to allow the rapid deployment of its product in response to year end tax deadlines or other constraints. The ability to fabricate the equipment in standard light metal shops allows the company to respond to large orders or to produce its product nearer to the site or in foreign countries.

For large projects, Power Kinetics will defer construction management and engineering to qualified firms. We have worked Chicago Bridge & Iron in Saudi Arabia and have communicated with several large firms over the years to monitor their interest and capabilities.

E. Potential for Sublicensing

Power Kinetics has oriented its design for small company deployment and for production near the site of installation. In response to the Saudi Arabian project, the company subcontracted 2/3 of its work to local light metal fabrication shops and vendors. Power Kinetics retained the production of high tolerance items and the microprocess or controls and sensors. The company would consider the establishment of a joint venture in China which would produce the majority of the heavy components in the concentrator. Power Kinetics would maintain control of the quality of its product through this joint venture or other subcontracting arrangement.

Attachment 5

PRELIMINARY DRAFT AGREEMENT

It is the intention of ANU, ERF, and PKI to reach a co-operative agreement in accordance with the following principles:

(A) ANU and ERF shall give to PKI sole commercial rights to thermochemical energy transfer patents and know-how for 10 years for all countries except Australia.

(B) In return PKI shall:

(1) pay to ANU and ERF a sum upon initiation of the agreement;

(2) agree to pay ANU and ERF royalties as and when they may fall due; and

(3) shall obtain within two (2) years of initiation of the agreement, funds sufficient for ANU to complete its thermochemical research program (as detailed in documentation already provided by ANU).

By: [signature] 26/May/1985
Prof. Stephen Kaneff
Head, Dept. of Engineering Physics
Research School of Physics
& President Energy Research Foundation

By: [signature] 26/MAY/85
Dr. Peter Carden
Head, Energy Conversion Group
Dept. of Engineering Physics
& Secretary Energy Research Foundation

Australian National University
GPO 4
Canberra City ACT 2601
AUSTRALIA

By: [signature] 5/26/85
Robert J. Rogers
President
Power Kinetics, Inc.
1223 Peoples Ave.
Troy, New York
U.S.A

and to effect separation of liquid ammonia without refrigeration. The pressure required for synthesis is up to 300atm. This pressure is however within the "thin wall" range for pressure vessels and the few required are of straightforward design having ambient temperature walls. Vessels suitable for 10MWe synthesisers have been developed for the ammonia synthesis industry.

The need for a high pressure is compensated for in a number of ways. High pressure leads to small components and high heat transfer coefficients. It enables the use of a gas turbine for extraction of work directly from the synthesis gas stream. This has significant beneficial consequences in improved efficiency and reduced cost resulting from the elimination of a steam loop and greater operational simplicity. A further benefit is that the energy transport pipelines may be operated at very close to the economically optimum level about 110atm: any higher and the walls become predominantly thick and expensive and also pumping losses tend to become significant; any lower and costs associated with the large diameter dominate.

Finally, looking well ahead there is the real prospect of incorporating economical seasonal storage into a network of ammonia based solar power plants. This would be achieved by using aquifers, underground storage reservoirs enclosed above by a water saturated dense cap rock and below by mobile ground water contained in porous rock or sand. These often contain natural gas which demonstrates their capability of being absolutely leak tight. This is true even with hydrogen. The mixture to be stored viz nitrogen and hydrogen is environmentally compatible with such storage. (Ammonia is easily stored in large refrigerated tanks at ambient pressure). The pressure of these reservoirs is determined by depth typically 1.1Km for the required 110atm. Costs are related to the power rating of the encased drill hole typically 10MWe. Thus seasonal storage might be provided for about $1 per electrical watt.

Configurations of the ammonia system

For systems generating power by means of a directly coupled gas turbine two configurations have been considered. They are the isobaric system operating at the single nominal pressure of 300atm and the dual pressure system operating at 300atm for the synthesiser and 110atm for the dissociators. The latter has the advantages that the lower pressure is more favourable for economic transport of the reactants and for the process of dissociation. Against this a feed stock compressor is required to overcome the pressure step. In practice this is not a separate item but manifests itself as a roughly 15% increase in the size of the compressor that is normally part of a closed loop gas turbine system. Ammonia liquid is released between the stages of compression and is available at a range of intermediate pressures.

Work may be recovered from this in the run down to the 110atm level but it is not sufficient to compensate for the compression of feed stock. The thermodynamic source of compensation for the net energy deficit is a decrease in the heat of reaction for dissociation at the lower pressure and, taking into account the mechanical efficiencies involved, this might be expected to be about 85% effective. Thus there are trade-offs to be assessed before the dual pressure

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system can be finally adopted. Nevertheless it is currently favoured.

Energy balance

Using available data (a large part of which was provided by this research group) it is possible to draw up an energy balance and reactant flow diagram in fig. 3 for a full scale module of about $10MW_e$. Depending on the configuration work recovery efficiencies of 32% with respect to received thermal energy appear practicable.

Costs

In 1979 Davy Pacific, a Davy International company, was commissioned to report on the feasibility of the solar ammonia process. They reported that it was possible to design a workable system for 10MWe. The cost would be \$29.2 million including auxiliary oil fired boilers and gas turbines for overnight power generation. The operating cost would be 15 cents per kW. (These figures were in \$Australian). At that time the direct coupled gas turbine concept had not been developed so their study was based on the employment of a steam loop. The costs included \$12.5M for the collectors and site preparation as well as a 20% contingency allowance. Using this report as a basis, and omitting the overnight facility, we estimate the cost of the gas turbine concept as 88% of the above and the net power output 63% greater.

In the long term one would expect further improvements as research data and operating experience are gained. For example it would pay if the cost of the turbine were increased by 50% in order to gain an additional 5% of mechanical efficiency. Turbine designers used to conventional power generation have yet to be confronted with this option. Again the sizes of reaction vessels are directly related to catalyst reactivity which in turn is very sensitive to temperature. Trade-offs between catalyst type and cost, catalyst life, temperature and reactivity need careful consideration once the relevant data becomes available most probably from research.

Answers to criticisms

Ammonia has poor heat of reaction.

Compared with other candidate reactions this is true on a molar basis. But what counts is energy density and this quantity is dependent on system pressure as well as heat of reaction. The pressure for the ammonia reaction adequately compensates for the low heat of reaction without being excessively high.

Ammonia synthesis is a high pressure reaction and is therefore "difficult".

To an industrial chemist interested in the easiest method for making a particular chemical the pressure necessary for the synthesis of ammonia must understandably appear to be a nuisance. But to an energy engineer interested in the cost-effective transportation of reactants over a pipeline, the optimum sizing of components, improved heat transfer and the matching of the reaction to a prime mover, the system pressure for ammonia should be seen as a desirable attribute. Operation of the pipeline at near optimum pressure is possible and the gas turbine will have an unusually high power/weight ratio.

Leakage is serious.

Leakage at the rate of 3% of the loop flow would render the system unworkable because the energy needed to manufacture the leaked reactants would about equal the energy output of the system. However the tolerance limit of 0.1% is readily obtainable according to the Davy report and is achieved regularly in current ammonia synthesis plant.

Experience of the ammonia synthesis industry is that there is a net energy input. Hence the exothermic end of the loop can't work in practice.

This observation comes from taking a very superficial view of the synthesis process. Energy goes into the commercial synthesis process in three main forms: the hydrogen for the feed stock comes from natural gas or naptha; the feedstock needs to be compressed from its formation pressure to the synthesis pressure; often refrigeration is employed to extract ammonia. The combined effect of these energies greatly exceeds the exothermic heat. However for thermochemical energy transport none of these three processes occurs apart from what is needed to prime the system initially. Therefore the above criticism is without rational foundation.

There will be an environmental problem if ammonia leaks out.

For the very good reason stated above the system would have to close down if leakage were above 0.1%. But if massive leakage did occur the danger to humanity and the environment would be no greater than currently exists in the vicinity of ammonia manufacturing, storage and shipping facilities. This is minimised by the fact that ammonia vapour is lighter than air and quickly ascends out of harms way. In high concentrations ammonia is dangerous to humans because of its caustic nature but at low concentrations it is thought sometimes to be beneficial (e.g. smelling salts). Ammonia leakage does no permanent damage to the environment because that part which reaches the upper atmosphere is dissociated by ultra violet radiation and the remainder returns to earth as a trace component of rain water. Plants use both naturally occurring and man-made ammonia as a vehicle for nitrogen fixation and consequently ammonia can be said to be the source of all protein both in plants and animals. It can therefore hardly be called a hazzard to the environment.

Catalysts are unavailable for the duty required.

The most commonly used synthesis catalyst, and the cheapest, is iron (with certain important additives). The recommended maximum operating temperature for this is 810K. Hence a suitable catalyst for the gas turbine concept exists. There is no known reason why this should not

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be adaptible to dissociation but data on space velocity in this application is unavailable. An estimate of the amount of catalyst required for dissociation can be made using the reaction rate equations developed to explain catalytic synthesis. Using this approach it appears that 10 to 20 cc/KWth is possible at 810K. These quantities are compatible with the large point-focusing collectors currently being contemplated. Other catalysts such as nickel may permit higher operating temperatures and may therefore be more effective. One of the important outcomes of operating the demonstration plant would be the acquisition of performance data for a range of catalyst candidates.

Corrosion is a problem.

Corrosion is only a problem where ammonia mixes with water as might occur around a leak. Even then there is no serious problem except with alloys containing copper. These must be avoided in the construction of the plant. Otherwise steel is the most satisfactory material the type being chosen to suit the temperature and strength required.

Additional heat is required to boil the ammonia before dissociation can occur and latent heat is lost during synthesis.

It is true that a low grade heat component "goes along for the ride" in the ammonia process. But in the gas turbine version this component contributes to the total work output and is neither an embarrassment nor a waste. As compensation the cost of the collectors may be reduced by lowering their precision: the distribution of angular error may be such that only 70% of the surface reflects to a cavity focus the remainder reflecting to an area surrounding the cavity entrance that operates at around 100C.

