ILC
from the view point of
Energy Management, Efficiency
and
Sustainability

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on behalf of the collaboration with
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LCWS13 Univ. of Tokyo 14/11/2013

Plan

1. Introduction
2. Current situation of Electric power supply in Japan
3. ILC : Accelerator component design in considering high power-efficiency
   - Klystron
   - Availability based on MTBF and MTTR
4. Summary

1. Introduction

Table 11.6
Estimated DKS power loads (MW) at 500 GeV centre-of-mass operation. 'Conventional' refers to power used for the utilities themselves. This includes water pumps and heating, ventilation and air conditioning, (HVAC). 'Emergency' power feeds utilities that must remain operational when main power is lost.

Accelerator section	RF Power	Racks	NC magnets	Cryo	Conventional		Total
					Normal	Emergency	
e^- sources	1.28	0.09	0.73	0.80	1.47	0.50	4.87
e^+ sources	1.39	0.09	4.94	0.59	1.83	0.48	9.32
DR	8.67		2.97	1.45	1.93	0.70	15.72
RTML	4.76	0.32	1.26		1.19	0.87	8.40
Main Linac	52.13	4.66	0.91	32.00	12.10	4.30	106.10
BDS			10.43	0.41	1.34	0.20	12.38
Dumps					0.00	1.21	1.21
IR			1.16	2.65	0.90	0.96	5.67
TOTALS	68.2	5.2	22.4	37.9	20.8	9.2	164

The electricity statistics on August 21, 2013, all in Japan

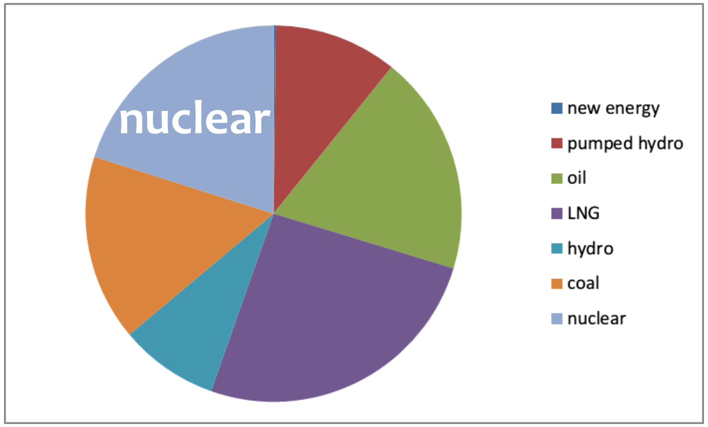
- **Availability: 169GWatt**
- **Amount usage: 154GW (91%)**

ILC electricity demand is 0.1% of the current availability in Japan.
We have to think about the realization of a better and sustainable electricity system from beginning of the project.

2. Current situation of electric power in Japan

The March 11, 2011 earthquake brought down serious damage to the Japanese electricity system. (Of course more severe damage to the people's life especially at FUKUSHIMA)

Now, no nuclear power plant is in operation. More than 20% of the total availability is disappearing.

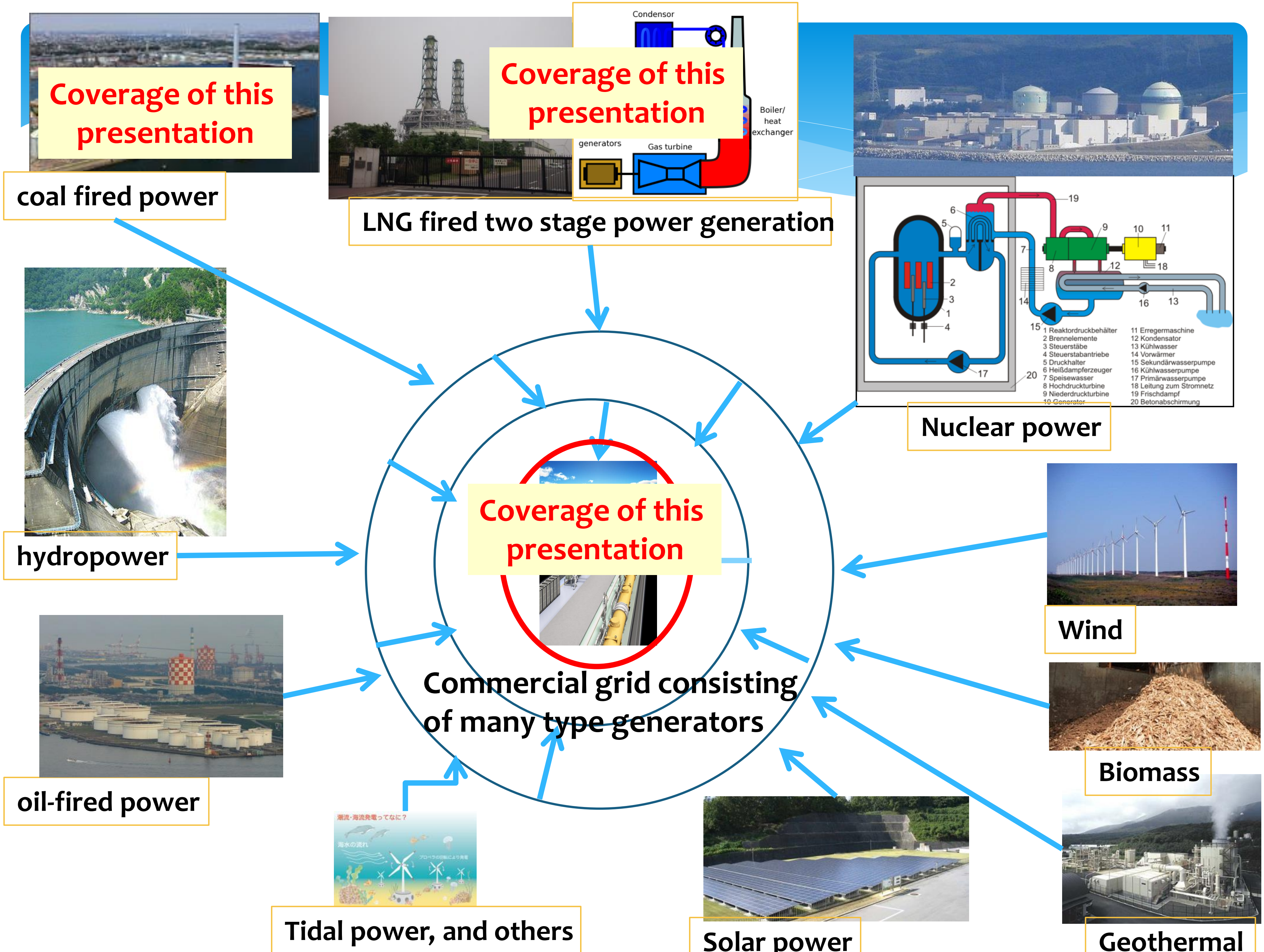


new energy	0.2
pumped hydro	10.6
oil	18.9
LNG	25.7
hydro	8.5
coal	16
nuclear	20.1
	100

This summer, it was very hot, high humid, and Japanese economy was bullishness.

Nevertheless we could survive without nuclear power,

- **by increasing electricity from fossil fuel, which results serious trade imbalance,**
- **and by saving electricity.**

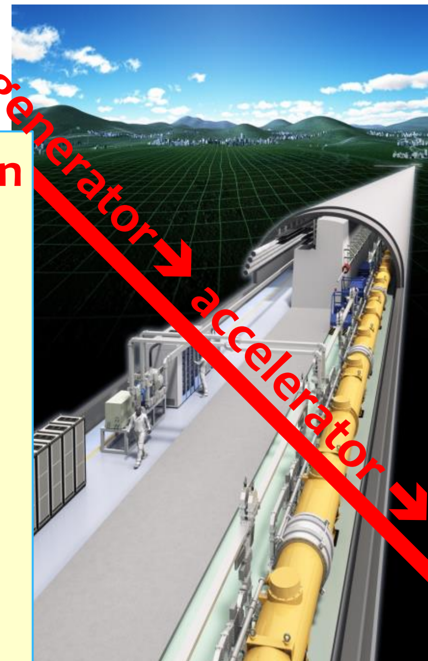


Coverage of this presentation
coal fired power
Condensor
Coverage of this presentation
Boiler/ heat exchanger
generators
Gas turbine
LNG fired two stage power generation
1 Reaktordruckbehälter
2 Brennelemente
3 Steuerstäbe
4 Steuerstabantriebe
5 Druckhalter
6 Heißdampferzeuger
7 Speisewasser
8 Hochdruckturbine
9 Niederdruckturbine
10 Generator
11 Erregermaschine
12 Kondensator
13 Kühlwasser
14 Vorwärmer
15 Sekundärwasserpumpe
16 Kühlwasserpumpe
17 Primärwasserpumpe
18 Leitung zum Stromnetz
19 Frischdampf
20 Betonabschirmung
Nuclear power
hydropower
Coverage of this presentation
Wind
Commercial grid consisting of many type generators
Biomass
oil-fired power
Tidal power, and others
Solar power
Geothermal

High energy density

Since, accelerators are electric power gluttonous
➔ we have to consider---------

Energy flow: generator → accelerator → cooling tower



1. Sustainable power generation

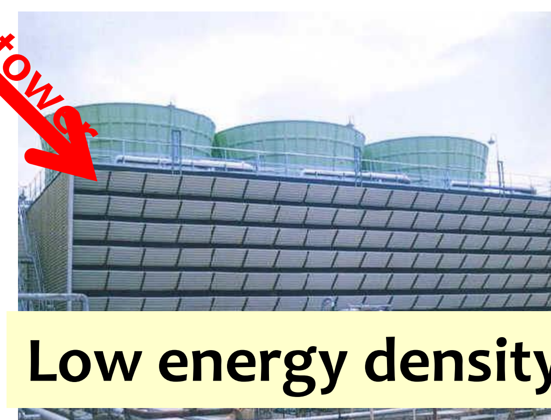
- As clean as possible
  - ➢ $DeNO_x$ and $DeSO_x$
  - ➢ De-Mercury
  - ➢ De-PM2.5
- High efficiency generation
  - ➢ Coal > 45%
  - ➢ LNG > 60%
- Grid power flow control
  - ➢ Margin should be as low as possible <3%
- Development of new energy
  - ➢ Wind, solar, biomass, geothermal------
  - ➢ Tidal wave, algal-------

2. ILC design and manufacturing should be made by considering-----

- ➢ performance/AC power
- ➢ component power efficiency
  - ➢ High power RF
  - ➢ MTBF and MTTR

