Present and Future of Fusion Energy Development

National Fusion Research Institute
M. KWON

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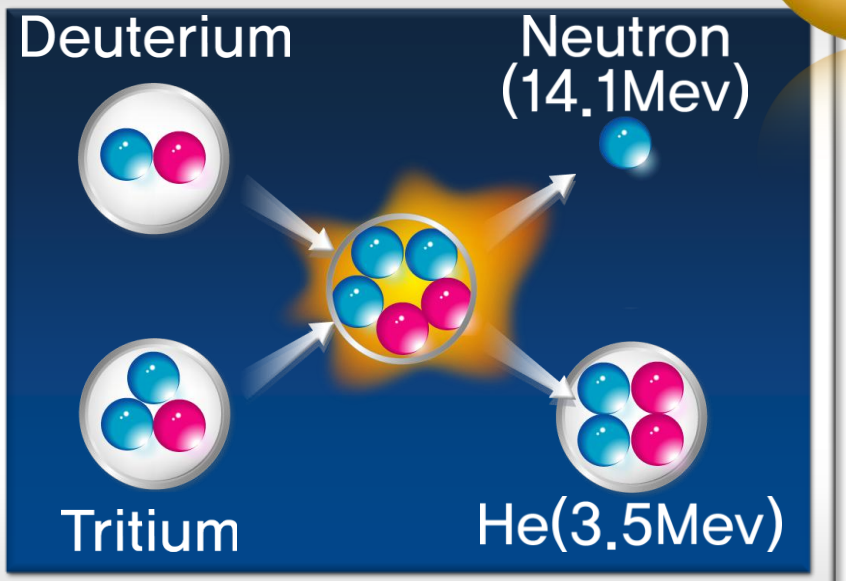
- Scientific Understandings on Fusion Energy
- Construction and Operation of KSTAR
- International Thermonuclear Experimental Reactor project
- Present of Major Countries
- Opinion on Fusion Energy
- Energy Policies and Fusion Energy

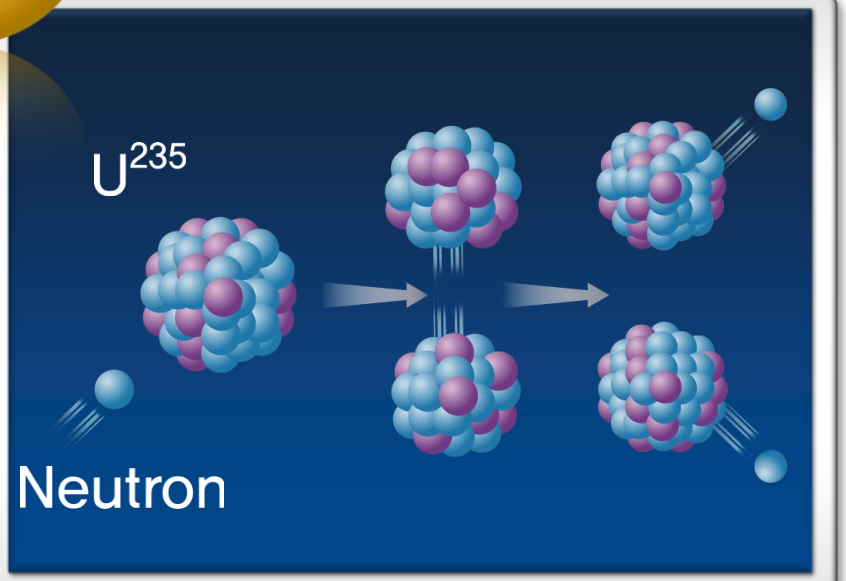
Scientific Understanding on Fusion Energy

Fusion
Future Vision of Green Energy

$\mathcal{E}=mc^2$



Principle for generation of fusion energy

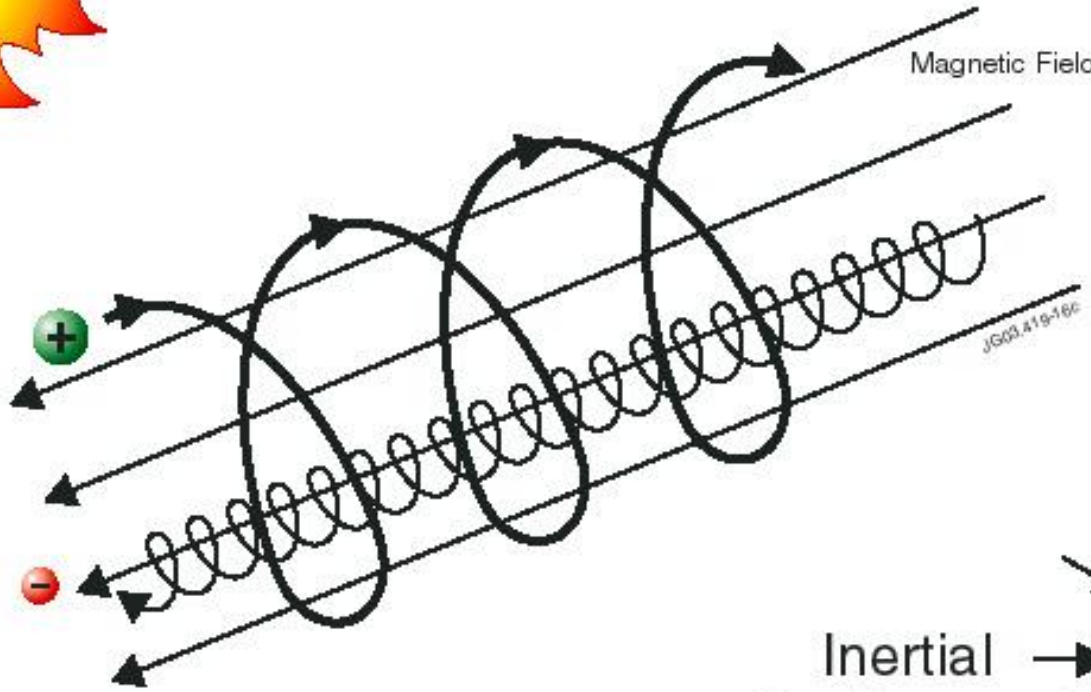


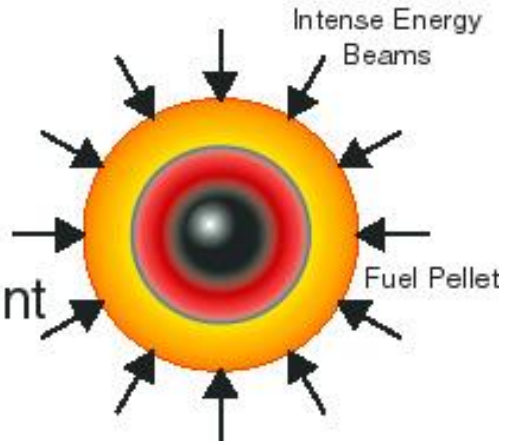
Principle for generation of nuclear energy

Confinement of Fusion

Gravitational Confinement

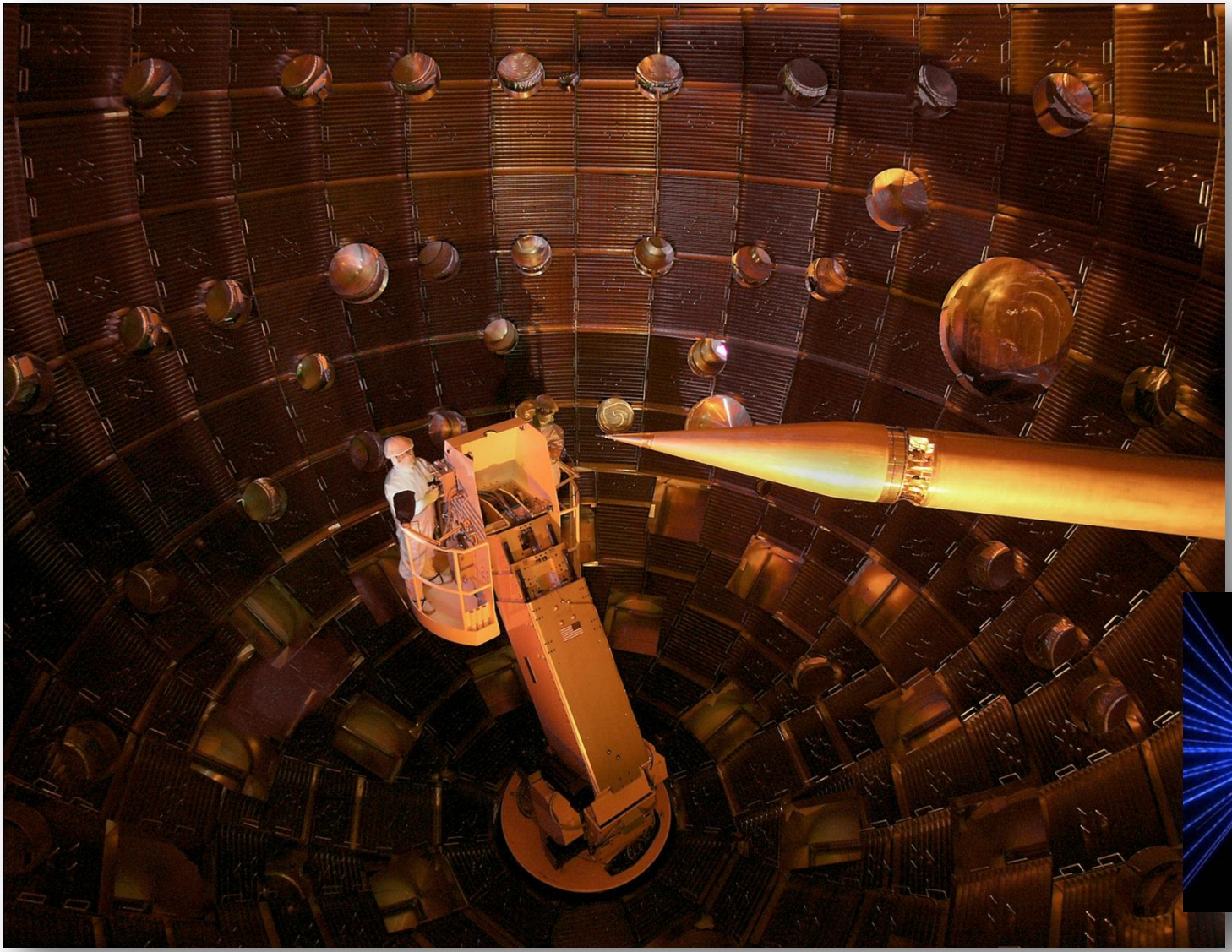
Magnetic Confinement





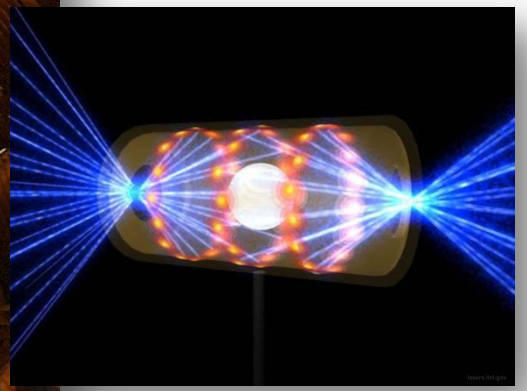
Inertial Confinement

Inertial confinement - Laser



< National Ignition Facility, Lawrence Livermore National Lab.>

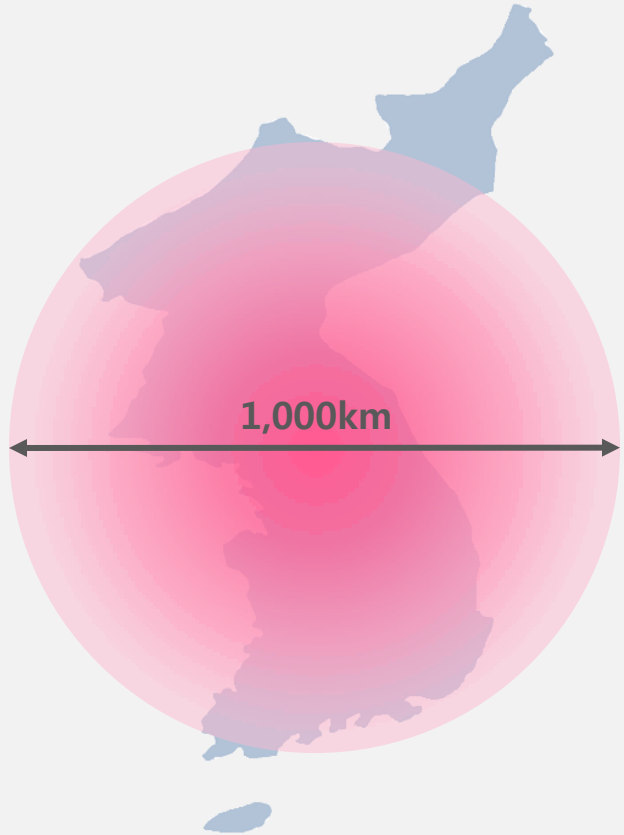
NIF Hohlraum



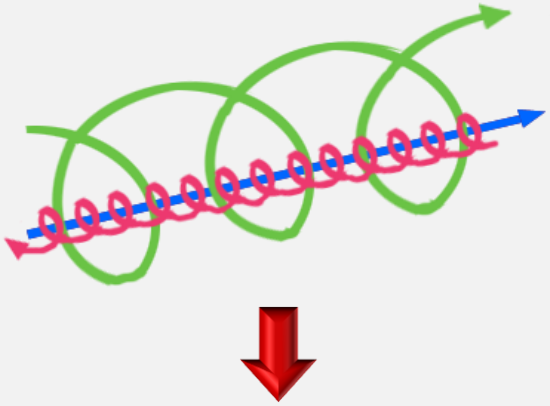
Magnetic confinement

✓ How to confine plasma of 100,000,000℃ during 1 second?

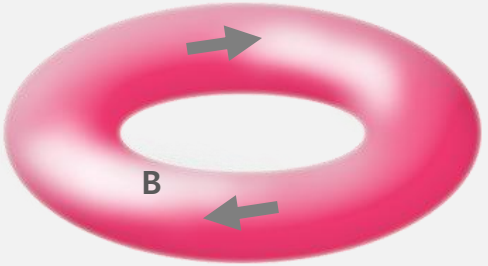
It needs container with 1,000km diameter.



Confine by magnetic fields

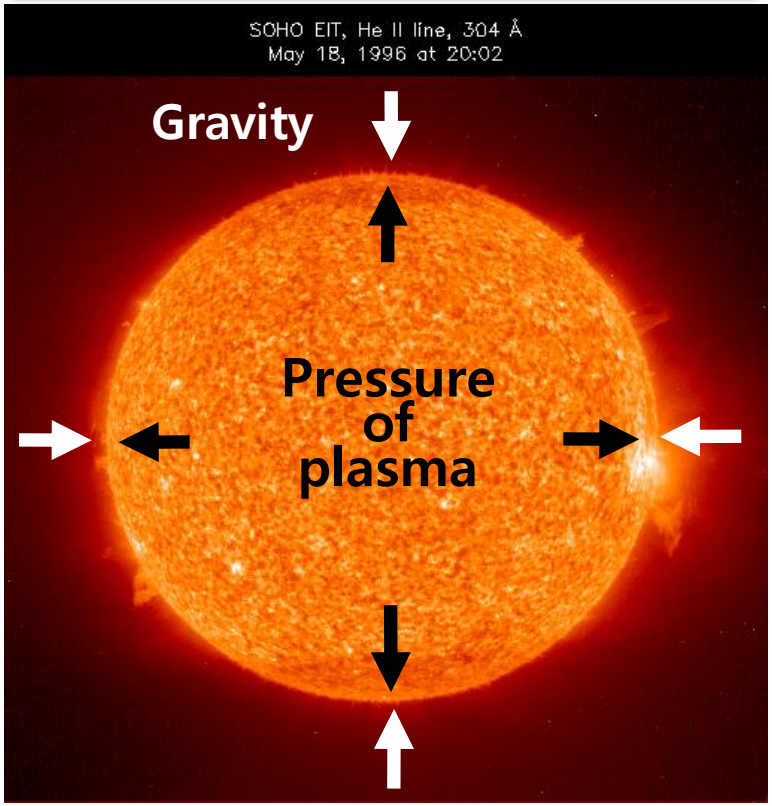


▪ Torus shape

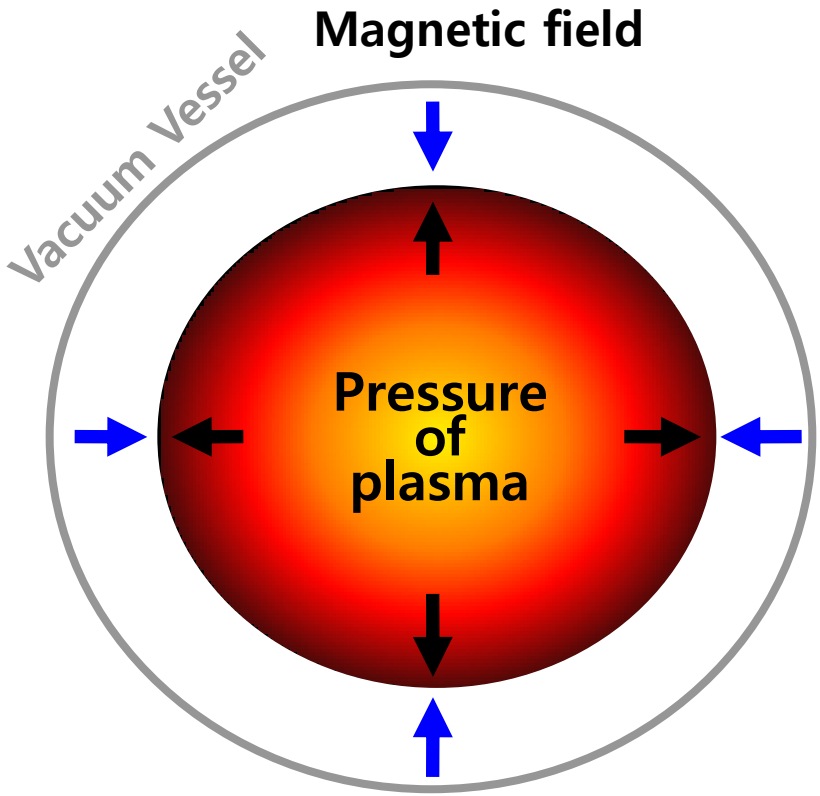


Principles of magnetic confinement

Reproduce Sun on Earth



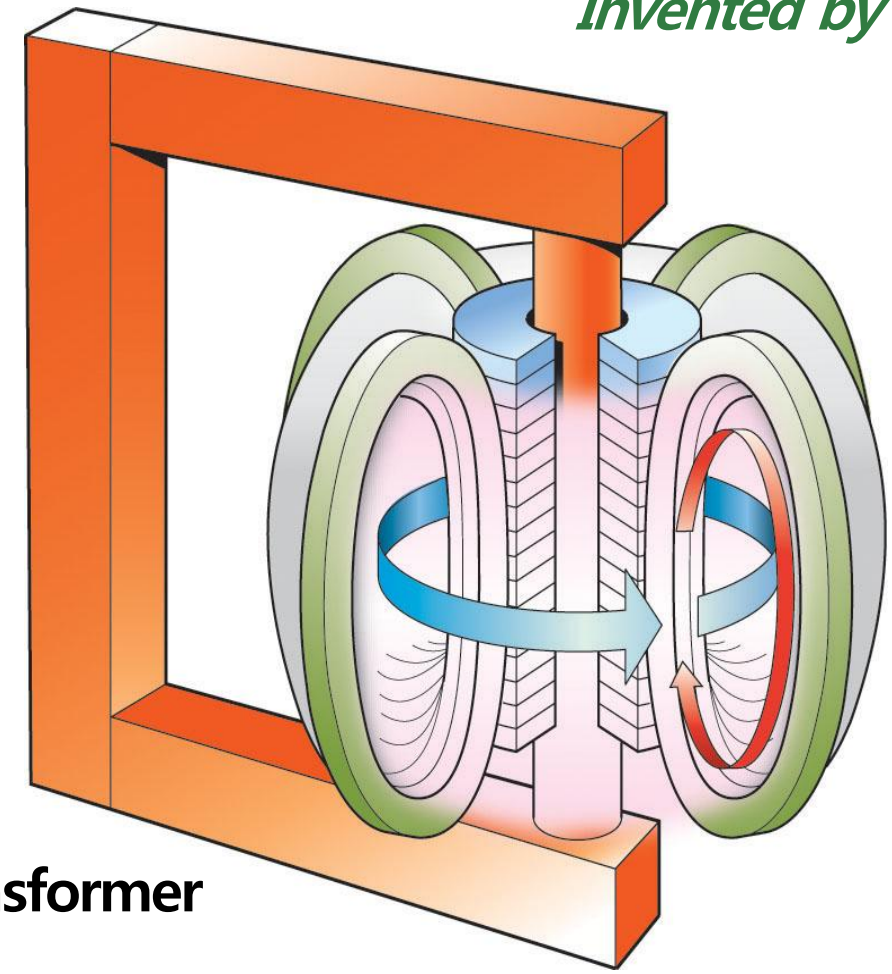
Steady state of Sun



Steady state on Earth

TOKAMAK

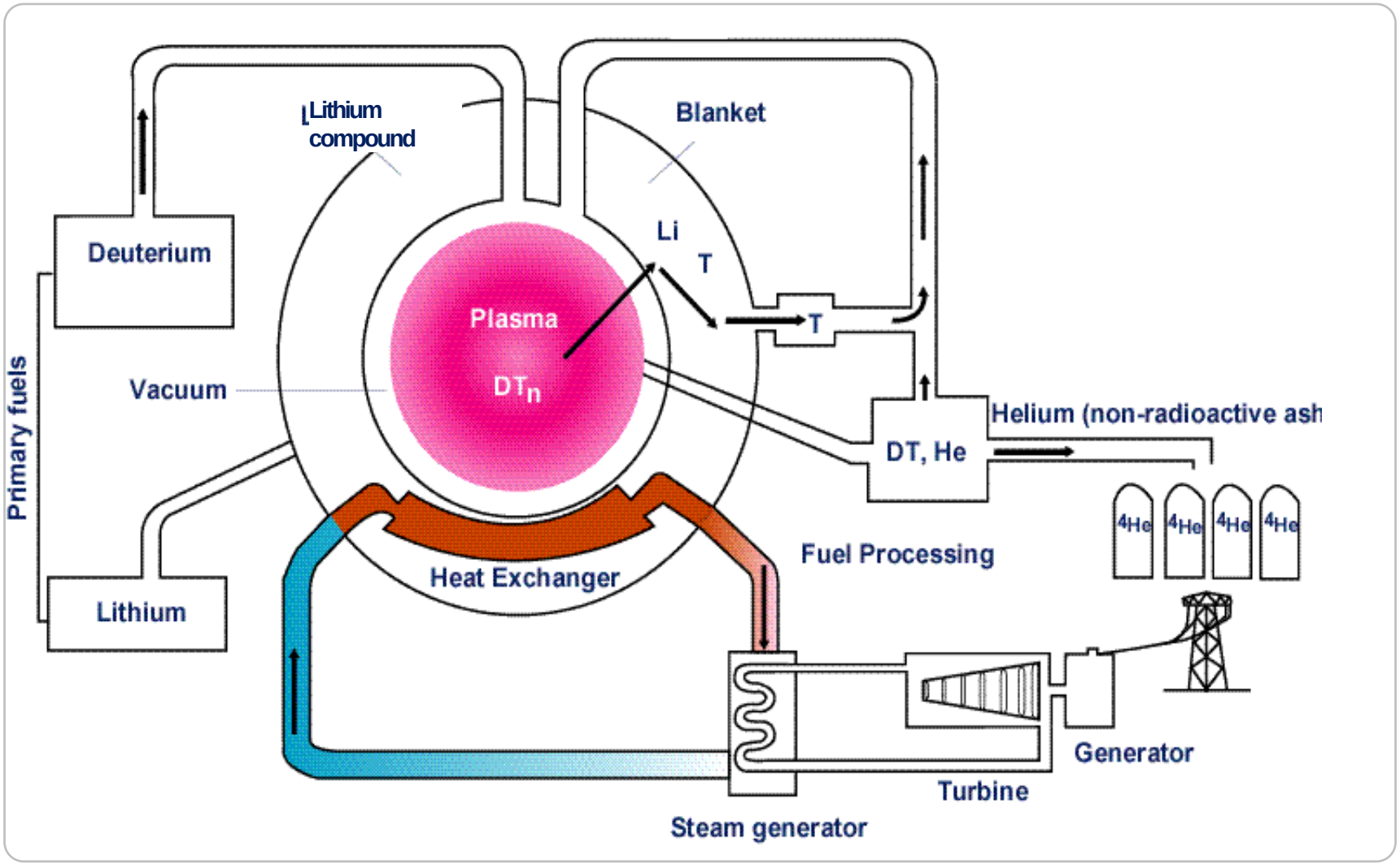
Invented by Tamm and Sakharov in 1952



Transformer

Toroidalnaja kamera magnitnaja katushka
(Toroidal chamber magnetic coil)

