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Development of Micro Cogeneration System with a Porous Catalyst Microcombustor

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Outline

1. Background & concept of micro-combustor
2. Characteristics of the combustor and the thermo-electric modules
3. Characteristics of the micro-blower
4. Design point of self-standing generation system and its performance
5. Summary

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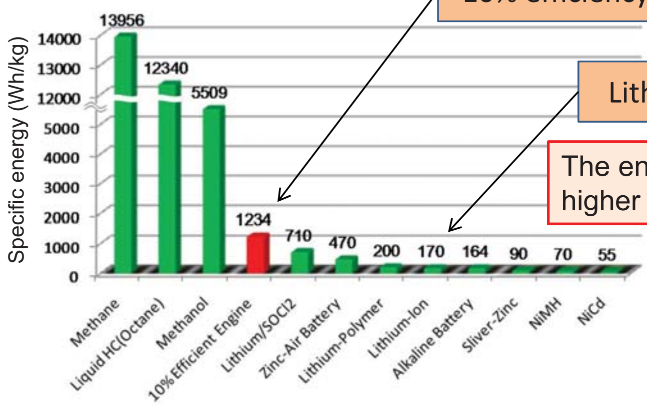
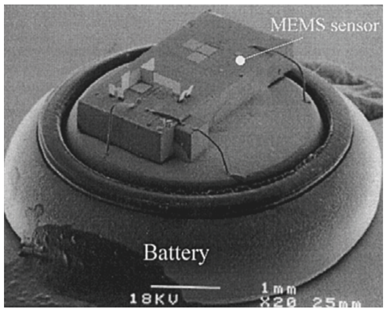
Background



10% efficiency engine

Lithium-ion battery

The energy density of the hydrocarbon is much higher than those of the conventional batteries.



Quenching problem

- Combustion in a narrow tube is suppressed due to large heat loss to the surroundings.
- The quenching diameter of methane-air flame is about 3mm in the normal condition.

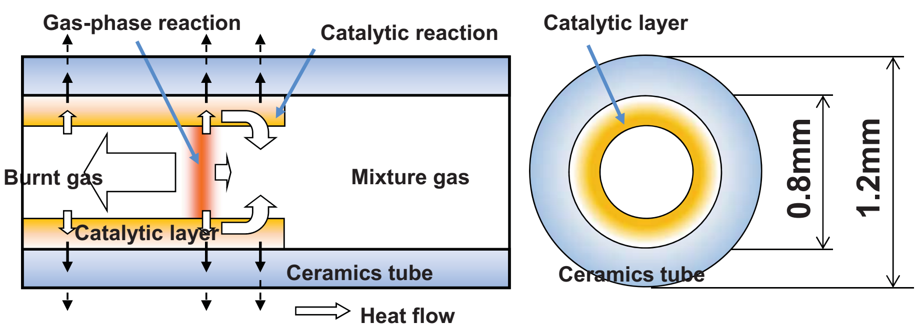
Concept of our microcombustor

■ Catalyst assisted gas-phase reaction

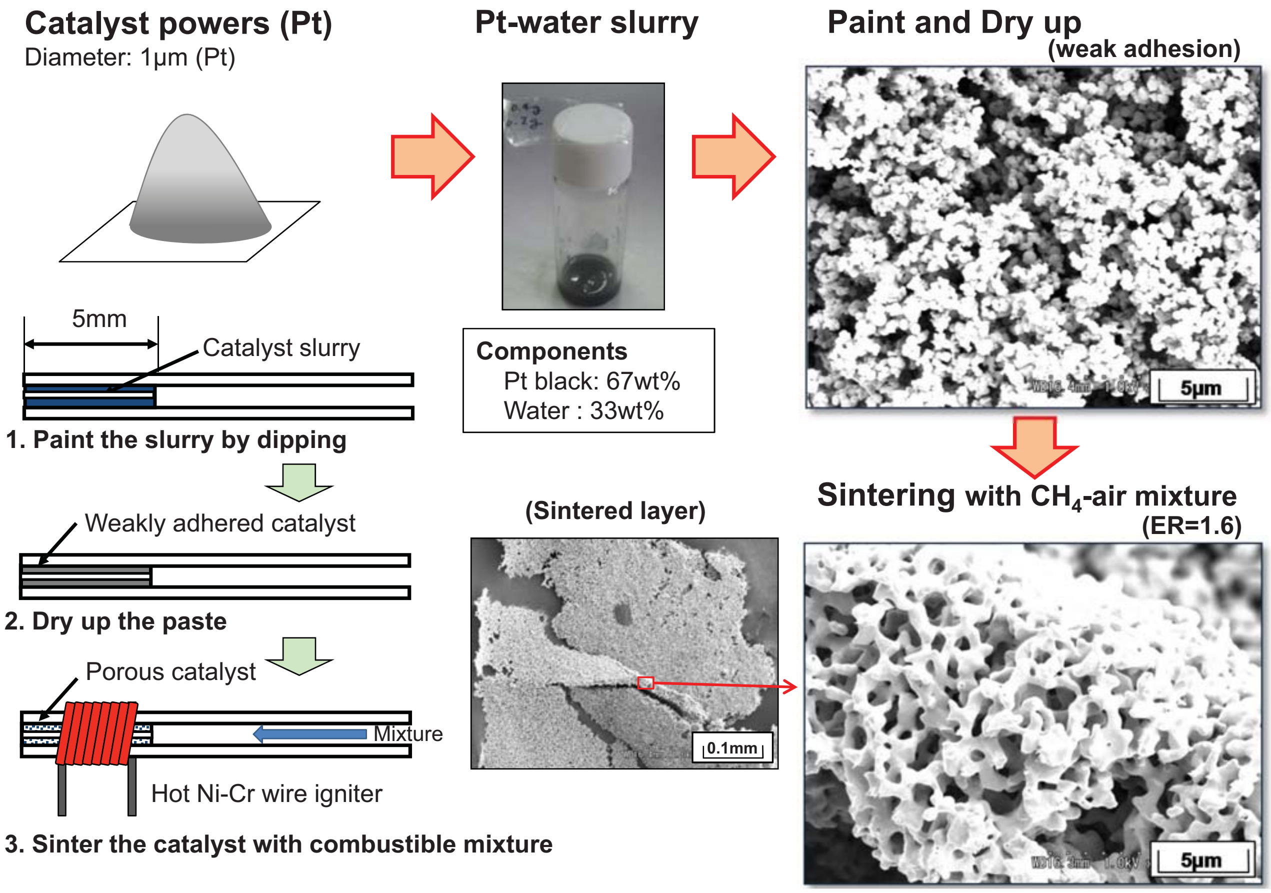
A part of mixture occur surface reaction that sustain gas-phase reaction of the rest mixture.

