MHPS

Mitsubishi Hitachi Power Systems

The Latest Coal-Fired Thermal Power Plant

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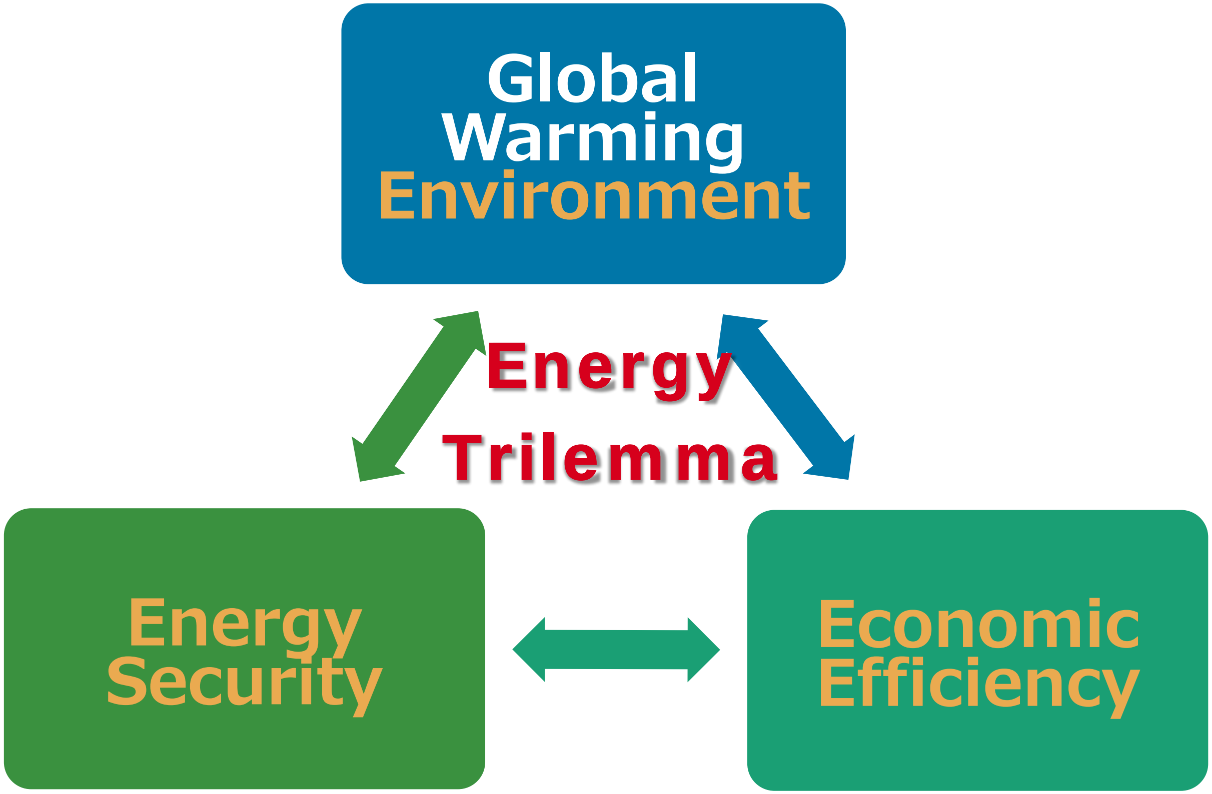
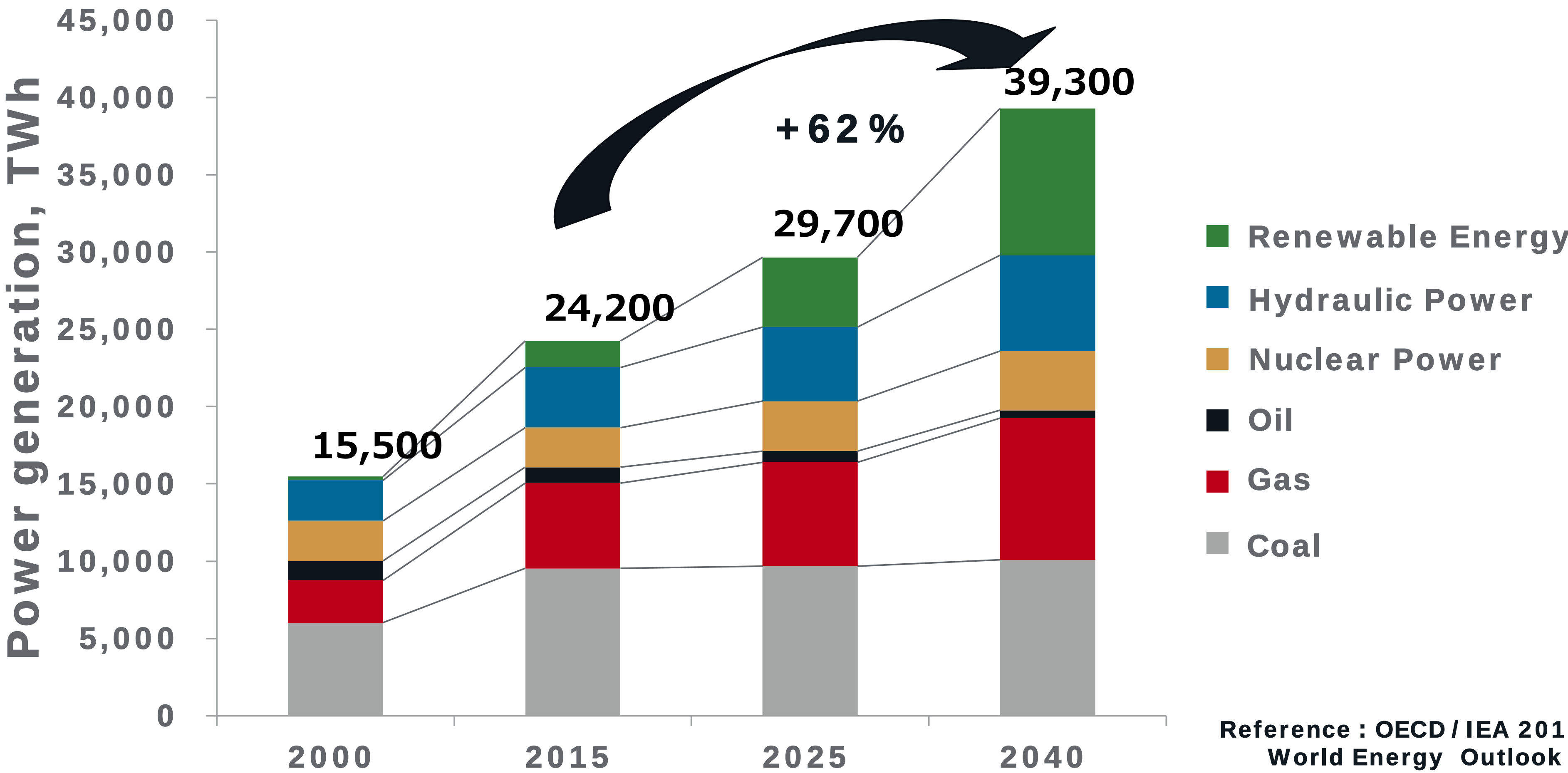


The Shift in Worldwide Power Generation

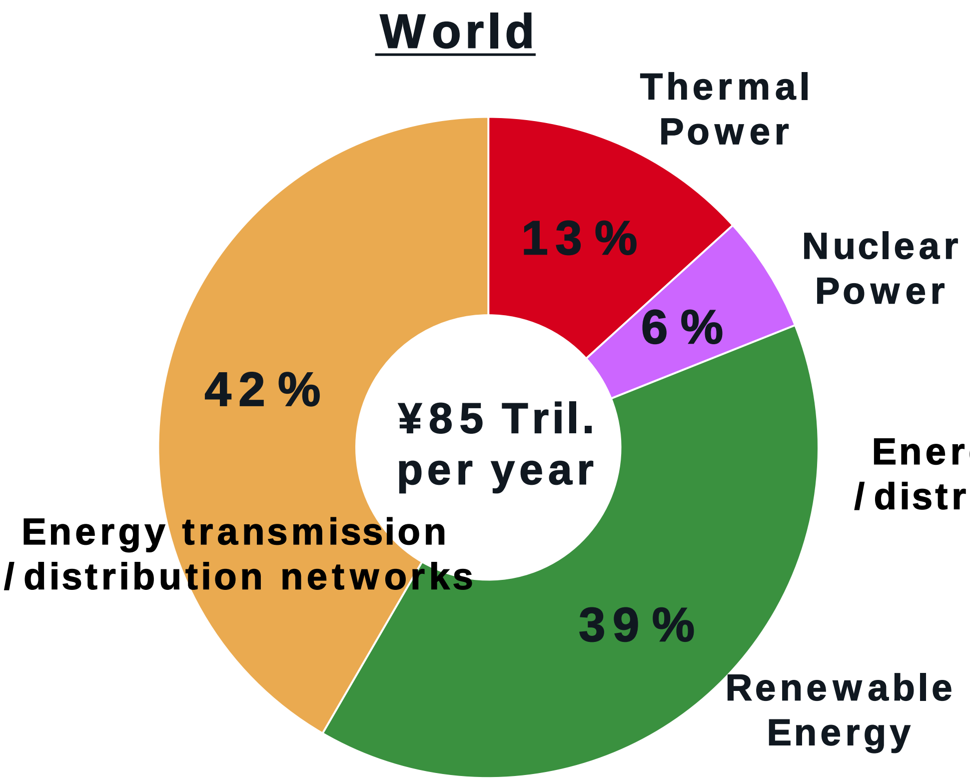
- Economic development will drive strong growth in power generation.
- Renewable energy will increase substantially.
- Total power generation output from coal and gas will be maintained, with coal share decreasing and gas share will slightly increasing.



