Cogeneration

- Singapore Energy Efficiency Symposium -

October 16, 2019

Mitsubishi Heavy Industries, Ltd.

CONTENTS

1. General outline of cogeneration

KEY WORDS; Dual Products / Distributed Network /Save Energy / CO2 Reduction

(1) Definition of Cogeneration

① Simple Definition

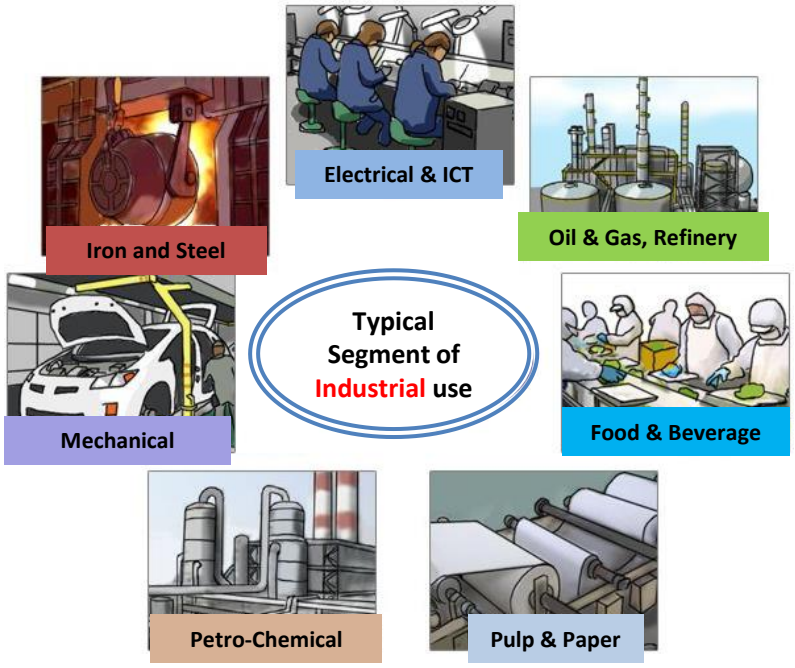
- to generate two or more energy by one fuel or one heat source
- to generate electricity together with steam or hot water (thermal energy) from one energy source
  ⇒ CHP (**C**ombined **H**eat and **P**ower)

② Wider definition

- to generate electricity, thermal energy and drive power

③ Narrow Definition

- to generate electricity and thermal energy by internal-combustion engine using fuel gas (gas cogeneration)



(2) Benefits of Cogeneration

- To create a higher level energy-saving ＋CO2 reduction due to an efficient generation of both electric and thermal energy
- To create a sustainable economic activities and life saving function
  ⇒ BCP (Business Continuity Plan)
- To create a kWh by a distributed power system
- To create a ΔkW (ancillary power) for increasing variable renewable energy

Value of Cogeneration	Tactics for realizing Value	Issues to do
Energy Saving & CO2 Reduction	• Enhancement of Cogeneration Installation • Beneficial use of generated electricity and heat	• Economical support (subsidy etc.) • Enhancement of waste heat recovery • Relaxation of grid regulation
BCP including both economic and life saving activity	• Installation of self-sustainable cogeneration in a distributed energy supply system	• Simpler development approval procedure • Establishment of value appreciation for BCP / energy security
Distributed Power	• Increase of power selling to grid • Enhancement of cogeneration in self-consumer	• Relaxation of regulations when connecting to grid
Ancillary Power	• Ancillary service for variable renewable energy network	• Better utilization of heat • Maximize of operating hours

(3) Harmonious operation between centralized network and distributed network

MITSUBISHI HEAVY INDUSTRIES

Load Leveling System
Total Efficiency Improvement
Total Cost Down

International Power Grid Connection

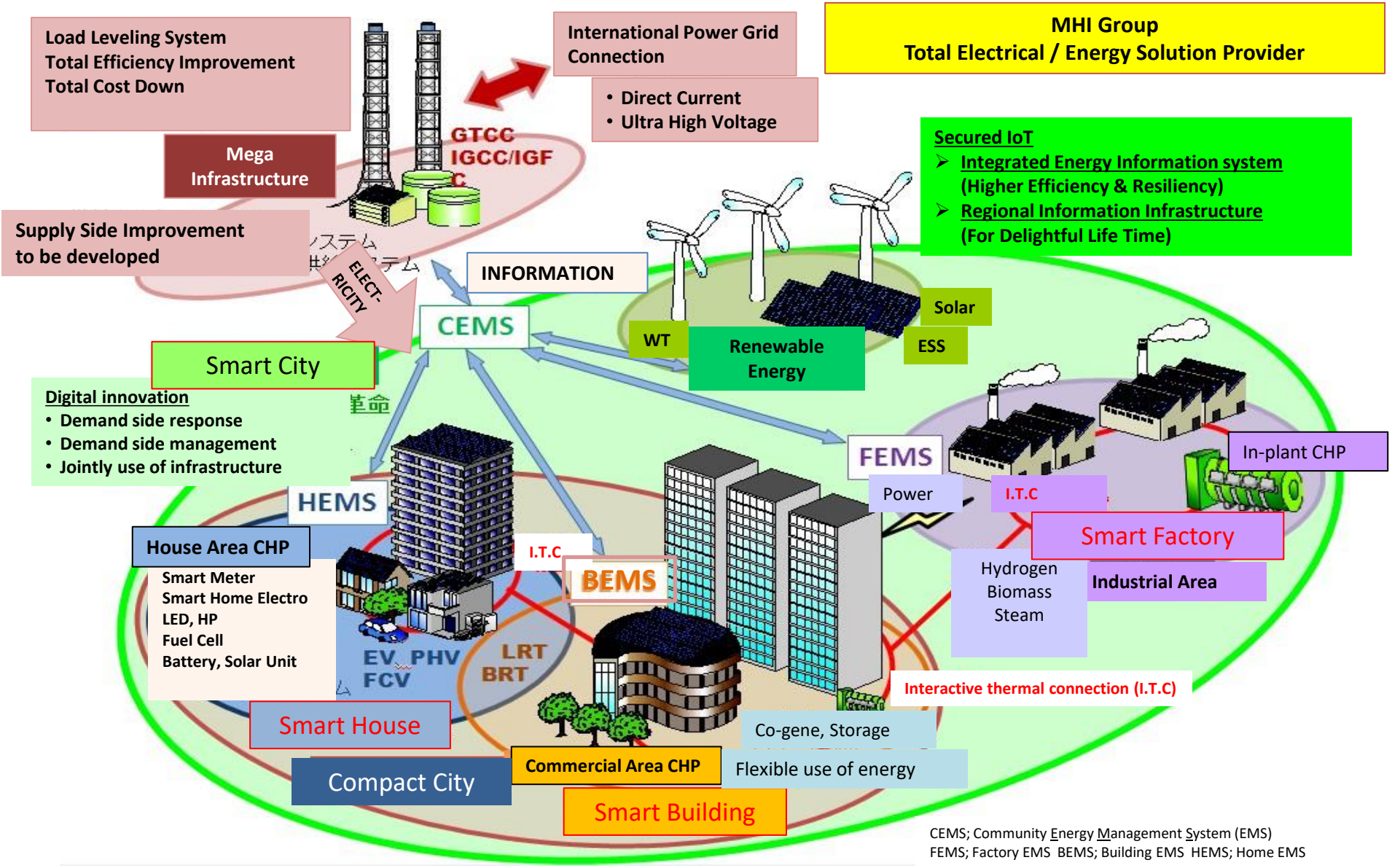
- Direct Current
- Ultra High Voltage

MHI Group
Total Electrical / Energy Solution Provider

Mega Infrastructure

Supply Side Improvement to be developed

Secured IoT
- Integrated Energy Information system (Higher Efficiency & Resiliency)
- Regional Information Infrastructure (For Delightful Life Time)



Digital innovation
- Demand side response
- Demand side management
- Jointly use of infrastructure

CEMS; Community Energy Management System (EMS)
FEMS; Factory EMS BEMS; Building EMS HEMS; Home EMS

2. Industrial cogeneration

KEY WORDS; Higher Energy Utilization / Steam power ratio

(1) Framework of Industrial Cogeneration

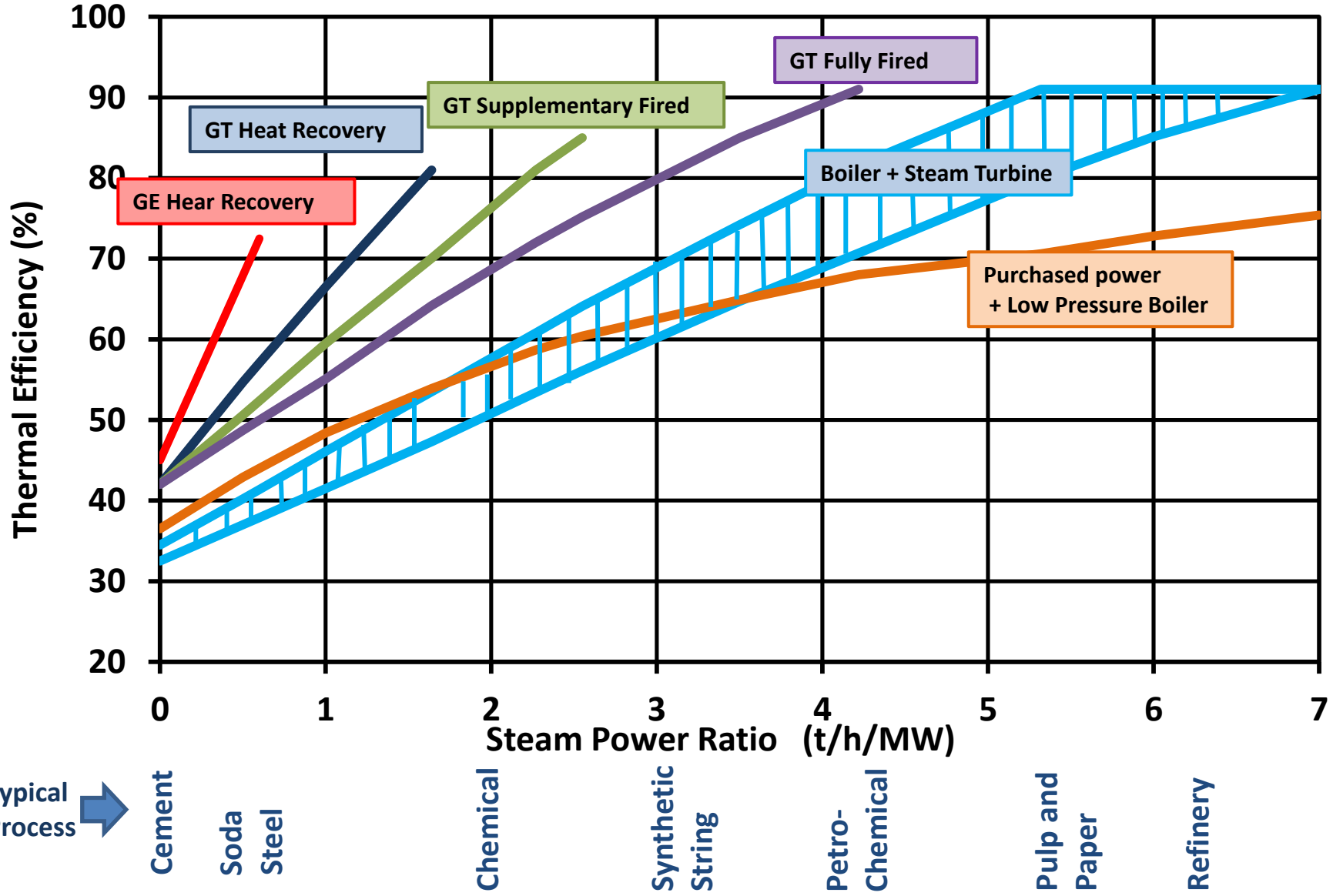
Considering futures of cogeneration, the following frameworks will promote the installation of 'Industrial Cogeneration' in various industrial sectors.

- Higher energy utilization due to combined generation of electricity and steam
- Effective utilization of by-product fuel gas
- Waste heat recovery
- Energy Management
- Business Continuous Plan
- Suppling ΔkW from distributed network to Grid which has a lot of variable RE

It is important to select a suitable type of cogeneration system, that is efficient prime mover, depending on the steam power ratio.
Steam power ratio stands for <Low pressure steam used in process in t/h> divided by <Electricity used in factory in MW>. (Refer to next slide.)