1. Porous Pt catalyst: large surface area to obtain sufficient reaction heat
2. Ceramics wall: low thermal conductivity to suppress the heat loss
3. Low blockage: low pressure drop to achieve high-load gas-phase combustion

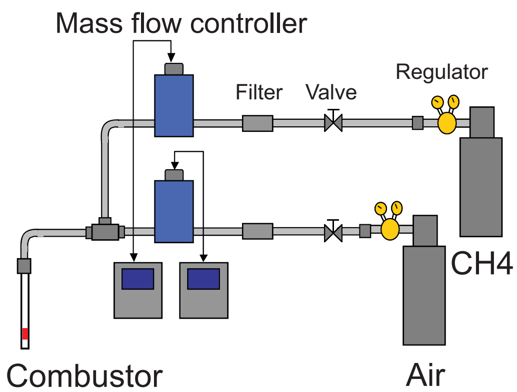
Porous thin catalytic layer on the inner wall of the ceramics tube



Fabrication of the porous catalytic layer

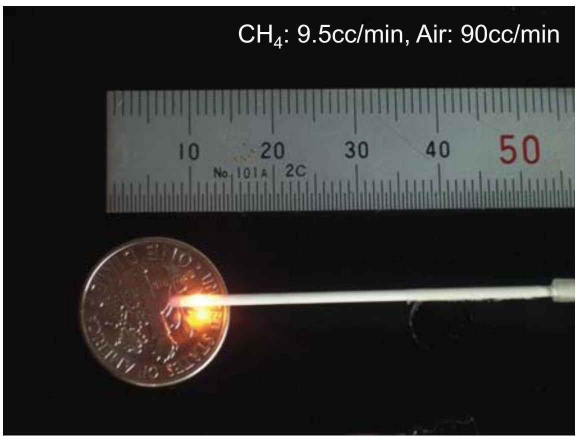


Characteristics of the microcombustor



Mixture: methane-air
Flow rate: 20-200cm^3/min@293K
Equivalence ratio: 0.6-8.0

Tube diameter: ID=0.8mm, OD=1.2mm
Material: mullite ceramics ($3Al_2O_3/2SiO_2$)
Catalyst: platinum (Pt)
Sintering condition: ER=1.6



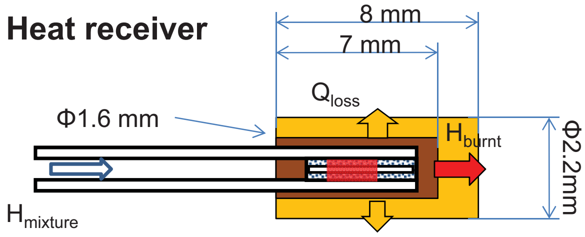
Features

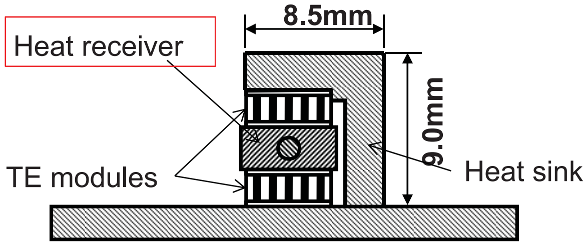
1. Very small output that allows human portability.
   Output:~5W
   (min. 1.04W, max 10.4W) High turndown ratio
2. Very large energy release density
   Output/Vol.:~5GW/m^3
   (Tube i.d.~0.8mm, high temp. zone length~2mm)
   Output/Area:~10MW/m^2 (@ tube exit)
3. High exhaust gas temperature: **>1100K**
4. Wide flammability **(Equivalence ratio: 0.8 ~ 8.0)**
5. High durability **(~1000 hours)**
6. Low product cost ($2.00 per tube at lab. Level)

Coupling with Bi-Te thermo-electric modules

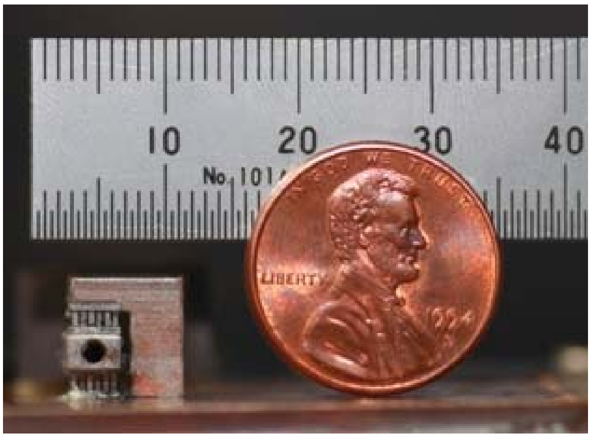
TE modules are installed between the heat receiver and the heat sink.

