Overview of Thermoelectric Power Generation Technologies in Japan

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OUTLINE

- **Introduction**

  Classification of applications of thermoelectric power generation (TEG)
  Experiences of major demonstrations for thermoelectric power generation system

- **Progress of the Development of TEG Applications**

  Waste heat recovery systems
  Renewable energy sources

- **Future Prospects**

  CREST project “Development of high-efficiency thermoelectric materials and systems”
  NEDO project “Development of nano-structured thermoelectric materials using Clathrates”

- **Conclusions**

Classification of TEG Applications at present in Japan

I. Large scale TEG systems recovering waste heat in the energy system

II. Applications to the renewable energy sources such as solar, geothermal and ocean

III. Dispersed small TEG systems as energy-harvesting or ubiquitous power sources

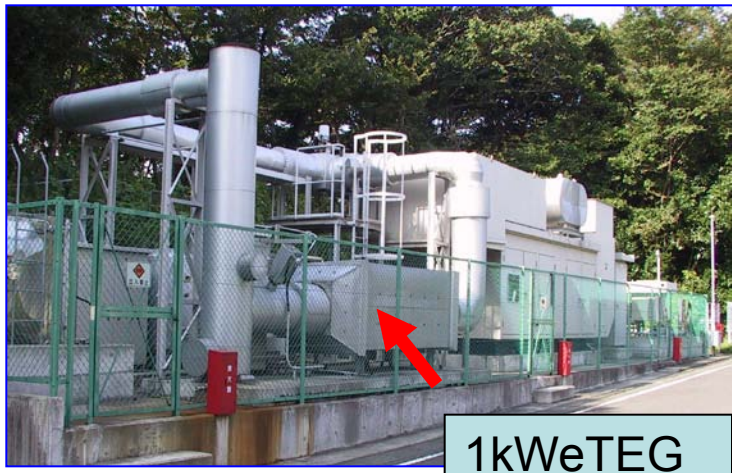
Impressive Records of TEG Demonstrations in Japan

- 500kW Diesel engine cogeneration TEG・・・(I)
- Municipal solid-waste TEG systems ・・・(I)

・Wall-embedded type,

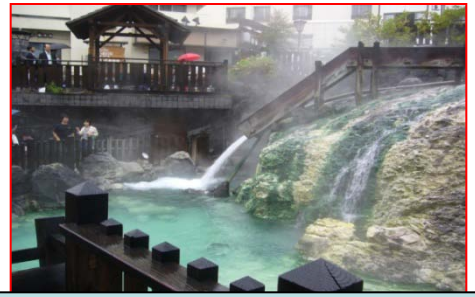
・Separate type using working medium such as air and organic fluid

・In-line type



1kWeTEG

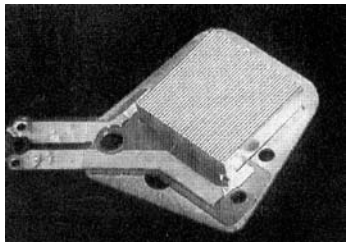
- Hot-springs TEG ・・・(II)



Kusatsu Hot springs

150W / 4.5 years run

- TEG Wristwatch ・・・(III)



Ongoing Developments of Thermoelectric Applications in Japan

- Waste Heat Recovery Systems
  - Industrial furnaces **(Komatsu/KELK, Showa Cable Systems)**
  - Solid waste incinerator **(Showa Denko)**
  - Motorcycles/Automobile **(Atsumitec)**
- Renewable Energy Sources
  - Solar thermal energy **(JAXA group &China, TDS group)**
  - Geothermal energy (Hot springs) **(TOS/Kusatsu)**

Waste Heat Recovery Systems

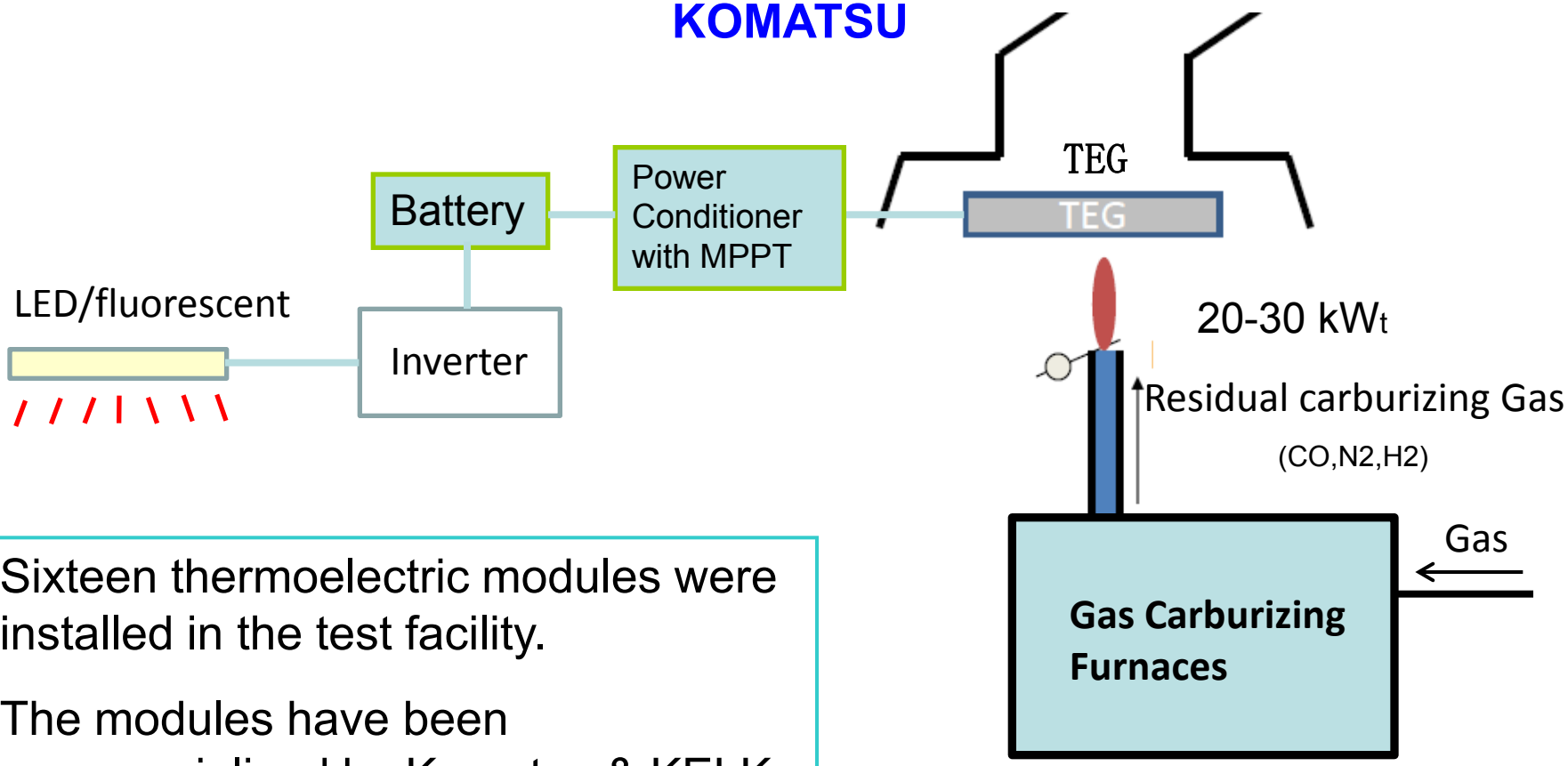
Industrial furnaces

(Komatsu/KELK, Showa Cable Systems)

Solid waste incinerator (Showa Denko)

Motorcycles/Automobile (Atsumitec)

TEG application to a gas carburizing furnace by KOMATSU



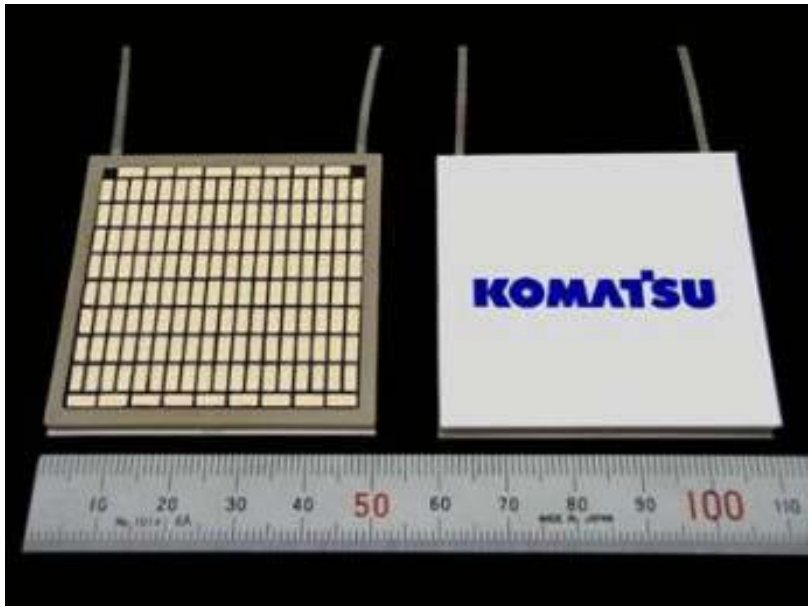
Sixteen thermoelectric modules were installed in the test facility.

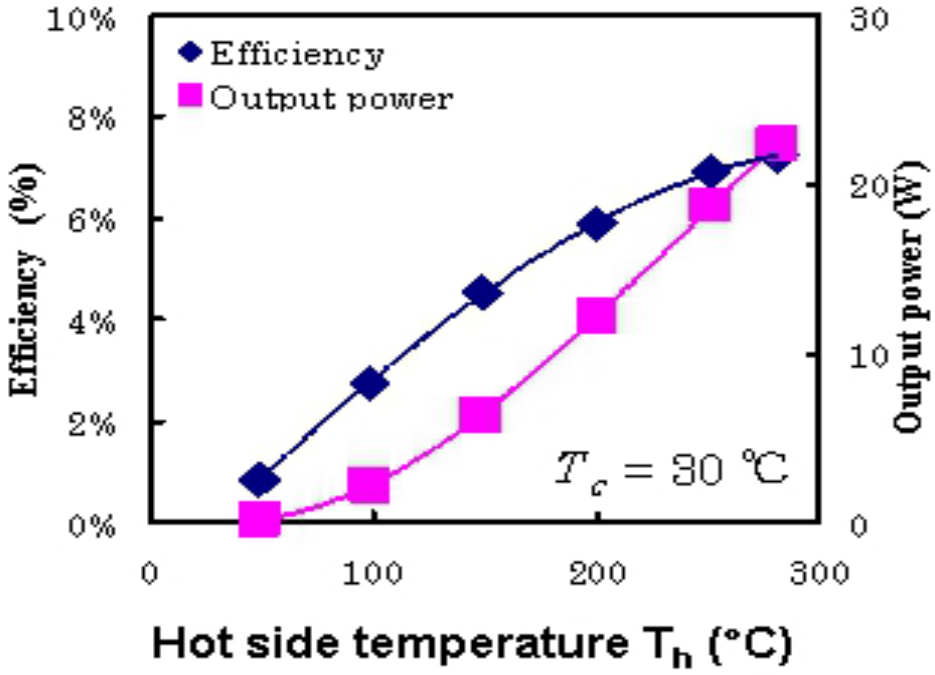
The modules have been commercialized by Komatsu & KELK as outcome of the JATeCS project.