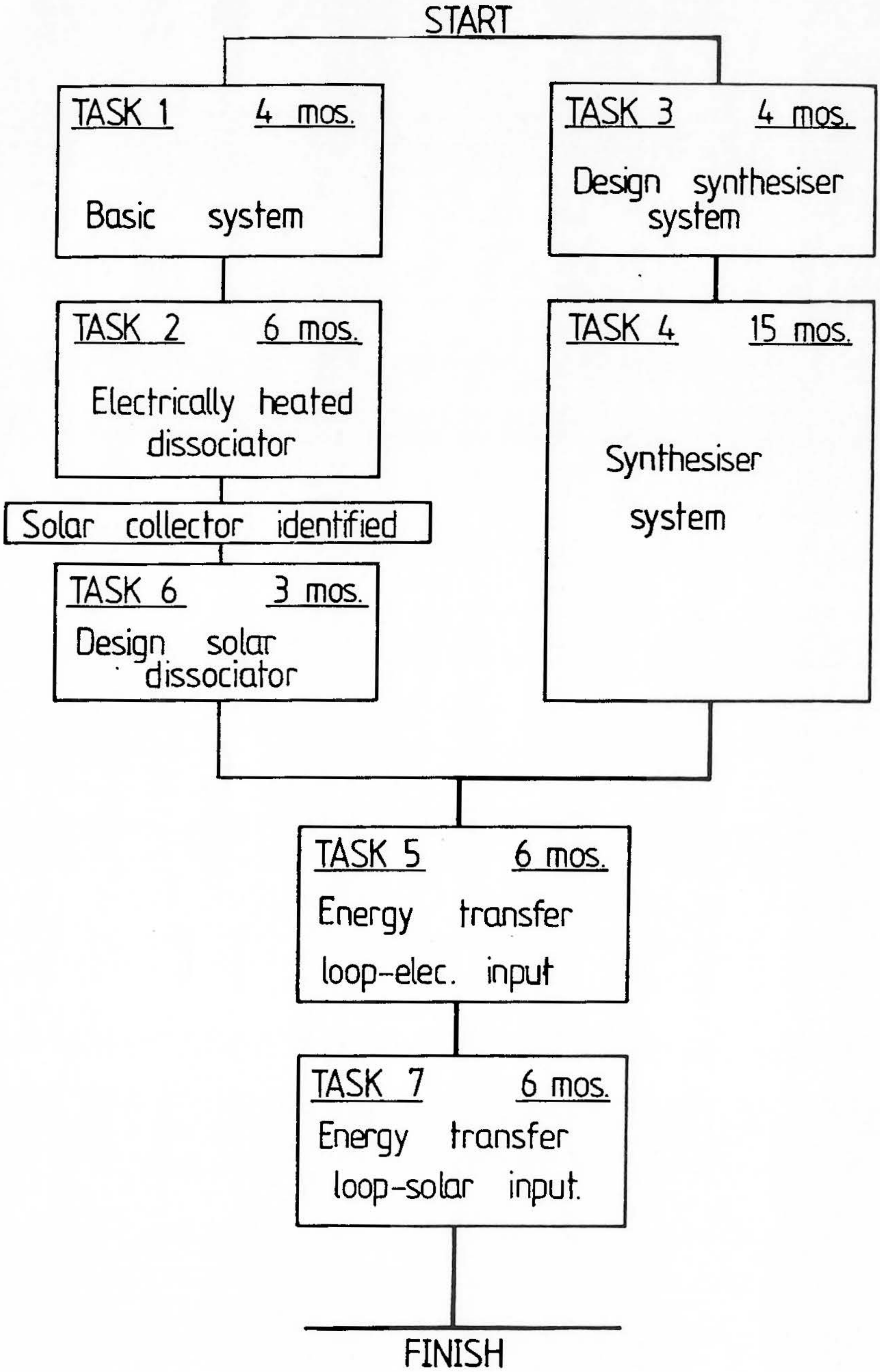
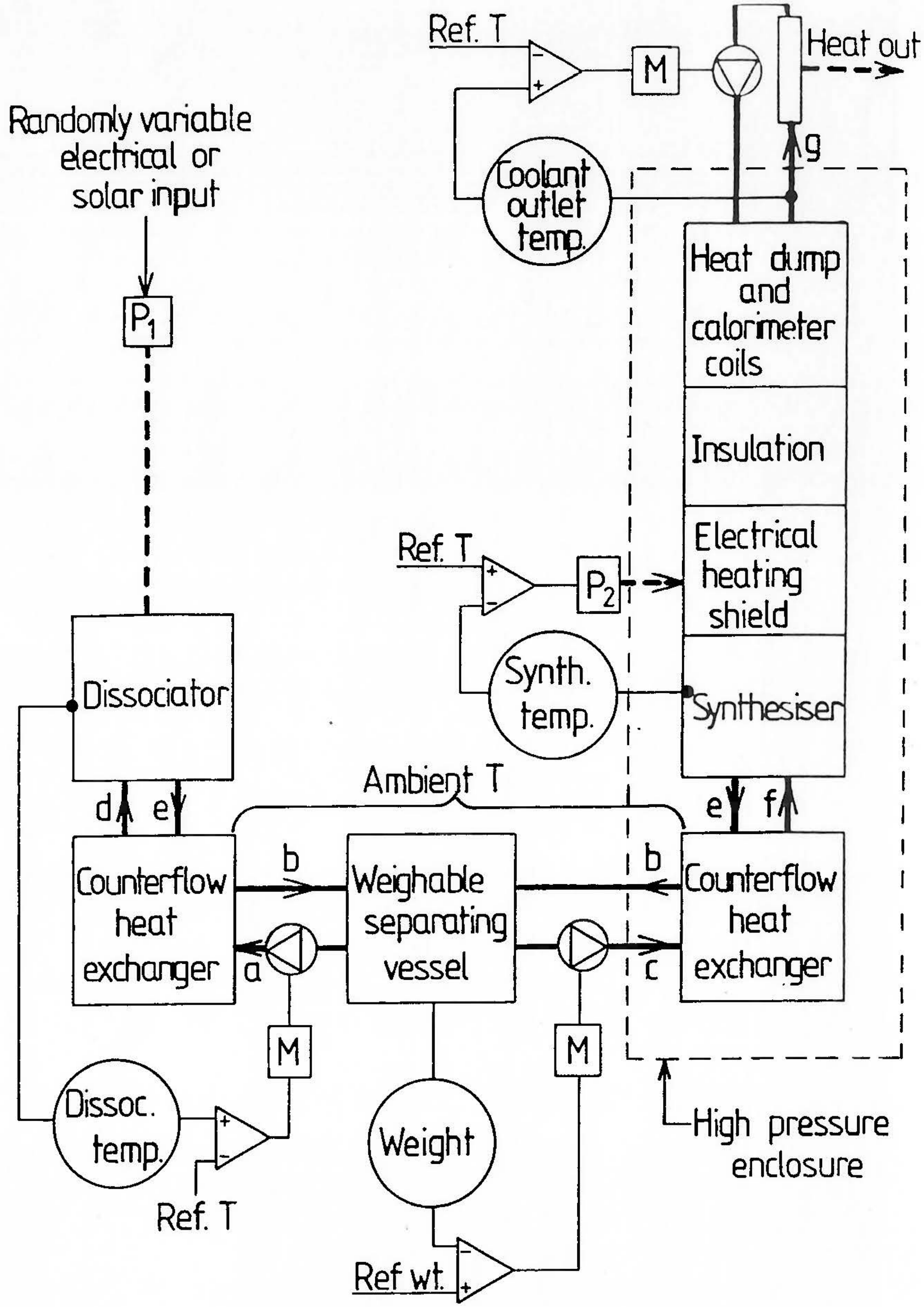


Fig. 1 WORK PROGRAM
(Critical path in heavy outline)



a Ammonia liquid – ambient temp.
b Ammonia+H_2+N_2 – ambient temp.
c H_2+N_2 mix – ambient temp.
d Hot ammonia gas
e Hot ammonia+H_2+N_2 gas mix
f Hot H_2+N_2 mix
g Circulating water: amb. t. IN, ~90C OUT
M Controllable motor
P Controllable power source

Fig. 2 BLOCK DIAG. OF PLANT

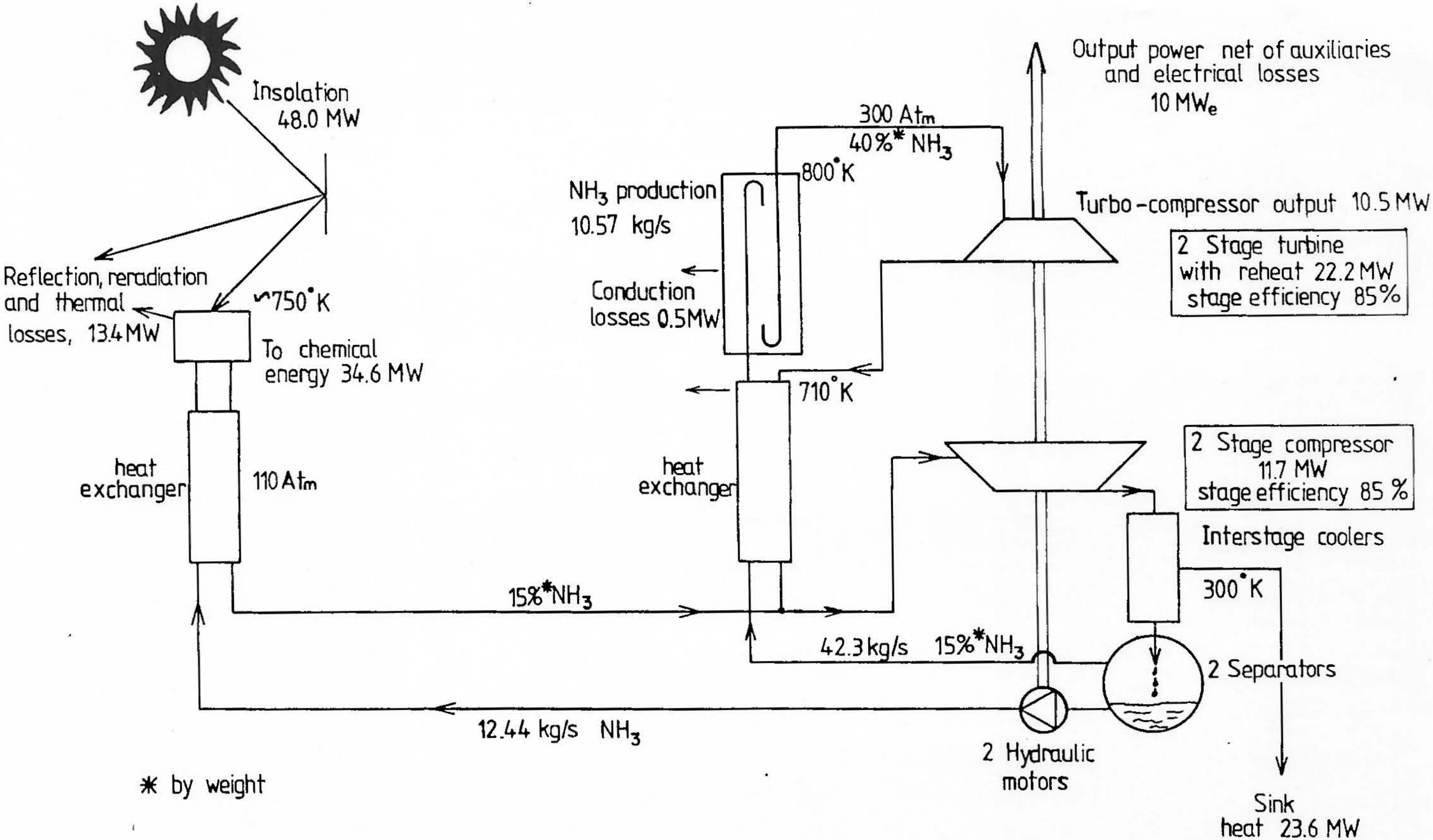


Fig. 3 REACTANT FLOWS AND ENERGY BALANCE

Attachment 6

Department of Engineering Physics

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Research School of Physical Sciences
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23rd July, 1984.

Dr. William R. Rogers,
Chairman of the Board,
Power Kinetics, Inc.,
1223 Peoples Avenue,
Troy New York U.S.A. 12180

Dear Bill,

Enclosed please find information on the Thermochemical Project we discussed recently in San Diego and by telephone on 11 July. If this is not adequate to your immediate needs, we would be pleased to provide more, as required.

As I mentioned by telephone, we hold patents on the Thermochemical Process in several countries, including U.S.A. This could be attractive to investors because of the protection possible through licensing (which should present no problems).

We ask you to accept the information enclosed on the basis of strict confidentiality, particularly in relation to the turbine operation.

Finally, we discussed the desirability of sending Dr. Peter Carden (who initiated and has worked through the ammonia system) and Mr. Robert Whelan (our head technical officer) to meet with you (and others of interest) face to face for a proper definition of what might be achieved in the joint project. For this purpose we understand it would be possible for you to arrange support for the visit (we find the costs would be around $US 6000 all up).

We look forward to your response.

With best wishes,

Yours sincerely,

(S. Kaneff)
Professor & Head of Department.

PROPOSAL FOR THERMOCHEMICAL DEMONSTRATION PLANT

P.O. Carden R.E. Whelan

Department of Engineering Physics,
Research School of Physical Sciences,
Australian National University.

20 July, 1984.

Identification of project

The project is to build an experimental plant that demonstrates thermochemical energy transfer based on the dissociation and synthesis of ammonia. The ammonia system is unique in that it is free from side reactions and is not hampered by undue corrosion problems or the need for excessive temperatures. It is based on well established industrial practice (both for synthesis and dissociation) from which considerable knowledge and technology can be drawn. It is a high pressure system, a characteristic that is often seen as a disadvantage but in fact considerable advantages lie in the resulting small component sizes, exceptionally high energy density and improved heat transfer coefficients. Optimum pressure for systems containing gas, such as the ammonia system, has been shown to be about 100 atm on the basis of minimising pipeline transmission costs. The system operating pressure for ammonia is close to this optimum, more so than for other currently proposed systems. Because it is a two-phase system a high degree of flexibility is inherent i.e. neither dissociation nor synthesis needs to proceed to completion since separation of the unreacted components is simple.

