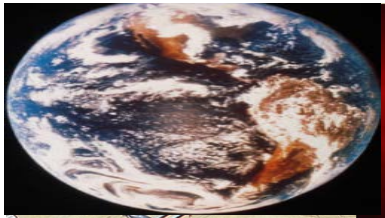


Fusion Power Associates 39th Annual Meeting and Symposium
Strategies and Expectations through the 2020s
December 4-5, 2018
At Grand Hyatt Washington Hotel

Research & Development Strategies and Expectations toward Fusion Energy through the 2020s

- ITER, Domestic Programs, and International Collaborations incl. Broader Approach toward DEMO -

Presented by
Kenichi KURIHARA

QST
Naka Fusion Institute
National Institutes for Quantum and Radiological Science and Technology

Contents

Phased R&D Programs toward Fusion Energy
(An example for the case of Japan)

Each R&D program steps forward by achieving the mission of the previous one.

In 1968-1974, the 1st Program

Mission: Improve Confinement Performance
= Construction of Small/Medium Size Tokamaks

In 1975-1991, the 2nd Program

Mission: Achieve the Breakeven Plasma
= Construction of JT-60

In 1992-now, the 3rd Program

Mission: Achieve the high-Q Steady-state DT Burn
= Construction of Experimental Reactor (=ITER)

If the scientific, technological, and social conditions are satisfied, …

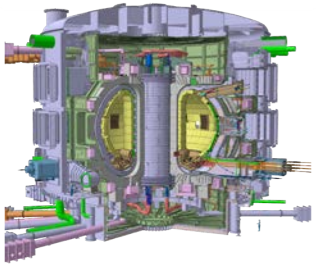
In 2030s, the 4th Program will start.