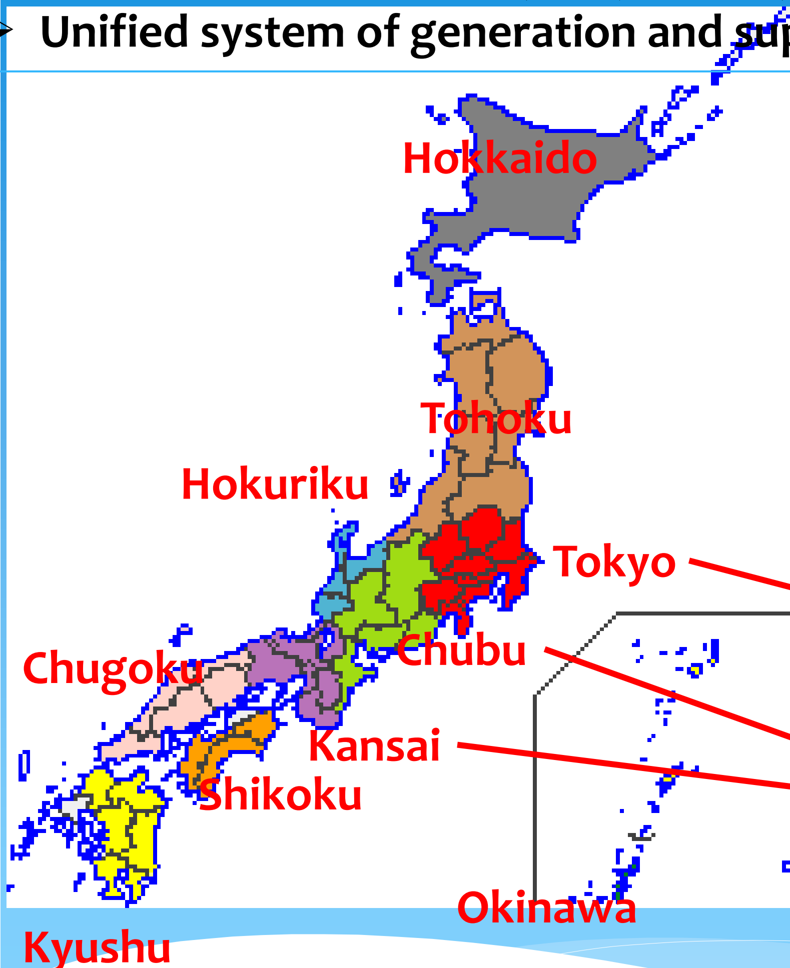
3. Energy recovery

- ➢ from cooling water
- ➢ from beam power, directly
- ➢ etc.



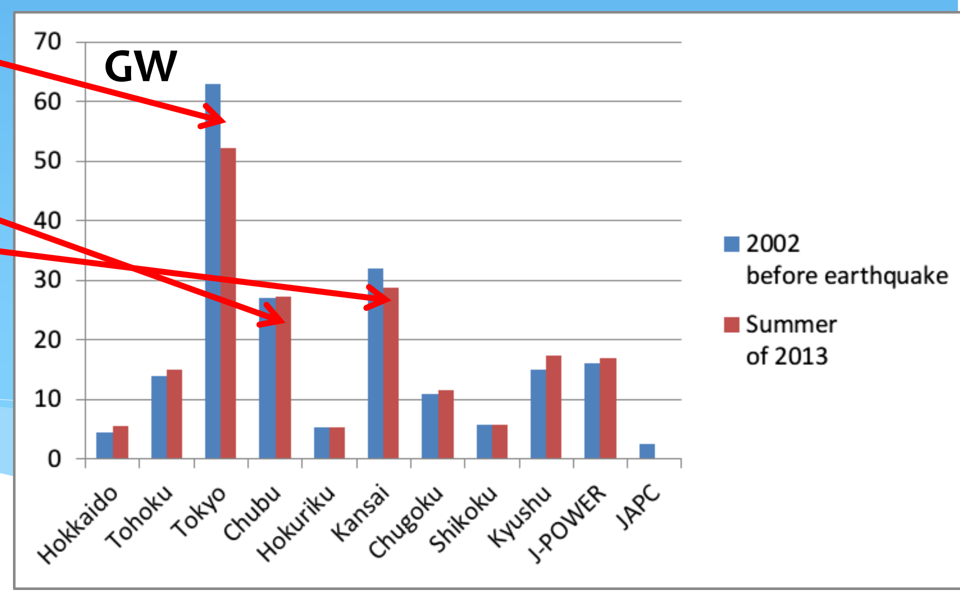
Low energy density

- 12 big electrical companies in operation
- 10 regional monopoly + J-POWER + JAPC
- Two frequencies: 50Hz (east), 60Hz (west)
- Unified system of generation and supply



Regional monopoly and unified generation/supply brings------

- good grid power flow control inside the region
- BUT,
  - poor inter-regional power interchange
  - less price competition



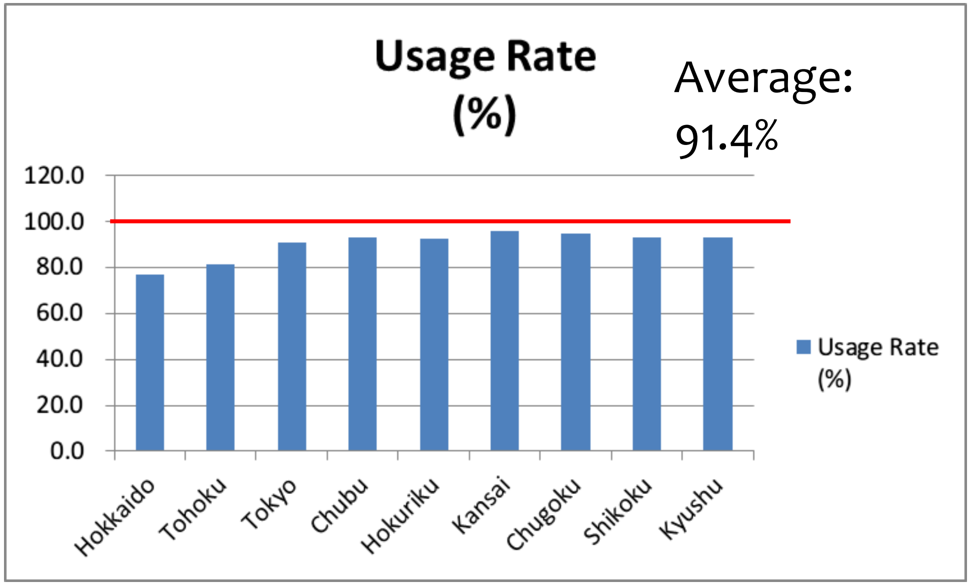
J-POWER: wholesale power company
Availability: 17.0GW (2013)
JAPC: Japan Atomic Power Company

Statistics of Aug.21, 2013

2013/8/21			
Company	Amount used (GW)	Instantaneous Availability (GW)	Usage Rate (%)
Hokkaido	4.23	5.50	76.9
Tohoku	12.18	14.96	81.4
Tokyo	47.42	52.09	91.0
Chubu	25.37	27.27	93.0
Hokuriku	4.86	5.26	92.3
Kansai	27.54	28.81	95.5
Chugoku	11.09	11.68	94.9
Shikoku	5.34	5.74	93.0
Kyushu	16.24	17.49	92.8
Okinawa		4.68(Max.)	
Total (excluding Okinawa)	154.27	168.80	91.4

Peak demand in summer appears when----

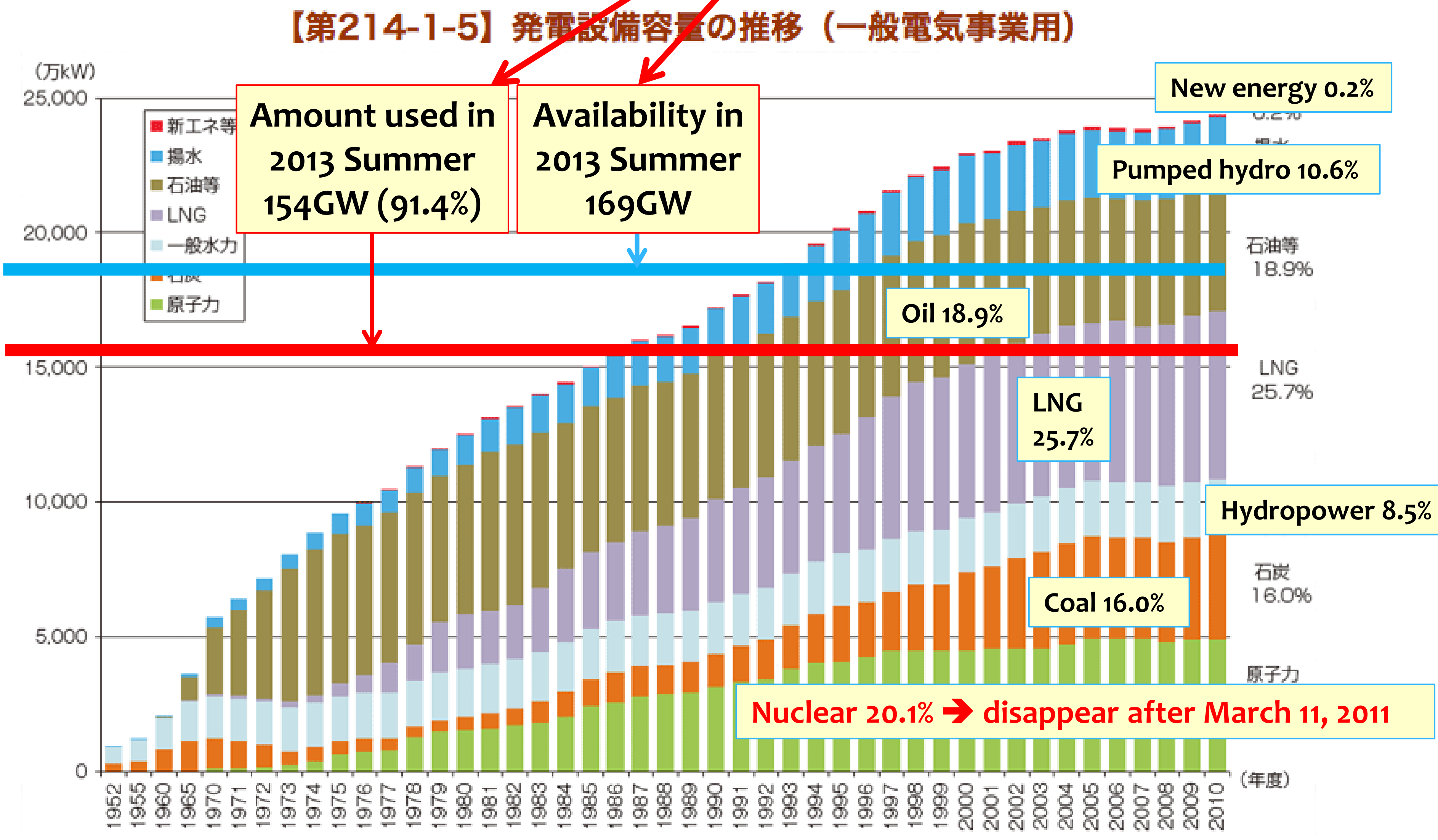
- Hot temperature
- High humidity
- Weekday
- High-school baseball tournament



Usage rate should be < 97% of availability to ensure stable supply (in Japan) based on excellent grid flow control