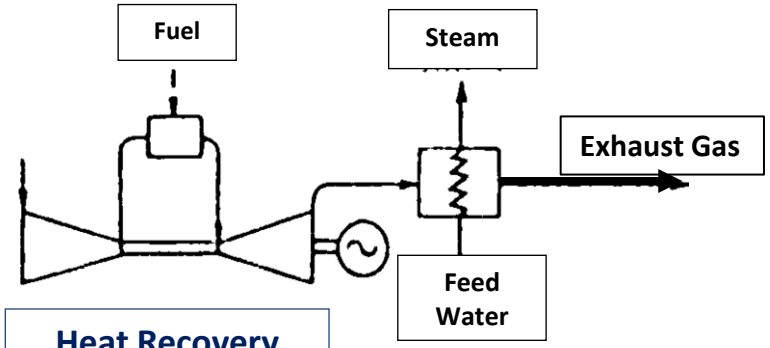
- In lower steam power ratio, gas engine or gas turbine would provide an efficient solution.
- In larger steam power ratio, steam power (boiler-steam turbine) would provide an efficient solution.
- Purchased power plus low pressure boiler solution shall be studied in lower steam power ratio zone, considering not only efficiency aspect but also economic aspect.

(2) Steam Power Ratio for selecting efficient prime mover

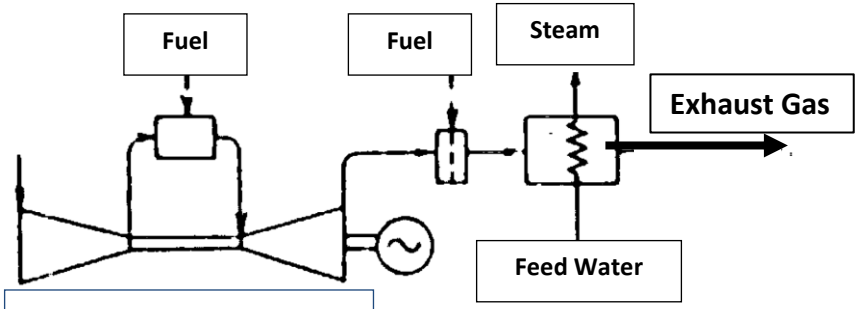


(3) Type of cogeneration

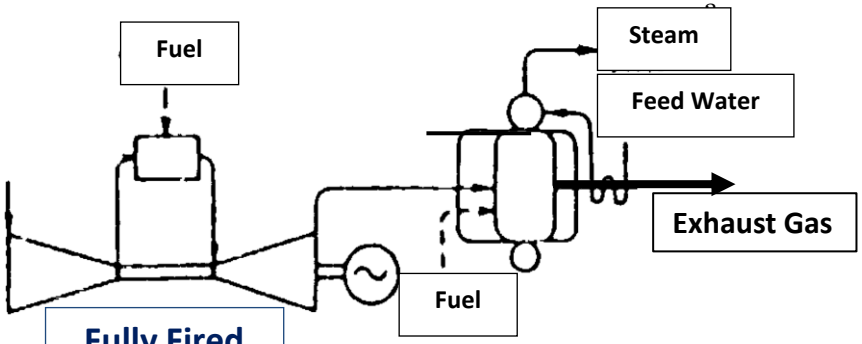
Type of Gas Turbine Heat Recovery



Heat Recovery



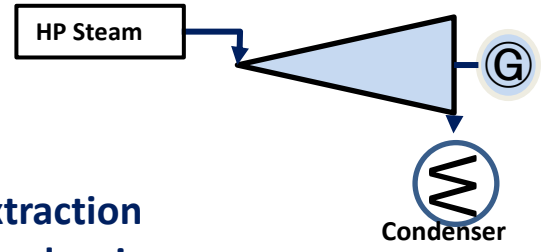
Supplementary Fired



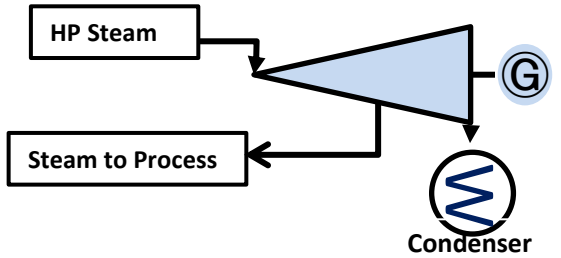
Fully Fired

Type of Steam Turbine

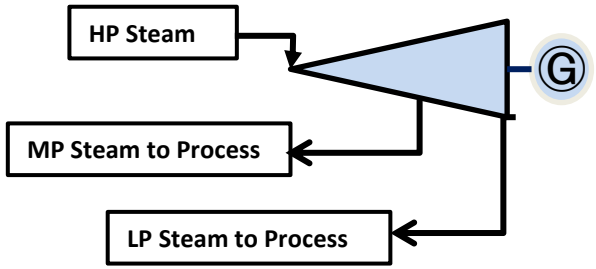
Condensing



Extraction Condensing



(Extraction) Back Pressure



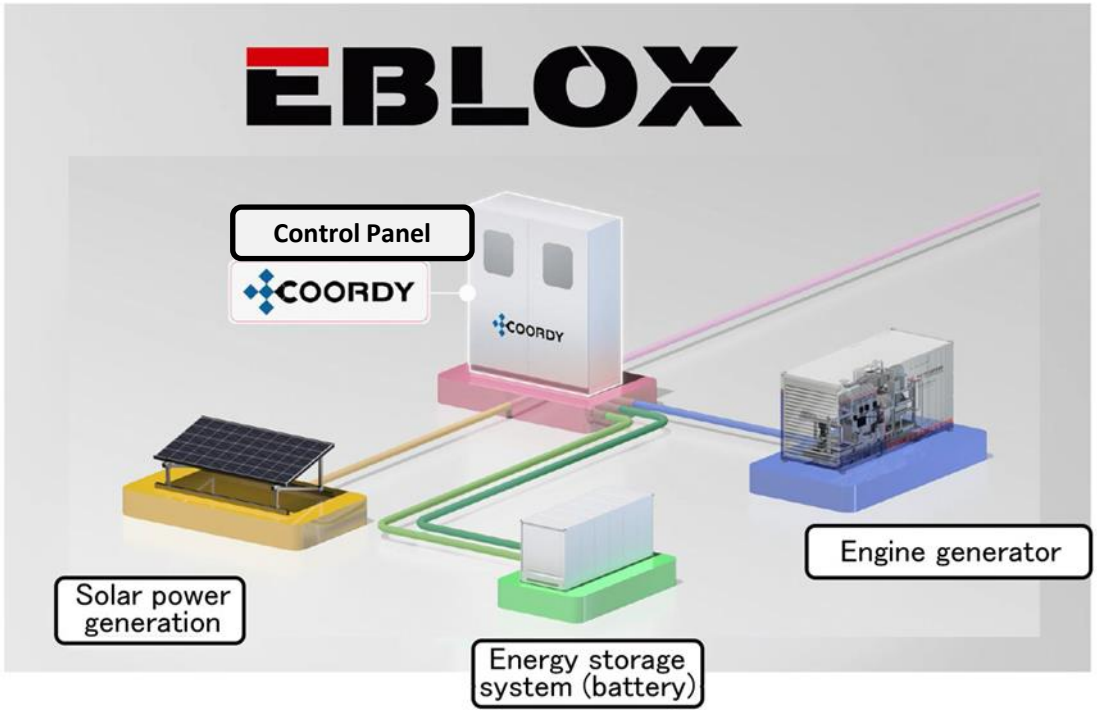
Zero

Steam Power Ratio

⇒Large

(4) Combination with Renewable Energy

- "How to use a renewable energy" is getting to an issue for management of industrial factory.
- MHI Engine and Turbocharger Ltd. (MHIET) has developed a "triple hybrid" autonomous power supply system that combines renewable energy such as solar power with a reciprocating engine generator and storage battery, allowing for optimal stabilization control.

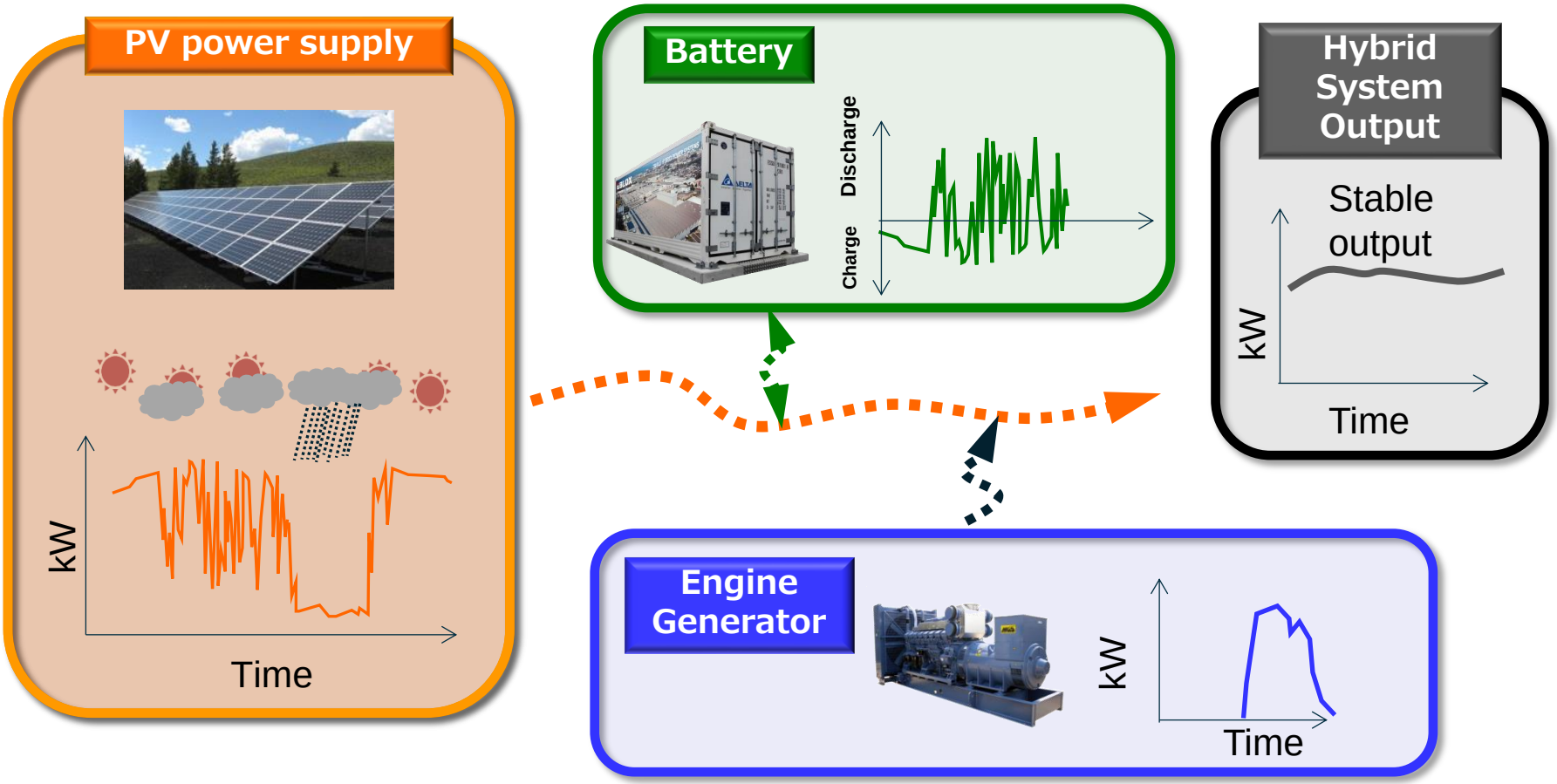


Triple Hybrid Power Generation system

(Brand name ; EBLOX for total system and COORDY for control system)

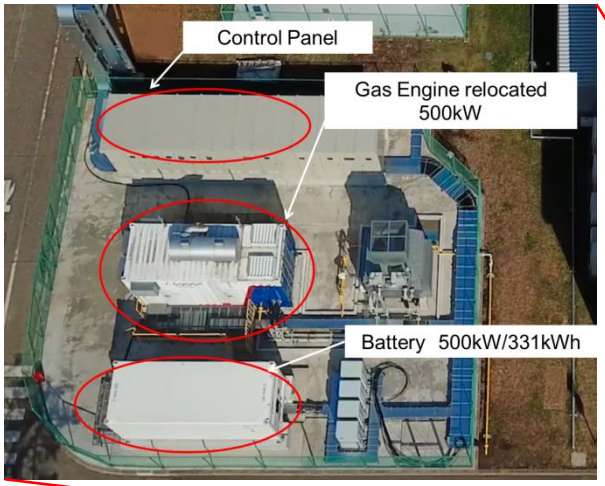
(5) Stabilization for Renewable Energy output