200 W class TEG recovering the exhaust heat for a gas carburizing furnace installed in the large gear manufacturing process

KOMATSU

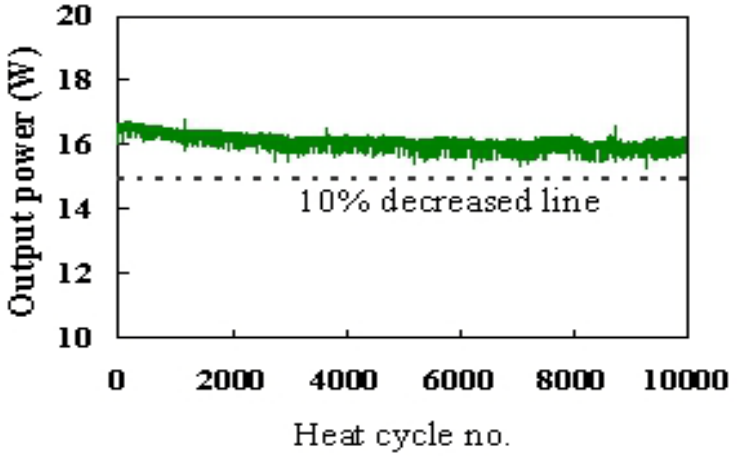
TEG Module using Bi-Te alloys





[Specifications of the thermo modules]
Size : 50mm x 50mm x 4.2mm
Weight : 47g
Output : Max. 24W
(when 280 °C in the hot side and 30 °C in the cold side)
Temperature range for use : 280 °C (max.) and 250 °C or
in the hot side and 150 °C (max.) in the cold side
Conversion efficiency : Max. 7.2%
Material : BiTe alloy

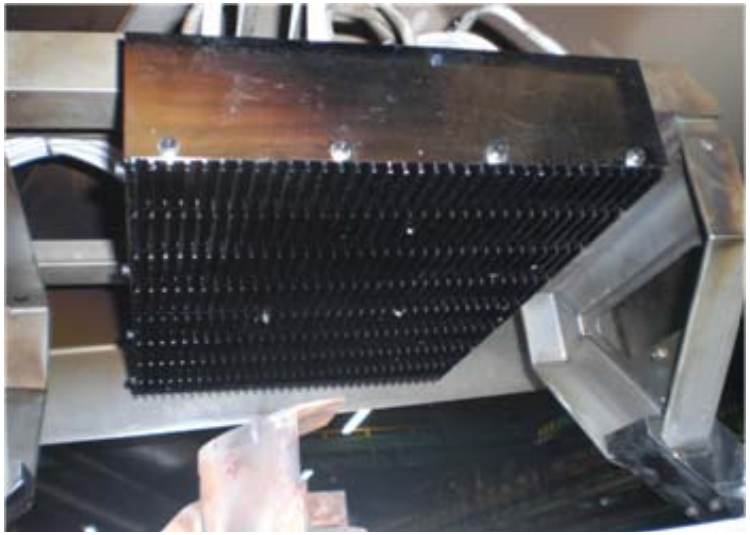
Heat cycle test



(TH = 250 -50 ° C and TC = 30 ° C in air)

TEG systems tested using two types heat collector

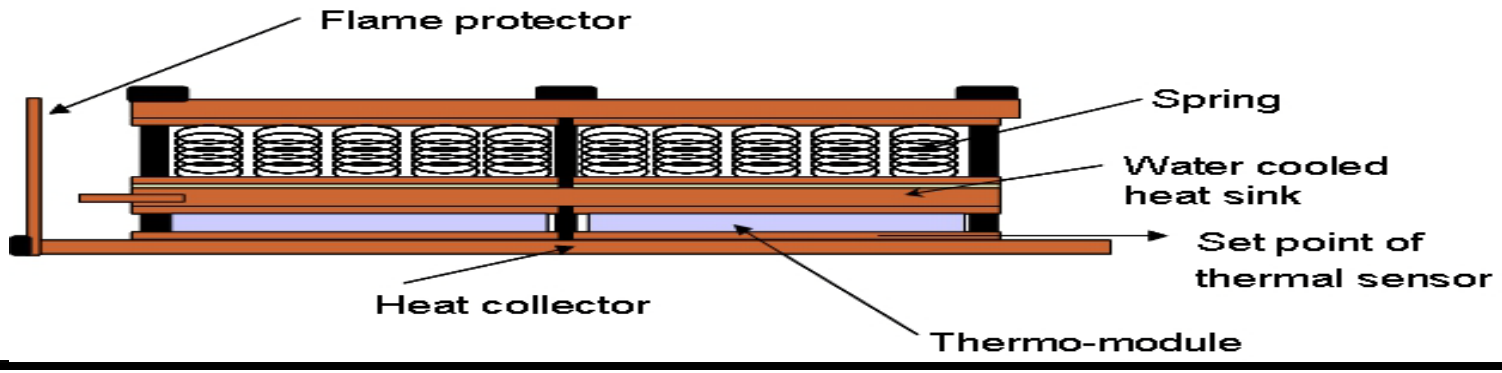
(a) Generator #1



(b) Generator #2

(a)Thermoelectric generator #1. Plain-type heat collector.
(b)Thermoelectric generator #2. Fin-type heat collector.

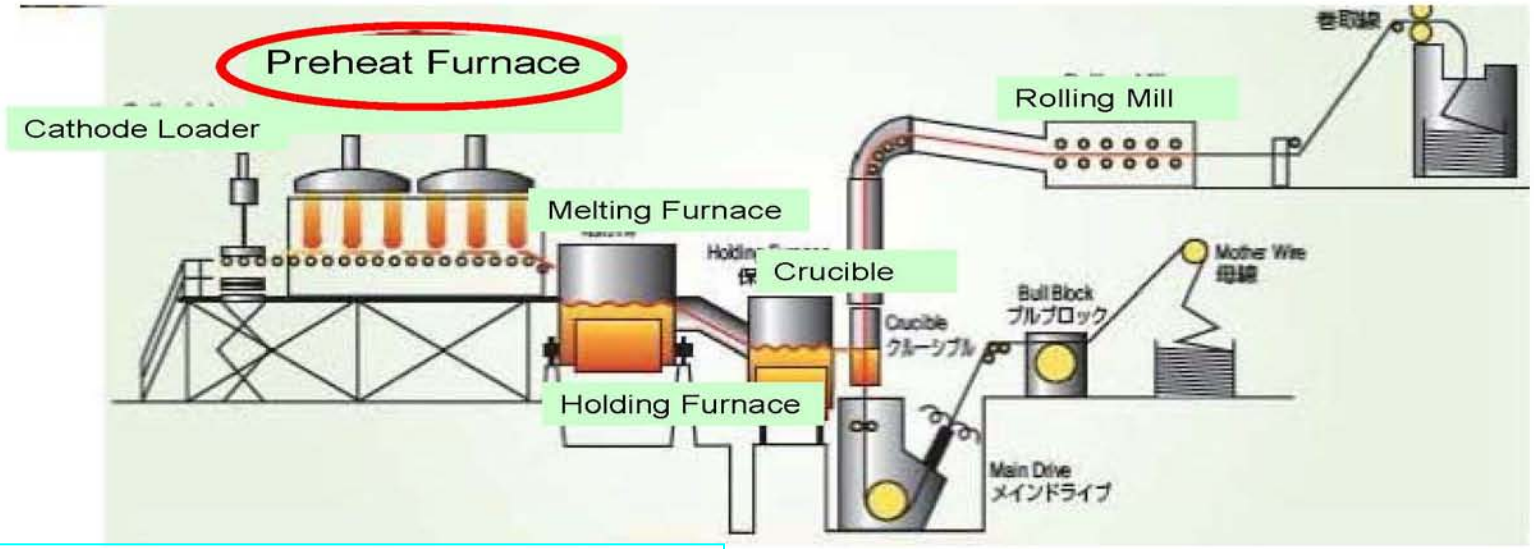
Test Results of TEG system for a gas carburizing furnace



Generator	Combustion heat (kW)	T_H (C)	Input heat (kW)	Output power (W)	Operation time (hours)
#1	21	200	3.5	153	2,000
#2	21	250	4.9	208	3,260

The overall system efficiency was about 4.4% for #1 generator and 4.2% for #2 one respectively. The conversion efficiency for the TE power conditioner with MPPT was obtained about 85%.

TEG Application to a preheating furnace for copper wire manufacture by SWCC Showa Cable Systems Co.Ltd.



Temperature is kept about 1123K.