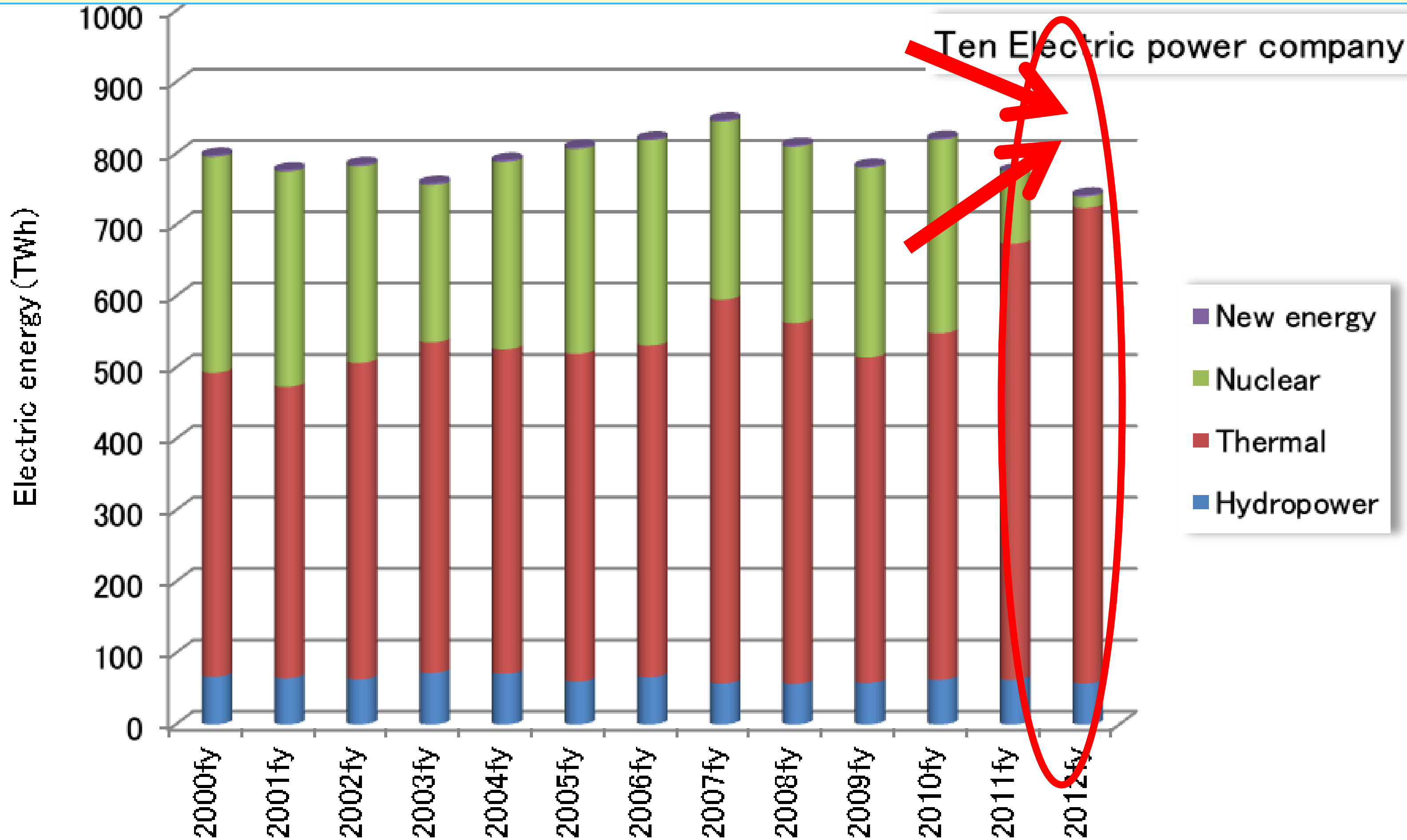
Tight supply-demand balance, but it is well controlled by the save on electricity !

Comparison before and after the earthquake



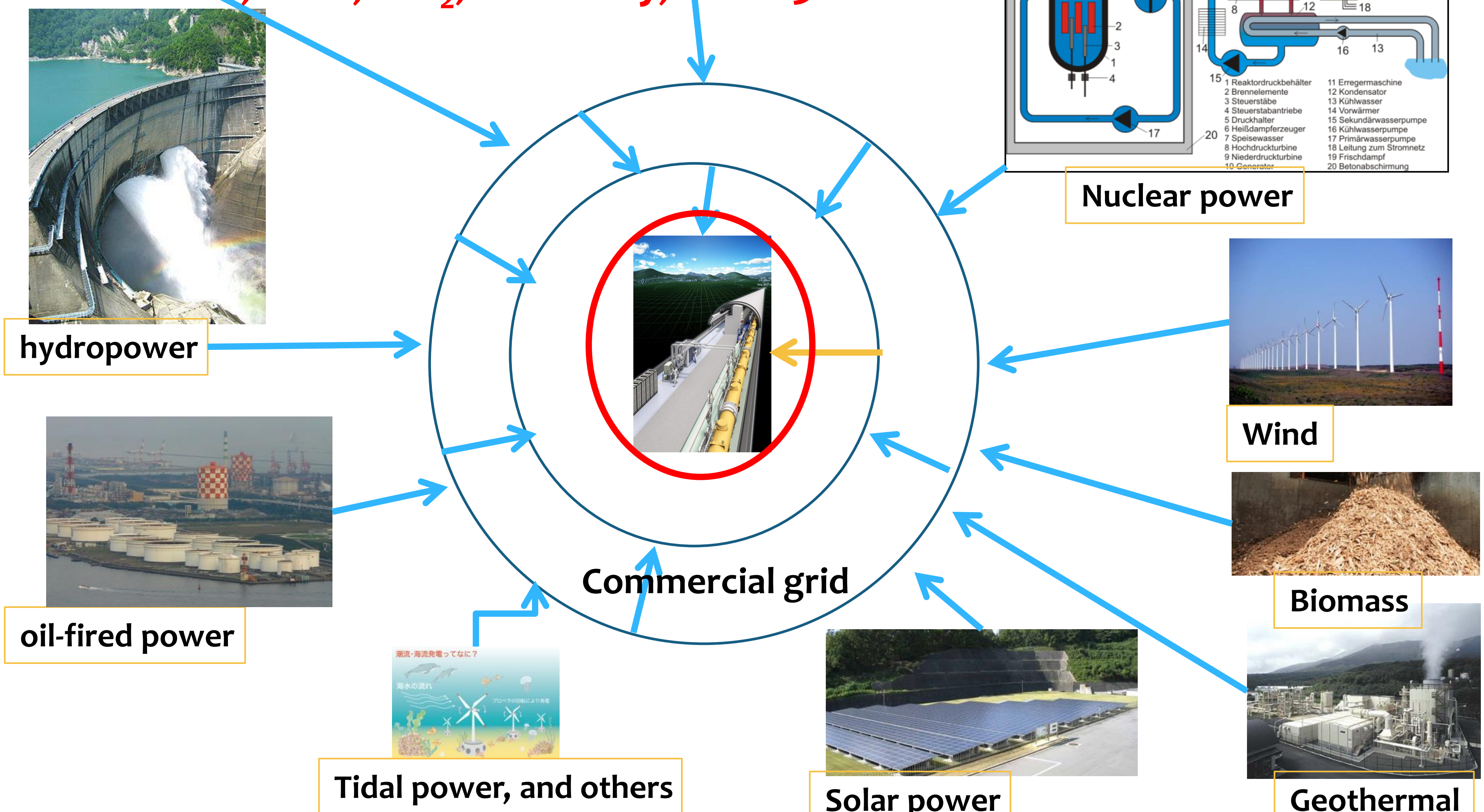
It is clearly seen that

- the lack of electricity is recovered with fossil fuel generation, resulting big problem of trade imbalance and
- the total demand is reduced by saving electricity.



Toward the green power:

- ◆ Improve the efficiency of COAL and LNG-DTCC
  - ➢ 0.1% improvement corresponds to ILC demand
- ◆ De-NOx, SOx, CO_2, Mercury, PM2.5------

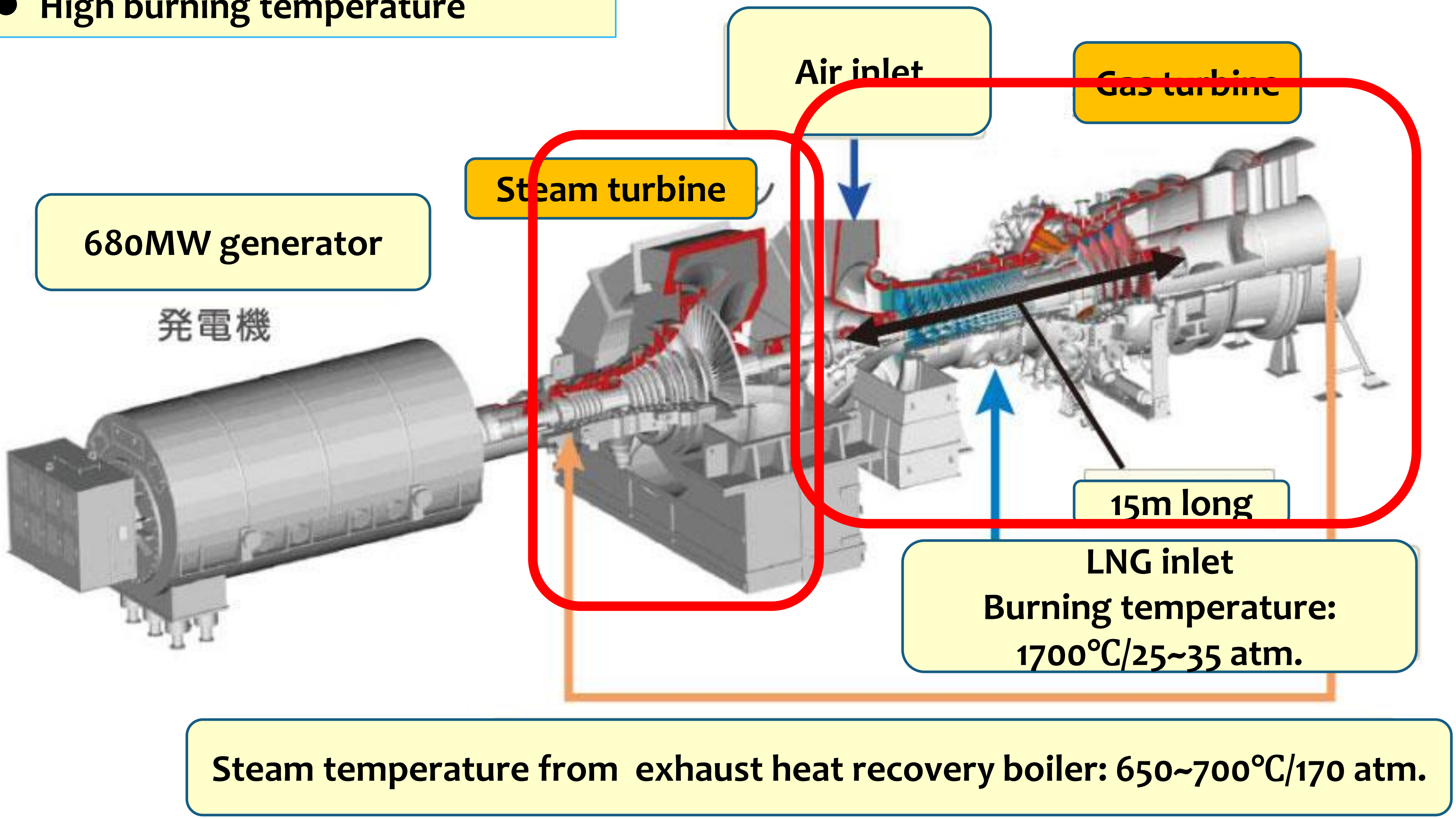


Solution-1: LNG GTCC(Gas turbine combined cycle) power plant

Gas turbine (similar to jet engine) + steam turbine using exhaust heat effectively