Block Diagram of a Fusion Power Plant



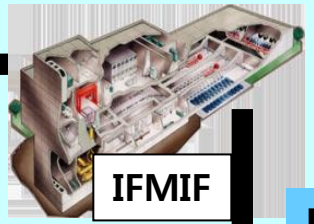
source : Sir Chris Llewellyn Smith ,2006

Roadmap to Fusion Energy

* IFMIF: International Fusion Materials Irradiation Facility

Structure Materials

Breeding Blanket



IFMIF

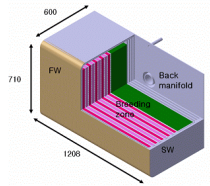
Heavy Irradiation

Fusion Engineering Research

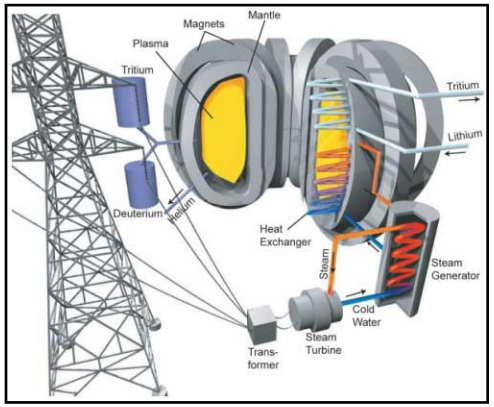
Component Technology

Blanket Technology

TBM (Test Blanket Modules)

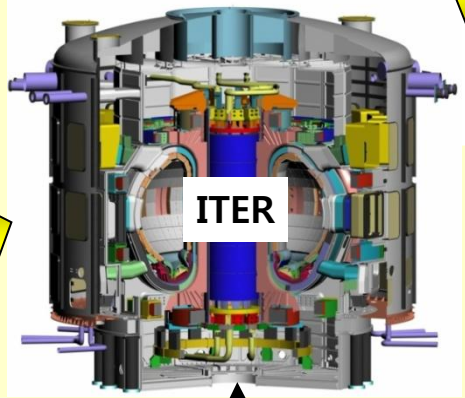


Fusion Materials



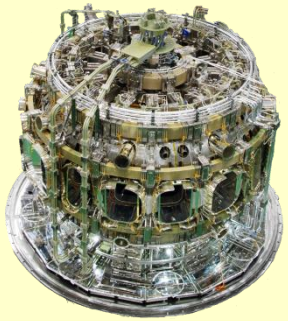
K-DEMO Reactor

Fusion Plasma Research



ITER

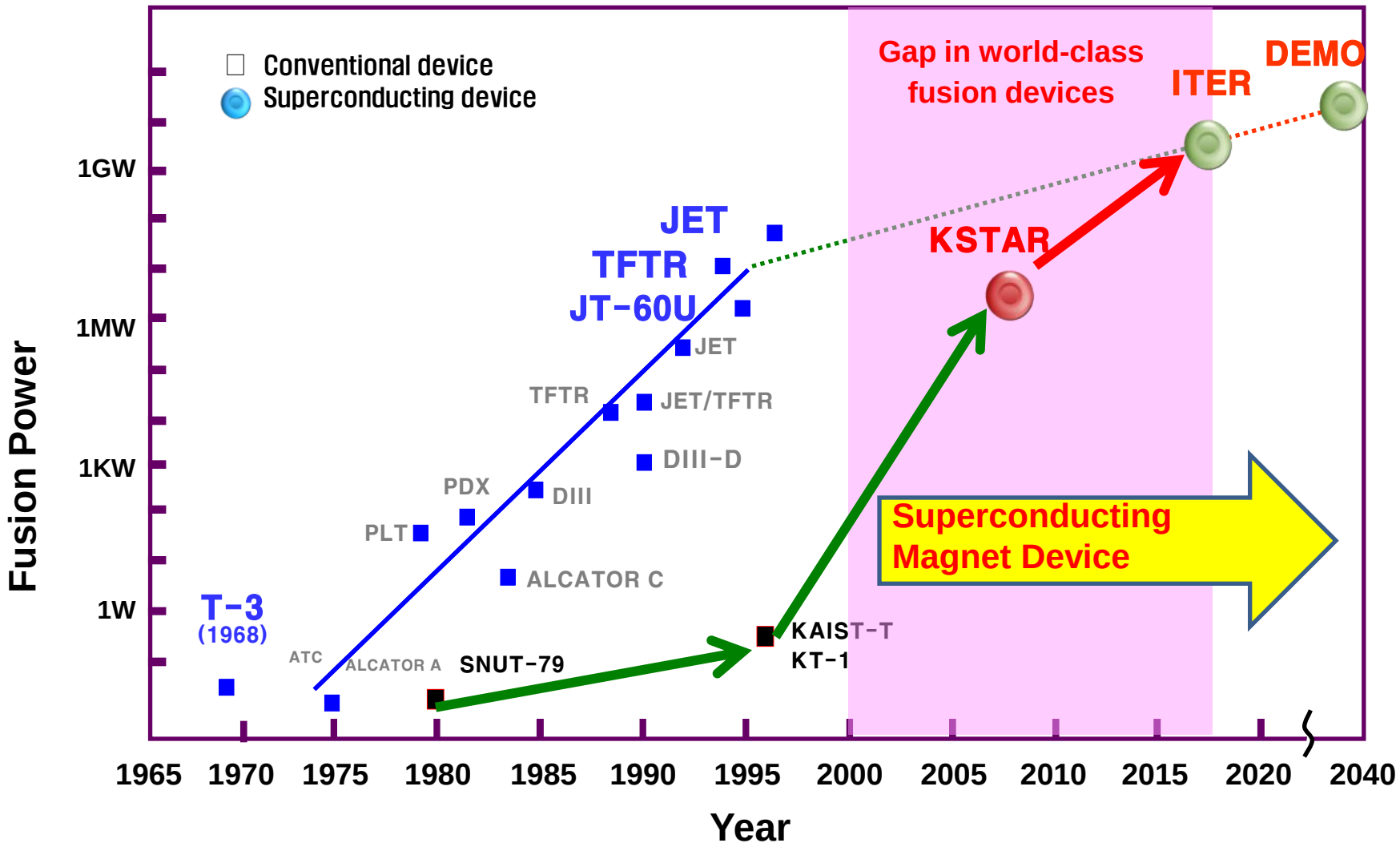
KSTAR



Integrated System Design and Engineering

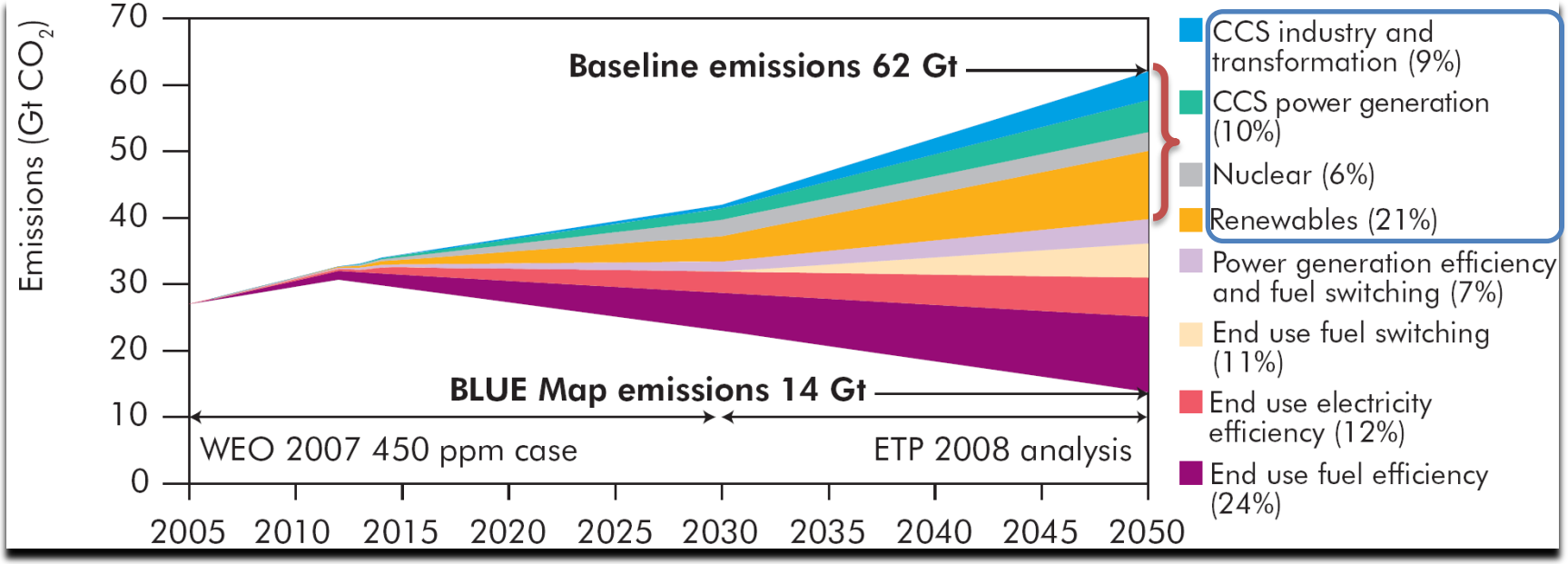
ITER & DEMO Physics Support Activities

Mid-Entry strategies and construction of KSTAR



IEA's Outlook toward 2050

- IEA "Energy Technology Perspectives 2008" said that the renewable and the nuclear would be the main drivers.



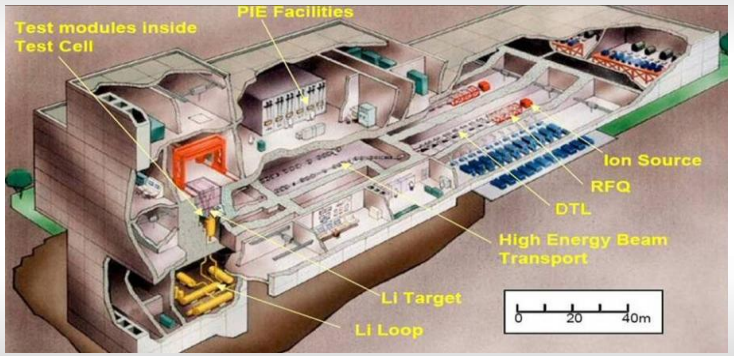
- IEA reports positively about the potential of fusion energy as well as the renewables.

> *A number of CO_2-free energy sources have huge potential. Solar, geothermal and nuclear fusion deserve special RD&D attention for the longer term, given their large resource potential and applicability in many parts of the world.*

Engineering challenges for fusion energy

Materials for extreme environments

Reliable materials under extreme environments for fusion



Ultra high temperature (100 million℃);

Ultra low temperature (-269℃);

and high vacuum (1×10^{-8} mbar)

Long-term Confinement of high-performance plasma

Commercial feasibility ensured by enhancing energy amplification rate

Energy amplification rate (Q): 10 for ITER; 30~50 or higher for commercial reactor

Construction and Operation of KSTAR

Construction of KSTAR

June 2008
First Plasma

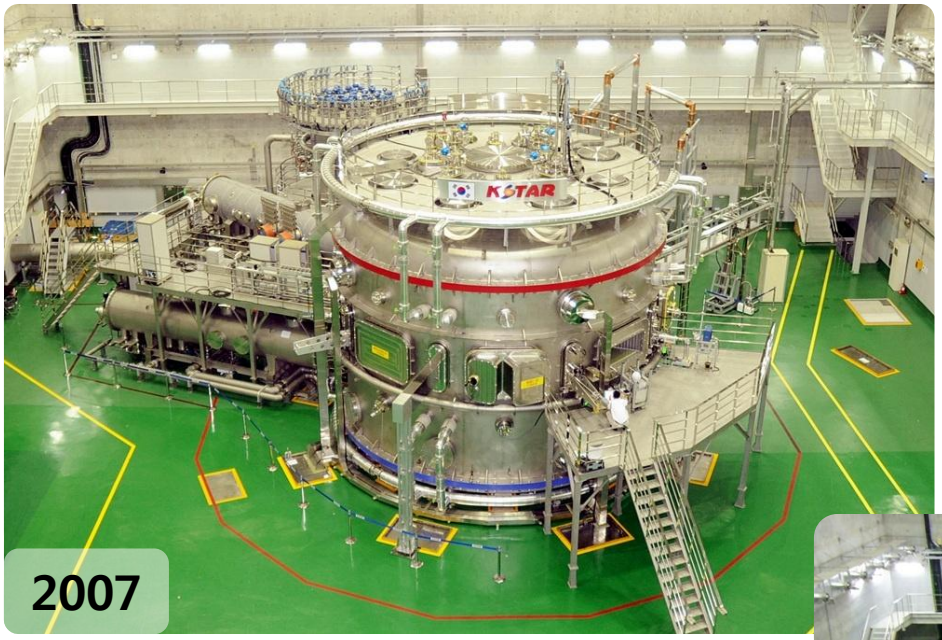
2002 ~ 2007
Construction of K-STAR

1998 ~ 2001
Engineering Design
and Facility Construction

1996 ~ 1997
Basic Design and R&D

1995
Launch of K-STAR Project

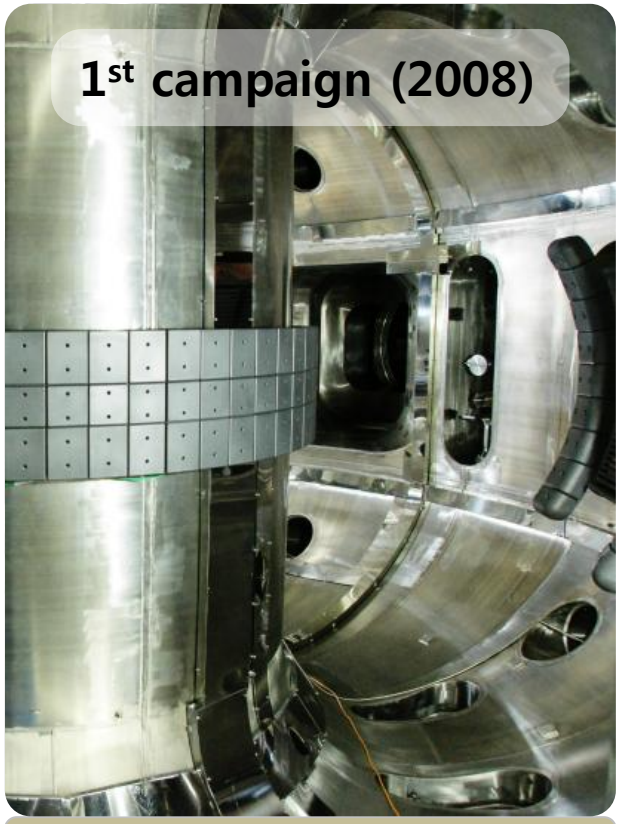
Panoramic view of KSTAR



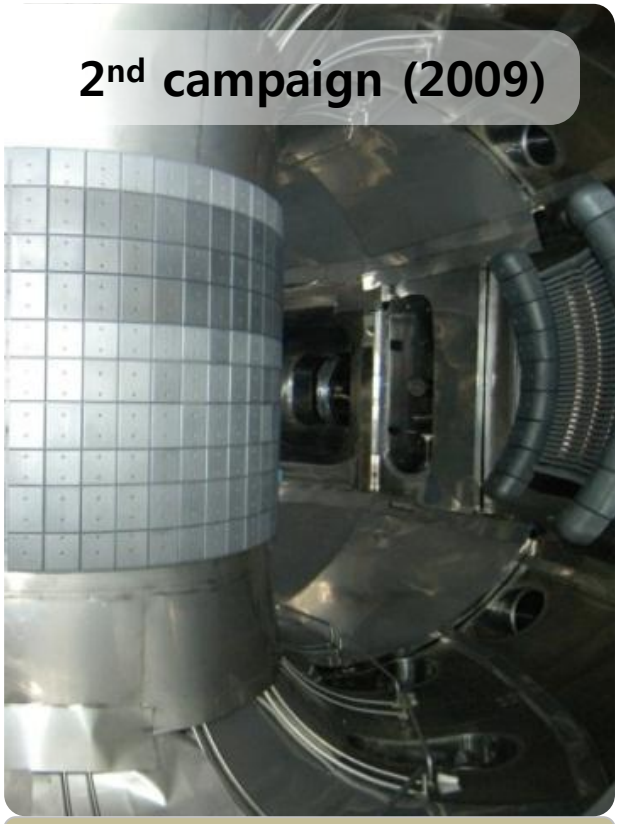
2007

2010

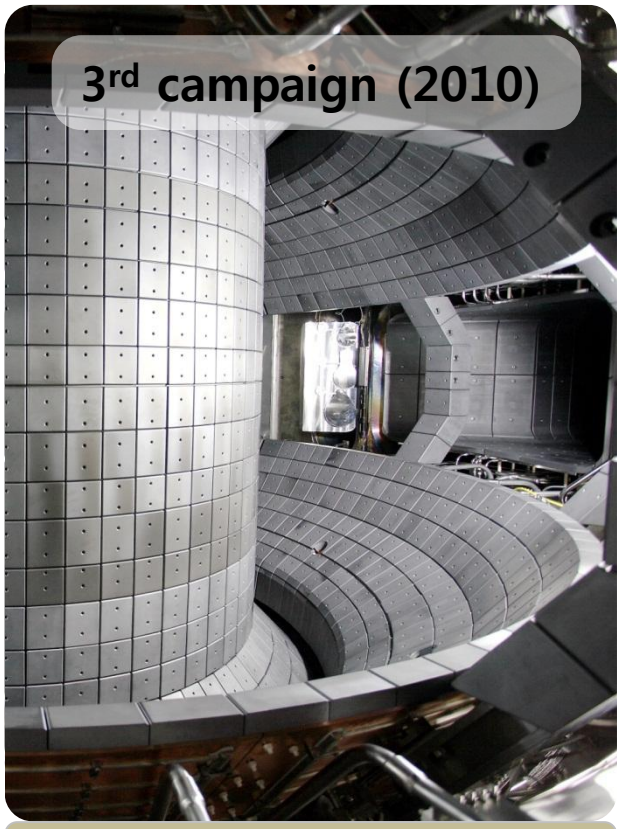
Development of Plasma Facing Component



PFC coverage : 1.54 m^2



PFC coverage : 11.08 m^2



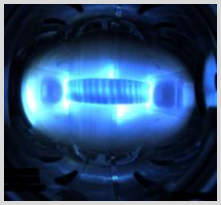
PFC coverage : 52.94 m^2

Long-Term Plan

KSTAR will be operated as an international collaboratory to exploit the key scientific and technological issues for the ITER and attractive fusion reactor.

