DOE High Efficiency Thermoelectric Workshop

A Roadmap for Waste Heat Recovery From Here to Successful Usage

Hylan B. Lyon Jr. Ph.D.

Chief Technical Officer

VP Research and Development

Marlow Industries

This presentation focuses upon what has to or should be done to go from this room to successful application of solid state (Thermoelectrics and Thermionics) technology application to the recovery of waste heat from the exhaust of diesel trucks.

Why diesel trucks? Because all analysis I know of says if this technology is going to work anywhere the recovery of heat from the exhaust of a 500 HP truck rolling down the highway is the most probably application.

The Concept of Success

- **Form follows function.**
  - **Managing expectations.**
  - **A DOE Energy Efficiency and Renewable Energy Initiative.**
    - **Opportunity in the transportation sector.**
      - **Direct conversion.**
      - **Vehicular air conditioning/heating.**
- **Structure for success.**
  - **The balance of efforts.**
    - **Qualitative sense.**
    - **Quantitative sense.**

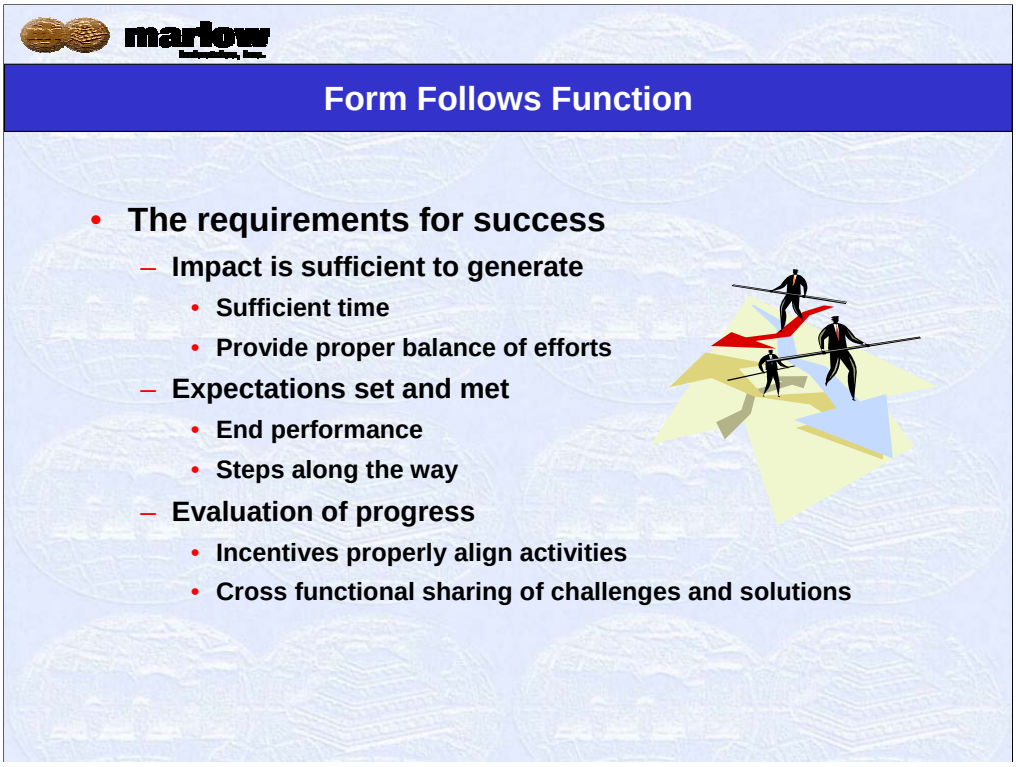
The point of this chart is that we have to add some functions into the mix and structure our approach to that mix. The structure we embrace will be a major determinant of whether the roadmap succeeds or not.

The assumption being that out of the thousands of options that exist there are success scenarios that are real and can be done.

Form Follows Function

- **The situation at this meeting.**
  - **A majority of active US material researchers.**
    - **Bulk.**
    - **Quantum confinement.**
    - **Super lattice.**
    - **Thermionic/thermoelectric.**
  - **Some assessment of system level requirements.**
  - **A great deal of work left to do.**

The point of this chart is that the meeting identifies a potential, no one single approach presented at this meeting has all the attributes of success but … when the system level considerations are put into context, the potential is great enough that we have to give it a shot.



The words on the chart say it all … in this case.