Each reversible chemical reaction possesses a characteristic effective Carnot source temperature which dictates the minimum efficient operating temperature. The ammonia system possesses one of the lowest effective temperatures (330C) which allows relatively low practical values of dissociation temperature (700C with current catalysts). On the other hand it possesses the unique chracteristic of spontaneously rejecting a fraction of its exothermic output as near-ambient heat and this enables the thermodynamic transformation of the remaining heat to well above the effective source temperature (again 700C is a typical achievable value). This has an important bearing on the production of mechanical work which for the ammonia system may be achieved by passing the synthesis gas directly through a gas turbine. Apart from the simplicity and efficiency of this scheme it naturally gives rise to two levels of pressure: 300atm and 110atm, a situation which may be exploited to enable the dissociators and pipeline to operate at the more suitable lower pressure whilst still allowing the synthesiser to operate at the higher pressure. The prospects for producing a simple yet economically viable system have therefore been considerably enhanced by the introduction of this concept.

The ammonia system is therefore well worth attention in its own right and is particuarly well suited for research and development into thermochemical energy transfer.

Advantages of building demonstration at A.N.U.

The key staff members have been working on aspects of the ammonia thermochemical system intermittently since 1974. This effort has been performed against a sound background of original theoretical work especially in thermodynamics and full scale (order of 10MW) system analysis. Funding from University and Government grants has been quite substantial and staffing levels have been at about five. Many major difficulties have been overcome including the explosion of an ammonia shipping container connected to the plant. Experimental work aimed at verifying the theoretical basis of thermochemical energy transfer began with high pressure dissociation and has extended to building all the major components required for an energy transport loop. A great deal of work has been done in designing and building a synthesiser. This has undergone preliminary testing with the result that certain inadequacies have now become apparent. Having done this foundation work we are now poised ready to go on to the next logical step: the completion of a loop. Over several years there has evolved a well equipped laboratory containing amongst other things components for producing high pressure nitrogen in quantity, evacuation and flushing systems, a facility for storing liquid ammonia and for pumping it to 300atm, a disposal facility in which ammonia is removed by washing the waste gas, an all-purpose reticulation system comprising high quality valves, filters, pressure reliefs and 6mm steel tubing, pressure vessels for the storage and separation of reactants, nitrogen backed accumulators, flow meters, pressure transducers, thermocouples, a computer-based data gathering and processing facility and a weighable pressure vessel for the absolute determination of synthesis, dissociation, flow rates and nitrogen/hydrogen ratio. Many of the components and instruments have been designed and built in-house because commercial suppliers were unobtainable.

Known Problems

These relate to the unique requirements of a small scale demonstration plant and do not in any way reflect on the practicability of a full scale system for which appropriately sized components developed for the ammonia industry are available.

Development of a low flow (1cc per sec) circulating pump suitable for high pressure (300atm) liquid ammonia capable of steady delivery and with tolerable seal leakage.

Design and procurement of a 300atm pressure vessel (internal dimensions approximately 300mm diameter, 1m long) capable of housing the synthesiser, synthesis heat exchanger, heat extraction tubes, thermal insulation and tubes for cooling the vessel walls (also used for calorimetry).

Procurement or development of pressure regulators (including back pressure regulators) and flow regulators suitable for low flows of liquid ammonia and synthesis gas.

Development or procurement of technology for making high temperature (600°C), hydrogen-tight joints with small bore tubing (3mm), preferably demountable.

Procurement and training of suitable staff.

Definition of Tasks

1. Produce an operational basic system comprising a high pressure loop, a source of high pressure liquid ammonia and a source of regulated high pressure nitrogen. The loop comprises a reservoir, weighable vessel, liquid circulating pump with flow regulator, liquid and gas flow monitors as well as all appropriate connecting tubing and valves. The source of high pressure

ammonia comprises a low pressure (10atm) storage tank and a pump. The source of nitrogen comprises a liquid nitrogen pump and heater together with pressure measuring and regulating equipment.

The loop is to be operated partly full of liquid so that gas may be circulated by displacement. This task will be complete when a steady circulation of liquid and gas is demonstrated whose absolute values may be determined by weighing.

2. Produce an operational electrically heated dissociator system coupled to the basic system described in (1) above. The dissociator system is to comprise a catalyst tube, heater, counterflow heat exchanger and appropriate temperature instrumentation. The task will be complete when acceptable levels of dissociation have been demonstrated and good data obtained on the working characteristics of the dissociator.

3. Design synthesiser system comprising the pressure vessel subsystem, heat dump subsystem and instrumentation. The pressure vessel subsystem comprises a catalyst container, heat exchanging tubing, counterflow heat exchanger, thermal insulation and instrumentation all housed in a cold wall pressure vessel. The heat dump subsystem comprises a water circulating pump and cooler. The task includes the development of a model for determining the optimum layout and estimated performance of the pressure vessel subsystem. It also includes the procurement of firm quotations for the major components.

4. Produce an operational synthesiser system which converts to ammonia a proportion of the feedstock generated by the dissociator system. This task will be complete when the synthesiser system is operating at an acceptable level and when consistent measurements have been obtained on its working characteristics.

5. Produce an operational energy transfer loop by coupling the dissociator and synthesiser systems together and by integrating their control and instrumentation. The task will be complete when automatic energy transfer is demonstrated for steady and varying heat inputs, and when reliable data has been obtained on the performance of the loop over a range of conditions.

6. Produce a design for a solar heated dissociator system based on data obtained to this point. This task will include a model study and the procurement of firm quotations for major components.

7. Produce an operational energy transfer loop using solar energy. The task will be complete when the loop is operating satisfactorily and good performance data has been obtained.

Present status

With regard to the current proposal, existing facilities put us in the position where Task (1) is complete except for flow and pressure regulation. (Pump seal leakage is also still a problem). Completion of Task (2) depends on refurbishing an existing dissociator and its temperature instrumentation. With regard to the remaining tasks we have considerable experience in relevant design and technology gained in the course of performing design studies, and in building and testing a range

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of components including a low pressure (120atm) synthesiser rated at about 0.5KW.

Resources required

P.O. Carden will be project leader and R.E. Whelan manager. The fast track approach to the management of this project is favoured. This could be implemented by commencing task (3) and the remainder of (1) immediately. Since the performance of the dissociator is presently unknown this method requires a particularly flexible approach to the design of the synthesiser. Two streams would progress in parallel one stream comprising tasks (1) and (2) and the other tasks (3) and (4). The testing phase of (4) would be the point of confluence of the two streams. Similarly task (6) could commence after the completion of (2) and in parallel with (5). Thus to implement this approach design and experimental assistance is required: for design, a mature design draftsman and for experimentation and building, two technical officers together with appropriate support from the Research School of Physical Sciences' workshop. Special assistance is also required with regard to the known problems listed and others as they might arise. It is envisaged that this assistance will be obtained from specialist manufacturers on a contractural basis where ever possible.

The times for each task, estimated on a "no major problems" basis and assuming the above human resources, are

task 1	4	months (includes 1 month for staff training and "clean up"
2	6	
3	4	
4	15	
5	6	
6	3	
7	6	

Total project time is estimated as follows:

task 1	4 months	task 3	4 months
2	6	4	15
		critical path time 19 months	
task 5	6		
7	6		
		critical path time 12 months	
		Total project time 31 months	

Salaries and overheads:

Procurement of full time management: $1000 per month:	$31,000
Design draftsman $30,000 p.a. for 13 months:	$33,000
2 Technical officers $20,000 p.a. each for 31 months:	$104,000
	$168,000

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Materials and equipment:

Current estimate	$80,000

External contracts:

Current estimate:	$150,000
Total estimated project cost in current $Australian	$398,000

Procedure:

(1) Firm up proposal in accordance with requirements of both parties.

(2) Both parties to enter into a contractural commitment for the entire project with provision for review at key points. Reporting to be on a task or time basis. Adoption of fast track implies that the project will be managed on the assumption that it will be successful i.e. tasks need not be carried out in strict sequence if the efficient use of resources dictates otherwise. On the other hand frequent reviews will be implemented to ensure that the work plan remains viable.

(3) The work will be carried out with an emphasis on understanding the underlying mechanisms, obtaining reliable measurements and correlation with known or developed theory.

Description of demonstration plant

The power level is set at approximately 1kW this being at about the optimum level determined by trade offs between scale proportional costs and the costs associated with small flows e.g. provision of accurate measuring instruments and the reduction of leakage. The synthesiser proves to be the most difficult component to design and the most costly. In practice it is necessary to bring the catalyst up to operating temperature before synthesis can commence. Thus an electrical heater located in the synthesiser system is almost mandatory and this is also required for initially reducing the oxide catalyst with hydrogen. Given that there has to be an electrical heater, its presence is exploited in the following way.

One of the important problems is the disposal of the high grade heat (500C) in the absence of an engine or other appropriate load and in a manner that will allow both a high degree of variability in synthesiser output as well as independent control of the synthesiser temperature. One method is to thoroughly insulate the synthesiser and take off the exothermic heat via a secondary fluid to an external heat dump. We have tried this approach. It led to a disproportionately large amount of thermal insulation; hence the choice of a hot wall pressure vessel; hence mechanical and thermal stress problems, difficulties with hot lead-throughs and with the selection of a suitable high temperature secondary fluid.

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The alternative approach is to deliberately reduce the amount of insulation so turning it into the escape path for the exothermic heat and at the same time degrading it to a manageable temperature. In this scheme the electrical heater is turned into a heat shield by which the synthesiser temperature may be controlled. Thus the sum of the exothermic heat and the electrical heat tend to remain constant and demonstration of energy transfer amounts to showing that the sum of the two electrical power inputs (pl and p2 in the diagram) is constant though each may vary widely.

We emphasise that the seemingly contrived nature of the scheme is only a consequence of the small scale of the demonstration and the unavailability of a suitable load. In no way does it reflect upon the practicability of a large scale system. The cold wall pressure enclosure simulates what is practical on a large scale and the apparent disproportionate amount of thermal insulation required to prevent undue loss is only a consequence of the volume-to-surface ratio which strongly disfavours miniturization.

Although the scheme lacks a certain realism it is on the other hand quite practical from the experimental and cost point of view. It allows the use of a reasonably sized cold wall pressure vessel enclosing all the associated high pressure components so converting them effectively into low pressure components with considerable benefits in cost reduction and in design flexibility.

It is intended that the exothermic output will be controlled primarily by means of the flow of feed stock (nitrogen and hydrogen). Increasing the flow should increase the heat output though not proportionately. Similarly the rate of heat absorption is to be controlled by the flow of ammonia to the dissociator. This in turn will be automatically varied so as to maintain a constant dissociator temperature through variations in heat input to the dissociator. The two processes of dissociation and synthesis will be kept in step by linking them to a common vessel kept partly full of liquid ammonia at a constant level. The level will be maintained by varying the flow of feedstock in response to changes in level thereby causing the manufacture of ammonia to match the rate at which it is dissociated.

Level changes in the common separator will be detected by weighing. The apparatus for doing this exists and was developed mainly for enabling the absolute determination of rates of dissociation and synthesis, calibration of flow meters and measurement of nitrogen hydrogen ratio (by weighing a pressurised gas sample).

POTENTIAL FOR MARKETABLE SYSTEM

Applications

The ammonia thermochemical system is particularly applicable to distributed point focusing solar energy systems of minimum size about 10MWe. There is no known inherent upper limit to system size. The concept relates essentially to heat transport from many receivers to a single heat recovery centre. The single striking feature that has caught the attention of engineers and entrepreneurs is that high temperature heat is effectively transported at ambient temperature and in fluids of high energy density.

Consequently the cost of transporting heat has been dramatically reduced, thermal losses have been eliminated and the prospect of lossless thermal storage has been introduced. The ammonia system is particularly well suited to power generation by gas turbine operating directly in the reactant gas stream. The output may also be configured for process heat up to 800C or cogeneration of heat and power.

Alternative systems

The two most prominent competitors of the ammonia reversible reaction are the SO2-SO3 reaction and the family of hydrocarbon reactions typical of which is the steam-methane system. Of these ammonia has the lowest heat of formation but as compensation it has the highest energy density. It has the lowest effective Carnot temperature but the least problem with high temperature materials and the least stringent requirements for mirror precision. The ammonia system is one of the least prone to corrosion. The hydrocarbon reactions invariably have difficulties with side reactions i.e. complete reversibility does not occur. The ammonia reaction has no such problem.