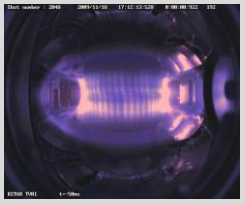
Operation Phase I 2008 ~ 2012	Operation Phase II 2013 ~ 2017	Operation Phase III 2018 ~ 2022	Phase IV 2023 ~
SC Tokamak operation	**Long-pulse operation**	**High performance operation**	**DEMO test bed**
• **Superconducting tokamak operation** • First plasma & inductive current ramp (2 MA) • Plasma shaping & heating (DN & SN, H-mode)	• **Steady-state operation & ITER pilot device roles (300 s+)** • Plasma heating & non-inductive current drive • Instability control in H-mode and AT-mode	• **Advanced scenario for DEMO beyond ITER** • High-beta and high bootstrap current scenario • Extreme operation of the superconducting tokamak	• **DEMO Engineering** • DEMO simulator • Reactor material test

First Plasma ('08)



133kA
0.25sec
1.5Tesla

Second Campaign ('09)



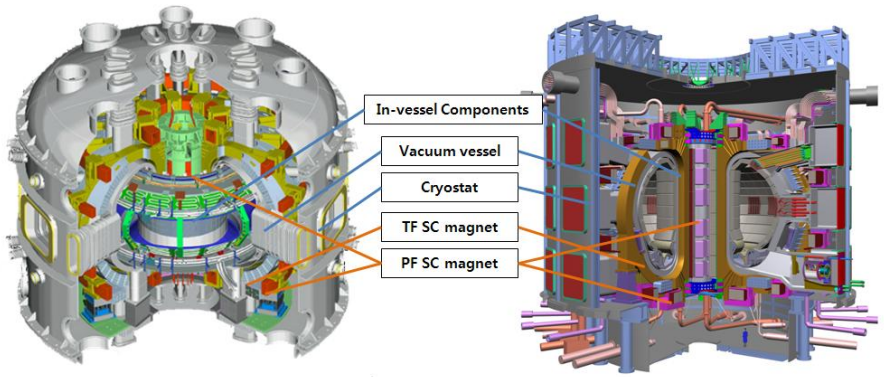
320kA
3.6sec
3.0Tesla

- ▶ Divertor plasma ('10)
- ▶ H-mode operation ('11)
- ▶ Fast stabilization ('12)

Mission and Achievements

KSTAR Mission

- ▶To achieve the superconducting tokamak construction and operation experiences, and
- ▶To develop high performance steady-state operation physics and technologies that are essential for ITER and fusion reactor development



KSTAR Parameters

PARAMETERS	Designed	Achieved
Major radius, R_0	1.8 m	1.8 m
Minor radius, a	0.5 m	0.5 m
Elongation, κ	2.0	2.0
Triangularity, δ	0.8	0.8
Plasma volume	17.8 m^3	17.8 m^3
Bootstrap Current, f_{bs}	> 0.7	-
PFC Materials	C, CFC (W)	C
Plasma shape	DN, SN	DN
Plasma current, I_P	2.0 MA	0.5 MA
Toroidal field, B_0	3.5 T	3.6 T
Pulse length	300 s	7 s
β_N	5.0	> 1.0
Plasma fuel	H, D	H, D, He
Superconductor	Nb_3Sn, NbTi	Nb_3Sn, NbTi
Auxiliary heating /CD	~ 28 MW	2.0 MW
Cryogenic	9 kW @4.5K	5 kW @4.5 K

•Black : achieved •Red : by 2010

Advanced Tokamak

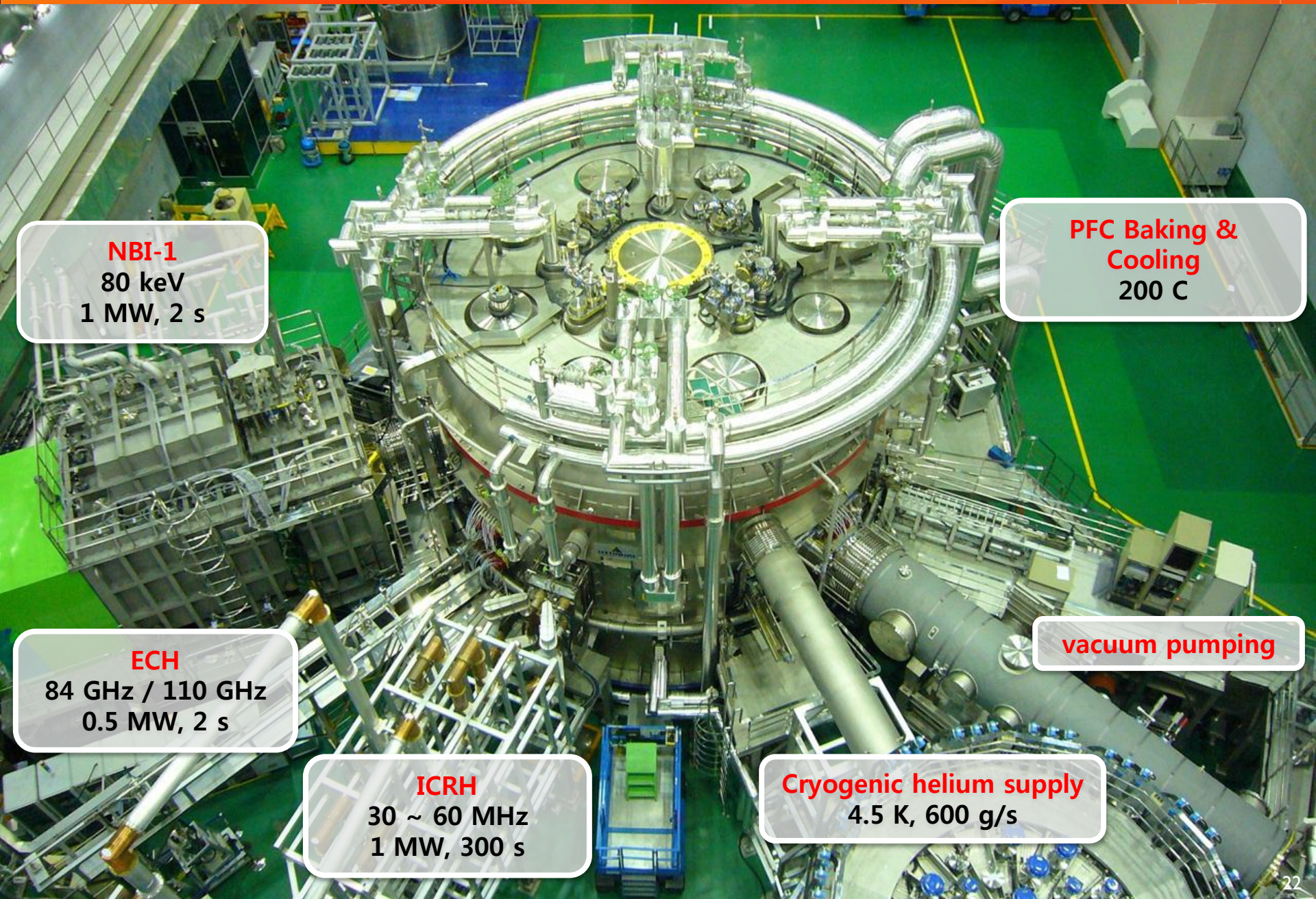
Standard

- Shaping (2010)
- H-mode (2011)
- $\beta_N < 3$ (2012)
- Current profile control (2012)
- Wall stabilization (2012)
- Transport barrier (2012)

Advanced

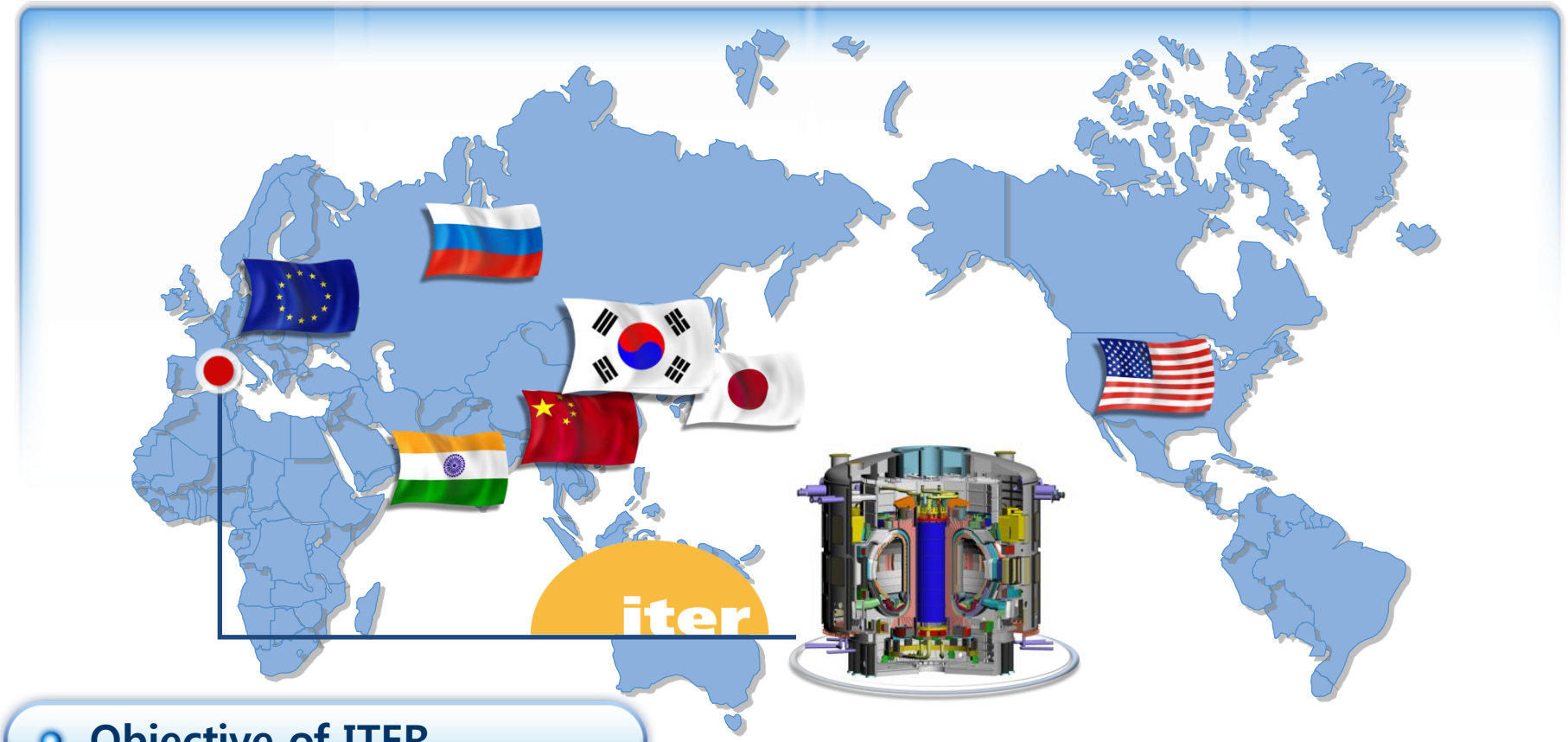
- High β, f_{bs}
- Long-pulse op.

KSTAR Device for 2010 Campaign



ITER project

Introduction of ITER project

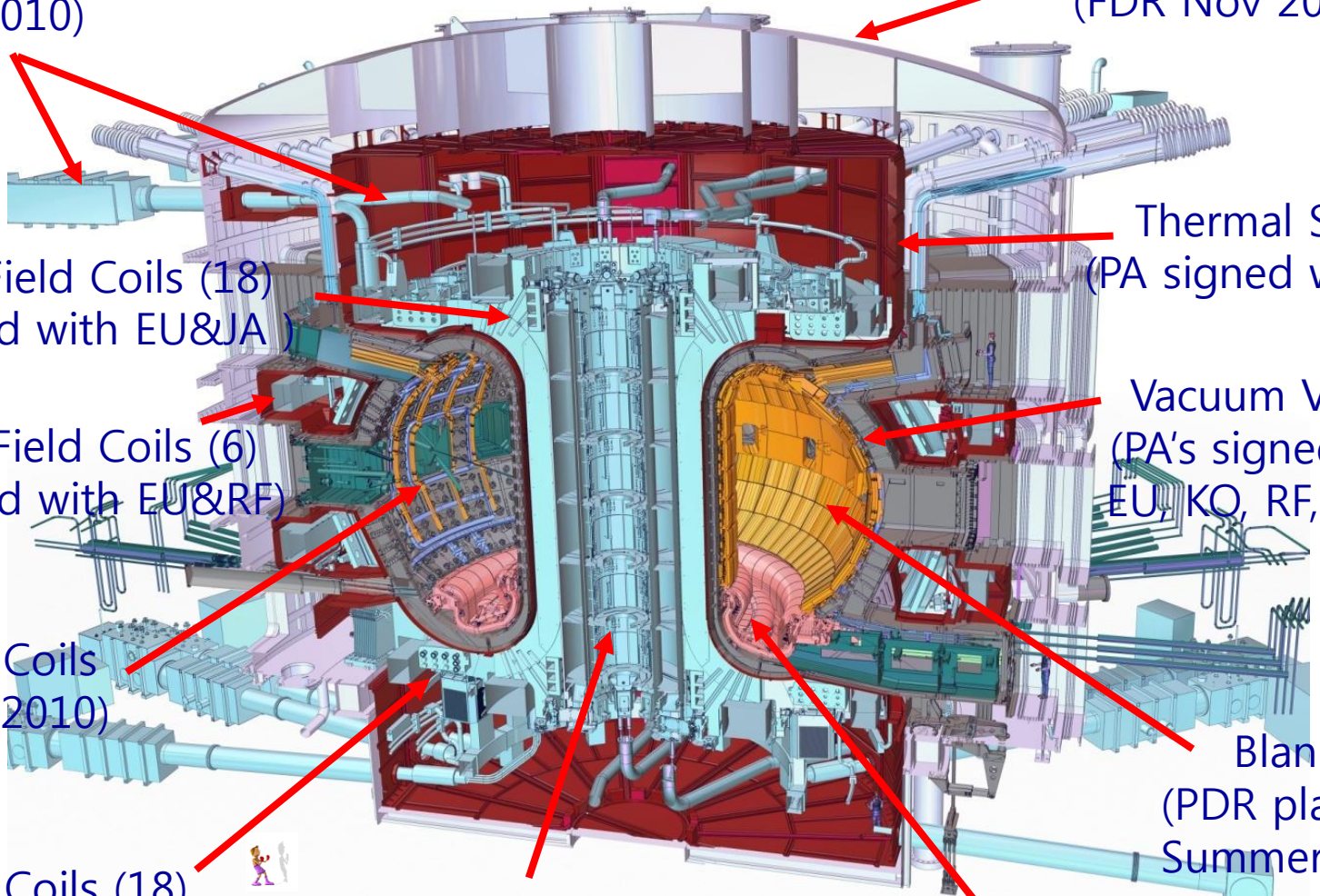


Objective of ITER

- The final scientific and technological feasibility of fusion power through the construction and operation of the ITER device which produces 500 MW of fusion power in condition where D-T would provide Q≥10

  ※ ITER : International Thermonuclear Experimental Reactor (Latin :"way")

ITER tokamak and status of each components



Feeders (31)
(FDR Oct 2010)

Cryostat
(FDR Nov 2010)

Thermal Shield
(PA signed with KO)

Toroidal Field Coils (18)
(PA's signed with EU&JA)

Vacuum Vessel
(PA's signed with
EU, KO, RF, & IN)

Poloidal Field Coils (6)
(PA's signed with EU&RF)

In-vessel Coils
(PDR Oct 2010)

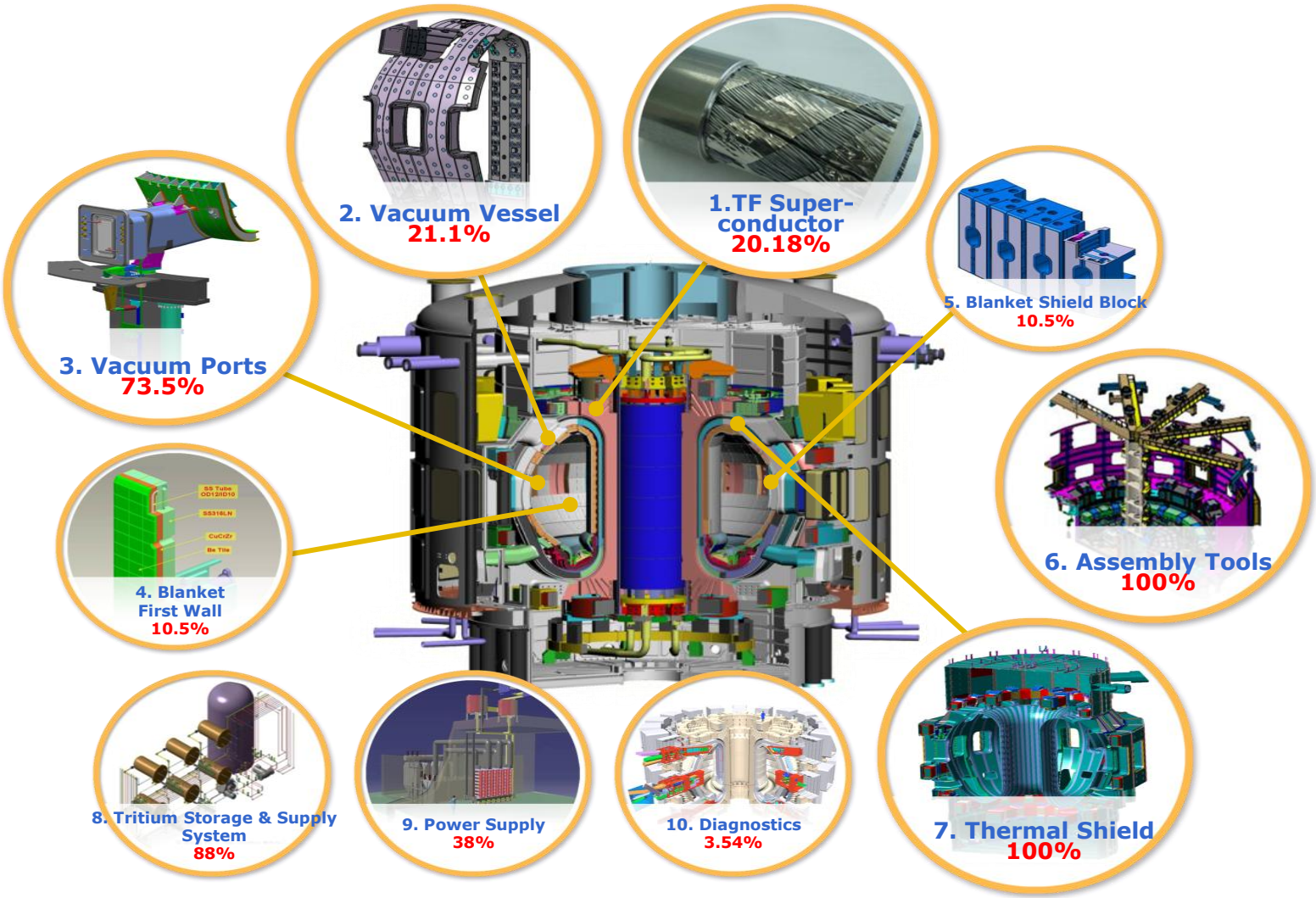
Blanket
(PDR planned-
Summer 2011)

Correction Coils (18)
(PA signed with CN)

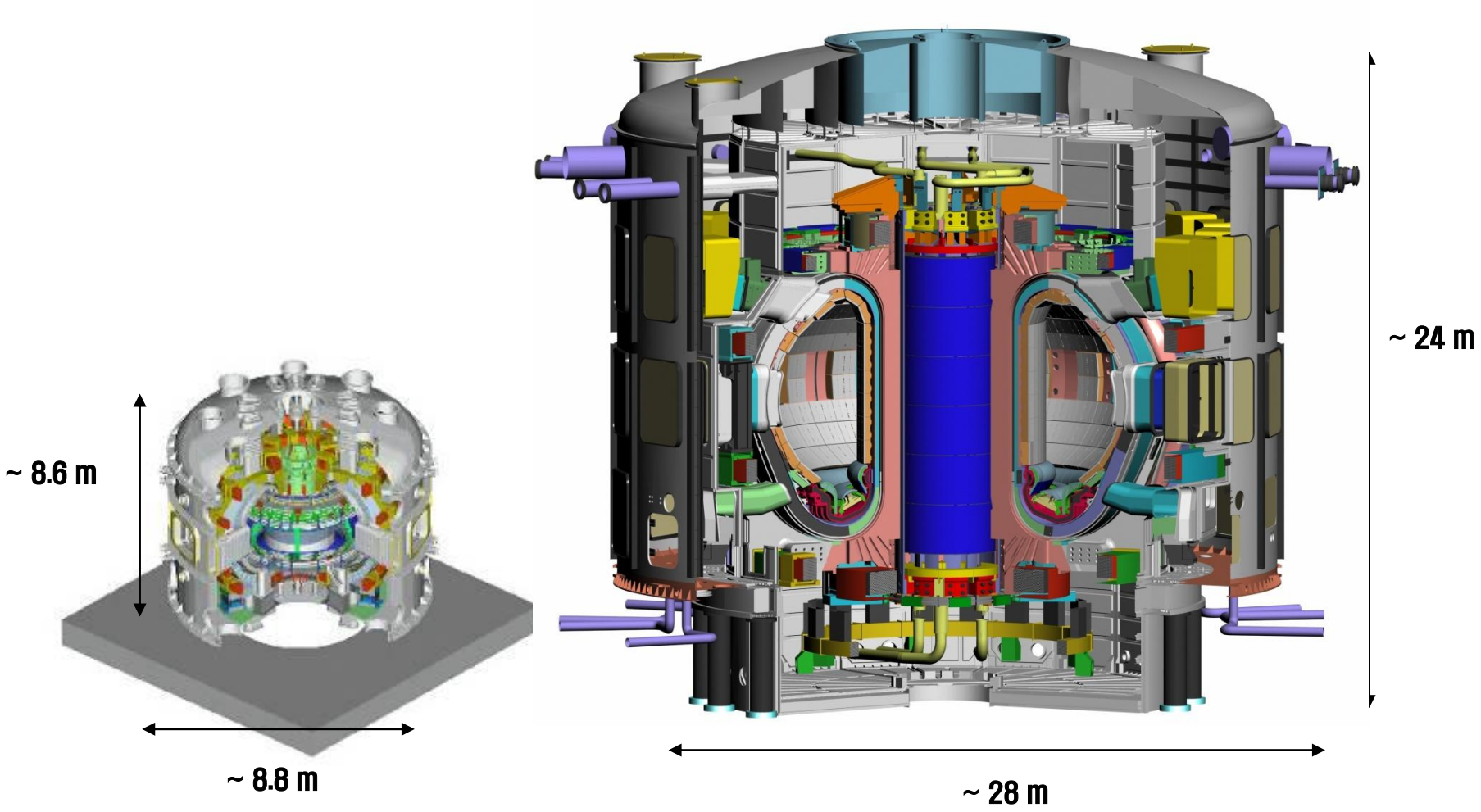
Central Solenoid (6)
(PA signed with US)

Divertor
(PA's signed with EU,
RF, and JA)

10 procurement items of the ITER Korea



Schematic view of KSTAR and ITER



Digging start!

iter

the way to new energy

china eu india japan korea russia usa

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30 Aug - 03 Sep, '10
Varenna-Lausanne Theory of Fusion Plasmas Meeting
Varenna, Italy

12 Sep - 16 Sep, '10
World energy Congress (WEC)
Montreal, Canada

27 Sep - 01 Oct, '10
26th Symposium on Fusion Technology (SOFT2010)
Porto, Portugal

03 Oct - 09 Oct, '10
http://www.superstrong2010.com/
Villa Monastero, Varenna, Italy

10 Oct - 16 Oct, '10
The 23rd IAEA Fusion Energy

iter newsline

03 Aug, 2010 - #143

view printable version

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On Site

Action!

-Robert Arnoux

The first days of August in southern France are usually very quiet. This is the heart of the summer holiday season; half the shops and businesses are closed and every serious decision has to be postponed until *la rentrée*, the first weeks of September when life finally gets back to normal.

On a small, 42 hectare-wide area of southern France, however, the first week of August was marked by renewed activity.

Bulldozers, scrapers and power shovels were back on the ITER platform: under the responsibility of the European Domestic Agency F4E, work was being started in the Tokamak pit and on the 14,000 square-metre area that will host the huge PF Coils Assembly Building.

A power shovel removes the first of some 230,000 cubic metres from the Tokamak Pit.