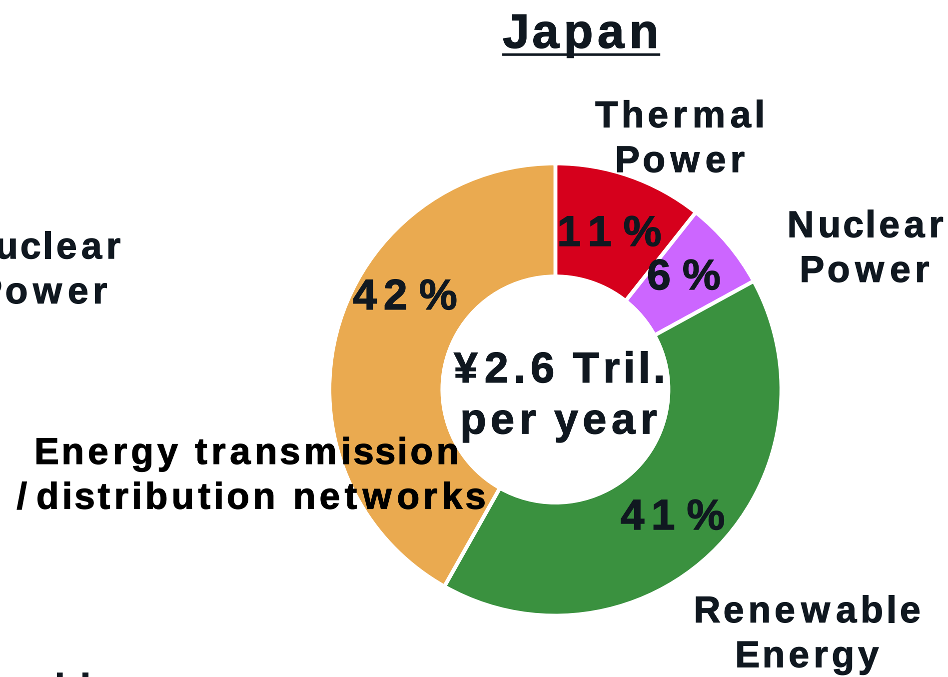
Reference : OECD / IEA 2016 World Energy Outlook

Investment in Power Generation: 2016-2040

- Total investment over the next 25 years forecast to be in excess of $19Tril. （¥2,100Tril. / ¥85Tril. per year）
- Approx. 80％ of total investment to be in renewables and energy transmission / distribution networks.
- Japan to follow same trend; $580Bill.(¥64Tril. / ¥2.6Tril.per year).



Reference : OECD / IEA “World Energy Outlook 2017”

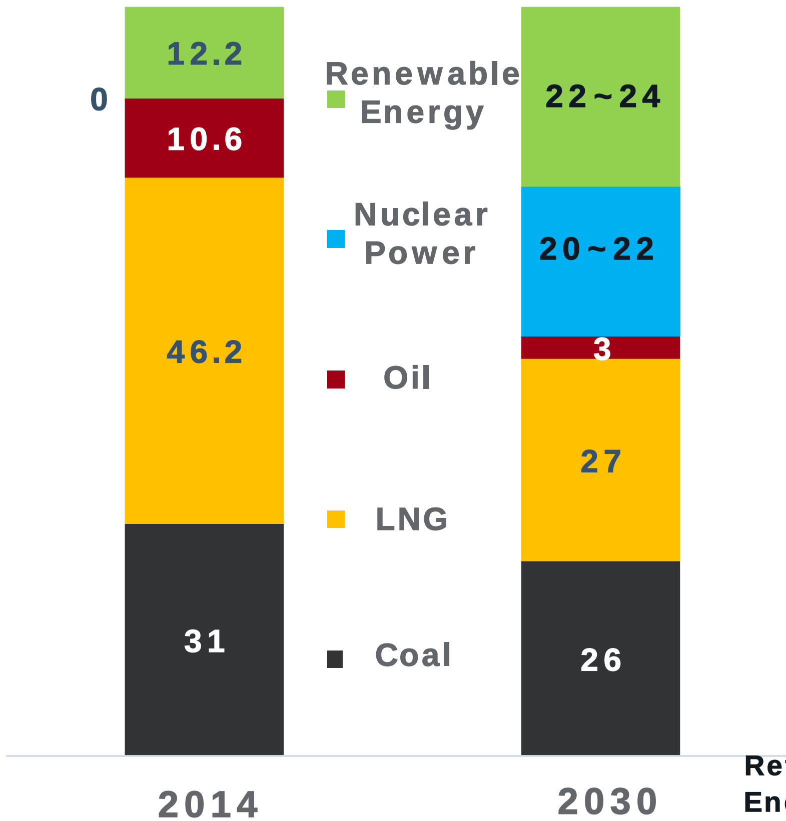


Reference : OECD / IEA “World Energy Outlook 2016”

The Shift in Japan's Power Generation

- The 5th Strategic Energy Plan of Japan (Cabinet approval on July 3th, 2018) follows "Energy mix" goal.
- Renewable energy will increase to 22~24% in 2030.
- The share of coal and gas thermal power will decrease.

Power Source Plan in Japan, 2030



Reference : Agency for Natural and Energy

Factors Driving the Evolution of Thermal Power Technology in Japan

Cause

- Electric Market Deregulation
- Increase of Renewable Energy
- Separation of Energy Generation and Transmission
- Nuclear Accident in Fukushima
- Shale Gas
- Paris Agreement
- The demand for Energy Saving and High Efficiency

Effect

- Increased demand for **Energy Security**, **reliable power sources** and **stable supply**
- The development of **Flexible power sources** to compensate for fluctuating renewable energy **(Fast startup, Wider operation load range, Higher ramp rate etc.)**
- **Fuel diversity** for reduction in CO_2 gas emission
- **Optimization of plant operation** and **innovation in maintenance technology** utilizing ICT
- Continuing development of **high efficiency thermal power plants** (IGCC etc.)
- Increasing investment from overseas for the **latest coal-fired thermal power technology**

2. Base Load Power Plants with Flexibility

2-1. Flexible Operation

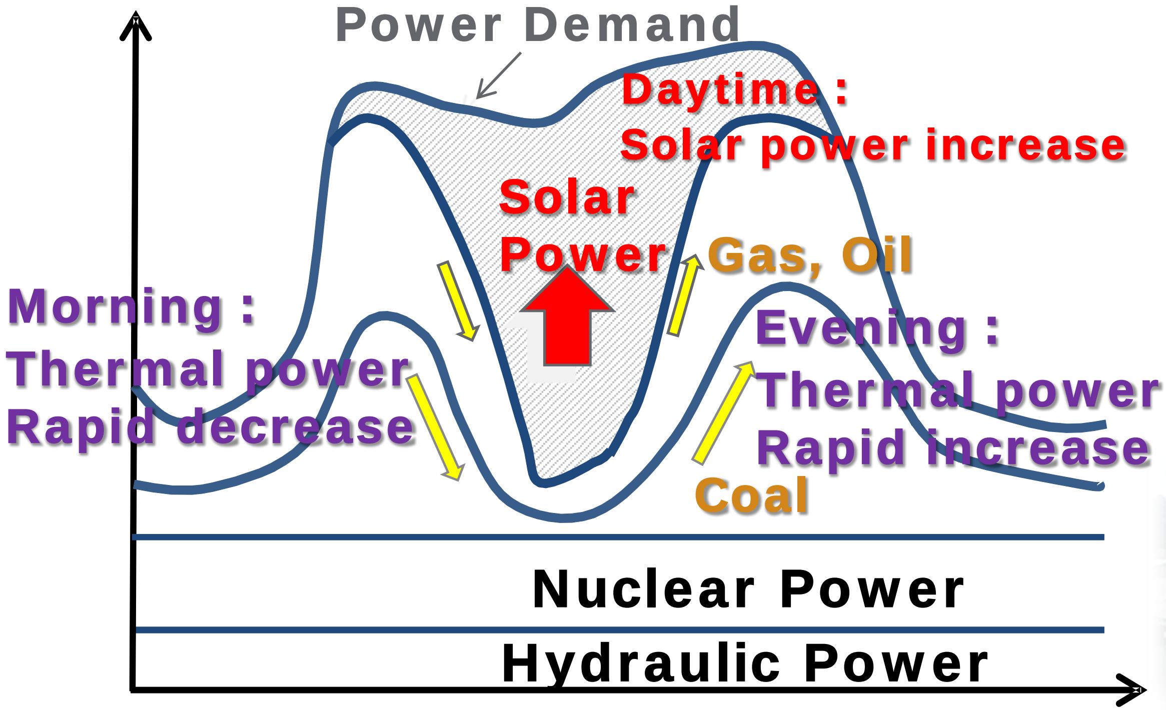
Reductions in CO_2 from Coal Fired Power Plants

CO_2 Reduction

- **Renewable Energy**
  - -Requires- → Flexible Operation
- **Coal-fired Thermal Power Plant**
  - **Flexible Operation**
    - Increase ramping rate
    - Reduce minimum load
    - Reduce startup time
  - **Efficiency Improvement**
    - To reduce energy loss
    - USC · A-USC (Higher steam temp)
    - IGCC (New heat cycle)
  - **Biomass Firing or Co-firing with coal**
    - Utilization as carbon neutral fuel (Including carbon-free hydrogen, carbon-free ammonia etc.)
    - Co-firing in PC boiler
    - CFB, BFB, Stoker
  - **CO_2 Scrubbing**
    - To capture CO_2 emission from flue gas
    - To remove carbon from fuel
    - CO_2 capture (Chemical absorption, amine, physical absorption, etc.)
    - Oxy-combustion
    - Chemical looping

The Demand for Thermal Power Plant Flexibility

- Power generation with renewable energy such as solar and wind is subject to variable weather conditions.
- Increasing output share from renewables increases system instability.
- Flexible operation, increased ramping rates and reduced startup times are increasingly being demanded from thermal power plants.