High temperature source: Copper block heated wit the microcombustor
Low temperature source: Environment through the back plate



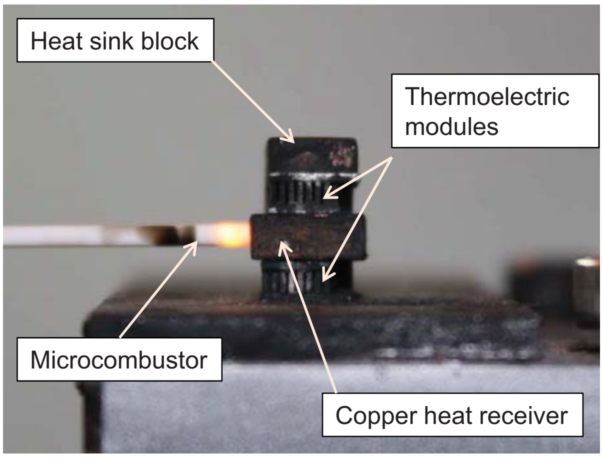


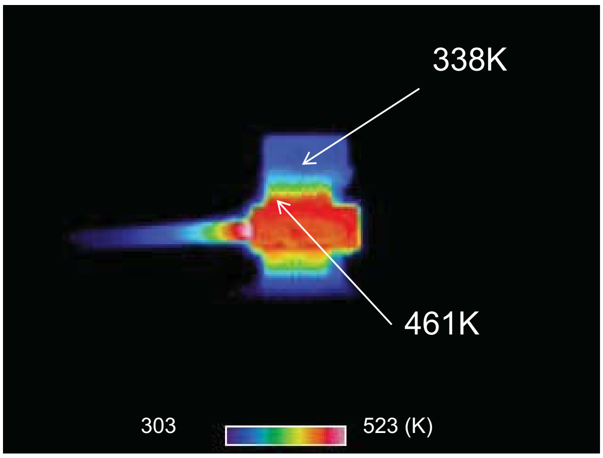
Front view



IR image of the co-generator

Side view



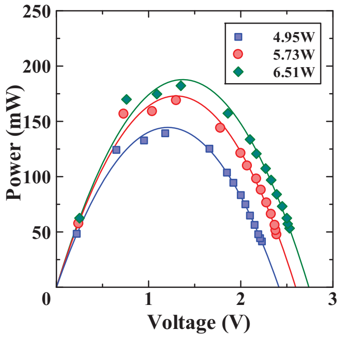


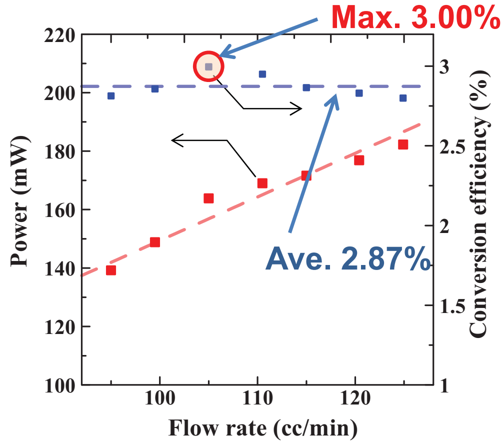
Thermoelectric modules: **Bi-Te** 1MD04-017-12 (RMT Ltd)
Size: 3.8mm x 3.8mm x t2.3mm
Performance: Z=2.4 x 10^{-3}/K (ZT=0.72@300K)

- Maximum allowed temperature of the above TE modules was 500K, therefore, the size of the TE module was selected so that the maximum temperature does not exceed 500K.

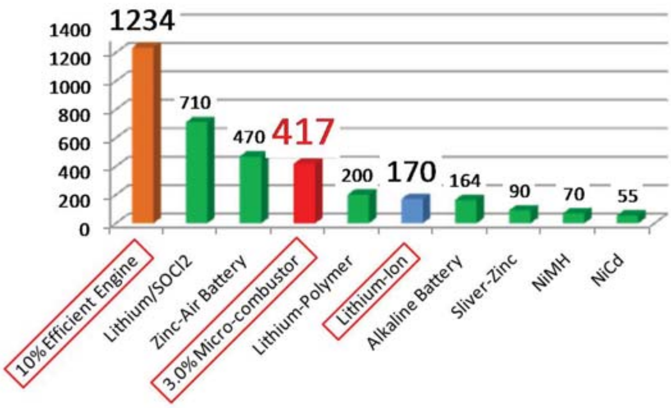
Electricity from the micro-cogenerator

Methane (ER=1.0)