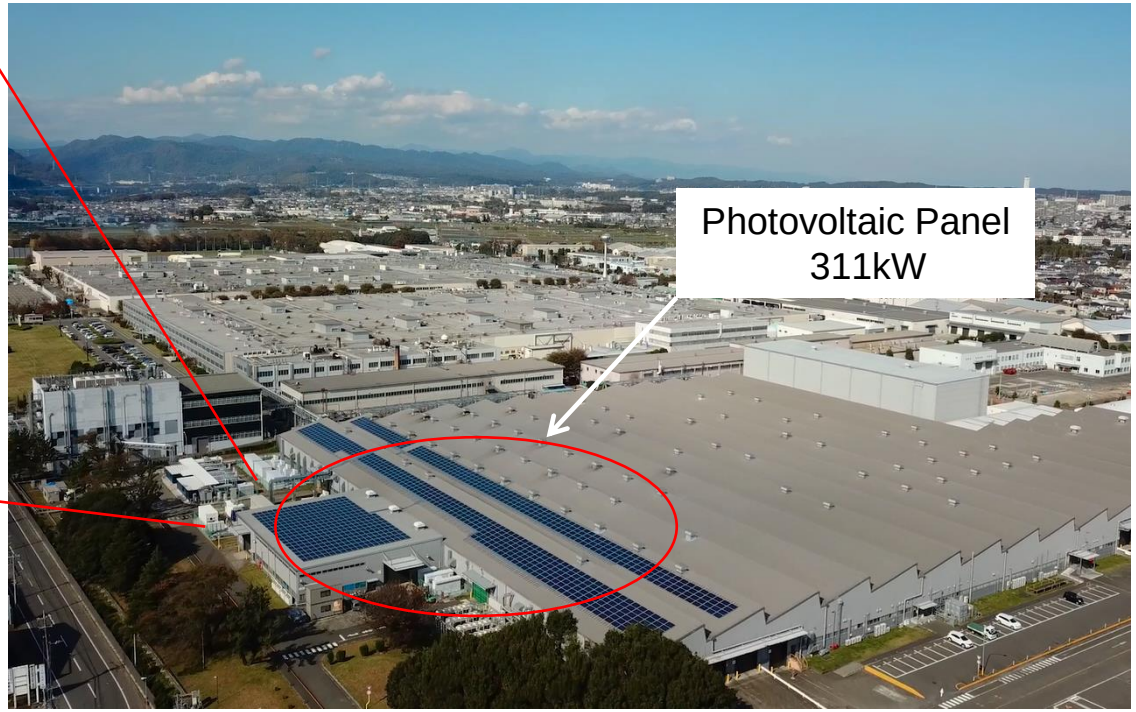
The fluctuating power from variable renewable energy is absorbed in storage batteries to level the supply, with backup from diesel or gas engines to generate power unaffected by changes in the weather or the time of day.



(6) Triple hybrid power station in SAGAMIHARA (MHIET Factory)

The Triple Hybrid Power Station demonstration facility, combining solar power generation equipment, storage batteries, and an engine generating plant, has been put into operation at MHIET's Sagamihara Plant.





3. Recovery from lower temperature waste heat sources （ORC Technology)

KEY WORDS; Waste Heat recovery / Save Energy / CO2 Reduction

(1) Heat Recovery from various waste heat sources

BIOMASS — Bi

GEOTHERMAL — Ge

HEAT RECOVERY — HR

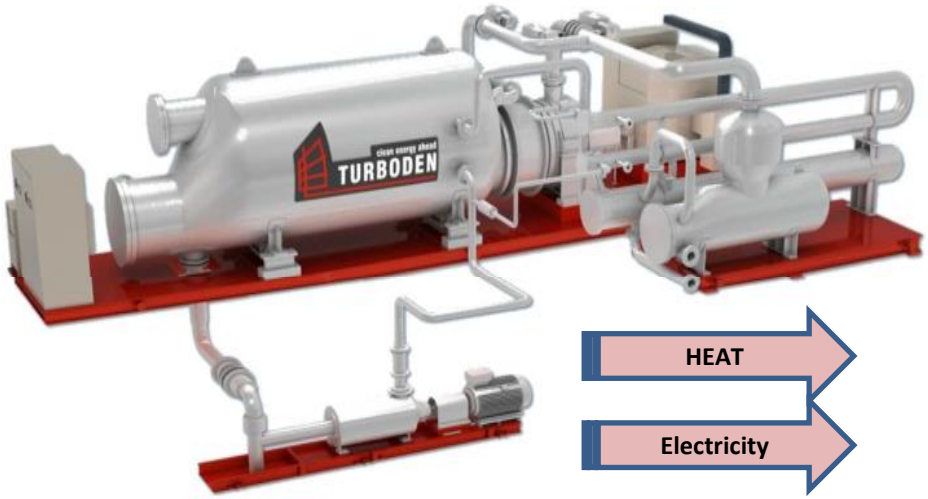
OIL & GAS Petrochemical — OG

WASTE TO ENERGY — WE

SOLAR THERMAL POWER — ST

NATURAL GAS COGENERATION — ST&P

KEY WORDS; Green Power / Save Energy / CO2 Reduction



- **Turboden, which is a group company of MHI, designs, develops and maintains turbo-generators based on the Organic Rankine Cycle (ORC), a technology for the combined generation of electric power and heat from various renewable sources, particularly suitable for distributed generation.**
- **Turboden solutions from 200 kW to 20 MW electric per single shaft.**

(2) ORC Technology: MEANING

Organic ← O R C → Cycle

O R C

↓

Rankine

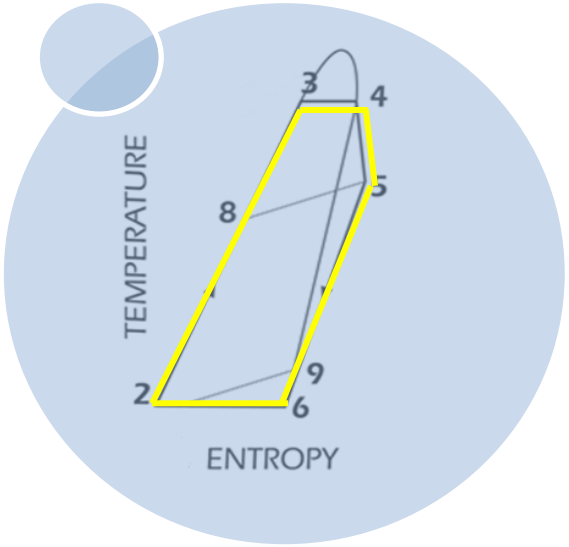
ORGANIC FLUID
(e.g. hydrocarbons, silicon oil, refrigerants)

instead of

WATER / STEAM

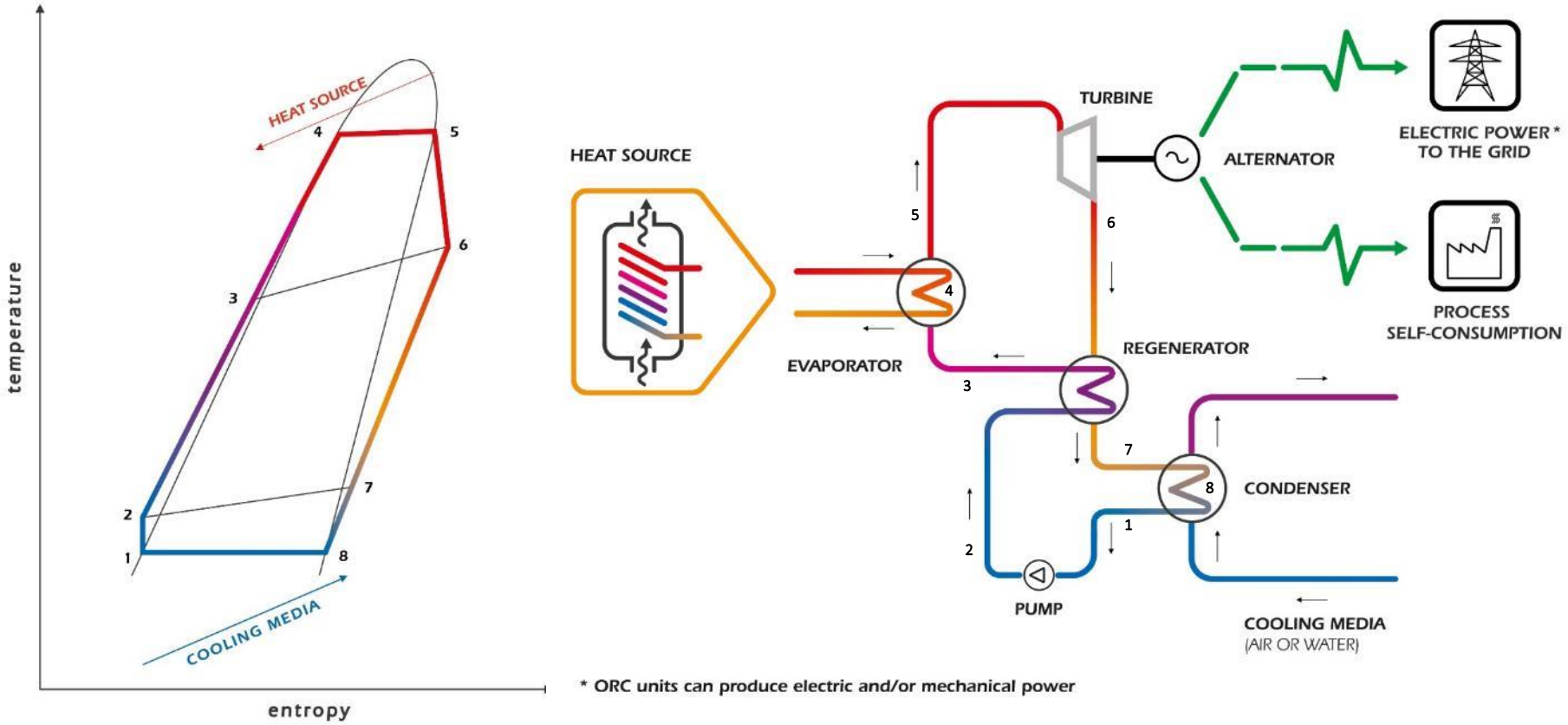
it exploits an organic working fluid

William John Macquorn Rankine
(5 July 1820 – 24 December 1872)



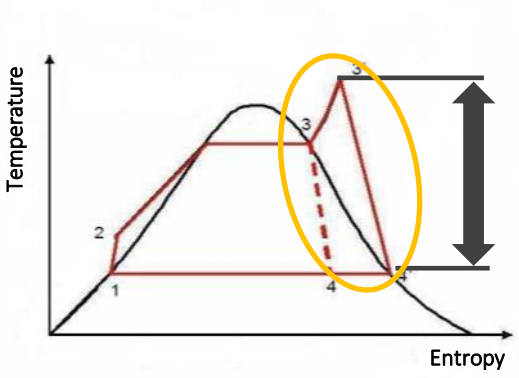
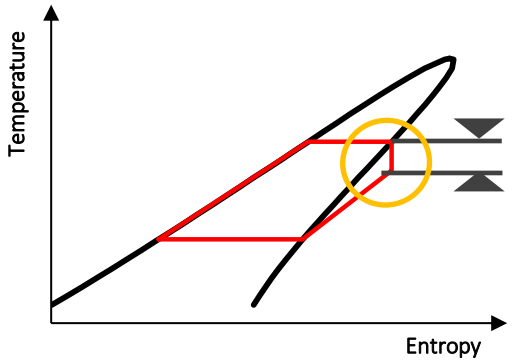
it is a thermodynamic cycle

(3) The ORC Cycle – How does it work



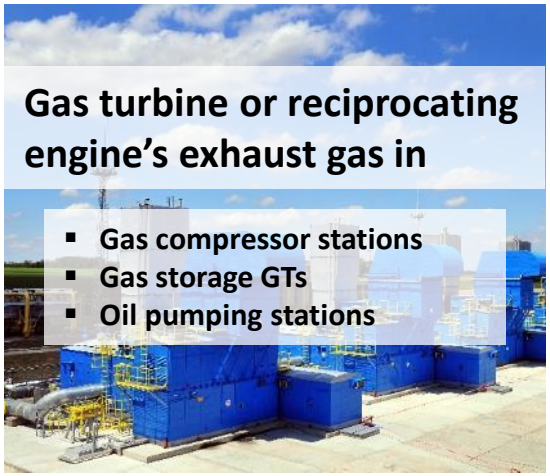
The ORC turbo-generator uses medium-to-high-temperature thermal oil to preheat and vaporize a suitable organic working fluid in the evaporator (4>5). The organic fluid vapour rotates the turbine (5>6), which is directly coupled to the electric generator, resulting in clean, reliable electric power. The exhaust vapour flows through the regenerator (6>7), where it heats the organic liquid (2>3) and is then condensed in the condenser and cooled by the cooling circuit (7>8>1). The organic working fluid is then pumped (1>2) into the regenerator and evaporator, thus completing the closed-cycle operation.

