Overview of Thermoelectric Power Generation Technologies in Japan

Takenobu Kajikawa,
Shonan Institute of Technology,
Fujisawa, Kanagawa, 251-8511 JAPAN
kajikawa.tk@sand.ocn.ne.jp
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
- Hot-springs TEG · · · (II)
- TEG Wristwatch · · · (III) Kusatsu Hot springs

150W / 4.5 years run
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)
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.
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

TH = 250 -50 °C and TC = 30 °C in air.
TEG systems tested using two types of heat collector

(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

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

Module specification
55mm×110mm×7.5mm
24 couples made of layered oxides such as \( \text{LaNiO}_3 \) for n-type, and \( \text{Ca}_3\text{Co}_4\text{O}_3 \) 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.

01/04/2011

TEG unit was installed at the monitor hatch for the durability test.
Thermoelectric performance of the module based on the filled Skutterudites

Power output was obtained 21.6W at 550K in temperature difference for a module. Power density was 2.4W/cm², 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

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

Goal: 2.5W/g, 1.4W/cm², 0.3W/cm³ at 300 K in ΔT

using Heusler alloy Fe₂VAI(Ir,Ti,Ta)

01/04/2011
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

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

**TEG System**

- $\Delta t \approx 225-375^\circ C$
- Power generated: 7,000kW
- Solar concentrated thermal energy medium storage
- $\eta_{TE}=10\%$

**Diagram Details**

- $Q_{in} = 6 \times 10^7$ kcal/h
- 4,000 kW
- RO type desalination plant
- Self consumption
- MED type desalination
- Seawater: 8,500 t/h
- Seawater Distillate: 7,000 t/h
- RO product: 1,500 t/h
- RO product: 1,000 t/h
Cost Competitiveness

Fresh water cost:

- 0.99 US$/m³ by the proposed concept
- 1.3 US$/m³ by PV/Desalination Plant

Assumptions for the cost estimation:

- Capacity: 10,000t/d
- Plant availability: 0.9
- Site: the Middle East
- Plant Life: 20 years
- 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.

Optimization of TE modules
AIST, KELK

Synthesis of bulk materials for modules by sintering technique
Yamaguchi Univ.

Project Goal; $ZT=1.3$ at 200-300 °C
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.

Power Output: 1.7W (217 mW/cm²)
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.)
Nanocube of La-doped SrTiO3 modifying grain boundary with 2DEG Nb-doped SrTiO3

ZT of 3D superlattice ceramics can reach ~1.0 @ 300K which is comparable to that of n-Bi₂Te₃ !!!
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

350W TEG system

Waste heat recovery TEG using Oxide modules

Concept of Solar Thermal TEG

Hybrid solar cell composed of dye-sensitized solar cell and TEG
Development of TEG power management technology

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

- Energy harvesting TEG (Bio-heat, ground heat, air, Solar)
- Waste heat recovery (Industrial, private, vehicle)
- Solar thermal
- Large scale waste heat recovery from industry
- Geothermal
- Solid waste combustion
- Quantum effect
- Structure control of complex compounds
- OTEC, LNG cold, Low-grade heat from plants
- Smart grid cogeneration TEG
- TEG car
- Large scale central TEG

Module Efficiency (%)

Year

- Energy harvesting TEG (Bio-heat, ground heat, air, Solar) η=8%
- Phonon Scattering η=15%
- Solid waste combustion η=20%
- Waste heat recovery (Industrial, private, vehicle) η=20%
- Solar thermal η=15%
- Geothermal η=15%
- Quantum effect η>30%
- TEG car
- Large scale central TEG
- Smart grid cogeneration TEG
- TEG car
- Large scale central TEG

Scale of TEG systems

- 10MW
- 1MW
- 100kW
- 10kW
- 1kW
- 1W
- 1mW
- 1μW

Structure Control of Complex Materials

PGEC

Synthesis of Atomic Network/Cluster Materials

Robust Nanostructured

Natural SL

Structure Control

01/04/2011
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.
The author would like to express his hearty gratitude to

Dr.H.Kaibe, KOMATSU,
Mr.K.Nakajima, Showa Denko Co.Ltd.,
Mr. M.Minowa, SWCC SHOWA CABLE SYSTEMS Co.Ltd.,
Mr.Y.Uchiyama, ATSUMITEC Co.Ltd.,
Dr.M.Niino, JAST, Dr.K.Kisara, JAXA
Prof. Y.Horita, Tokyo Institute of Tech., Dr.Y.Saito, JGC Corp.,
Prof. T.Takabatake, Hiroshima University,
Prof. K.Koumoto, Nagoya University, and
Mr.T.Oishi, Mr.T.Shindo, TOSHIBA
for their cooperation and sincere support.

Thank you for your kind attention!