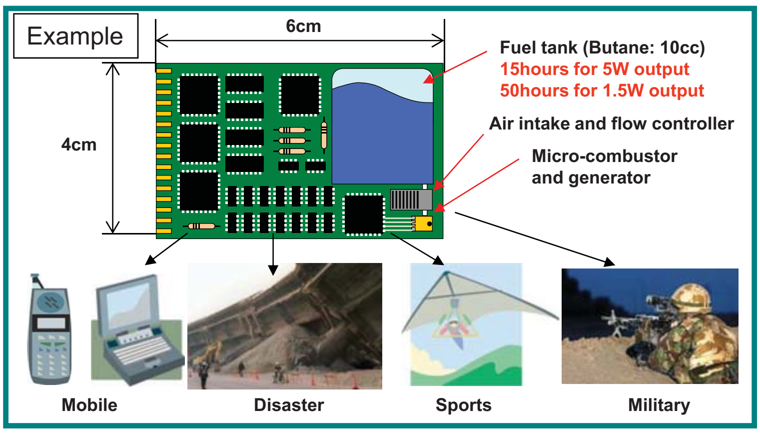


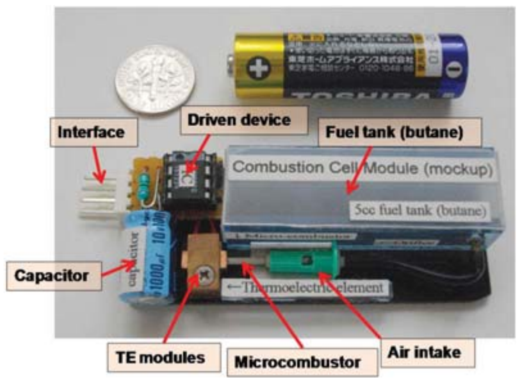
Averaged efficiency: **2.87%**
Champion record: **3.00%**
Energy density: **417Wh/kg**
Matching resistance: **10 Ω**
Mean voltage: **1.28V**



Issues to set up self-standing cogeneration system

- Compressed fuel, such as butane, can be supplied easily, but supply of air to the combustor is hard when the dimension is small.
- Large pressure drop due to catalyst layer and high temperature are expected.
- Control of air flow rate is difficult by entrainment method.





Forced air supply is preferable.

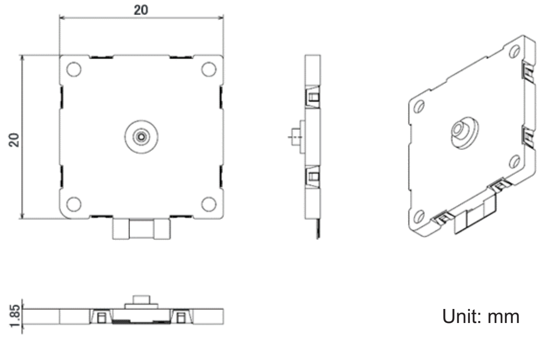
⇨ Micro-blower driven by the generated electricity

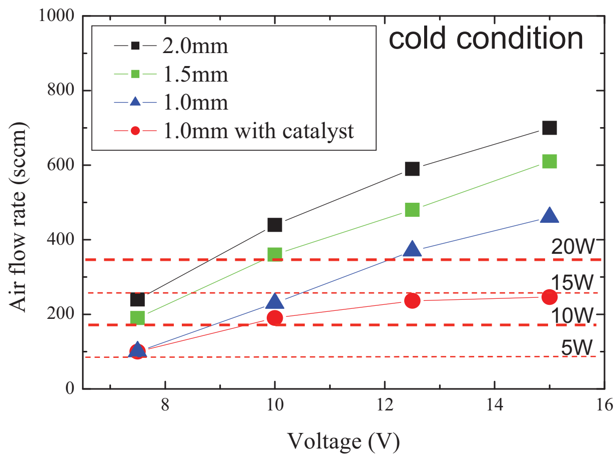
Micro-blower (Murata Manufacturing Co., Ltd.)

- 20x20x1.85mm
- Diaphragm is vibrated by piezoelectric element

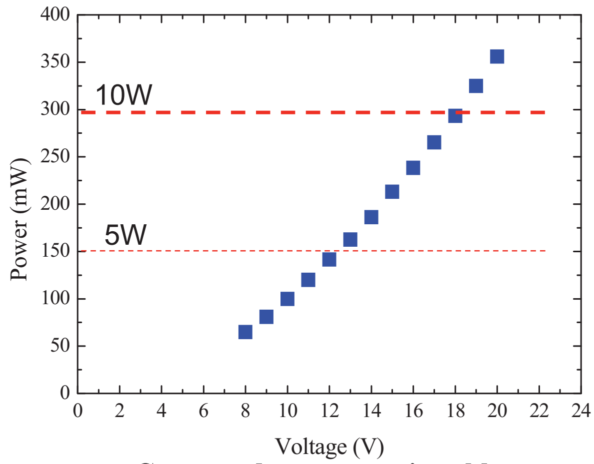
- Large air flow rate for 5W class MC
- High driving voltage for the TE modules

Find the design point.