Installation of test unit ,TEG module and Test results

Installed TEG unit
at the monitor hatch

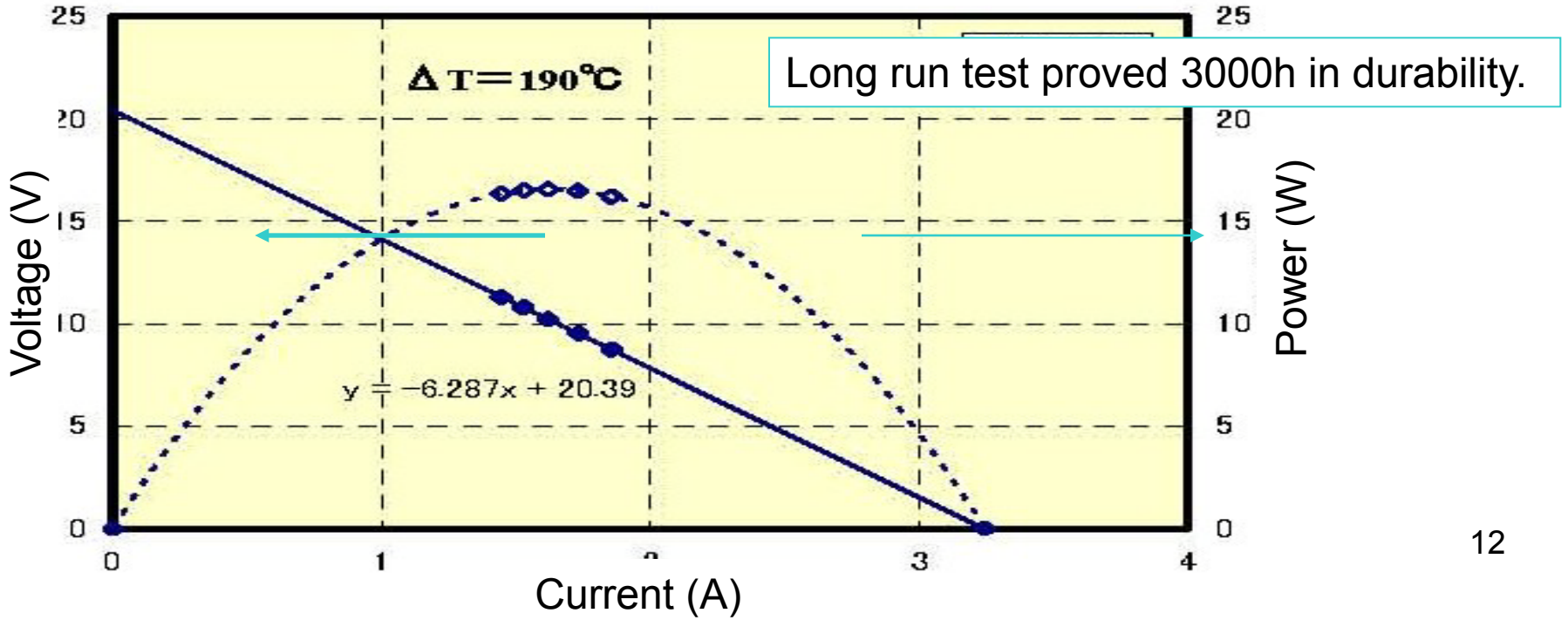
Module specification

55mmx110mmx7.5mm

24 couples made of layered oxides such as $LaNiO_3$ for n-type, and $Ca_3Co_4O_3$ for p-type.

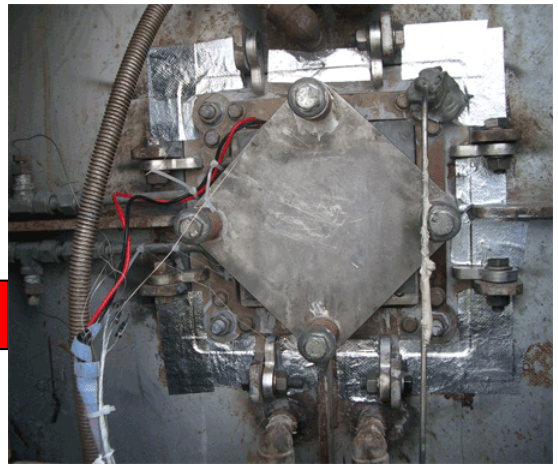
Max. ZT is 0.14 at 1123K.

Test unit consists of 32 modules.



Long run test proved 3000h in durability.

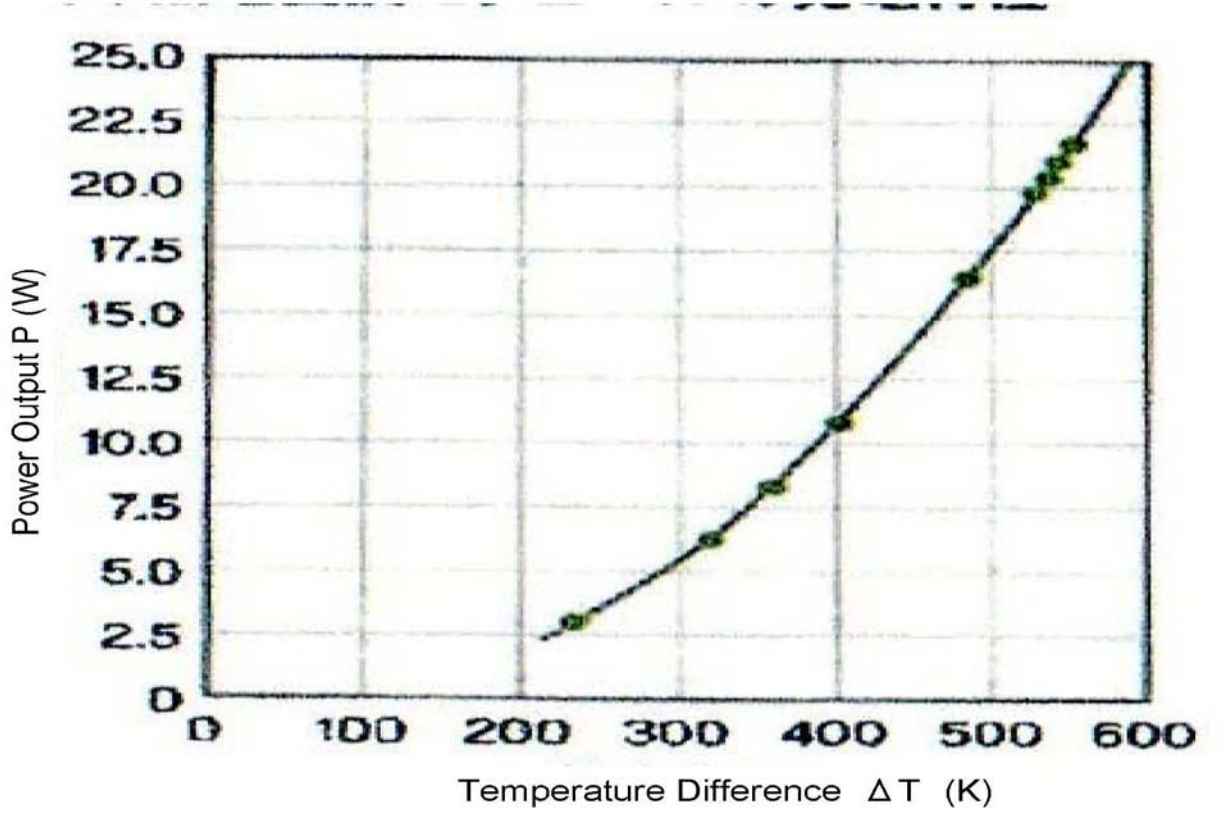
TEG Application to the recovery of the combustion heat for industrial solid waste incinerator **by PLANTEC and SHOWA DENKO**

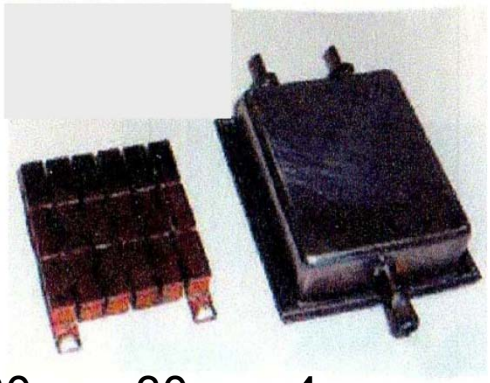


Overall view of the industrial solid waste incinerator system in Chiba Pref..

TEG unit was installed at the monitor hatch for the durability test.

Thermoelectric performance of the module based on the filled Skutterudites





30mmx30mmx4mm

18 couples

Ce-Co-Sb for n-type

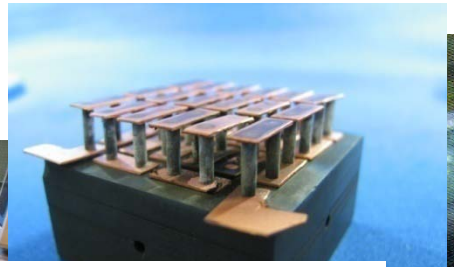
La-Fe-Sb for p-type

Power output was obtained 21.6W at 550K in temperature difference for a module. Power density was 2.4W/cm^2, and module efficiency was about 6%. The durability was proved over 3000h.

Waste heat recovery from Motorcycle

by ATSUMITEC Co.Ltd.