The steam-methane reaction which has been developed in West Germany for the extraction of heat from a nuclear power plant for distribution to numerous surrounding factories requiring process heat is not particularly suited to solar energy where the reverse configuration is required: numerous heat sources and a single load. This is because for most reactions one end of the transport loop is more complex than the other and for practical reasons the complex end aught to be the one with the single connection.

The distribution pipes for the SO2-SO3 system must be operated at and insulated for 100C otherwise they will become blocked with a thick viscous sludge of SO3. Moreover the pipes must be fitted with trace heaters to enable start-up.

No such problem exists with the ammonia system. In fact the two phase nature of this system is exploited to great advantage giving it certain unique features which greatly add to its practicability. At ambient temperature the two sides of the reaction are represented by a liquid: ammonia, and a gas: a mixture of nitrogen and hydrogen, which spontaneously separate from one another. This means that neither the endothermic nor exothermic reaction need proceed to completion or to any predetermined extent. This unique feature provides a useful degree of flexibility: the control of reactant flow to each receiver may be decoupled from the reaction extent or quality of the exiting fluid; when each receiver is deliberately oversupplied automatic temperature regulation occurs by virtue of the fact that the temperature will always assume that value which endows the catalyst with a reactivity commensurate with absorbing the heat input. The high density of liquid ammonia allows the economical provision of a buffer storage facility that permits decoupling of the exothermic end from the endothermic ends for short periods.

The ammonia system is also unique in that it is a high pressure system: high pressure is required to favourably influence the equilibrium constant for synthesis, to increase the concentrations at the catalyst surfaces

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Attachment 7

Power Kinetics, Inc.

SOLAR PRODUCT DESIGN • R & D • AUTOMATION

1223 PEOPLES AVE. TROY, NEW YORK 12180 (518) 271-7743

December 17, 1984

Australian National University
ATTN: Prof. Stephen Kaneff
Head, Dept. Engineering, Physics,
Research School of Physics
GPO Box 4
Canberra, ACT 2601
AUSTRALIA

Dear Stephen:

After one more round with Earl Rush and his boss Jim Leonard of Sandia, we have arrived at a final position to propose to them. They indicated that the work would probably be bid formally but the bid announcement would be written according to their best information, which may be the unsolicited proposal we are sending them.

We tried to stay as close to your proposal as we could but made some modifications. Although we included the positions you requested, we may have to keep one of the positions you proposed open for the ammonia producer. This means that if they can get involved financially early on, they may want to fit into the research in some way. Also, we tried to shorten the process of closing the two loops since Earl seems to think that the two loop technologies are ready to hook up today. I proposed that Power Kinetics with the ammonia producer take on the dissociator responsibility while tying into the work you have completed in this area to date. Otherwise, everything else stays pretty much the same.

I need you and your collegues to look at our proposal carefully and recommend changes soon so that when we bid formally we can incorporate needed changes. The material costs listed I pulled out of thin air, so I will expect some adjustments here. I also tried to interpret your proposed figures and may have missed important features. Where you proposed $150,000 in outside contracts, I directed these costs to the ammonia producer. I listed your figures as American dollars and hope you will correct these numbers if appropriate.

Again, let me know as soon as possible where we stand, in terms of the enclosed proposal and our legal agreement.

Sincerely,

POWER KINETICS, INC.

Robert J. Rogers

Robert J. Rogers
Vice President Finance

FOR YOUR INFORMATION

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INTRODUCTION

Power Kinetics, collaborating with the Department of Engineering Physics, Research School of Physical Sciences, Australian National University (ANU), namely P.O. Carden and R.E. Whelan, and with anticipated support of a major ammonia producer, proposes to build an experimental plant that demonstrates thermochemical energy transfer based on the dissociation and synthesis of ammonia. The ammonia system is unique in that it is free from side reactions and is not hampered by undue corrosion problems or the need for excessive temperatures. It is based on well established industrial practice (both for synthesis and dissociation) from which considerable knowledge and technology can be drawn. It is a high pressure system, a characteristic that is often seen as a disadvantage, but in fact considerable advantages lie in the resulting small component sizes, exceptionally high energy density, and improved heat transfer coefficients. Optimum pressure for systems containing gas, such as the ammonia system, has been shown to be about 100atm on the basis of minimizing pipeline transmission costs. The system operating pressure for ammonia is close to this optimum, more so than for other currently proposed systems. Because it is a two-phase system a high degree of flexibility is inherent i.e. neither dissociation nor synthesis needs to proceed to completion, since separation of the unreacted components is simple.

POC → for

Each reversible chemical reaction possesses a characteristic effective Carnot source temperature which dictates the minimum efficient operating temperature. The ammonia system possesses one of the lowest effective temperatures (330°C) which allows relatively low practical values of dissociation temperature (700°C with current catalysts). On the other hand it possesses the unique characteristic of spontaneously rejecting a fraction of its exothermic output as near-ambient heat and this enables the thermodynamic transformation of the remaining heat to well above the effective source temperature (again 700°C is typical achievable value). This has an important bearing on the production of mechanical work which for the ammonia system may be achieved, by passing the synthesis gas directly through a gas turbine. Apart from the simplicity and efficiency of this scheme it naturally gives rise to two levels of pressure: 300atm and 110atm, a situation which may be exploited to enable the dissociators and pipeline to operate at the more suitable lower pressures. The prospects for producing a simple yet economically viable system have therefore been considerably enhanced by the introduction of this concept.

The ammonia system is therefore well worth attention in its own right and is particularly well suited for research and development into thermochecmial energy transfer.

APPLICATIONS

The ammonia thermochemical system is particularly applicable to distributed point focusing solar energy systems of minimum size of about 10 MWe. There is no known inherent upper limit to system size. The concept relates essentially to heat transport from many receivers to a single heat recovery center. The single striking feature that has caught the attention of engineers and entrepreneurs is that high temperature heat is effectively transported at ambient temperatures and in fluids of high energy density. Consequently the cost of transporting heat has been dramatically reduced, thermal losses have been eliminated, and the prospect of lossless thermal storage has been introduced. The ammonia system is particularly well suited to power generation by gas turbine operating directly in the reactant gas stream. The output may also be configured for process heat up to 800°C or cogeneration of heat and power.

ALTERNATIVE SYSTEMS

The two most prominent competitors of the ammonia reversible reaction are the SO_2-SO_3 reaction, and the family of hydrocarbon reactions typical of which is the steam-methane system. Of these, ammonia has the lowest heat of formation but as compensation it has the highest energy density. It has the lowest effective Carnot temperature, but the least problem with high temperature materials and the least stringent requirements for mirror precision. The ammonia system is one of the least prone to corrosion. The hydrocarbon reactions invariably have difficulties with side reactions, i.e. complete reversibility does not occur. The ammonia reaction has no such problem.

The steam-methane reaction which has been developed in West Germany for the extraction of heat from a nuclear power plant for distribution to numerous surrounding factories requiring process heat, is not particularly suited to solar energy where the reverse configuration is required: numerous heat sources and a single load. This is because for most reactions one end of the transport loop is more complex than the other, and for practical reasons the complex end should be the one with the single connection.

The distribution pipes for the SO_2-SO_3 system must be operated at and insulated for 100°C, otherwise they will become blocked with a thick viscous sludge of SO_3. Moreover, the pipes must be fitted with trace heaters to enable start-up.

No such problem exists with the ammonia system. In fact, the two-phase nature of this system is exploited to great advantage gving it certain unique features which greatly add to its practicability. At ambient temperature the two sides of the reaction are represented by a liquid--ammonia, and a gas--a mixture of nitrogen and hydrogen, which spontaneously separate from one another. This means that neither the endothermic nor exothermic reaction need proceed to completion or to any predetermined extent. This unique feature provides a useful degree of flexibility: the control of reactant flow to each receiver may be decoupled from the reaction extent or quality of the exiting fluid; when each receiver is deliberately oversupplied automatic temperature regulation occurs by virtue of the fact that the temperature will always assume that value which endows the catalyst, with a reactivity commensurate with absorbing the heat input. The high density of liquid ammonia allows the economical provision of a buffer storage facility that permits decoupling of the exothermic end from the endothermic ends for short periods.

The ammonia system is also unique in that it is a high pressure system: high pressure is required to favorably influence the equilibrium constant for synthesis, to increase the concentrations at the catalyst surfaces, and to effect separation of liquid ammonia without refrigeration. The pressure required for synthesis is up to 300atm. This pressure is however within the "thin wall" range for presure vessels and the few required are of straightforward design having ambient temperature walls. Vessels suitable for 10MWe synthesizers have been developed for the ammonia synthesis industry.

The need for a high pressure is compensated for in a number of ways. High pressure leads to small components and high heat transfer coefficients. It enables the use of a gas turbine for extraction of work directly from the synthesis gas stream. This has significant beneficial consequences in improved efficiency and reduced cost resulting from the elimination of a steam loop and greater operational simplicity. A further benefit is that the energy transport pipelines may be operated at very close to the economically optimum level (about 110atm): any higher and the walls become thick and expensive and also pumping losses tend to become significant; any lower and costs associated with the large diameter dominate.

Finally looking well ahead there is the real prospect of incorporating economical seasonal storage into a network of ammonia based solar power plants. This would be achieved by using aquifers, underground storage reservoirs enclosed above by a water saturated cap rock, and below by mobile ground water contained in porous rock or sand. These often contain natural gas which demonstrates their capability of being absolutely leak tight. This is true even with hydrogen. The mixutre to be stored i.e. nitrogen and hydrogen is environmentally compatible with such storage. (Ammonia is easily stored in large refrigerated tanks at ambient pressure). The pressure of these reservoirs is determined by depth, typically 1.1Km for the required 110atm. Costs are related to the power rating of the encased drill hole typically 10 MWe. Thus seasonal storage might be provided for about $1/electrical watt.

KNOWN PROBLEMS

The major problems relate to the unique requirements of a small scale demonstration plant and do not in any way reflect on the practicability of a full scale system for which appropriately sized components developed for the ammonia industry are available.

- Development of a low flow (1cc/sec) circulating pump suitable for high pressure (300atm) liquid ammonia capable of steady delivery and with tolerable seal leakage.
- Design and procurement of a 300atm pressure vessel (internal dimensions approximately 300mm dia, 1m long) capable of housing the synthesizer, synthesis heat exchanger, heat extraction tubes, thermal insulation and tubes for cooling the vessel walls (also used for calorimetry).
- Procurement or development of pressure regulators (including back pressure regulators) and flow regulators suitable for low flows of liquid ammonia and synthesis gas.
- Development or procurement of technology for making high temperture (600°C), hydrogen-tight joints with small bore tubing (3mm), preferably demountable.
- Procurement and training of suitable staff.

Although these problems may require additional design time, each item is expected to be produced or procured within the time scheduled for the task in which they will be used.

The major chemical problem may be that the proposed research deals with the catalysts under high pressure. Dissociation catalysts are widely used under low pressure conditions, final information on space velocities over dissociation catalysts at 20-30 Mpa pressure is not available. It is essential, therefore, to note carefully during research the behavior of catalysts to provide a reliable basis for design of the focal absorber coils in the solar collectors.

DEFINITION OF PHASE I TASKS

1. Produce an operational basic system including a high pressure loop, a source of high pressure liquid ammonia and a source of regulated high pressure nitrogen. The loop comprises a reservoir, weighable vessel, liquid circulating pump with flow regulator, liquid and gas flow monitors, as well as appropriate connecting tubing and valves. The source for high pressure ammonia requires a low pressure (10atm) storage tank and pump. Providing a

source of nitrogen requires a liquid nitrogen pump and heater together with pressure measuring and regulating equipment.

The loop is to be operated partly full of liquid so that gas may be circulated by displacement. This task will be complete when a steady circulation of liquid and gas is demonstrated whose absolute values may be determined by weighing.

2. Produce an operational electrically heated dissociator system coupled to the basic system described in #1 above. The dissociator system is to comprise a catalyst tube, heater, counterflow heat exchanger and appropriate temperature instrumentation. The task will be complete when acceptable levels of dissociation have been demonstrated and good data obtained on the working chartacteristics of the dissociator.

3. Design synthesizer system comprising the pressure vessel subsystem, heat dump subsystem and instrumentation. The pressure vessel subsystem comprises a catalyst container, heat exchanging tubing, counterflow heat exchanger, thermal insulation and instrumentation all housed in a cold wall pressure vessel. The heat dump subsystem comprises a water circulating pump and cooler. The task includes the development of a model for determining the optimum layout and estimated performance of the pressure vessel subsystem. It also includes the procurement of firm quotations for the major components.