Typical Power Demand Allocation
based on “Energy Mix” at 2030 (clear day)

The Flexibility of Coal and Gas

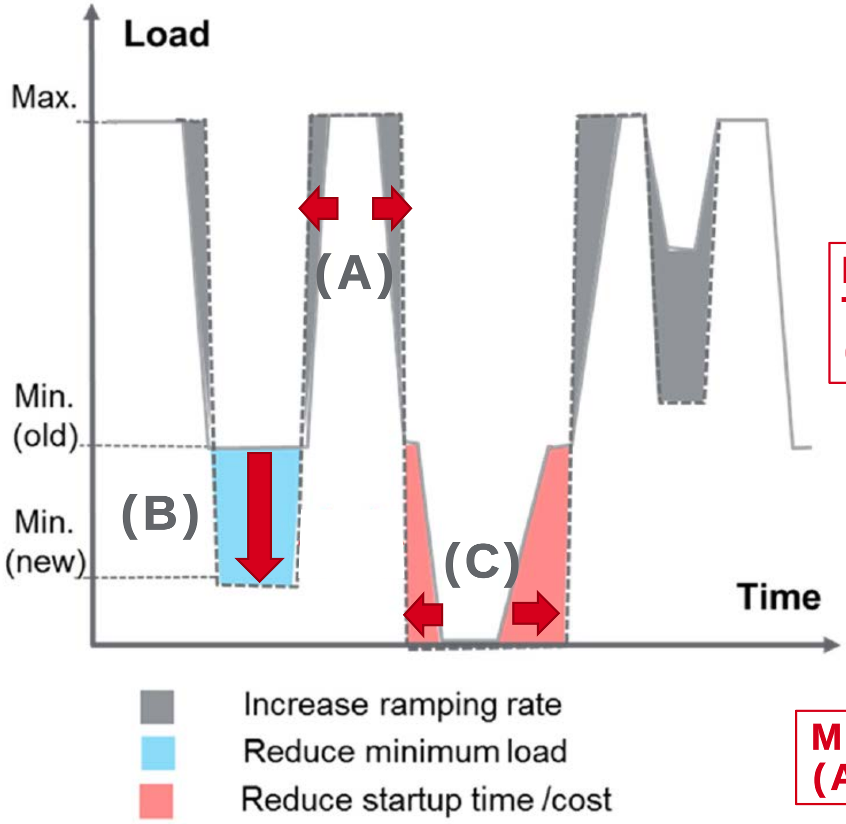
- **Gas Turbine (GT) / Gas Turbine Combined Cycle (GTCC) Plant:**
  - High ramping rate and fast startup time
  - Power supply source for peak demand
- **Coal-fired Supercritical (SC) / Ultra Supercritical (USC) Plant:**
  - Longer startup time, but lower minimum load
  - Can provide for both intermediate and base load demand

Fuel		Coal		LNG
Power Plant		SC/USC	IGCC	GT/GTCC
Minimum load	Present	15% (Coal exclusive firing)	35%	30%
	Target	10%	35% or less	25%
Ramping rate (Note2)	Present	3～5%/min.	3～10%/min. (Note4)	20%/min.(GT) 15%/min.(GTCC)
	Target	～7%/min. 10%/min. (Note1)	5%/min.～ 10%/min. or more	30%/min. (GT) 20%/min. (GTCC)
Startup time (Note3)		Hot: 2hr Cold:10hr (Ignition ～ Full load)	Cold : 15hr	Hot: 0.2hr(GT)/0.5hr(GTCC) Cold: 0.2hr(GT)/3hr(GTCC)

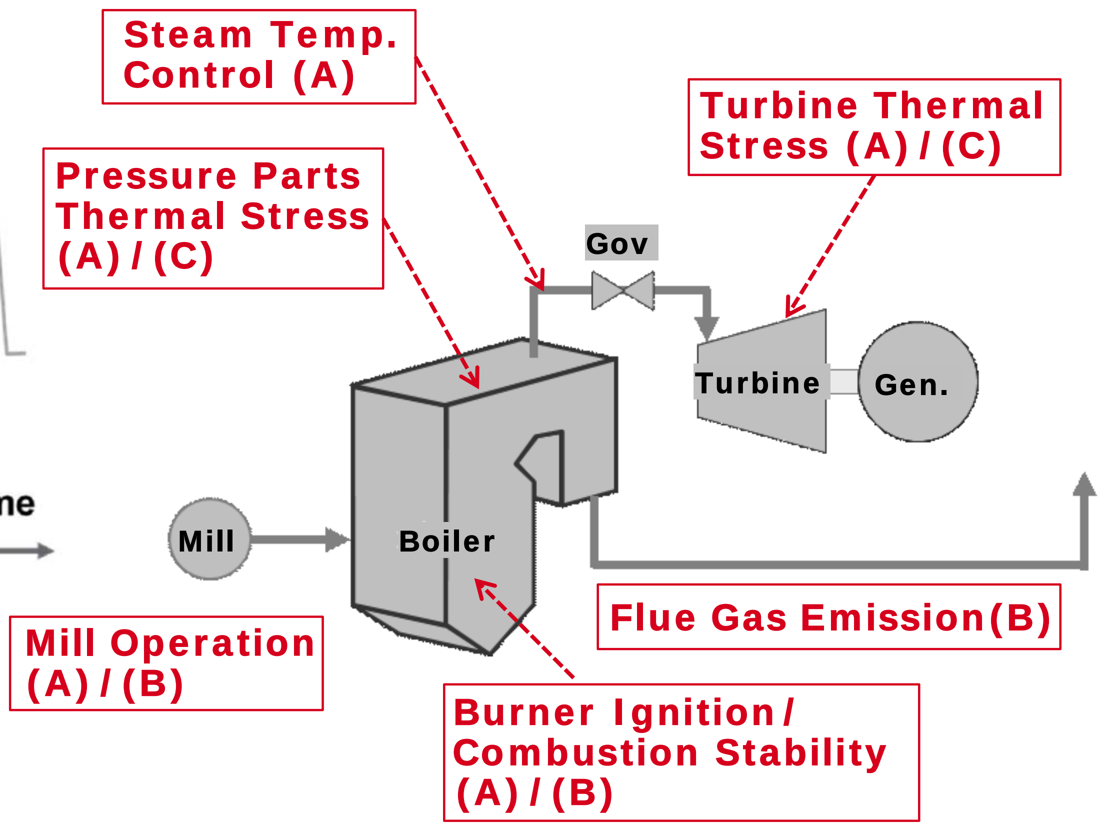
Note 1) Indirect Firing System
Note 2) Coal-fired Thermal Power Plant : Ramping Rate at 50～90% Load
Note 3) Hot: Night time shut-down (approx. 8hr), Cold: One week shut-down (more than 150hr)
Note 4) The details are covered by next presentation.

Improving Coal Fired Power Plant Flexibility

■ Challenges for the future are (A) Increase ramping rate, (B) Reduce minimum load, (C) Reduce startup time.



Technical Challenges



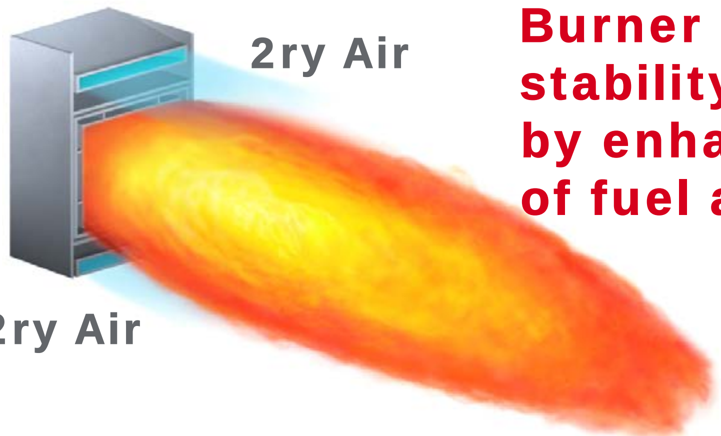
Measures to Improve Coal Fired Power Plant Flexibility

(A) Increase ramping rate (B) Reduce minimum load (C) Reduce startup time

Technical Challenges	Measures (*Challenges for the future)
Burner ignition / combustion stability(A) / (B)	● **Burner Modification** ①
Mill operation (A) / (B)	● **VVVF modification of mill motor** ② ● Mill capacity increase ● **Indirect firing system (Bin System)** ③
Steam temperature control (A)	● Improvement of control method ● **Parameter tuning utilizing ICT** ④
Pressure parts thermal stress (A) / (C)	● Reinforcement of pressure part ④ ● Structure modification ④ ● Replacement to high-grade material ④
Turbine thermal stress (A) / (C)	● **Lifetime evaluation / optimization of operation utilizing ICT** ④
Flue gas emission(B)	● Installation of gas bypass for prevention of SCR catalyst degradation

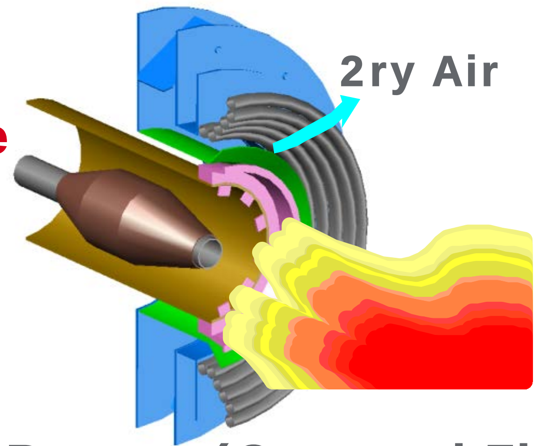
① Burner Modification

■ The latest burner design is capable of stable ignition at low load, allowing for lower minimum boiler load operation.

