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THERMOELECTRIC POWER FROM LEAD - WHAT'S PRACTICAL? WHAT'S POSSIBLE?

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There has been much conversation in newspapers and trade journals about exciting developments in the exotic and nonconventional new fields of power generation. Not the least of these has been the field of thermoelectricity. New Product publicity people are performing a valuable service to the public and to industry by keeping them informed of new technical advances and products. Sometimes, however, the semantics used in their stories are deceiving. Like an April Fool's Day chocolate, what they hold out to you looks delectable...but you had better not bite into it too deeply, because all is not what it appears to be on the outside. It pays to know what's inside, and to know what to look for or expect when you bite into these newsy tidbits. Readers see in an article the things they would like to see, pertaining to their own interests. As suppliers to the new thermoelectric effort, you too, view these articles in the light of your own interests. You no doubt wonder how much of this is sweet and nourishing and how much is soft soap. I suspect that is why you have asked me here today. If that is so, I will try to give you something that is at least digestible.

First of all, Thermoelectricity is here to stay. There have been and still are many knotty problems involved with its development that hinder its fast rise to prominence. Slowly these knotty problems are being untied...or at least loosened. The loosening of one knot, however, does not constitute a breakthrough (as some articles suggest), because there are more knots still in the way. One of the biggest problems is that sometimes in the loosening of one knot, others become tighter. Some of our knotty problems are connected with the improvement of thermoelectric material characteristics. Unfortunately, these desirable characteristics cannot be independently optimized. These desirable material characteristics are such things as -

1) High Seebeck coefficient (200μv/°C) over large temperature range
2) Low electrical resistivity
3) Low thermal conductivity
4) Mechanical strength
5) Mechanical and thermal shock resistance
6) Chemical stability
7) Low vapor pressure
8) Low coefficient of expansion
9) Low cost

Thus the program is one of constant compromise, to embody as much of the desirable characteristics into one material as nature will allow.

Fortunately, we do not have to wait until all of these problems are solved before we make practical use of thermoelectricity. Each accomplishment extends the outward limits of use, allowing us to build and market devices within those limits. The acceptance and success of these devices are dependent entirely on the optimization of these material parameter values, plus the design and production technology employed to give the highest degree of efficiency in the end product.

Speaking of efficiency, here is also a term by which one can easily be misled. The usual question asked by most people is...How efficient is this thermoelectric device? A simple answer is not easy to give... unless the person is familiar with what is meant by "efficiency". In simple terms, "efficiency" is an expression showing "what you get" for "what you pay for". This sounds simple enough. Now then, how "efficient" is a thermoelectric generator under today's state of the art? Fig. 1 is a simple schematic diagram of a typical thermoelectric generator with a heat source on one side, a heat sink on the other side, and a bank of thermoelectric materials in between, housed in a heat exchanger. To determine the efficiency of this generator, we must compare "what we get out" - electricity, with "what we put in" - heat. There are many steps to consider in this comparison.

$$\eta \text{ (efficiency)} = \frac{\text{"what you get out"}}{\text{"what you put in"}}$$

Combustion efficiency of the burner

$$\eta = \frac{\text{heat output (watts)}}{\text{fuel input (Btus)}} = 60\% \text{ approx.}$$

Heat transfer efficiency of the heat exchanger

$$\eta = \frac{\text{heat out (watts)}}{\text{Heat in (watts)}} = 70\% \text{ approx.}$$

Conversion efficiency of the thermoelectric materials

$$\eta = \frac{\text{electricity out (watts)}}{\text{heat in (watts)}} = 13\% \text{ approx.}$$

Conversion efficiency of the voltage converter (when used)

$$\eta = \frac{\text{power out (watts)}}{\text{power in (watts)}} = 85\% \text{ approx.}$$

Overall efficiency of the generator

$$\eta_{overall} = \eta_{burner} \times \eta_{heat\ tr.} \times \eta_{materials} \times \eta_{converter}$$

$$\eta \text{(overall)} = 60\% \times 70\% \times 13\% \times 85\% = 4.6\%$$

$$\eta_c \text{ (Carnot efficiency)} = \frac{T_h - T_c}{T_h}$$

where T_h = temperature of the hot side
T_c = temperature of the cold side

In connection with materials efficiencies, if materials research men were able to make a "perfect" thermoelectric material, its efficiency would be determined by the laws of thermodynamics as a heat engine. At typical operating temperatures for present day materials this would be a maximum of 54%. By comparison, the steam turbine power plant produces electricity at 25% to 40%. An increase in any one of these efficiencies will improve the useful efficiency of the device. It is easy to see that there is a lot of room for improvement.