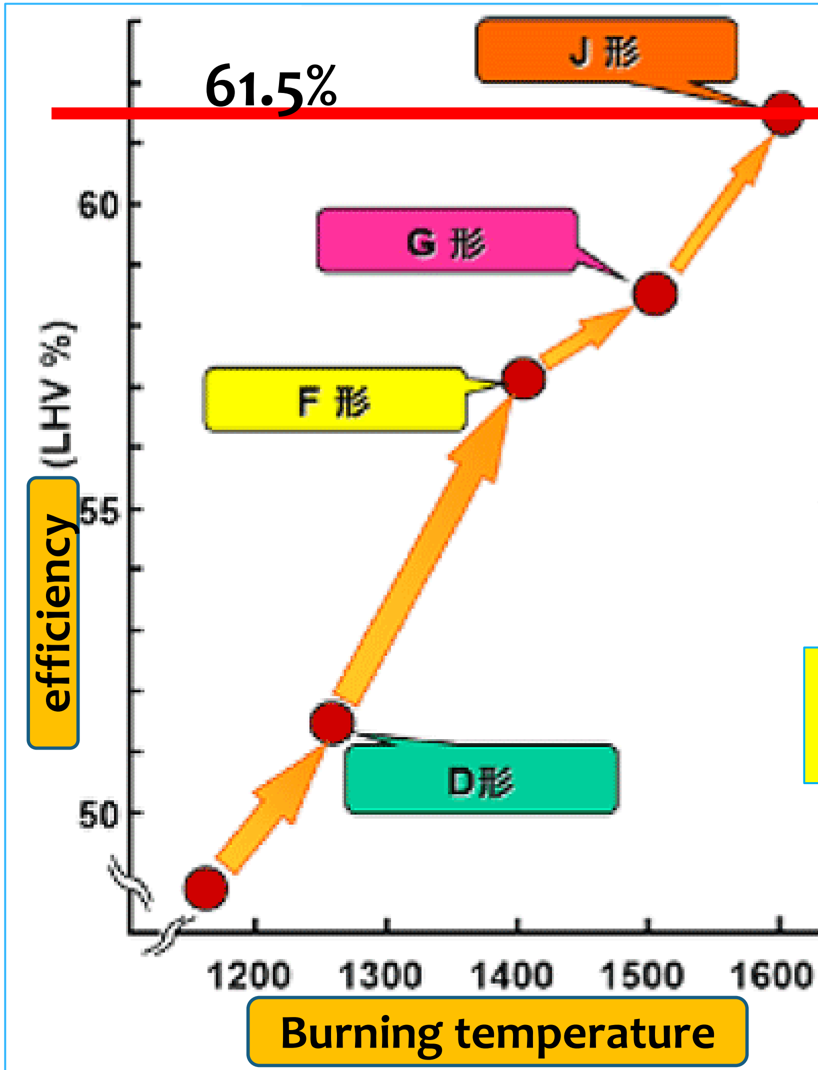
Key technologies to increase efficiency

- Combined cycle
- High burning temperature



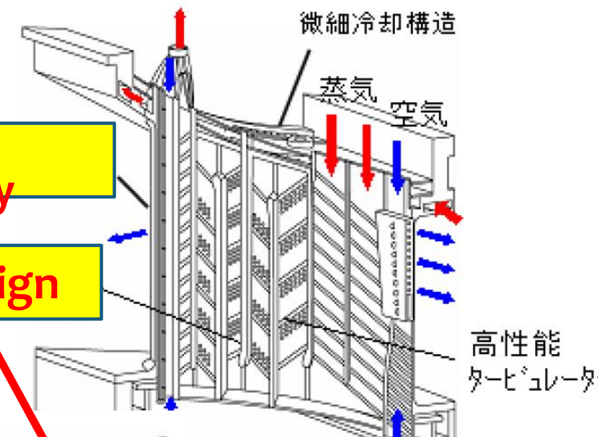
Challenge of burning temperature up to 1700℃
By Mitsubishi Heavy Industries

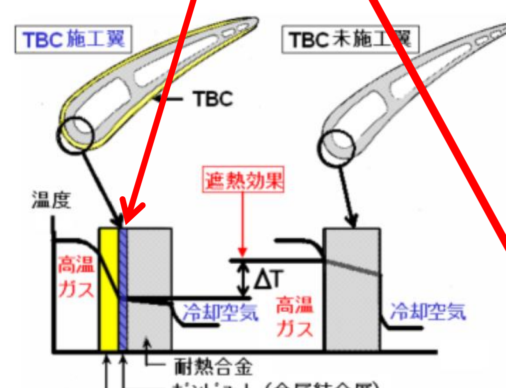
1700℃ turbine blade design



Cooling efficiency

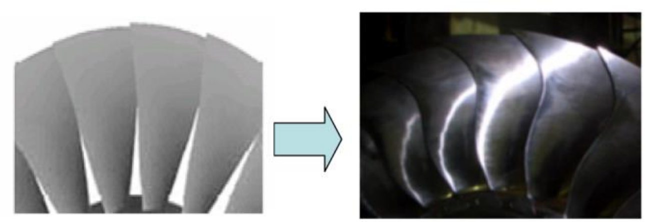
Mechanical design





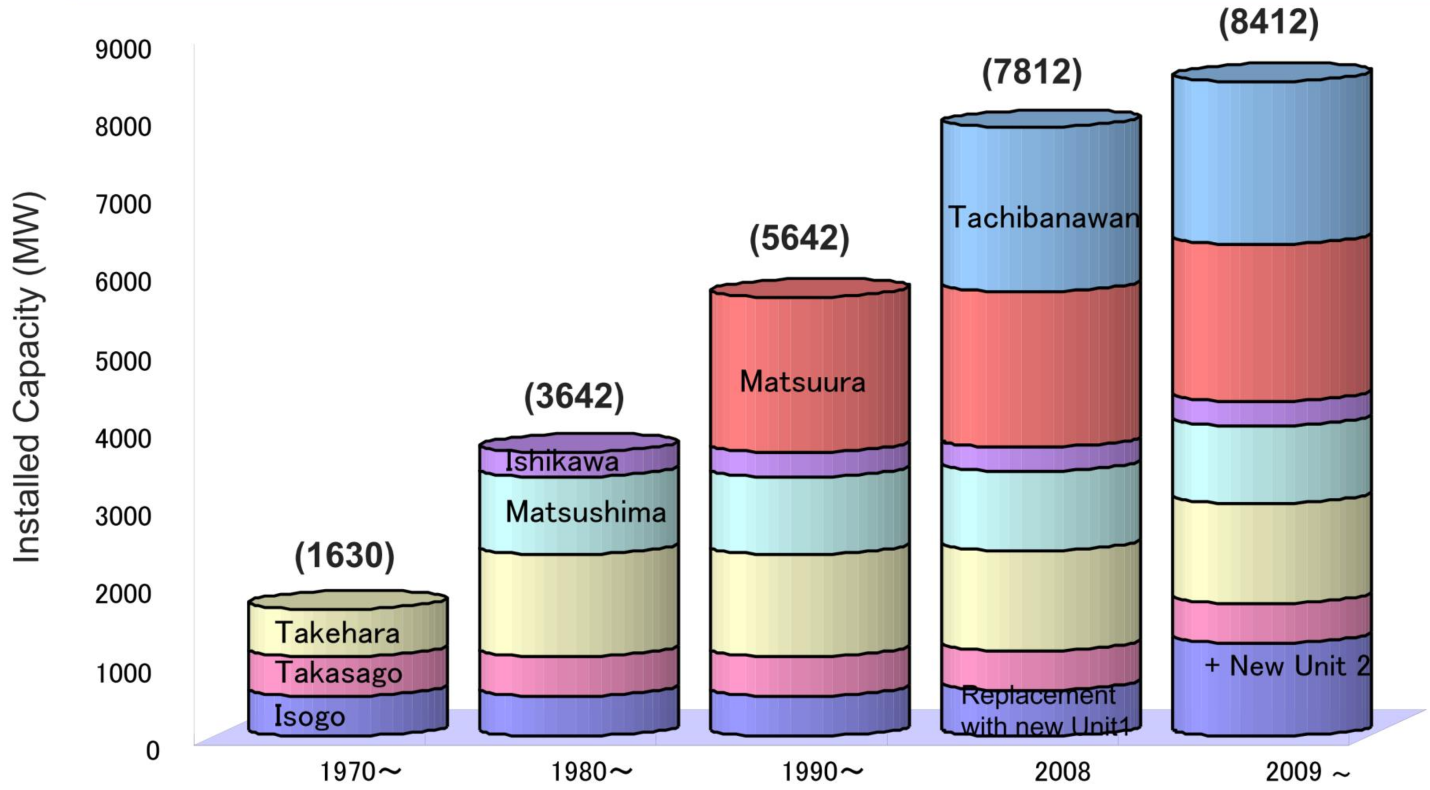
Multi-layer structure to increase ΔT

Decrease pressure loss



Solution-2: Coal power plant with high burning temperature
Steam condition: Sub-critical → Super-critical → Ultra-super-critical
DeSOx, NOx, CO_2, Mercury, PM2.5, Coal gas plant in future → Fix CO_2

J-POWER: leading company of Japan to develop new type of coal fired power plant.
Present availability: 8.4GW