Air flow rate in ceramics tube vs. driving voltage

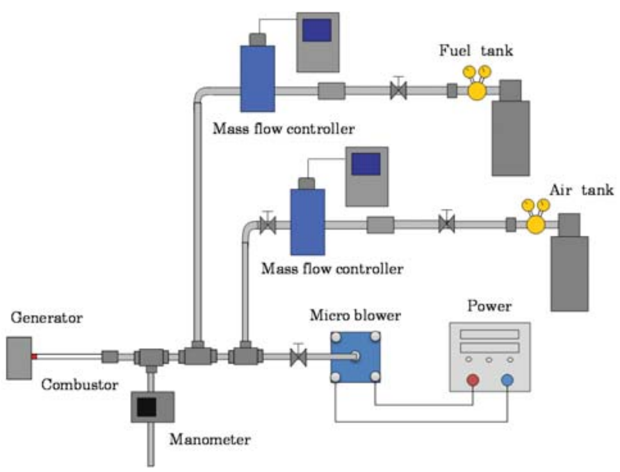


Consumed power at micro-blower

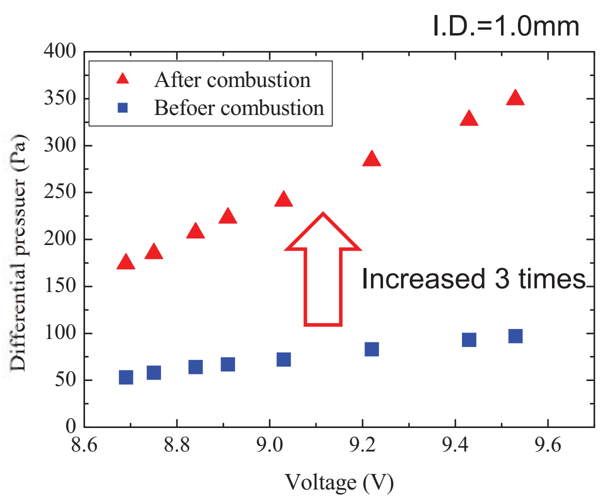
Pressure drop during combustion

- Raised temperature due to combustion increases viscously.
- Pressure drop in the tube increases 3 times during combustion

Air flow rate decreases 1/3 than that in cold condition



Schematic of experimental setup



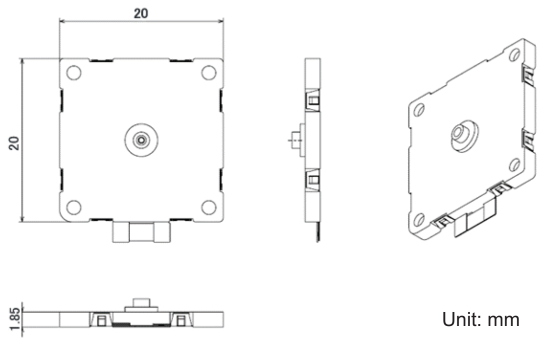
Pressure drop in the microcombustor

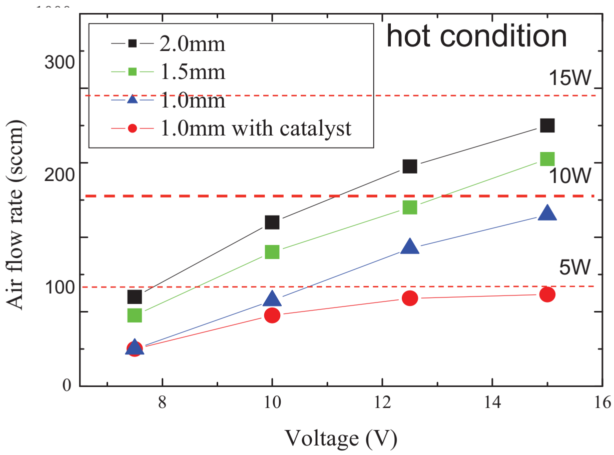
Micro-blower (Murata Manufacturing Co., Ltd.)

- 20x20x1.85mm
- Diaphragm is vibrated by piezoelectric element

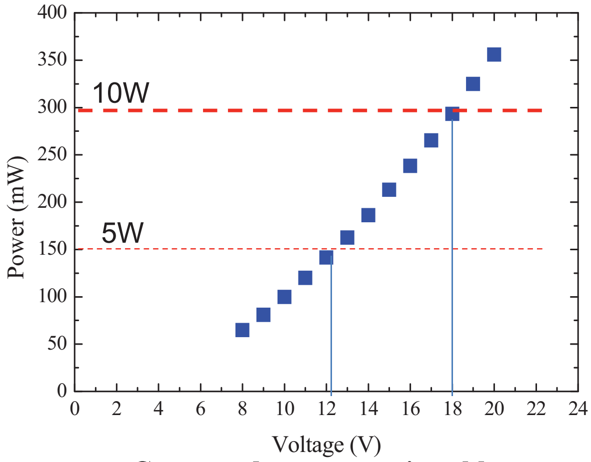
- Large air flow rate for 5W class MC
- High driving voltage for the TE modules

Optimize the design point.





Air flow rate in ceramics tube vs. driving voltage



Consumed power at micro-blower

Optimizing the inner diameter

- Excess heat input causes erosion of the mesh structure.

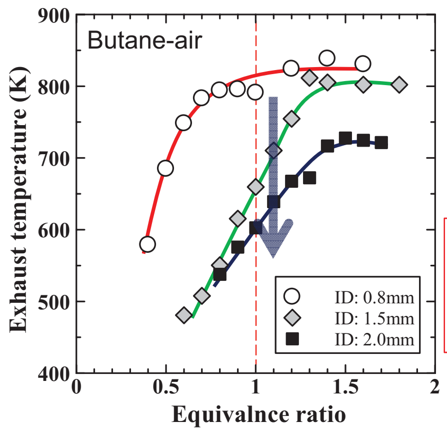
MC with large diameter allows larger fuel input.

ID=0.8mm → 7W
ID=1.5mm → 15W
ID=2.0mm → 20W

- Large diameter also decreases pressure drop → low power consumption

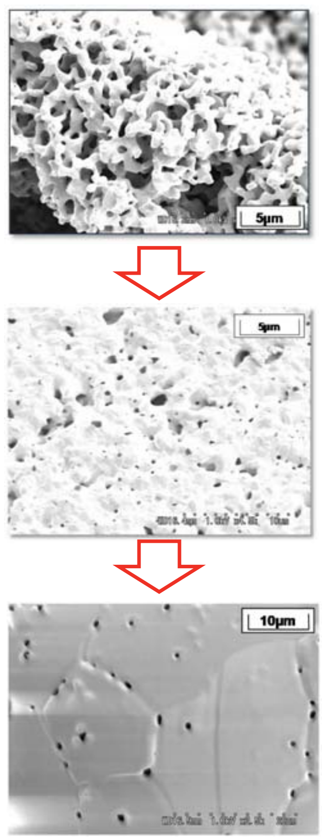
Conflict!!