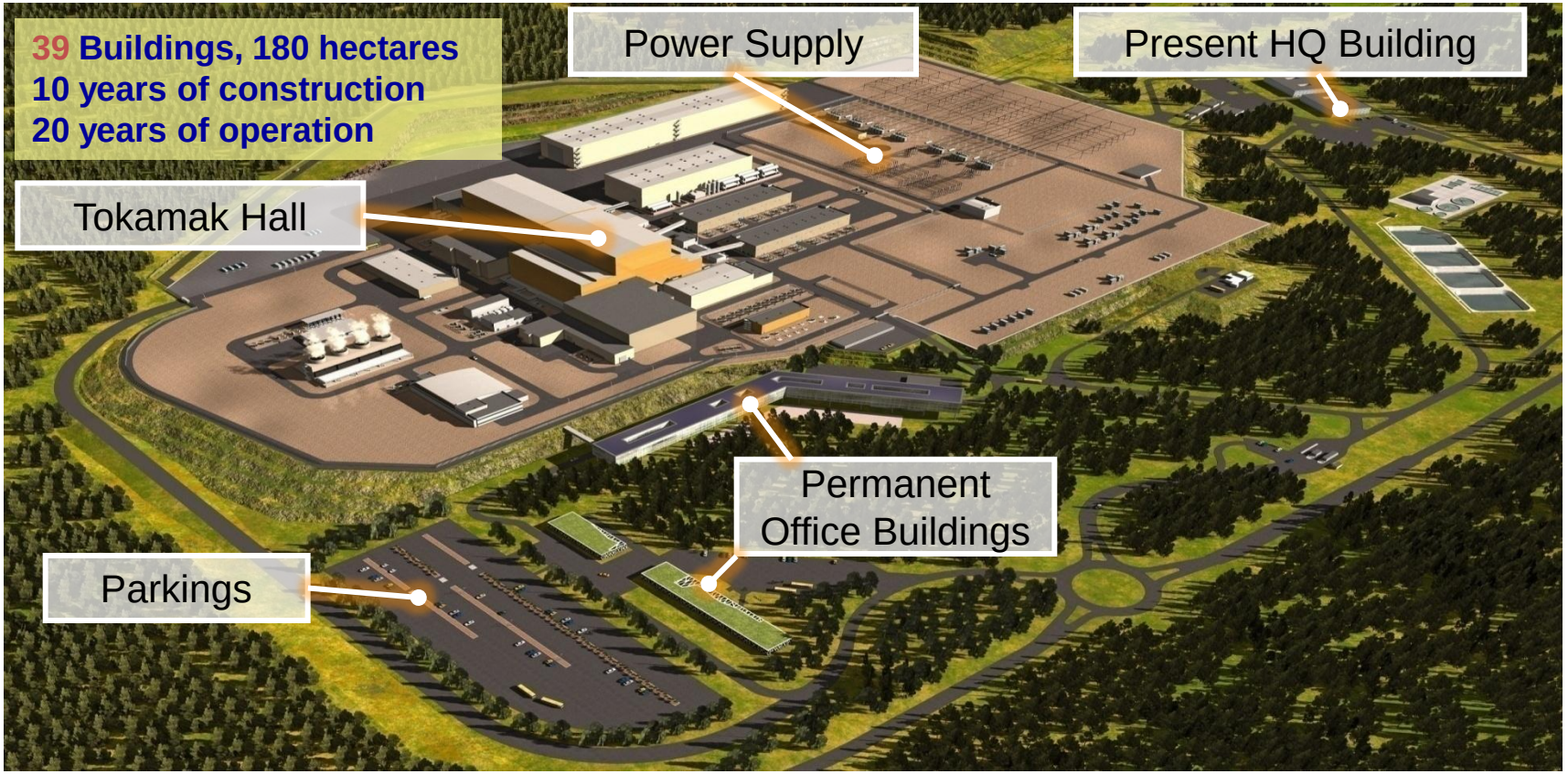
On Wednesday 4 August , after some preparatory works had been done during the previous week, a lone power shovel began removing the top soil from the Tokamak pit — the first of some 230,000 cubic metres that will have to be extracted in order to make room for the installation.

Operations and Safety on the ITER Platform are being carefully coordinated by the Engage Consortium and the French company APAVE.

In a little more than three weeks, blasting specialists will move in for two months. Explosives will be used to blast some of the rock layer at an average rate of 4,000 cubic metres per day.

Some 250 metres away, bulldozers and scrapers were busy levelling the PF Coils Assembly Building area and preparing a smooth "sub-base" on top of

ITER site in Cadarache, France



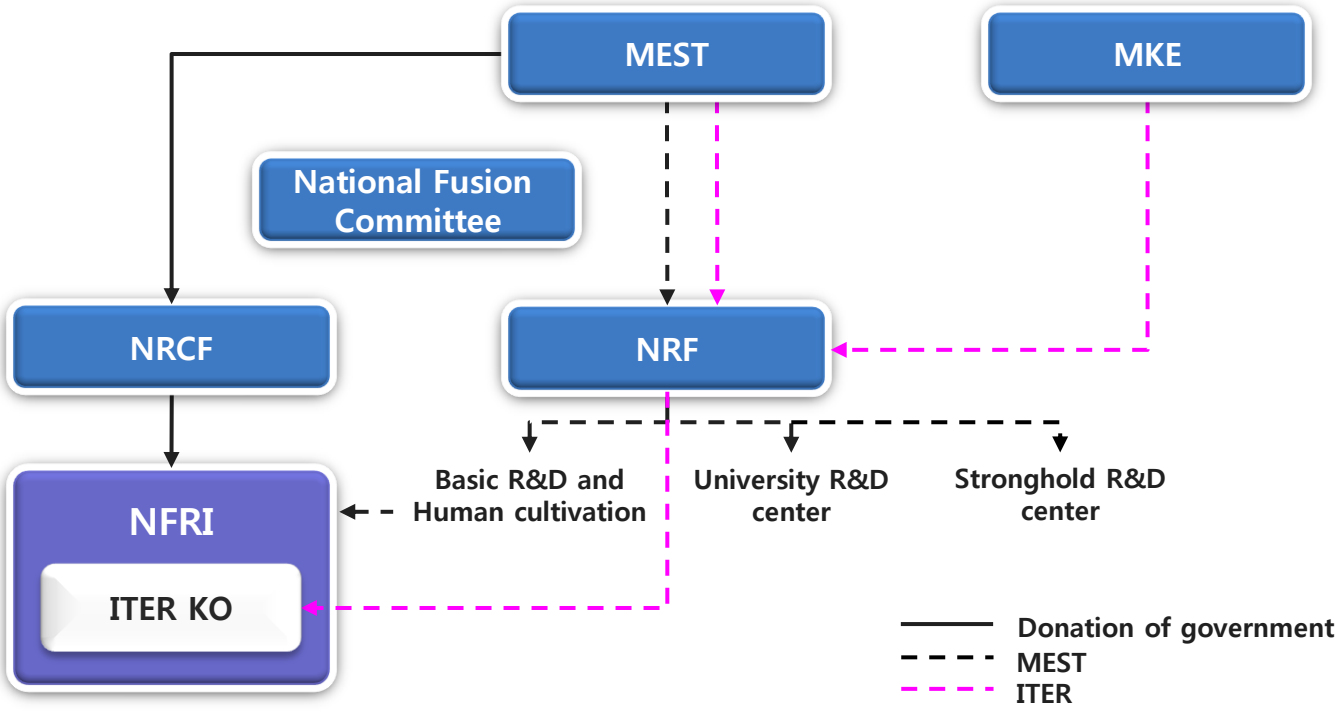
Governance of Fusion R&D in Korea

Fusion Energy Development Promotion Law(FEDPL)

- To establish a long-term and sustainable legal framework for fusion energy development phases
- To promote industries and institutes which participating the fusion energy development by supports and benefit
- The first country in the world prepared a legal foundation in fusion energy development

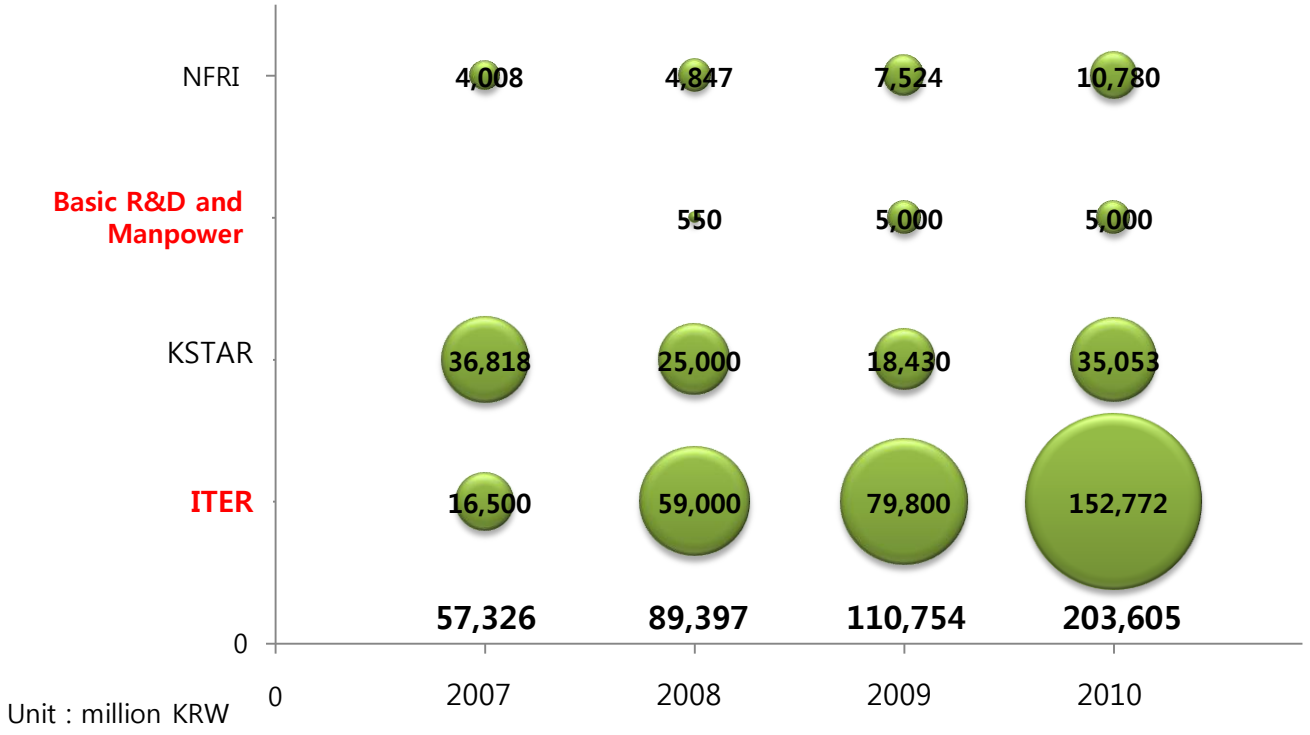
- History of the FEDPL
  - 1995. 12 : National Fusion R&D Master Plan
  - 2005. 12 : National Fusion Energy Develop. Master Plan
  - 2007. 3 : Fusion Energy Development Promotion Law
  - 2007. 4 : Ratification of ITER Implementation Agreement and entrusted to IAEA
  - 2007. 8 : Framework Plan of Fusion Energy Development

Governance Framework of Fusion R&D in Korea



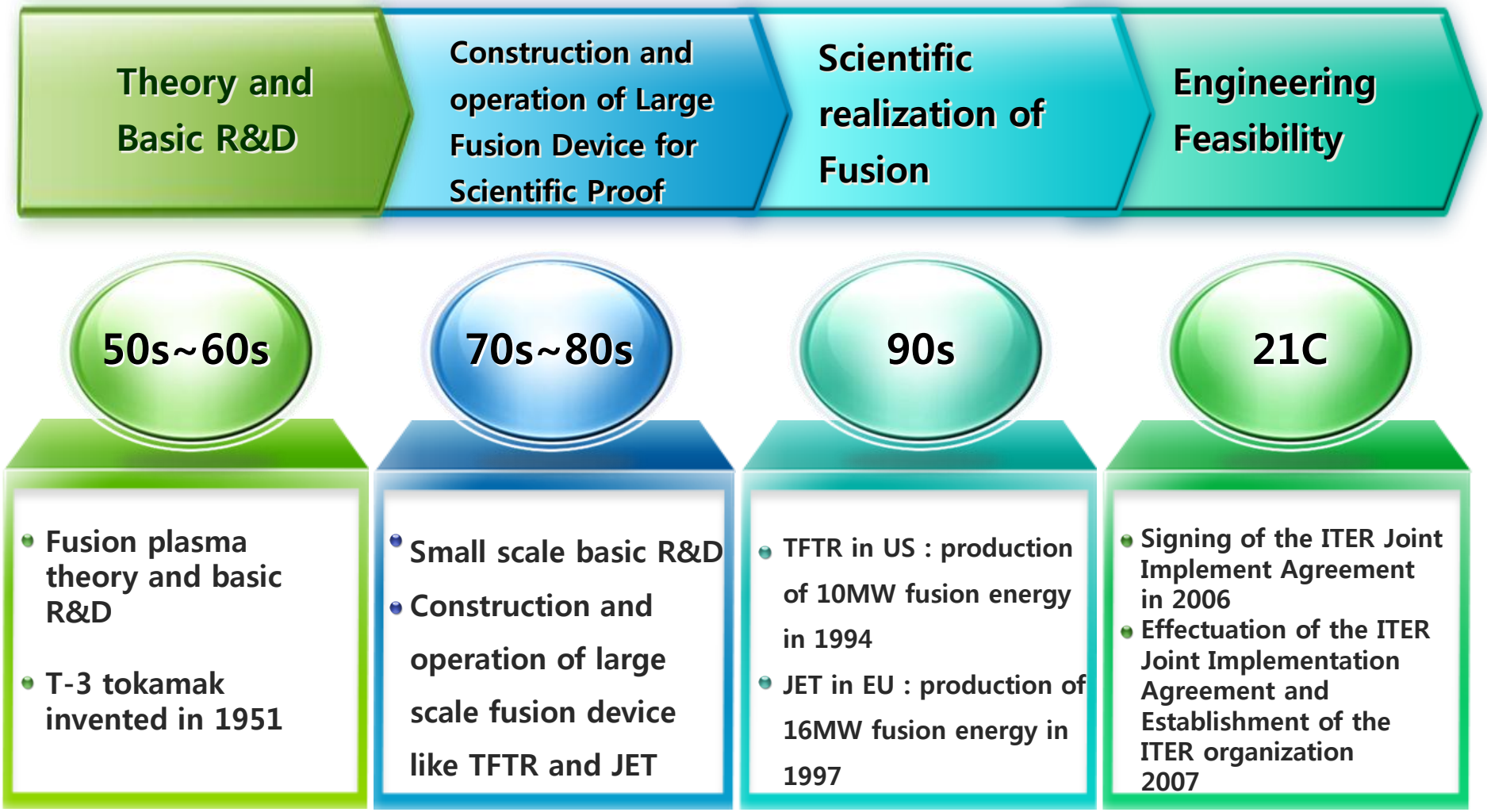
Budget of Fusion R&D

- ✓ Seventy five percent of total fusion R&D budget in Korea account for ITER project.
- ✓ In US or Japan, budget of ITER project is about 10 to 30 percent of total fusion R&D cost.

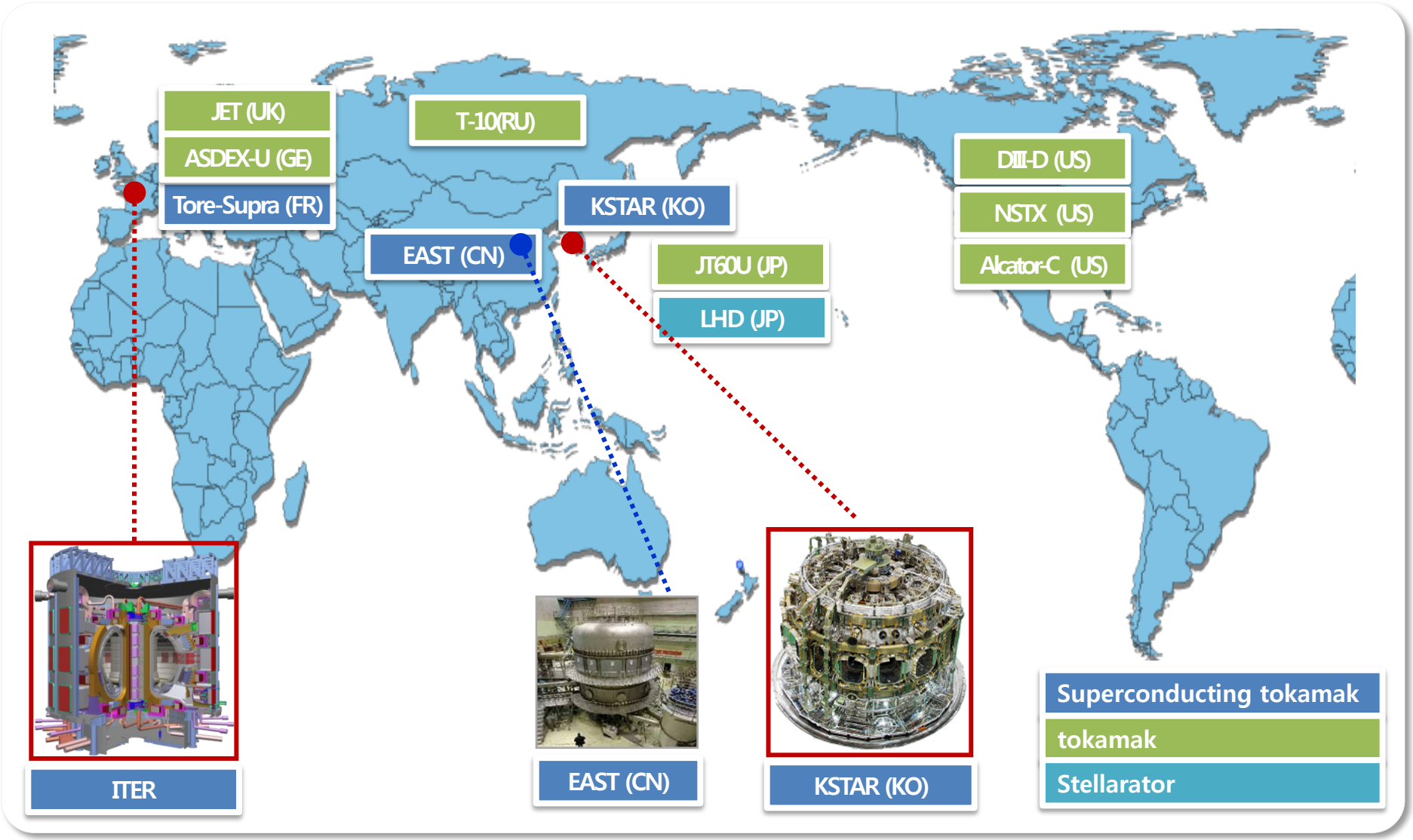


Present of Major Countries

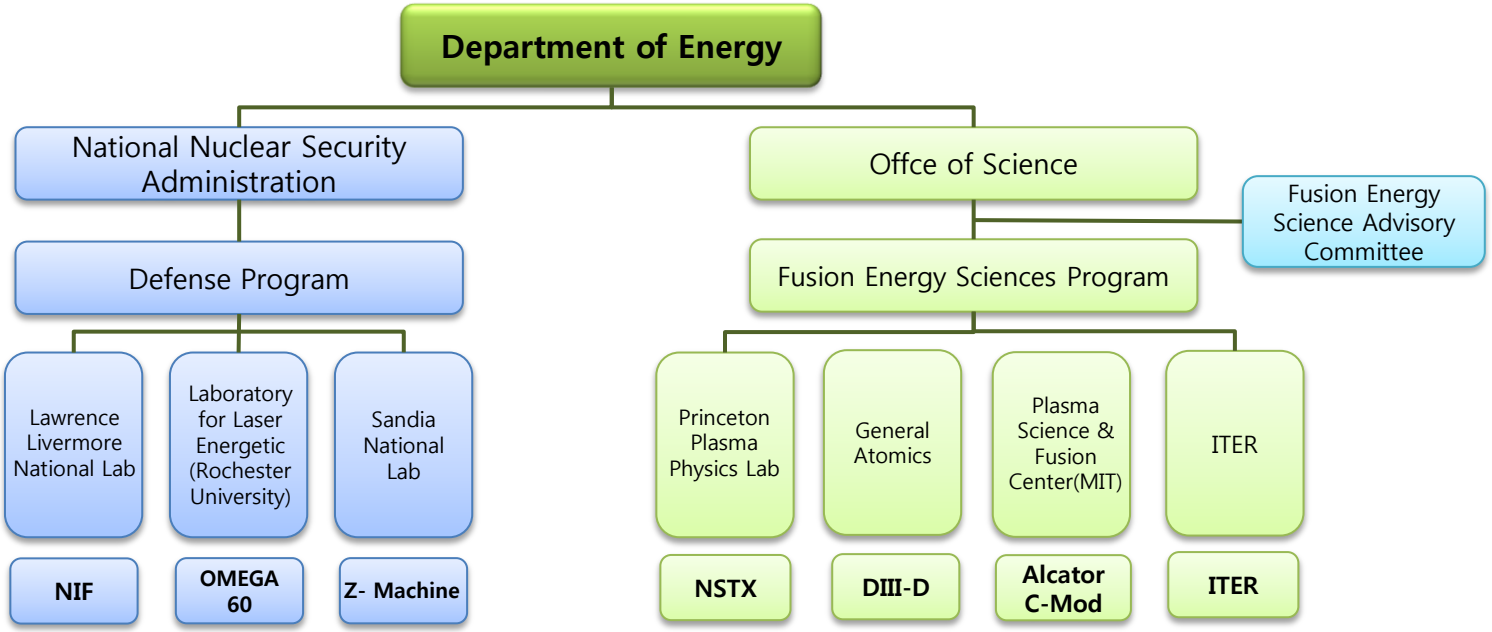
International Trends of Fusion R&D



Fusion devices of major countries



Governance framework of US



Inertial Confinement Fusion

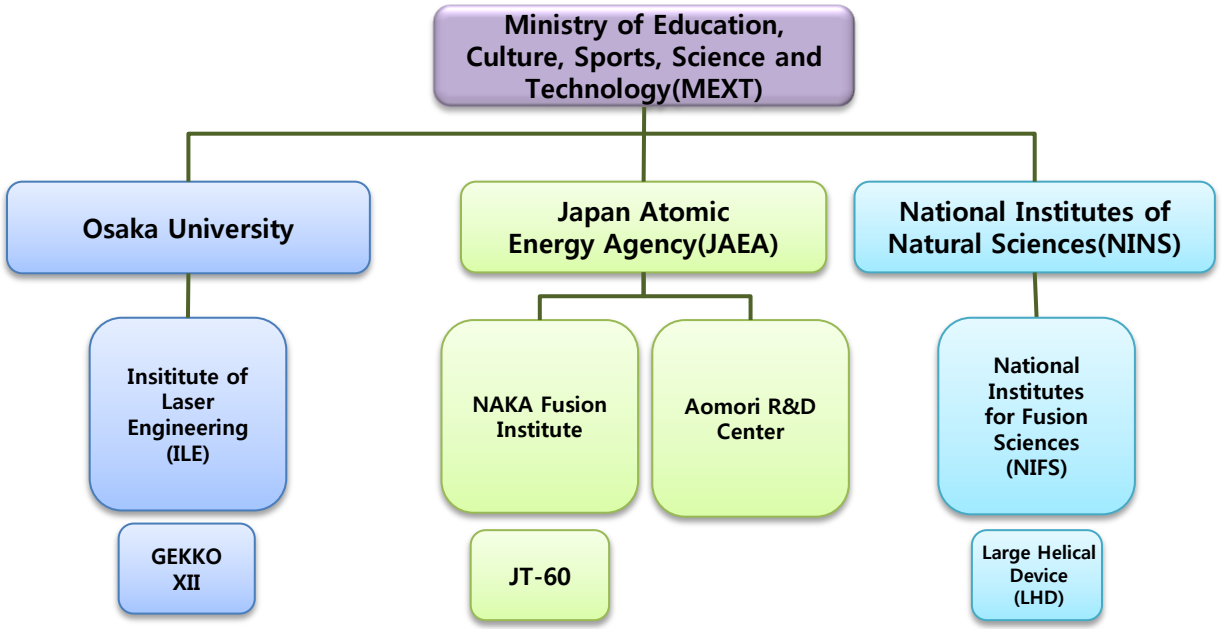
Magnetic Confinement Fusion

(unit: M USD)

YEAR	LLNL	LLE	SNL	TOTAL	PPPL	GA	PSFC	ITER	TOTAL
'07	12	-	2		69	56	22	60	207
'08	13	-	2		72	61	25	26	184
'09	14	-	3		71	62	24	124	281

	Inertial	Magnetic	계
'07	489	311	800
'08	470	294	764
'09	436	394	830

Governance framework of Japan



(unit: 100M JPY)

YEAR	ITER	Broad Approach(BA)	Large Helical Device(LHD)	TOTAL
'07	28	26	52	106
'08	102		53	155
'09	51	60	52	163

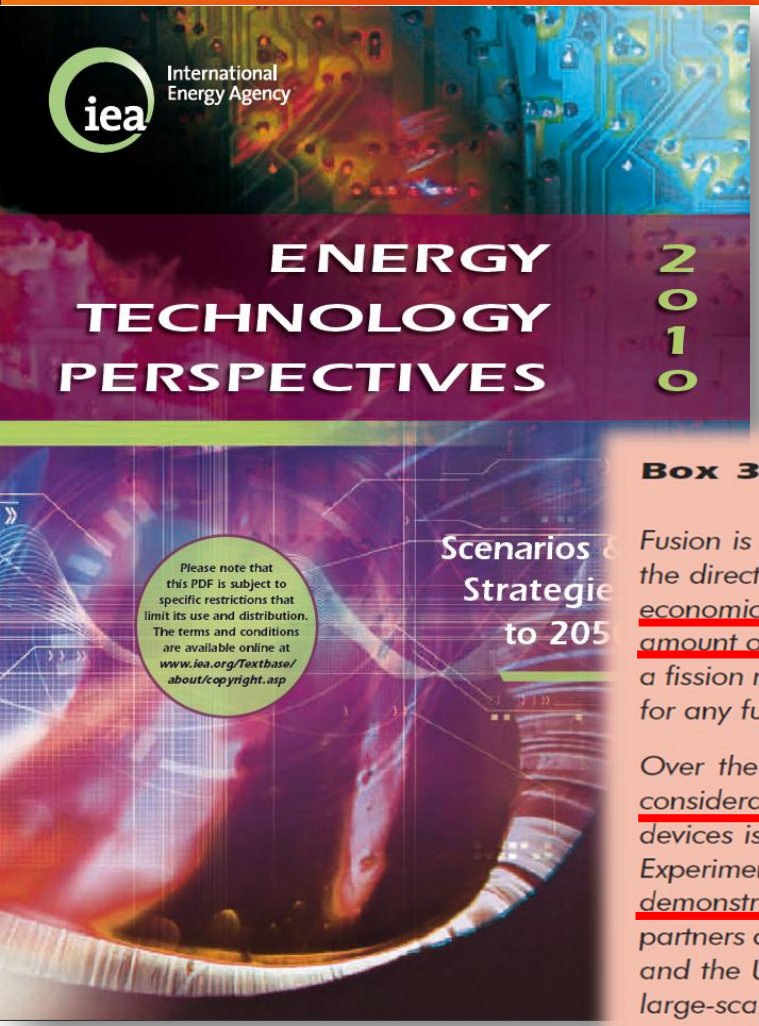
*Excludes JT-60U, GEKKO XII, NIFS and JAEA

Opinion on Fusion Energy

Two point of views

- ✓ Can / When FUSION save the Earth?
  - ❖ Can : is it true?
  - ❖ When : when it come true?