➔ Construction of DEMO

JFT-2

JT-60

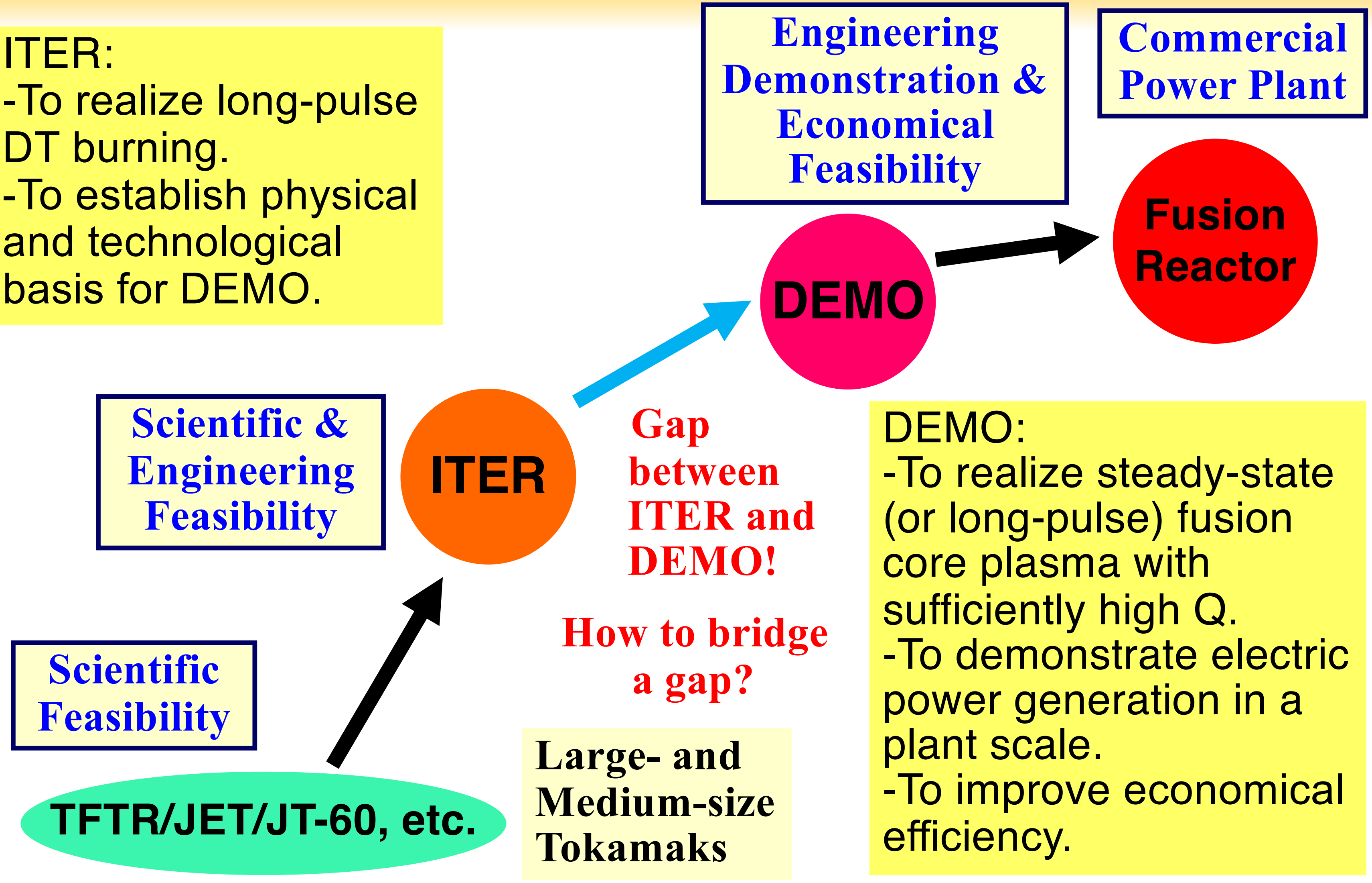
ITER



DEMO

Major Devices toward a Fusion Reactor

ITER:
- To realize long-pulse DT burning.
- To establish physical and technological basis for DEMO.



Engineering Demonstration & Economical Feasibility

Commercial Power Plant

Fusion Reactor

DEMO

Scientific & Engineering Feasibility

ITER

Gap between ITER and DEMO!

How to bridge a gap?

Scientific Feasibility

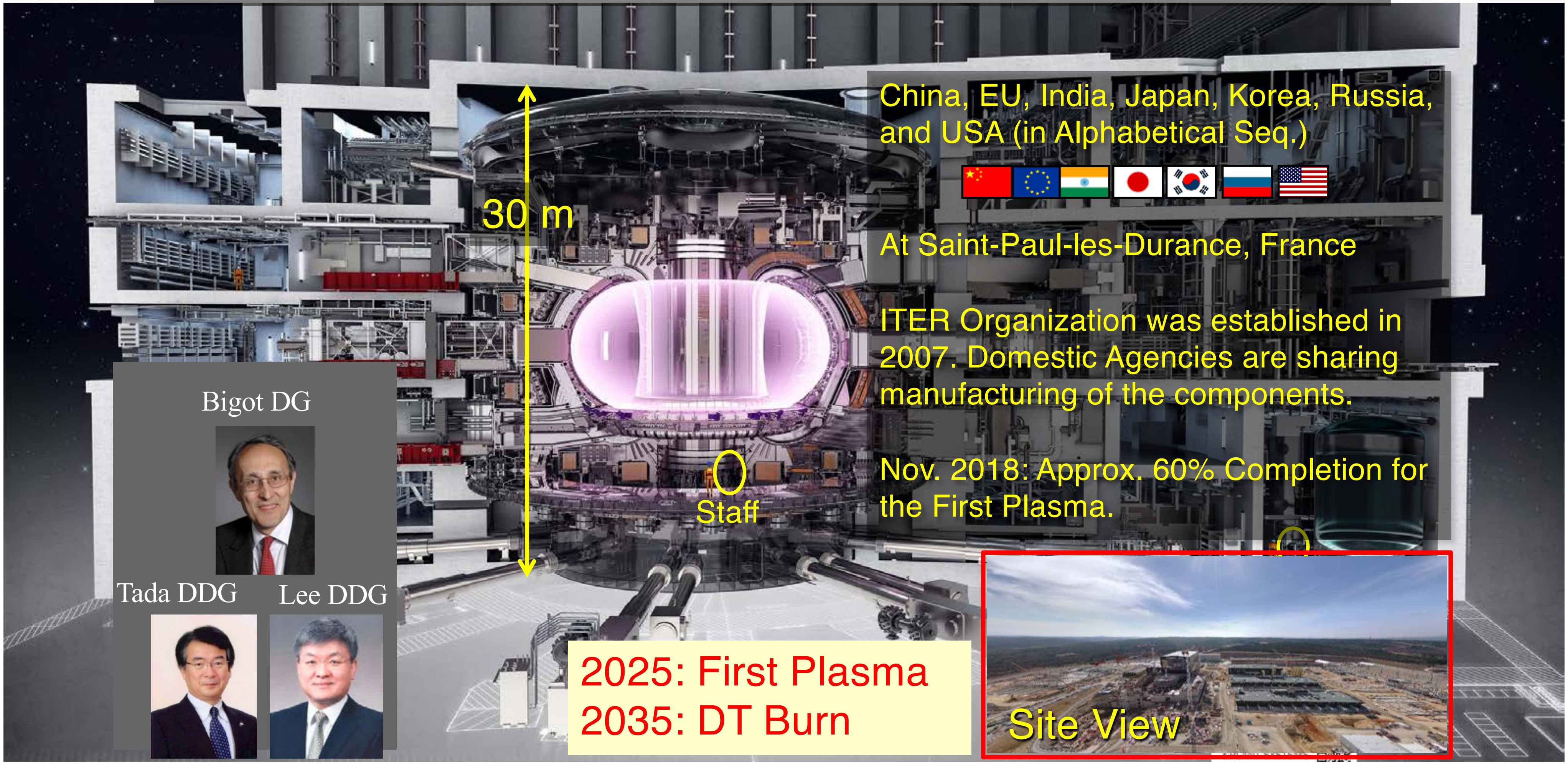
TFTR/JET/JT-60, etc.