Thermoelectric generators are by no means impractical at this state of the art. There are many applications where higher efficiencies are not important, but where lower cost and extended life are important. Generators even in the lower ranges of power, have many uses, where a reliable continuous power source is needed in remote areas.

The graph in Fig. 2 indicates the relative position of thermoelectric generators with respect to batteries or engine generators. In the 100 mw to the 100 watt range, thermoelectric generators enjoy a favorable position in terms of cost per kwh.

Our company has now introduced to the market a product line of such portable gas fired thermoelectric generators which have been on display. These are 12 volt DC generators, ranging in power up to 15 watts. Yet to follow, hopefully this year, are a 30 and a 60 watt model. A prototype 250 watt model has already been completed.

Some of the proposed uses for these generators are shown in the following applications: (See list in Addenda)

These applications are real for today. Yet in development for tomorrow, is a thermoelectric gas central heating furnace, which will develop all power needed for operation of its own controls and air circulating system. This program is bringing about a trend toward low cost, reliable, mass producible generator modules, such as those shown in Fig. 3 diagram. Once completed, these types of module structures should be applicable to any gas burning appliance that needs electricity to complete its function.

Today the price of portable generators (from pilot plant production) is about $30 a watt size. Just three years ago these same generators would have cost $3000 a watt. Advances in materials and design technology have brought about this reduction. Mass production will lower this figure in the future to $10 a watt. The ultimate goal of our furnace generator program is to lower this figure to less than $1.00 per watt, by the modular approach. Surely, if one can project the growth rate of the last five years for the next five years, it is not at all unreasonable to foresee the beginning of a widespread use of thermoelectric power in such things as home appliances. A thermoelectric auxilliary power plant for domestic loads would offer a degree of reliability heretofore unknown.

There are still some pretty tough "knots" left to untie before this becomes a reality ... higher materials efficiencies, greater stability for higher temperatures, greater mechanical strength, to name a few. There is no magic by which this will be accomplished, except by persistent and concentrated effort - the same type of effort that has advanced the state of the art to its present position.

It is very difficult to predict what this might mean to you in the Lead Industry. All of the devices we have made and are making use lead. Our thermoelectric material is lead telluride, which is still today the most commonly used material.

Perhaps we can portray this market potential by some suppositions.

The maximum annual supply from presently available sources of tellurium is purported to be in the neighborhood of 375 tons. Suppose that the total output of tellurium were used to make lead telluride. Since lead telluride is made up of approximately 38% tellurium and 62% lead, 612 tons of lead would be needed annually. However, there are other telluride thermoelectric materials made and used that do not employ lead. Conversely, some are made of lead in conjunction with materials other than tellurium.

Materials for thermoelectric cooling use tellurium but no lead at all.

The present output of tellurium would not necessarily constitute a limit to the manufacture of thermoelectric materials. Surely an increase in demand would stimulate a search for additional sources and added reserves of tellurium. In anticipation of this, work is already underway by the Government and some private concerns to uncover additional reserve sources.

Other promising non lead metallic compounds are certain to take their place along with lead in the production of thermoelectric devices. It is impossible to predict which material will assume the role of major importance in the future. At this point the crystal ball is very unclear. Surely, lead in the pure form that it has been supplied, has played a most prominent part in the development of thermoelectricity. It un - doubtedly will continue to do so for a long time to come.