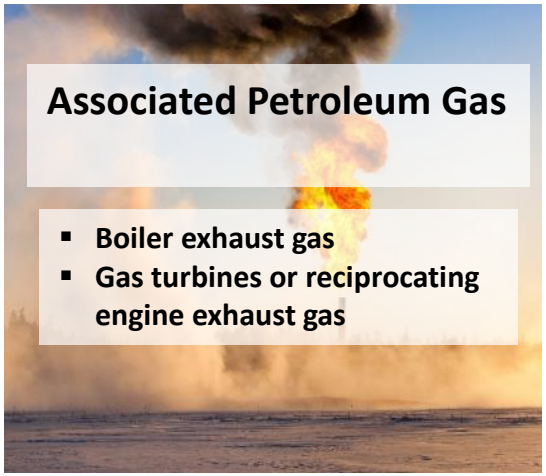
(4) ORC or Steam? Advantages and Disadvantages

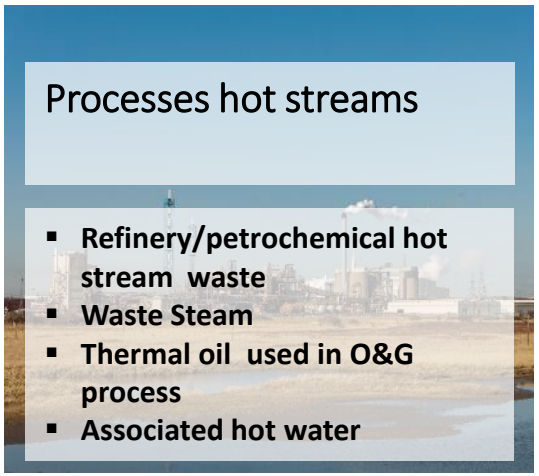
	Steam Rankine Cycle	Organic Rankine Cycle (ORC)
		
Thermodynamic features and consequences	• High enthalpy drop • Superheating needed • Risk of blade erosion	• Small enthalpy drop • No need to superheat • No supercritical pressure • No risk of blade erosion
Operation and maintenance costs	• Water treatment required • Highly skilled personnel needed • High pressures and temperatures in the cycle	• Non-oxidizing working fluid with no corrosion issues • Minimum personnel and O&M (1) • Completely automatic (2) • No blow down – no water consumption
Other features	• Convenient for large plants and high temperatures • Low flexibility with significantly lower performances at partial load	• High flexibility and good performances at partial load • High availability (average >98%) • Possibility to work at low temperatures (90+°C)

(1) Standard maintenance: 2-3 days per year
(2) Fast start-stop procedure (ca. 20 min), partial load operation (down to 10% of nominal load)

(5) Energy Efficiency Improvement in O&G / Petrochemical Business







Waste heat streams available in different O&G/Petrochemical processes and facility can be exploited as energy sources by energy efficiency technologies as Organic Rankine Cycle

The ORC transforms the waste heat into useful power.
This permits to:

- **Reduce the domestic consumption of primary energy**
- **Obtain a reliable source of electricity**
- **Reduce the CO_2 country emissions**
- **Improve O&G/Petrochemical company sustainability**

Various Case Studies for O&G (1/2)

ITEM	Unit	Country			
Country	-				
Process	-	Oil refining	Gas processing	Oil refining	Various
Heat recovery from		Arab light crude oil stream	Incinerator exhaust gas	Fluid Catalytic Cracking flue gas	Flare gas
Heat source flow rate	t/h	514	558	79	2,900 (m3/h)
Heat source temperature	℃	165	350	270	-
Heat source temperature after heat recovery	℃	90	150	135	-
Thermal power recovered	kW	23,000	35,000	3,400	28,500
ORC net production	kWe	1,850	7,000	500	6,500
Avoided electricity consumption for cooling	kW	200	-	-	-
Ambient temperature	℃	35	35	20	35

Various Case Studies for O&G (2/2)

ITEM	Unit	Country		
Country	-			
Process	-	Oil refining	Gas processing	Petrochemical
Heat recovery from		Hot Water	LP Steam	MP / LP Steam
Heat source flow rate	t/h	3,150	120	9 / 39
Heat source temperature	℃	150	160	177 / 148 (Vapor)
Heat source temperature after heat recovery	℃	90	86	176 / 147 (Liquid)
Thermal power recovered	kW	235,000	80,000	28,000
ORC net production	kWe	20,000	10,000	4,200
Avoided electricity consumption for cooling	kW	-	-	-
Ambient temperature	℃	35	35	33

4. SOFC (Solid Oxygen Fuel Cell) application

**KEY WORDS; Direct Power Generation from Various Fuel /
Heat & Power / Future Hydrogen Society**

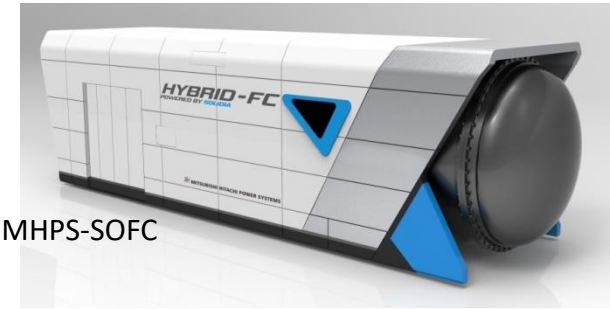
(1) SOFC (Solid Oxygen Fuel Cell) application

MITSUBISHI HITACHI POWER SYSTEMS

MHPS-SOFC is a hybrid power generating system consisting of SOFC and micro gas turbine. It is used to supply electricity & heat for commercial and industrial purposes with a high flexibility to use various types of gas as fuel. There would be various applications to reinforce low carbon society. SOFC is a key to complete "energy supply chain" for community with digital solutions.

Key Product Characteristics

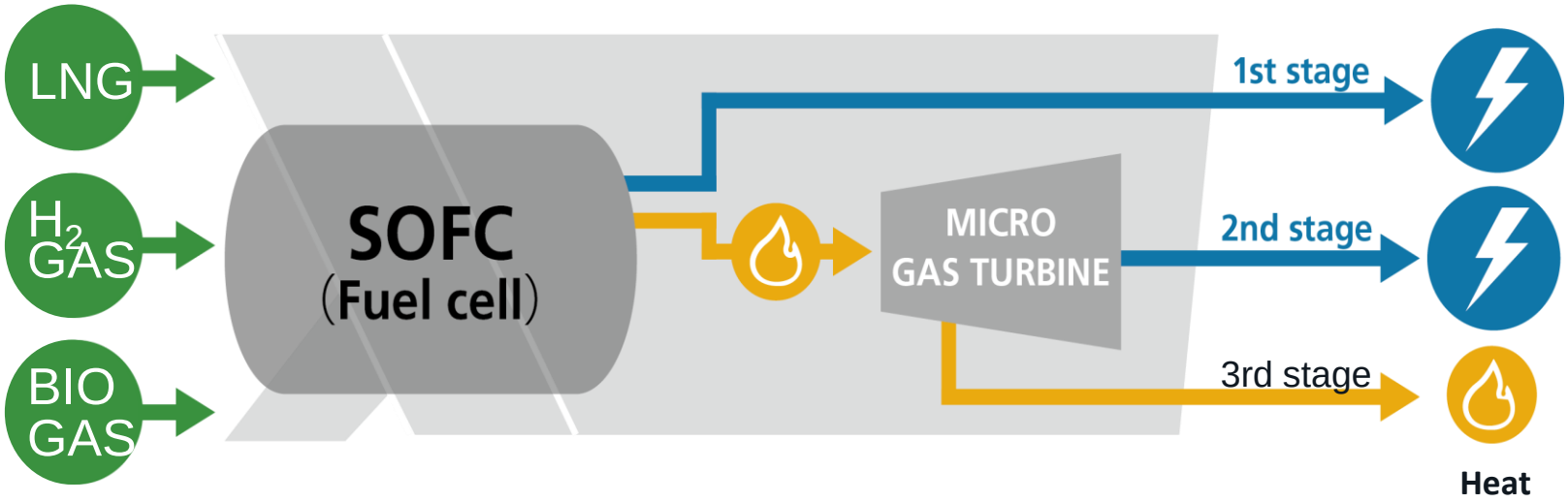
- **Distributed Energy Resource (DER)**
- **High energy efficiency**
- **Cogeneration *CHP-Combined Heat and Power production**
- **Offers variety of fuel (natural gas, bio gas, Hydrogen, Propane etc.)**
- **High Reliability**
- **Low noise**
- **Low emission (NOx, PM)**



MHPS-SOFC

(2) Product Concept

- **MHPS-SOFC is a hybrid power generating system consisting of SOFC (Solid Oxide Fuel Cell) and micro gas turbine. It is used to supply electricity and heat for commercial and industrial purposes.**
- **It has high flexibility to use various types of gas as fuel.**



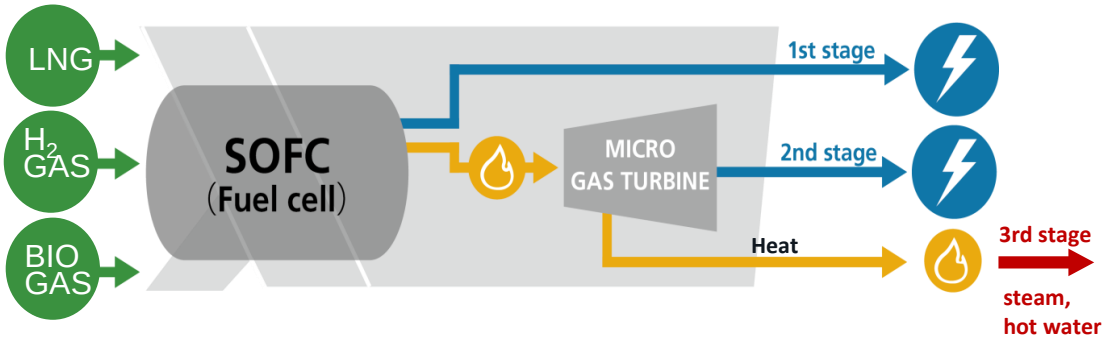
(3) Multi-stage power & heat generation

MITSUBISHI HITACHI POWER SYSTEMS

- MHPS-SOFC converts various types of fuel into electricity directly while micro gas turbine utilizes excess fuel from SOFC to generate power.

Electrical Efficiency 55%

Electrical&Thermal Efficiency 73% (hot water)



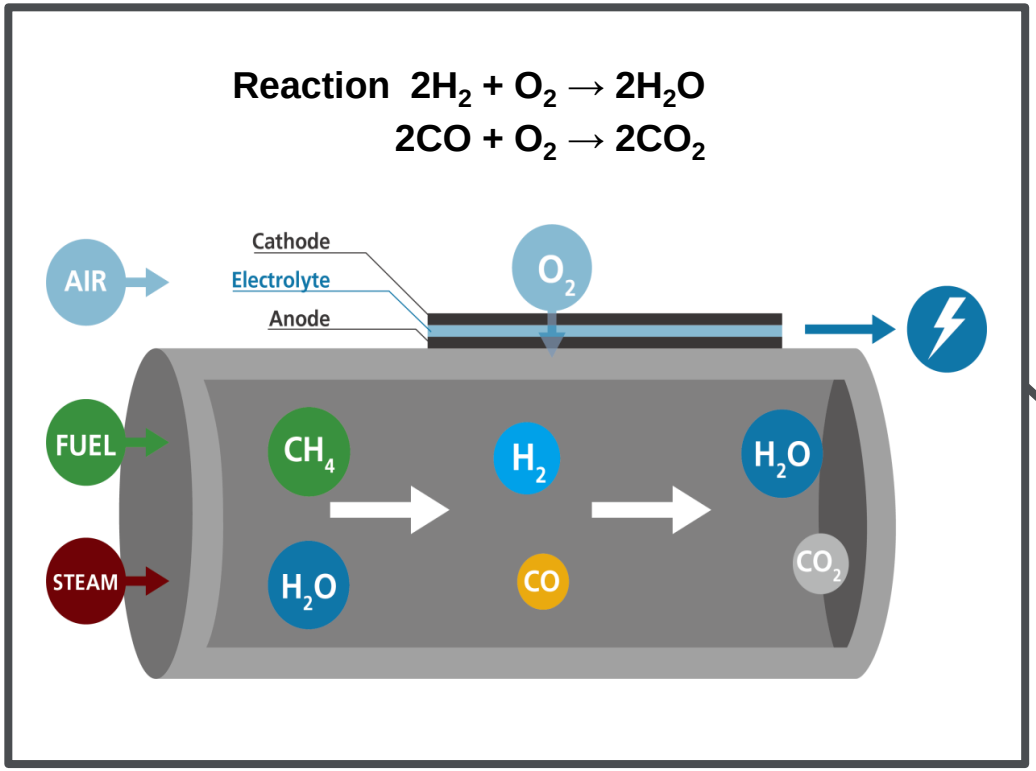
- Due to multi-stage power generation, our SOFC system has proved to have the highest efficiency in all other Distributed Energy Resources at same capacity range.

