Energy Management in Japan, Consequences for Research Infrastructures

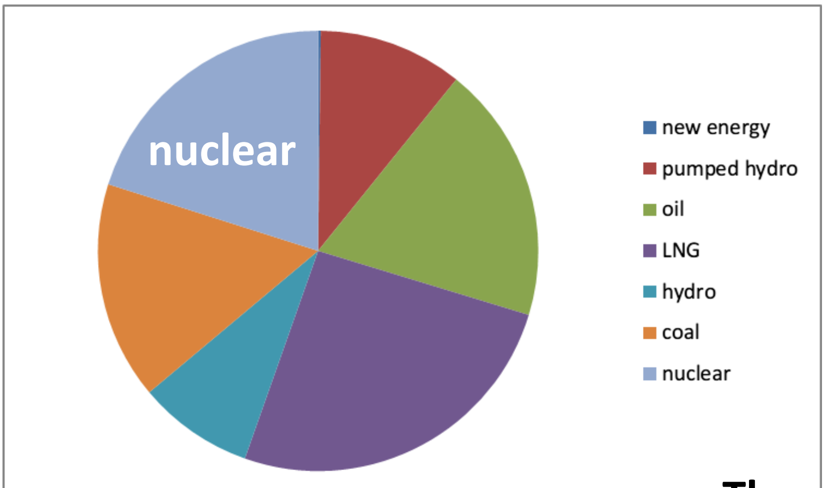
Masakazu Yoshioka (KEK)

1. Electric power supply in Japan, before and after March 11, 2011 earthquake
   - High efficiency and "almost" environmental pollution-free electricity generators can save Japan, and contribute to reduce global CO_2 problem
2. KEK Electricity contract as an example of large-scale RIs
3. Accelerator design by considering optimization of luminosity/electricity demand
   - Example: Super-KEKB
   - ILC
4. Accelerator component design by considering high power-efficiency
   - Klystron
   - Availability based on MTBF and MTTR
5. Summary

Current situation of electricity 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.



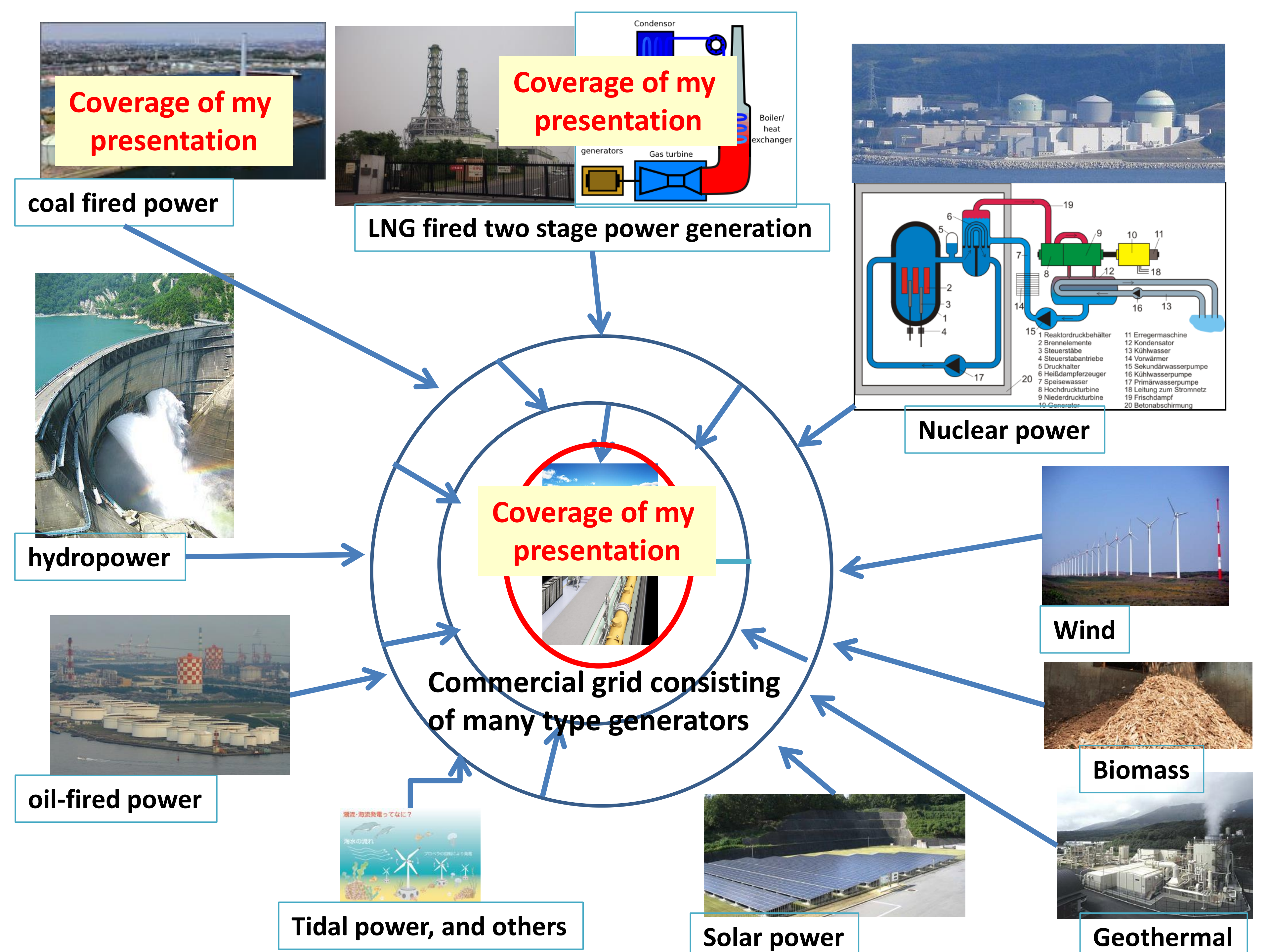
This summer, it is very hot, high humid, and Japanese economy is bullishness.

Nevertheless we could survive without nuclear power,
- by increasing electricity from fossil fuel, which results serious trade imbalance,
- and by saving electricity.

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

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. This amount does not give a big impact, but we have to think about the realization of a better and sustainable electricity system.

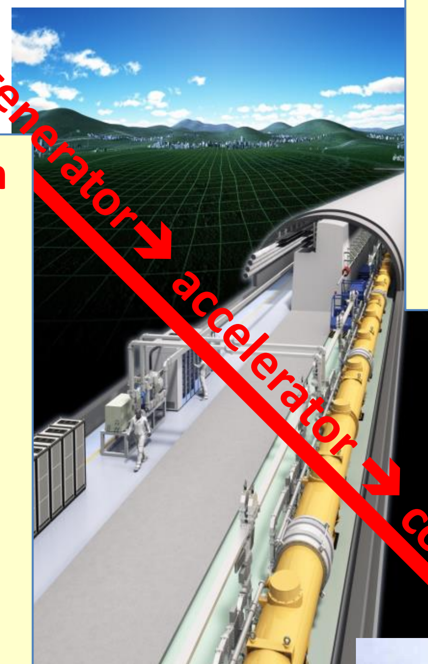

Coverage of my presentation
coal fired power
Condensor
Coverage of my presentation
Boiler/ heat exchanger
generators
Gas turbine
LNG fired two stage power generation
1 Reaktordruckbehälter
2 Brennelemente
3 Steuerstäbe
4 Steuerstabantriebe
5 Druckhalter
6 Heißdampferzeuger
7 Speisewasser
8 Hochdruckturbine
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 my presentation
Wind
Commercial grid consisting of many type generators
Biomass
oil-fired power
潮流・海流発電ってなに？
Tidal power, and others
Solar power
Geothermal

High energy density

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

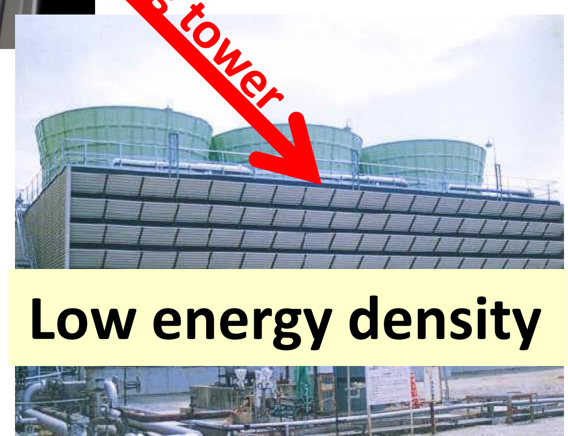
Energy flow: generator ➔ accelerator ➔ cooling tower

2. Accelerator design and manufacturing
should be made by considering-----
- performance/AC power
  - Super-B factory
  - ILC
- component power efficiency
  - High power RF
  - MTBF and MTTR



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-------

3. Energy recovery
- from cooling water
- from beam power, directly
- etc.

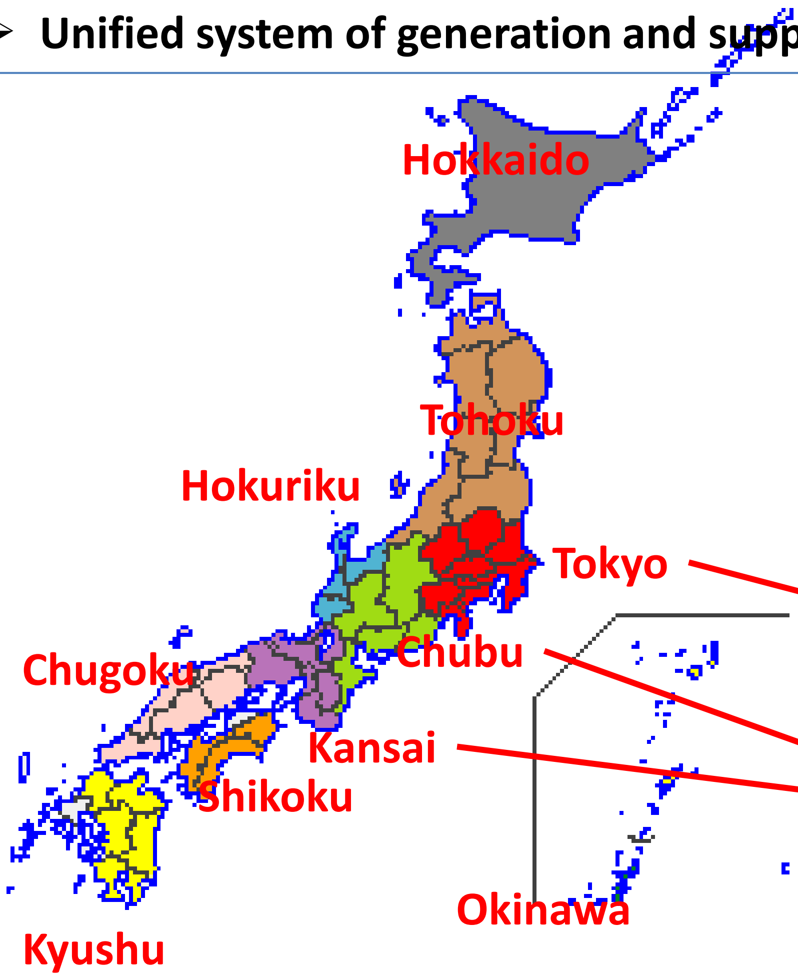


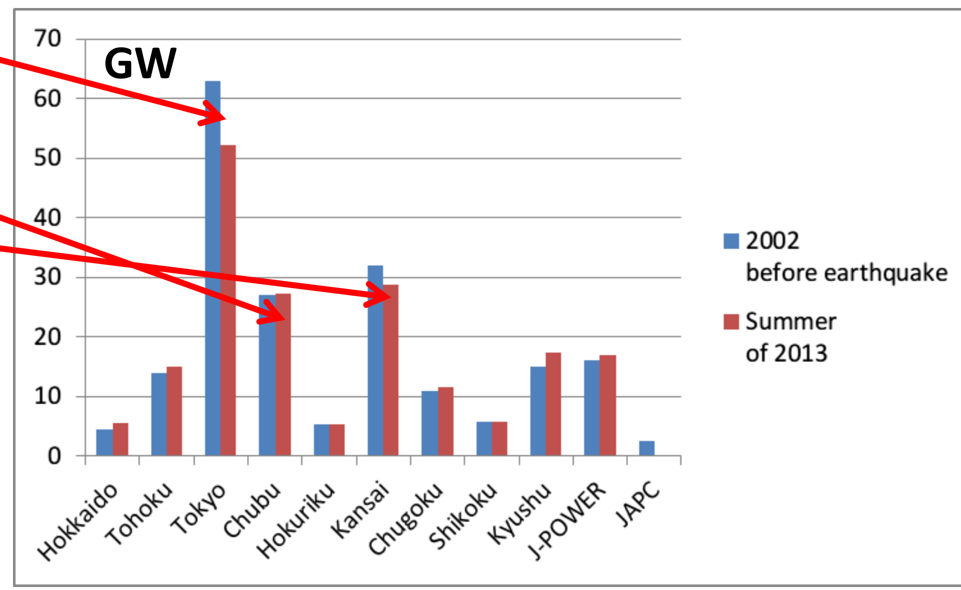
Low energy density

- 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





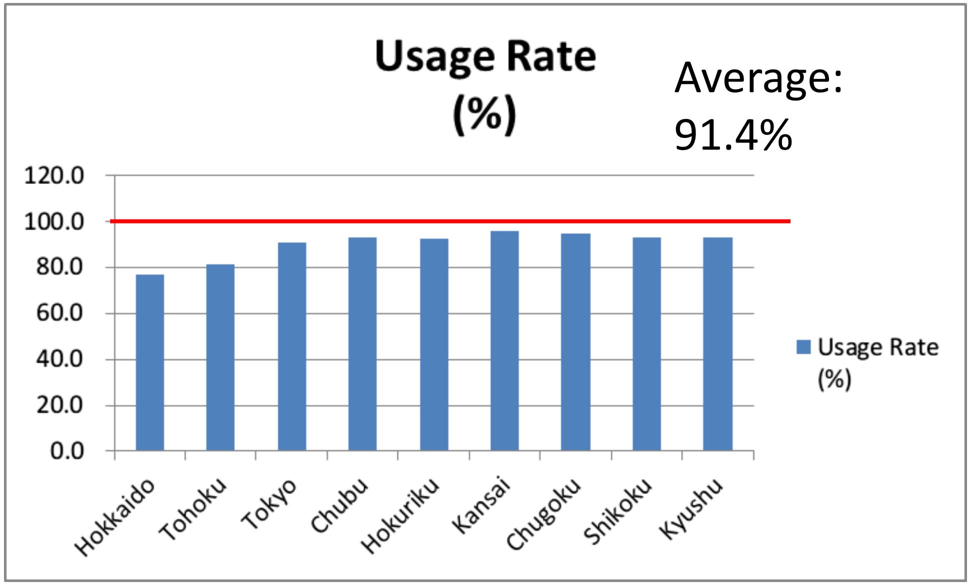
J-POWER: wholesale power company
Availability: 17.0GW (2013)
JAPC: Japan Atomic Power Company