AUTOMOTIVE

(Autos, trucks, tractors, engine powered equipment, camp & travel trailers)

- Battery charging
- Clearance & parking lights
- water pressure pumps
- refrigeration
- two way radio power
- emergency warning light flashers

AVIATION

- Remote airstrip
  - beacon flashers
  - communication
  - engine starting battery maintenance
- Mountain top beacons
- Elevated structure clearance lights

COMMUNICATIONS

- Forest rangers
  - fire tower transceivers
  - fire fighters portable or mobile sets
- Telephones
  - portable temporary phone booths
  - lineman signal generators
  - substation standby power
- Microwave station standby power
- Civil defense emergency
- Wilderness outposts
  - mining
  - cattle range
  - missionary

CONSTRUCTION

- Field communications
- PA system amplifier
- Recharge source for battery powered tools
- Ventilation fanpower
- Detour warning flashers

DATA RECORDING & TELEMETERING

- Remote data gathering
  - weather stations
  - temperature
  - rainfall
  - wind direction & velocity
  - barometric pressure
- Field scientific research
  - soil bacteriology
  - forestry
  - atmospheric (balloon flights)
  - seismographic
  - radiation
- Geophysical surveys
  - watershed studies
  - lake and waterway levels
- Civil Defense
  - radioactive fallout levels
- Pipelines
  - volume, pressure, flow

MARINE

- Battery chargers
- Emergency starting battery maintenance
- Emergency communications power
- Standby power for shipboard navigation, running, or anchor lights
- Towed vessel running lights
- Power for ventilation of boat at anchor
- Cathodic protection of hull
- Security alarms (burglar, fire)
  - channel marker buoys
- Standby emergency power for communications on "Texas Tower" type installations

RAIL

- Caboose communication power
- Emergency warning signals
- Switch heat[illegible] control power

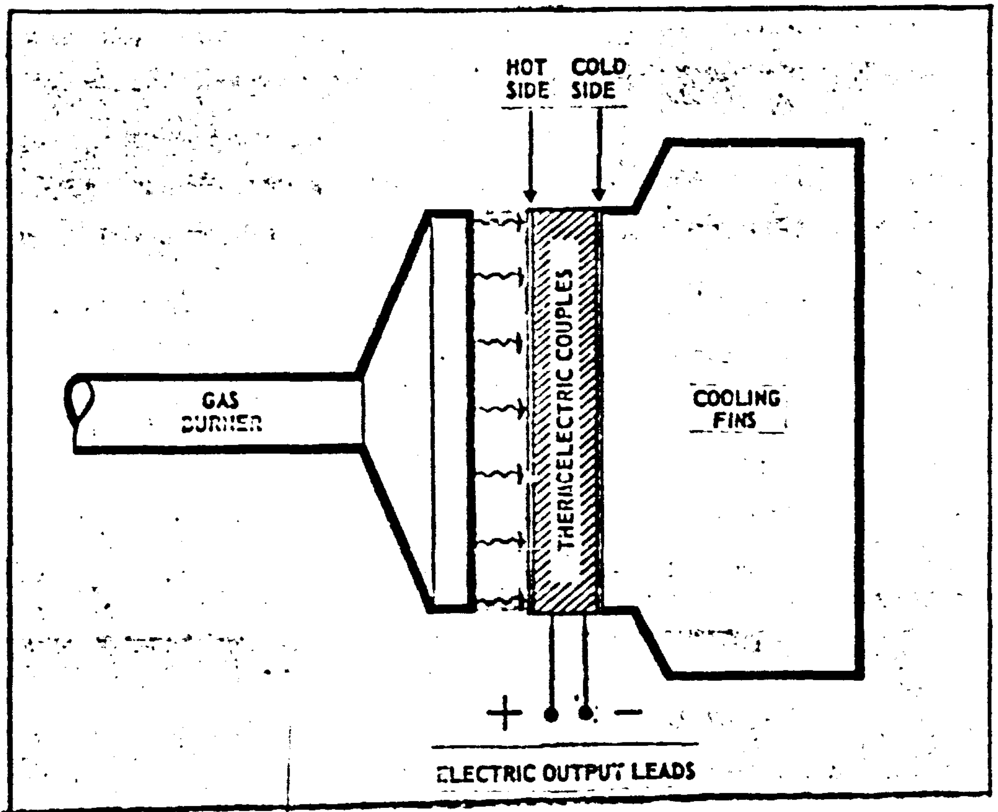
RECREATION

- Portable radio & TV
- Sportsman heater - generator (fish shanties, camps, etc.)
- Barbecue spits
- Outdoor PA systems (field sports events, group picnics, public gatherings)