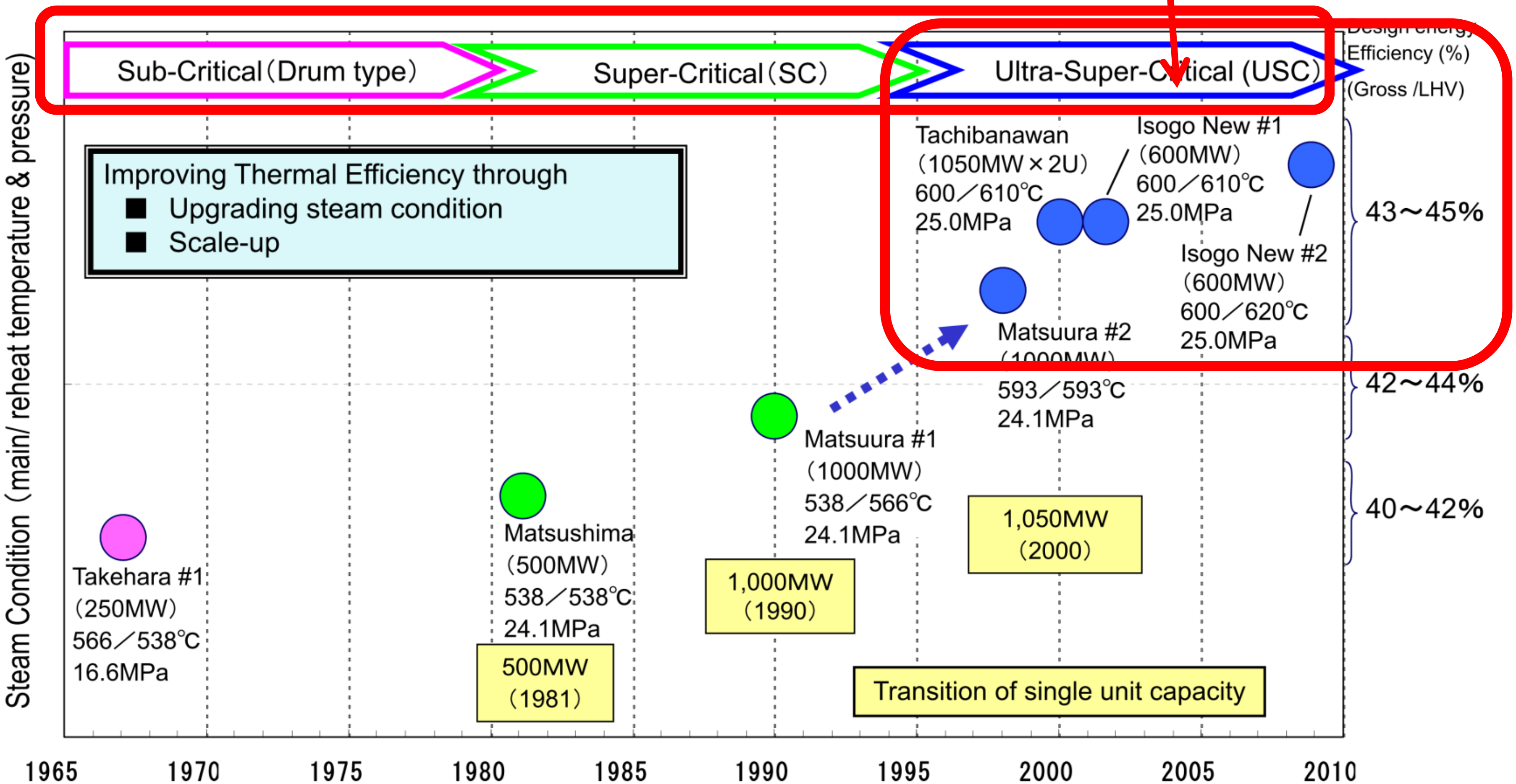


USC steam condition makes better efficiency

History of J-POWER's Thermal Efficiency Improvements

J-POWER

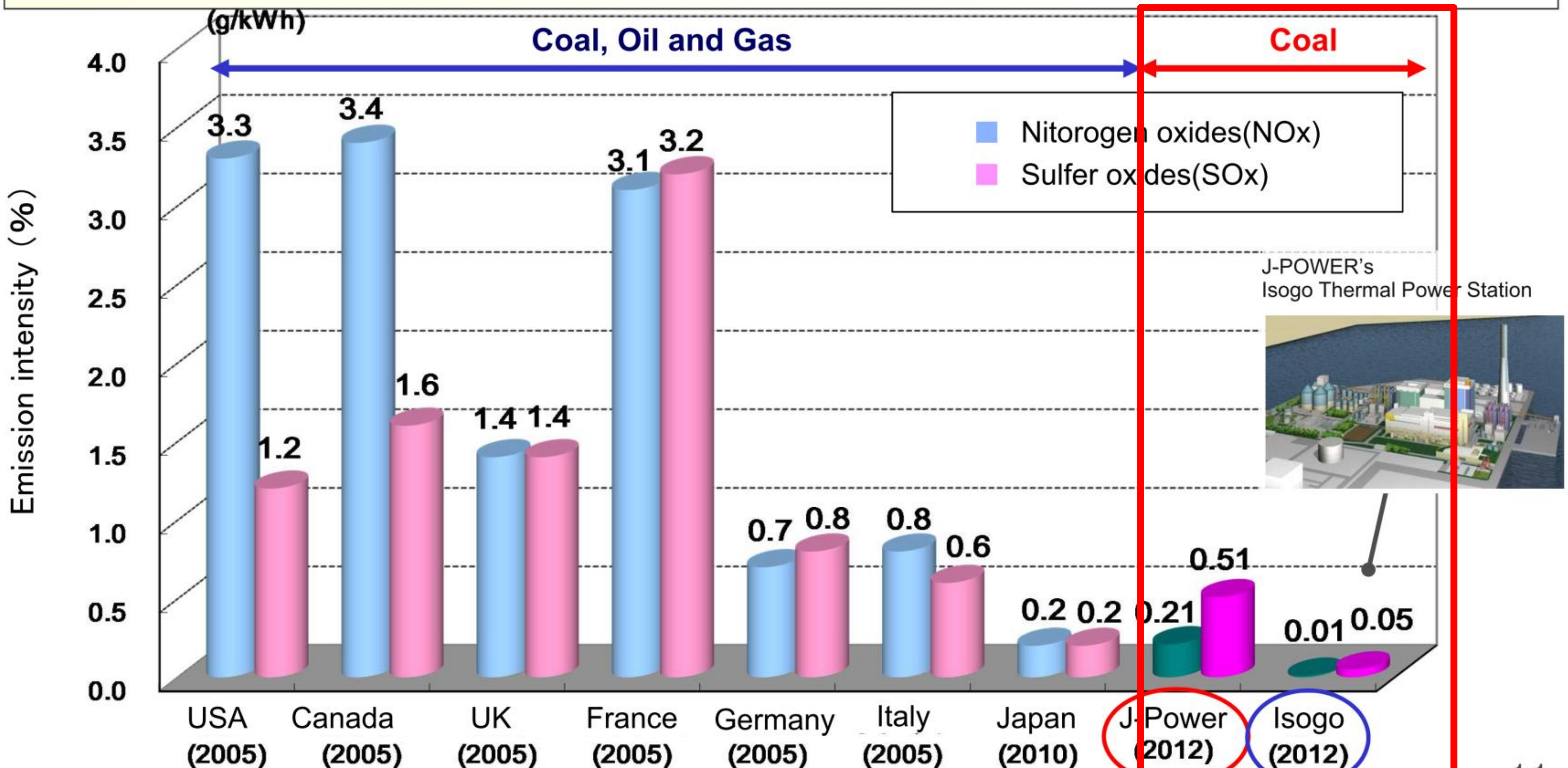
- The world's highest level of thermal efficiency has been achieved at Isogo Power Station by continuous efforts on upgrading steam conditions since 1960s.



LHV: Lower Heating Value ➔ generated electric power/total input energy

SOx and NOx Emissions of Fossil-fired Power Generation by Country

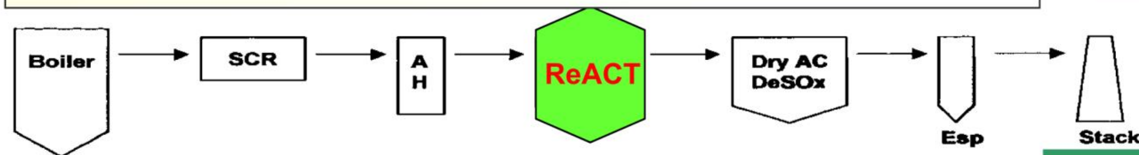
- SOx and NOx emissions from J-POWER's coal-fired power stations are much lower than that from the major developed countries' fossil-fired power stations
- With the most advanced clean coal technologies, SOx and NOx emissions from Isogo PS are at almost the same level of gas-fired power plants.

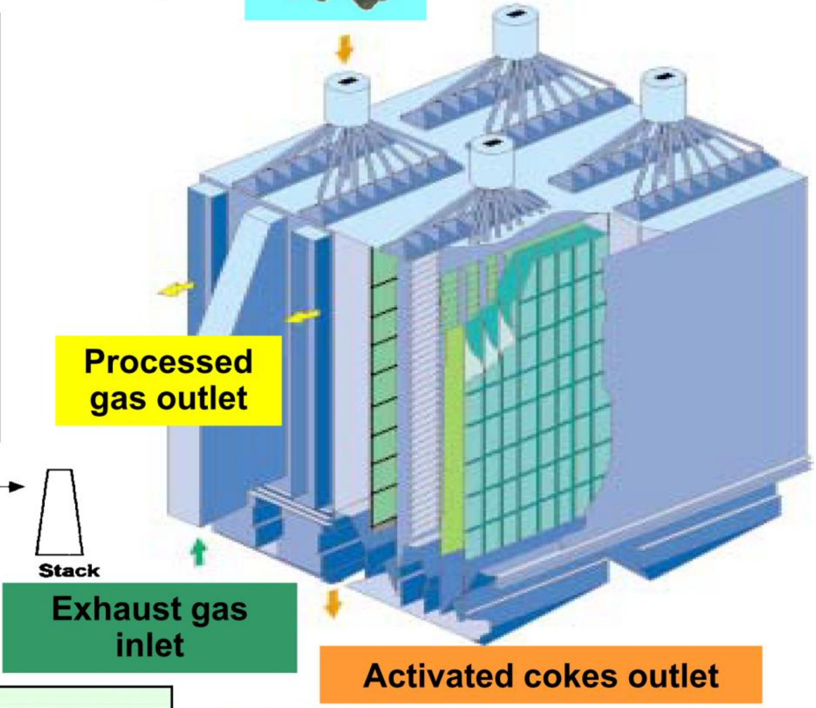


Made from FEPC (Federation of Electric Power Companies)

Dry DeSOx/DeNOx System in Isogo PS

- Dry-type DeSOx/DeNOx system (ReACT) using Activated Cokes
- ReACT removes multiple pollutants simultaneously
  SOx - 99% over NOx - 20-80% over
  Mercury - 90% over Dust - 20-30 mg/Nm3 or less
- Water consumption is 1/100 of the wet-type process. Thus waste water is substantially less.
- Only small space required for installation.
- Various type of Bi-products (sulfuric acid, gypsum and others)