Statistics of Aug.21, 2013

Peak demand in summer appears when----

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

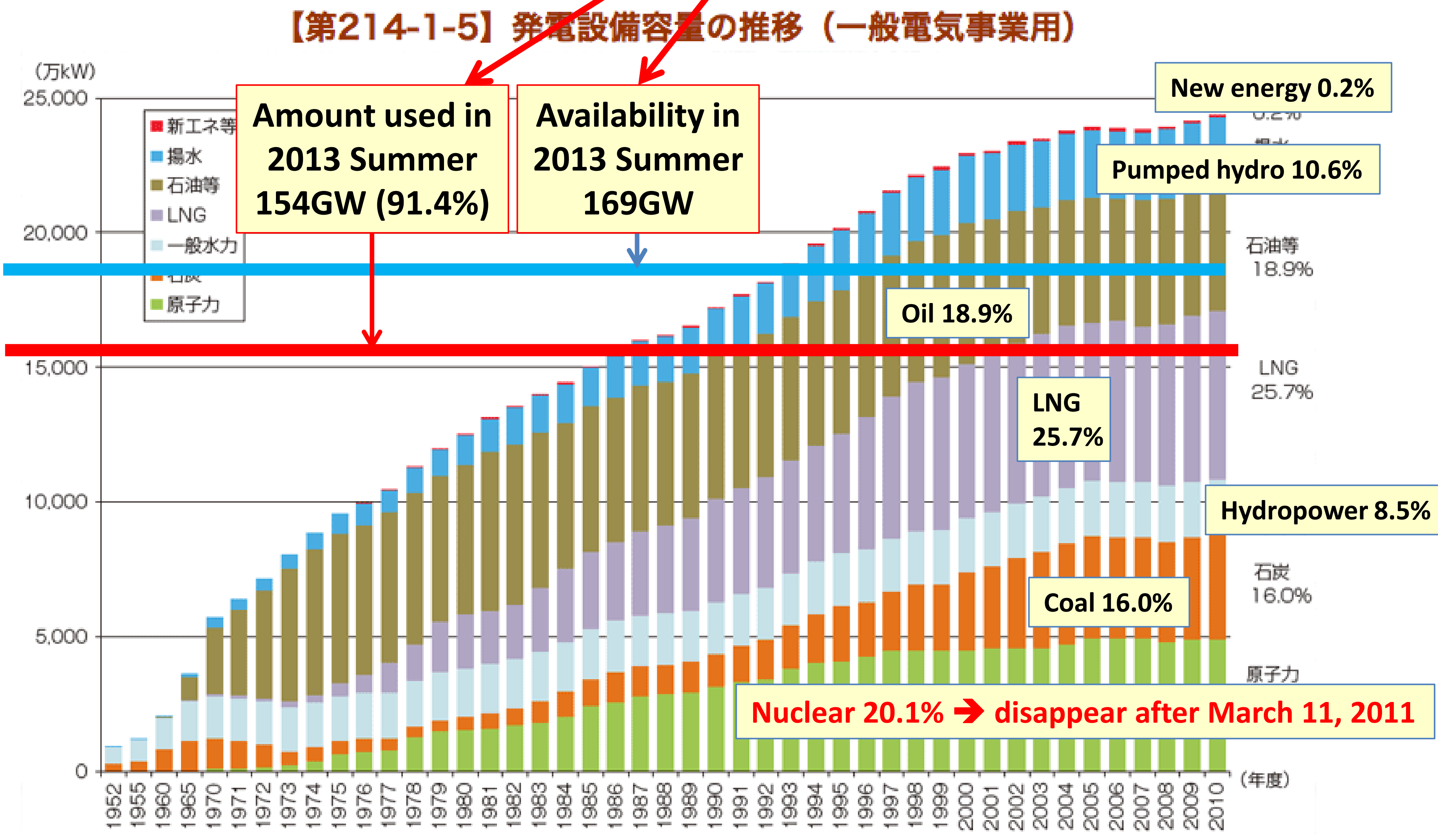
2013/8/21			
Company	Amount used (GW)	Instantaneous Availability (GW)	Usage Rate (%)
Hokkaido	4.23	5.50	76.9
Tohoku	12.18	14.96	81.4
Tokyo	47.42	52.09	91.0
Chubu	25.37	27.27	93.0
Hokuriku	4.86	5.26	92.3
Kansai	27.54	28.81	95.5
Chugoku	11.09	11.68	94.9
Shikoku	5.34	5.74	93.0
Kyushu	16.24	17.49	92.8
Okinawa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



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

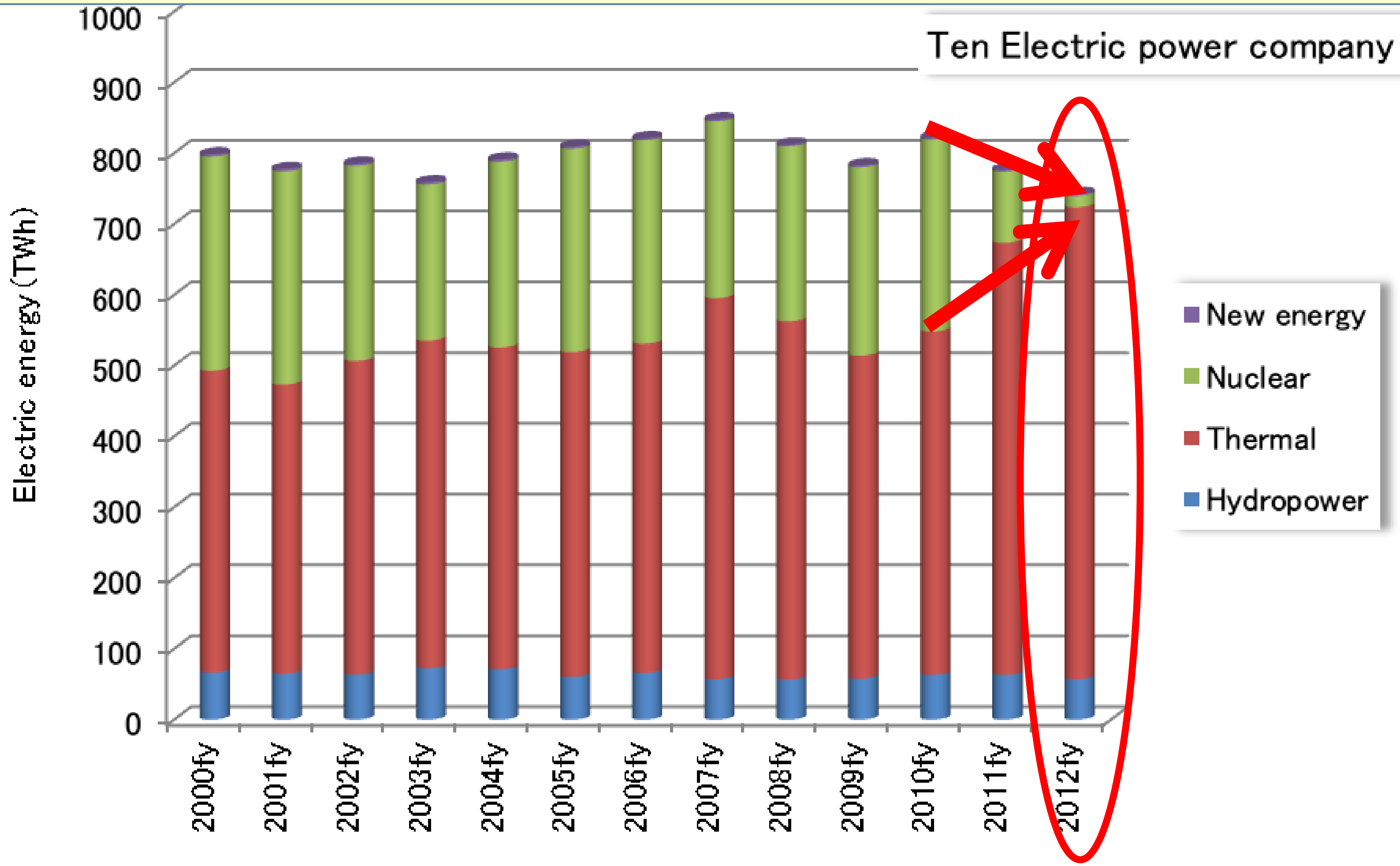
Tight supply-demand balance, but it is well controlled by the save on electricity !

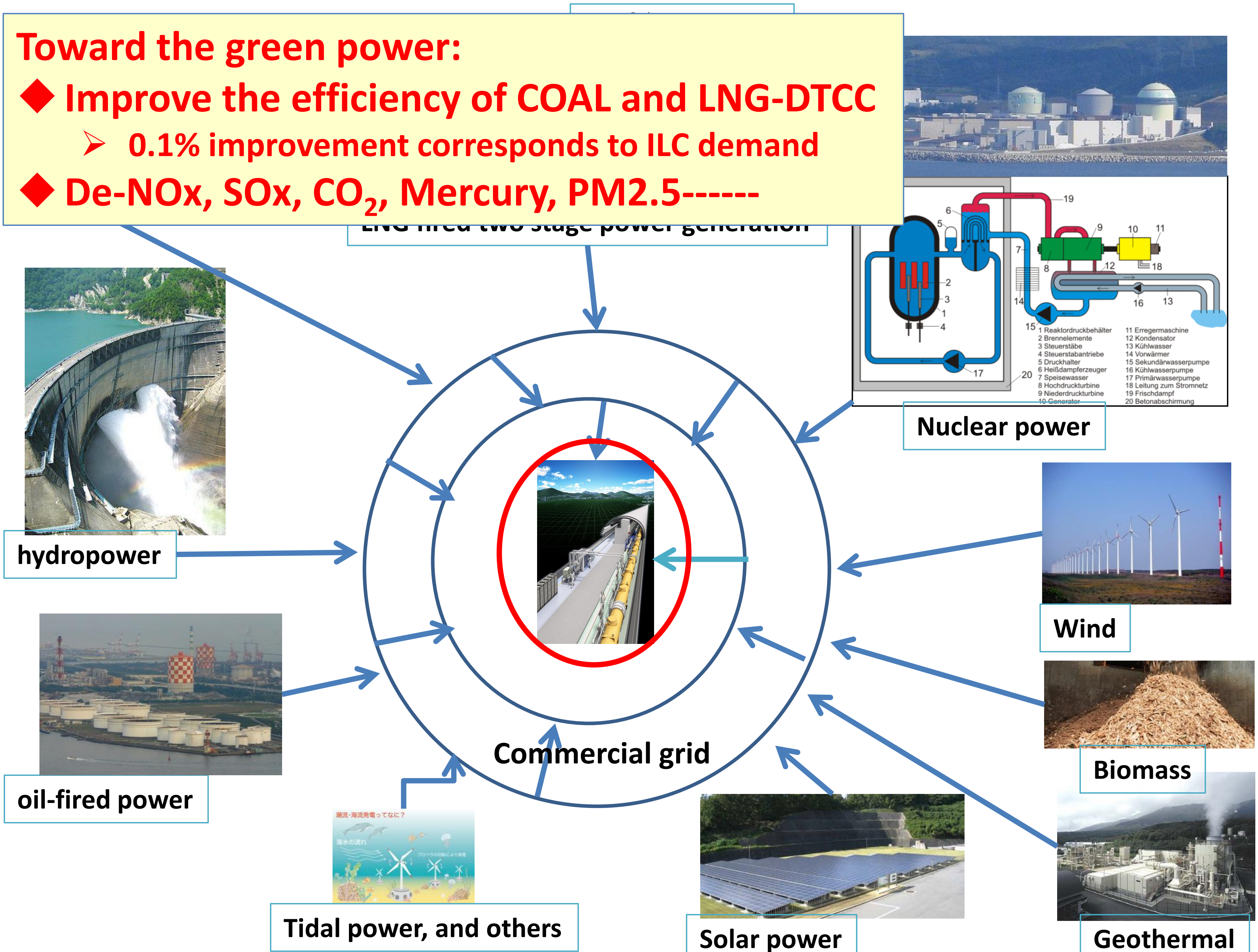
Comparison before and after the earthquake