- Large diameter results in low combustion efficiency.



Exhaust gas temperature for different ID

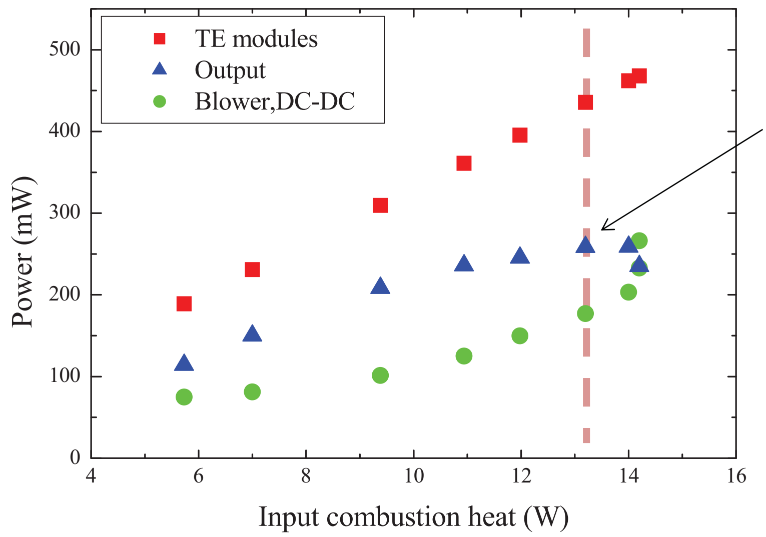
ID of 1.5mm is choosen.



SEM image of catalyst layer

Optimizing the input heat

■The consumption power at the blower is estimated by multiplying the result in cold condition by 1/3.
■Assuming the conversion efficiency at 3.3%, the net output is calculated by subtracting consumption power at the blower from the estimated electricity at TE modules.

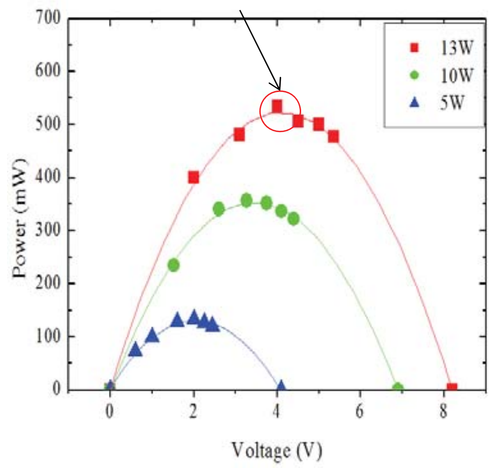


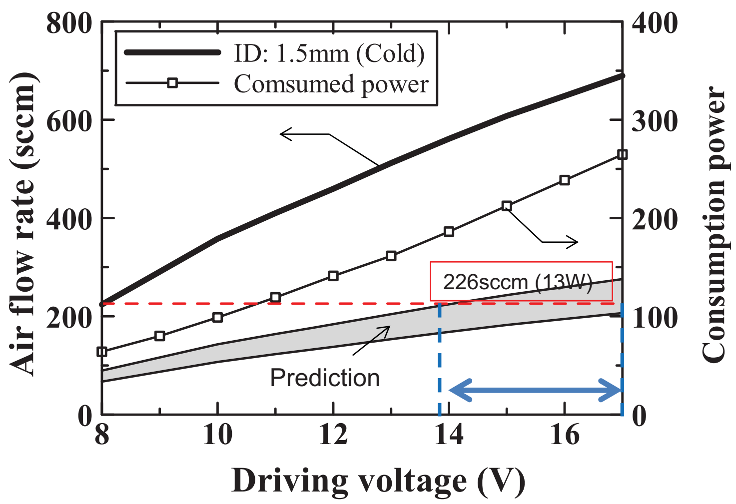
Input heat of 13.2W is optimal.

Design point of the self-standing system

■The input heat was selected 13W to avoid excess power consumption at the micro-blower.
■The diameter was selected 1.5mm for its relatively low pressure drop and durability for higher input heat.
■The number of TE modules was 6 to avoid the temperature over 500K.
■The output from TE modules were estimated as 430mW. (η=3.3%)
■The estimated driving voltage was from 14V to 17V.