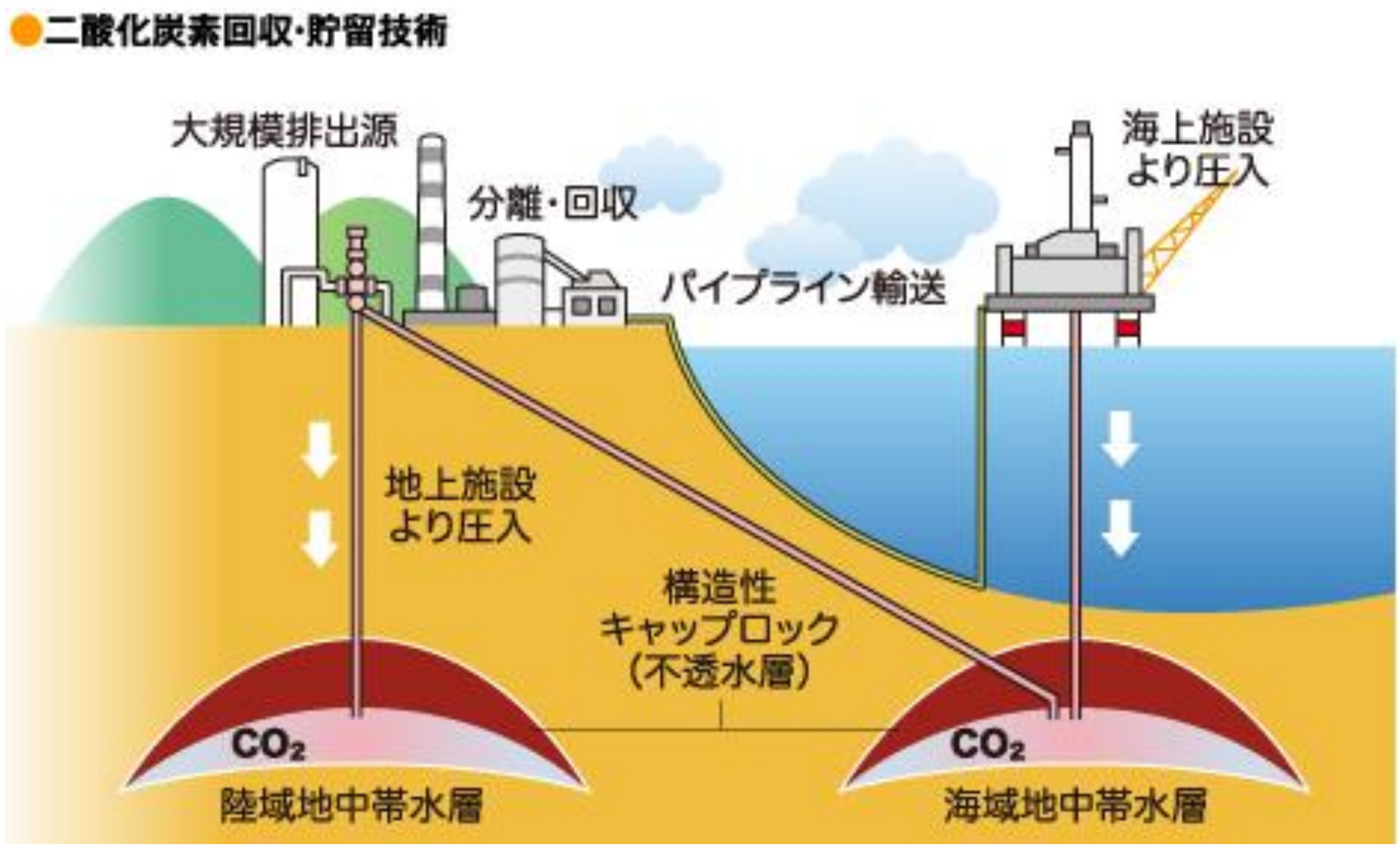


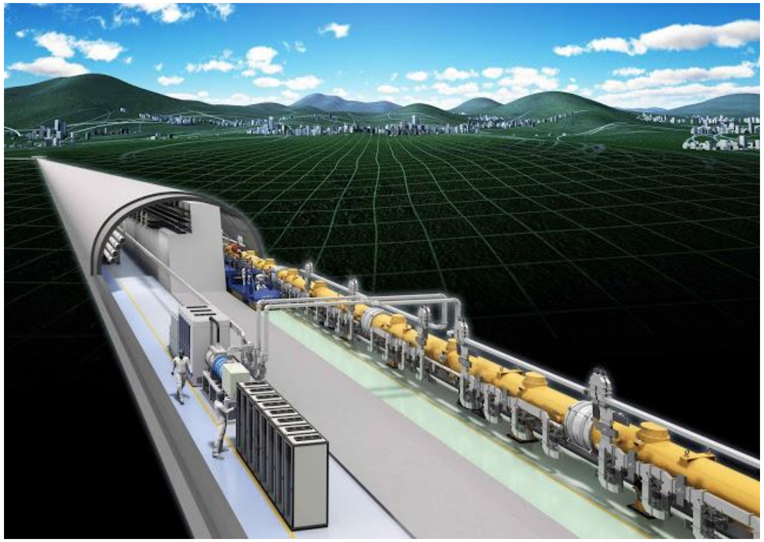
Pollutant	Regulated Value	Operation Results		
		Efficiency	Inlet concentration	Outlet Concentration
SOx	20 ppm	>98%	<410ppm	1 to 6ppm
NOx	20 ppm	10 to 50%	<20ppm	10 to 15ppm
Dust	10 mg/Nm^3	>95%	<100mg/Nm^3	1 to 3mg/Nm^3
Mercury	----	>90%	2.50µg/m3N	0.14 to 0.25µg/m3N

Key element ➔ Activated coke (AC) is a carbonaceous material produced by steam activation (at approximately 900°C [1650 F]). ➔ very strong adsorption power

Nm3: normal volume

Remaining issue of fossil fuel power generation is to fix CO2, as much as possible





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500 GeV Parameters

Physi…

Max. E_{cm}	500 GeV
Luminosity	1.8×10^{34} $cm^{-2}s^{-1}$
Polarisation (e-/e+)	80% / 30%
δ_{BS}	4.5%

…ction poi…t)

σ_x / σ_y	574 nm / 6 nm
σ_z	300 µm
$\gamma\varepsilon_x$ / $\gamma\varepsilon_y$	10 µm / 35 nm
β_x / β_y	11 mm / 0.48 mm
bunch charge	2×10^{10}

Number of bunches / pulse	1312
Bunch spacing	554 ns
Pulse current	5.8 mA
Beam pulse length	727 µs
Pulse repetition rate	5 Hz

…ccelerator (general)

Average beam power	10.5 MW (total)
Total AC power	163 MW
(linacs AC power	107 MW)

tiny emittances
nano-beams at IP
strong beam-beam

High-power high-
current beams. Long
bunch trains.
→ SCRF

Table 11.6
Estimated DKS power loads (MW) at 500 GeV centre-of-mass operation. 'Conventional' refers to power used for the utilities themselves. This includes water pumps and heating, ventilation and air conditioning, (HVAC). 'Emergency' power feeds utilities that must remain operational when main power is lost.

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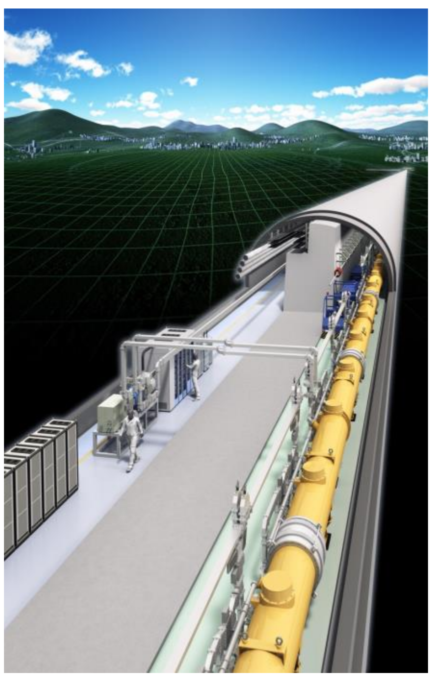