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------
LNG fired two stage power generation
Nuclear power
1 Reaktordruckbehälter
2 Brennelemente
3 Steuerstäbe
4 Steuerstabantriebe
5 Druckhalter
6 Heißdampferzeuger
7 Speisewasser
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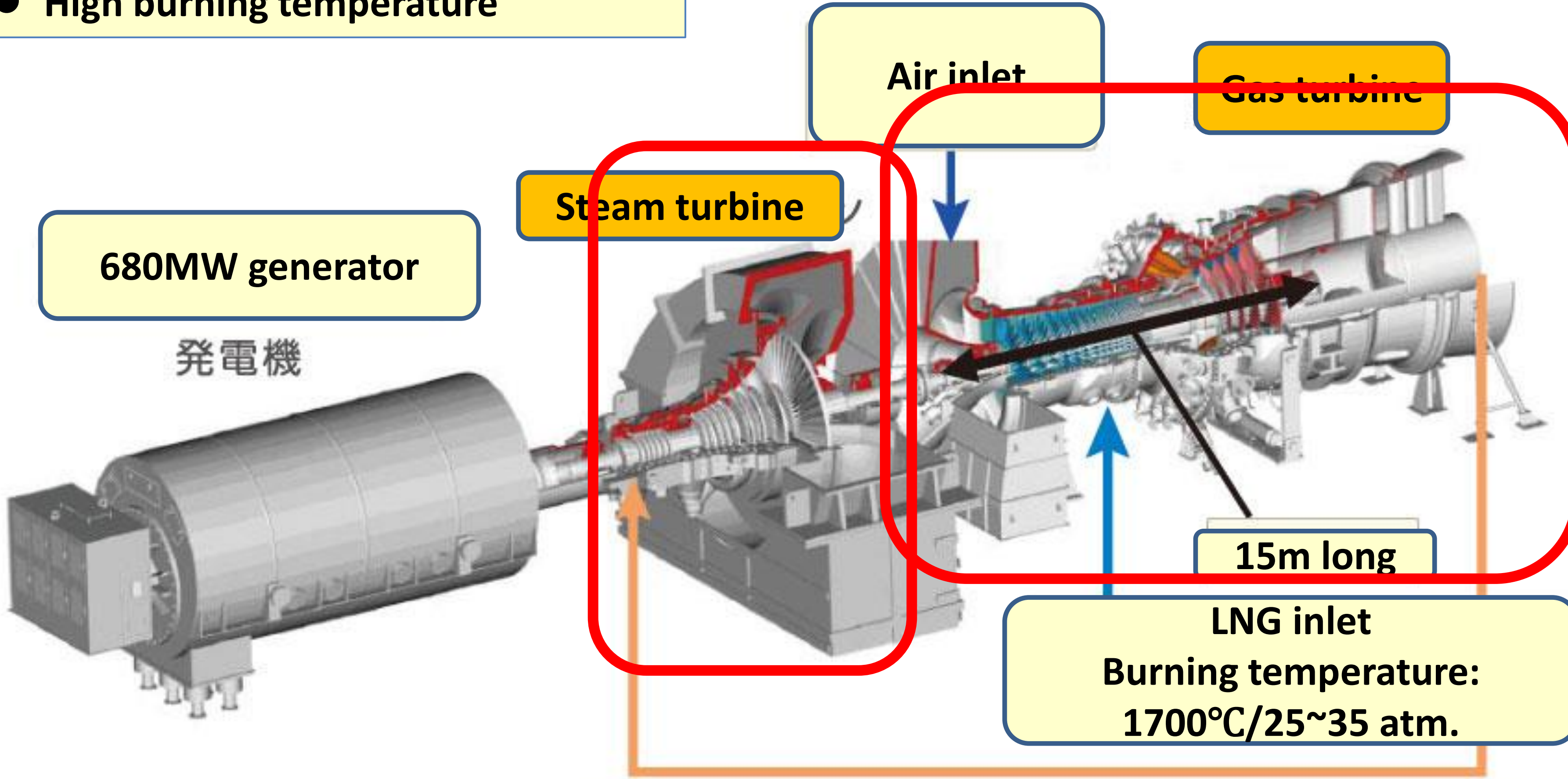
10 Generator
11 Erregermaschine
12 Kondensator
13 Kühlwasser
14 Vorwärmer
15 Sekundärwasserpumpe
16 Kühlwasserpumpe
17 Primärwasserpumpe
18 Leitung zum Stromnetz
19 Frischdampf
20 Betonabschirmung
hydropower
Wind
Biomass
oil-fired power
Commercial grid
Tidal power, and others
Solar power
Geothermal

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

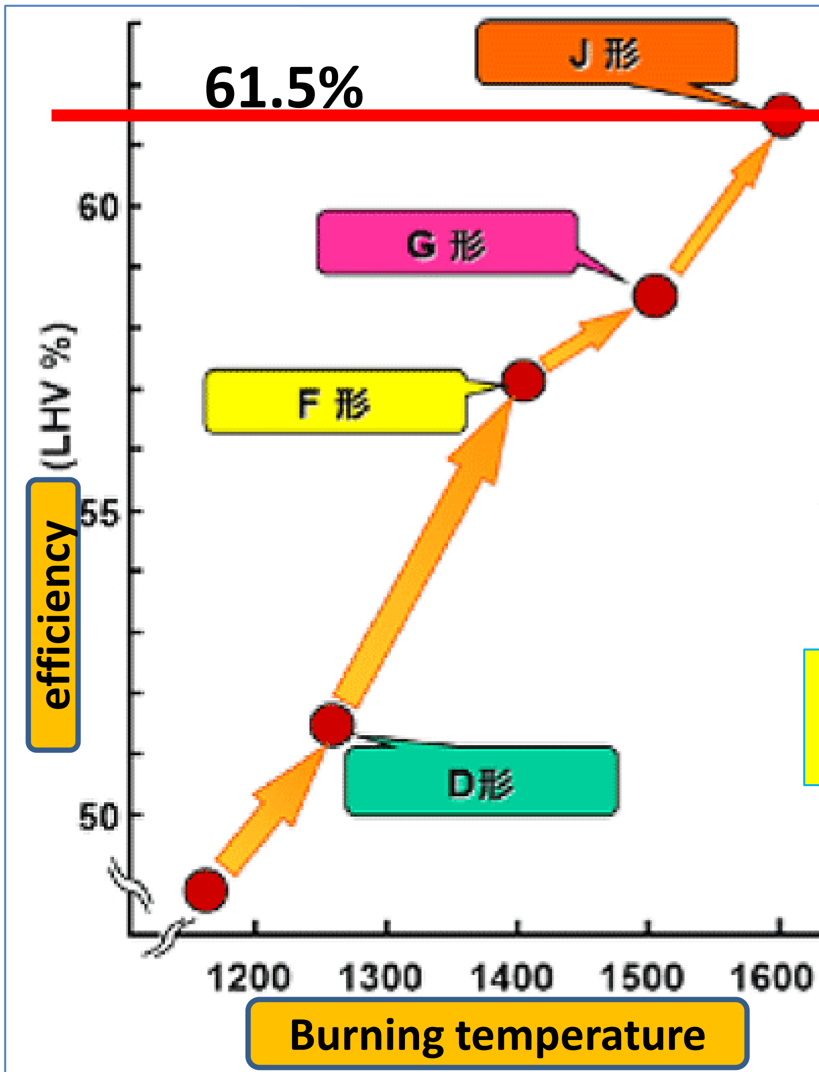
- Combined cycle
- High burning temperature

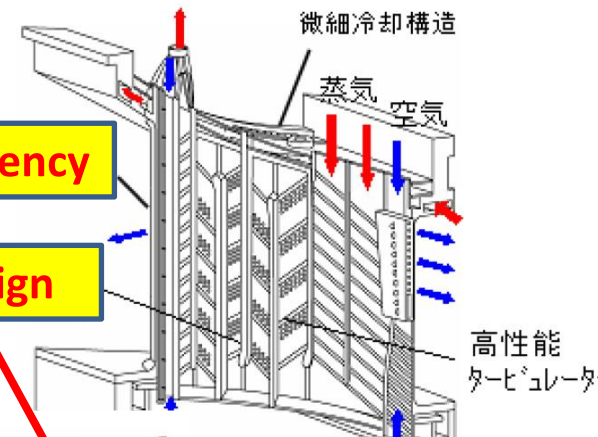


Steam temperature from exhaust heat recovery boiler: 650~700℃/170 atm.

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

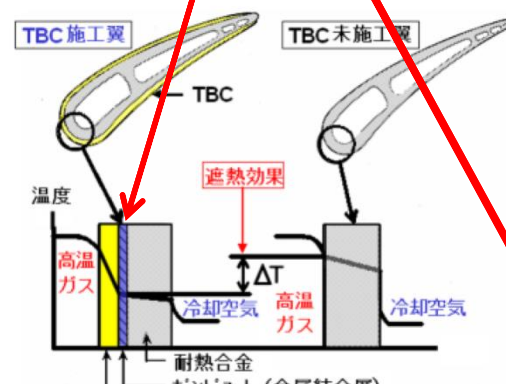
1700℃ turbine blade design





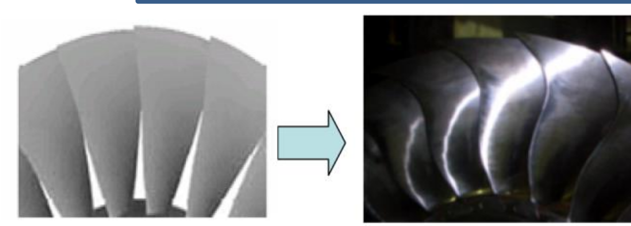
Cooling efficiency

Mechanical design



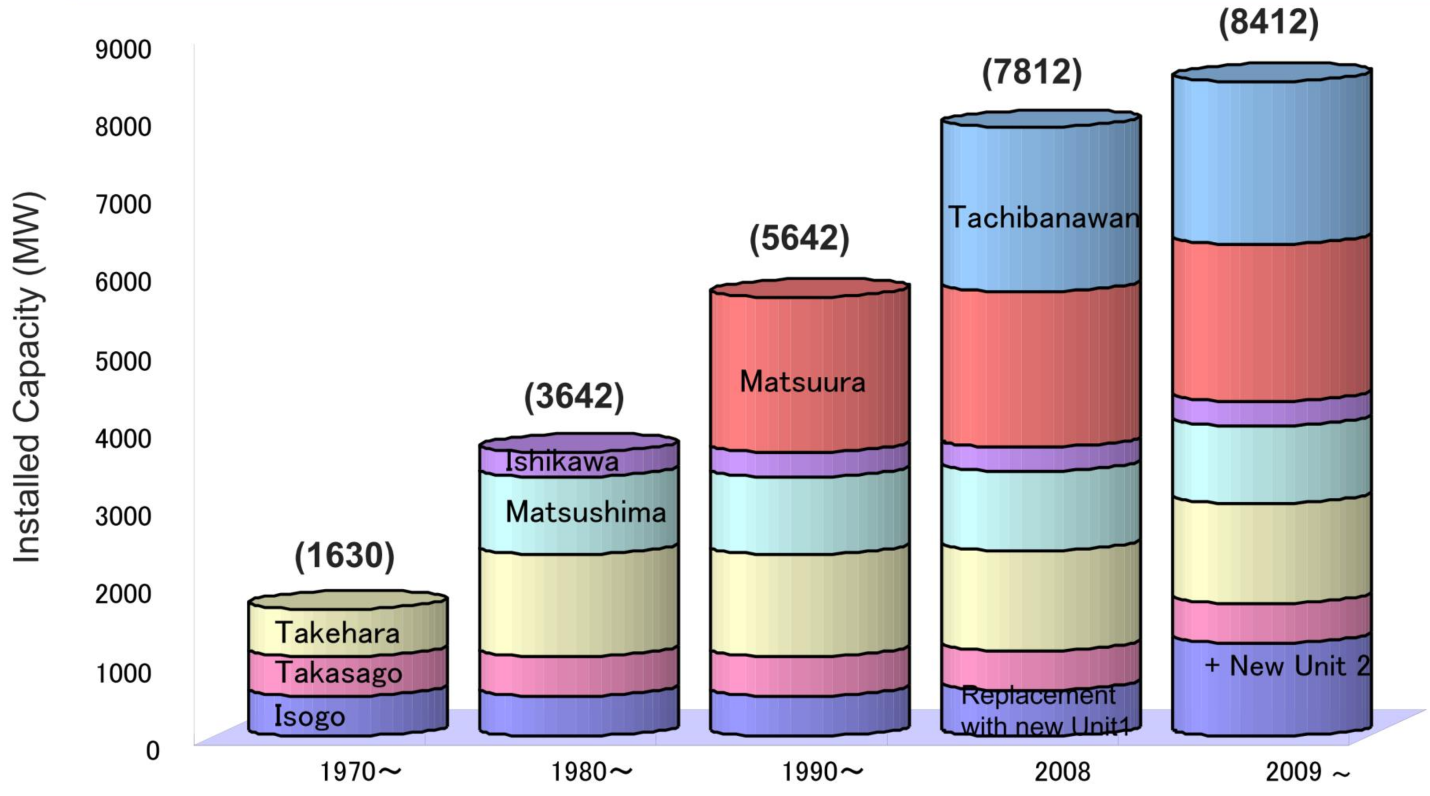
Multi-layer structure to increase ΔT

Decrease pressure loss



Solution-2: Coal power plant with high burning temperature
Steam condition: Sub-critical → Super-critical → Ultra-super-critical
DeSOx, NOx, CO2, Mercury, PM2.5, Coal gas plant in future → Fix CO2