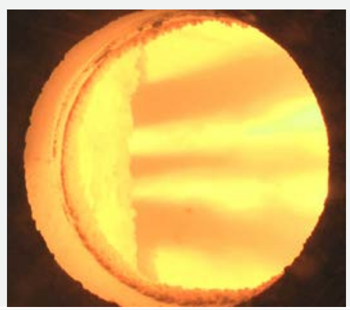
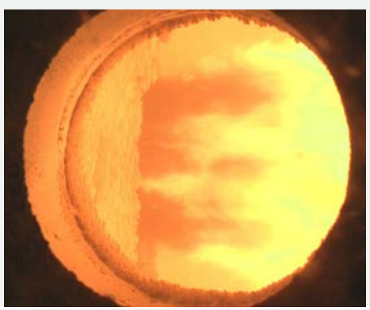
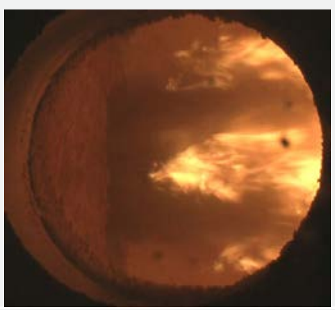


M-PM Burner (Circular Firing)

Burner ignition stability is improved by enhancing mixture of fuel and 2ry air.



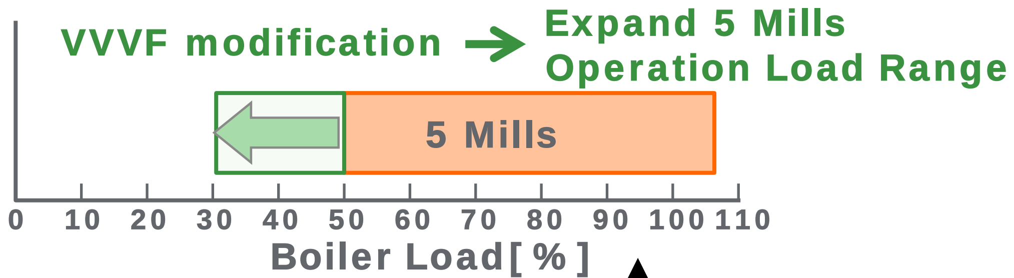
NR3 Burner (Opposed Firing)

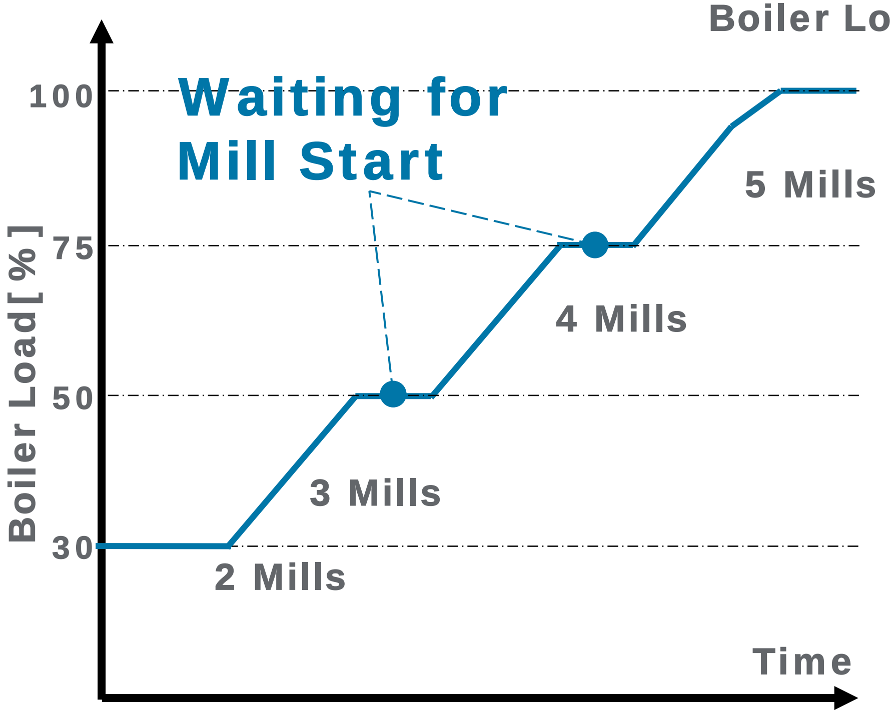
Ignition condition			
Burner Load	100%	50%	20%
Boiler Load	100%	30%	8%

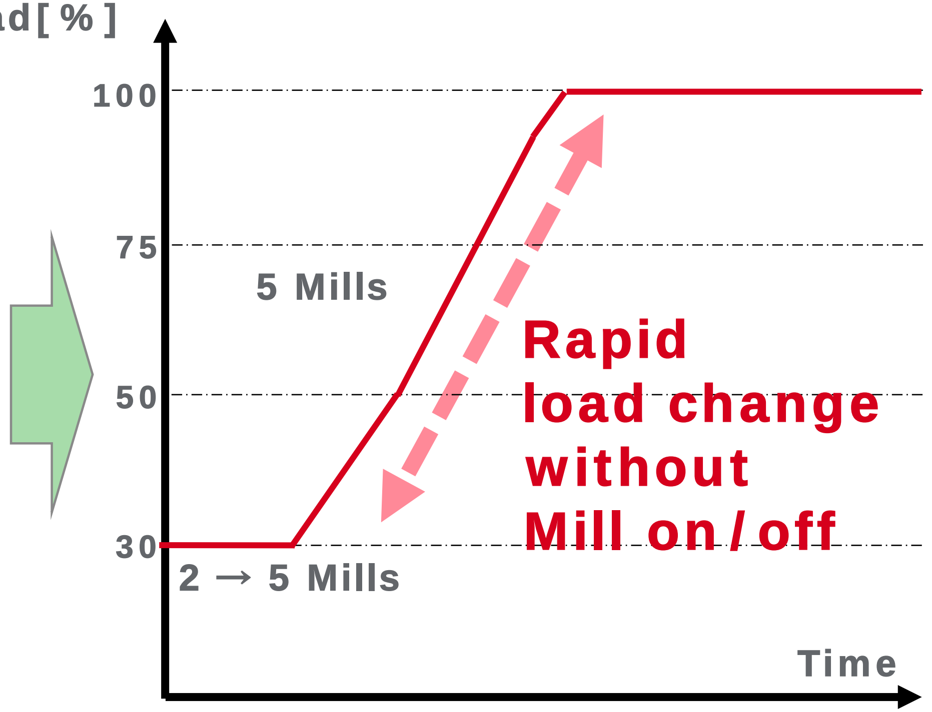
Stable ignition can be maintained at 20% burner load with the latest burner.

② VVVF modification of mill motor

- Mill table rotation speed is decreased by VVVF and mill minimum load is lowered.
- 5 mills operation load range is expanded to 30% load and rapid load change at 30%~100% load is achieved.
  VVVF : Variable Voltage Variable Frequency

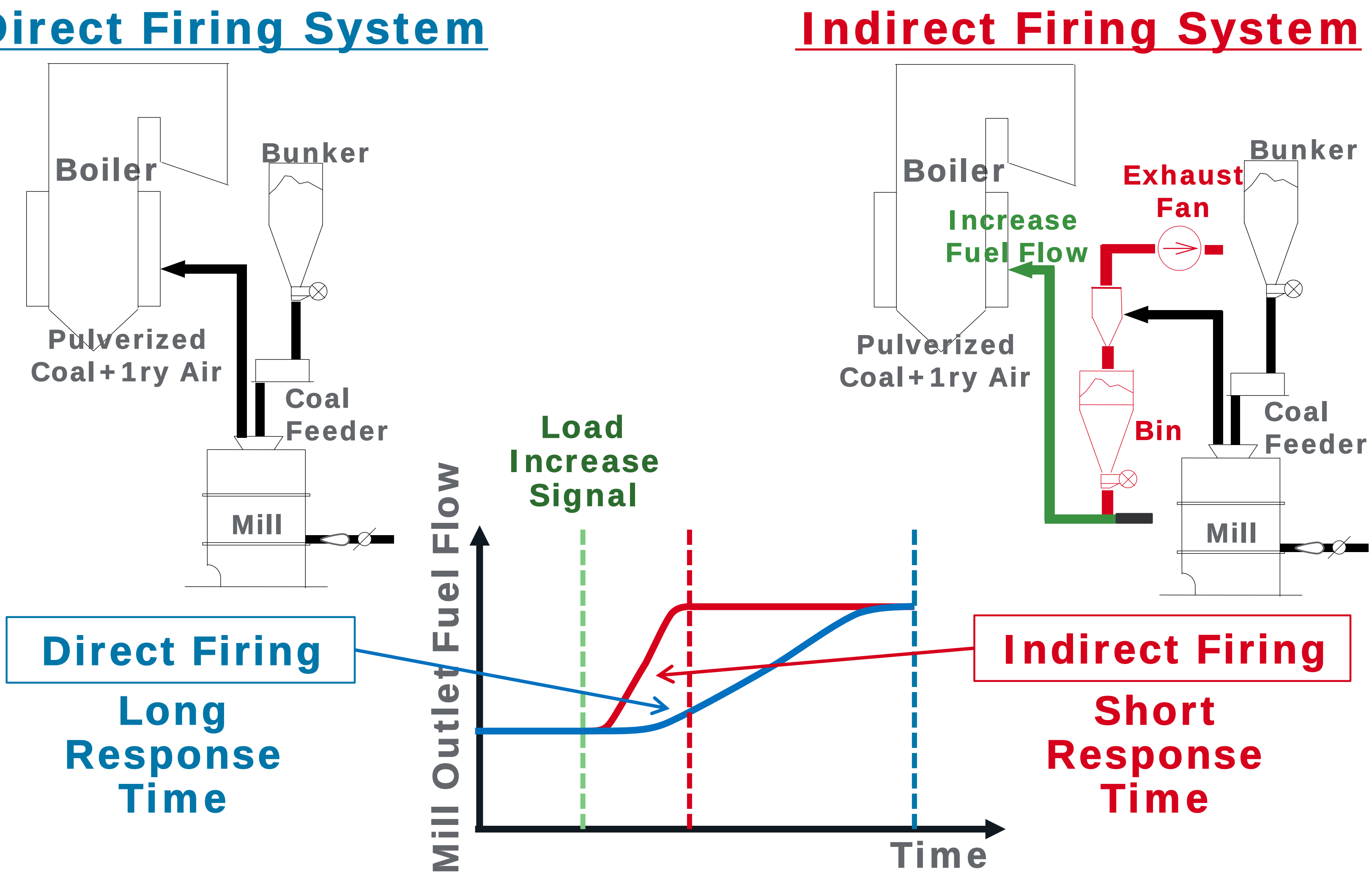






③ Indirect Firing System (Bin System)

- Higher ramping rate and lower minimum load can be developed by utilizing indirect firing system technology.