4. Produce an operational synthesizer system which converts to ammonia a proportion of the feedstock generated by the dissociator system. This task will be complete when the synthesizer system is operating at an acceptable level and when consistent measurements have been obtained on its working characteristics.

5. Produce an operational energy transfer loop by coupling the dissociator and synthesizer systems together and by integrating their control and instrumentation. The task will be complete when automatic energy transfer is demonstrated for steady and varying heat inputs, and when reliable data has been obtained on the performance of the loop over a range of conditions.

6. Produce a design for a solar heated dissociator system based on data obtained to this point. This tasks will include a model study and the procurement of firm quotations for major components.

PHASE II

7. Produce an operational energy transfer loop using solar energy. The task will be complete when the loop is operating satisfactorily and good performance data has been obtained.

PHASE III

8. Construct prototype plant of a magnitude sufficient to predict performance of a commercial plant.

CURRENT STATUS OF THE TECHNOLOGY

Existing facilities in Australia put this work in the position where Task 1 is complete except for flow and pressure regulation. (Pump seal leakage is also still a problem). Completion of Task 2 depends on refurbishing an existing dissociator and its temperature instrumentation in Australia and transferring this technology and that from Sandia to Power Kinetics to modify the existing technology for developments brought about by the rest of this program. With regard to the remaining tasks, the team has considerable experience in relevant design and technology gained in the course of performing design studies, and in building and testing a range of components including a low pressure (120atm) synthesizer rated at about 0.5KW.

DESCRIPTION OF DEMONSTRATION PLANT

The power level is set at approximately 1 kW, this being at about the optimum level determined by trade-offs between scale proportional costs and the costs associated with small flows; e.g. provision of accurate measuring instruments and the reduction of leakage. The synthesizer proves to be the most difficult component to design and the most costly. In practice it is necessary to bring the catalyst up to operating temperature before synthesis can commence. Thus an electrical heater located in the synthesizer system is almost mandatory and this is also required for initially reducing the oxide catalyst with hydrogen. Given that there has to be an electrical heater, its presence is exploited in the following way.

One of the important problems is the disposal of the high grade heat (500°C) in the absence of an engine or other appropriate load, and in a manner that will allow both a high degree of variability in synthesizer output, as well as independent control of the synthesizer temperature. One method is to thoroughly insulate the synthesizer and take off the exothermic heat via a secondary fluid to an external heat dump. The Australian team has tried this approach. It led to a disproportionately large amount of thermal insulation; hence the choice of a hot wall pressure vessel; hence mechanical and thermal stress problems, difficulties with hot lead-throughs and with the selection of a suitable high temperature secondary fluid.

The alternative approach is to deliberately reduce the amount of insulation so turning it into the escape path for the exothermic heat and at the same time degrading it to a manageable temperature. In this scheme the electrical heater is turned into a heat shield by which the synthesizer temperature may be controlled. Thus the sum of the exothermic heat and the electrical heat tend to remain constant and demonstration of energy transfer amounts to showing that the sum of the two electrical power inputs (p1 and p2 in the diagram) is constant though each may vary widely.

We emphasize that the seemingly contrived nature of the scheme is only a consequence of the small scale of the demonstration and the unavailability of a suitable load. In no way does it reflect upon the practicability of a large scale system. The cold wall pressure enclosure simulates what is practical on a large scale and the apparent disproportionate amount of thermal insulation required to prevent undue loss in only a consequence of the volume-to-surface ratio which strongly disfavors miniturization.

Although the scheme lacks a certain realism, it is on the other hand quite practical from the experimental and cost point of view. It allows the use of a reasonably sized cold wall pressure vessel enclosing all the associated high pressure components, so converting them effectively into low pressure components with considerable benefits in cost reduction and in design flexibility.

It is intended that the exothermic output will be controlled primarily by means of the flow of feedstock (nitrogen and hydrogen). Increasing the flow should increase the heat output though not linearly. Similarly the rate of heat absorption is to be controlled by the flow of ammonia to the dissociator. This in turn will be automatically varied so as to maintain a constant dissociator temperature through variations in heat input to the dissociator. The two processes of dissociation and synthesis will be kept in step by linking them to a common vessel kept partly full of liquid ammonia at a constant level. The level will be maintained by varying the flow of feedstock in response to changes in level, thereby causing the manufacture of ammonia to match the rate at which it is dissociated.

Level changes in the common separator will be detected by weighing . The apparatus for doing this exists and was developed mainly for enabling the absolute determination of rates of dissociation and synthesis, calibration of flow meters, and measurement of nitrogen ratio (by weighing a pressurized gas sample).

CONFIGURATION OF COMMERCIAL AMMONIA TRANSPORT SYSTEM

For systems generating power by means of a directly coupled gas turbine two configurations have been considered. They are the isobaric system operating at the single nominal pressure of 300atm, and the dual pressure system operating at 300atm for the synthesizer and 110atm for the dissociators. The latter has the advantages that the lower pressure is more favorable for economic transport of the reactants and for the process of dissociation. Against this a feedstock compressor is required to overcome the pressure step. In practice this is not a separate item but manifests itself as a roughly 15% increase in the size of the compressor that is normally part of a closed loop gas turbine system. Ammonia liquid is released between the stages of compression and is available at a range of intermediate pressures.

Work may be recovered from this in the run down to the 110atm level, but it is not sufficient to compensate for the compression of feedstock. The thermodynamic source of compensation for the net energy deficit is a decrease in the heat of reaction for dissociation at the lower pressure, and taking into account the mechanical efficiencies involved, this might be expected to be about 85% effective. Thus there are trade-offs to be assessed before the dual pressure system can be finally adopted. Nevertheless, it is currently favored.

ENERGY BALANCE

Using available data (a large part of which was provided by the Australian research group) it is possible to draw up an energy balance and reactant flow diagram in Figure 3, for a full scale module of about 10MW. Depending on the configuration work recovery efficiencies of 32% with respect to received thermal energy appear practicable.

COSTS OF A COMMERCIAL PLANT

In 1979 Davy Pacific, a Davy International Company, was commissioned to report on the feasibility of the solar ammonia process. They reported that it was possible to design a workable system for 10MWe. The cost would be $29.2 million including auxiliary oil fired boilers and gas turbines for overnight power generation. The operating cost would be 15¢/watt (these figures were in $Australian). At that time the direct coupled gas turbine concept had not been developed, so their study was based on the employment of a steam loop. The costs included $12.5M for the collectors and site preparation, as well as a 20% contingency allowance. Using this report as a basis, and omitting the overnight facility, we estimate the cost of the gas turbine concept as 76% of the above and the net power output 63% greater. This figure includes anticipated cost reductions due to the size of the PKI "Square Dish" solar collector and its future estimated production cost. It also assumes that 1979 Australian dollars are

1984 American dollars with a 50% additional cost increase on the synthesizer, storage vessel and field piping.

In the long term one would expect further improvements as research data and operating experience are gained. For example, it would pay if the cost of the turbine were increased by 50% in order to gain an additional 5% of mechanical efficiency. Turbine designers used to conventional power generation have yet to be confronted with this option. Again, the sizes of reaction vessels are directly related to catalyst reactivity, which in turn is very sensitive to temperature. Trade-offs between catalyst type and cost, catalyst life, temperature and reactivity need careful consideration once the relevant data becomes available, most probably from research.

ANSWERS TO CRITICISMS

- Ammonia has poor heat reaction

Compared with other candidate reactions, this is true on a molar basis. But what counts is energy density and this quantity is dependent on system pressure as well as heat of reaction. The pressure for the ammonia reaction adequately compensates for the low heat of reaction without being excessively high.

- Ammonia synthesis is a high pressure reaction and is therefore "difficult"

To an industrial chemist interested in the easiest method for making a particular chemical, the pressure necessary for the synthesis of ammonia must understandably appear to be a nuisance. But to an energy engineer interested in the cost-effective transportation of reactants over a pipeline, the optimum sizing of components, improved heat transfer and the matching of the reaction to a prime mover, the system pressure for ammonia should be seen as a desirable attribute. Operation of the pipeline at near optimum pressure is possible and the gas turbine will have an unusually high power/weight ratio.

- Leakage is serious

Leakage at the rate of 3% of the loop flow would render the system unworkable because the energy needed to manufacture the leaked reactants would about equal the energy output of the system. However, the tolerance limit of 0.1% is readily obtainable according to the Davy report and is achieved regularly in current ammonia synthesis plants.

- Experience of the ammonia synthesis industry is that there is a net energy input. Hence the exothermic end of the loop can't work in practice

This observation comes from taking a very superficial view of the synthesis process. Energy goes into the commercial synthesis process in three main forms: The hydrogen for the feedstock comes from natural gas or naptha; the feedstock needs to be compressed from its formation pressure to the synthesis pressure; often refrigeration is employed to extract ammonia. The combined effect of these energies greatly exceeds the exothermic heat. However, for thermochemical energy transport none of these three processes occurs apart from what is needed to prime the system initially. Therefore, the above criticism is without rational foundation.

- There will be an environmental problem if ammonia leaks out

For the very good reason stated above, the system would have to close down if leakage were above 0.1%. But if massive leakage did occur the danger to humanity and the environment would be no greater than currently exists in the vicinity of ammonia manufacturing, storage and shipping facilities. This is minimized by the fact that ammonia vapor is lighter than air and quickly ascends out of harms way. In high concentrations ammonia is dangerous to humans because of its caustic nature, but at low concentrations it is thought sometimes to be beneficial; e.g smelling salts. Ammonia leakage does no permanent damage to the environment because that part which reaches the upper atmosphere is dissociated by ultra-violet radiation and the remainder returns to earth as a trace component of rainwater. Plants use both naturally occuring and man-made ammonia as a vehicle for nitrogen fixation and consequently ammonia can be said to be the source of all protein both in plants and animals. It can therefore hardly be called a hazzard to the environment.

- Catalysts are unavailable for the duty required

The most commonly used synthesis catalyst, and the cheapest, is iron (with certain important additives). The recommended maximum operating temperature for this is 810K. Hence a suitable catalyst for the gas turbine concept exists. There is no known reason why this should not be adaptable to dissociation, but data on space velocity in this application is unavailable. An estimate of the amount of catalyst required for dissociation can be made using the reaction rate equations developed to explain catalytic synthesis. Using this approach it appears that 10 to 20 cc/KWth is possible at 810K. These quantities are compatible with the large point-focusing collectors currently being contemplated. Other catalysts such as nickel may permit higher operating temperatures and may therefore be more effective. One of the important outcomes of operating the demonstration plant would be the acquisition of performance data for a range of catalyst candidates.

- Corrosion is a problem

Corrosion is only a problem where ammonia mixes with water as might occur around a leak. Even then there is no serious problem except with alloys containing copper. These must be avoided in the construction of the plant. Otherwise steel is the most satisfactory material, the type being chosen to suit the temperature and strength required.

- Additional heat is required to boil the ammonia before dissociation can occur and latent heat is lost during synthesis

It is true that low grade heat component "goes along for the ride" in the ammonia process. But in the gas turbine version this component contributes to the total work output and is neither an embarrassment nor a waste. As compensation the cost of the collectors may be reduced by lowering their precision: the distribution of angular error may be such that only 70% of the surface reflects to a cavity focus, the remainder reflecting to an area surrounding the cavity entrance that operates at around 100°C.

RESEARCH CAPABILITIES

Power Kinetics is a spin-off of Rensselaer Polytechnic Institute's Mechanical and Aeronautical Engineering research and development program with a dedication to effecting major cost reductions in high temperature solar collection. The PKI Square Dish solar collector received the major design time of the Company and has been the only point focusing concept incorporated in the Department of Energy's commercialization programs since 1980. The Company can now meet DOE's 1990 goal for cost and performance for a concentrator, but lacks the compliment to that product -- a high performance engine. In lieu of that engine, the chemical transport system proposed offers the goal which the Company can rally behind to advance its centerpiece technology. Besides the driving force which intends to bring the necessary capital and commitment to this ammonia transport system, Power Kinetics will provide complementary expertise and management capabilities to this research effort and permit this technology to log the necessary amount of operating history and exposure to offer the point focusing technology a viable counterpart.