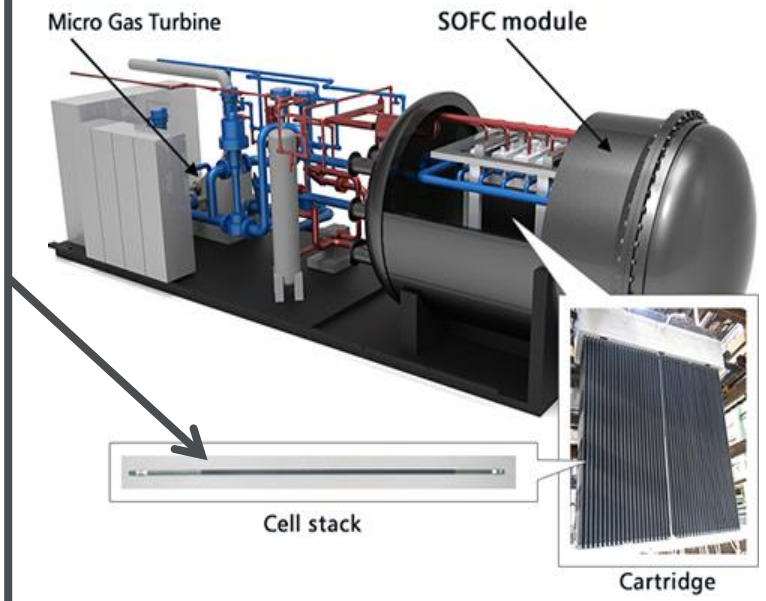
Efficiency Comparison Chart

	PEFC Polymer Electrolyte Fuel Cell	PAFC Phosphoric Acid Fuel Cell	MCFC Molten Carbonate Fuel Cell	MHPS-SOFC Solid Oxide Fuel Cell
Temperature (℃)	60～100	150～200	600～650	750～1000
Fuel	Hydrogen	Hydrogen	Natural Gas	Flexible
Efficiency (%LHV)	35～40	38～42	～45	～55

(4) Product concept

Inside SOFC module, there are a lot of cartridges filled with cell stacks which convert fuel to electricity directly through chemical reaction.

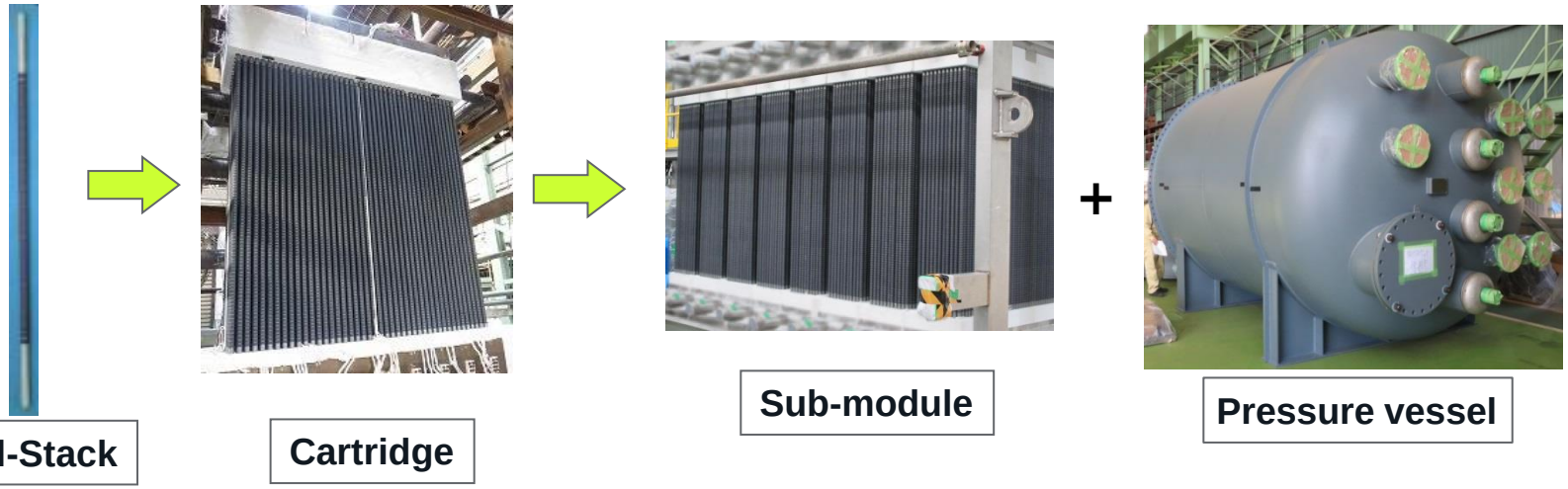


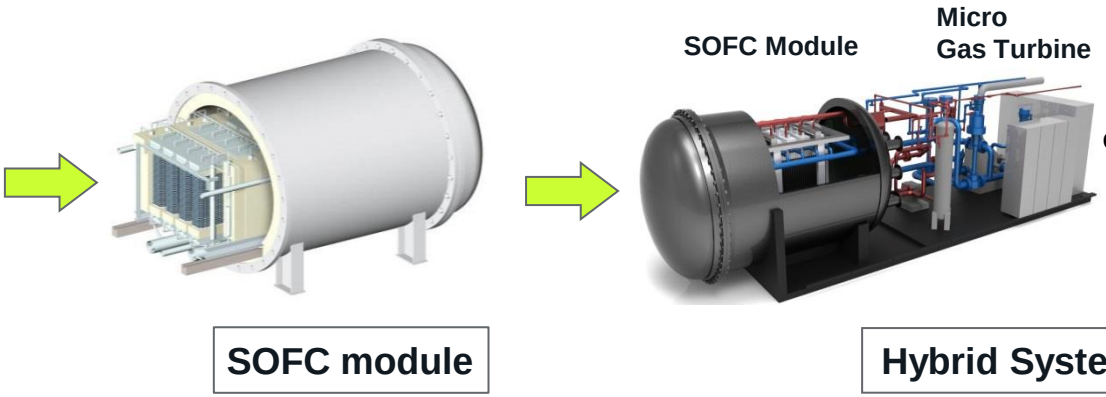


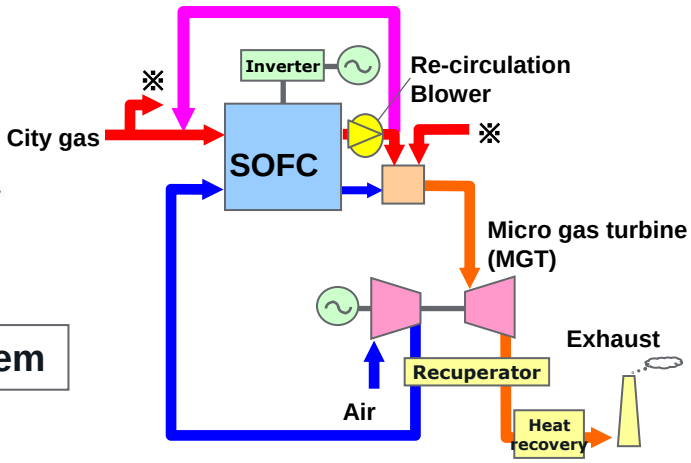
What happens inside 1 unit on a cell stack

(5) SOFC module components

- A Cartridge consists of 400 Cell Stacks.
- A Sub-module consists of 8 Cartridges .
- A Sub-module would be loadded into a pressure vessel to become SOFC module.







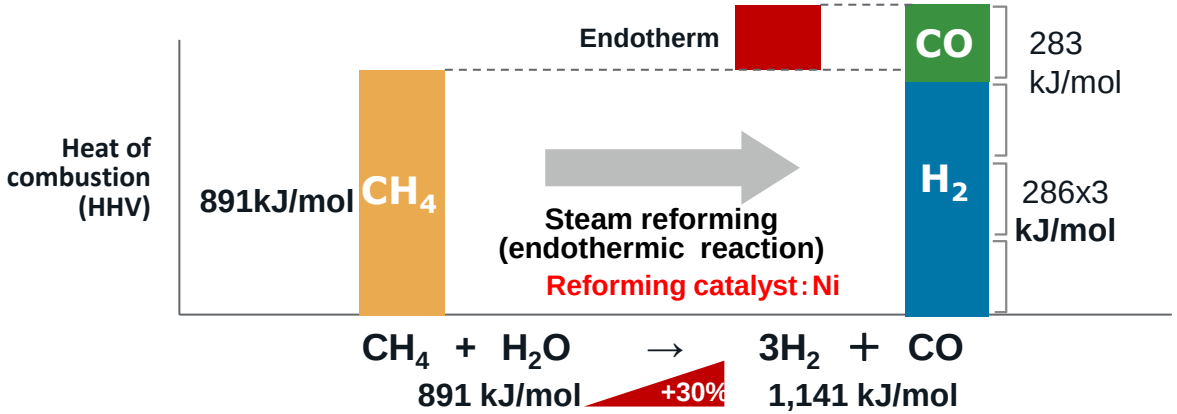
(6) Internal Reforming

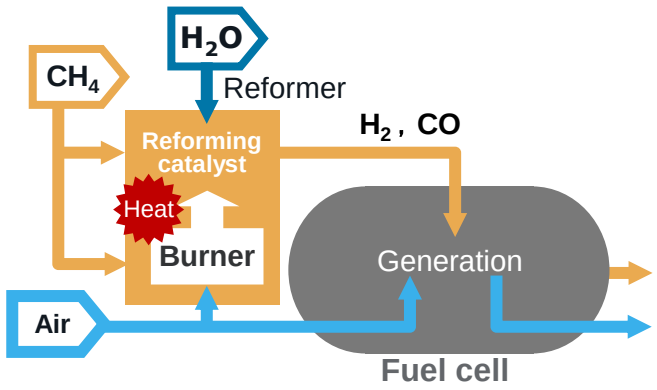
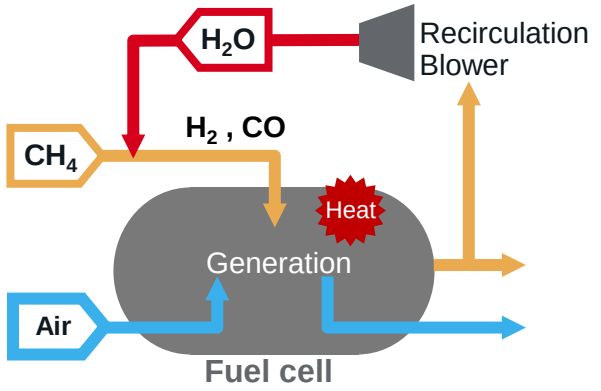
MITSUBISHI HITACHI POWER SYSTEMS

- **Internal reforming system realizes fuel flexibility and maximum energy efficiency.**
- **MHPS-SOFC is considered as the best example of exergy.**

Generates power from direct feed of natural gas

Heat and steam essential for reforming circulates inside the system.

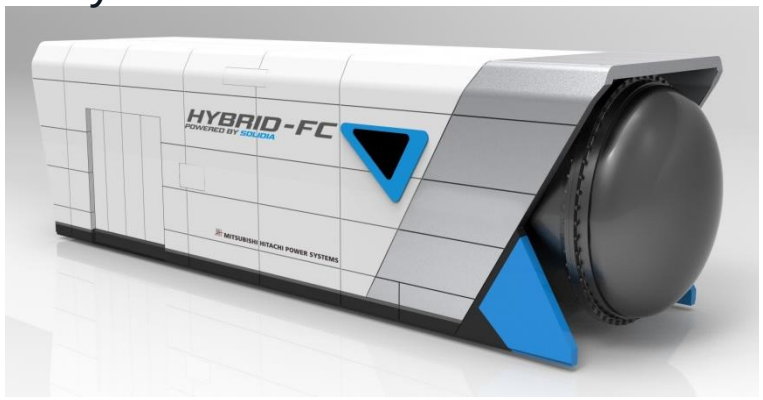


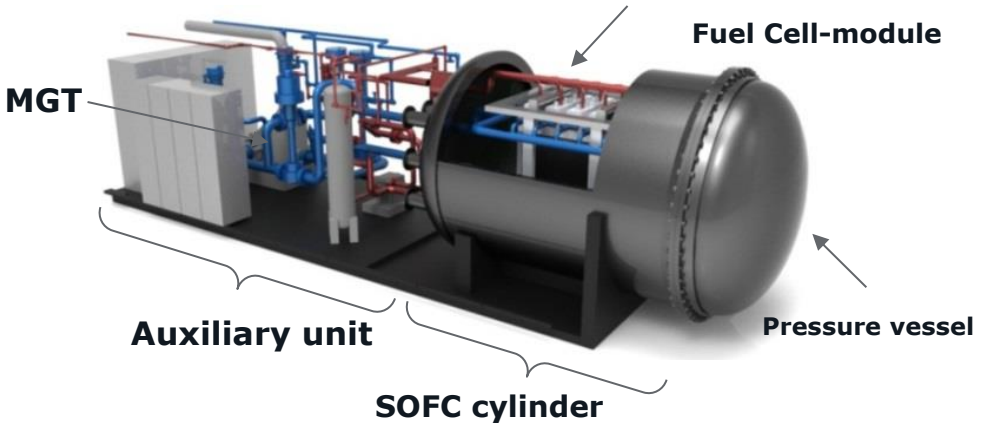
Reforming	External reforming	Internal reforming (applied)
Constitution		
Reformer	Required (separate placement reforming system)	Not required Compact / Low cost
Heat source	Externally-supplied (Heat of generating is waste)	Use of Heat of generation High efficiency

(7) 250kW-class SOFC specification

Expected specification	
Electrical output	250kW
Electrical Efficiency (LHV)	55%
Hot water / Steam output	86kW/50kW
Total Efficiency(LHV) Electrical + thermal (e.g. hot water at 88℃ /steam at 175℃)	73%/65%
NOx (16% O_2)	<5ppm
Unit Size	W 3.2 m × L 9.5 m × H 3.3 m
Weight	37 ton
Noise level	65dB

- System unit



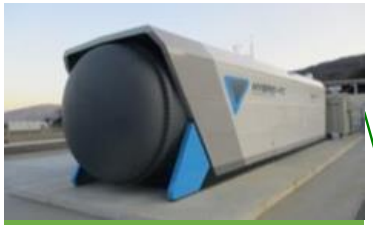


(8) Track Records

MITSUBISHI HITACHI POWER SYSTEMS

➢ **In addition to 250kW-class, the 1MW-class is now under development.**

250kW-Class

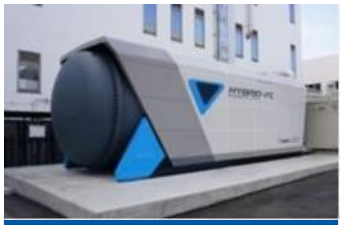


J Power

Mono-generation

Visit site (May,8th)

250kW-Class



TAISEI Corp.