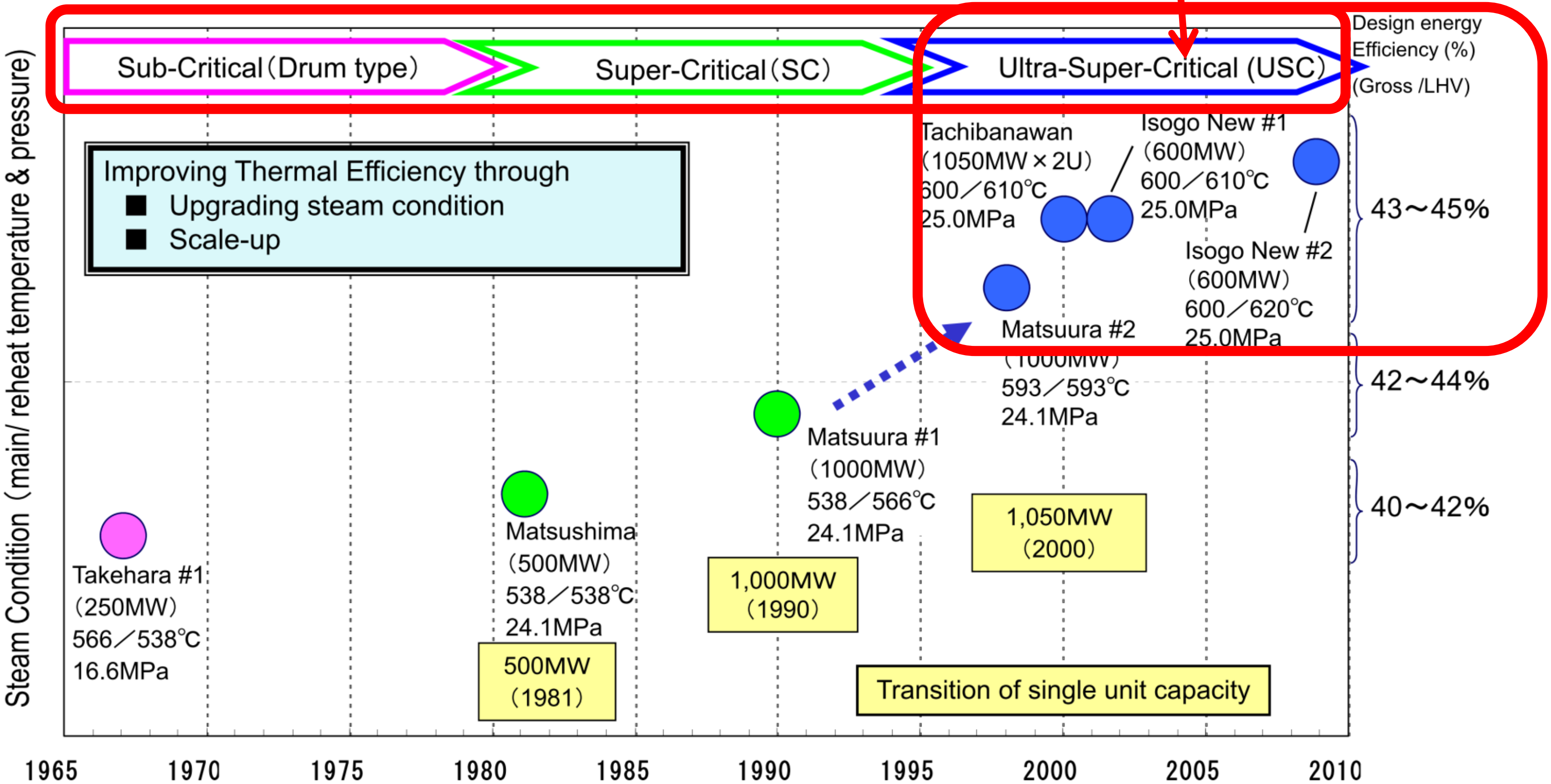
J-POWER: leading company of Japan to develop new type of coal fired power plant.
Present availability: 8.4GW



USC steam condition makes better efficiency

History of J-POWER's Thermal Efficiency Improvements

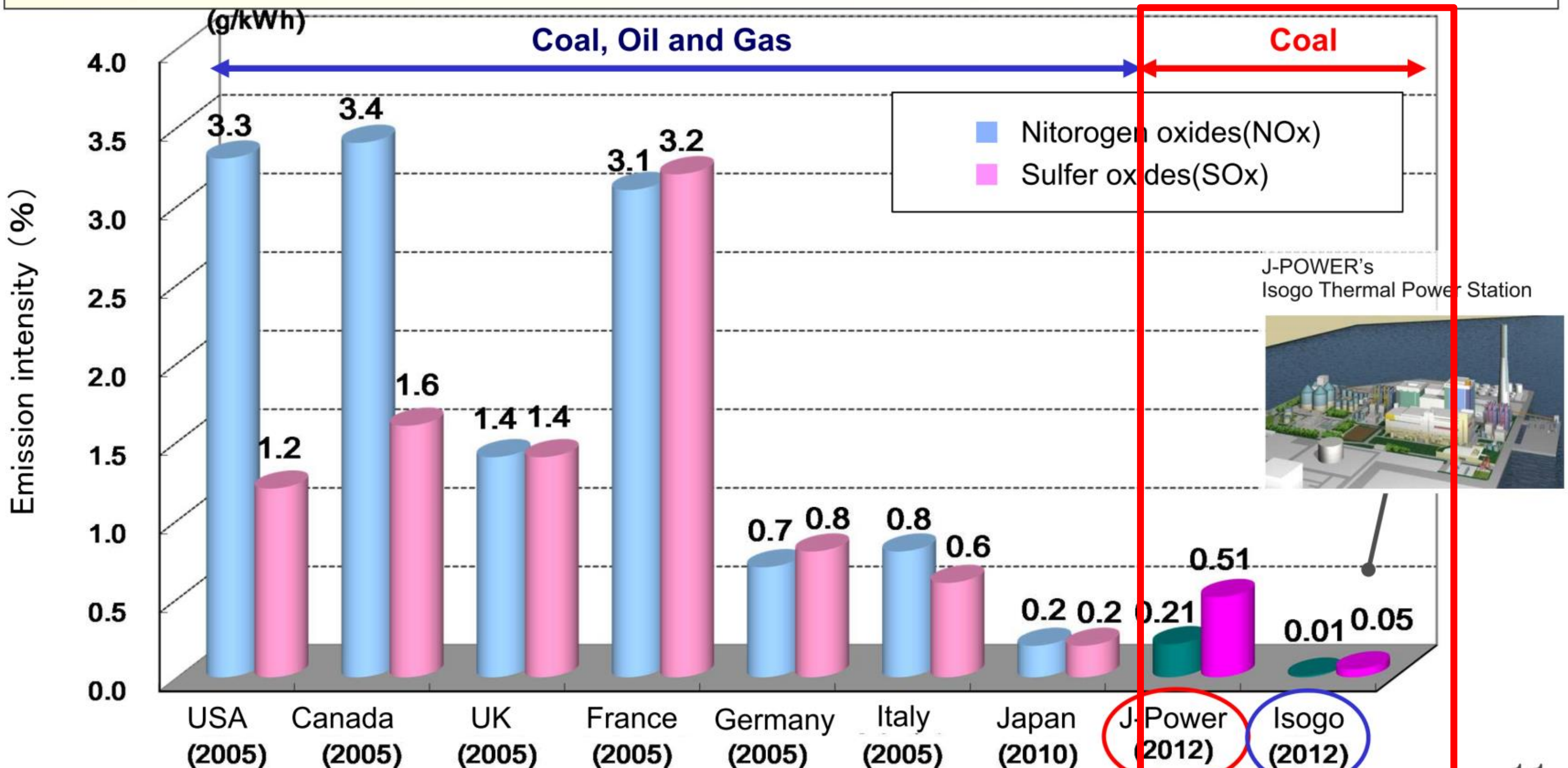
- The world's highest level of thermal efficiency has been achieved at Isogo Power Station by continuous efforts on upgrading steam conditions since 1960s.



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

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

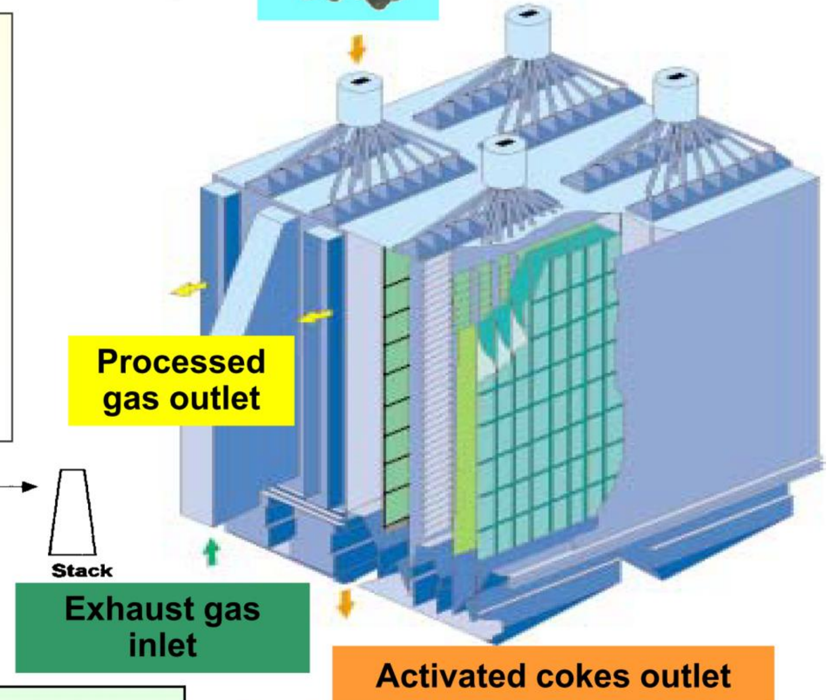
- SOx and NOx emissions from J-POWER's coal-fired power stations are much lower than that from the major developed countries' fossil-fired power stations
- With the most advanced clean coal technologies, SOx and NOx emissions from Isogo PS are at almost the same level of gas-fired power plants.

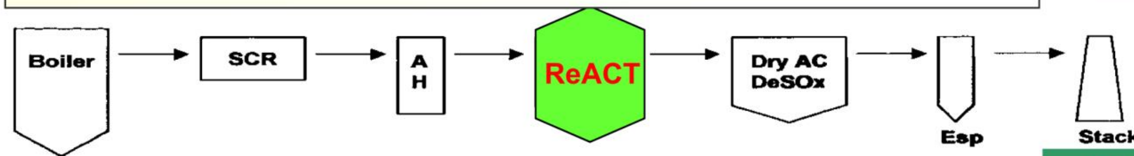


Made from FEPC (Federation of Electric Power Companies)

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)



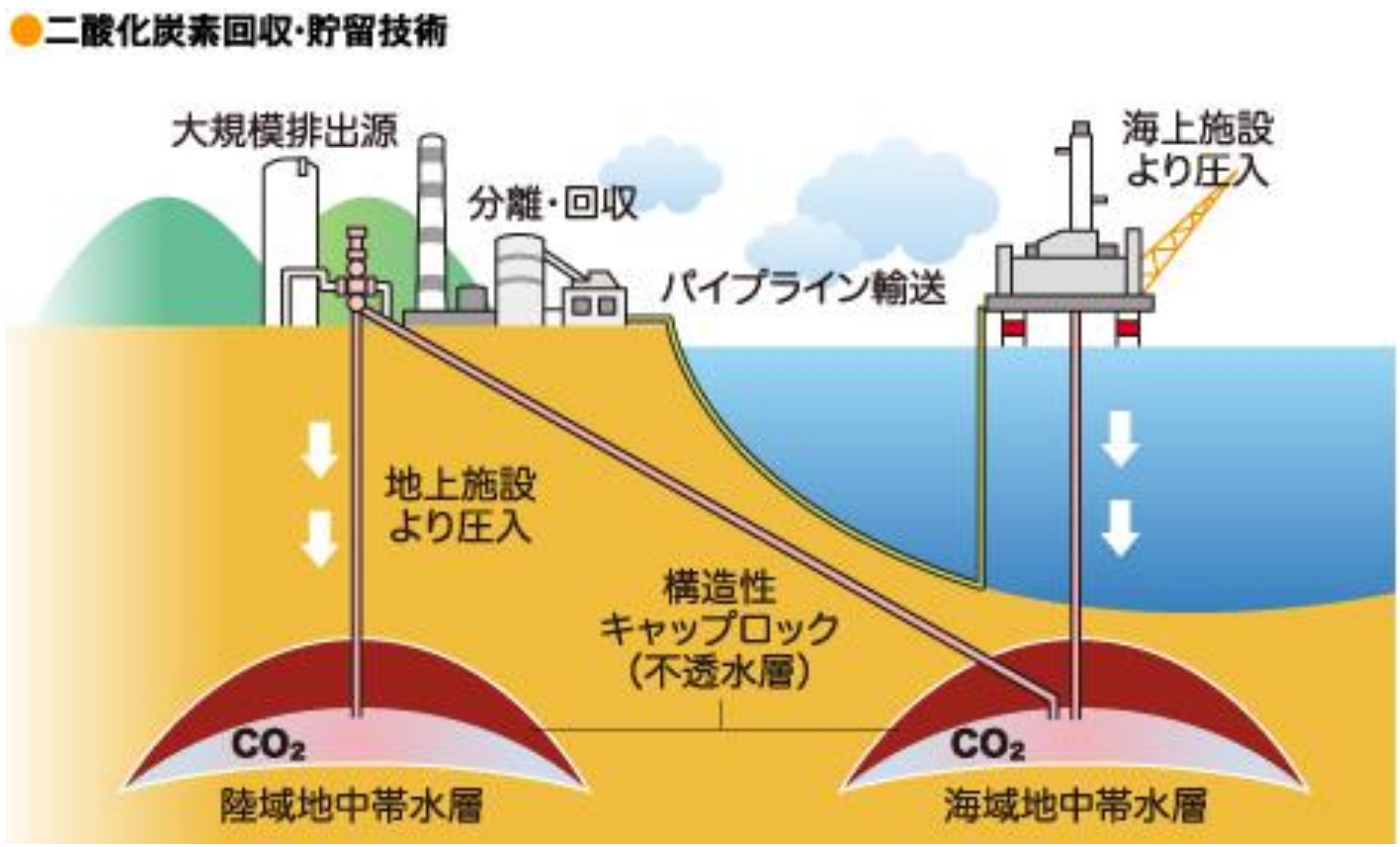


Pollutant	Regulated Value	Operation Results		
		Efficiency	Inlet concentration	Outlet Concentration
SOx	20 ppm	>98%	<410ppm	1 to 6ppm
NOx	20 ppm	10 to 50%	<20ppm	10 to 15ppm
Dust	10 mg/Nm^3	>95%	<100mg/Nm^3	1 to 3mg/Nm^3
Mercury	----	>90%	2.50μg/m3N	0.14 to 0.25μg/m3N