On the test bench



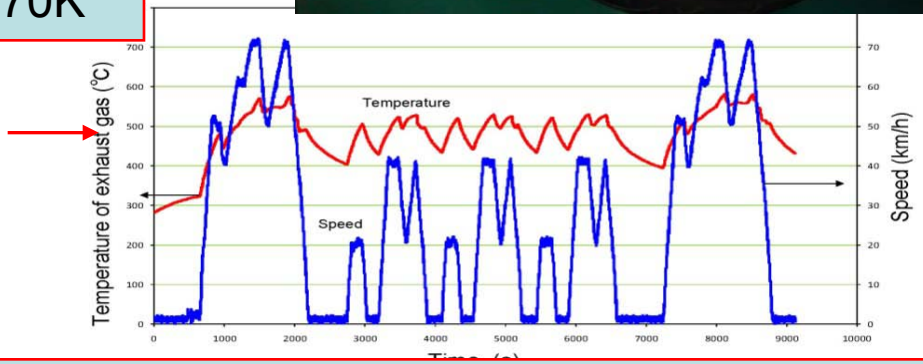
Heusler alloy TE module

823K to 670K

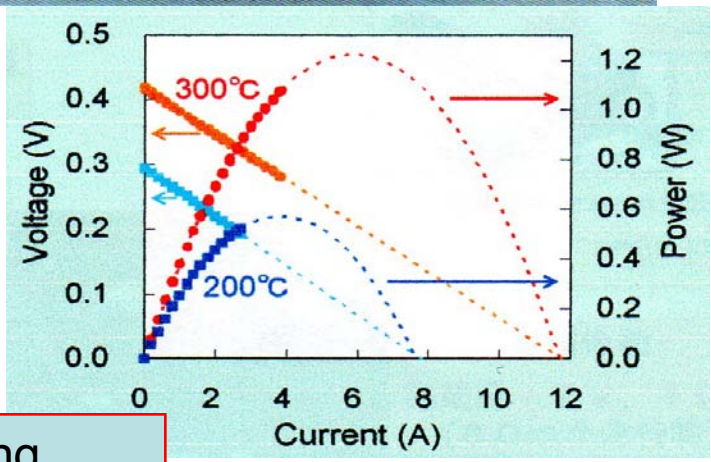
On the streets

TEG system

Load: LED Lighting

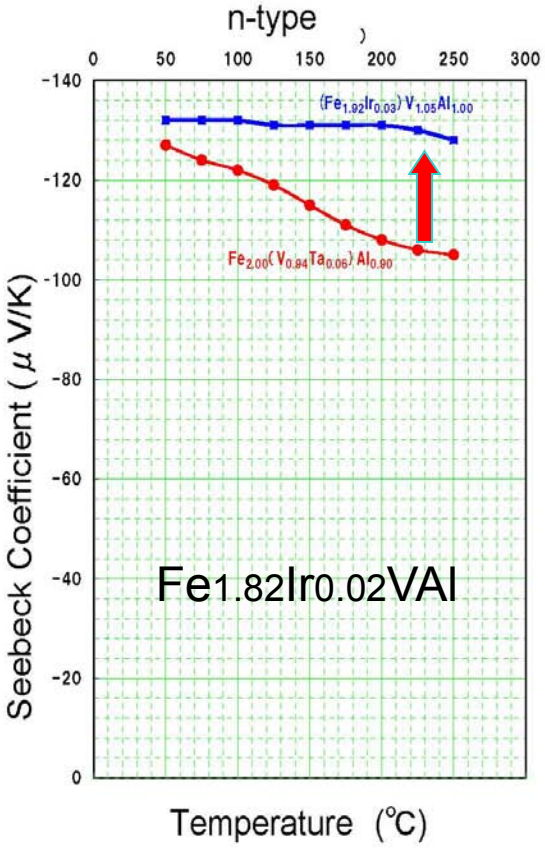


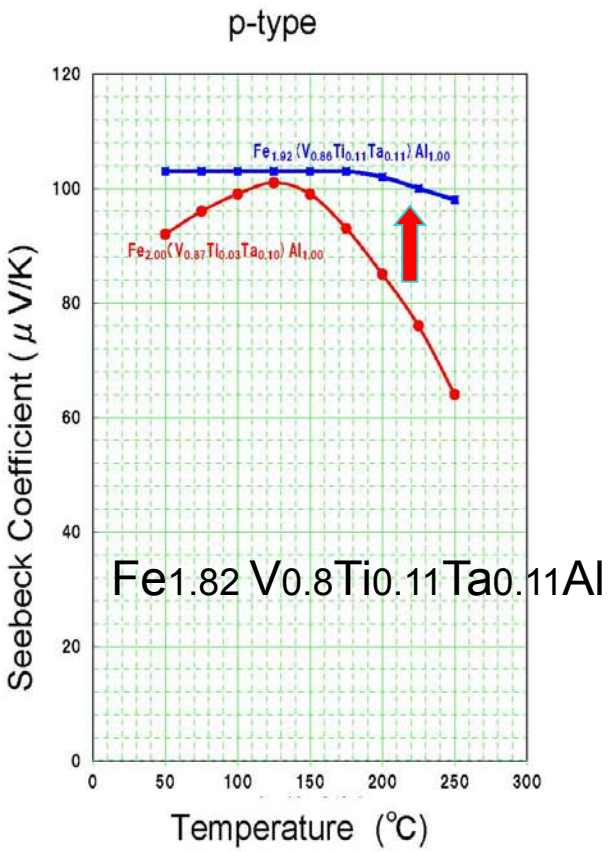
Time variation of exhaust gas temperature with driving modes; Mode variations are insensitive to gas temperature.

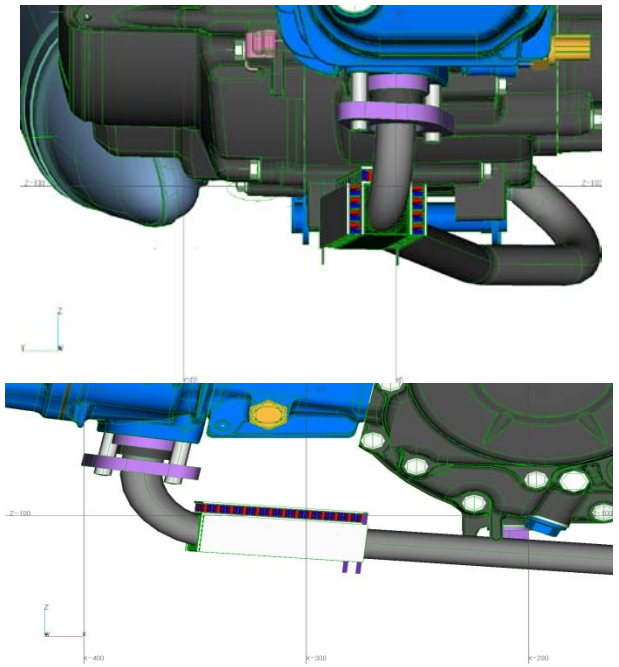


Power Characteristics

Improvement of TE performance for Heusler alloy







Advanced TEG unit design of 25mmx70mm mounted 12 modules

Goal: 2.5W/g, 1.4W/cm^2,0.3W/cm^3 at 300 K in ΔT

using Heusler alloy Fe$_2$VAl(Ir,Ti,Ta)

Renewable Energy Sources

Solar thermal energy

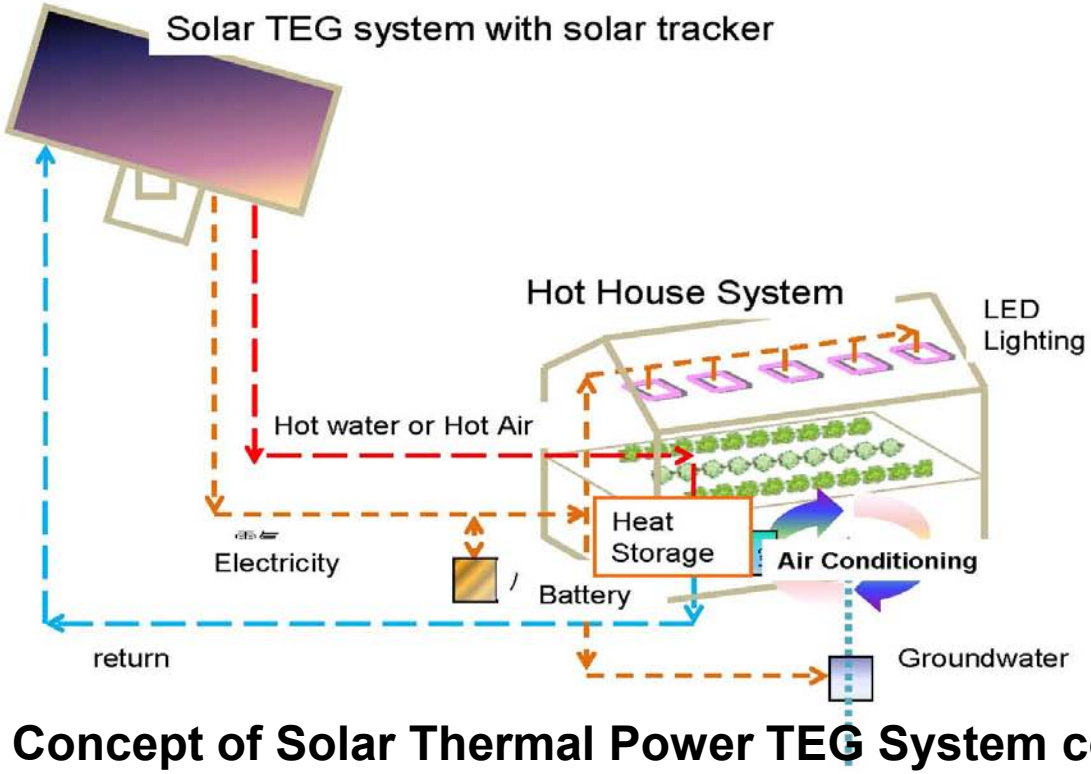
(JAXA group & China,TDS group)

Geothermal energy (Hot springs)

(TOSHIBA/Kusatsu)

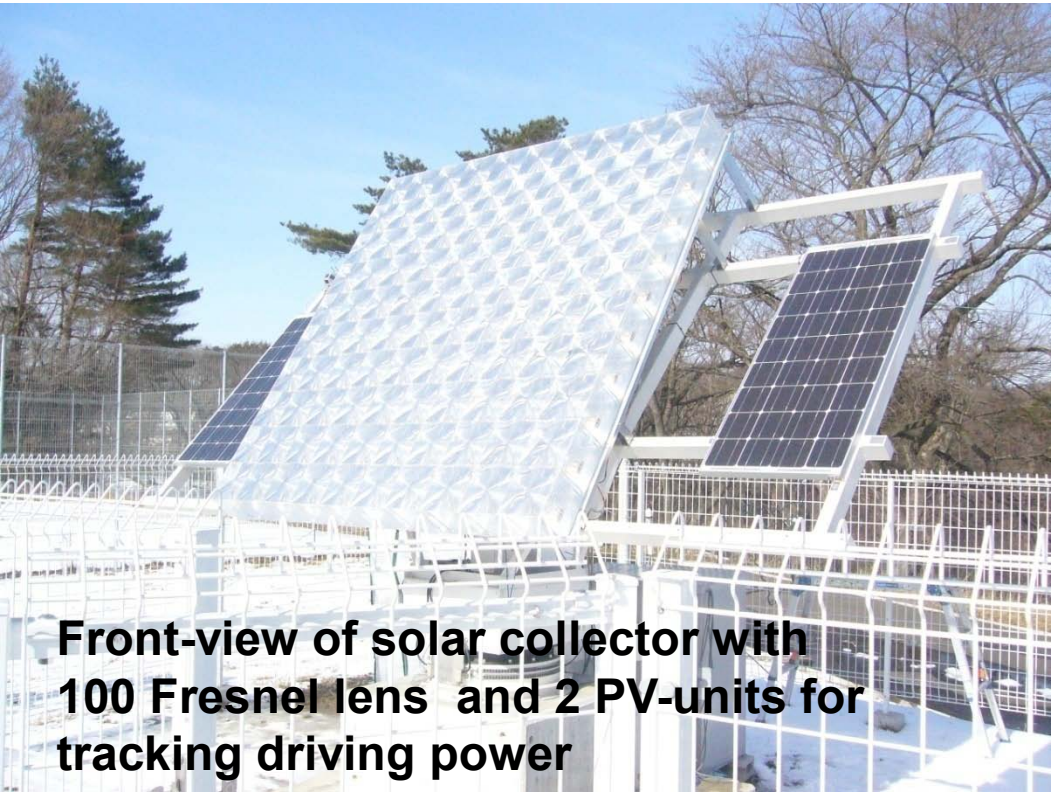
Development of Solar Thermo Hybrid Generation System