Opinion of IEA on fusion energy



source : IEA, 2010.

Box 3.5 ▶ Nuclear fusion

Fusion is a nuclear process that releases energy by combining light elements – it is essentially the direct opposite of fission. In principle, fusion holds the promise of a long-term, sustainable, economic and safe energy source for electricity generation, with relatively inexpensive fuel. The amount of radioactive waste produced from fusion devices is hundreds of times less than that of a fission reactor, the fusion process produces no long-lived radioactive waste and it is impossible for any fusion reactor to undergo a large-scale runaway chain reaction.

Over the past two decades, the operation of a series of experimental devices has enabled considerable advances in this technology. However, the plasma created in current prototype devices is not significant enough to achieve sustained power. The International Thermonuclear Experimental Reactor (ITER) is a new, significantly larger, prototype fusion device designed to demonstrate the scientific and technological feasibility of fusion energy on a large scale. Seven partners are involved in the ITER project: the European Union, China, India, Japan, Korea, Russia and the United States. ITER is planned to be the bridge towards a first demonstration plant of large-scale production of electrical power.

If work with ITER goes as planned, then a first demonstration plant will start operations in the early 2030s, with fusion power into the grid expected in the 2040s. As fusion is not likely to be deployed for commercial electricity production until at least the second half of this century, it is not considered in the ETP 2010 *scenarios.*

Opinion of Dr. Hawking on fusion energy

guardian.co.uk

Gods of science: Stephen Hawking and Brian Cox discuss mind over matter

We paired up Britain's most celebrated scientists to chat about the big issues: the unity of life, ethics, energy, Handel – and the joy of riding a snowmobile

Stephen Hawking and Brian Cox
The Guardian, Saturday 11 September 2010

A larger | smaller

Brian Cox and Stephen Hawking: A meeting of minds. Photograph: Alastair Thain for the Guardian

What problem do you hope scientists will have solved by the end of the century?

SH: Nuclear fusion. It would provide an inexhaustible supply of energy without pollution or global warming.

BC: I share that view, that the provision of clean energy is of overwhelming importance. What frustrates me is that we know how to do it as physicists, how it works. It is an engineering solution that is within our grasp. I don't understand why we don't seem to want it enough at the moment. As a society, do you think we invest enough in scientific education and research?

SH: I don't think we invest enough. They are why we are not still in the Middle Ages. Many badly needed goals, like fusion and cancer cure, would be achieved much sooner if we invested more.

Prospect of Forbes on fusion energy

- ✓ 2019
  - ❖ First large scale nuclear fusion experiments commence in France.

Forbes.com

Special Report

News From The Future

Forbes Staff, 09.27.10

Futurism favors the bold: Look decades ahead, as George Orwell did in *1984* and Arthur C. Clarke in *2001*, and critics will forgive your inaccuracies. We've attempted a thought experiment with tougher standards: predicting a future that's just around the corner. Our vision is sketched from real data, projections and facts, though we injected a dose of rigorous science fiction to fill in the gaps.

Let us know your thoughts on the future too. Visit Forbes.com/2020 to comment and vote on which of these events are most likely to occur. Don't hold back. As Malcolm Forbes would say, "Being right half the time beats being half right all the time." And time has proved him right.

2011

Politics: Kim Jong Il dies at age 70. Son Kim Jong Un, 29, succeeds him as North Korean leader. Seeks trade with U.S.
Finance/Economy: Bernie Madoff found hanged in cell. Prison officials will not rule out foul play.
Society/Environment: UN chief Ban Ki Moon arrives at Cairo hospital to welcome world's 7 billionth child, Malika Hussein. Declares start to Gender Justice Decade.
Technology: Russian scientists uncover giant U.S./Israeli cyberespionage network.
Technology: The Terrafugia Transition flying car goes on sale for $200,000.

2012

Politics: Islamist group Al Shabab seizes power in Somalia. Imposes Sharia law, takes over Gulf of Aden piracy operations.
Energy: Oil prices skyrocket following Israeli raid on Iranian nukes. President Ahmadinejad threatens to close Strait of Hormuz.
Finance/Economy: Facebook IPOs at $40 billion value. Founder Zuckerberg first twentysomething worth $10 billion-plus.
Society/Environment: First double amputee qualifies for 400-meter Olympic sprint in London. Places fourth.
Technology: Dept. of Justice probes Apple over monopoly of tablet computer market.
Health: Omni-drug-resistant, contagious tuberculosis infects children in Mexico City, spreads to Texas, Guatemala, Brazil. U.S.-Mexico border closed.

2016

Politics: First Internet balloting for U.S. President, with 7% of votes cast online. Widespread accusations of
Politics: New York elects Chelsea Clinton to Senate. First to hold office while pregnant.
Energy: New U.S. nuke reactor goes online in Georgia, first since Three Mile Island crisis. Industry hails "n
Society/Environment: Murderless Meat™, grown in labs, goes on sale at Whole Foods for $10 a pound. Ta
Technology: America's first virtual world employee farm opens in South Carolina. Minimum-wage workers bodyguards, gold harvesters in online games.

2017

Energy: Price of switchgrass-based ethanol now cheaper than gasoline, even without government subsidie
Finance/Economy: Harvard endowment doubles in seven years to $50 billion. Free tuition to lure top students from China.
Health: Two Australian women conceive first fatherless child using synthetic sperm derived from one mother's stem cell.

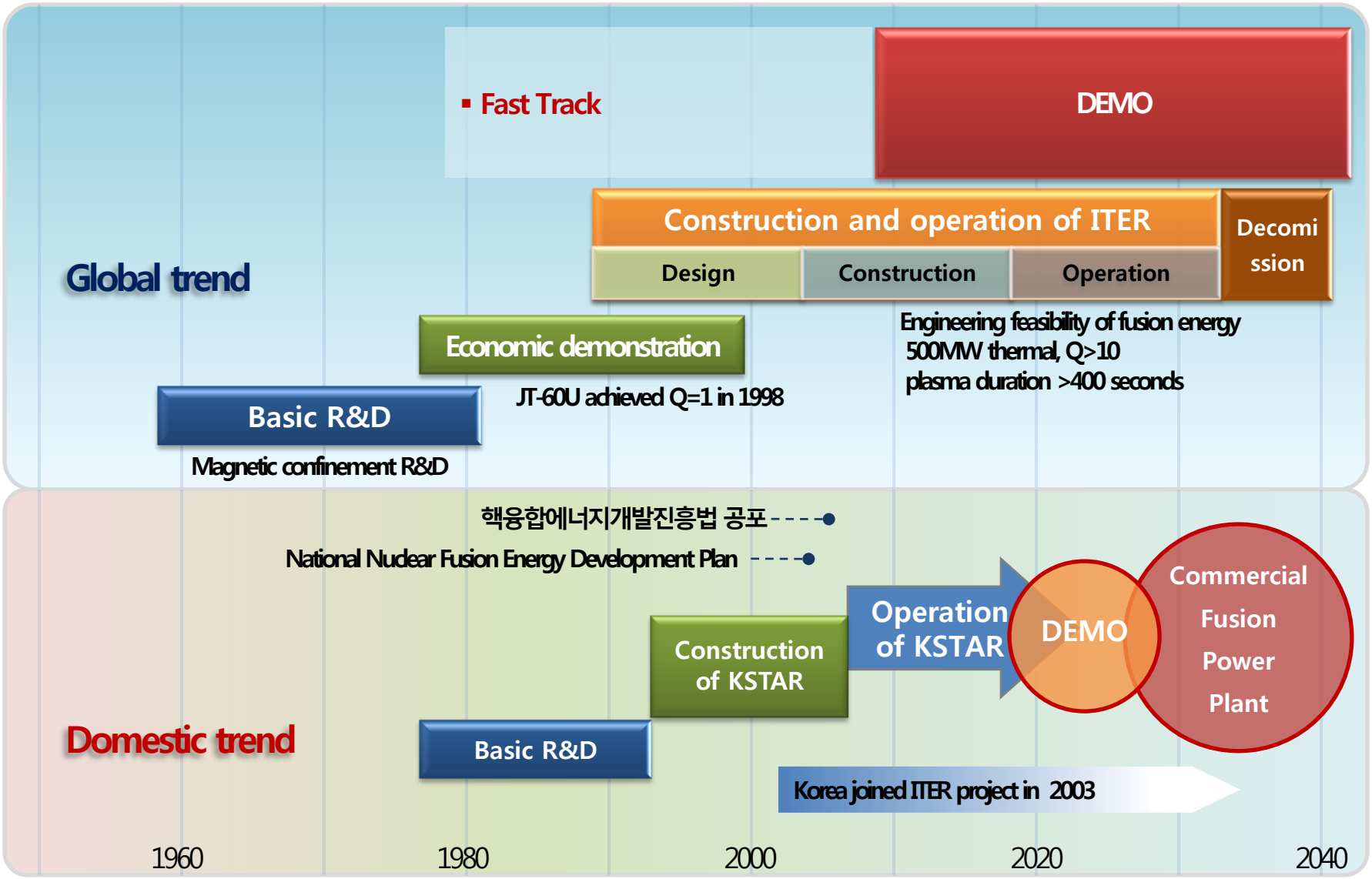
2018

Politics: Last combat troops leave Afghanistan. Longest-ever U.S. land war officially ends. Taliban and U.S. claim victory.
Finance/Economy: U.S. unemployment finally drops below 7%. Worst of quadruple-dip recession likely over.
Technology: World's fastest train arrives in Paris from Beijing, breaks 300mph record.

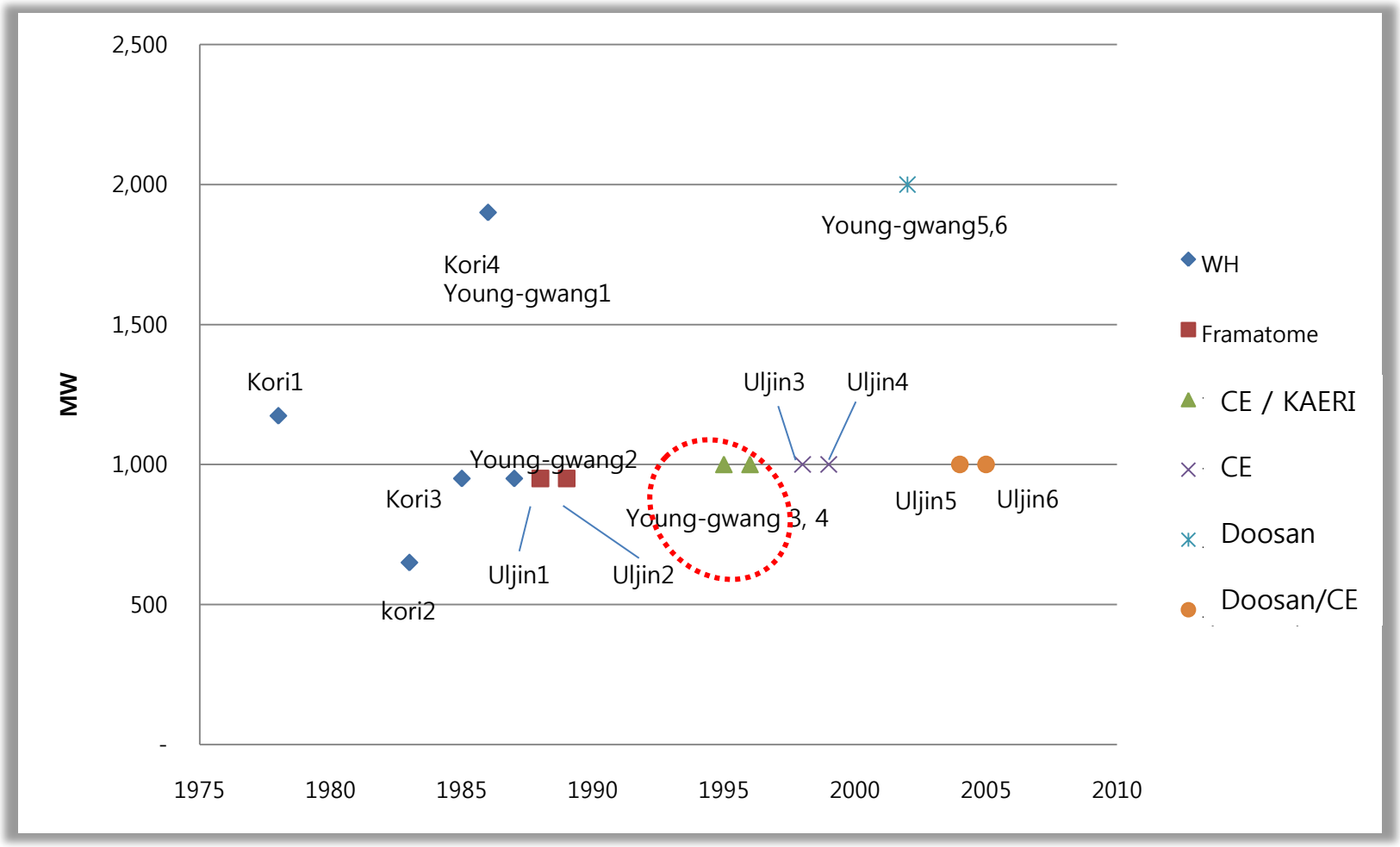
2019

Energy: First large-scale nuclear fusion experiments commence in France, prompting new promises of limitless clean power.
Society/Environment: China, facing dire lack of women, legalizes same-sex marriage. Creates pro-homosexual propaganda, financial incentives.
Technology: Steve Jobs retires. Pledges $50 billion upon his death to Gates Foundation. Jonathan Ive named Apple CEO.
Health: U.S. life expectancy declines for first time in a century. Doctors blame 55% obesity rate.

How to lead ITER project by KSTAR?



Self-supporting of Nuclear power plant in Korea



Recommendations of ADL to "Make or Buy" fusion tech

dti
Department of Trade and Industry

Evaluation of the UK Fusion Programme

Part A

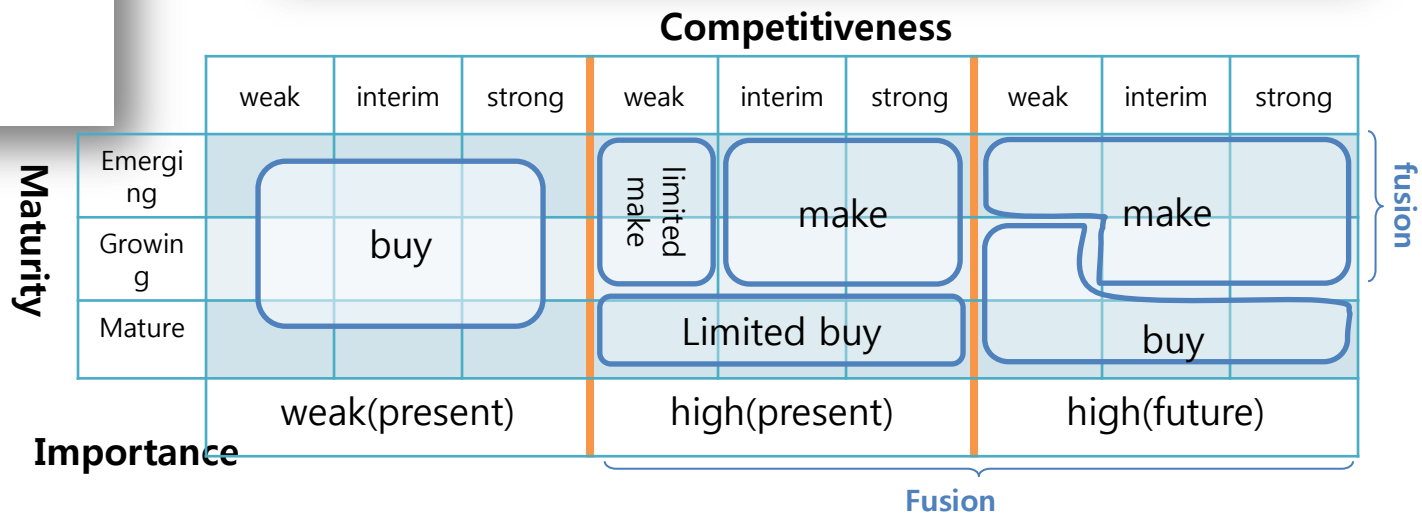
Final Report to the
Department of Trade and Industry
by
Arthur D Little Limited

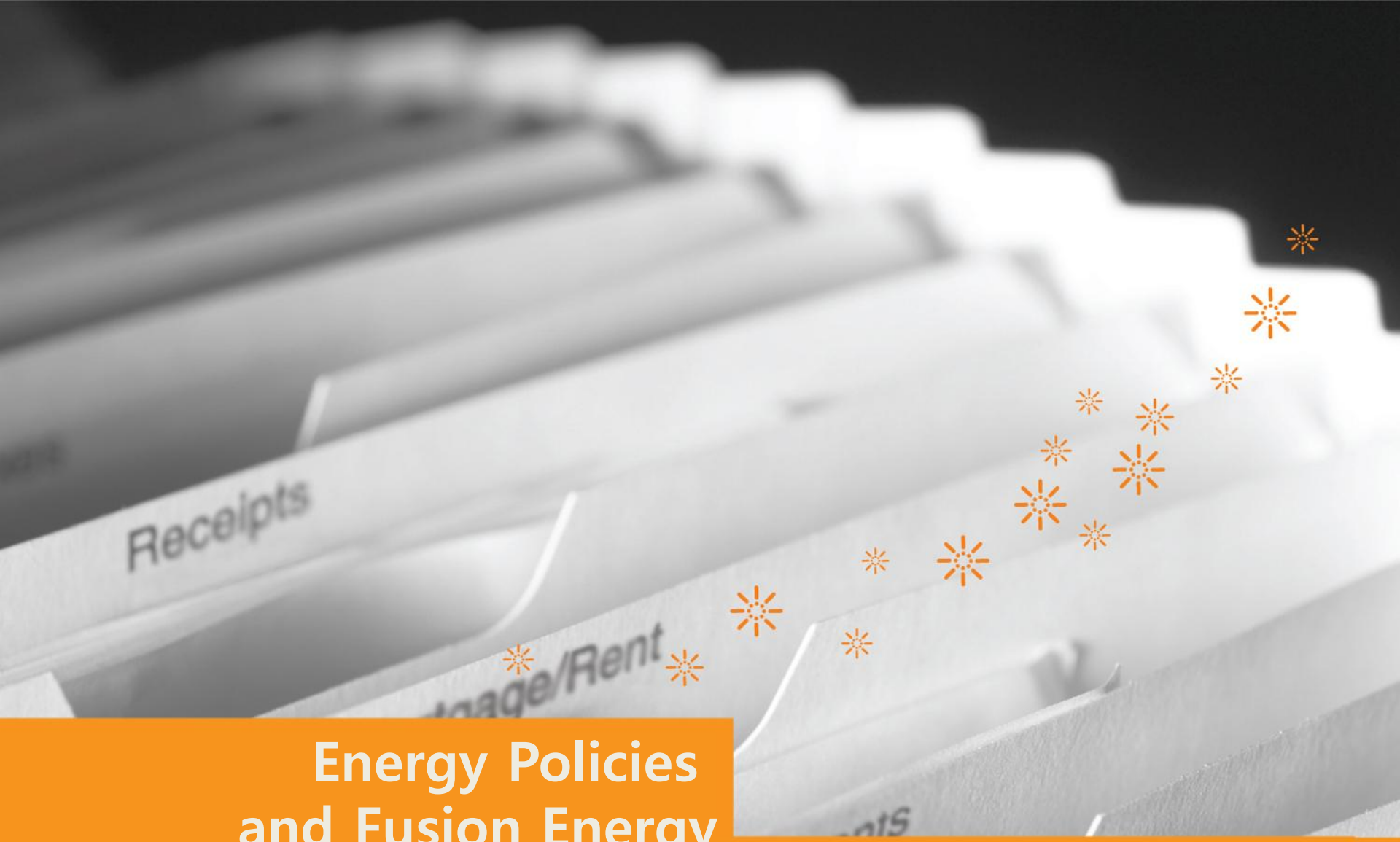
November 2001

DTI Evaluation
Report Series
No. 4

42. A similar argument is sometimes advanced by companies as a justification for cutting R&D, and it is often (sometimes too late) found to be flawed. In the context of UK fusion R&D, the argument may equally be flawed, for similar reasons. Those that apply to R&D investments in general can be expressed as follows:

- One can buy the technology, but one cannot buy (quickly) the skills and competencies needed to use it effectively – this issue, the lack of an absorption capacity, is the reason many technology investments by firms fail. Building up such a capacity is slow, expensive and an organisation that needs to do it is likely to stay behind its competitors for a long time. Keeping such a capacity is the main reason why many firms run R&D / technical activities in specific fields. Economic models may not take account of this factor *(the 'absorption risk')* at all
- Without an internal capacity to understand the issues in detail, one will not know what sort of plant to buy, nor how to specify it in the most advantageous way *(the 'rip-off' risk)*
- The buyer may still be highly dependent on (perhaps few) suppliers, e.g. for spare parts and engineering services *(the 'over a barrel' risk)*
- The ability of the buyer to develop the technology further, and sell it on, will be limited because other people own the rights *(the 'hands tied' risk)*

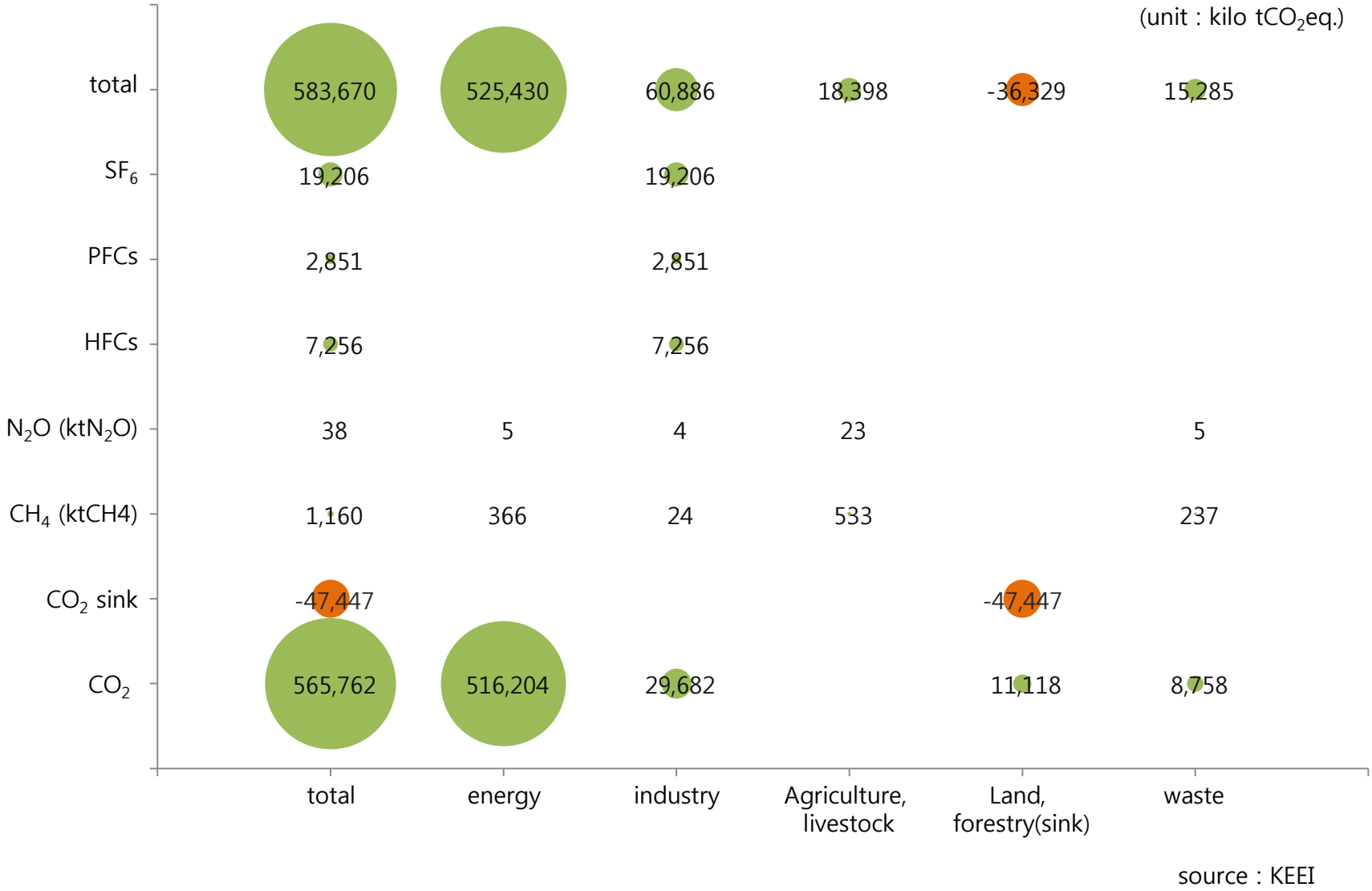




Energy Policies and Fusion Energy

- ✓ Interrelation of GHG and energy sectors
  - ❖ GHG emissions of each sector in Korea
  - ❖ Electric vehicle, electric plane
- ✓ Prospect of power sector
  - ❖ Fuel mix
  - ❖ Electricity generation

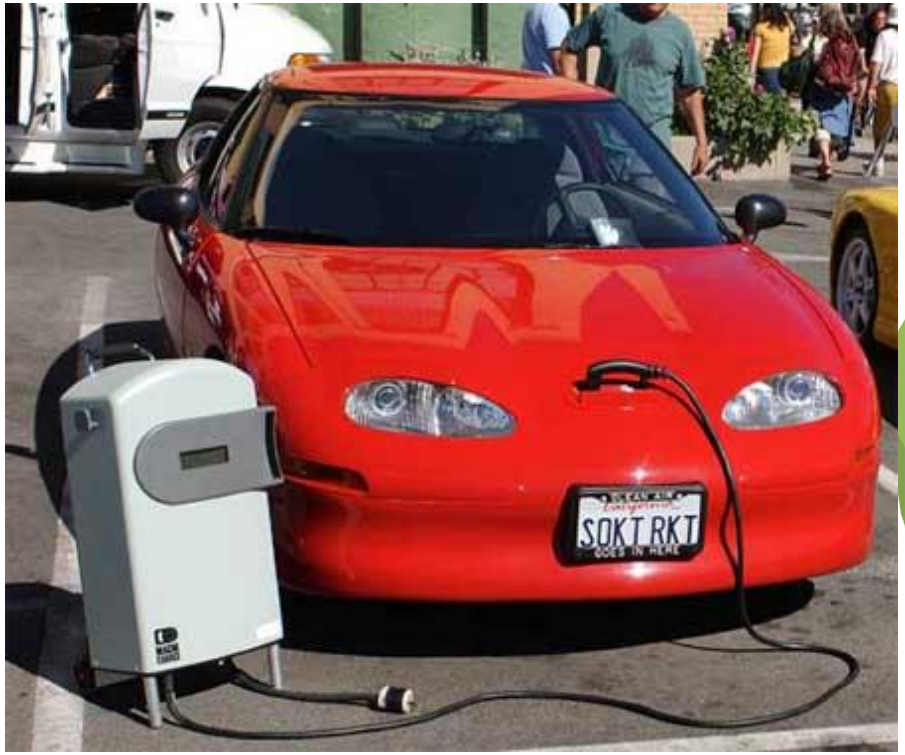
GHG emissions of each sector in Korea(2007)

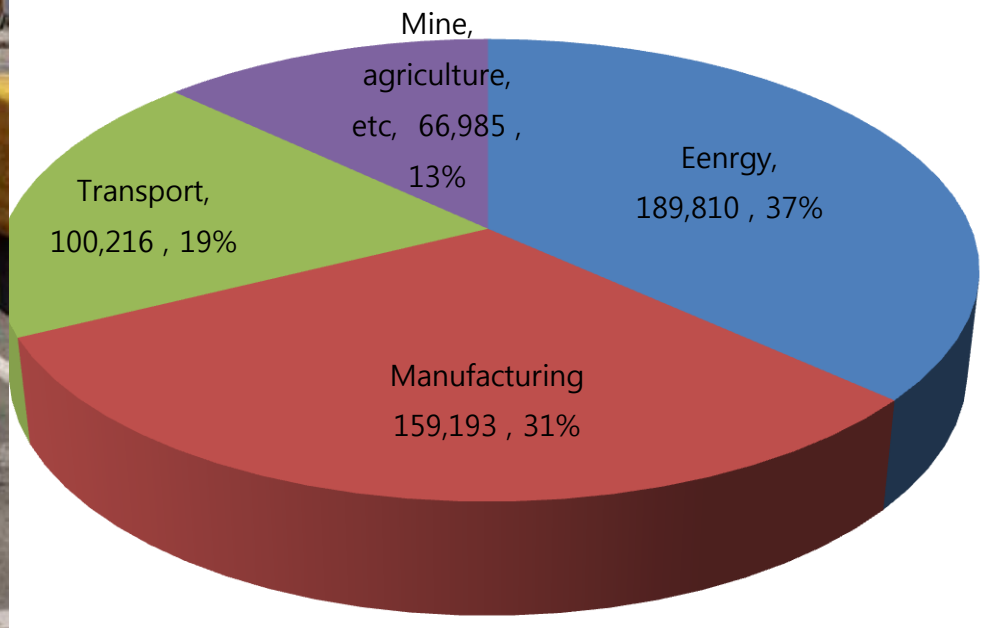


source : KEEI

Is it true that electric transport mitigate GHG?

<Electric plane Yuneec e430>
($89,000 USD)

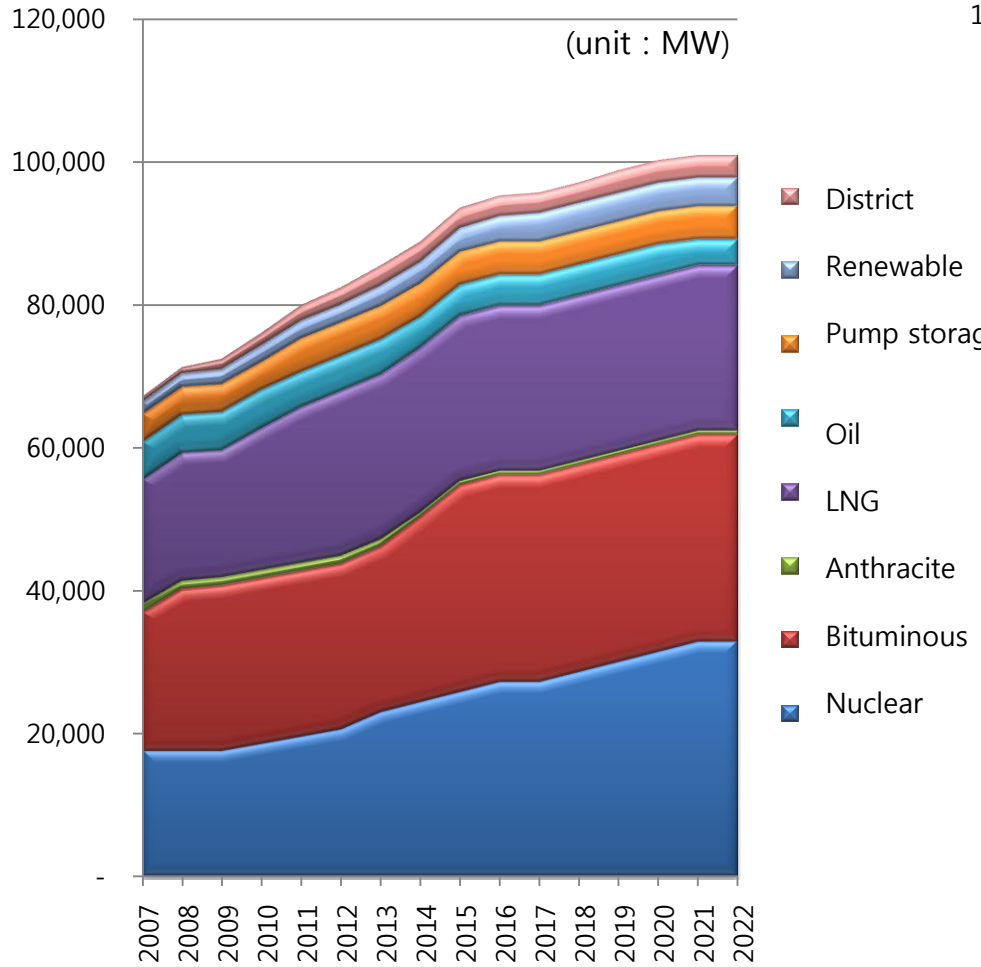


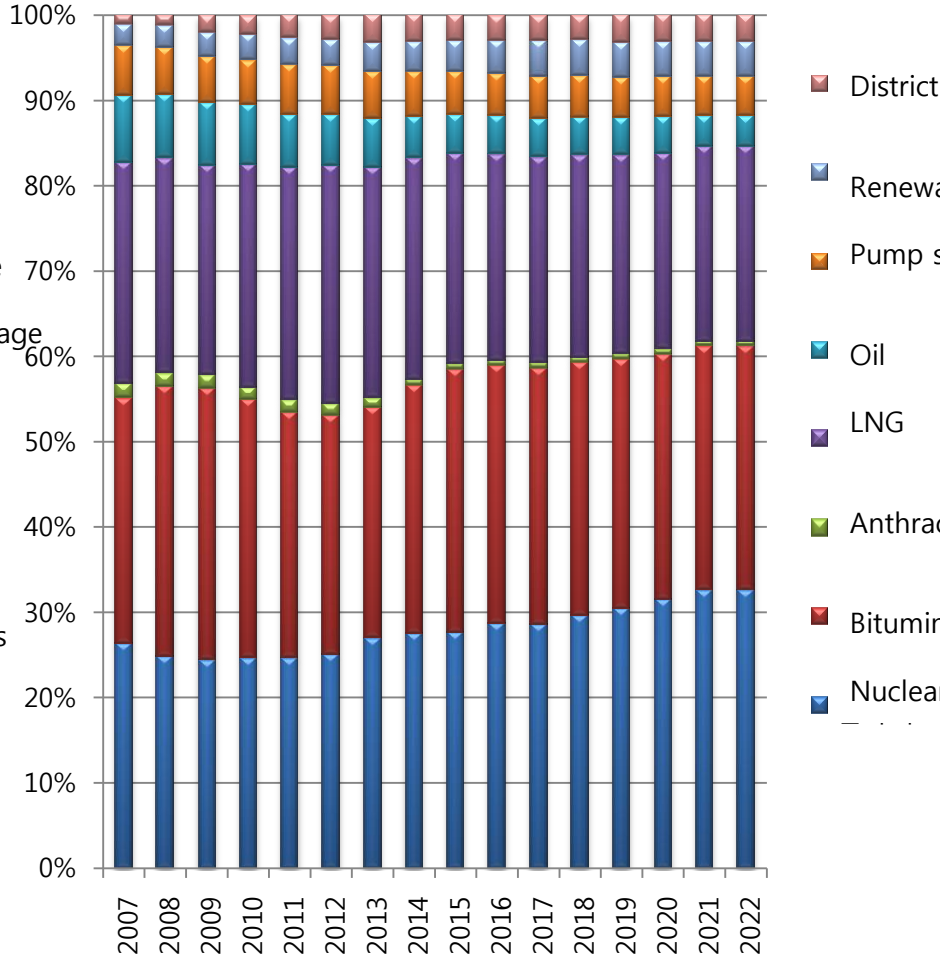


<GHG of energy sector>

Prospect of fuel mix in Korea

✓ Fuel mix of fossil fuel still accounts for more than half percent in 2022.

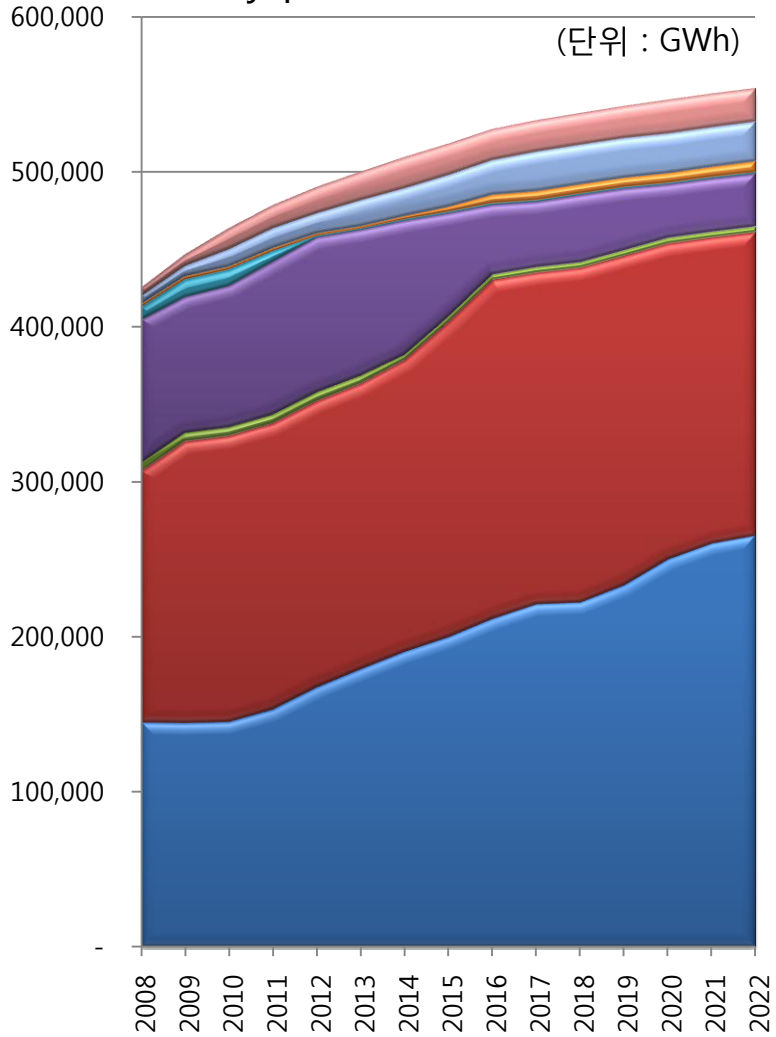


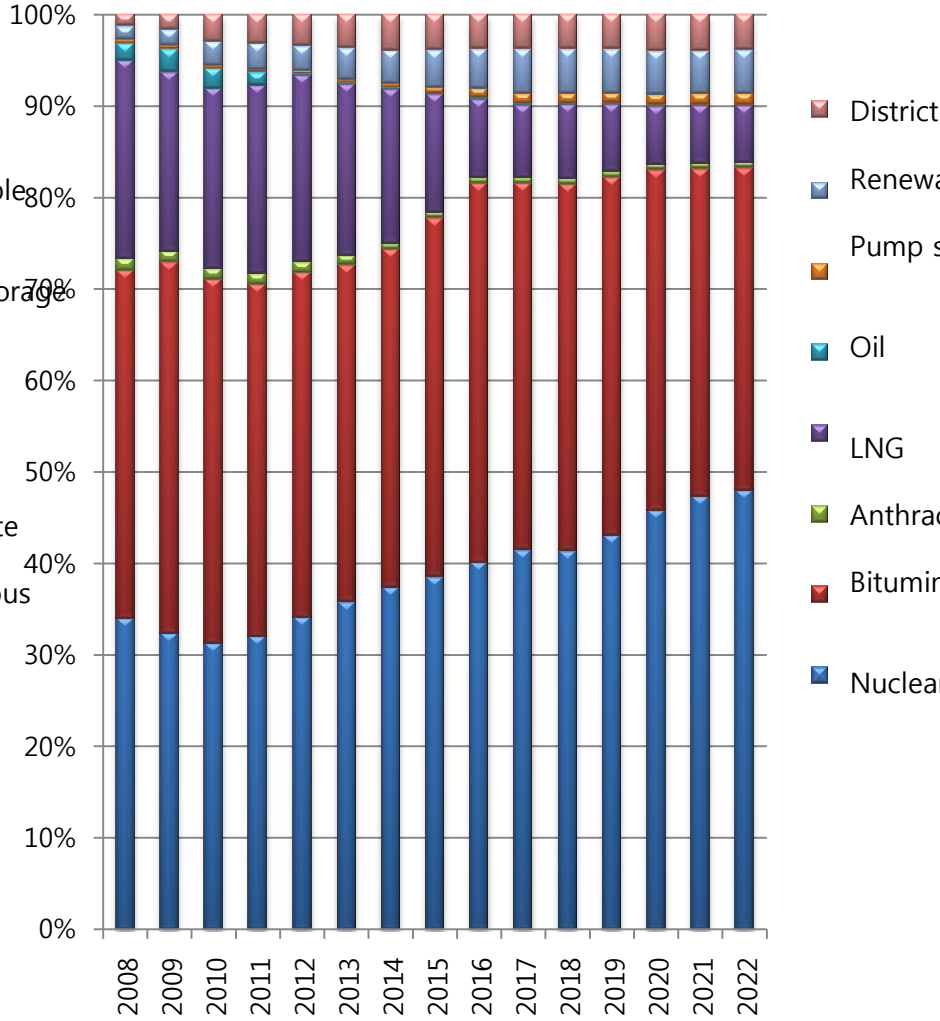


Source : 4th Basic plan for supply and demand of Electricity

Prospect of electricity generation

✓ Generation of nuclear accounts for about half percent and fossil fuel more than forty percent.





Source : 4th Basic plan for supply and demand of Electricity

Role of fusion power in future electricity market

- ✓ Facts about nuclear
  - ❖ Renaissance of nuclear and construction cost
  - ❖ Yucca Mountain
- ✓ Renewable energy
  - ❖ Challenges for operating grid
  - ❖ Matter of frequency and density
- ✓ Which will be the competitor of fusion power?
- ✓ Global view
  - ❖ Asian countries
  - ❖ Target market?

Nuclear renaissance : Nuclear cost – clouded, but rising

✓ Yes! It's renaissance era for nuke!

German Nuclear Industry Gets A Life Extension

A compromise gives the industry until 2036 to hang on to the existing fleet, with strings attached

Under a plan approved by a center-left government under different circumstances in 2000, Germany's 17 perfectly safe nuclear plants were to be shut down by 2022. This despite the fact that in the US, France and the UK, the industry has been encouraged to extend the life of the existing units to 60 years or so since it has proven difficult to build any new ones.

Nuclear Costs Clouded But Rising

The cost of nuclear power, like the age of a beautiful woman, is not easy to tell and even more problematic if you must ask

As anyone who has studied the subject would tell you, figuring out exactly what it costs to get a kWhr from a nuclear reactor is complicated and comes with so many caveats as to border on meaningless. To be sure, there are many variables and many implicit and explicit subsidies. The cost of capital used to finance the construction of a typical reactor in nearly all parts of the world, but especially in countries where the state has a strong say on energy matters, is a heavily political issue and is often shrouded in multiple layers of secrecy and ambiguity making direct cost comparisons to other technologies – who often have their own forms of subsidy – difficult at best.