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 CO_2, as much as possible



J-PARC at Tokai campus

TRISTAN and KEKB-factory at Tsukuba campus

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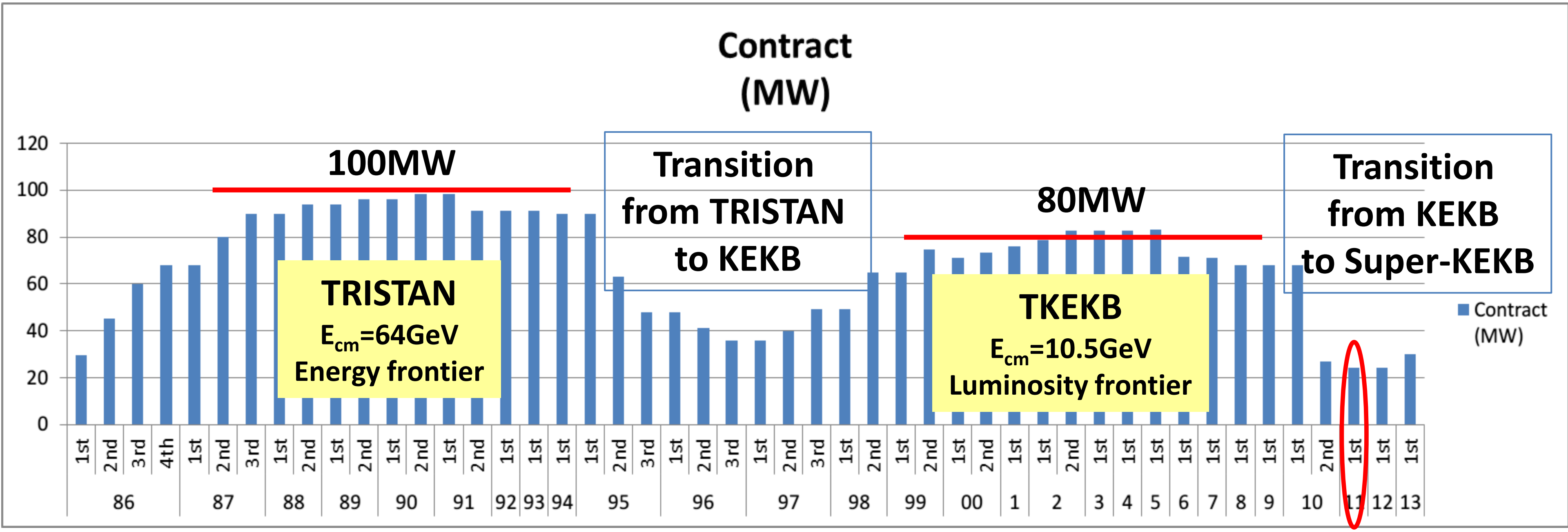
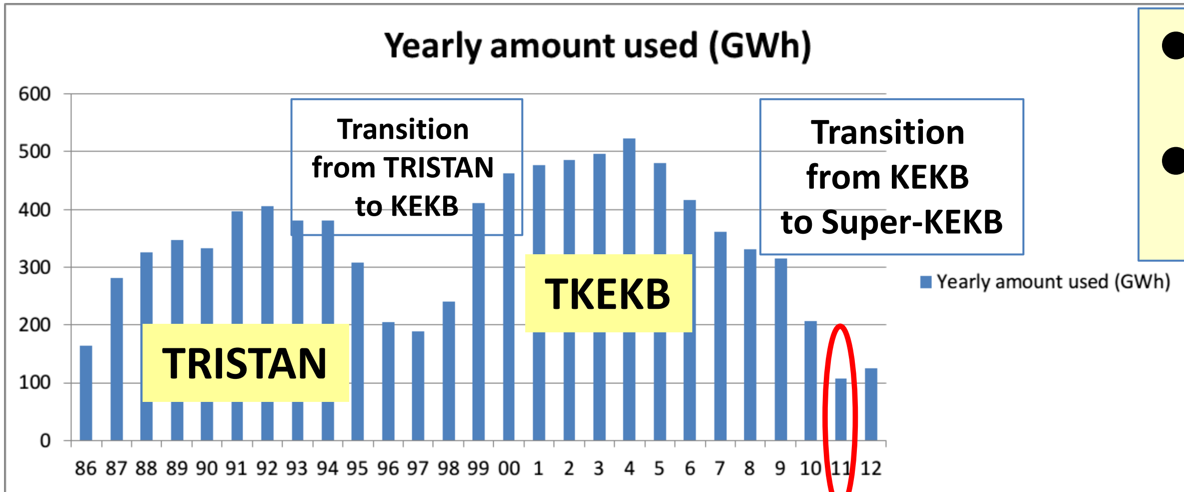
Experiences of electricity usage at KEK Tsukuba-campus since TRISTAN-era

Electric load of KEK
= (TRISTAN or KEKB: main 85%) + (Photon Factory: <8MW) + (others: fractional)

TRISTAN: Energy frontier machine ➔ Huge amount of RF power is demanded
KEKB: Luminosity frontier machine ➔ High current and high availability

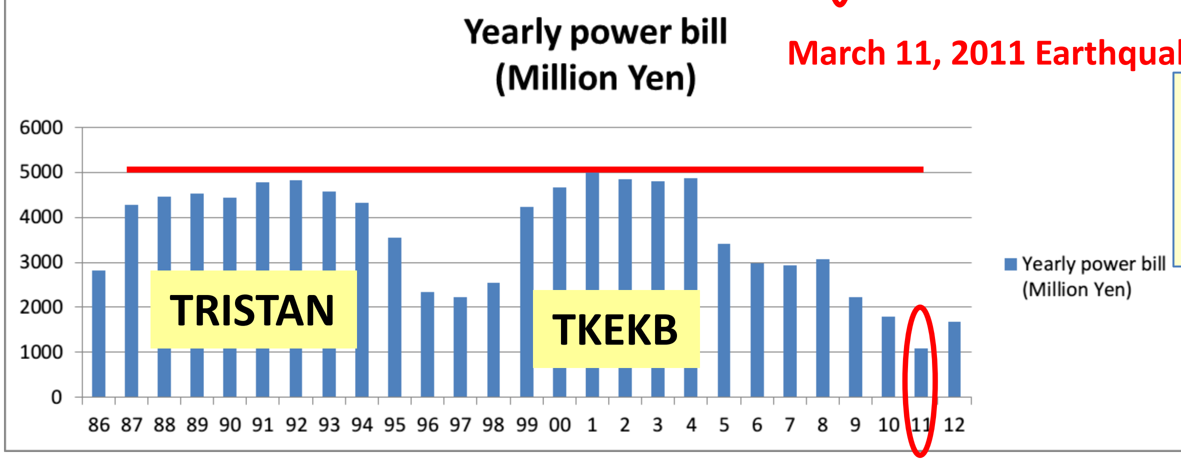


March 11, 2011 Earthquake

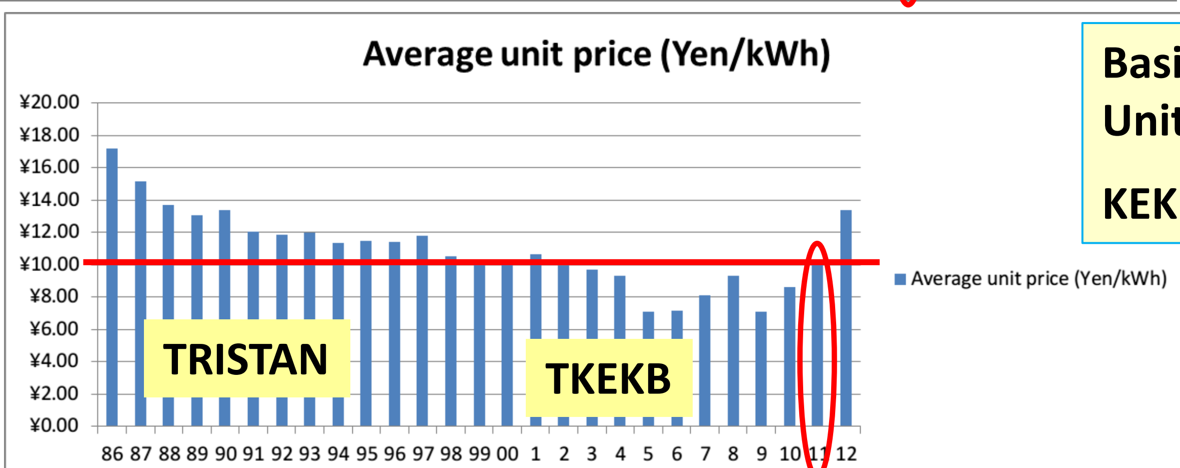


- Contract (Peak Power Demand):
  TRISTAN = 1.15 KEKB
- Yearly amount usage:
  TRISTAN = 0.8 KEKB

March 11, 2011 Earthquake



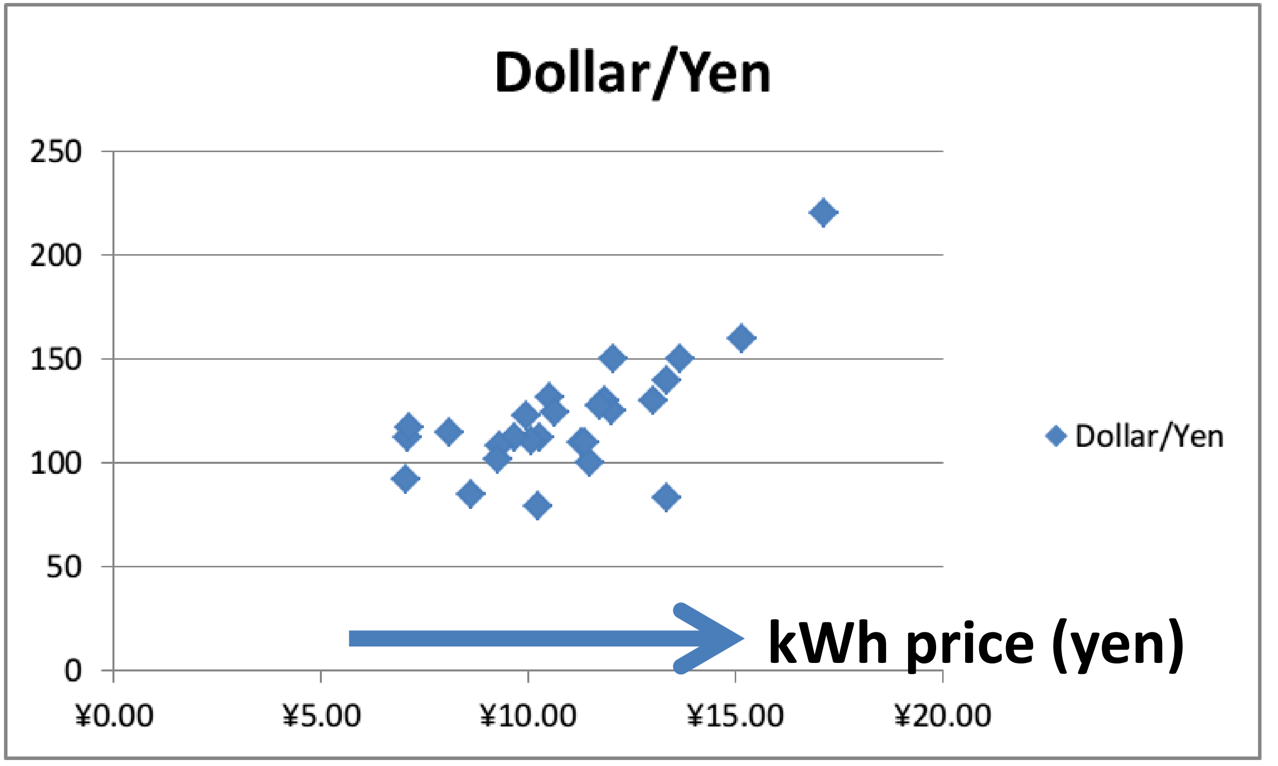
Electric charge
= Basic charge + metered charge
Depends on contract method



Basic charge is fixed but------
Unit price depends on Dollar/Yen rate

KEKB was very lucky, Yen was strong!