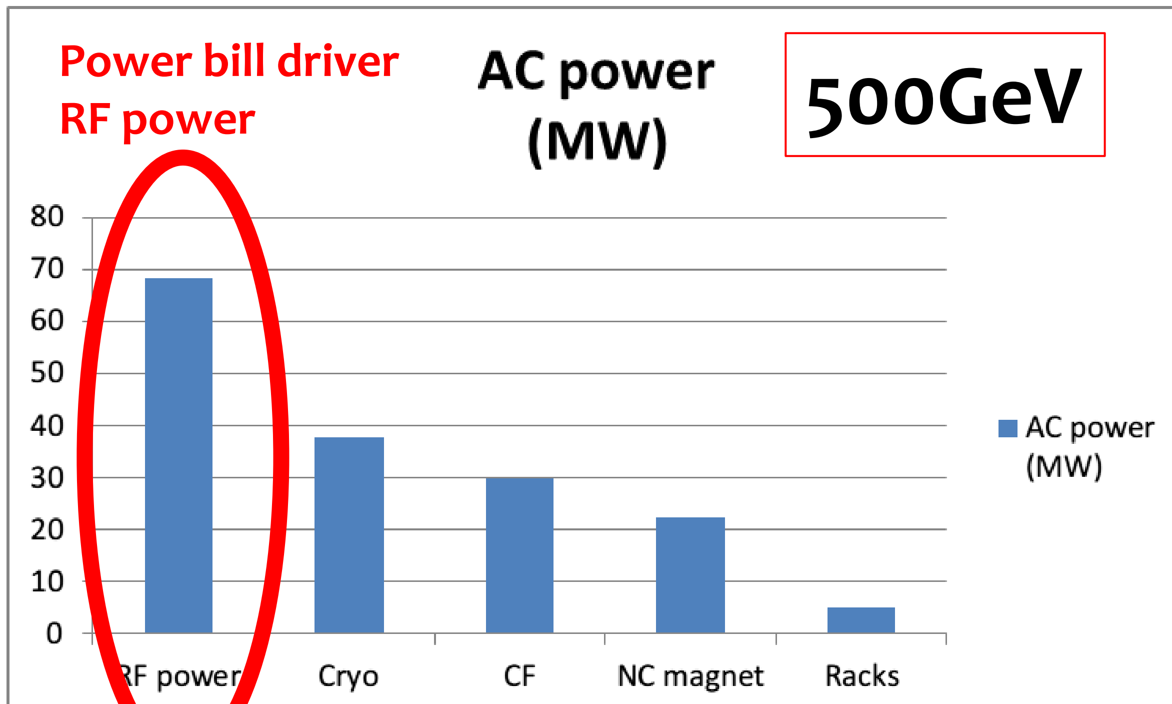
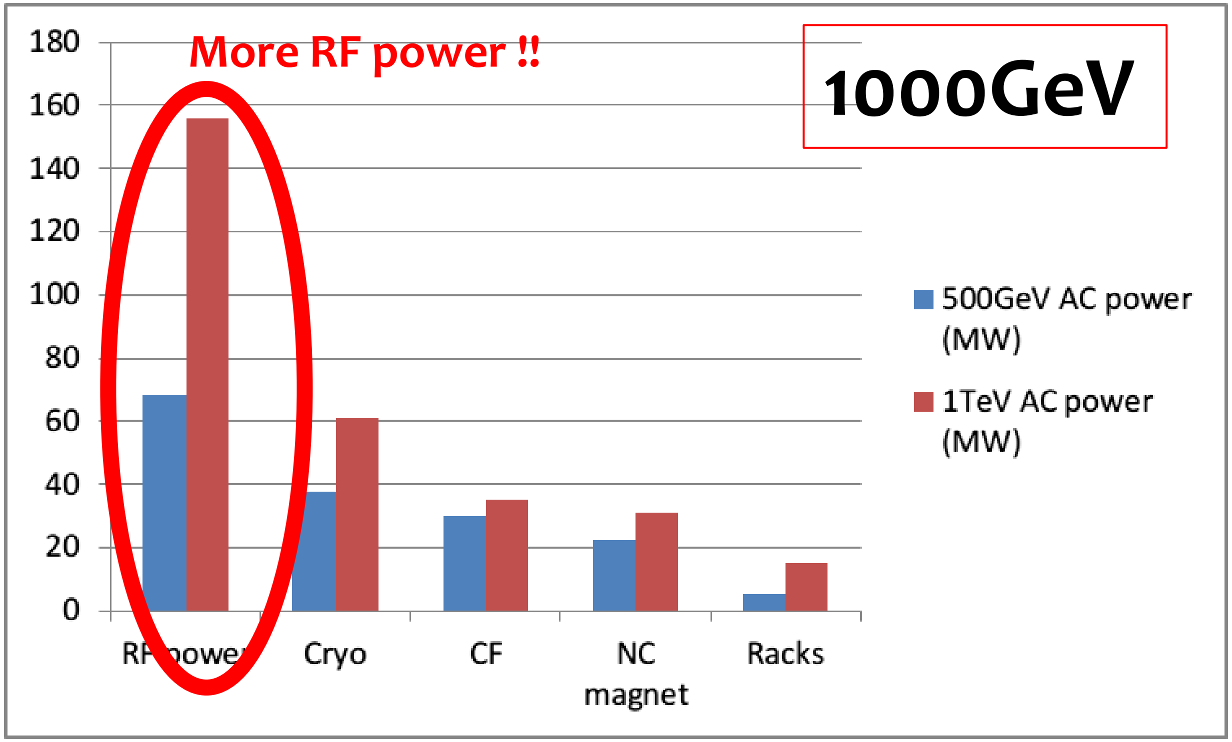
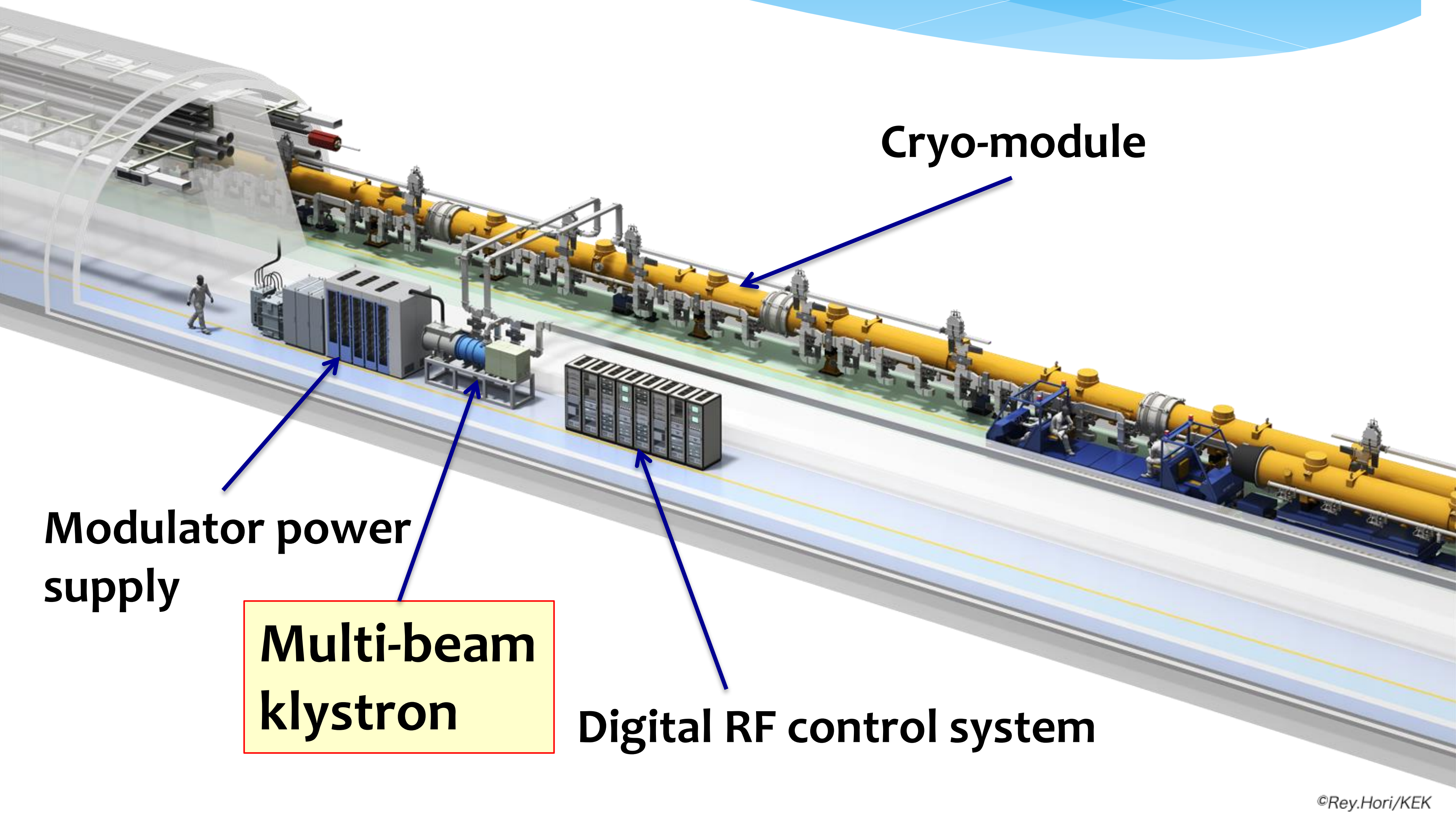


Table 12.6
Rough estimate of the power requirements (in MW) for the 1 TeV upgrade (scenario B), based on extrapolation of the baseline design parameters using simple scaling laws [232].

	RF Power	RF Racks	NC Magnets	Cryo	Conventional load Normal	Conventional load Emergency	Total
e^- source	1.3	0.1	0.7	0.8	1.0	0.2	4.1
e^+ source	1.4	0.1	4.9	0.6	2.2	0.4	9.6
DR	12.8		4.5	1.5	2.6	0.1	21.5
RTML	7.2	0.3	2.1	2.0	0.1	0.1	11.8
ML (base)	59.2	7.4	0.9	28.3	7.8	5.2	108.8
ML (upgrade)	74.2	7.4	0.7	25.1	10.2	3.9	121.3
BDS			16.1	0.4	0.2	0.3	17.1
Dumps					1.0		1.0
IR			1.2	2.7	0.1	0.2	4.2
Total	156	15	31	61	25	10	300



ILC tunnel

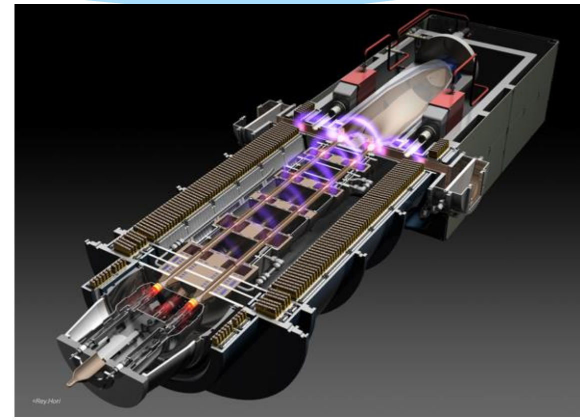


Cryo-module
Modulator power supply
Multi-beam klystron
Digital RF control system
©Rey.Hori/KEK

➢ Klystron

For High power efficiency

Lower the perveance



【Conventional】

- Single electron beam
- Higher the cathode loading, shorter the lifetime
- efficiency　40－50%
- ~180　KV high voltage gun

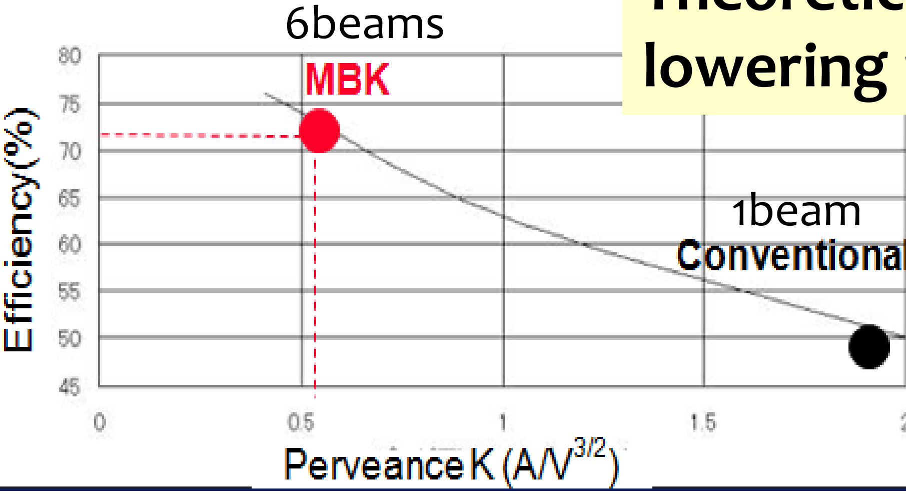
➡

【Multi-beam】

- Multi-beam (6 beams)
- Lower the cathode loading, the longer the lifetime
- Efficiency > 65%
- <120　KV lower voltage

TOSHIBA Multi-Beam Klystron(MBK) E3736

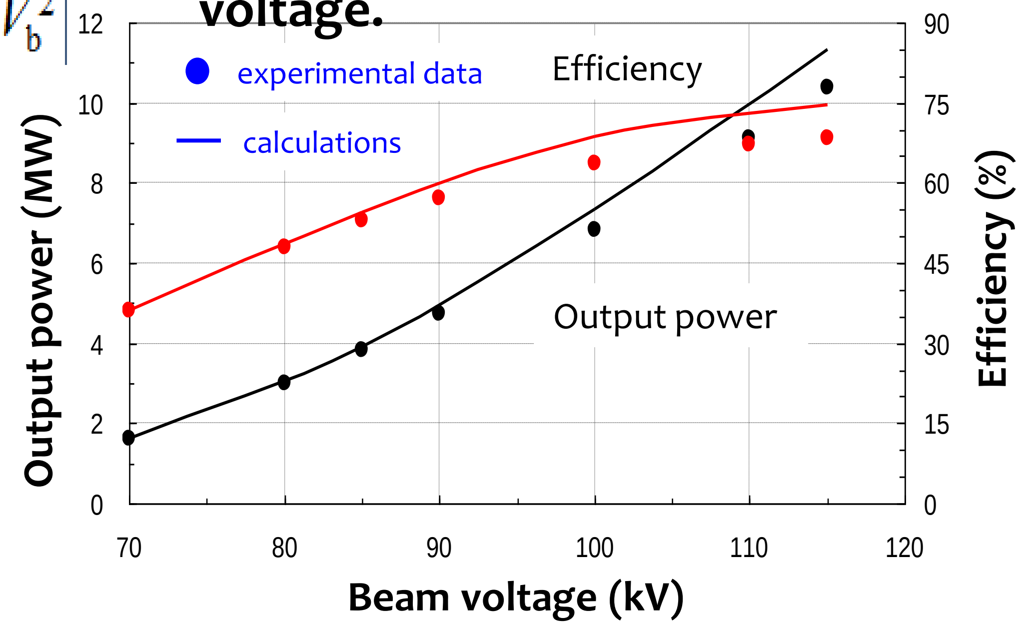
Theoretical efficiency improvement by lowering perveance.