We have an expectations management problem as we approach this new capability, and we have to set time, balanced criteria and measurable performance goals to be successful. At this time and place we have a very difficult challenge in doing so.

Managing expectations

- Transportation consumes 26.7% of Total Energy
- Of that 17.1% is consumed by medium/heavy trucks. (over 2X the airline consumption)
- And 20% - 40% of that goes to turning the wheels
- Leaving 3.6% of the total energy to be recovered.

The science and engineering challenge is:

How much of the rest can be converted to electrical energy? …. Hold that thought for a couple of minutes

The point of this chart is that there is an impact that can make a difference at the national level. That impact has to be the basis for a governmental program.

Managing expectations

REPORT OF THE BESAC SUBPANEL ON BASIC RESEARCH NEEDS TO ASSURE A SECURE ENERGY FUTURE

FEB 2003

New Scientific Opportunities

Scientific research on new material systems which properties approach the theoretically predicted improvements should include nanocomposites and crystals with glass-like thermal conductivity. New concepts to synthesize the new materials in industrial quantities must be explored. New concepts for the optimal use of these materials in complete TE systems, in which segmentation of the thermocouples, the efficiency of the heat exchange with the working fluids, and the problems of making low-resistance contacts to the TE materials are paramount, will greatly improve the efficiency and the economics of heat recovery systems and air conditioners.

The Basic Energy Science report on “Basic Research Needs to Assure a Secure Energy Future” did identify the thermoelectric opportunity. The questions is whether the new material systems truly are reflecting the theory that has been proposed … now for nearly a decade.

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The point of this chart is to stress that the implementations for these new physics in the lab are really not industrial processes, in capacity or cost. A great deal of work must be done in this regard.

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The experience in this field does point out that simple assertions of good are often very difficult to transition to working devices. Especially devices that carry forward the efficiencies claimed in the laboratory. Thermoelectric history is a minefield of claims that didn't make it into devices…. Yet. In some cases results still escape us after a decade of claims.

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The litany in this slide, goes to the point that there are several factors that are not Seebeck, Peltier or Thermionic in nature that dramatically inhibit the device level performance.

Managing expectations

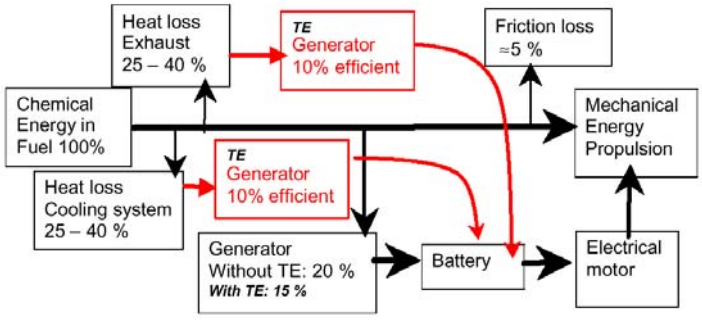
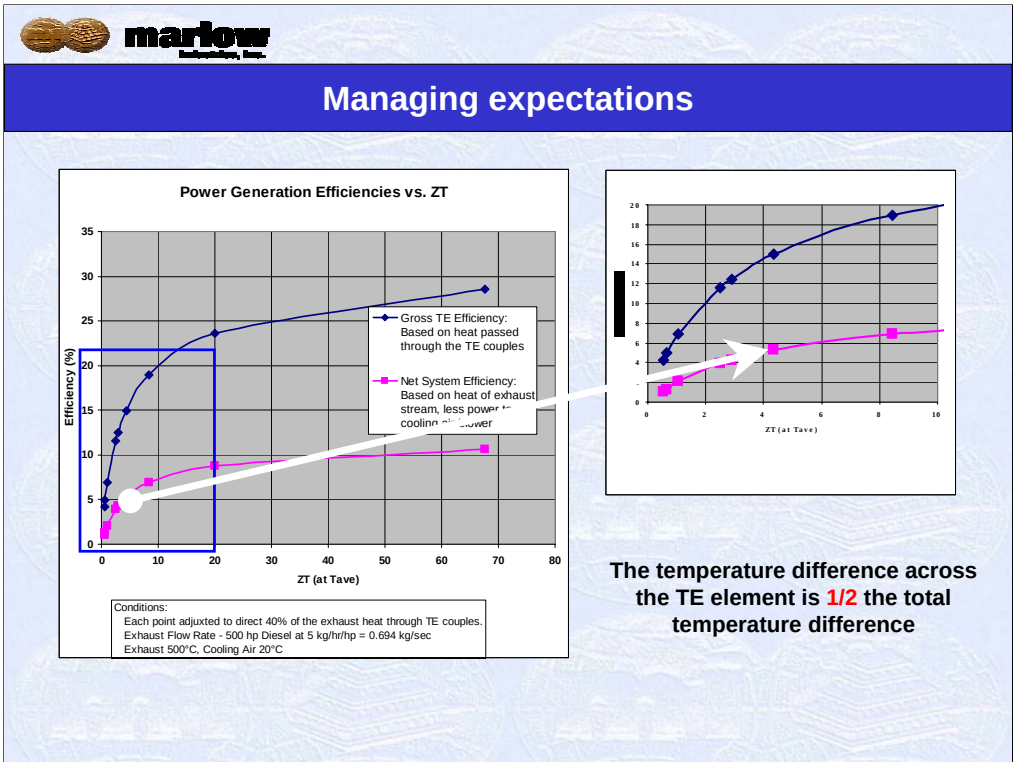