Co-generation/ Hot water

Tokyo gas

Co-generation /Hot water

250kW-Class

Kyushu Univ.

Mono generation

Operation time : 23,000hrs

250kW-Class

HAZAMA ANDO Corp.

Co-generation /Hot water

1MW demonstration

Mono generation

250kW-Class

NGK Spark Plug

Co-generation/Steam

250kW-Class

Toyota Motor

Co-generation/Steam

250kW-Class

MITSUBISHI ESTATE

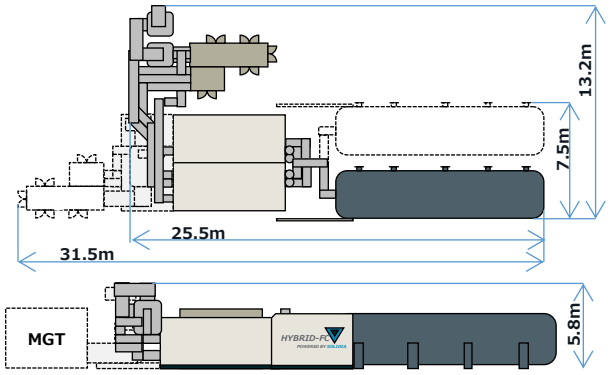
Co-generation/Steam

Technical development of SOFC is sponsored by NEDO

(9) About 1MW-class SOFC system (under development)

- 1MW-class output SOFC, aiming to support industrial demand
- 1MW-class module is using the same proven Cell Stacks but it is larger and operated under high pressure of 0.6MPa compared to 0.23Mpa in 250kW-class module.

	Half module test unit	Full-scale 1MW-class
output	680kW	1250kW
operating pressure	0.6MPa	0.6MPa
number of cartridges	20 units	40 units



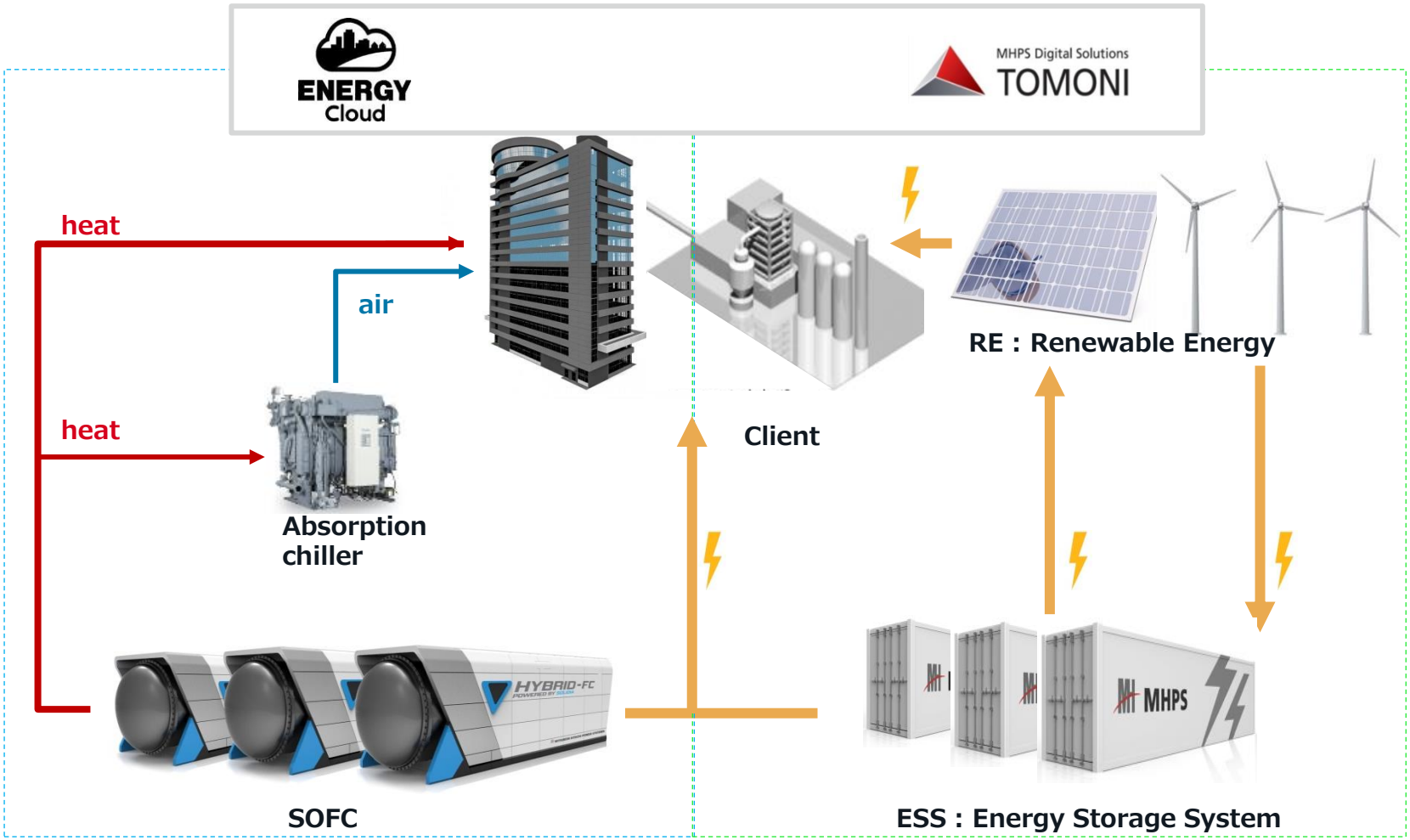
1MW-class system layout
(※solid line：half module、dotted line：full module)

Site photo : Auxiliary unit (left) SOFC Module vessel (right)

(10) Microgrid System Solution with MHPS-MEGAMIE (Concept)

MITSUBISHI HITACHI POWER SYSTEMS

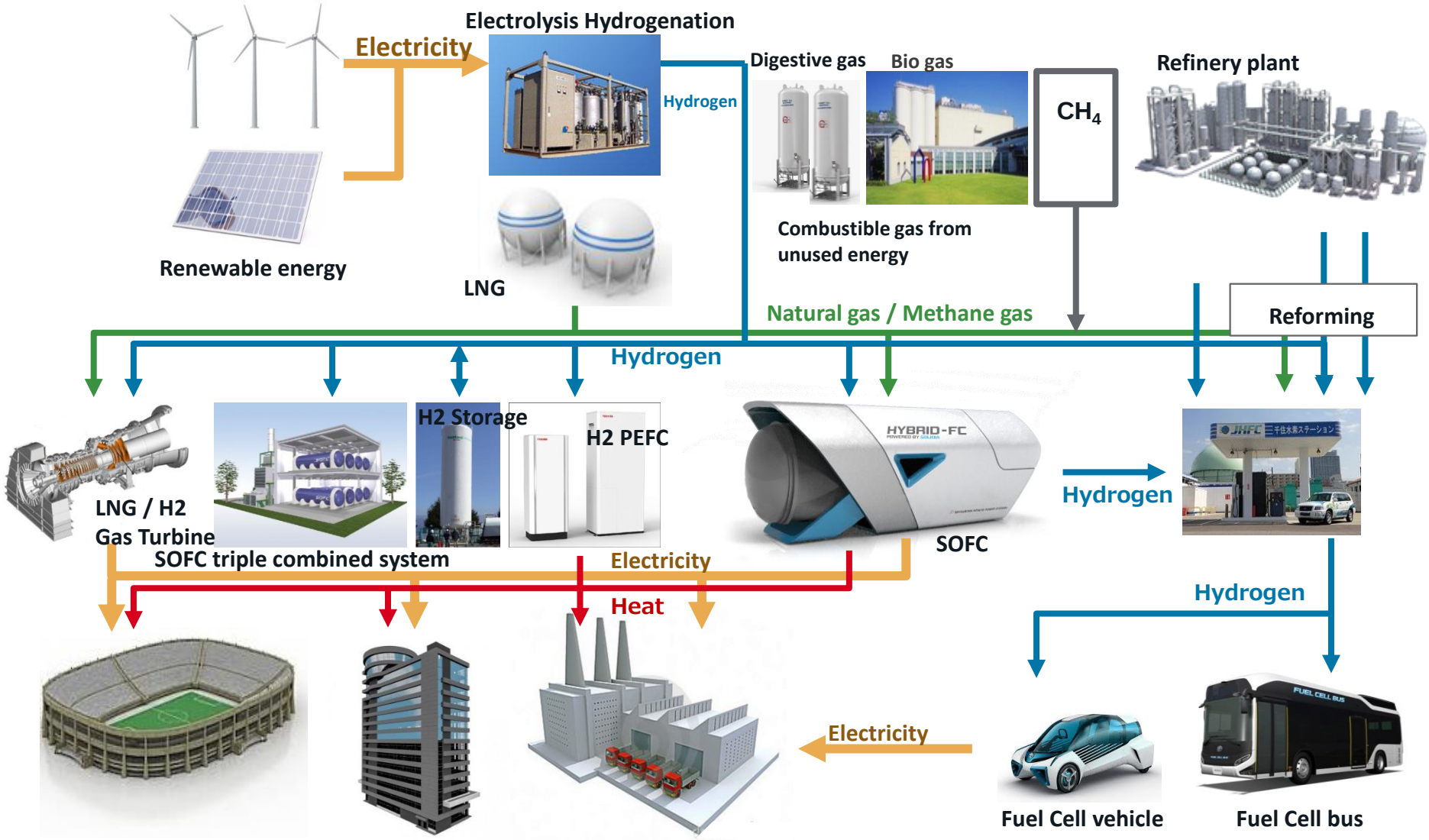
- **With digital soutions, MHPS can integrate a whole sustainable microgrid for commercial and industrial power and heat users.**



(11) Various applications to reinforce low carbon society

MITSUBISHI HITACHI POWER SYSTEMS

➢ **MHPS-SOFC is the key to complete "energy supply chain" for community in the future.**



5. ENERGY CLOUD™

KEY WORDS; AI / Prediction / Save Energy / Power & Energy Solution Provider

(1) ENERGY CLOUD™

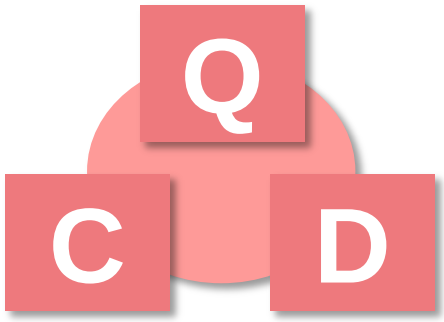
MHI is offering the ENERGY CLOUD™ service, a solution that will help increase the enterprise value of industrial factory through optimized energy use. This service is realized by applying MHI's analytical prediction technology utilizing AI & IoT.

Energy QCD **Optimizing Energy**

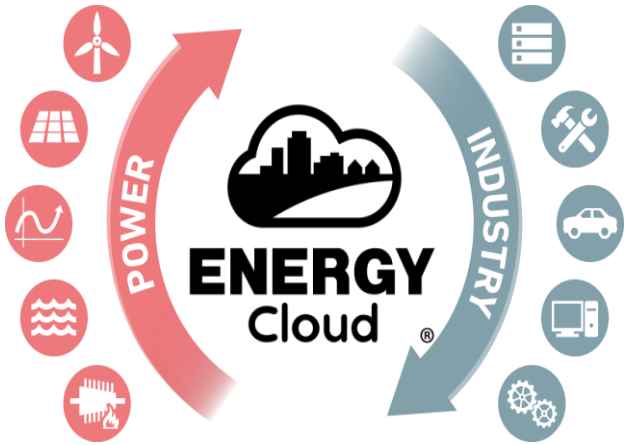
Manufacturing QCD **Demand prediction using AI**

Optimize QCD of energy

Carbon free

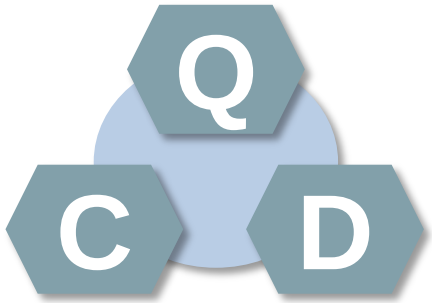


Cost saving Stable supply



Optimize QCD of manufacturing

Product quality



Total cost saving Delivery optimization

(2) Step of ENERGY CLOUD™ Service

Standardized procedure in creating solution makes it effective and prompt to introduce ENERGY CLOUD™.