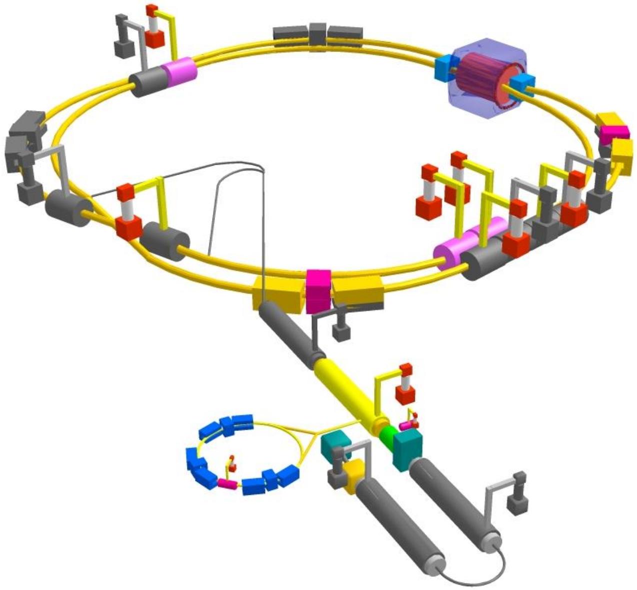
Correlation between unit price (horizontal) and Dollar/Yen ratio (vertical)

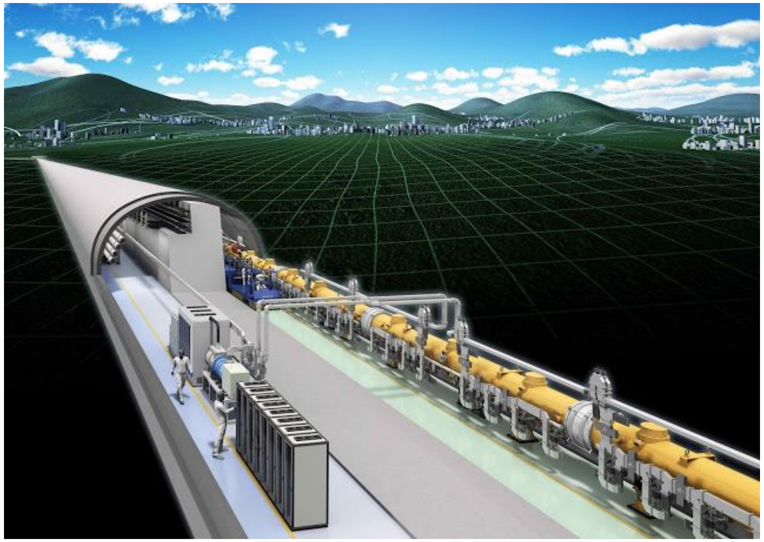


KEK contract with TEPCO to reduce yearly power bill:

- Long shutdown for maintenance ➔ July, August, September
- Turn off accelerator whenever it is requested by TEPCO

TEPCO: Tokyo Electric Power Company





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Proceedings of PAC09, Vancouver, BC, Canada MO3RAI01

A FEW ISSUES ON THE UPGRADE OF KEKB B–FACTORY

K. Oide, T. Abe, K. Akai, Y. Funakoshi, T. Kageyama, H. Koiso, K. Ohmi, Y. Ohnishi,
K. Shibata, Y. Suetsugu, M. Tobiyama
KEK, Oho, Tsukuba, Ibaraki 305-0801, Japan

**Two references
on Super-B factory
by Oide and Masuzawa**

**High current ?
or
Nano-beam ?**

Next Generation
B–factories

Mika Masuzawa (KEK)

Next Generation B–factories IPAC10

Three major factors determining luminosity of KEKB:

Power bill factor

Stored current:

1.7 / 1.4 A (e^+/ e^- KEKB)

Beam-beam parameter:

0.09 (KEKB)

Lorentz factor

$$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

Classical elec. radius

Beam size ratio

Geometrical correction factors due to crossing angle and hour-glass effect

Luminosity:

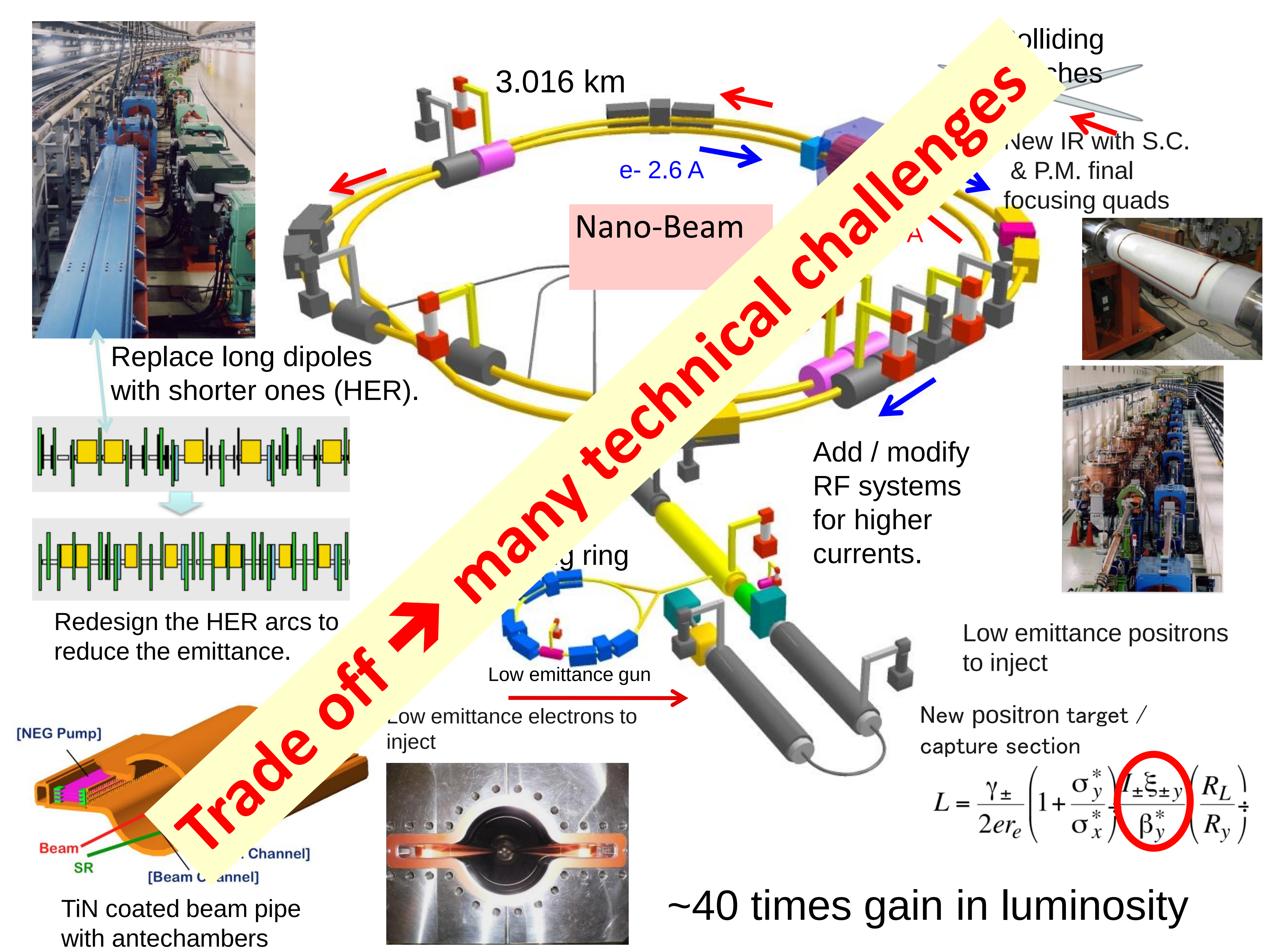
0.21 $\times 10^{35}$ $cm^{-2}s^{-1}$ (KEKB)

Vertical β at the IP:

5.9 /5.9 mm (e^+/ e^- KEKB)

Comparison of Parameters

	KEKB Achieved : with crab	SuperKEKB High-Current	SuperKEKB Nano-Beam
Energy (GeV) (LER/HER)	3.5/8.0	3.5/8.0	4.0/7.0
β_y^* (mm)	5.9/5.9	3/6	0.27/0.30
ε_x (nm)	18/24	24/18	3.2/4.6
σ_y(mm)	0.94	0.85/0.73	0.048/0.062
ξ_y	0.129/0.090	0.2/0.3	0.09/0.08
σ_z (mm)	~ 7	5/3	6/5
I_{beam} (A)	1.64/1.19	9.4/4.1	3.6/2.6
$N_{bunches}$	1584	5000	2500
Luminosity (10^{34} cm^{-2} s^{-1})	2.11	~40	80
Total Electric Power (MW)	~ 50	~ 100	~ 75
Luminosity/AC power	0.042	0.04	1.07



Trade off → many technical challenges
3.016 km
e- 2.6 A
Nano-Beam
New IR with S.C. & P.M. final focusing quads
Replace long dipoles with shorter ones (HER).
Redesign the HER arcs to reduce the emittance.
Add / modify RF systems for higher currents.
Low emittance positrons to inject
Low emittance gun
Low emittance electrons to inject
New positron target / capture section
[NEG Pump]
Beam
SR
[Beam Channel]
TiN coated beam pipe with antechambers
$L = \frac{\gamma_\pm}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$
~40 times gain in luminosity

The ILC Accelerator Complex

Nick Walker – DESY/GDE

International Linear Collider – A Worldwide Event
12 June 2013
CERN, Geneva, Switzerland.

500 GeV Parameters

tiny emittances
nano-beams at IP
strong beam-beam

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

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…)	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
A…elerator (general)	Average beam power	10.5 MW (total)
	Total AC power	163 MW
	(linacs AC power	107 MW)

TRC report in 2003 for LC technology choice

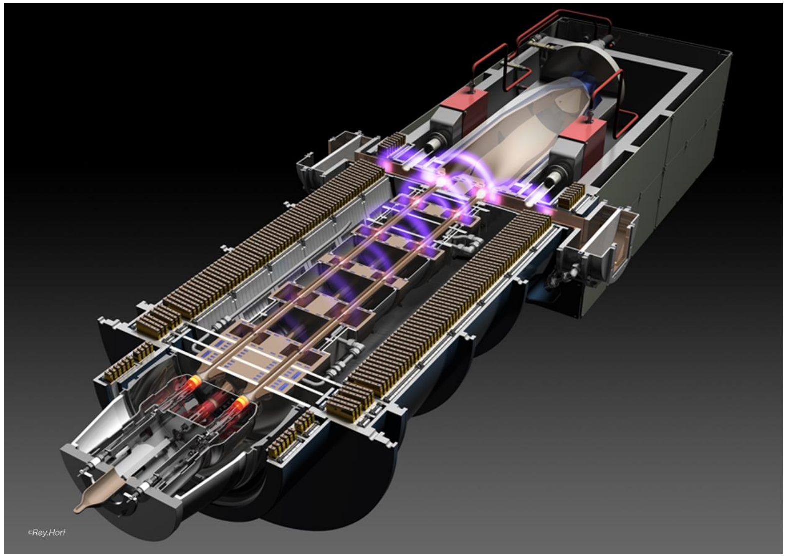
TABLE 2: Summary of Machine Parameters

	TESLA		JLC-C		JLC-X/NLC[a]		CLIC	
Center of mass energy [GeV]	500	800	500	1000	500	1000	500	3000
RF frequency of main linac [GHz]	1.3		5.7	5.7/11.4[b]	11.4		30	
Design luminosity [10^{33} cm^{-2}s^{-1}]	34.0	58.0	14.1	25.0	25.0 (20.0)	25.0 (30.0)	21.0	80.0
Linac repetition rate [Hz]	5	4	100		150 (120)	100 (120)	200	100
Number of particles/bunch at IP [10^{10}]	2	1.4	0.75		0.75		0.4	
$\gamma\varepsilon_x^* / \gamma\varepsilon_y^*$ emit. at IP [m·rad × 10^{-6}]	10 / 0.03	8 / 0.015	3.6 / 0.04		3.6 / 0.04		2.0 / 0.01	0.68 / 0.01
β_x^* / β_y^* at IP [mm]	15 / 0.40	15 / 0.40	8 / 0.20	13 / 0.11	8 / 0.11	13 / 0.11	10 / 0.05	16 / 0.07
σ_x^* / σ_y^* at IP before pinch[c] [nm]	554 / 5.0	392 / 2.8	243 / 4.0	219 / 2.1	243 / 3.0	219 / 2.1	202 / 1.2	60 / 0.7
σ_z^* at IP [μm]	300		200	110	110		35	
Number of bunches/pulse	2820	4886	192		192		154	
Bunch separation [nsec]	337	176	1.4		1.4		0.67	
Bunch train length [μsec]	950	860	0.267		0.267		0.102	
Beam power/beam [MW]	11.3	17.5	5.8	11.5	8.7 (6.9)	11.5 (13.8)	4.9	14.8
Unloaded/loaded gradient[d] [MV/m]	23.8 / 23.8[e]	35 / 35	41.8/31.5	41.8/31.5 / 70/55	65 / 50		172 / 150	
Total number of klystrons	572	1212	4276	3392/4640	4064	8256	448	
Number of sections	20592	21816	8552	6784/13920	12192	24768	7272	44000
Total two-linac length [km]	30	30	17.1	29.2	13.8	27.6	5.0	28.0
Total beam delivery length [km]	3		3.7		3.7		5.2	
Proposed site length [km]	33		33		32		10.2	33.2
Total site AC power[f] [MW]	140	200	233	300	243 (195)	292 (350)	175	410
Tunnel configuration[g]	Single		Double		Double		Single	

E_{CM} = 500GeV	TESLA	JLC-C	JLC-X/NLC	CLIC
Total site AC power (MW)	140	233	243	175
Design Luminosity 10^{33}cm^{-2}s^{-1}	34.0	14.1	25.0	21.0
Luminosity/AC power	0.243	0.061	0.103	0.120

it. The 300 m long CLIC drive beam accelerator is located in a tunnel with a separate klystron gallery on the surface.