Figure 6-2. Energy use in a vehicle in which supplemental electrical propulsion is available (black lines). A thermoelectric generator (red line) can supplement the electrical generator, leading to a fuel economy improvement of up t

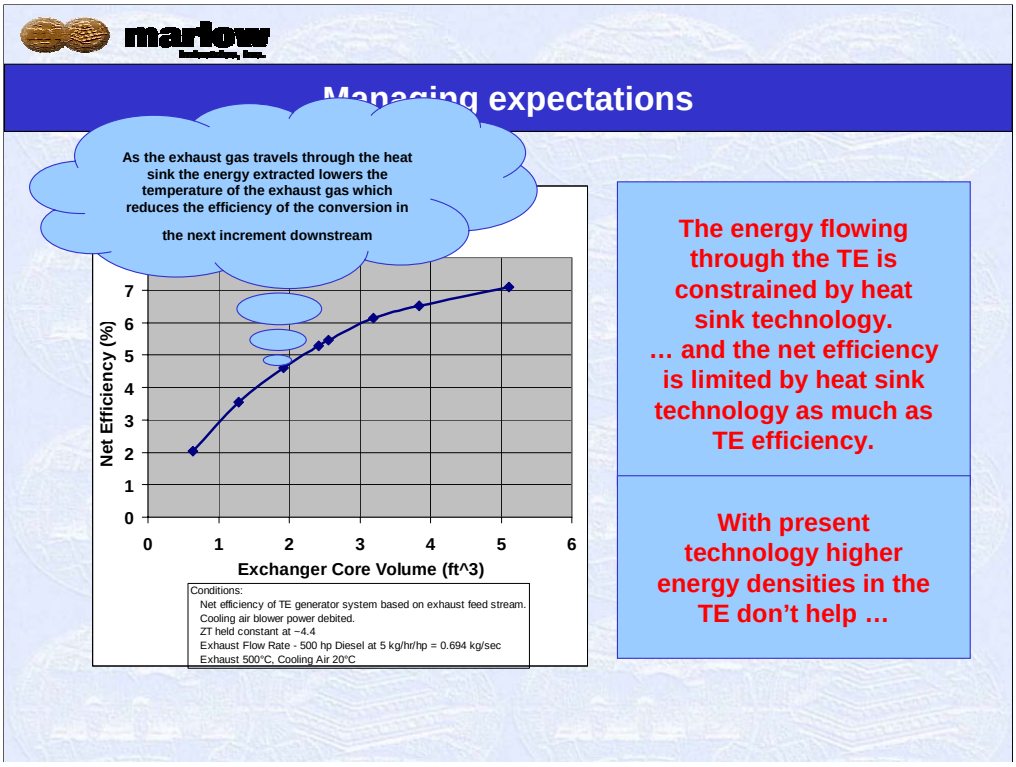
Now there's an expectation!

The point of this chart is that 20% efficiency at the lab level is a very strong expectation which may not materialize in the device level itself.



What these charts propose to say is that the impact of parasitic losses on the process of transition is a very great challenge.

Regardless of the ZT values claimed there are very profound limits on the system level efficiencies due to a few major factors. In this case the point being that the heat path out of the exhaust pipe and through the thermo element, results in only half of the temperature difference appearing across the thermoelectric elements which convert the thermal energy into electricity. Only half the available temperature difference across the thermoelectric elements significantly reduces the expectations of many of the presentations.