One of Strategic international Cooperative Program on Science and Technology : JAXA group and China



Concept of Solar Thermal Power TEG System combined with Hot House System

Demonstration solar thermal powered TEG test facility with solar tracker



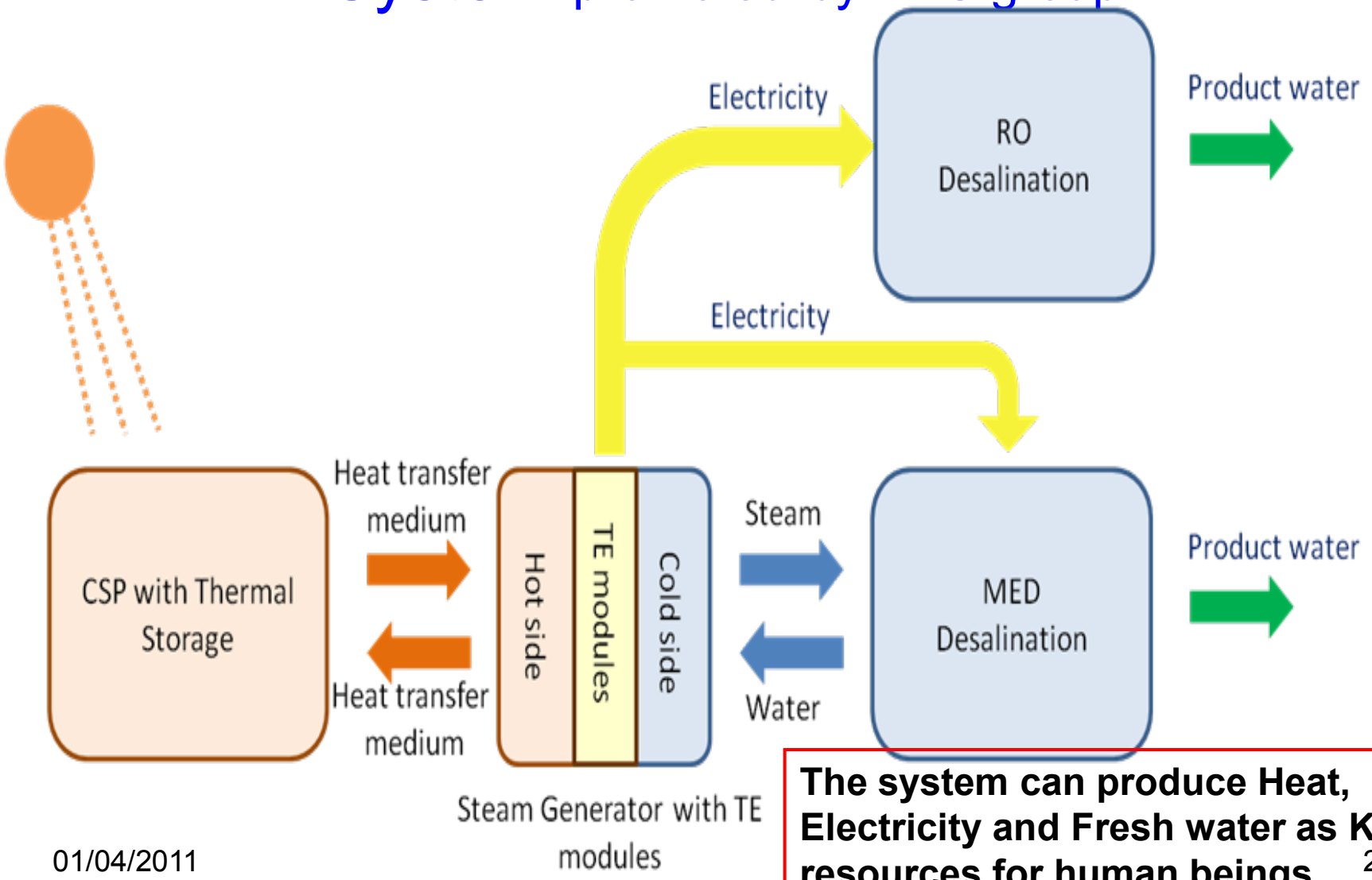
Front-view of solar collector with 100 Fresnel lens and 2 PV-units for tracking driving power

Inside view of single Fresnel lens collector

Back-view of the collector mounted TEG/Fin units

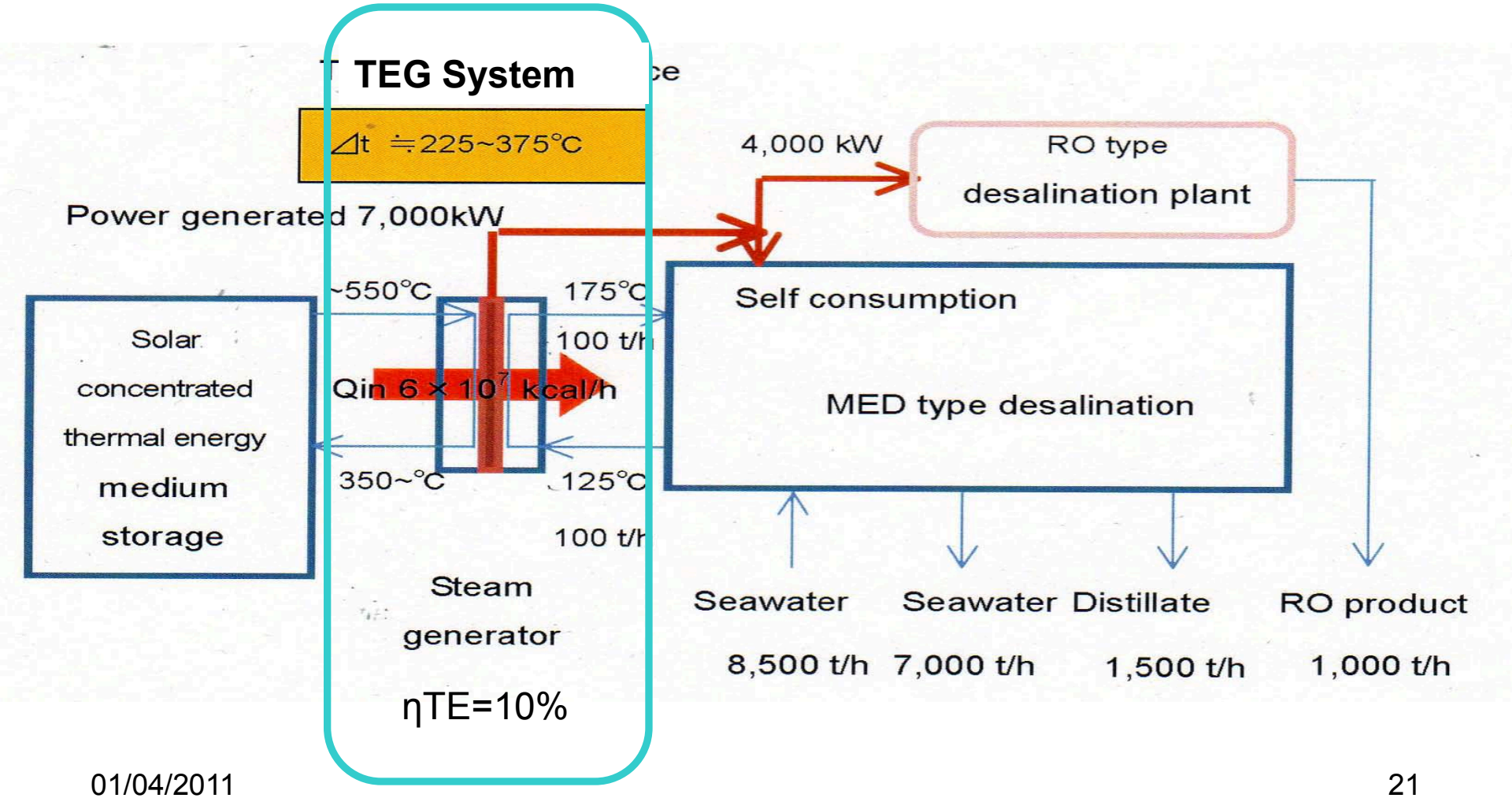
Surface temperature was obtained 563K, power output was only 0.65W although the rating value was 4W, because of unexpected thermal resistance in the system and insufficient tracking performance.

Solar Thermal Powered TEG /Desalination System promoted by TDS group



The system can produce Heat, Electricity and Fresh water as Key resources for human beings.