The key staff members from the Australian team have been working on aspects of the ammonia thermochemical system intermittently since 1974. This effort has been performed against a sound background of original theoretical work, especially in thermodynamics and full scale (order of 10MW) system analysis. Funding from University and Government grants has been quite substantial and staffing levels have been at about five. Many major difficulties have been overcome including the explosion of an ammonia shipping container connected to the plant. Experimental work aimed at verifying the theoretical basis of thermochemical energy transfer began with high pressure dissociation and has extended to building all the major components required for an energy transport loop. A great deal of work has been done in designing and building a synthesizer. This has undergone preliminary testing with the result that certain inadequacies have now become apparent.

This foundation work being complete, the Australian team is now poised ready to go on to the next logical step: the completion of a loop.

Over several years there has evolved a well equipped laboratory containing among other things, components for producing high pressure nitrogen in quantity, evacuation and flushing systems, a facility for storing liquid ammonia and for pumping it to 300atm, a disposal facility in which ammonia is removed by washing the waste gas, an all-purpose reticulation system comprising high quality valves, filters, pressure reliefs and 6mm steel tubing, pressure vessels for the storage and separation of reactants, nitrogen backed accumulators, flow meters, pressure transducers, thermocouples, a computer-based data gathering and processing facility, and a weighable pressure vessel for the absolute determination of synthesis, dissociation, flow rates and nitrogen/hydrogen ratio. Many of the components and instruments have been designed and built in-house because commercial suppliers were unobtainable.

RESEARCH APPROACH

Gene Bilodeau PE of Power Kinetics, will be the project manager of this work. Power Kinetics will involve William Rogers, Chairman and chief design engineer, throughout this project to provide the maximum amount of technical expertise and technology transfer among parties. Two positions may be provided by an ammonia producer, who is targeted to fund a portion of this research as a third party and benefactor of the resulting technology.

Phase I will accomplish the connection of the dissociator and synthesizer loops after thorough analysis has established the best configuration for these loops. Work on hardware to date in Australia is significant but in light of unforseen low prices for traditional energy today and the demands this puts on alternative solar systems, a thorough reconstruction of current loops is warranted to derive the best information for use in later scale up calculations.

Phase II will use solar energy to drive the system. This will introduce environmental conditions not present in Phase I and will provide an important step to a possible full scale plant of a Phase III effort. Phase III may be sized according to Davy Pacific's 10 Mwe minimum to achieve some economies of scale and use of existing ammonia technology.

P.O. Carden will be the principal investigator for the Australian team. R.E. Whelan will manage the Australian effort. Task 3 and the remainder of Task 1 will begin immediately in Australia after the team has met to discuss the details of the work. Two streams would progress in parallel -- one stream includes Tasks 1, 3, and 4. The testing phase of Task 4 would be the point of confluence of the two streams.

The Australian team would employ the services of a senior design draftsman; and two senior technical people together with appropriate support from the Research School of Physical Sciences' workshop. Special assistance is also required with regard to the known problems listed and others as they might arise. It is envisioned that this assistance will be obtained from Power Kinetics, through the support of the ammonia producer.

The second stream of development would take place in Troy, N.Y. under Power Kinetics using consultants from RPI and would transfer known technologies from Sandia and Australia to develop an electrically and solar heated dissociator. This stream consists of tasks 2 and 6. Since the performance of the dissociator is presently unknown, this method requires a particularly flexible approach to match the design of the synthesizer.

START-UP PROCEDURE

Because of the distance between the parties involved, the start-up is especially important. Some proceedures are as follows:

1. Firm up proposal in accordance with requirements of both parties.

2. Both parties to enter into a contractual commitment for the entire project with provision for review at key points. Reporting to be on a task or time basis. Adoption of fast track implies that the project will be managed on the assumption that it will be successful; i.e. tasks need not be carried out in strict sequence if the efficient use of resources dictates otherwise. On the other hand frequent reviews will be implemented to ensure that the work plan remains viable.

3. The work will be carried out with an emphasis on understanding the underlying mechanisms, obtaining reliable measurements, and correlation with known or developed theory.

A discription of the involvement by person is not included here but is detailed numerically in the cost proposal for this work.

FIGURE I WORK PROGRAM

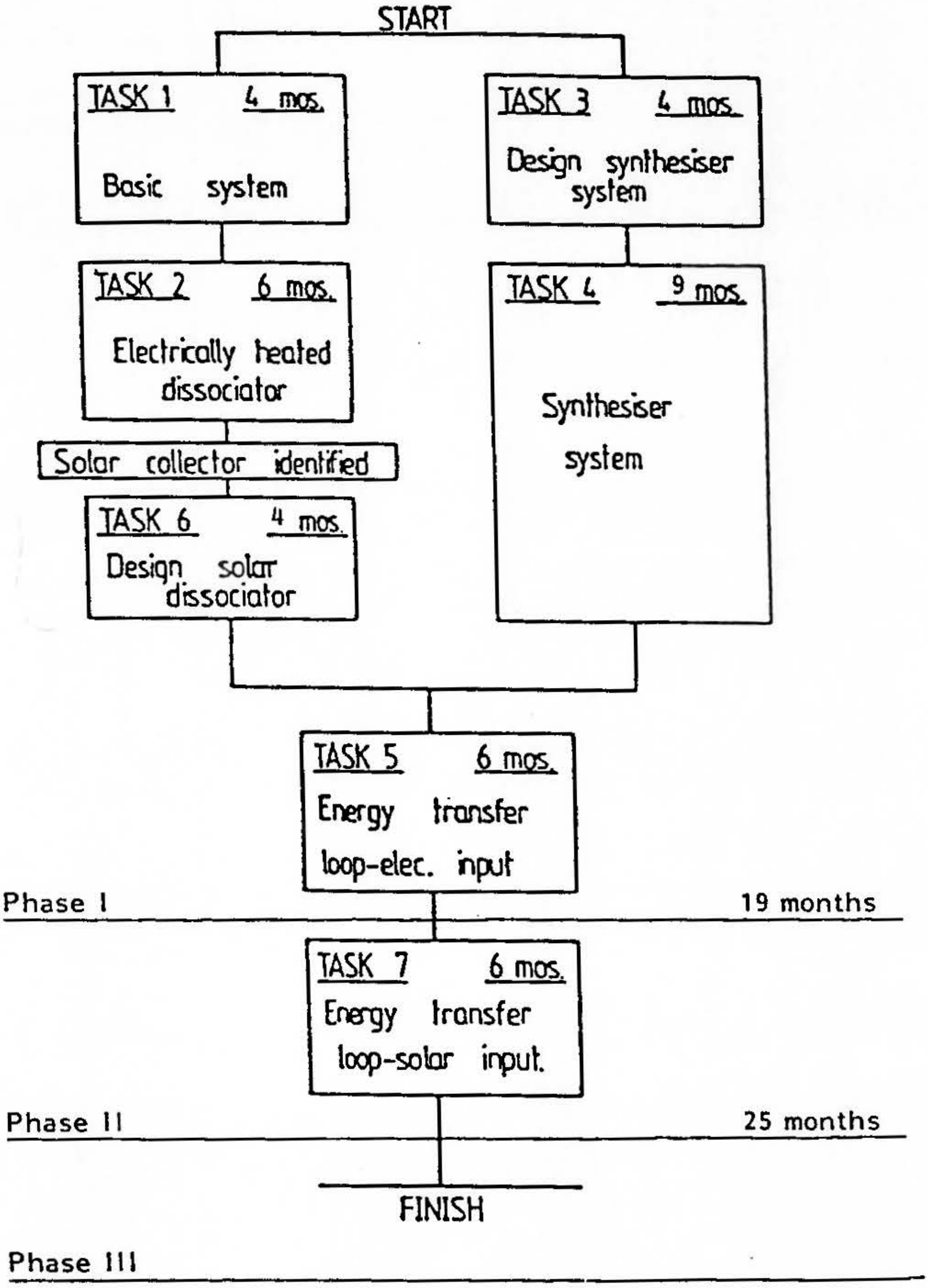
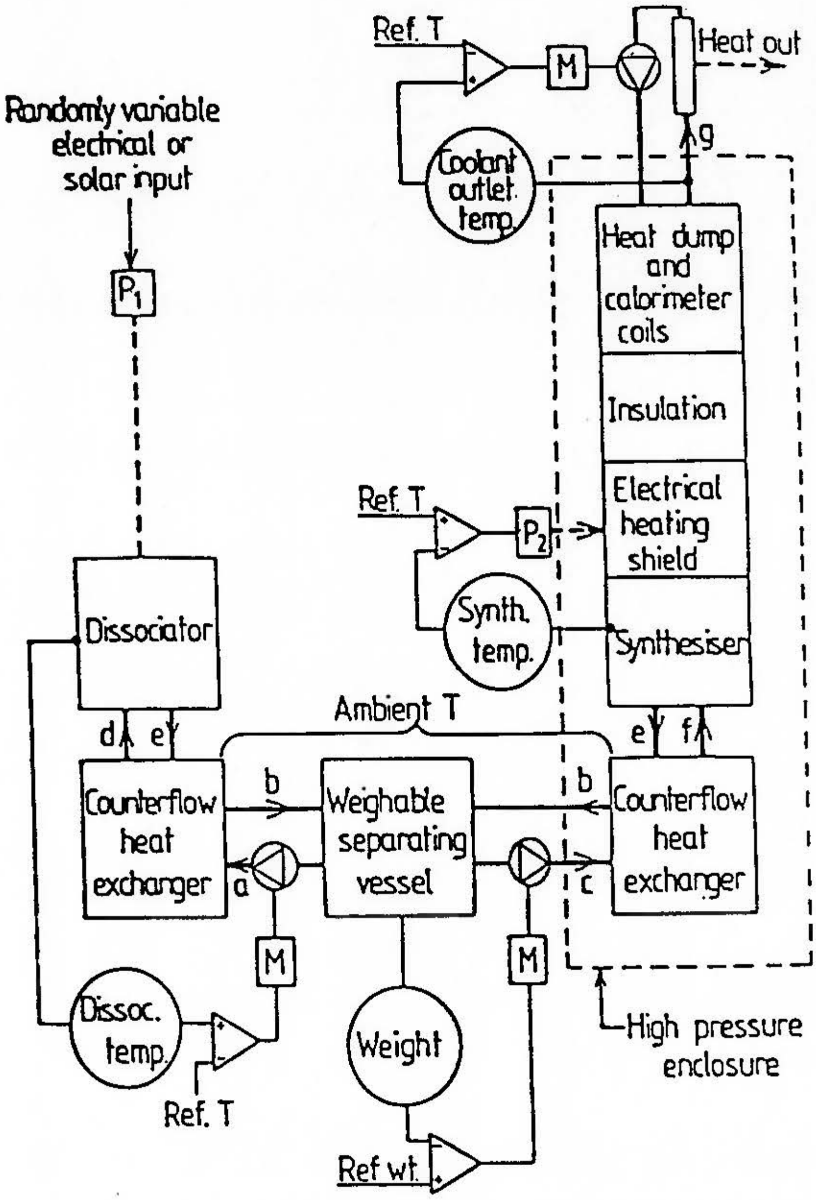


FIGURE II BLOCK DIAGRAM OF PLANT



a Ammonia liquid – ambient temp.
b Ammonia+H_2+N_2 – ambient temp.
c H_2+N_2 mix – ambient temp.
d Hot ammonia gas
e Hot ammonia+H_2+N_2 gas mix
f Hot H_2+N_2 mix
g Circulating water: amb. t. IN, ~90C OUT
M Controllable motor
P Controllable power source