Large- and Medium-size Tokamaks

DEMO:
- To realize steady-state (or long-pulse) fusion core plasma with sufficiently high Q.
- To demonstrate electric power generation in a plant scale.
- To improve economical efficiency.

ITER Project：7 Members Collaboration

Demonstrate Long-pulse or Steady-state DT Burn
Fusion Output = 500 MW, Q = 10（Aux. Heating 50 MW）



China, EU, India, Japan, Korea, Russia, and USA (in Alphabetical Seq.)

At Saint-Paul-les-Durance, France

ITER Organization was established in 2007. Domestic Agencies are sharing manufacturing of the components.

Nov. 2018: Approx. 60% Completion for the First Plasma.

2025: First Plasma
2035: DT Burn

ITER – Japanese In-kind Contribution

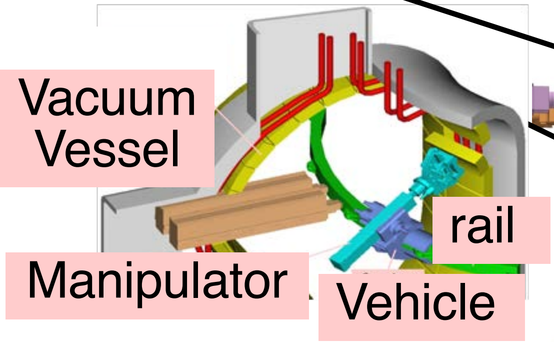
Manufacturing technology of ITER components is also indispensable for construction of DEMO .

CS Coil

- All 49 conductors were completed, and delivered to U.S. Mar. 2018.

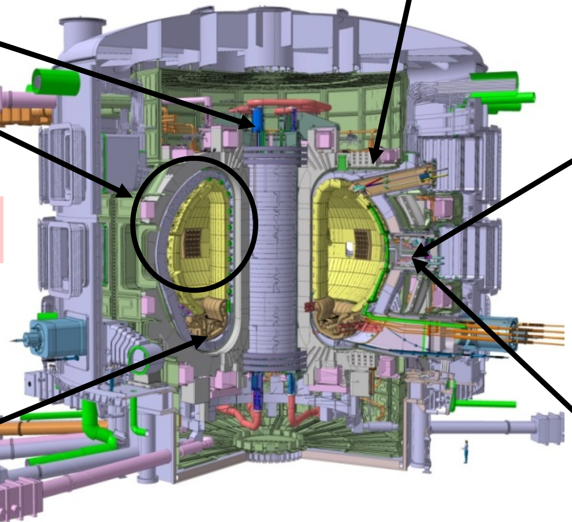
TF Coil

- 9 out of 19 TF Coils and all 19 Coil Structures are procured by JA.
- 1st WP impregnation was achieved in Sep. 2017.
- 2 Coil Structures were completed.
- First TF coil will be completed in 2019.



Remote Handling

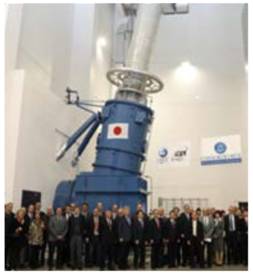
- Manufacturing design activities are in progress.