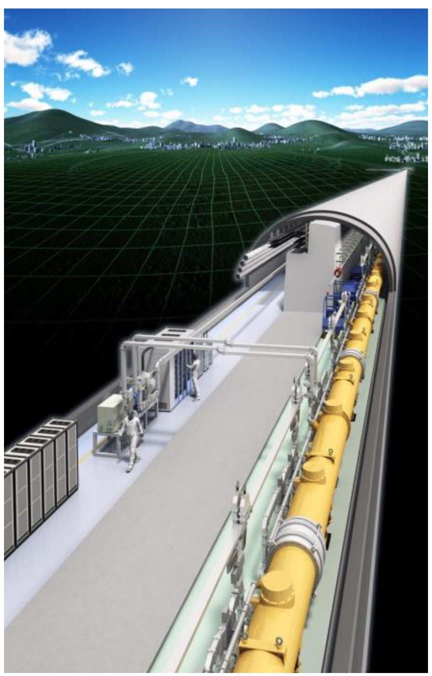
ILC 500GeV design = 0.11 (baseline)➔ 0.18 (upgrade)



1. Electric power supply in Japan, before and after March 11, 2011 earthquake
   - ➢ High efficiency and "almost" environmental pollution-free electricity generation can save Japan, and contribute to reduce global CO_2 problem
2. KEK Electricity contract as an example of large-scale RIs
3. Accelerator design by considering optimization of luminosity/electricity demand
   - ➢ Example: Super-KEKB
   - ➢ ILC
4. **Accelerator component design by considering high power-efficiency**
   - ➢ **Klystron**
   - ➢ **Availability based on MTBF (mean time between failure) and MTTR (mean time to repair)**
5. Summary

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



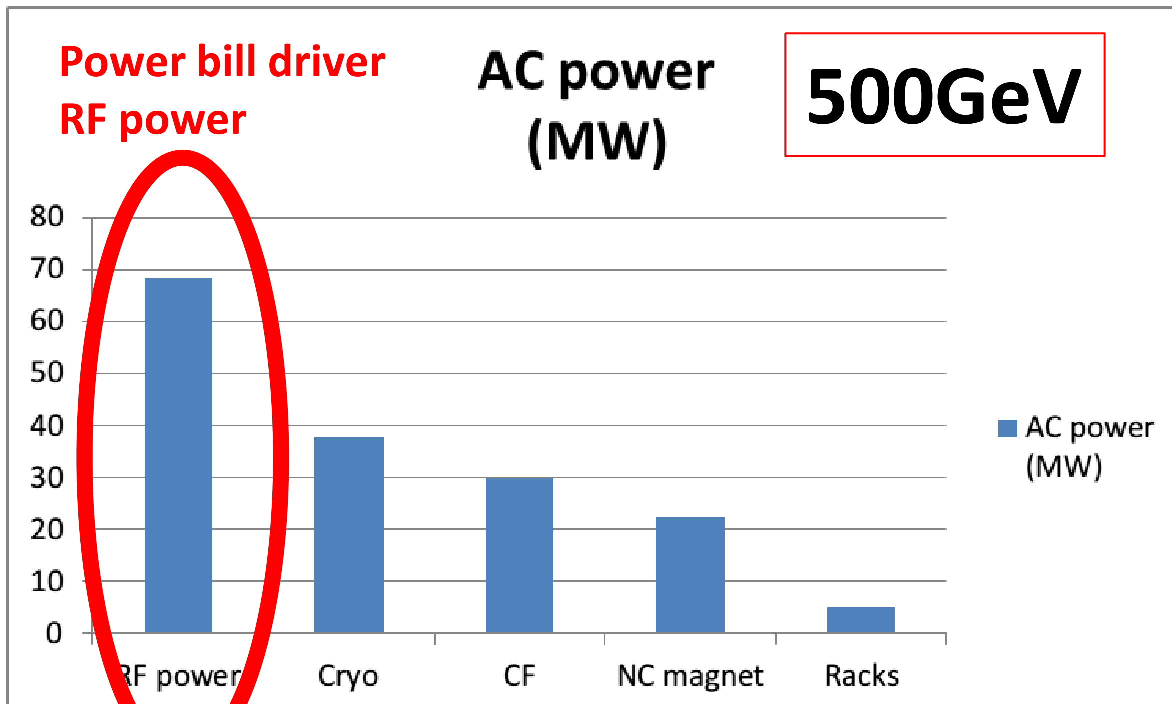
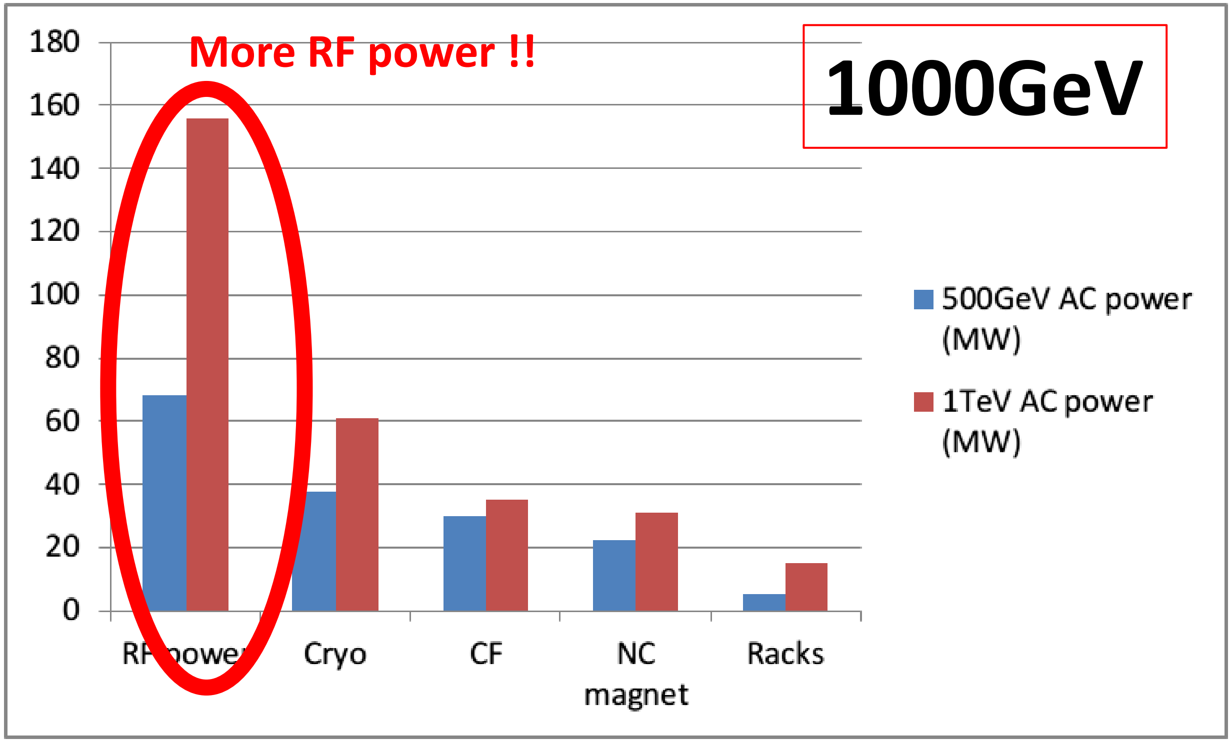
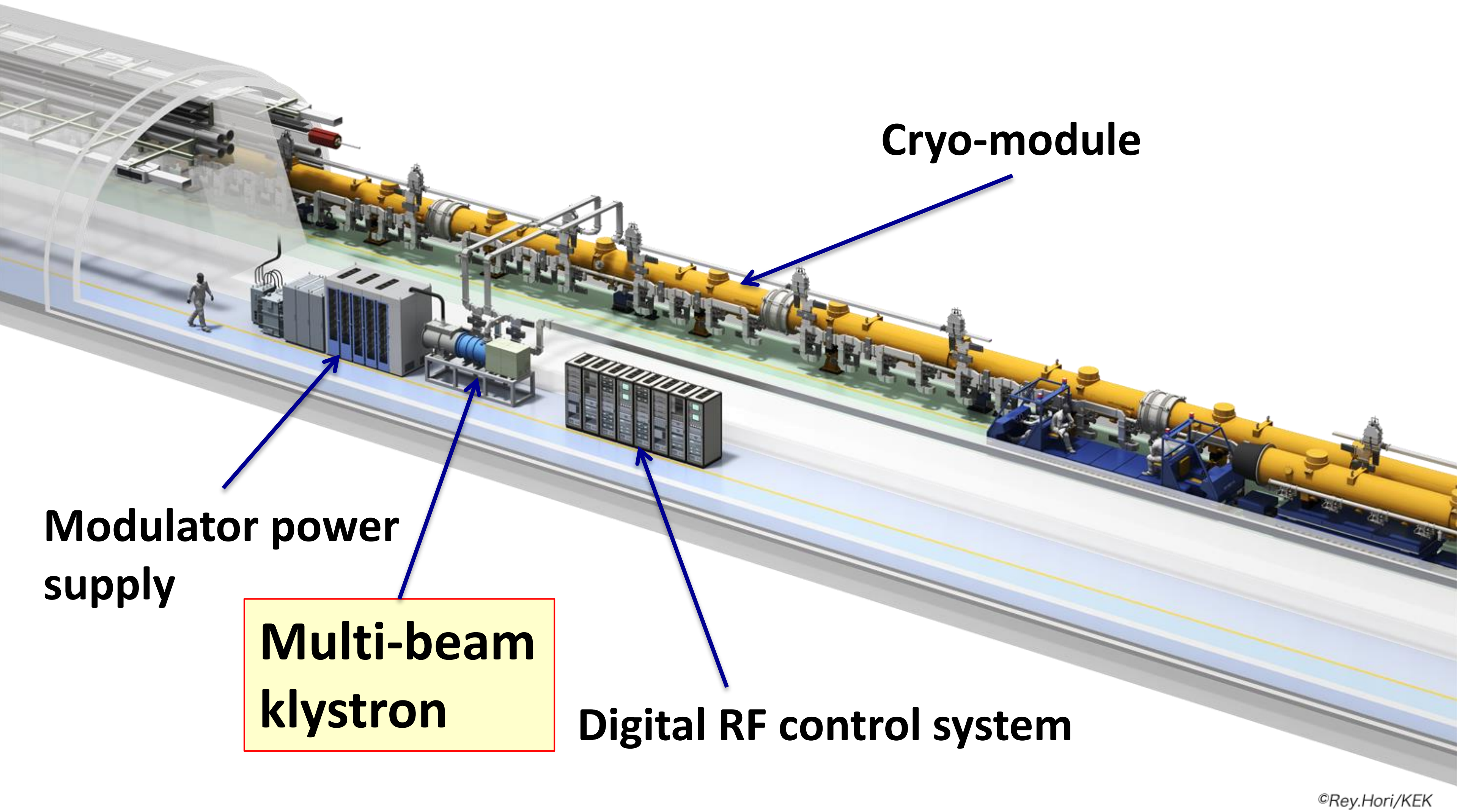


Table 12.6
Rough estimate of the power requirements (in MW) for the 1 TeV upgrade (scenario B), based on extrapolation of the baseline design parameters using simple scaling laws [232].

	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

Effort to increase klystron efficiency

Lower the perveance

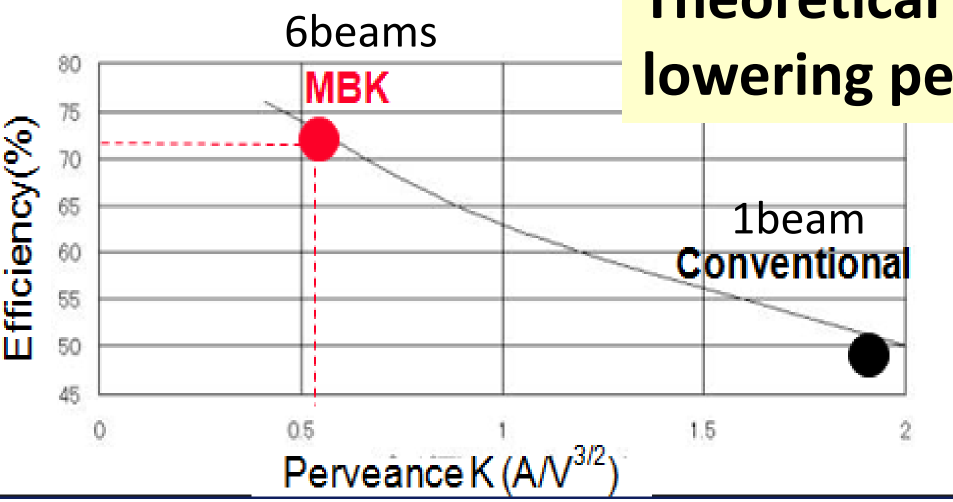
【Conventional】

- 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

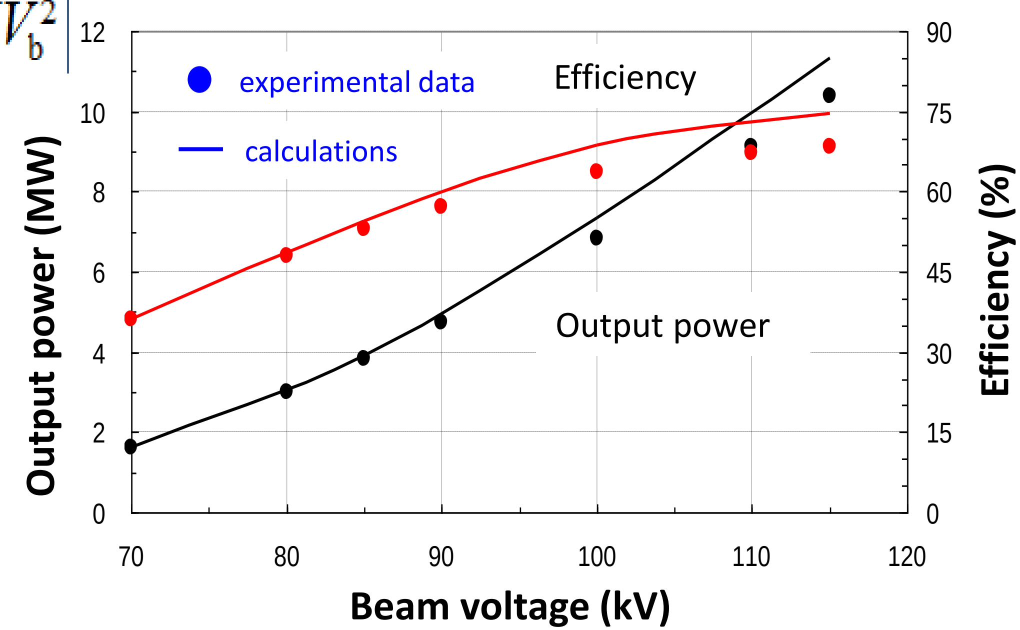


Theoretical efficiency improvement by lowering perveance.