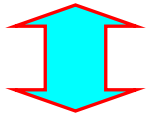
Conceptual Energy Balance & Temperature Allocations



Cost Competitiveness

Fresh water cost :

0.99 US$/$m^3$ by the proposed concept



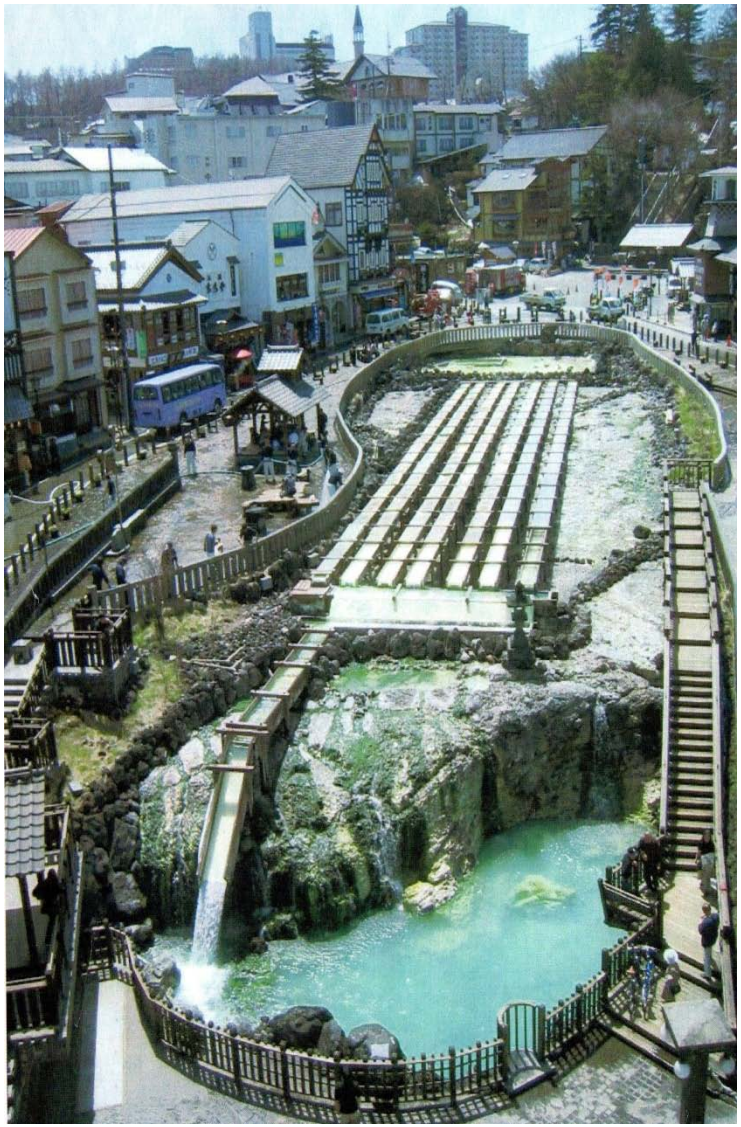
1.3 US$/$m^3$ by PV/Desalination Plant

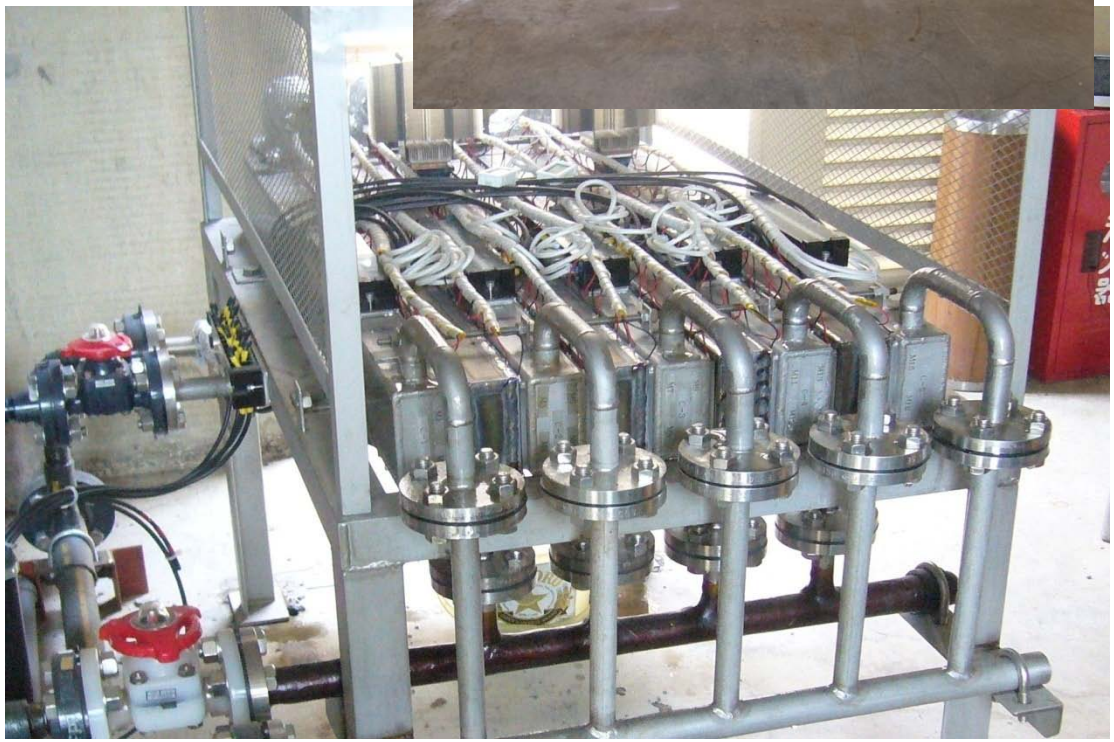
Assumptions for the cost estimation:

Capacity:10,000t/d、 Plant availability:0.9, Site: the Middle East, Plant Life: 20years, Inflation rate:2.0%, Construction year:2010, Efficiency of TEG:5%, Efficiency of PV:20%

Continuation in Kusatsu Hot-springs TEG System

by TOSHIBA /Kusastu





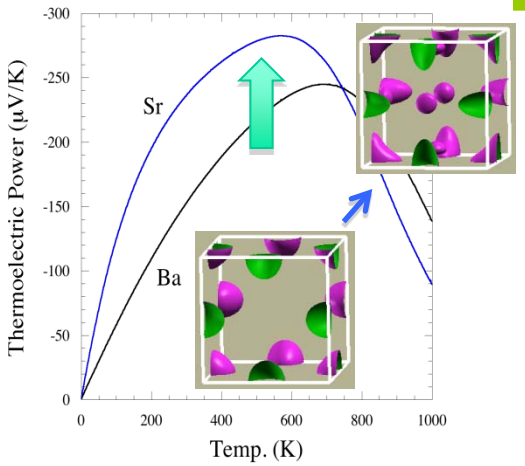
Future Prospects

- Two major projects aiming the enhancement of thermoelectric performance supported by the government (NEDO,JST)
- Development of TEG Power Management Technology
- Roadmap for TEG Applications

NEDO project "Development of Nano-Structured Thermoelectric Materials using Clathrates" FY2009-2011

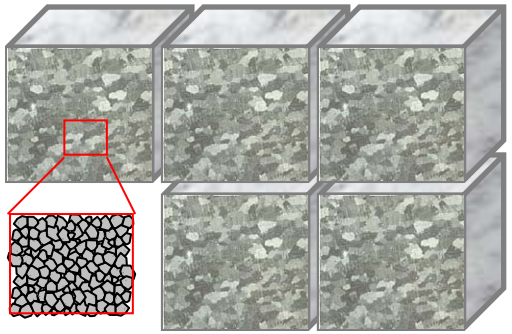
Design of novel clathrates by first-principle calculations

Yamaguchi Univ.



Synthesis of single crystals toward higher ZT

Hiroshima Univ.

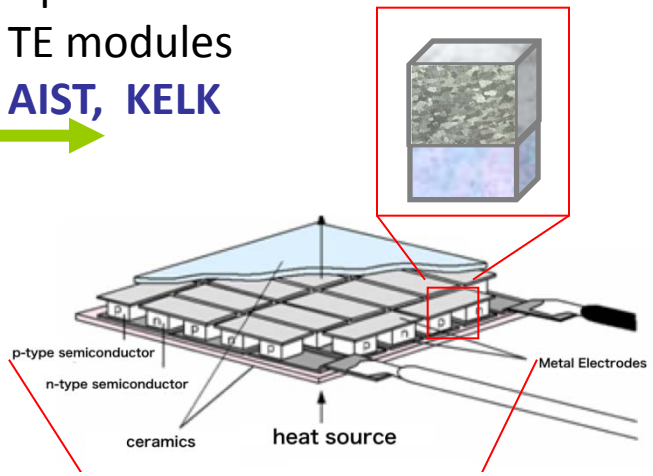


Synthesis of bulk materials for modules by sintering technique

Yamaguchi Univ.

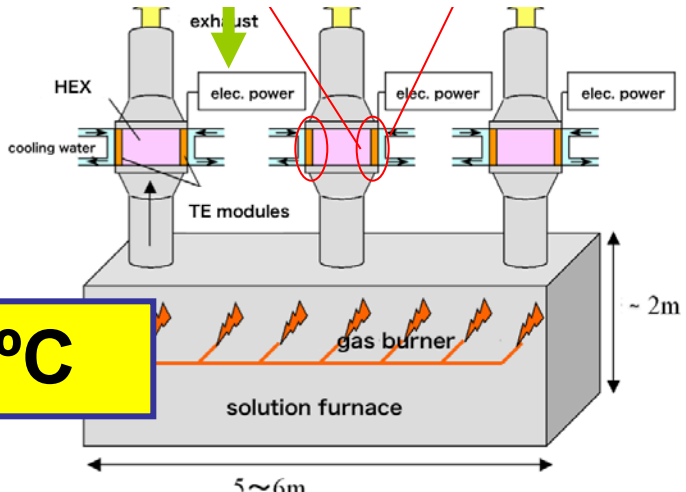
Optimization of TE modules

AIST, KELK



Design of TE power generation unit for furnaces

DENSO 500 W/unit



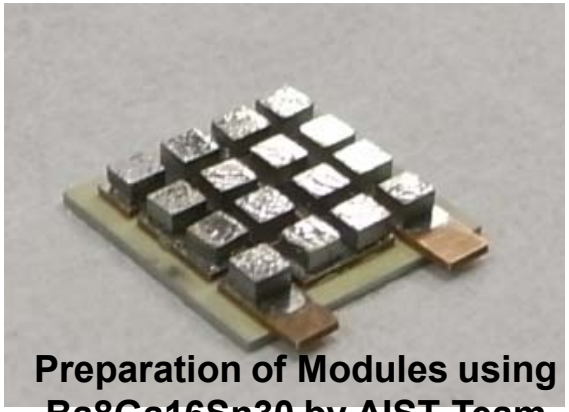
Project Goal; *ZT*=1.3 at 200-300 ºC

ZT for type-VIII $Ba_8Ga_{16}Sn_{30}$ and Al substituted samples

1. ZT values are 1.0 for n-type, and 1.2 for p-type around 200 C.

2. A module of p- and n-types can be made from the same compound.

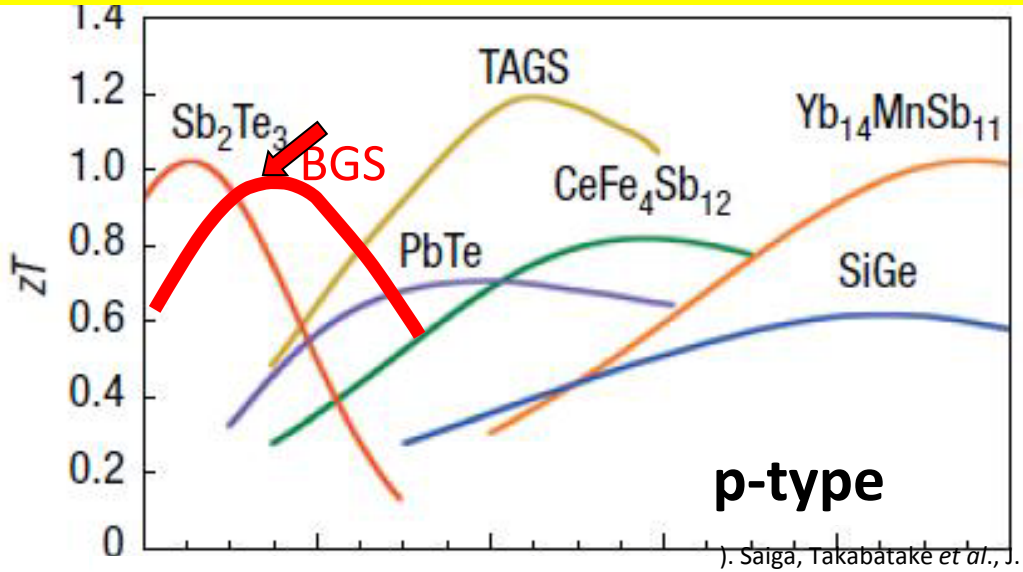
3. Preparation of Module was successful.