According to a 2009 update of an earlier 2003 study by the **Massachusetts Institute of Technology**, **Du & Parsons** at MIT's **Center for Energy & Environmental Policy Research** say it currently costs an average of 8.3 ¢/kWh to produce electricity from nuclear power plants, higher than 6.5 ¢/kWh for natural gas and 6.2 ¢/kWh for coal – not accounting for the cost of carbon.

source : EEenrgy Informer, 2010.

Citi's advice to investors of nuclear

- ✓ Citigroup's advice to private investors is to stay clear of the nuclear option until there is clarity in the price of carbon – and that may be long wait.

(source : Electricity Currents, 2010.)

Why Nukes Continue To Face Uphill Battle

Nuclear proponents on both side of the Atlantic Ocean remain hopeful that better days are just around the corner. There have been encouraging signs in the U.S., where a handful of new reactors are likely to receive licenses from the **Nuclear Regulatory Commission** (NRC) to begin the long construction process. In Europe, **Finland** appears poised to proceed with possibly two new reactors. But for every promising sign, there is a setback.

In late May, **Citigroup** released a report titled ***New Nuclear: The Economics and Politics*** that concluded that prospects for equity investors has further deteriorated. It lists rising nuclear construction costs and more positive long-term prospects for availability and price of natural gas among the reasons why the nuclear option remains an expensive proposition. While the Citigroup's study is primarily focused on the UK and continental Europe, the implications are equally applicable to the U.S.

Citigroup reckons that it is *unlikely* for a new reactor built in Europe to cost *less* than €3,000/kW based on a €4.8 billion price tag for a 1,600 MW station. Moreover, these costs have been – and continue to be – rising, so the ultimate cost can conceivably be *considerably higher*. Adding €18/MWh for operating costs and making further assumptions on construction to begin in 2013 and the plant to be completed by 2019, it figures a new nuclear reactor would need a price of €76.7/MWh to break even. This compares with €63/MWh for a new coal plant, €65/MWhr for a new gas-fired plant, and somewhere in between for an offshore wind farm. Clearly, without additional government subsidies or some other stimulus – perhaps a price on carbon emissions – few private investors would choose the nuclear option over alternatives, especially considering the large lump-sum upfront investment and the long and uncertain construction period

Citigroup's advice to private investors is to stay clear of the nuclear option until there is clarity on the price of carbon – and that may be a long wait.

The numbers may be different for the U.S., but the nuclear option rarely comes up as the most cost-effective, unless a hefty price is assigned to carbon – and that is even less likely for the U.S. than for Europe. The latter at least has an existing market price for carbon, due to its **emission trading scheme** (ETS). Moreover, in the U.S., as in Europe, the issue of nuclear waste continues to dent prospects for a nuclear revival.

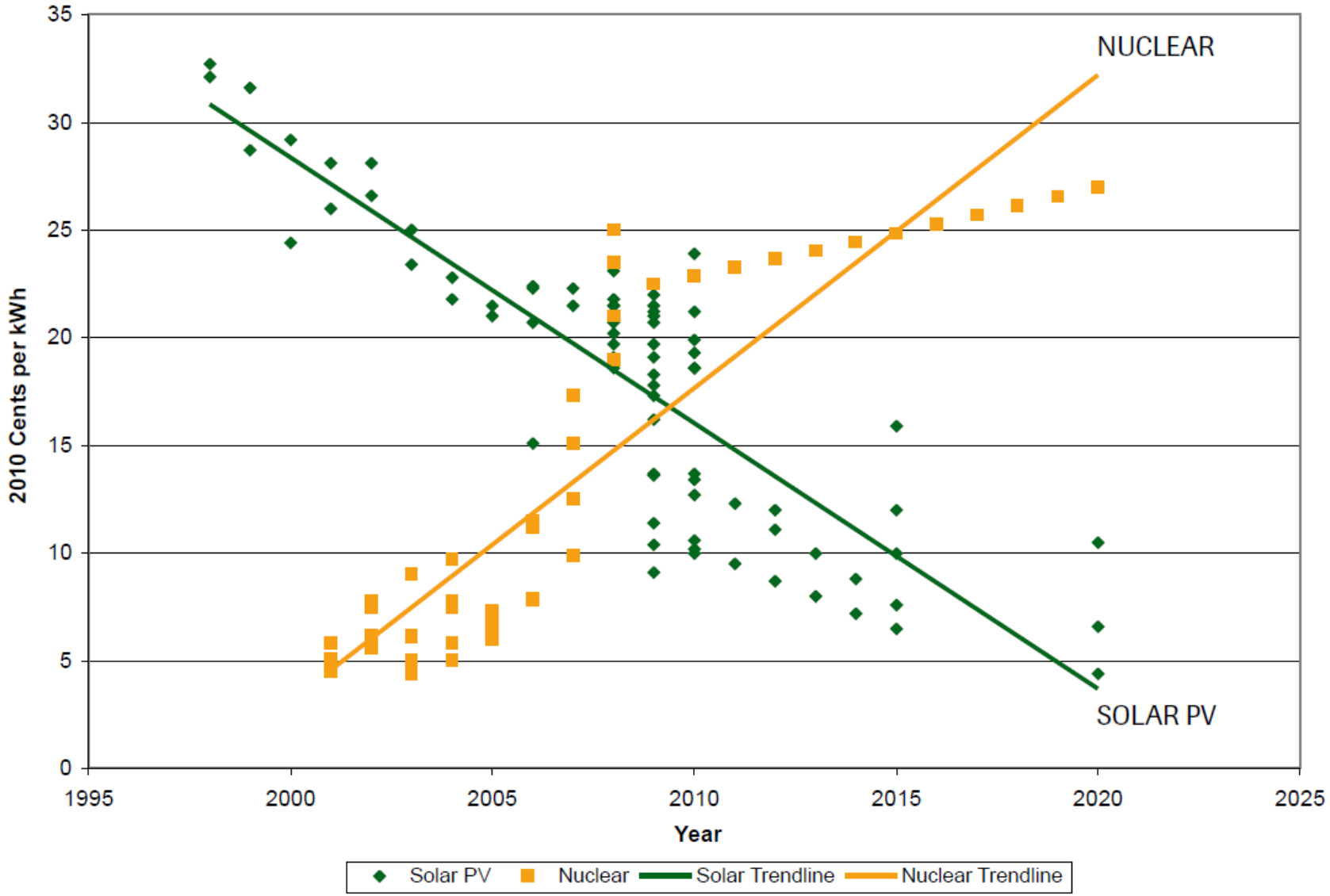
Any hope for a permanent waste repository evaporated after the U.S. **Department of Energy** (DOE) canceled plans for the **Yucca Mountain** nuclear waste repository in Nevada last year. The industry, which continues to pay $770 million a year into a fund set up for this purpose, is now considering whether to stop making the payments – the matter has gotten hopelessly mired in regulatory and legal hurdles. **Ellen Ginsberg**, general counsel of the **Nuclear Energy Institute**, a nuclear lobbying group based in Washington, DC, says, "We don't want to pay any more fees until the government has a waste plan." In other words, no waste pickup, no fees. Sounds reasonable. ■

doi:/10.1016/j.tej.2010.07.012

Surprise: Calif. Approaching Ambitious 20% RPS Target

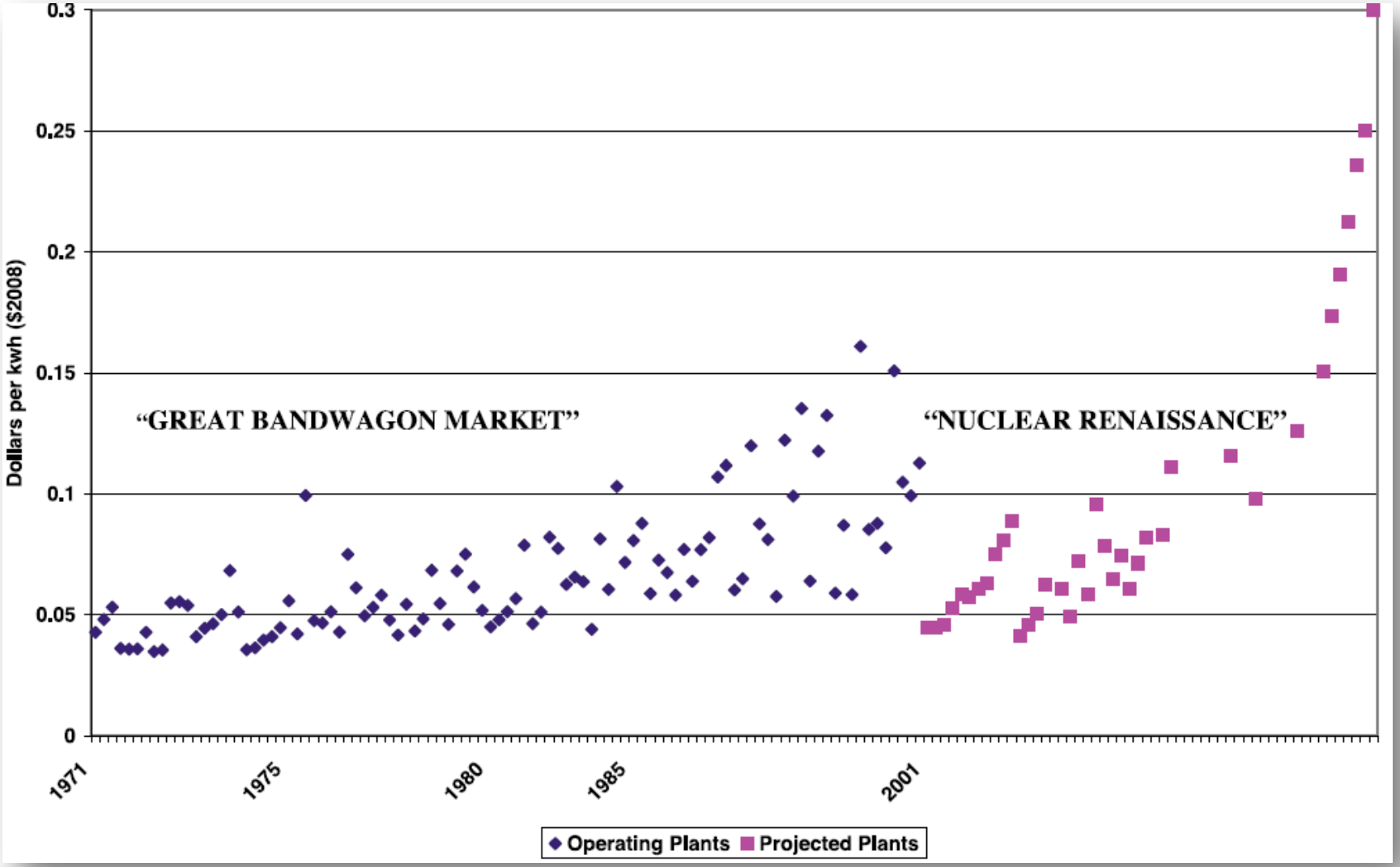
A binding regulatory mandate set in 2002 required California's three **investor-owned utilities** (IOUs) to increase their intake of *new* renewable resources by 1 percent per annum, reaching 20 percent of their retail electricity sales by 2010. Existing hydro does *not* count towards this goal. For sometime, it has been recognized that this **renewable portfolio standard** (RPS), among the most ambitious in the U.S., could not be met by 2010. And that was before the recent

Solar vs. Nuclear kWh cost comparison



source : Balckburn and Cunningham, 2010.

Trends of nuclear power generation cost



source : Balckburn and Cunningham, 2010.

Yucca Mountain

Yucca Or No Yucca?

The fate of a permanent US nuclear waste repository remains up in the air, and that is the good news

Back in 1982, the US Congress passed the **Nuclear Waste Policy Act** (NWPA) essentially tasking the **US Department of Energy** to develop a permanent nuclear waste repository to collect and keep all spent fuel from the nation's civilian reactors. Utilities with nuclear plants were to focus on building and running the reactors, the DOE was to pick up the garbage and keep it in a safe dump. That was the plan.

Utilities kept their side of the bargain by paying a fee for the waste dump, collected through a small tax from their customers. Over the past 27 years, ratepayers have paid approximately $17 billion into the **Nuclear Waste Fund** (NWF). Moreover, the fund has earned an additional $13.5 billion in interest, bringing the total to about $30 billion, a handsome amount, according to the **National Association of Regulatory Utility Commissioners** (NARUC).

Following years of conducting studies and exploring alternative loc
Yucca Mountain in the Mojave Desert, roughly 90 miles northwes
voluminous application to the **Nuclear Regulatory Commission** (
dump. But Nevada politicians were never happy with the plan. Mu
other studies followed with little progress.

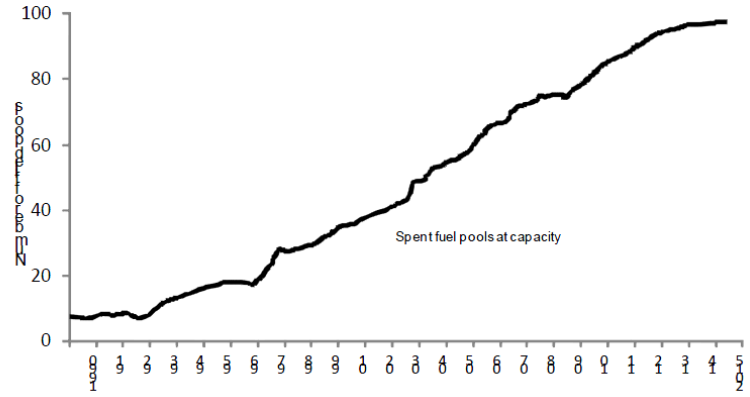
Last year, Energy Secretary **Steve Chu** decided that Yucca Mounta
asked NRC to withdraw the 17-volume, 8,600-page license applica
2008 under the **Bush Administration**. The **Obama administratio**

Commission to recommend a new nuclear disposal strategy, while cutting virtually all funding for the Yucca Mountain project – a symbolic move since the project was not going anywhere.

In June 2010, a three-judge panel at NRC unanimously rejected the DOE's motion, stating that the withdrawal was illegal. Specifically, the judges pointed out that NWPA does *not* give the Energy Secretary the discretion to substitute his policy for the one established by Congress under NWPA. Small technicality, according to the White House press office.

Piling up with nowhere to go

Cumulative number of spent fuel pools reaching capacity at US nuclear power plants, 1990-2015



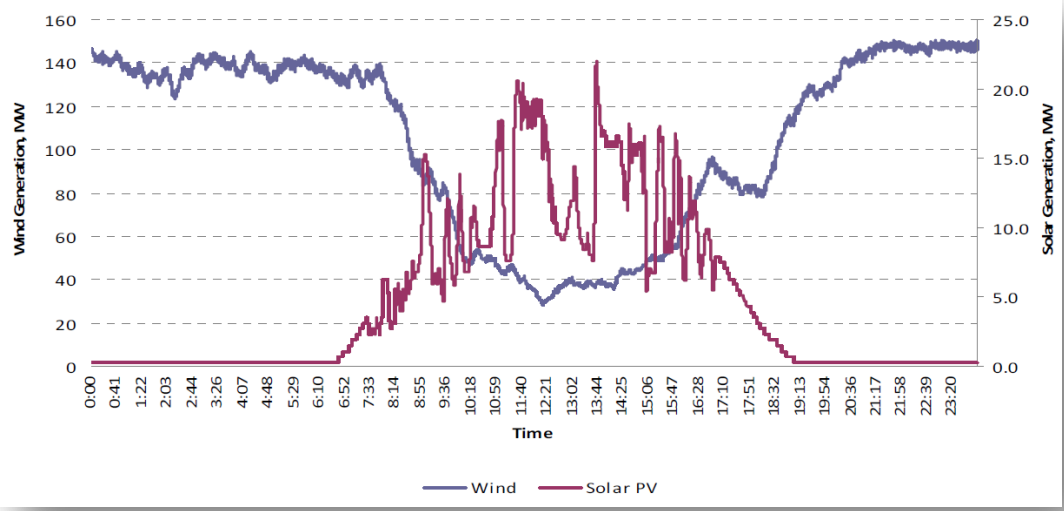
Source: NRC

In the mean time, 77,000 tons of high-level waste, including 57,000 tons of commercial spent fuel generated at 104 operating reactors is being stored at 121 temporary locations in 39 states. In April 2010 NARUC, which represents the state level utility regulators from across the country, followed the lead of several utilities by filing a lawsuit. NARUC argues, correctly, that the collection of fees paid by utility customers to fund DOE's unsuccessful efforts to collect and dispose of the spent nuclear fuel should stop until the DOE comes up with a viable permanent nuclear waste storage dump.

source : EEnergy Informer, 2010.

RPS and challenge to operation of power grid

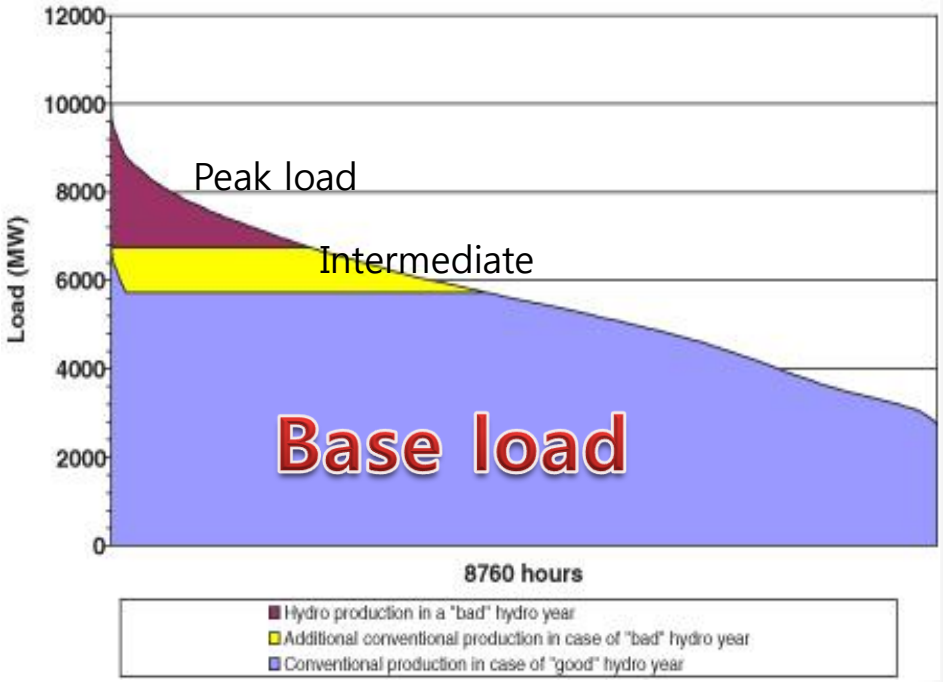
- ✓ As RPS(Renewable Portfolio Standard) higher in California, operating the grid is going to become more of a challenge as wind and solar generation – the biggest 2 contributors with the most hourly and daily variations – grow over time.
- ✓ The more intermittent renewable generation will mean that the thermal units will have to work much harder, ramping up and down, with adverse consequences on their efficiency. This will also increase their greenhouse gas emissions since units may operate away from their optimum design levels.
- ✓ PV and wind generation during sunny day in California



source : California ISO, 2010.

Competitors of fusion power?

- ✓ Load type
  - ❖ Base load
  - ❖ Intermediate load
  - ❖ Peak load
- ✓ Which power sources can do 'load following'?



ELSEVIER

Fusion Engineering and Design 49–50 (2000) 33–39

Fusion Engineering and Design

www.elsevier.com/locate/fusengdes

Which are the competitors for a fusion power plant?

Ronald L. Miller *

Fusion Energy Research Program, University of California, San Diego, La Jolla, CA 92093-0417, USA

Abstract

The (future) competitive position of central-station fusion power will depend on the resolution of several broad public-policy issues, including the provision of adequate electrical energy to a growing world population and the interaction of economic and environmental considerations meeting evolving standards of public acceptance and regulatory compliance. Candidate baseload central-station power plants, fusion or other, will be expected to contend for preferential market penetration against an evolving set of performance indicators or metrics (e.g. cost of electricity) reflecting societal 'customer preferences' for abundant, affordable, safe, reliable, and environmentally benign sources. This competition is enhanced by transitions to price-deregulated regimes, overlaid by nuclear uncertainites and evolution beyond carbon-based fuels toward more renewables in the energy mix. From these top-level considerations, quantifiable attributes, including plant size (output), system power density, surface heat flux, recirculating power fraction, power-conversion efficiency, waste streams, and forced- and planned-outage rates emerge.

Keywords: Fusion power plant; Performance indicators; Customer preferences

1. Introduction

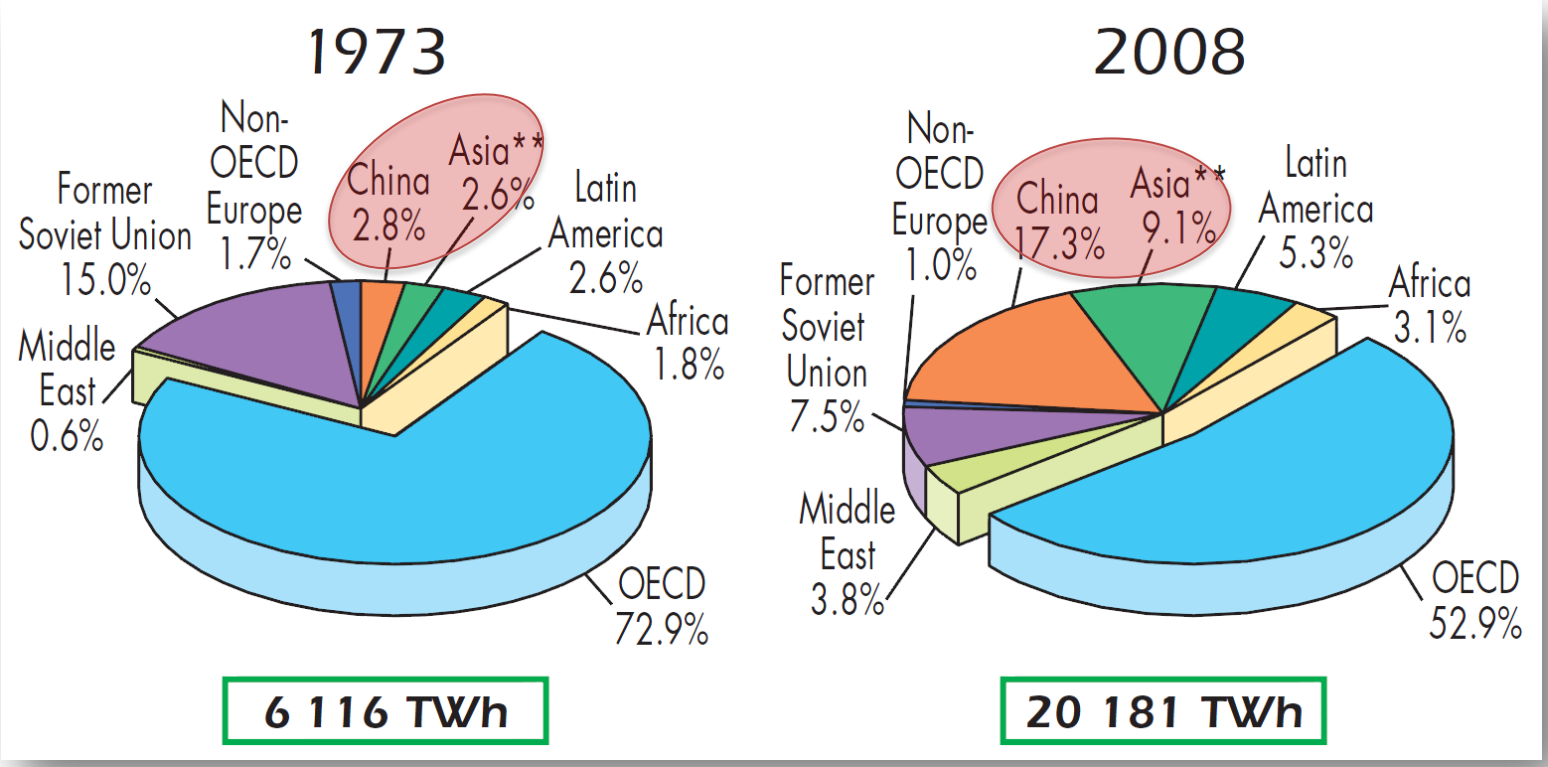
Human history has never been so well-behaved and predictable that the naive scenario: that, following a period of scientific inquiry and technical innovation, fusion power would emerge (just in time) to solve human energy needs for the indefinite future under a continuation of the business-as-usual rules. Rather more interestingly, new concerns (or the anticipations of concerns) are being heaped upon the energy-planning activity, just as the present operating framework is being overthrown in various ways. Yet, sensible progress can still be made.