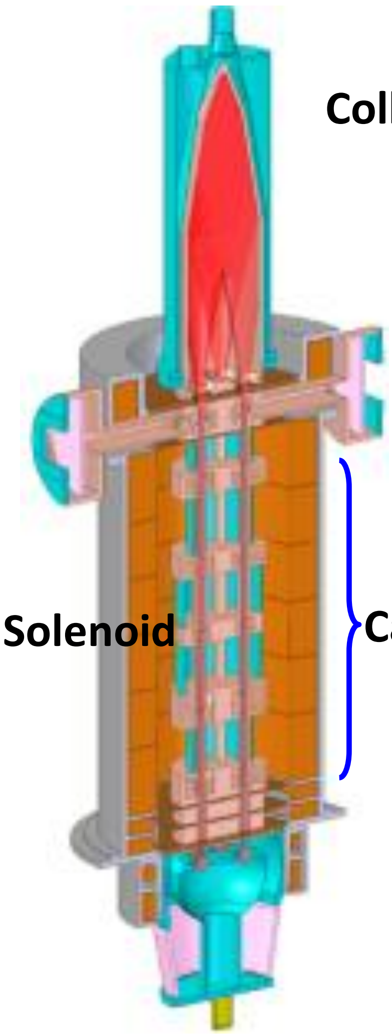
$$P_0 = \eta(K) \cdot V_b I_b = \eta(K) \cdot nKV_b^{\frac{5}{2}} \qquad I_b = nKV_b^{\frac{3}{2}}$$

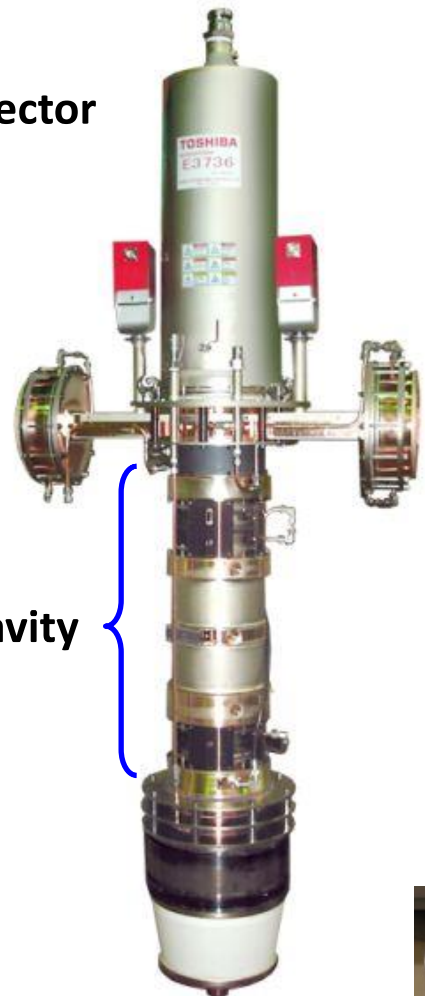
Perveance: $I_b = PV^{2/3}$

Output power and efficiency as a function of beam voltage.



TOSHIBA Multi-Beam Klystron(MBK) E3736

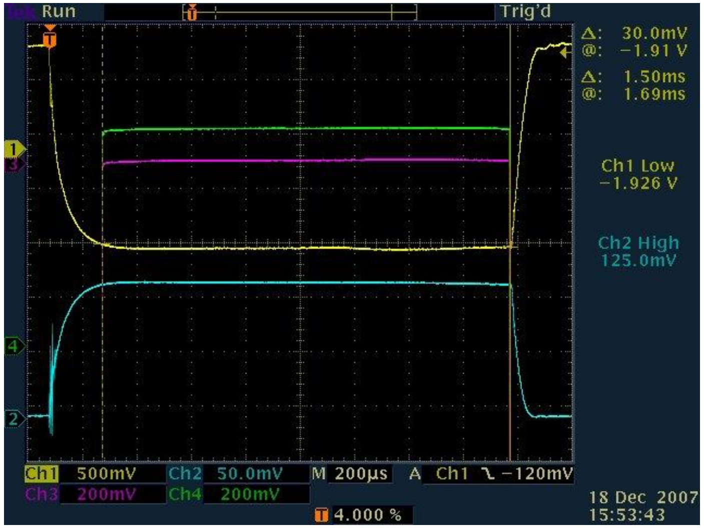




	Design	Achieved	
Frequency 1.3	1.3	GHz	
Output power	10	10.2	MW
Output power (Av.)	150	153	kW
Beam voltage	115	115	kV
Beam current	132	134	A
Efficiency	**> 65**	**67**	**%**
RF pulse width	1.5	1.5	ms
Repetition rate	10	10	pps
Saturation gain	47	49	dB
Number of beams	6		
Cathode loading	< 2.0	2.0	A/cm^2
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

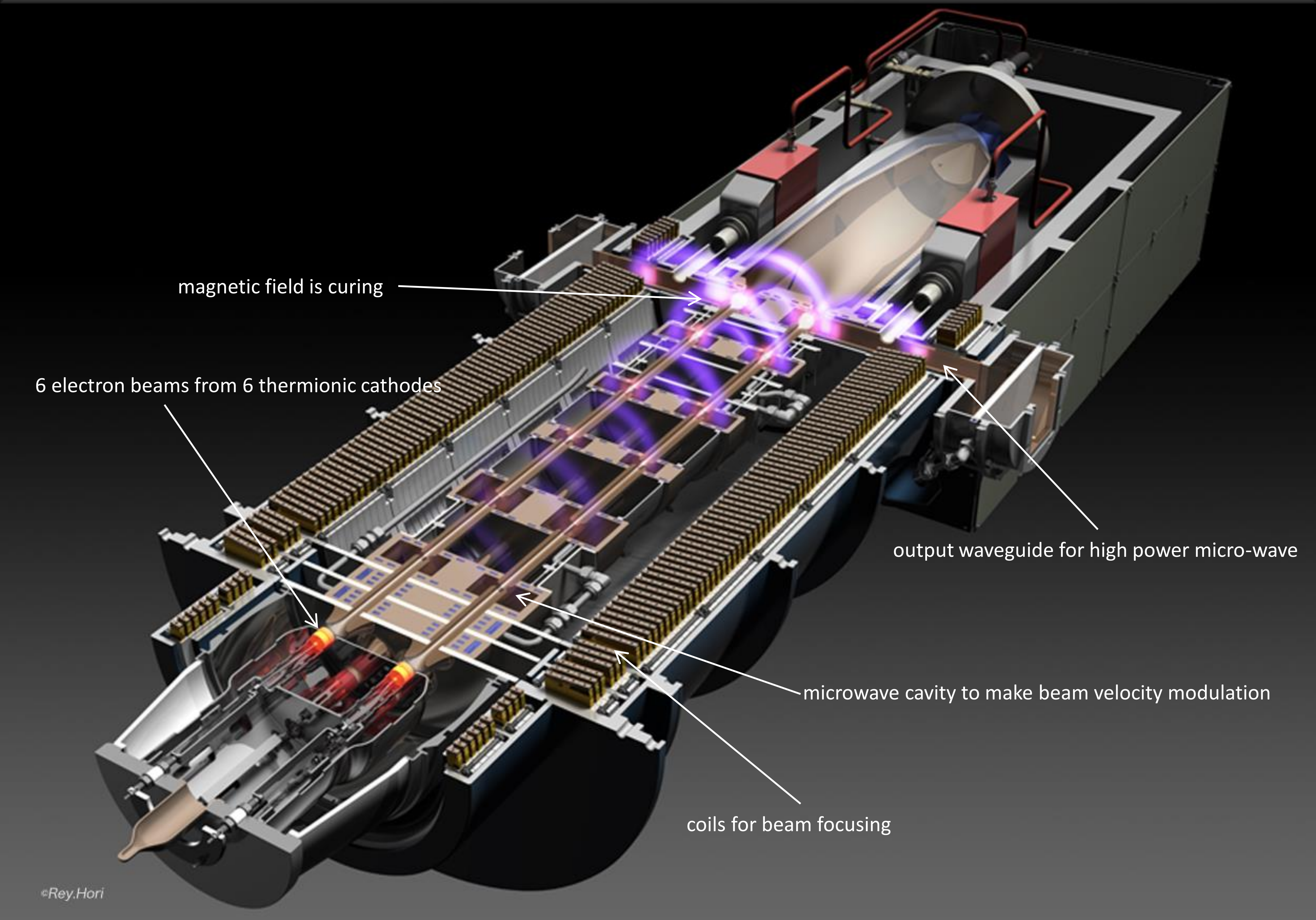
Effort to realize high efficiency klystron → Multi-beam (6 beams)



Toshiba
E3736H

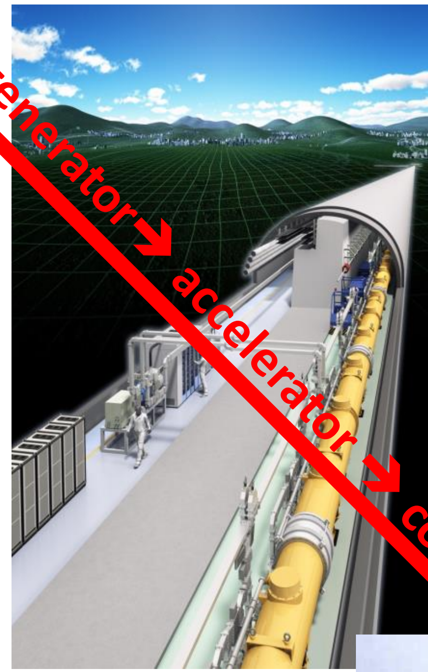
6 beams
10MW
1.5ms
67% efficiency

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.


magnetic field is curing
6 electron beams from 6 thermionic cathodes
output waveguide for high power micro-wave
microwave cavity to make beam velocity modulation
coils for beam focusing
©Rey.Hori

R: **r**eliability
A: **a**vailability → **A = 1- (MTTR/MTBF)**
M: **m**aintainability

MTTR: **m**ean **t**ime **t**o **r**epair (or **r**ecover)
MTBF: **m**ean **t**ime **b**etween **f**ailures



Improve availability

↓

Reduce idling time

Idling time

↓

Waste of electricity

SLC: 3km long, 50GeV

KEKB: 0.6km long, 8GeV

ILC should learn from the past experiences

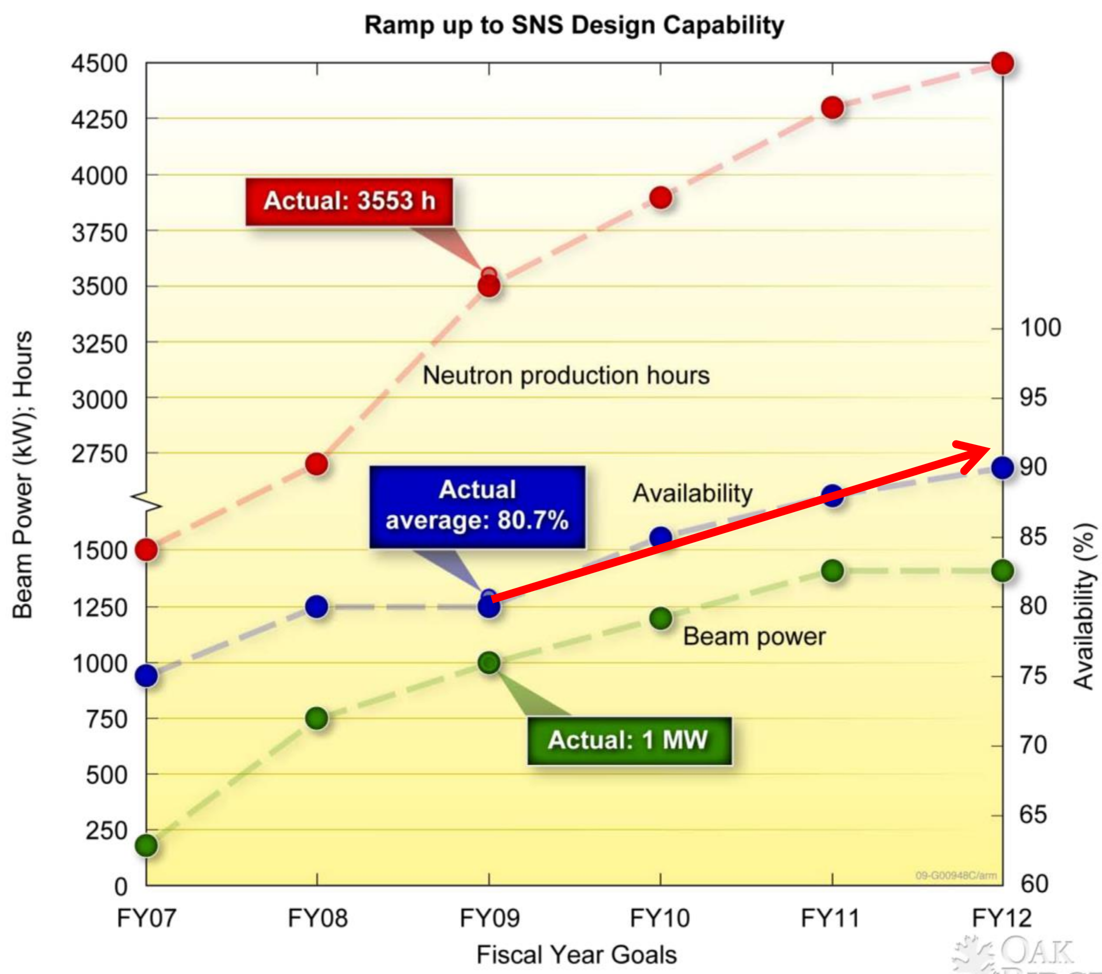
	SLC 1991~1995	KEKB Linac User run	KEKB Linac Commissioning phase
No. of Modulator	244	59	59
Modulator MTBF (hours)	707	327	177
Modulator MTTR (min.)	25.4	3	17
System MTBF (hours)	2.9	5.5	3
Availability (%)	85	99	91

Availability of klystron modulator is the most important.

SNS Operations: beam power will reach 1.2 MW by 2010 and 1.4 MW by 2011

SNS Operating Statistics (FY 2009)

- Neutron production hours: 3553
- Average availability 80.7%; availability as high as 98%
- Beam power on target: 1 MW
- Proton bunch intensity: 1.55 x 10^{14} protons per pulse



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   - Klystron
   - Availability based on MTBF and MTTR

5.Summary

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

2. Accelerator design and manufacturing
should be made by considering-----
- performance/AC power

y

1. Susta
- As cl
  -
  -
  -
- High
  -
  -
- Grid power flow control
  - Margin should be as low as possible <3%
- Development of new energy
  - Wind, solar, biomass, geothermal------
  - Tidal wave, algal-------

All efforts from electricity upper stream to down stream should be carried out.

r
directly