Preparation of Modules using Ba8Ga16Sn30 by AIST Team

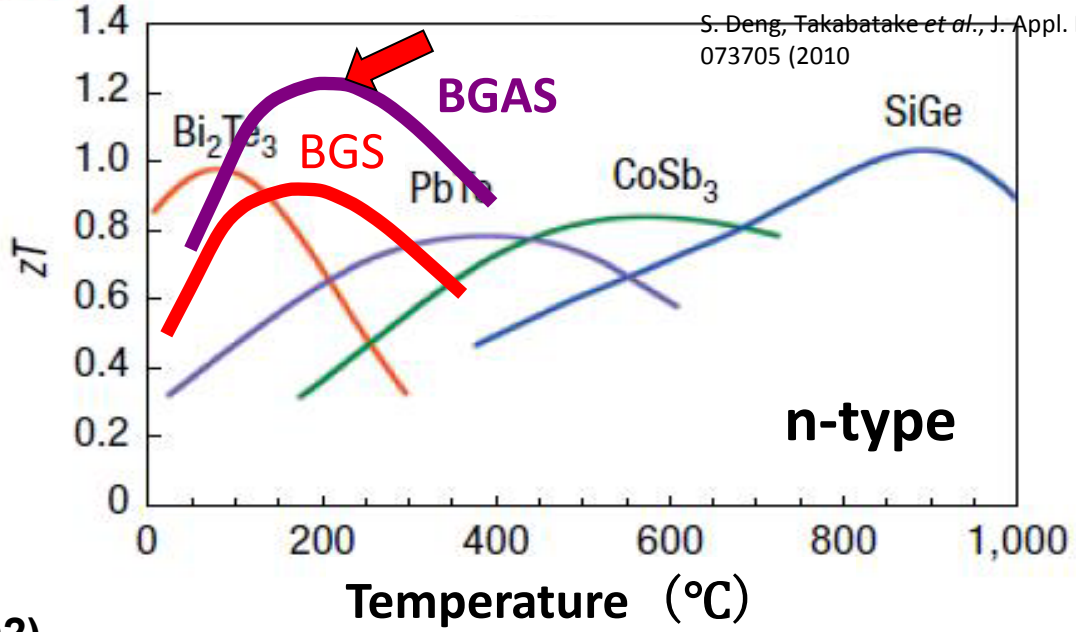
01/04/2011

Power Output: 1.7W (217 mW/cm2)



). Saiga, Takabatake *et al.*, J. Alloys and Compds, 507, 1 (2010).

S. Deng, Takabatake *et al.*, J. Appl. Phys. 108, 073705 (2010



Japan Science and Technology Agency - CREST Project

<2008.10.1 ~ 2014.3.31>

"Exploration of Innovative Technology
to Reduce Carbon Dioxide Emission"

Development of High-Efficiency Thermoelectric Materials and Systems

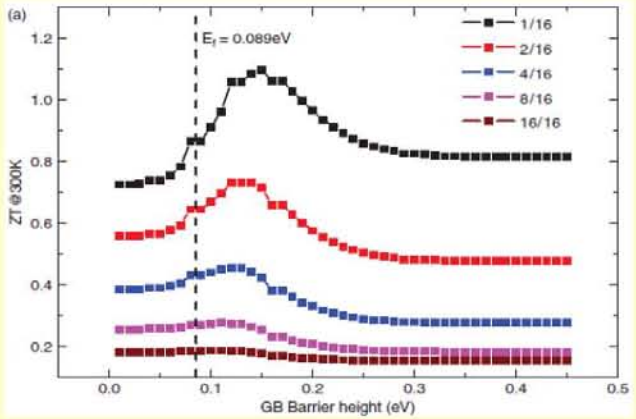
K. Koumoto (Nagoya University)

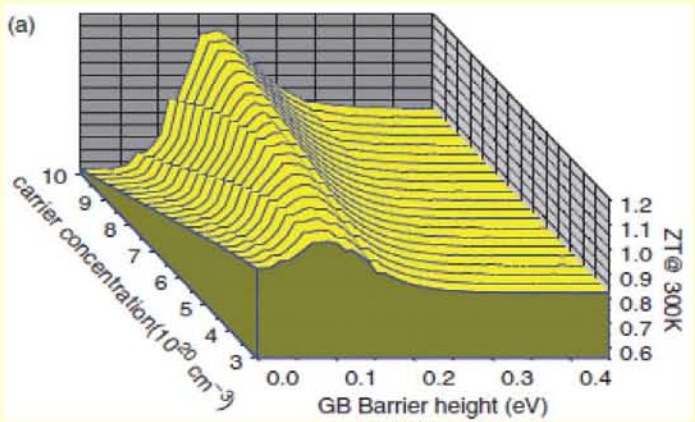
Nontoxic, Nonhazardous, Nat. Abundant Elements !

Collaborating Group Leaders:
R. Funahashi (AIST)
H. Anno (Tokyo Univ. of Sci.)
R. Suzuki (Hokkaido Univ.)

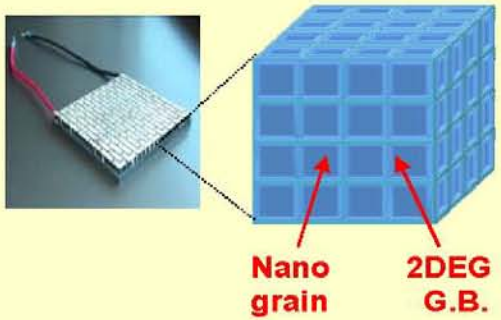
3D Superlattice Ceramics

Nanocube of La-doped SrTiO3 modifying grain boundary with 2DEG Nb-doped SrTiO3

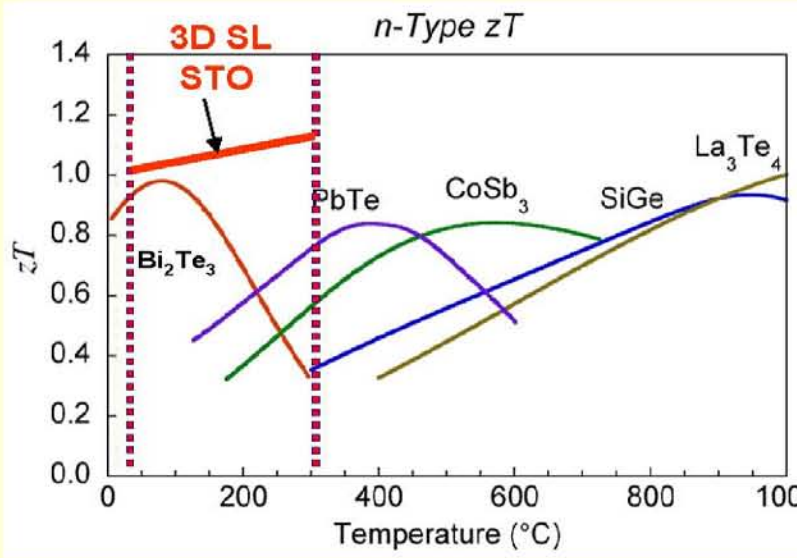




3D Superlattice Ceramics

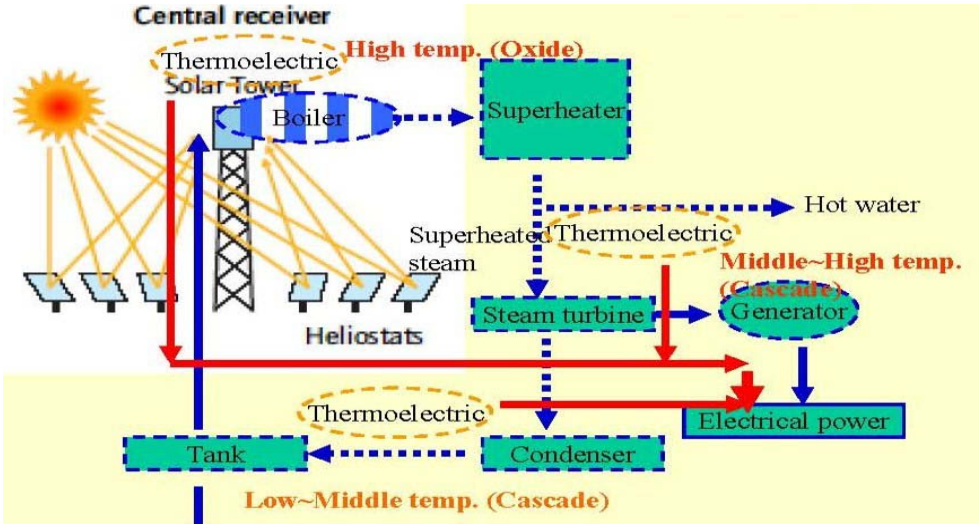


***ZT* of 3D superlattice ceramics can reach ~1.0 @ 300K which is comparable to that of n-Bi_2Te_3 !!!**

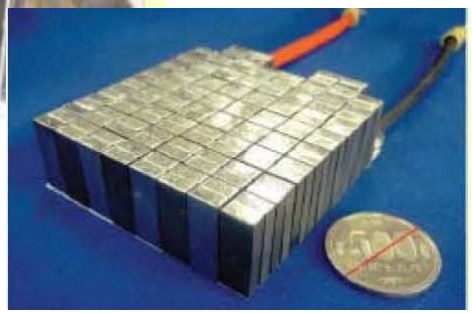


TEG Applications in CREST Project

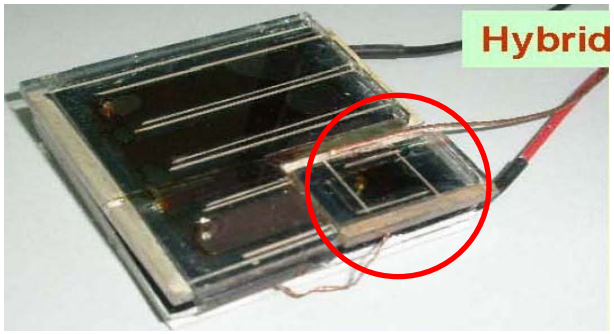
- Waste Heat Recovery from various sectors of our society, industries, infrastructures, public welfare, transportations
- Renewable Energy such as Solar Energy