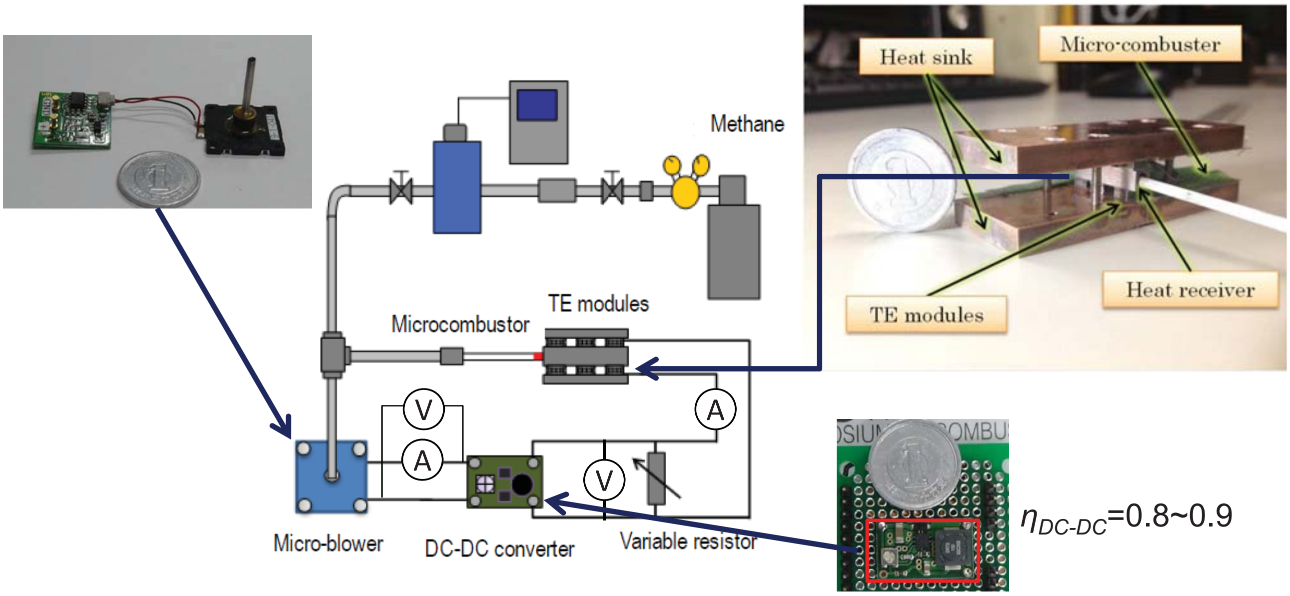
Conversion efficiency: 4.1% (champion record)
Output : 533mW (matching resistance: 30Ω)





Schematic of the self-standing generation system

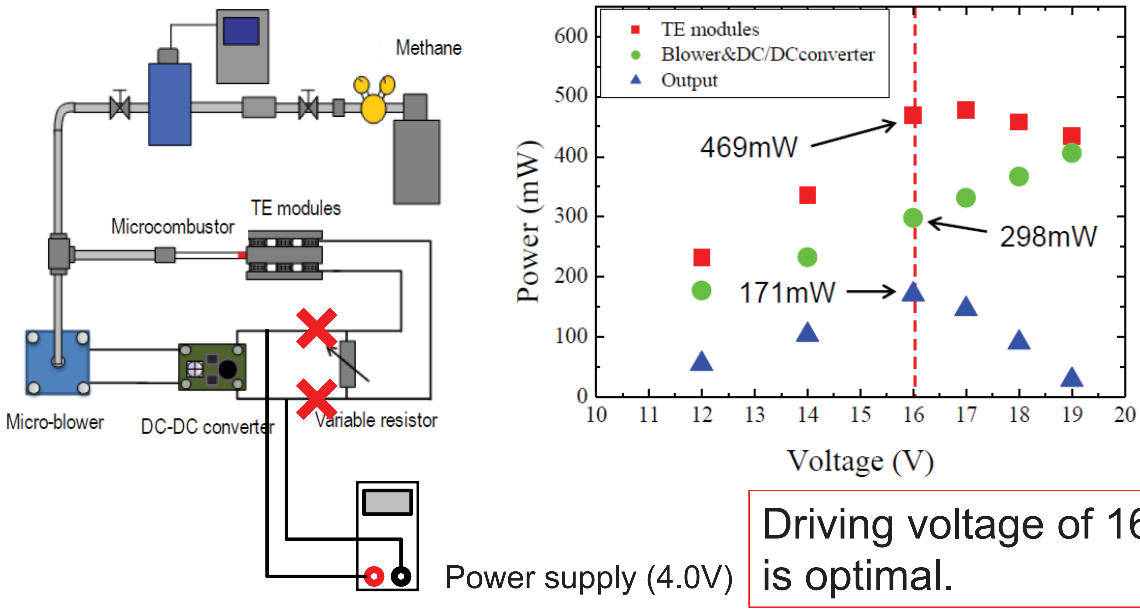
■The fuel, methane, is supplied by the mass flow controller.
■The air is supplied by the micro-blower.
■A part of electricity from the TE modules is supplied to DC-DC converter to pull up the voltage to 14-17V.
■The rest electricity is consumed at the variable resistor and the net output is measured.



$\eta_{DC\text{-}DC}$=0.8~0.9

Determination of driving voltage of micro-blower

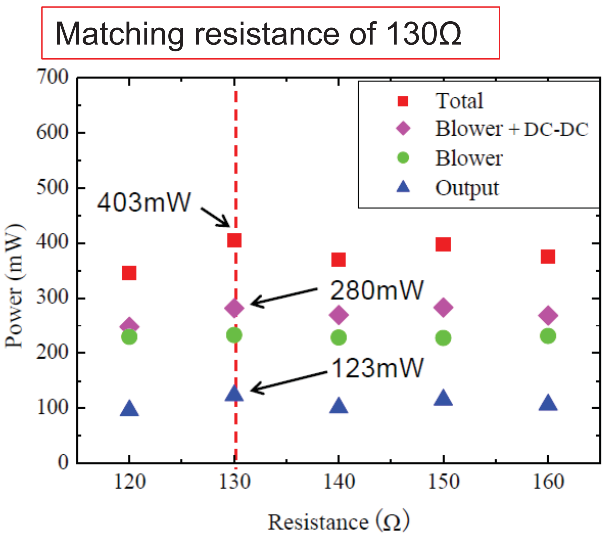
■The gloss output from TE modules are measured at the variable resistor of matching resistance (30Ω).
■The micro-blower with DC-DC converter is driven by the separated power source of 4.0V, and the driving voltage for the blower is varied.