Heat sink technology developments and system design may be as important and possibly more important than the material developments themselves. Heat spreading from very high energy density materials may actually be a detriment to system level efficiencies.

The Structure for Success

- Avoid unrealistic expectations … we all suffer when that happens.
- The history of TE is replete with non-reproducible claims.
- Program management experience teaches that a major portion of costs of systems are determined early on… like right now in TE systems.
- Capacities must be demonstrated in the 2 to 4 kW range or greater.
- Cost, Cost, Cost …. Something like $0.10 to $0.50 per watt with probably over half of that in heat sinks.
- TE device therefore must be $0.05 to $0.25 per watt.
- Coefficient of thermal expansion issues have to be considered as well … the internal stresses in these devices generated in assembly can destroy the MTBF in operations.
- … otherwise we are simply generating another "niche" market which is nice, but doesn't lead to the national energy reduction.

This chart is self explanatory, the point of this is that there will be niche markets, that is a given. But the sponsors of this meeting are not in the business of supporting niche markets, they need efficiency gains that can be demonstrably argued at a national level, significantly reducing the amount of oil that has to be imported,

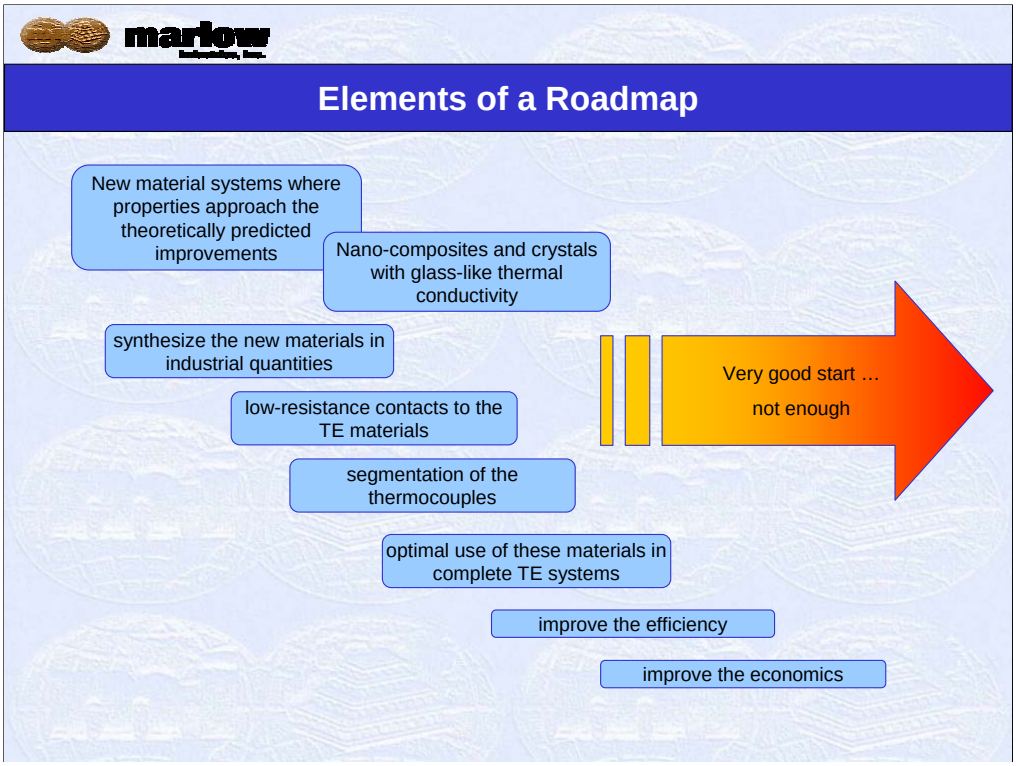
The Structure for Success - Qualitative

- **We won't get there if we continue to have material systems competing with each other for the next renewal of their contract.**
  - **The original intent from my perspective was to elaborate the physics so well articulated by Millie Dresselhaus and others.**
    - **And then transfer as much of that physics to material systems that meet the constraints as possible.**