Solution with AI System Operation

6 Optimization ⇔ PDCA

ENERGY Cloud™

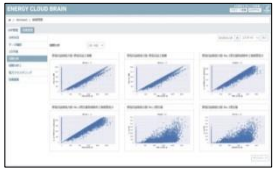
With AI applied to tasks, expert's knowledge and experience can be widely utilized and business processes are more optimized.

5 Model creation → Implementation

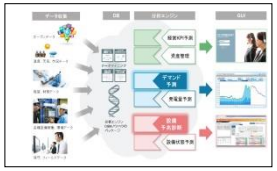
- Analyze the accumulated data, create the model fitting to the purpose, and implement it into the system.

AI Analysis

4 Grasp Correlation → Define Goal



Correlation analysis



Model creation → System implementation

3 Data Accumulation

- First, accumulate the data without taking time and effort.
- Important to get a whole picture without focusing on detail data.
- Find the current situation by arranging collected data in time series.

Preliminary Analysis

2 Visualization

eFinder™ Netmation

- Preliminary analysis using past data to understand facts

1 Understand Facts

Equipment operation
Environment data

Maintenance
Field data

Management
Financial data

(3) Understand Facts

- It's possible to decide, classify and predict by using data mining technique suitable for problem solving.
- New insights can be obtained from combination of diverse information.

Broad and shallow data

[Open data]
- Market trend
- Economic trend

[Plan/Result]
- Production instruction
- Result
- Quality

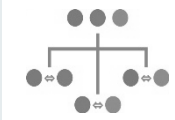
[Equipment operation]
- Equipment operation
- Equipment energy
- Status

[Field information]
- Maintenance
- Failure history

Narrow and deep data

Data mining

Association rule	Clustering
Regression analysis	Classification



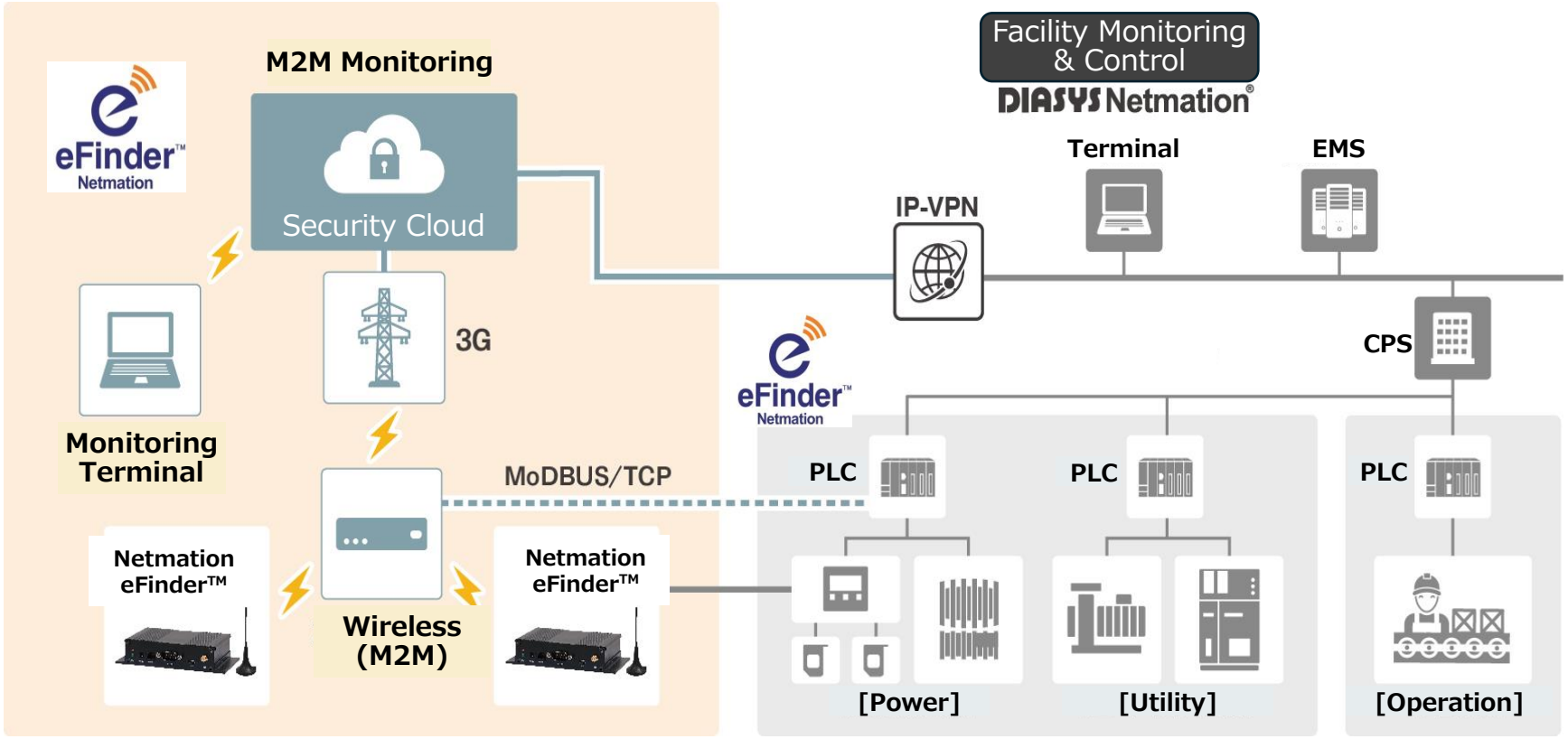
Decide — Make decision in management by using the correlation analysis and the prediction model

Classify — Extract patterns in future by classifying a wide variety of data from various fields

Predict — Predict what happens next by combining the past events with the related information

(4) On-site 'Visualization' Tool ; Netmation eFinder™

- Construct the high-security service network that can utilize IoT data without using the internet.
- No influence on facility operation due to independent wireless network.
- Applicable to any facilities and any devices.

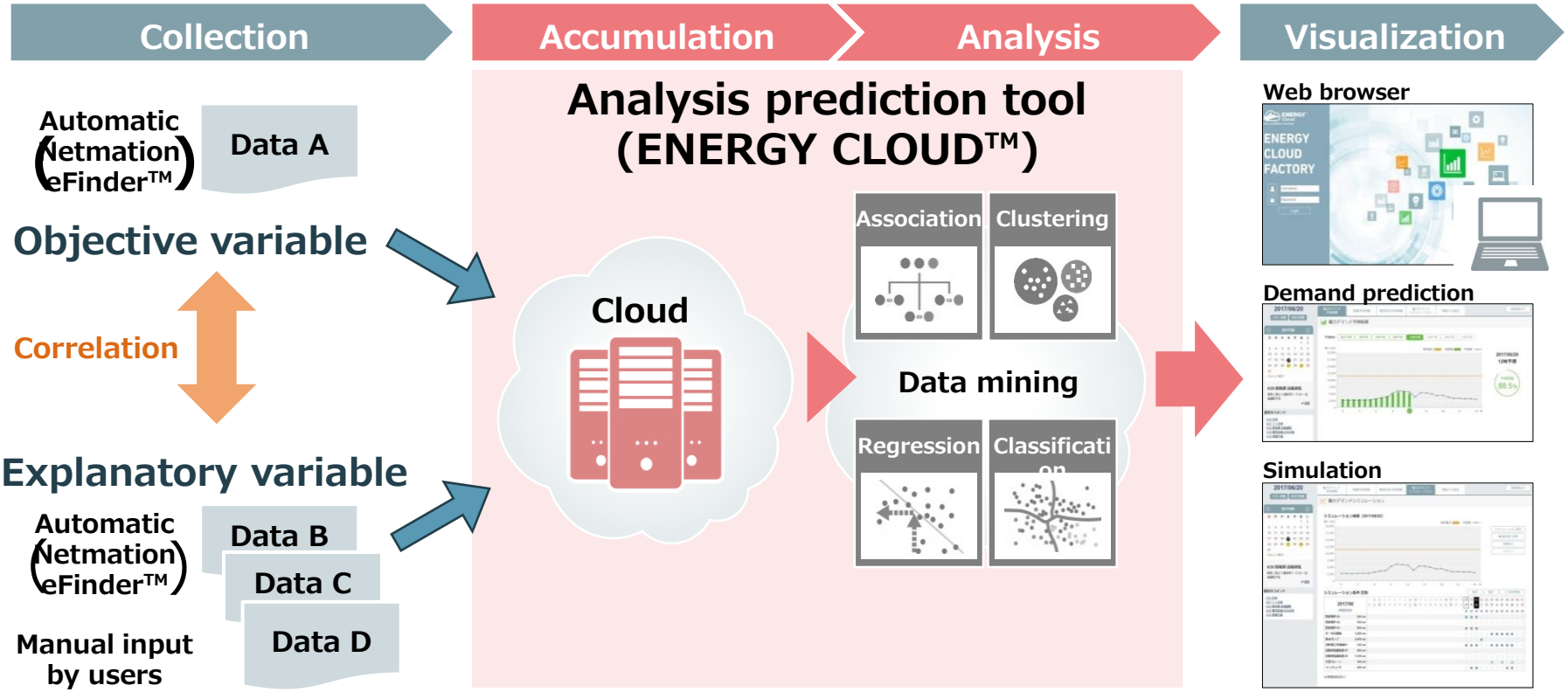


Ref. : https://www.cs.mhps.com/products/e-finder.html (Japanese version)

EMS : Energy Management System
CPS : Compact Process Station
PLC : Programmable Logic Controller

(5) Prediction applicable to various utility demand

Prediction by ENERGY CLOUD™ can be applied to various utilities such as power, heat, water, fuel and etc.



Power

Renew-able

Fuel

Water

Vapor

Price

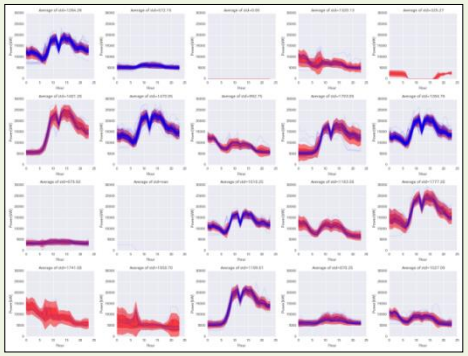
Prediction results go to solution various scene

(6) Our original prediction technique using AI

Prediction by ENERGY CLOUD™ can meet various purposes through taking long-, medium- or short-term prediction.

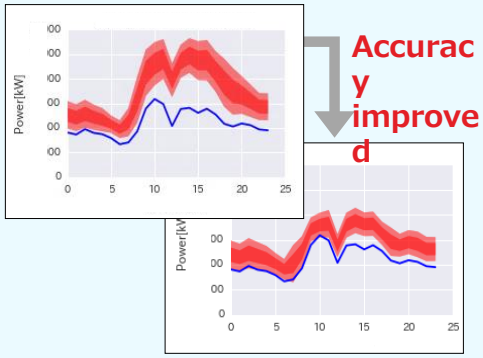
Long-term
Analyze actual demand

Use annual calendar and factory operation plan considering working day and holiday



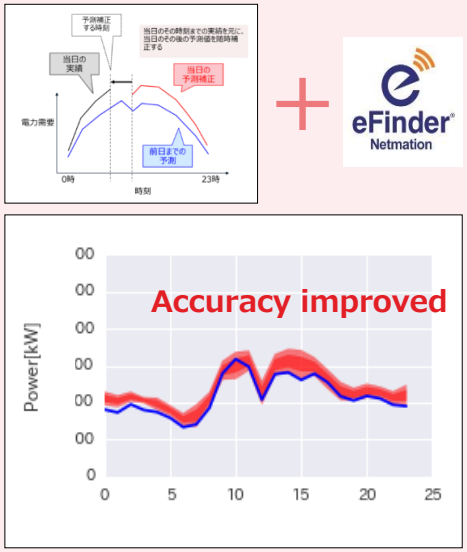
Medium-term
Adjust operation plan

Accuracy improvement
Use monthly and weekly operation schedule for factory and facilities



Short-term
Calibrate by real-rime data

Accuracy improvement
Use real-time data of demand and facility operation



Get better accuracy by periodical learning process with daily demand data.