MHPS-TOMONI Solution Samples / ICT Solutions

- MHPS ICT solution provides value-added services to our customers.
- Customer benefits are delivered through our three service categories.

GTCC

Coal-fired

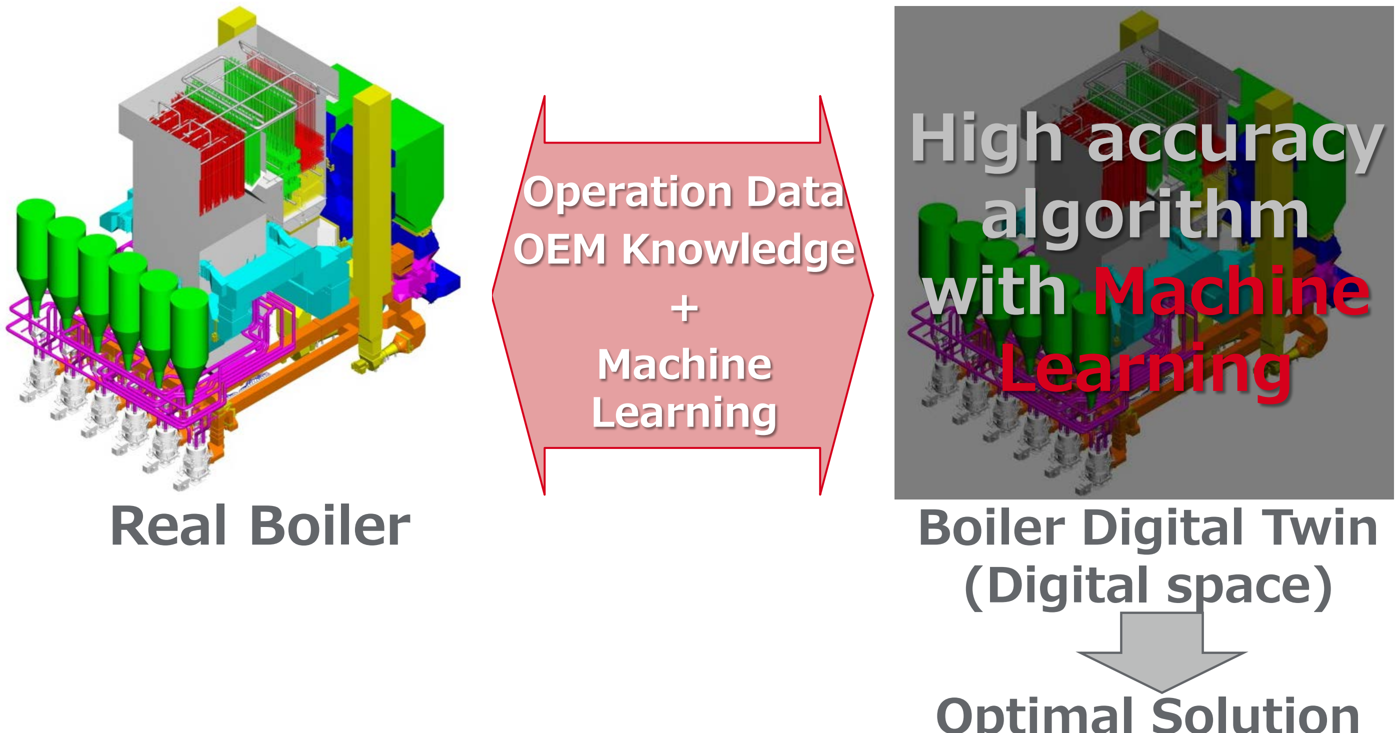
Geothermal

IGCC

Customer Benefits	ICT Service Categories	Service Example
1. Efficiency improvement by centralized monitoring 2. Unplanned outage reduction by predictive analytics 3. Maintenance optimization 4. Operation improvement by utilizing expert know-how 5. Startup reliability improvement	**O&M Optimization**	Remote Monitoring Service +Predictive analytics
6. Grid support and Frequency response 7. Turndown improvement 8. Peak power response 9. Faster startup 10. Fuel Diversity	**Flexible Operation**	AI Technology for Coal-fired Power Plant
11. Thermal performance improvement 12. Part load efficiency improvement 13. Reduction of auxiliary power	**Performance Improvement**	Plant Optimization System (POPS)

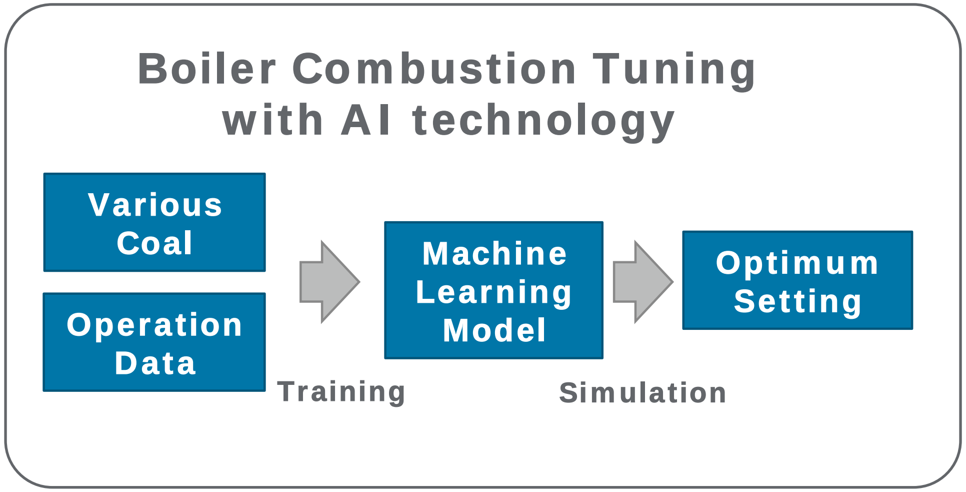
Boiler Digital Twin

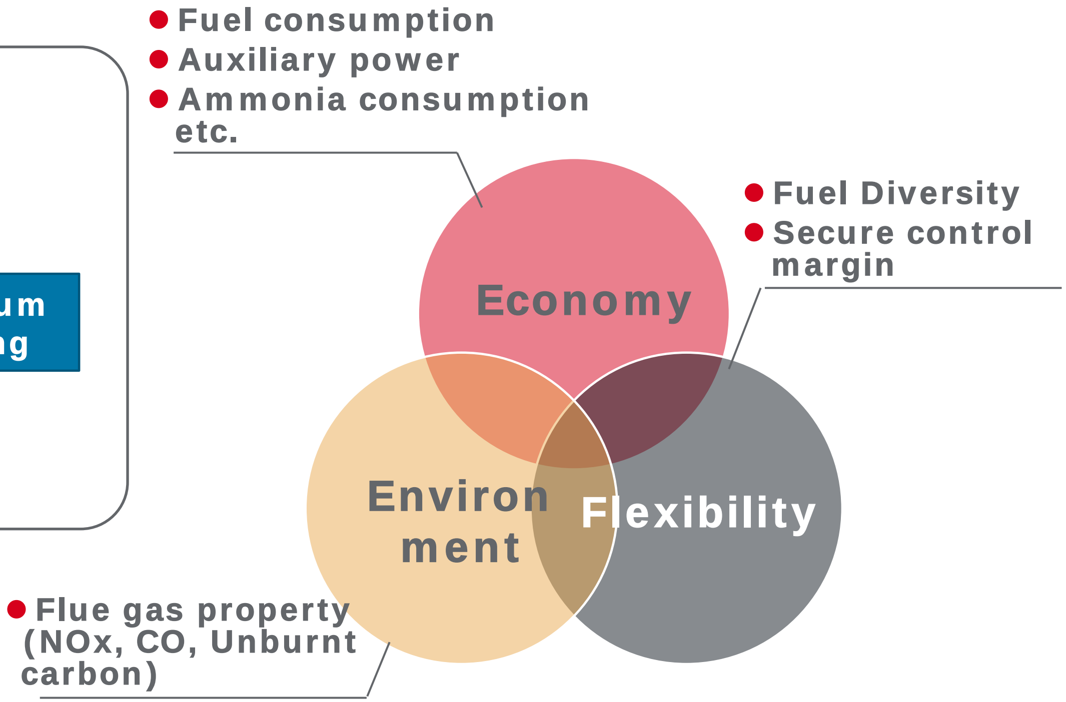
- Boiler Digital Twin; a model based simulation program that utilizes AI machine learning technology to optimize operational performance and efficiency.
- MHPS applies its OEM knowledge to provide customized solutions based on customer needs.
- An economic benefit of approx. $1.0Mil. is being realized at Taiwan's Rinkou thermal power plant due to AI Combustion Tuning.



④ Parameter tuning utilizing ICT

- The AI machine learning model is equipped with a range of coal and combustion operational data .
- Highly accurate settings for boiler combustion are tuned automatically to optimize economic, environmental and flexibility performance.