FIGURE III REACTANT FLOWS AND ENERGY BALANCE

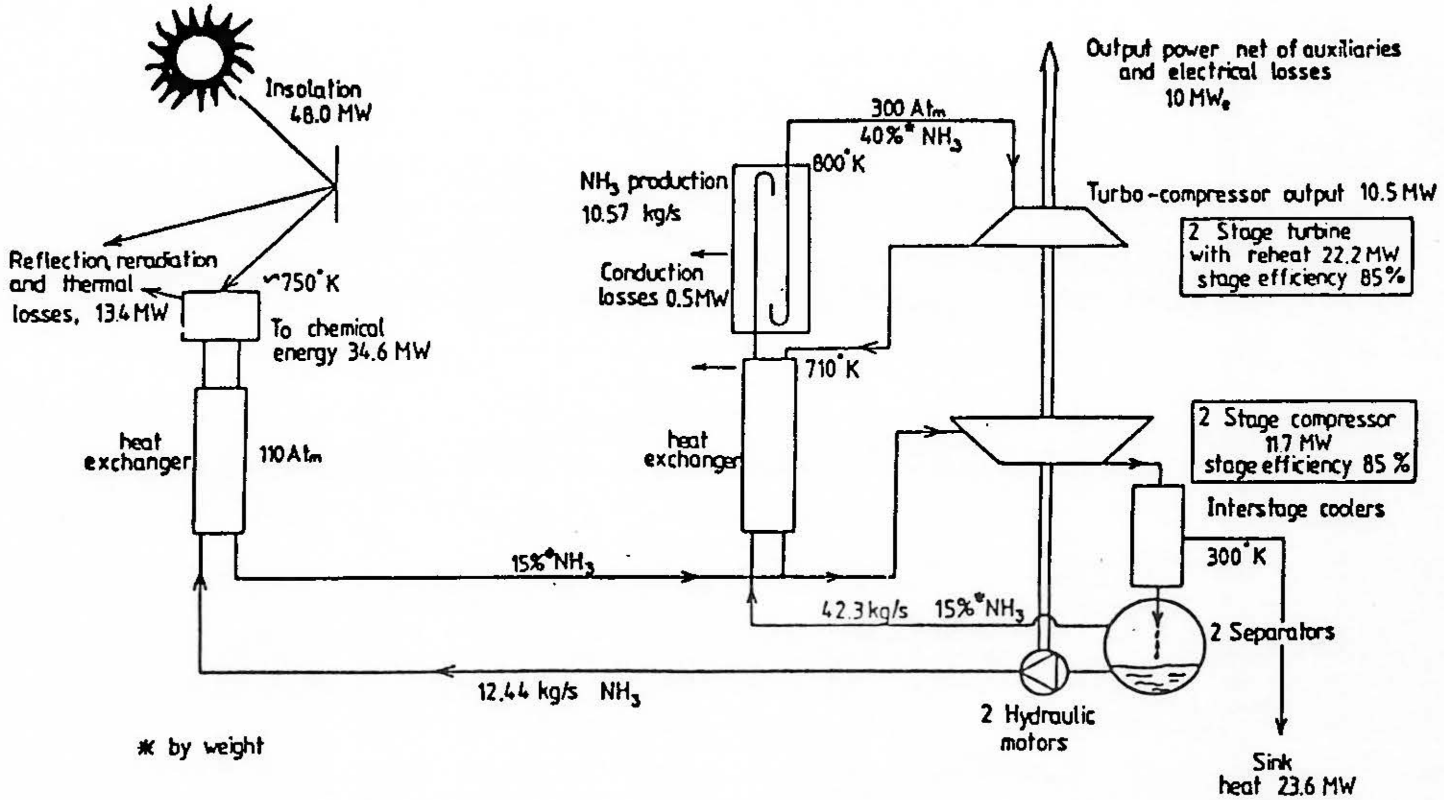


EXHIBIT I

POWER KINETICS, INC.
FIELD COST OF 10.00 MWTH SOLAR POWER PLANT
(TO PRODUCE ELECTRICITY)

SUMMARY OF SOLAR COLLECTOR COST AND QUANTITY NEEDED:

SIZE OF PLANT	10.00	MEGAWATTS
EFFICIENCY OF SYSTEM *	21.67	% (FOR ELECTRICAL PRODUCTION)
TOTAL COLLECTION AREA	46156	METERS
# OF COLLECTORS *	210	
220.00 SQ. METERS/UNIT		
COST PER UNIT *	$26,039	
TOTAL - INSTALLED COLLECTORS	$5,462,999	

SUMMARY:
AREA AND COST OF SOLAR COLLECTORS

TOTAL M2	TOTAL FT2	$/M2	$/FT2
46156	496636	$110.36	$11.00

	ITEM OF EXPENSE:	ITEM COSTS	% OF TOTAL COSTS	$ PER M2	$ PER FT2	$ PER WATT	SENSITIVITY ANALYSIS (+/-%)	HIGHEST POSSIBLE COST
1.	INSTALLED COLLECTOR UNITS	$5,462,999	24.75	$118	$11.00	$0.55	20.0%	$6,555,599
2.	FIELD INSTALLATION (1)	1,339,357	6.07	29	2.70	0.13	20.0%	1,607,228
3.	BUILDING & MECHANICAL AREA	916,000	4.15	20	1.84	0.09	40.0%	1,282,400
4.	CONTROL AND INSTRUMENTATION	6,500	0.03	0	0.01	.00	50.0%	9,750
5.	CONSTRUCTION/INSPECTION MANAGEMENT (3)	617,988	2.80	13	1.24	0.06	30.0%	803,385
6.	ELECTRICAL PRODUCTION UNIT W/O STANDBY EQUIPT. (4)	12,300,000	55.73	266	24.77	1.23	25.0%	15,375,000
7.	ELECTRICAL CONDITIONING		0.00	0	0.00	0.00	20.0%	0
8.	STORAGE		0.00	0	0.00	0.00	40.0%	0
9.	CONTINGENCY (3)	540,740	2.45	12	1.09	0.05	25.0%	675,925
10.	SYSTEM DESIGN (3)	386,243	1.75	8	0.78	0.04	25.0%	482,803
11.	STARTUP	500,000	2.27	11	1.01	0.05	100.0%	1,000,000
	TOTALS FOR ELECTRICAL PRODUCTION	$22,069,827	100.00	$478	$44.44	$2.21	25.9%	$27,792,090

(1) FIELD INSTALLATION:		PER COLLECTOR UNIT COSTS	TOTAL COSTS	$ PER M2	$ PER FT2	$ PER WATT
SITE WORK @	$500,000 /KM2	$2,383	$500,000	10.83	1.01	0.05
COLLECTOR FOUNDATIONS		1,800	377,638	8.18	0.76	0.04
ELECTRICAL		160	33,568	0.73	0.07	.00
PIPING (FROM (2) BELOW)		1,041	218,352	4.73	0.44	0.02
INSULATION		N/A	0	0.00	0.00	0.00
STEEL		N/A	0	0.00	0.00	0.00
MISCELLANEOUS		1,000	209,799	4.55	0.42	0.02
TOTALS		$6,384	$1,339,357	29.02	2.70	0.13

POWER KINETICS, INC.
DETAIL TO ANALYSIS OF POWER PLANT (CONT'D):

(2) PER COLLECTOR COST FOR CHEMICAL TRANSPORT

	# UNITS	COST PER COL'TOR UNIT	TOTAL COST
CONTROL VALVES	358	$100	$35,748
HIGH PRESSURE FLEX COUPLINGS W/ 1/8" NOM SEAMLESS HYD PIPI	358	$290	$103,957
FLUID RETICULATION NETWORK	358	$220	$78,647
TOTALS	1075	$203	$218,352
APPROXIMATE COST PER COLLECTOR			$1,041

(3) CONSTRUCTION/INSPECTION MANAGEMENT ETC.:

		PERCENTAGES	
CONSTR/INSP MGMT.	$617,988	40.0%	8.0%
CONTINGENCY	540,740	35.0%	7.0%
SYSTEM DESIGN	386,243	25.0%	5.0%
TOTAL @ 20% TOTAL	$1,544,971	100.0%	20.0%

(4) ELECTRICAL PRODUCTION UNIT:

		AMOUNT
1 SYNTHESISER & RELATED PLANT FOR STEAM		
SYNTHESIS GAS STORAGE VESSEL		
CENTRAL LIQUID/GAS SEPARATOR (50 M3)	$1,165,500	
AMMONIA SYNTHESIZER (1100T/DAY @ 200 ATS)	3,750,000	
MISCELLANEOUS @ 100%	4,915,500	$9,831,000
2 TURBO GENERATORS @ 5 MW		2,469,000
TOTAL EQUIPT. COST OF SOLAR W/O BACKUP		$12,300,000
STAND-BY EQUIPMENT: 2 STEAM BOILERS 22.7 T/H CAPACITY 2 GAS TURBINES 2.5 MW EA. AND SWITCHGEAR		2,326,000
TOTAL EQUIPT. COST OF SOLAR & BACKUP		$14,626,000

(5) O & M ANALYSIS:

O & M COSTS OF 10 MW POWER PLANT

	ITEM OF EXPENSE:	PER	SOLAR	DIESEL
1.	FUEL OIL @	200 /TON		238000
2.	DISTILLATE @	216 /TON		1319976
3.	LABOR AND SUPERVISION			500000
4.	OVERHEADS:			400000
5.	MAINTENANCE:			
6.	0.02 % CAPITAL SOLAR	19102356	382047	
7.	0.05 % CAPITAL DIESEL	2326000		116300
	TOTALS		$382,047	$2,574,276
12.	LAND ($0.05 /WATT X		10.00 MEGAWATTS)	$500,000

COMPARISON TO ENERGY PRODUCED:

TOTAL ENERGY PRODUCED PER COLLECTOR	$10,862
TOTAL NUMBER OF COLLECTORS	210
TOTAL ENERGY PRODUCED	$2,278,786
LESS PARASITICS	64,183
TOTAL NET ENERGY PRODUCED	$2,214,603
AS % OF ENERGY	17.3%

POWER KINETICS, INC.
SIMPLE PAYBACK CALCULATION
USING STEAM TURBINE WITH SOLAR GENERATED STEAM
(W/O EFFECT OF FINANCING MECHANISMS OR O & M COSTS)

PER UNIT CALCULATION OF ENERGY GAIN:

220	METERS SQUARE PER SOLAR COLLECTOR UNIT	
6.50	KWH/M2/DAY	(AVERAGE FOR CALIFORNIA)
1430	KWH/DAY/SOLAR COLLECTOR UNIT	
365	USAGE (DAYS PER YEAR)	
521950	KWH/YEAR	(AT .85 KW/METER TOTAL - USAGE IS 2791 HOURS PER YEAR)

TRANSLATES TO:

17814	THERMS/YEAR/UNIT	(0.034130 FACTOR)
1781	MMBTU/YEAR/UNIT	(0.003413 FACTOR)

EFFICIENCIES OF VARIOUS COMPONENTS:

	COMPONENT EFFICIENCY	CUMULATIVE EFFICIENCY	ANALYSIS/DAVY PACIFIC CUM EFF	75.20 MWR
MIRRORS (UNCLEANED)	0.84	0.840	79.9%	60.10 MWR
ABSORBER	0.92	0.773	71.9%	54.10 MWT
FIELD PIPING	0.99	0.765	50.8%	38.20 MWT
GENERATOR UNIT	0.32	0.245	15.0%	11.30 MWE
PARASITICS	0.88	0.217	13.3%	10.00 MWE

PKI ESTIMATE @ 162.9% OF THE DAVY PACIFIC STUDY

VALUE OF ENERGY USED:

		% OF TOTAL USED	$ PER KWH	$ PER THERM	$ PER MMBTU
$9,612	ELECTRICAL	21.7%	0.085	2.49	24.90
$0	THERMAL	0.0%	0.024	0.69	6.94
$9,612	TOTAL	21.7%			

PRICE/THERM - OIL

155000	BTU/GAL OF OIL
0.80	$/GAL
0.55	OIL BOILER EFFICIENCY
0.94	$/THERM

PRICE/THERM - GAS

102000	BTU/GAL
0.46	$/GAL
0.65	CONVERSION
0.69	$/THERM

SIMPLE PAYBACK CALCULATION:

10.94 YEARS FOR ELECTRICAL PRODUCTION WITHOUT THE USE OF
USE OF THERMAL WASTE HEAT (DISPLACING GAS AS FUEL), OR
THE EFFECT OF THE BENEFITS OF ADDING THE BACKUP DIESEL CAPABILITY

Attachment 8

The ANU-PKI Thermochemical Project

Based on past contacts and discussions on 25-26 May, 1985.

Five steps are identified

1. Preparation of document to convey information for gaining funds from appropriate sources.

2. Physical demonstration of a first closed loop, leading to the obtaining of useful parameters and data.

3. Designing of a solar dissociator and testing this dissociator on a PKI dish to reveal useful parameters and performance data.