(7) System example of demand prediction

Minimum records and power data are required to launch demand prediction system.

Data from customer

Objective variable
Actual demand

Explanatory variable
Calendar

Explanatory variable
Operating plan for specific facilities
(e.g. equipment with large load fluctuation)

ENERGY Cloud

Association
Classification
Clustering
Regression

Demand data from all equipment

eFinder Netmation

Demand data

Equipment operation data

Factory A
Demand data
Actual data of specific equipment
Equipment data

Factory B
Demand data
Equipment data

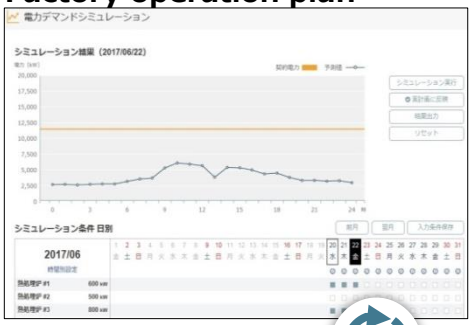
Factory C
Demand data
Equipment data

Demand prediction

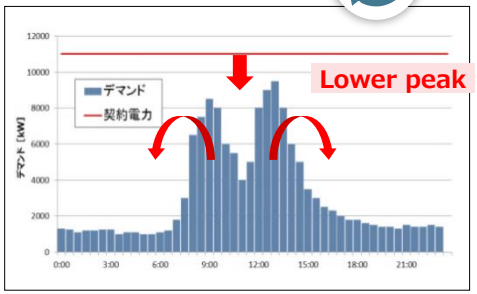
- Long-term
- medium-term
- short-term

Accuracy 90% or more

Factory operation plan



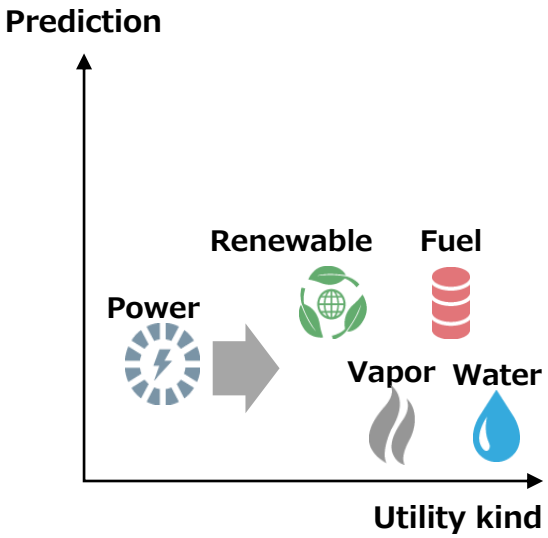
Demand simulation

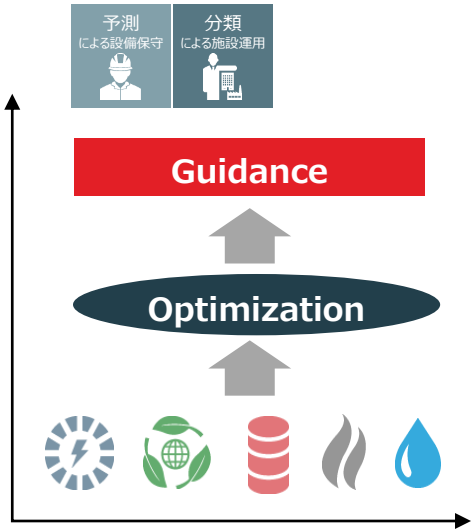


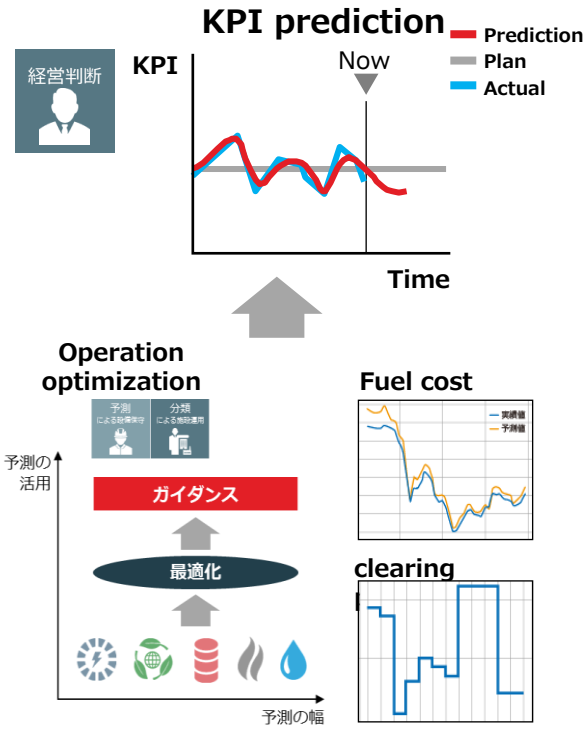
(8) Go to solution service by ENERGY CLOUD™

Energy-related solution for various scene

Predict target value → **Command from prediction** → **Support management**







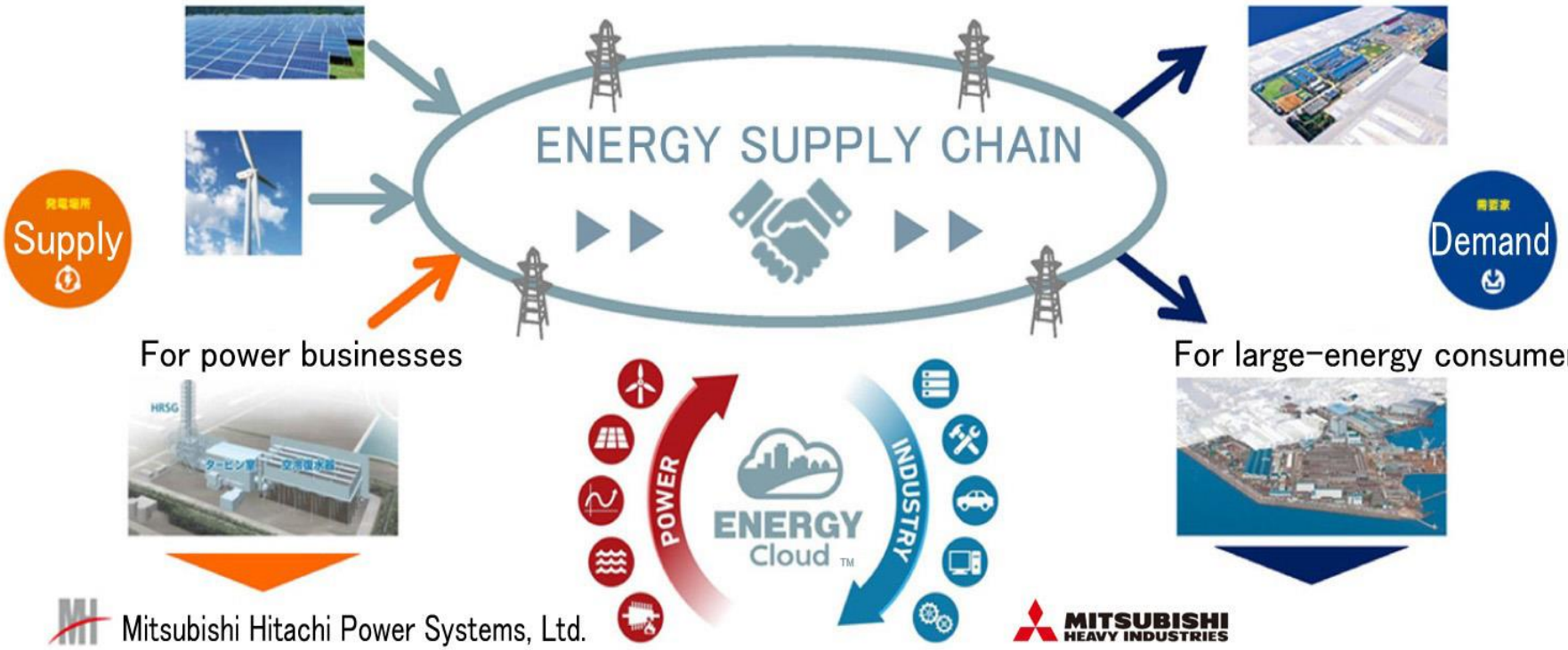
- Applicable to various utility

- **Provide guidance** to optimize command plant operation
- **Optimize plant operation** through skilled engineer judge

- **Predict KPI** for business operation
- **Support plant operation optimization**

(9) Power & Energy Solution Provider

POWER & ENERGY SOLUTION PROVIDER



Mitsubishi Hitachi Power Systems, Ltd.

MHPS-TOMONI™

- Operational improvement
- Performance improvement
- O&M optimization

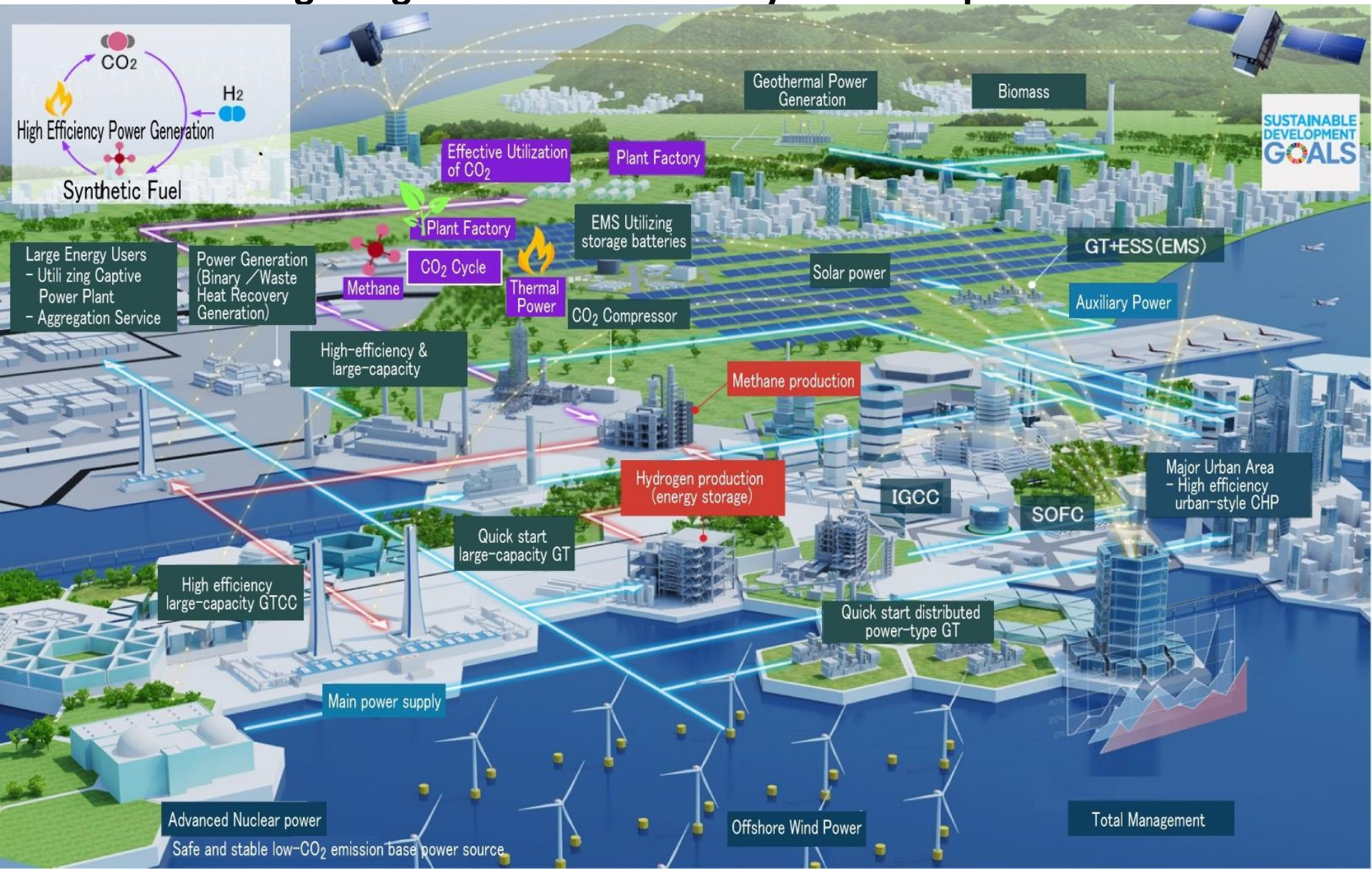
MITSUBISHI HEAVY INDUSTRIES

ENERGY CLOUD™

- Support for energy infrastructure and O&M
- EMS*/Total optimization system
- Predictive diagnosis, preventive maintenance

*Energy Management System

(10) Ultimate energy infrastructure contributing to maintaining the global environment by MHI Group



MOVE THE WORLD FORWARD

MITSUBISHI HEAVY INDUSTRIES GROUP