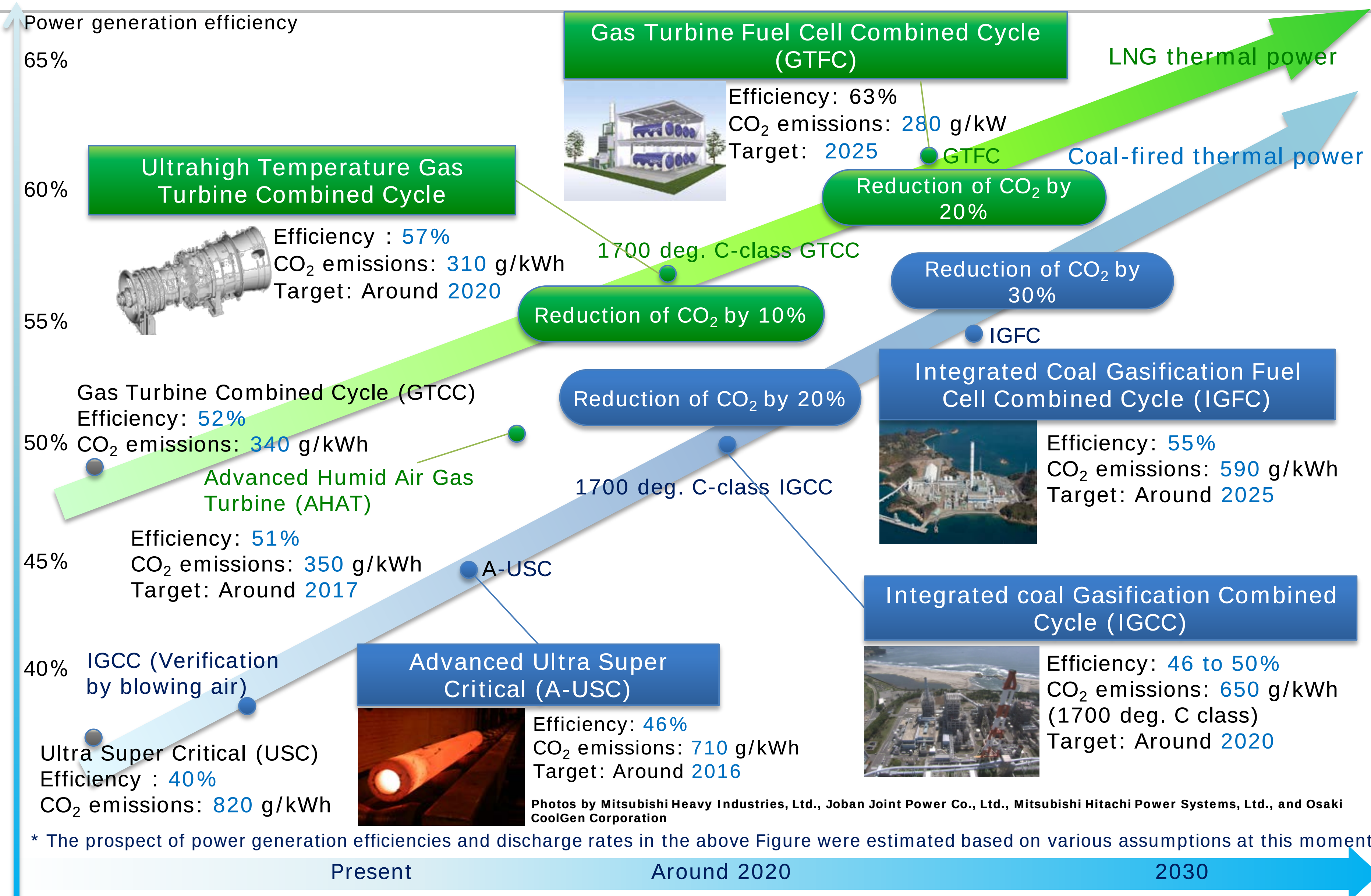




2. Base Load Power Plants with Flexibility

2-2. Reductions in CO2

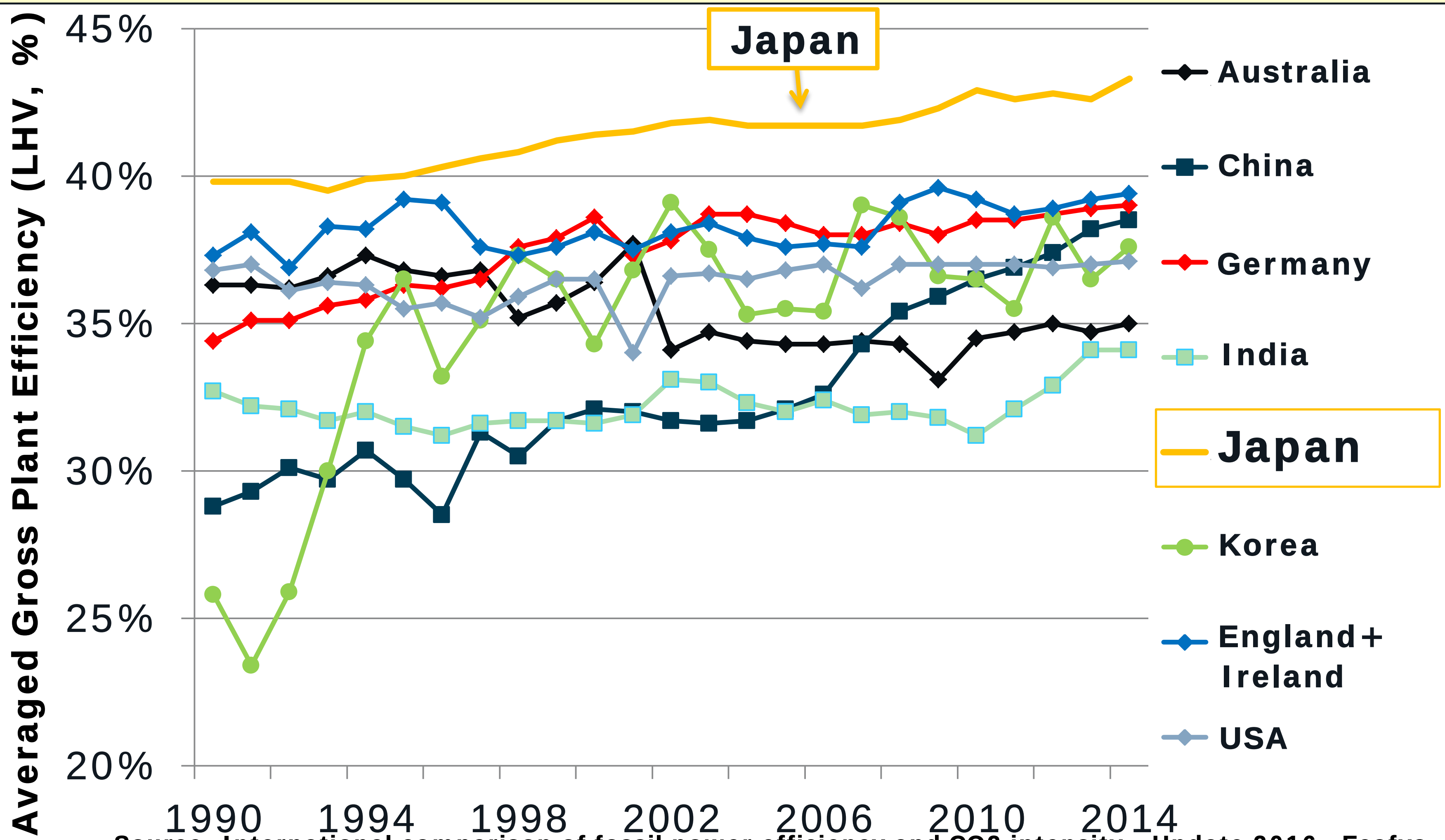
Roadmap of next-generation Thermal Power Technology



Source: METI News Release, Jun 30, 2016 http://www.meti.go.jp/press/2016/06/20160630003/20160630003.html

Efficiencies of Coal-fired Power Plants Around the World

- Japan boasts the highest efficiencies in the world thanks to the widespread use of Supercritical / Ultra Supercritical thermal power plants.
- Worldwide CO2 emissions can be reduced by more than 10 % if efficiencies in other countries are improved to similar levels as those found in Japan.



Source: International comparison of fossil power efficiency and CO2 intensity - Update 2016, Ecofys

The Contribution of SC / USC / IGCC to Reductions in CO2

CO_2 Emission Intensity (approx. value)

Reference : Agency for Natural Resources and Energy (March, 2015)

unit : kg/kWh

Sub-C	SC	USC	IGCC/A-USC
0.9	0.85	0.8	0.7

- Sub-C: Sub-Critical pressure
- SC: Super Critical pressure
- USC: Ultra Super Critical pressure
- IGCC: Integrated Gasification Combined Cycle
- A-USC: Advanced Ultra Super Critical pressure

CO_2 emission reduction (When Compared to Sub-C plant)

- **Indonesia Sub-bituminous Coal-fired 3 projects**
  (1,000MW×5units / USC under construction by MHPS)
  Approx. 4 million ton reduction in CO2 per year
  Equivalent to approx. 0.3% reduction in total CO_2 emissions from Japan*
- **Fukushima Revitalization Power IGCC Project**
  (540MW×2units / IGCC)
  Approx. 1.8 million ton reduction in CO2 per year
  Equivalent to approx. 0.1% reduction in total CO_2 emissions from Japan*
- **Total number of SC / USC Plants supplied by MHPS**
  (170units total / Japan:26units / Overseas:144units)
  Approx. 100mil. ton reduction in CO2 per year
  Equivalent to approx. 8%** reduction in total CO2 emissions from Japan*

* 1.3 billion ton at FY2015(Environment ministry 2nd review meeting（July 10,2017)

** Assume all plants as USC/800MW (averaged output of SC/USC plants in Japan)

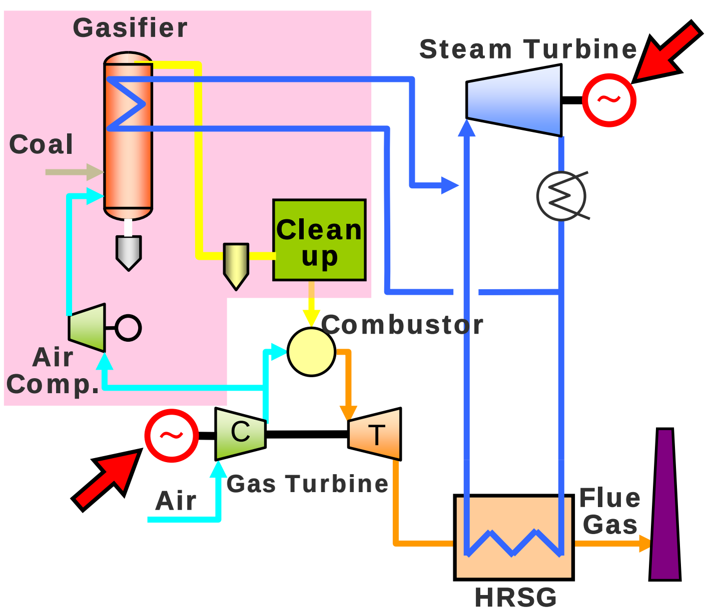
IGCC Technology

What is IGCC?