OTHER FIXED INSTALLATION USES

- Remote building security
    - burglar alarms
    - fire alarms
    - temperature monitoring devices
- Electric stock fences
- Controls systems power
- Self luminous signs
- Cathodic protection
    - pipelines
    - oil wells
    - silos
- Traffic control signals
- Blower power for air supported buildings

FIGURE 1


HOT SIDE
COLD SIDE
GAS BURNER
THERMOELECTRIC COUPLES
COOLING FINS
+
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ELECTRIC OUTPUT LEADS

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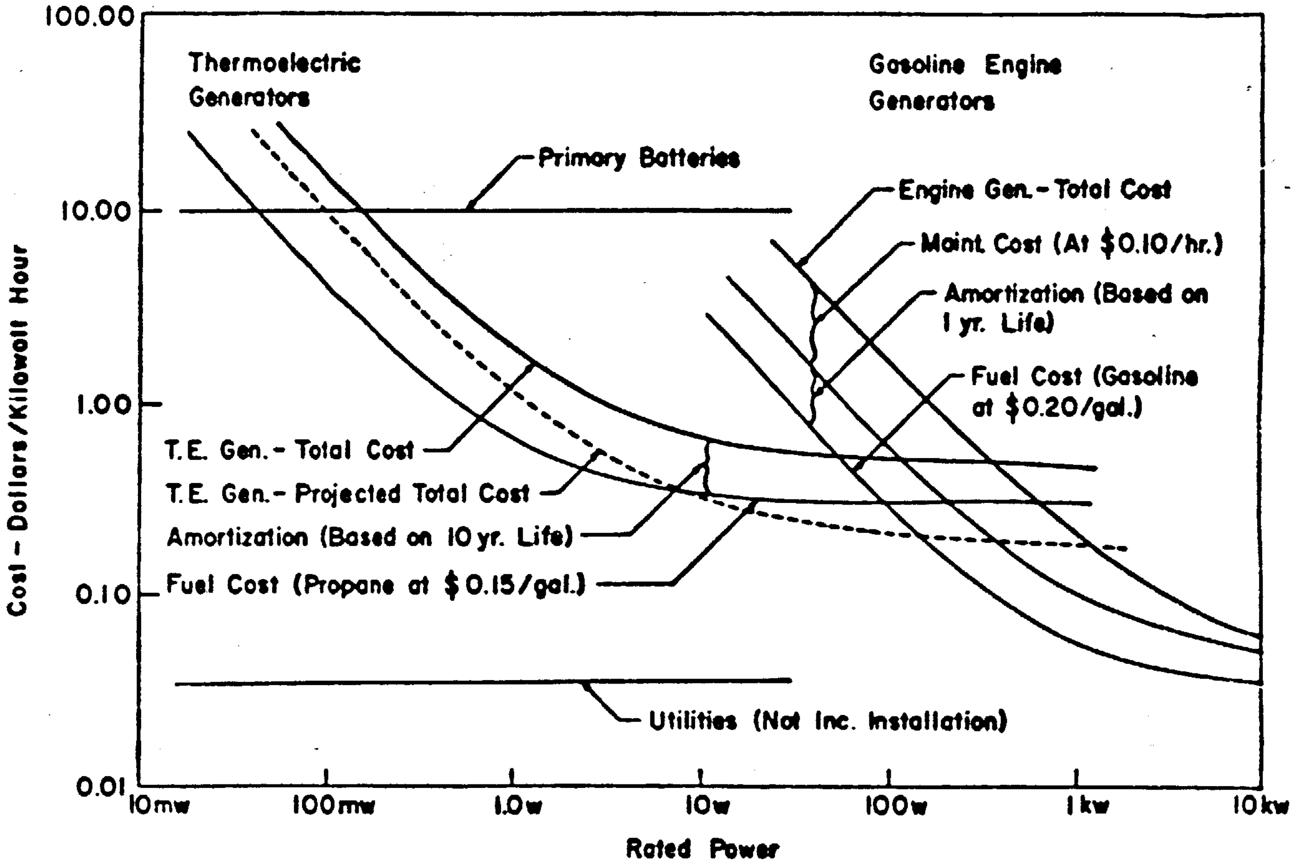

Figure 2. A rough comparison of the cost of various power sources, operating continuously.

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FIGURE 3