Concept of Solar Thermal TEG

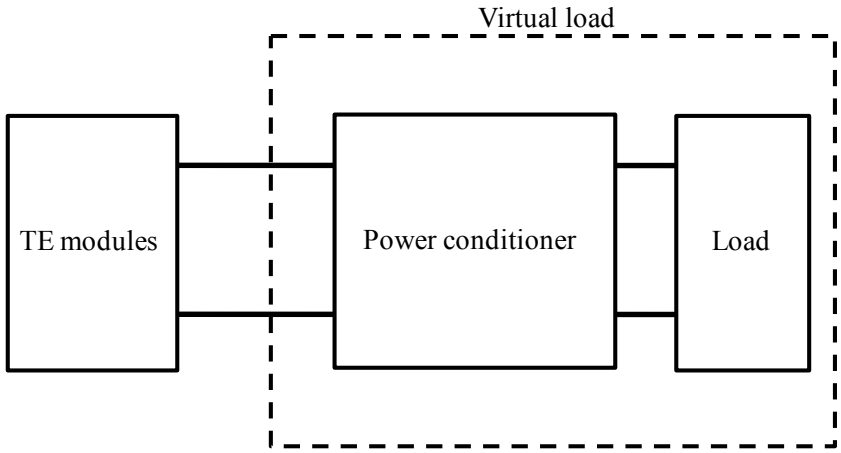


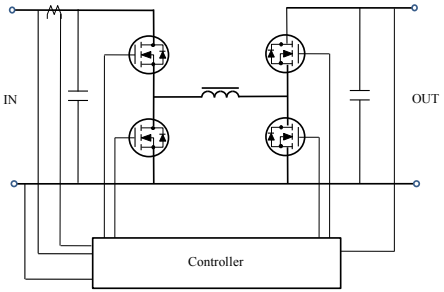
Waste heat recovery TEG using Oxide modules



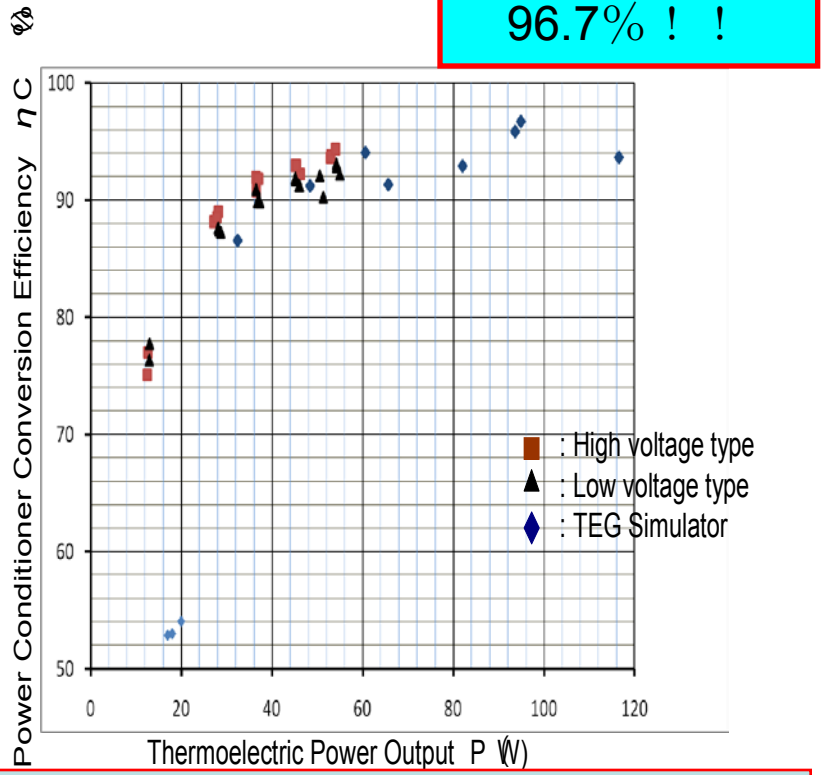
Hybrid solar cell composed of dye-sensitized solar cell and TEG

Development of TEG power management technology

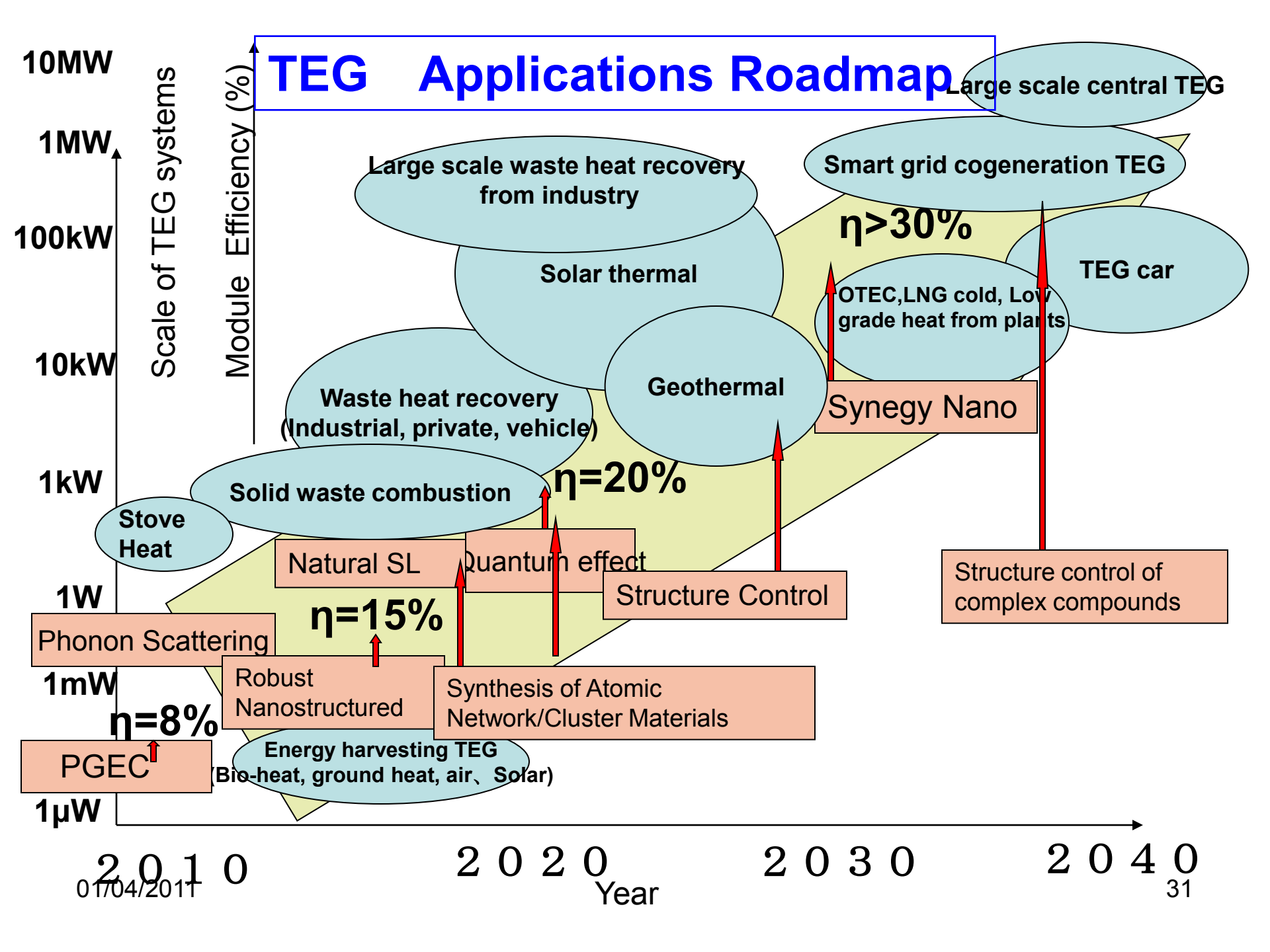




96.7% ！ ！



The DC-DC converter installed MPPT (Maximum Power Point Tracking) control has been successfully developed to achieve 96.7% in conversion efficiency as a 100W class power conditioner.


TEG Applications Roadmap
10MW
1MW
100kW
10kW
1kW
1W
1mW
1μW
Scale of TEG systems
Module Efficiency (%)
Large scale central TEG
Large scale waste heat recovery from industry
Smart grid cogeneration TEG
η>30%
Solar thermal
TEG car
OTEC,LNG cold, Low grade heat from plants
Geothermal
Waste heat recovery (Industrial, private, vehicle)
Synegy Nano
Solid waste combustion
η=20%
Stove Heat
Natural SL
Quantum effect
Structure Control
Structure control of complex compounds
η=15%
Phonon Scattering
Robust Nanostructured
Synthesis of Atomic Network/Cluster Materials
η=8%
PGEC
Energy harvesting TEG
(Bio-heat, ground heat, air、Solar)
2010
2020
2030
2040
Year

Conclusions

- **Several ongoing demonstration tests on TEG systems applying to various fields such as industrial furnace, solid waste incinerator, motorcycle and solar thermal energy system have been actively progressed by private companies mostly. Durability of TEG systems for practical fields is the key at the next stage.**
- **The establishment of the advanced thermoelectric material technology is the urgent matter on the realization of TEG system in the society. Two ongoing national projects are introduced, in which the goal in ZT is 1.3~1.5 for the medium and wide temperature range applications.**
- **The roadmap on TEG systems is presented for forthcoming 30 years as well as the prospect on the enhancement of module efficiency with several key-words of materials innovation.**

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