Driving voltage of 16V is optimal.

Performance at the design point

■Matching resistance is 130Ω, the driving voltage of the blower is 16V.
■Input fuel enthalpy is 13.2W. The fuel and air flow rates are 23.8sccm and 226sccm, respectively. The equivalence ratio is 1.0.



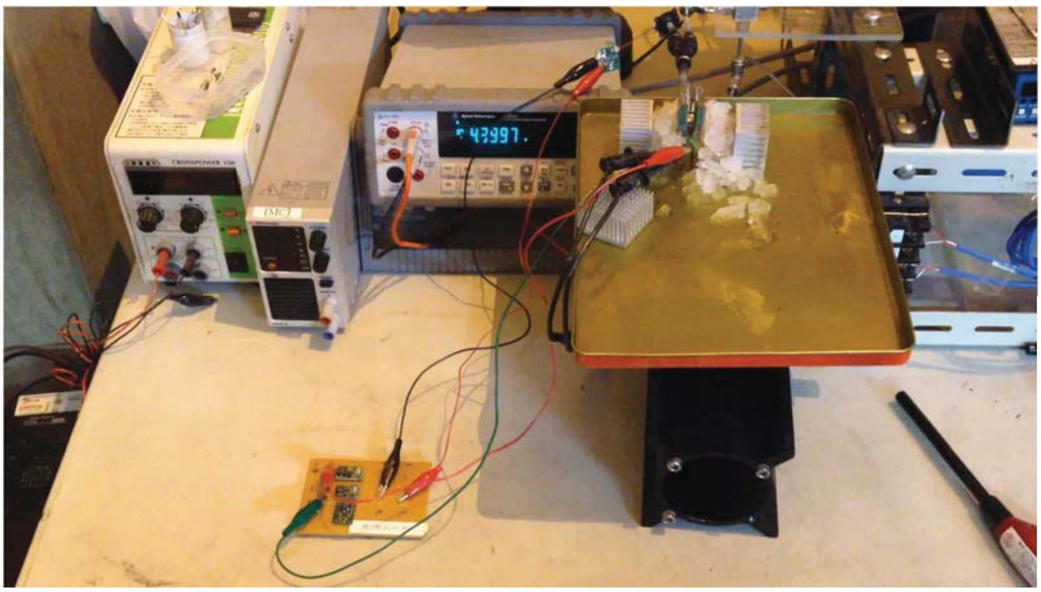
Input fuel enthalpy	13.2W
Inner/outer diameters	1.5/2.5mm
Methane/air flow rate	23.8/226sccm
Size and number of TE modules (17 pairs)	4mm x 4mm 6 (in series)
Matching load resistance	130Ω
Output voltage	4.0V
Gross electricity from TE modules	403mW
Efficiency of TE modules	3.35%
Consumed power at micro-blower	247mW
Consumed power at DC-DC converter	33mW
Net output electricity	123mW
Final thermal efficiency	0.93%

Performance at the design point

■Matching resistance is 130Ω.
■The cold sides are cooled by ice.

The output voltage is 4.56V

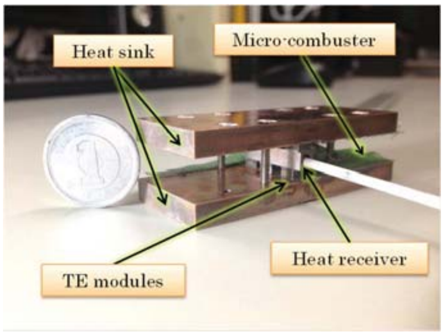
⇨ 160mW, η=1.21%
Running more than 1 hour



Comparison with conventional model engine

■The thermal efficiency of the world smallest internal combustion engine is estimated about 1.5%.
■The developed self-standing cogeneration system has efficiency of the same order although the thermal input is 1/20.

COX
Tee Dee 01 (glow plug type)
Bore 6.02 mm
Stroke 5.74 mm
Rpm 30,000 rpm
Displacement 0.163 cc
Air flow rate 4890 sccm
Thermal efficiency 1.5%



Air flow rate 226 sccm
Thermal efficiency 1%

Summary

- We developed a small self-standing generation system in which the air supply system was driven by a part of the generated electricity. The thermal input was 13.2W and the final output was 123mW; thus the final thermal efficiency was 0.93%.
- The magnitude of the efficiency was close to the world smallest conventional reciprocal engine Tee Dee 01 although the power size was less than its 1/20.

Future work

- To manufacture a portable power source including fuel supplying device.

Acknowledgements
A part of this study was supported by Industrial Technology Research Grant Program from NEDO of Japan.

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Recent conventional model engine

■Recent model engines are incredibly small and their heat input are comparable to that of our microcombustor.

Ronald Valentine Engines
Mini Bee 0.021 Mk II (Diesel type)
Bore 3.0 mm
Stroke 3.0 mm
Rpm 16,200 rpm
Displacement 0.021 cc
Air flow rate 340 sccm
Thermal efficiency ???

Ronald Valentine Engines
Nano Bee 0.006 (Diesel type)
Bore 2.0 mm
Stroke 2.0 mm
Rpm 16,200 rpm
Displacement 0.006 cc
Air flow rate 97.2 sccm
Thermal efficiency ???