Prudence suggests that is is not possible, or even necessary, to propose a longterm scenario under which a fusion power plant, the specific characteristics of which are obtained from present conceptual design studies [1] as informed by recent experimental results and plausible extrapolations of technology, could be shown to be cost competitive at some period in the distant future. Such design studies, together with projective energy and environmental scenarios, have value in (re)directing near-term R&D efforts along what are percieved to be the most promising lines. The success or inefficiency of this process is probably no better or worse than for other endeavors. In updating a previous consideration [2] of these issues, it is appropriate to reformulate the discus-

* Tel.: +1-858-5347842; fax: +1-858-5347716.

IEA data confirms the dawn of the Asian century

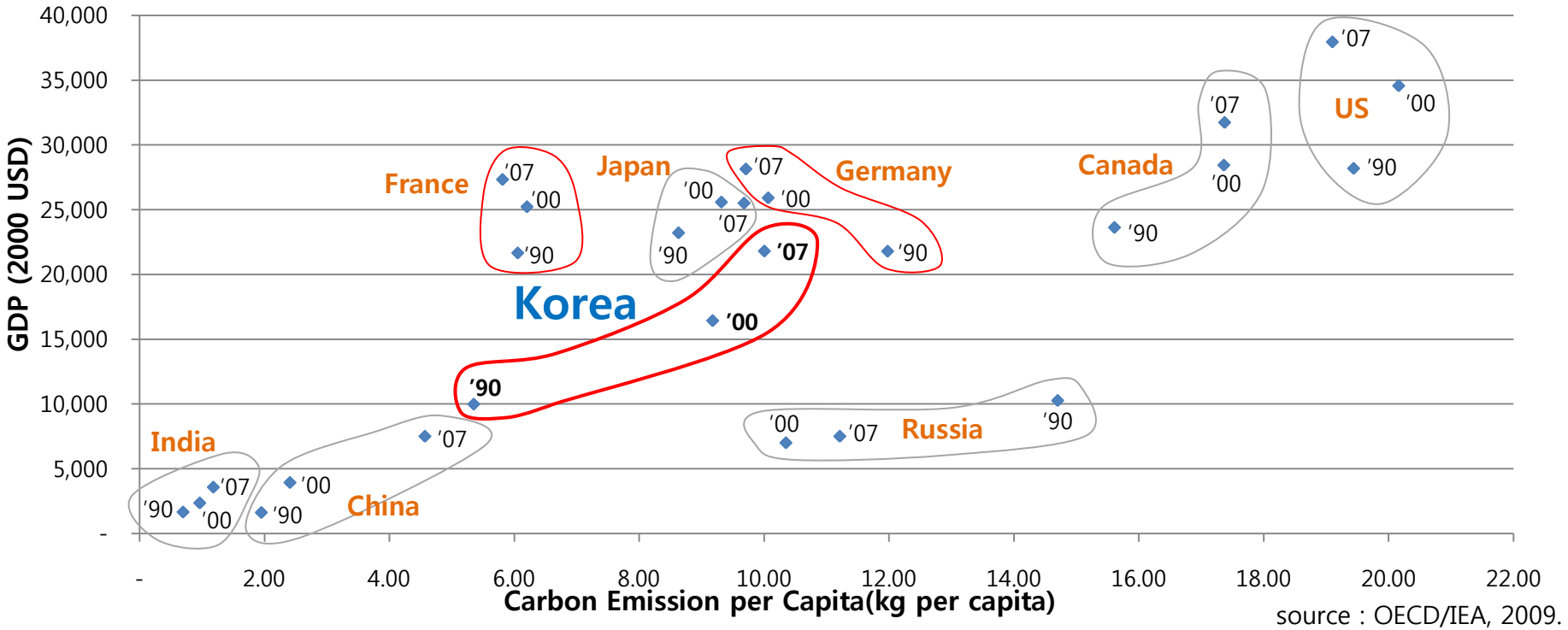
- ✓ Rapidly growing economies of Asia will dwarf tepid growth in the West.



source : OECD/IEA, 2010.

GDP vs. carbon emission per capita

- ✓ We have to move left upper to achieve 'green growth'.
- ✓ What if China and India move right and right and right?
  - ❖ Fusion power must penetrate emerging countries.

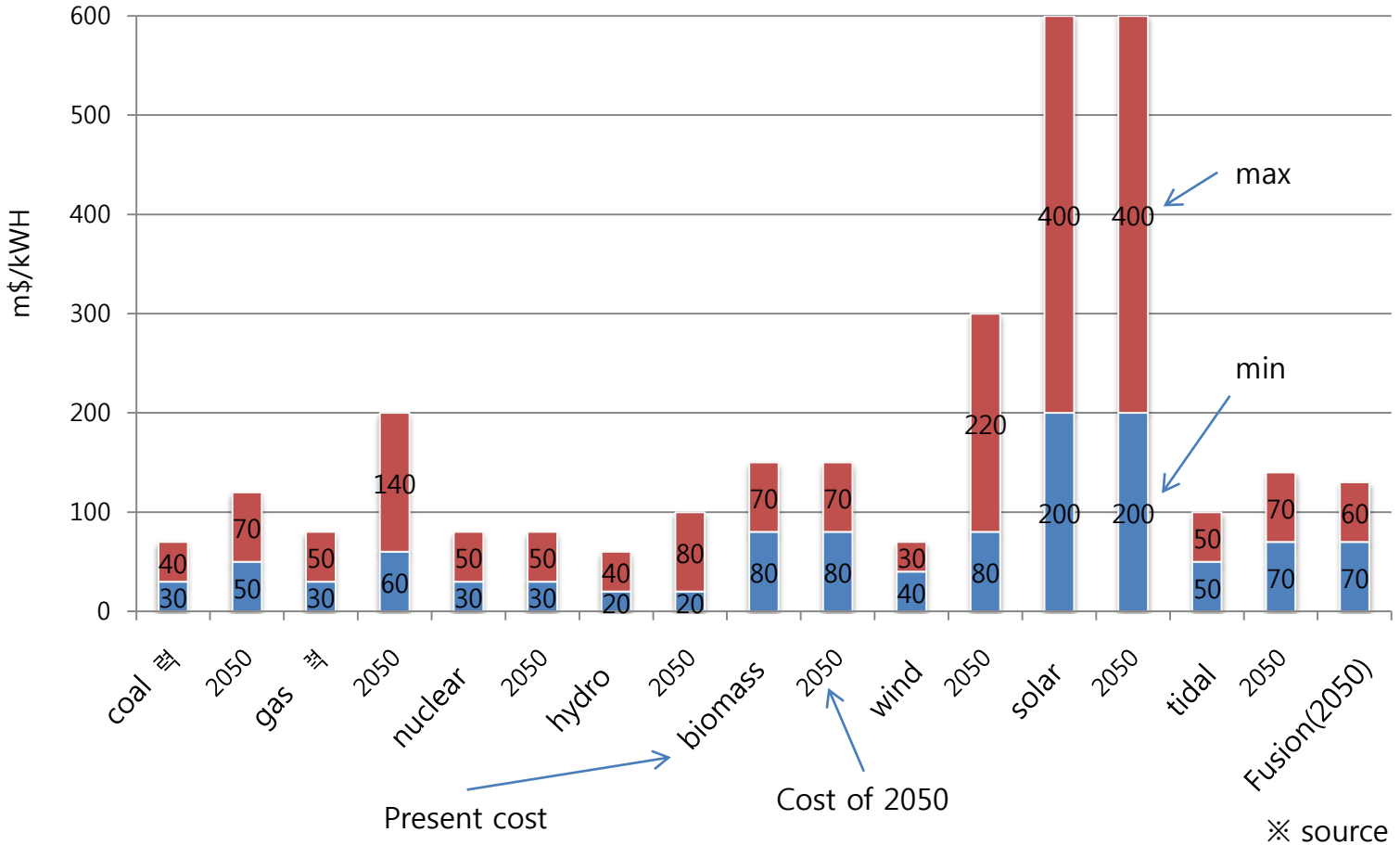


source : OECD/IEA, 2009.

Forecasts about fusion power

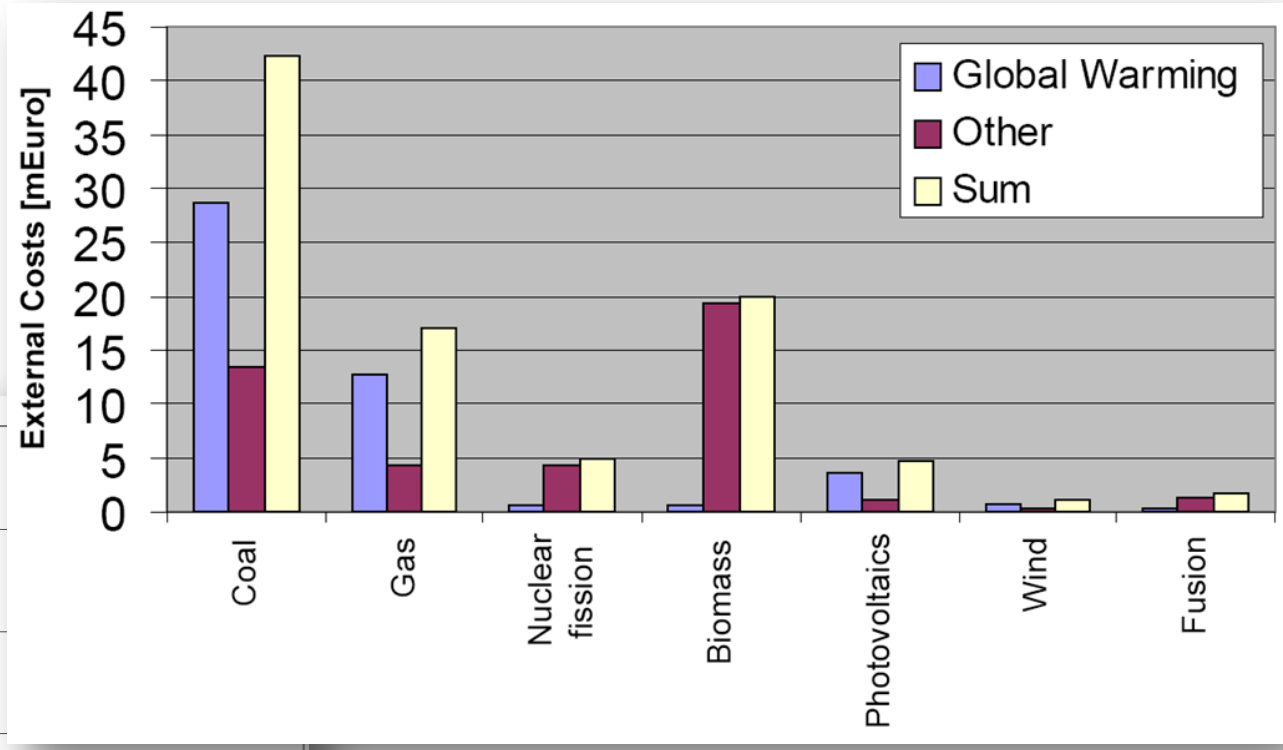
- ✓ Generation cost
- ✓ Inclusion of external cost
- ✓ CO_2 emissions
- ✓ Aspect of safety, economics, fuel resources, CO_2 and radwaste

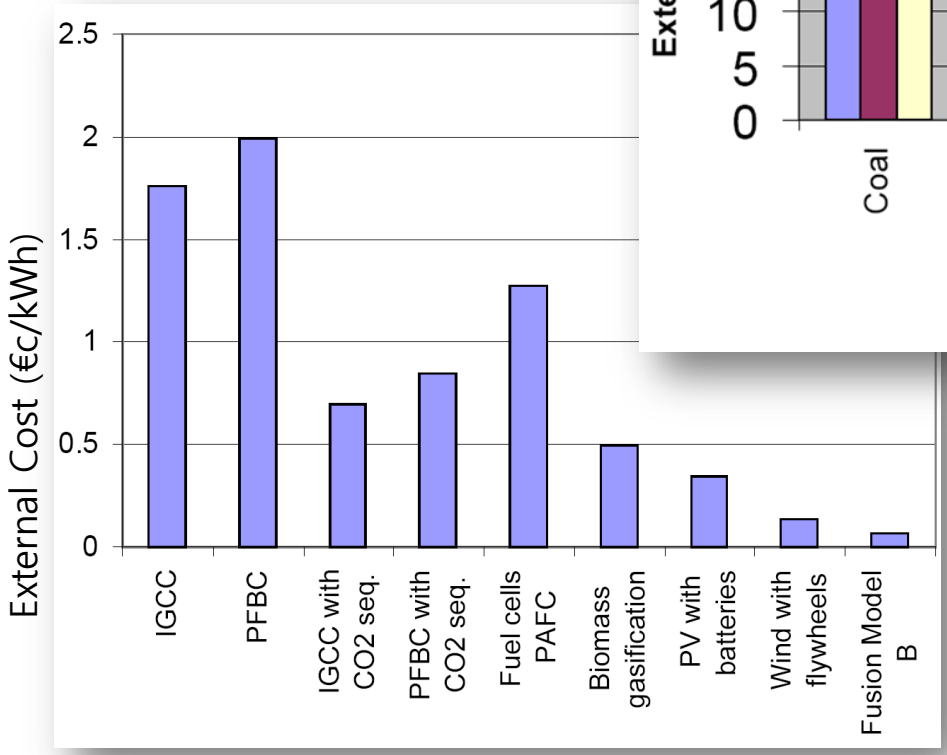
Forecasts of each generation cost



※ source : Ward et al., 2000

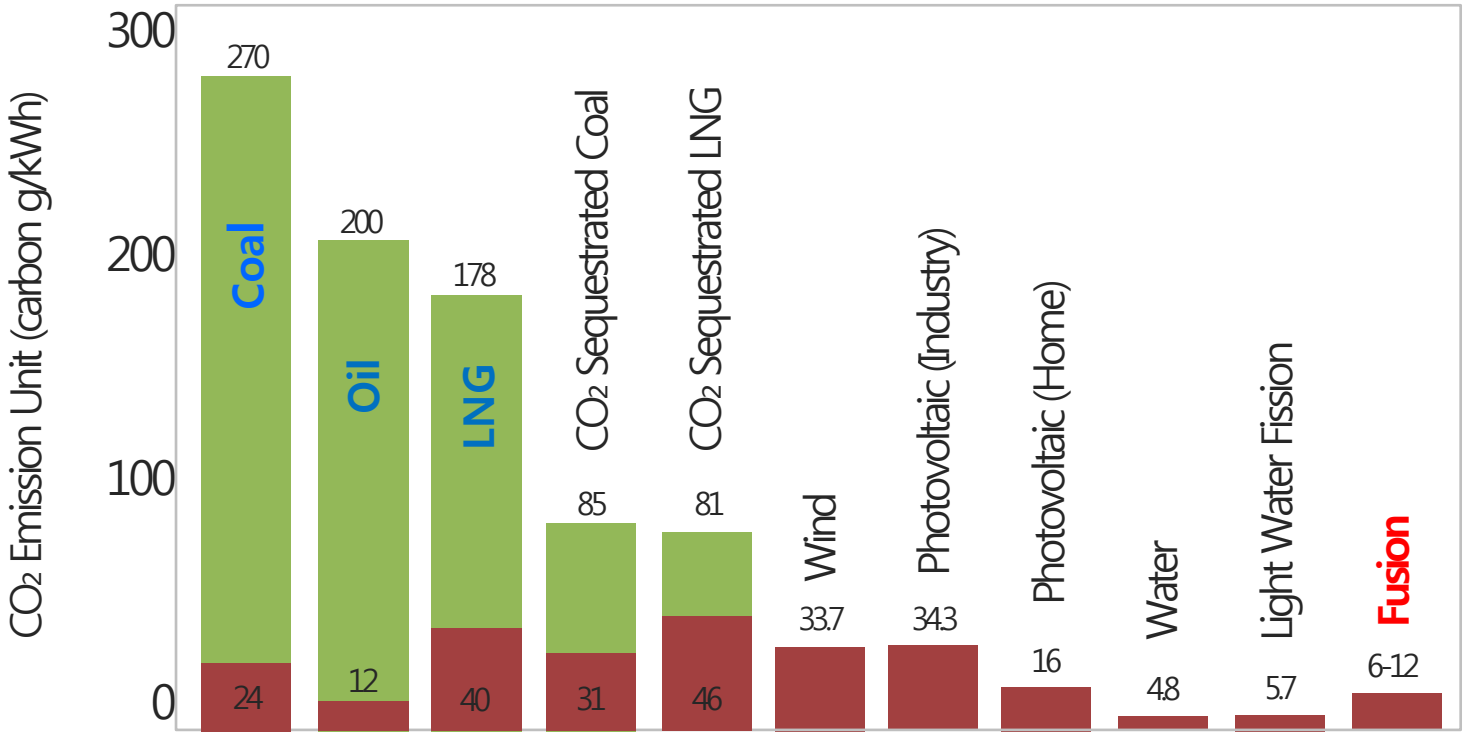
Inclusion of external cost





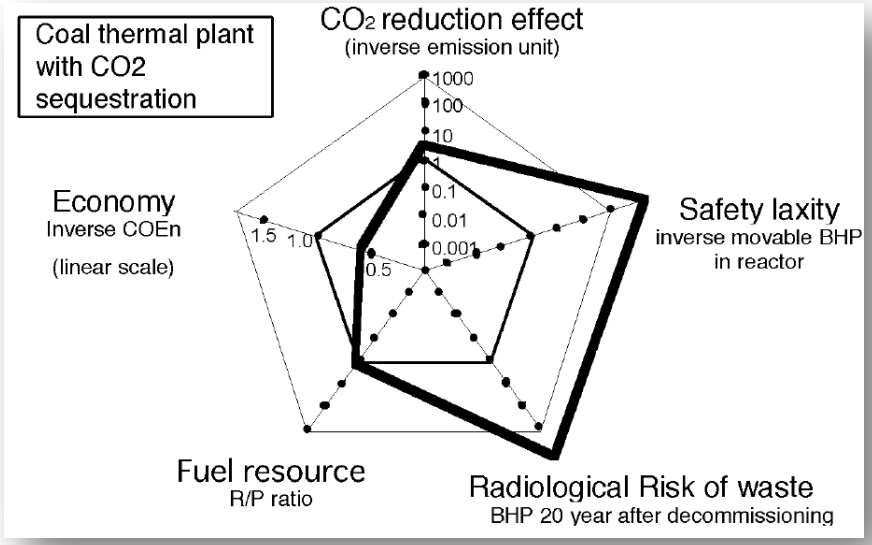
※ source : Ward et al.(2005), Cook et al.(2002)

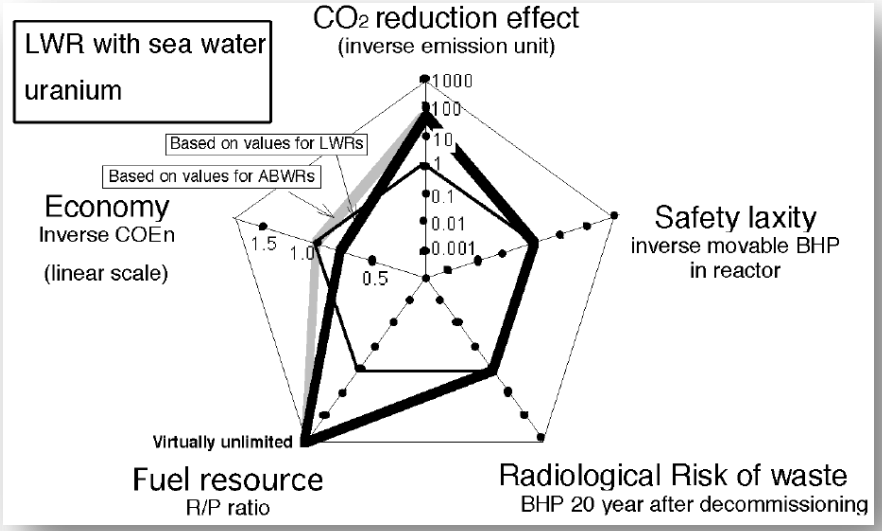
Aspect of CO_2 emission

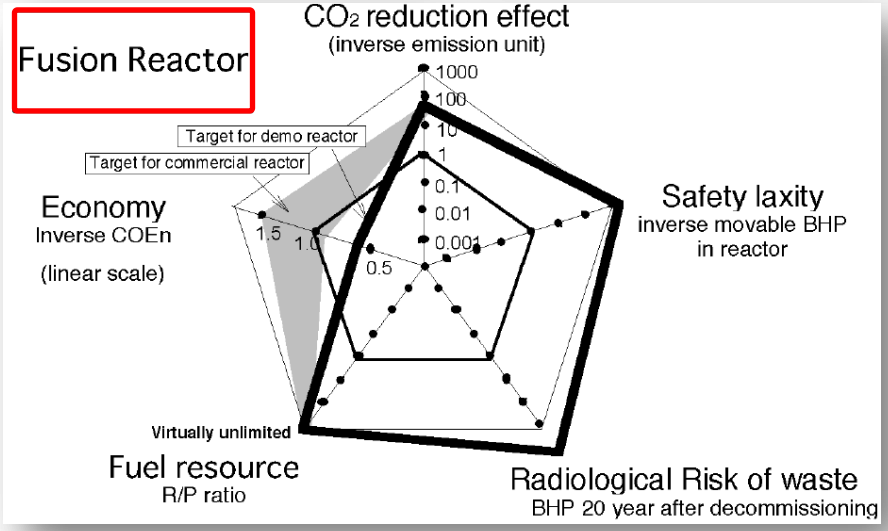


※ 출처 : JAERI, 2000

Aspect of safety, economics, fuel resources, CO_2 and radwaste







※ source : JAERI, 2000

Thank you!!