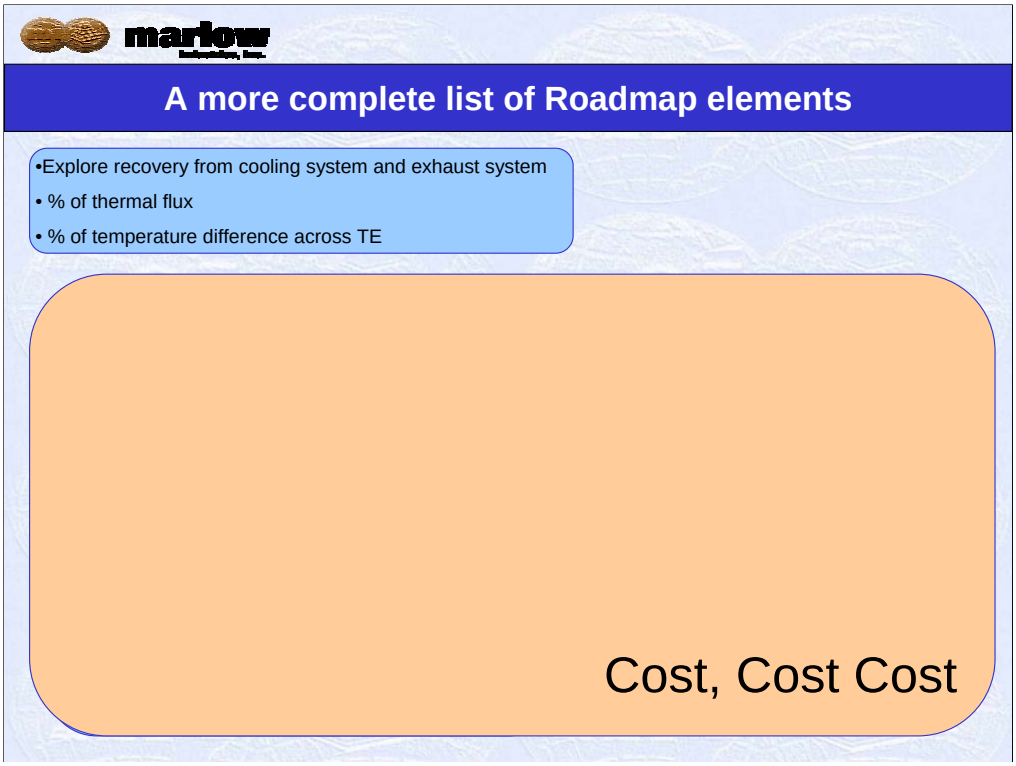
      … as a community we will not do this spontaneously… but it has to happen.
  - **While progress in material physics is remarkable and holds forth great promise, the bulk of the work lies ahead.**

    It takes a community to solve this problem … lets take the DOE report at face value.

The point of this chart is we need to recast the approach from the physics to the engineering issues. Even thought the materials are not ready to transition, we need to begin to address some of the engineering issues, in a much more systematic and thorough manner than we have in the recent years.



This chart simply takes the language of the BES report and places them in the roadmap context, and indicates that, in my opinion, this roadmap is not enough.



This chart adds in some more elements into the roadmap but not all. It highlights that at the end of the roadmap, cost is the dominant issue. This chart is only a beginning, and very rough beginning to what has to be put in place.

A target (indicative only)

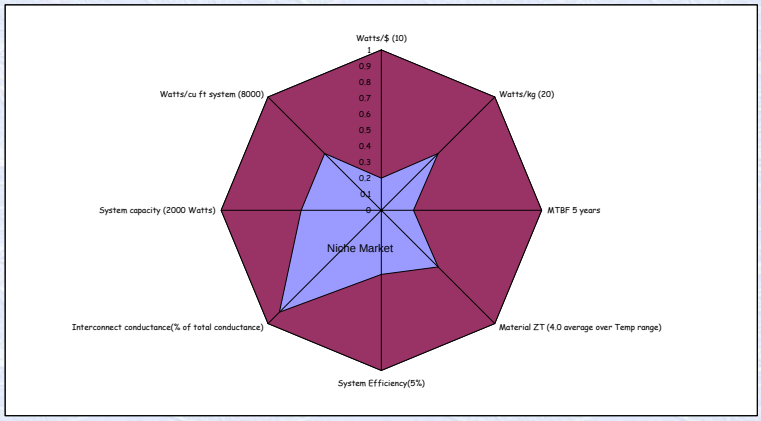


Chart is only to make a point, the numbers and dimensions must be redefined as part of setting up the road map.

This chart says that no approach at present holds forth the potential of meeting all of the success criteria. We have to address an approach that does. The numerous necessary conditions that have been achieved, pale in the face of that which needs to be done, and implicit in this is that all this must be done in a window of opportunity that is compressing in time.