4. Derivation of a computer model for a 10 MWe system (thermochemical) for producing electricity and ammonia.

5. Building of a 10 MWe Solar Thermical Power/Ammonia System.

ADVANTAGES OF THE THERMOCHEMICAL SYSTEM USING AMMONIA

Advantages include:

1. All the reactions are simple without side-effects.

2. Energy transport (and storage) occurs at ambient temperature, no insulation is therefore required.

3. Efficiency of conversion of heat energy to chemical energy is high even at low insolation levels, thereby allowing collection of almost all available solar heat energy even near sunrise and sunset and during periods of low insolation.

4. Storage of energy for very long periods is possible.

5. The handling of ammonia is a standard technology; pipelines, tankers, cylinders etc. The material is relatively benign, being lighter than air and therefore rising when released (being a gas at ambient temperatures and pressures).

6. Because of the ready transport of the reactants in an ammonia thermochemical system, collector (and storage) field can be separated from the synthesis plant.

7. The site for a solar plant working thermochemically can be selected as non-prime land; restrictions on layout of collectors and synthesis plant are not significant - layout is extremely flexible.

8. Because of the highly non-linear behaviour of the dissociation process with respect to temperature, the flow control system is non-critical.

9. As the dissociation process is self-compensating, no temperature control is required for each dissociator.

10. A Solar thermochemical system based on ammonia has many potential outputs: process heat, electricity, ammonia production (with byproducts of oxygen, and rare gases from the atmosphere), hydrogen and synthetic fuels. Waste heat from the plant could be used for water desalination.

11. Overall system efficiency for electricity production from solar energy is potentially in the region of 24-28%. Cost-effectiveness is enhanced through the application of a direct output to the synthesiser, rather than via a heat exchanger and appropriate working fluid.

12. Comparison of a Solar Thermochemical Power System based on Ammonia with a Dish/Steam system of the same rated output.

Based on PKI dish/steam system for 10 MWe peak system.

Component	10 MWe output Dish/Steam Turbine Efficiency Med. glass	Excel.glass	10 MWe output Thermochemical Ammonia/Ammonia Turbine Efficiency Med. glass	Excl. glass
Concentrator	0.834	0.91	0.834	0.91
Absorber	0.923	0.923	0.923	0.923
Regeneration	1.054	1.054		
Concentrator piping	0.994	0.994	1.000	1.000
Field piping (storage	0.951	0.951		
Efficiency Th.Ch.)			0.970	0.970
Engine Unit	0.290	0.290	0.350	0.350
Generator Unit	0.954	0.954	0.954	0.954
Parasitics	0.914	0.914	0.95	0.95
Overall Efficiency	0.194	0.212	0.237	0.258

Cost Comparisons

Item of Expense	Item Costs	Item Costs
Collector units	13,876,800	11,370,000
Field Installation	1,000,000	570,000
Construction, Inspection, Management	644,130	700,000
Electrical Production Unit	2,300,000	6,720,000*
Contingency	1,288,260	1,400,000
System Design	644,130	700,000
Start Up	200,000	160,000
Totals for Electrical Production.	$19,953,320	$21,600,000

*Includes synthesis components.

Does not include the reduction in cost due to a smaller cooling tower.

Both systems have essentially the same order of cost within the accuracy of the study.

Annual Collection Efficiency

The Ammonia Thermochemical System can collect almost all energy from sunrise to sunset with good (relatively high) collection efficiency. A solar steam system generally loses the energy below about 400 W/m^2. On this basis, measurements indicate that the thermochemical system could gather about 18% extra energy relatively to the steam system. Moreover, the steam system's overall efficiency drops significantly from ideal (peak) as insolation levels drop. Insulation losses or heat storage during the warm up period are not recovered near shut-down, causing other losses. These factors add a further loss of about 12-15%.

The ammonia based system is therefore likely to gather some 30% more energy annually than a steam system.

Operation and Maintenance

Steam system plant needs a deal of attention, especially as regards water quality control; turbines which operate intermittently on steam pose special problems. Steam absorbers require also some care in operation and attention. The ammonia system appears less likely to suffer impurity and other problems and is expected to have a lesser operation and maintenance component. The handling of ammonia and ammonia equipment is well developed.

Size of Systems

A 10 MWe Dish/Steam Turbine system is approaching the maximum practicable size for such units; a 10 MWe Solar thermochemical system based on ammonia is at the lower limit of effective unit: 100 MWe and higher units appear practicable and may be more cost effective.

13. Compared with other thermochemical alternatives, for example SO_3 or CO_2/CH_4, solar dishes for an ammonia system need not be so accurate therefore can be cheaper - because ammonia does not require such high temperatures. Moreover, the receivers for the other systems will have higher losses and lower efficiency than ammonia receivers working at their lower temperatures.

14. The Potential for Electricity/Ammonia Production Combinations

Because of the presence of the synthesiser in a Solar Ammonia thermochemical system, there is potential for producing ammonia when the sun is not shining, using off-peak electricity at discount rates.

The attachment outlines a hybrid system for this purpose.

HYBRID SOLAR SYSTEM for producing ELECTRIC POWER and AMMONIA

Summary. Primarily the system is a 10MWe solar power station using PKI collectors, ammonia based thermochemical energy transfer and centralised power generation using turbines situated directly in the thermochemical fluid streams. During the night the ammonia synthesis components are employed to produce ammonia at a rate equivalent to 1000 tons per day, the feedstock being (a) electrolytic hydrogen and (b) nitrogen from air liquifaction. Off-peak grid power is used at this time. Thus during 8 hours 333 tons may be produced.

The two modes of operation are shown in the accompanying diagram.

The cost of day-time solar derived electricity is based on the amortization of solar collectors and thermochemical fluid lines. The cost of night-time ammonia is based on the cost of off-peak power plus the amortization of (a) the ammonia synthesiser components and (b) electrolysis and air liquifaction plant. The cost of electricity is therefore 13.7 cents per KWhr (on total capital of $15M) subject to further reduction through tax benefits.

The cost of ammonia is $77/ton made up of (a) $57/ton electrical energy component based on an off-peak price of 1cent/KWhr and (b) $20/ton amortization of the balance of the plant cost.

Capital costs (millions of dollars).

Collectors	11.37
Field installation	.57
Construction, inspection and management	.70
Electrical production unit	6.72 *
Contingency	1.40
System design	.70
Start up	.16
Electrolyser and air liquifaction	3.4
	25.0

*includes synthesis components

The above total cost has been split two ways, $15M being attributed to solar power and $10M to ammonia production.

Amortization has been at 25%. The cost of solar derived electric power has been derived on a pro rata basis from PKI figures (the comparatively small O&M component has been included for convenience). Thus cost of solar power is

$$(15/19.953) \times 18.21 = 13.7 \text{ cents/KWhr}$$

For the ammonia component the calculation is

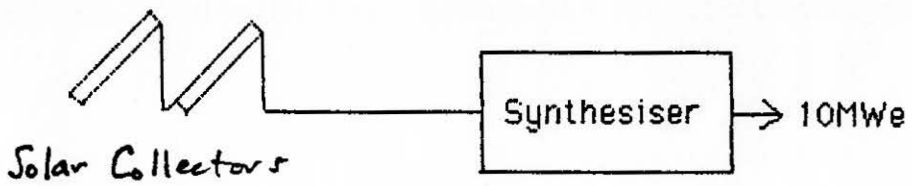
$$(\$10M \times 0.25) / (365 \text{days} \times 333 \text{ tons per day}) = 20.6\$/\text{ton}$$

Peak efficiencies.

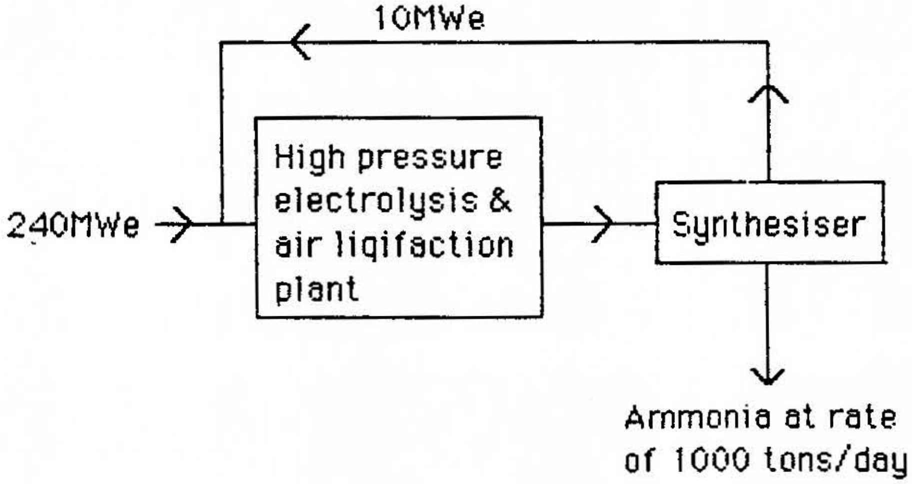
Concentrators	.834
Absorbers	.923
Piping	.970
Engine	.350
Generator	.954
Parasitics	.950
Cumulative overal efficiency	.237

ENERGY BALANCE

DAY



NIGHT



REVIEW OF THE THERMOCHEMICAL DEMONSTRATION PLANT PROGRAM

During July 1984, following preliminary discussions, an outline for an experimental program to demonstrate thermochemical energy transfer using ammonia was prepared by P. Carden and R. Whelan and presented to PKI for appraisal. This initial ANU document was based on assumptions that the benefits to the parties concerned would involve differing time scales; to the ANU group, an immediate increase in research activity with adequate financial support; and for PKI a license to use a patent protected system in their future developments of large scale solar energy installations, ensuring their compeditiveness in the new technology area.

The initial proposal was costed by the authors without detailing items such as staff-related costs, travel charges (for liason meetings), establishment service charges, etc., but was used to document an approach to Sandia National Laboratories for DOE funding. Interest from ammonia manufacturers was sought by PKI, the intention being to expand beyond the two-party agreement and offer long term benefits to the third party. The long term benefits the ammonia producer might receive were not indicated in the ANU document. In the proposal to Sandia an additional parallel program by PKI for Troy was included where the dissociator developments, both electrical and solar, would occur. Because of the unknown details of the synthesiser design, the parallel program was noted as requiring a "flexible" approach.

Recent firming of concepts has changed the attitudes to, and the appraisal of the manner by which ammonia loop should be demonstrated and has reinforced the need for an experimental program that will provide firm data for scaling and costing predictions. The changed attitudes are reflected in the following:

(1) It would not be feasible for PKI to conduct a parallel program except to test and demonstrate a dissociator on their solar collector. The role of PKI would be more entrepreneurial.

(2) There is evidence that Sandia is accepting ammonia as having equal standing with SO_3 and CH_4 in the thermochemical energy transfer investigations.

(3) Significant differences in the pricing between peak and off-peak will continue and hence provide a more viable economic argument to attract ammonia producer funding.

(4) There shoud be simplifications possible in producing a demonstration loop, this loop being a new concept proposed in addition to the experimental loop at the ANU

Accepting these points ANU still considers that the original document, modified to include the above points and detailed charges, is a firm basis

for an experimental program. These modifications do not alter the estimated timing of 31 months. A reduction in this overall time can be achieved if the aim is altered so as to delete solar-sourced energy transfer. This new goal would reduce the time by 6 months and assumes that solar developments are a separate program. If however the original aims are retained then the costing changes are as follows.

Salaries and overheads.

Position	Year 1	Year2	Year3	
Management services	12312	12927	7918	33157
Snr. Des. Draftsman	40937	3312		44249
Tech Officer	27291	26501	16232	70024
Tech Officer	27291	26501	16232	70024
Totals	107831	69241	40382	217454

Notes. Base salaries as June 85. Year 3, 7 months only all positions. Year 1 on-costs 33%. Year 2, year 3 on-costs 23%.

Travel.

Initial meeting	4 people	6600
First review Australia	3	4950
Review at Sandia	3	4710
Review at Australia	3	4950
Review at Sandia	3	4710
		25920

Notes. PKIs suggested travel program. Includes plane, auto and per diem.

Materials and equipment.

86400

Note. Currency devaluation compensated by 8%.

External contracts and consulting.

162000

Note. Currency devaluation compensated by 8%.

Total estimated project cost in current AUS$ 491774