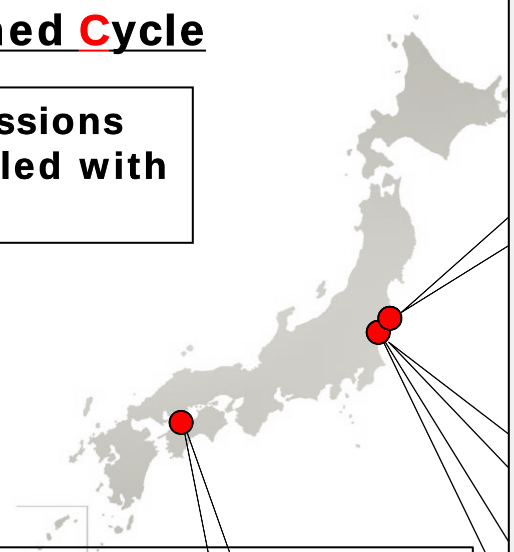
Integrated coal Gasification Combined Cycle

Higher efficiencies and reduced CO_2 emissions through a coal gasification process coupled with a combined cycle (CC) system

Combined Power Generation
(Combination of Brayton & Rankine Cycles)



IGCC Projects in Japan



Fukushima Revitalization Power

543MW Hirono (COD : 2021)

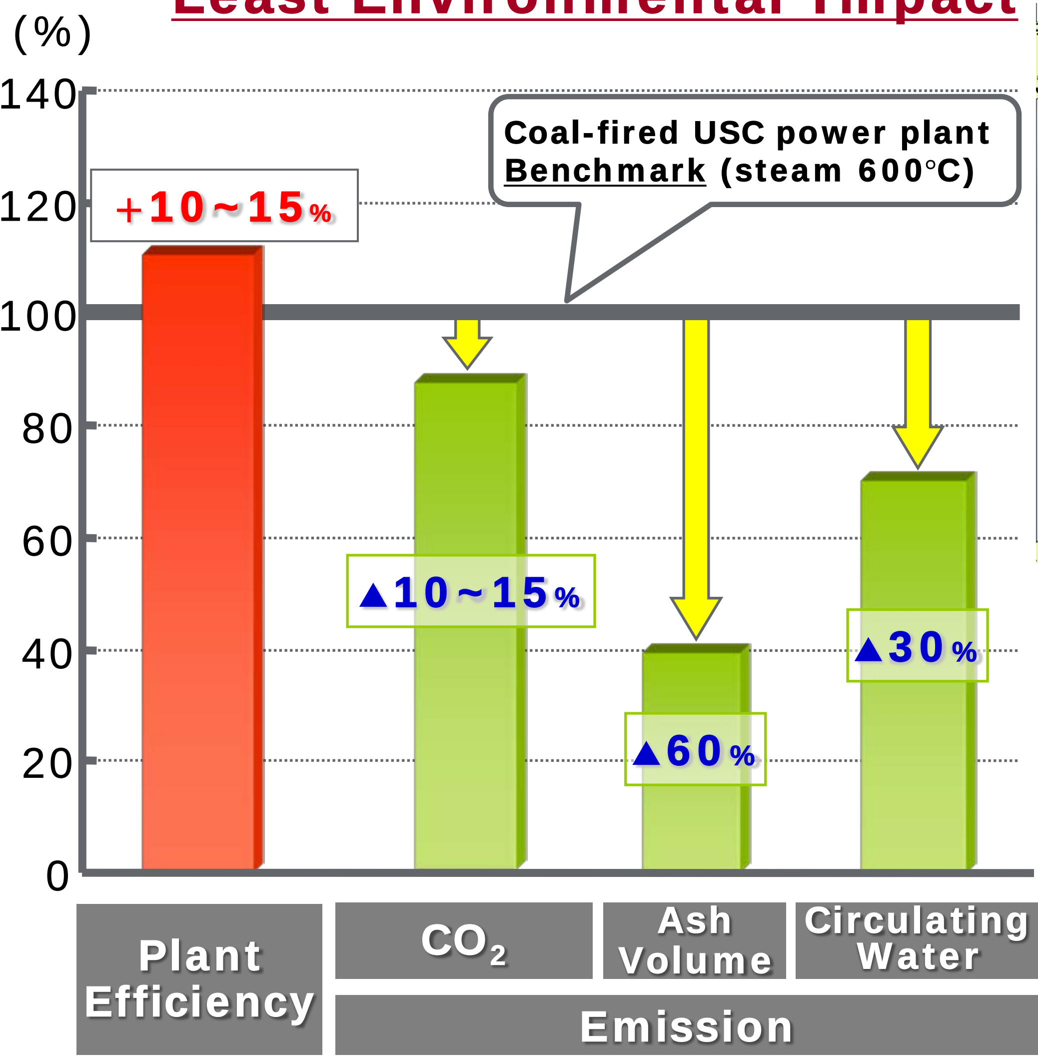
543MW Nakoso (COD : 2020)

Osaki CoolGen Corp.
Osaki CoolGen Project
(Demo. 2017-)

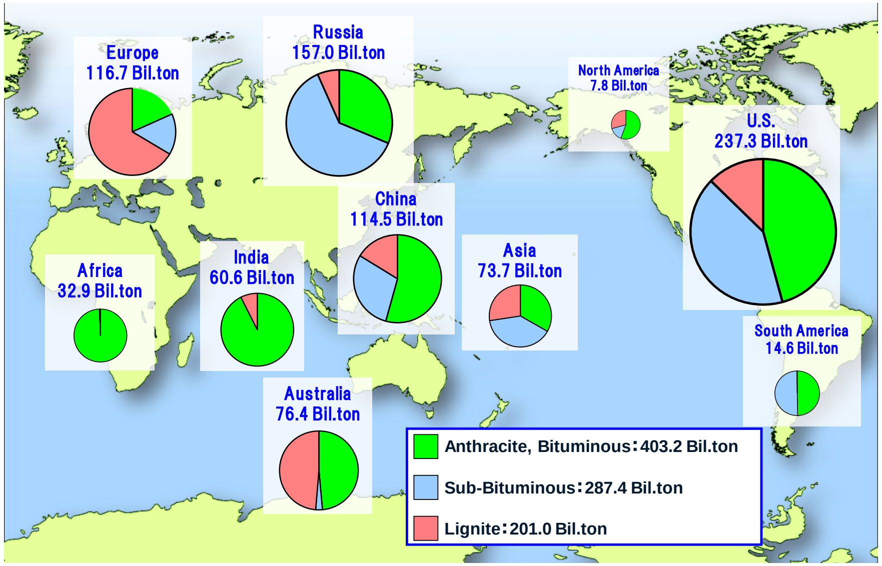
Joban Joint Power Co. LTD
Nakoso #10
(Demo.2007-,Commercial2013-)

Benefits of IGCC: Environmental Performance / Fuel Diversity

Higher Efficiency and Least Environmental Impact



"Diversity of Coal"



Merits of IGCC

(1) The gasifier unit turns coal into Syngas and molten ash, which collects on the inside wall by way of centrifugal force

(2) The molten ash is then drained from the gasifier into a water bath

⇒ This process allows IGCC to minimize gasifier size while utilizing a wide range of coal types

Fukushima Revitalization Power IGCC Project

Construction status of Nakoso 543MW IGCC (As of July, 2018)

Major Specification

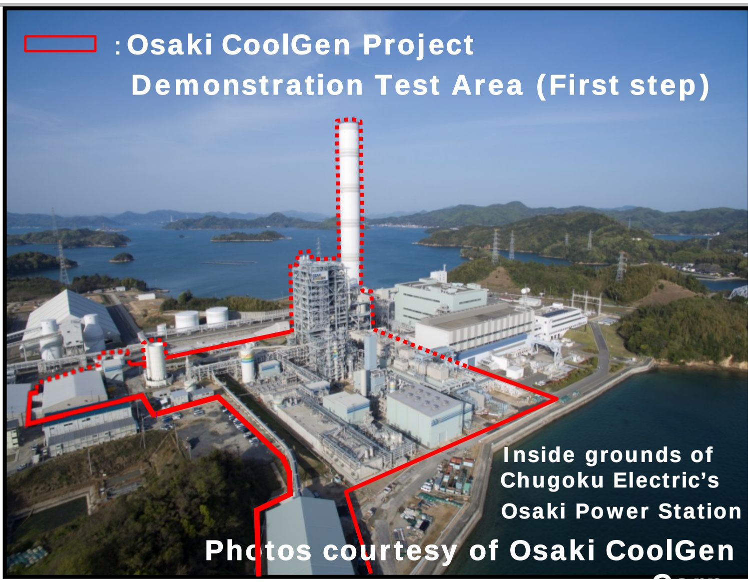
Output	543 MW (gross)
Gasifier	Air-blown Dry Feed
Gas Clean-Up	MDEA (Methyl diethanol Amine)
Gas Turbine	M701F GT (1 on 1)
Operation Start	2020 (Nakoso site) 2021 (Hirono site)