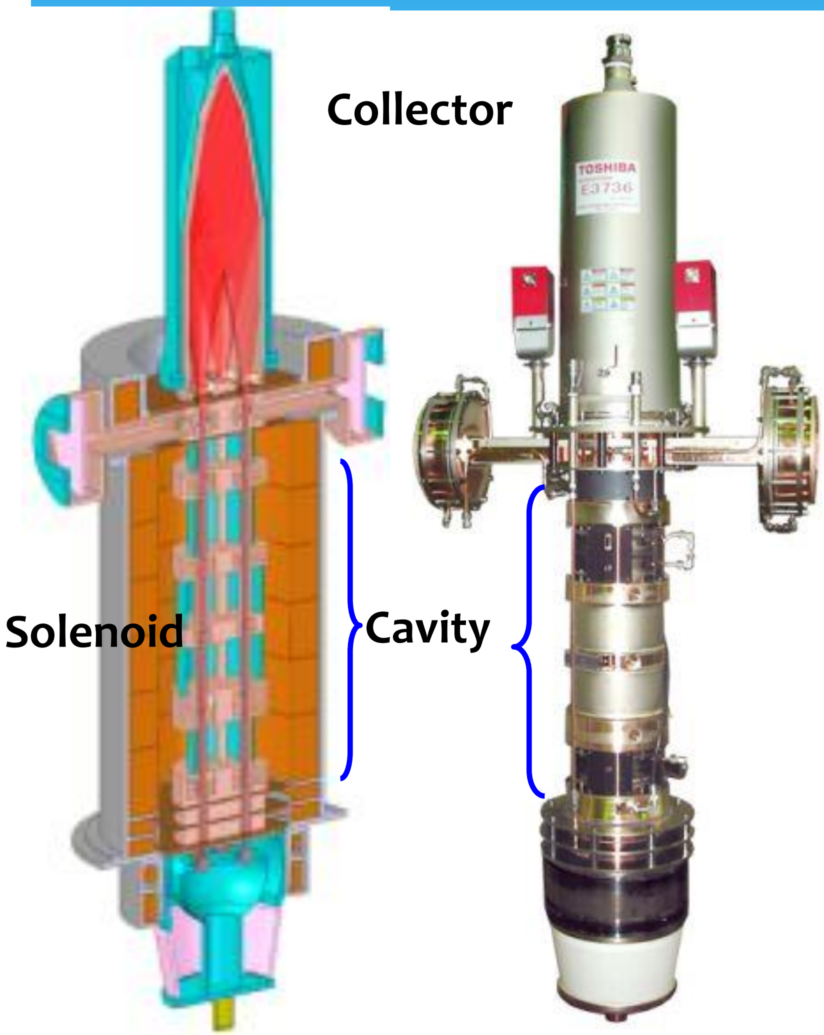
$$P_0 = \eta(K) \cdot V_b I_b = \eta(K) \cdot nKV_b^{\frac{5}{2}} \qquad I_b = nKV_b^{\frac{3}{2}}$$

Perveance: $I_b = PV^{3/2}$

Output power and efficiency as a function of beam voltage.



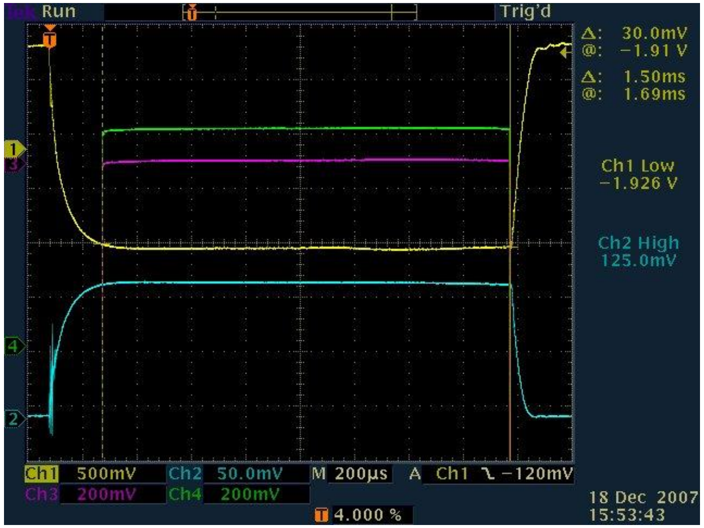
TOSHIBA Multi-Beam Klystron(MBK) E3736



	Design	Achieved	
Frequency 1.3	1.3	GHz	
Output power	10	10.2	MW
Output power (Av.)	150	153	kW
Beam voltage	115	115	kV
Beam current	132	134	A
Efficiency	**> 65**	**67**	**%**
RF pulse width	1.5	1.5	ms
Repetition rate	10	10	pps
Saturation gain	47	49	dB
Number of beams	6		
Cathode loading	< 2.0	2.0	A/cm²
Structure	6		cavities
RF window	Pill box with WR-650		
Tube length	2270	2270	mm
Solenoid Power	**< 4**	**3.6**	**kW**

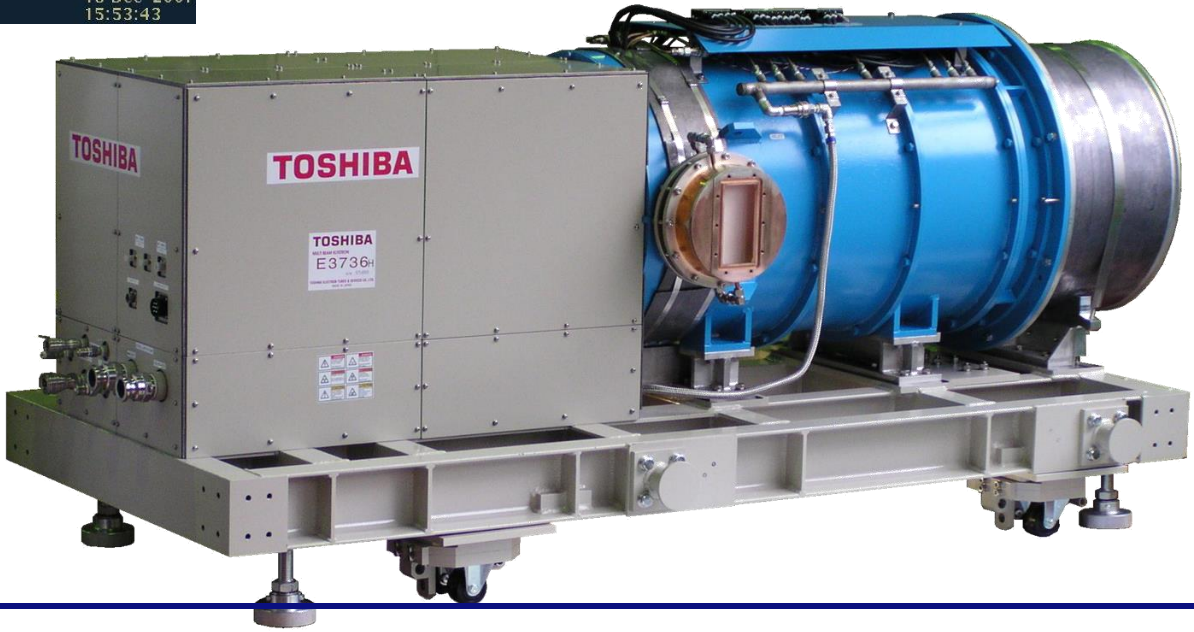
Electron gun : 6 beams

Effort to realize high efficiency klystron ➔ Multi-beam (6 beams)



Toshiba
E3736H

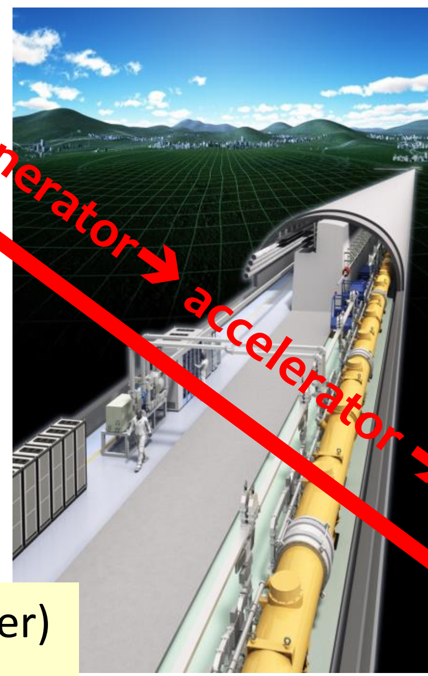
6 beams
10MW
1.5ms
67% efficiency



Scope picture of the klystron test.
The lines show the klystron voltage
(116 kV) in yellow, the current
(128 A) in blue and RF output
(5 MW each) in magenta and green.

➢ Availability based on MTBF and MTTR

Energy flow: generator → accelerator → cooling tower



Improve availability

↓

Reduce idling time

Idling time

↓

Waste of electricity

R: reliability
A: availability
M: maintainability

A = 1- (MTTR/MTBF)

MTTR: mean time to repair (or recover)
MTBF: mean time between failures

SLC: 3km long, 50GeV

KEKB: 0.6km long, 8GeV

ILC should learn from the past experiences

	SLC 1991~1995	KEKB Linac User run	KEKB Linac Commissioning phase
No. of Modulator	244	59	59
Modulator MTBF (hours)	707	327	177
Modulator MTTR (min.)	25.4	3	17
System MTBF (hours)	2.9	5.5	3
Availability (%)	85	99	91

Availability of klystron modulator is the most important.

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5. **Summary**

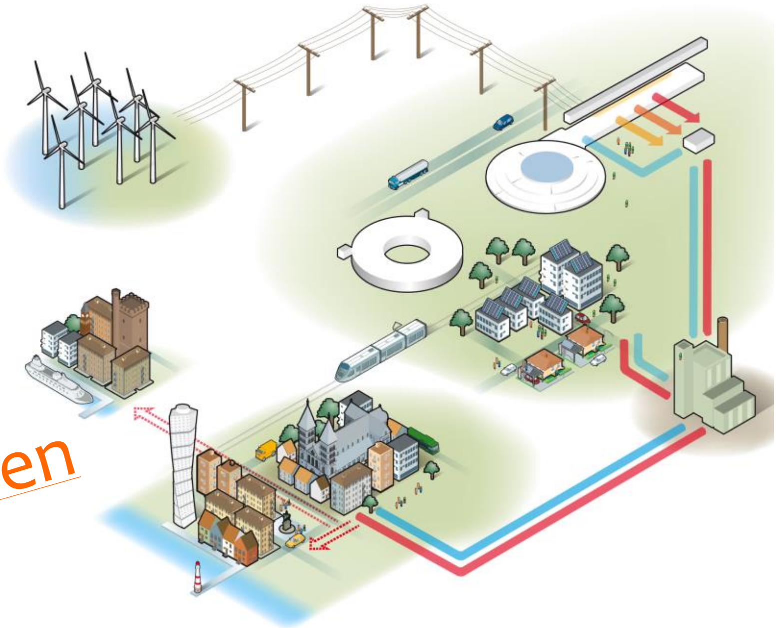
EUROPEAN SPALLATION SOURCE

The ESS Green Requirement

Carbon Neutral

Innovative

Green



Since, accelerators are electric power gluttonous
➔ we have to consider---------

2. ILC design and manufacturing
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All efforts from electricity upper stream to down stream should be carried out.

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➢ etc.

1. Sustaina
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- High ef
  - Co
  - LNG > 60%
- Grid power flow control
  - Margin should be as low as possible <3%
- Development of new energy
  - Wind, solar, biomass, geothermal------
  - Tidal wave, algal-------