Schedule

- 2016.10 Site Mobilization Started
- 2016.12 EPC FTK Contracts Awarded
- 2017.4 Construction Started
  Fabrication of Main Equipment Started

The project is continuing to proceed on schedule

Osaki CoolGen Project

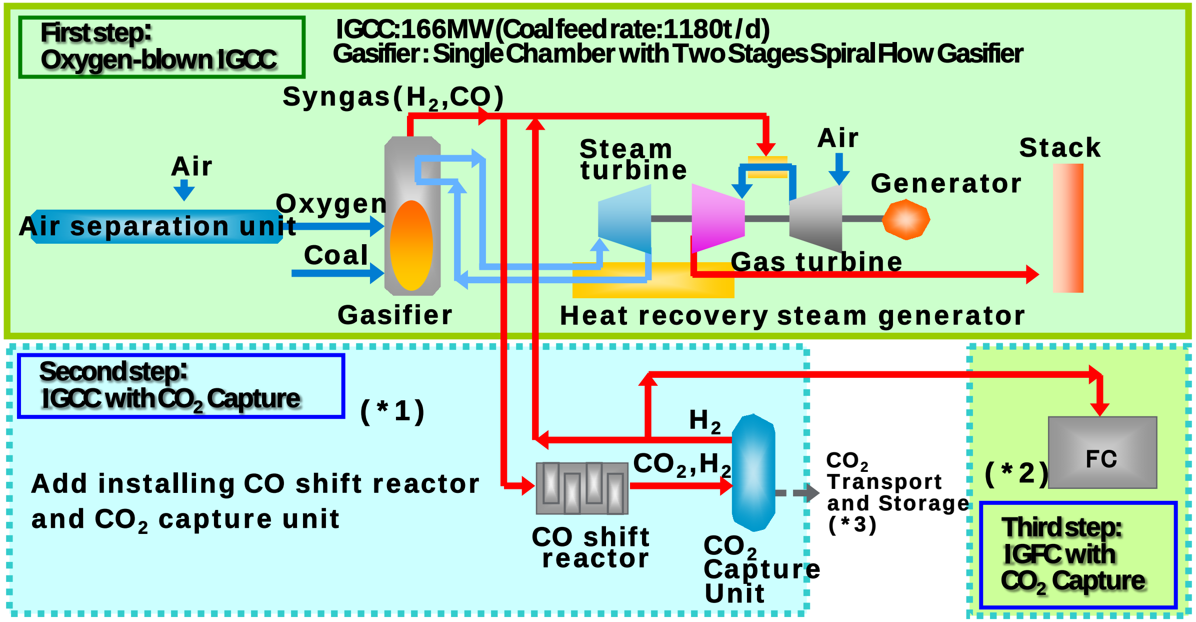


Major Specification

Output	166 MW (gross)
Gasifier	Oxygen-blown Single-chamber Two-stage Entrained-flow
Gas Clean-Up	MDEA (Methyldiethanol Amine)
Gas Turbine	H-100 GT (1 on 1)
Plant Efficiency	42.7% (LHV, net)

Project Schedule

Construction Started	March 2013
Demo. Ope. Started	March 2017 (First step)



(*1) Demo. Operation of Second step will start in FY 2019

(*2) Demo. Operation of Third step will start in FY 2021

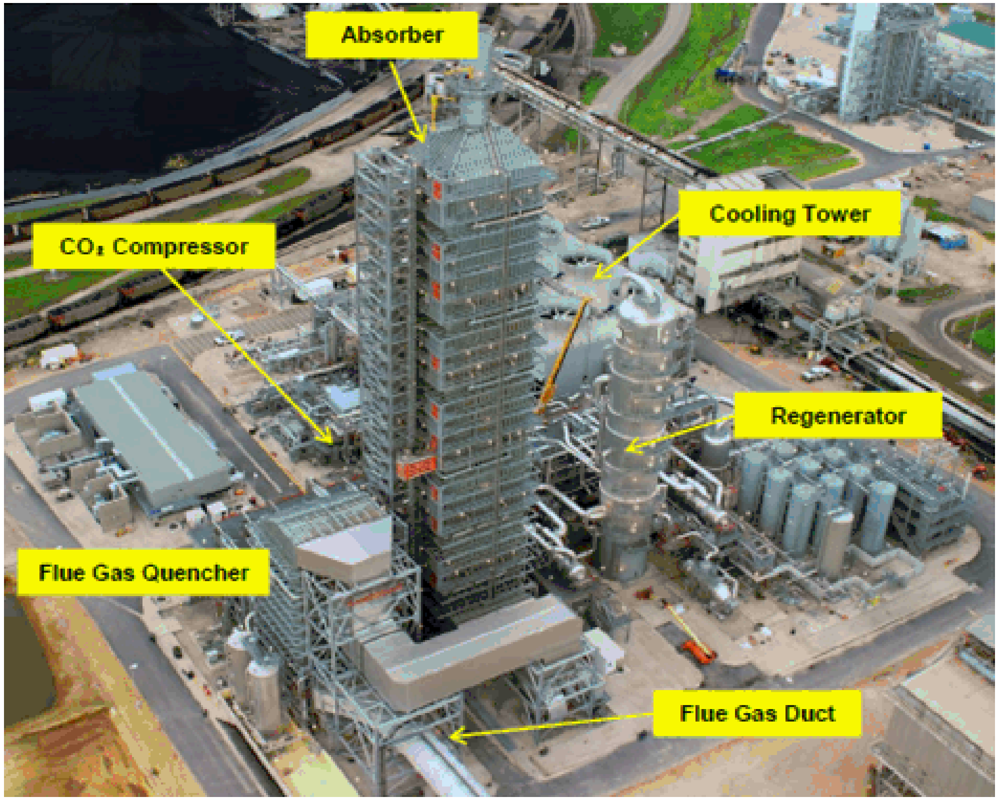
(*3) CO_2 Transportation and Storage are outside of the Osaki CoolGen Project.

Sponsored by METI and NEDO

Carbon Capture Process for Low Carbon Society

- **Co-developed technology by MHI Engineering and Kansai Electric since 1990**
- **Save energy through proprietary KS-1™ high performance solvent**
- **Reliable & proven technology with 14 operating plants worldwide**

Commercial Carbon Capture plant in Texas for EOR*1



- Client : Petra Nova, 50/50 joint venture of NRG Energy and JX Nippon Oil & Gas Exploration
- Plant : NRG WA Parish power plant
- Flue gas : from coal fired power plant
- CO_2 capture capacity : 4,776ton/day*2
- Capture efficiency : 90%
- Commercial operation : Dec., 2016

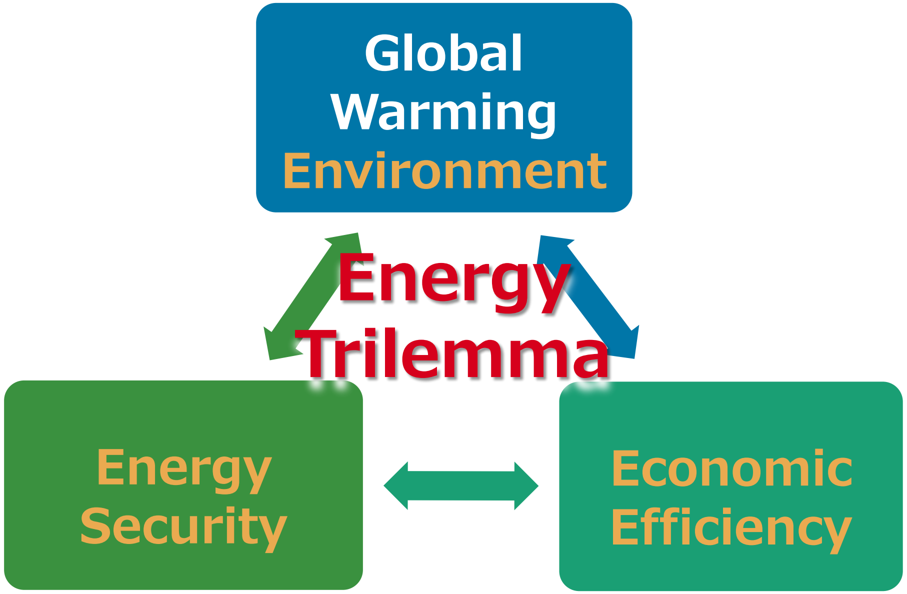
***1 EOR: Enhanced Oil Recovery**

***2 World largest in capacity**

The MHPS Approach

The challenge of solving the energy trilemma…

MHPS continues to develop and refine power system technology to meet the evolving challenges of today’s world.



The MHPS approach

- **Environment :**
  Biomass Firing or Co-firing, Bio-jet Fuel, High Efficiency CCS, Utilization/Combustion of Carbon-free Hydrogen & Ammonia, AQCS etc.
- **Economic Efficiency :**
  High efficiency GT, USC/A-USC, IGCC, SOFC etc. which utilize economical and limited fossil fuels effectively in the developing countries
- **Energy Security :**
  Effective use of Lignite/Sub-bituminous Coal, Biomass Fuel Fabrication, Geothermal Power Generation, Higher Efficiency and Ramping Rate of PC Plant for Power System Stability etc.

The MHPS Approach

- **Power generation with renewable energy will increase in order to reduce CO_2 emissions.**
- **Thermal power is essential to balance the power fluctuations brought about by increases in renewable energy.**
- **MHPS continues to contribute to power system stability through highly efficient and flexible next generation thermal power technologies.**

Power for a Brighter Future