NBI system

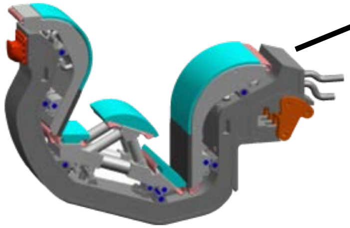
1-MV PS were installed in the NBTF site at RFX in Italy.

- Commissioning is now going.



ECH system

- 8 out of 24 gyrotrons are procured by JA.
- Two gyrotrons were manufactured and performance tests started in 2017.



Divertor (Outer Target)

- Based on the major design change to full tungsten divertor, prototype manufacturing is starting.

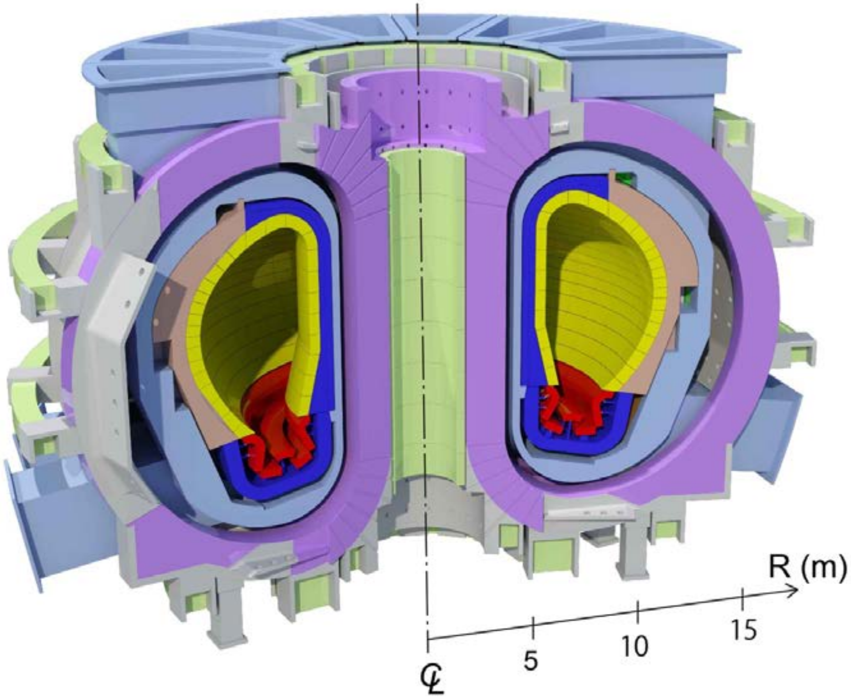
JA DEMO (2018)

Major Parameters

R_p = 8.5 m ← Sufficient Volt-sec supply for operational flexibility

P_{fus} ~ 1.5-2 GW ← Divertor heat removal, W mono-block < 10 MW/m^2

Breeding Blanket (BB) : Water-cooled Solid Breeder (WCSB)



R_p	**8.5**	**m**
A	**3.5**	
k_{95}	**1.65**	
q_{95}	**4.1**	
I_p	**12.3**	**MA**
B_T (Nb_3Sn)	**5.94**	**T**
P_{fus}	**1.46**	**GW**
n_e	**0.66**	**10^{20} m^{-3}**
HH_{98y2}	**1.31**	
β_N	**3.4**	
Neutron WL	**1.0**	**MW/m^2**

K. Tobita, et al, Overview of the DEMO conceptual design activity in Japan, FED 136 (2018) 1024-1031

ITER – Essential and Crucial for DEMO –

ITER provides the most essential information for DEMO construction, because….

- Manufacturing technology of the components such as SC coils, heating & current drive systems, divertor, remote handling, diagnostics, tritium handling, etc., for ITER provides a basis for DEMO.
  (e.g. precise welding, gyrotron, ion source, ….)
- ITER has similar power-plant-scale facilities to DEMO.
- Plant integration & project management experience could be valuable lesson learned for DEMO.
- ITER Test Blanket Modules directly contribute to ones for DEMO.
- Licensing procedures for ITER are surely a good example of the DEMO regulation for any country.
- DT burning plasma operation generates a physics basis for DEMO.

Success in ITER construction and operation is necessary for DEMO.

Gap between ITER and DEMO ?

On the basis of ITER, key technological elements for DEMO – Gap – are categorized as follows:

1. DEMO design
2. Superconducting Magnets
3. Blanket
4. Divertor
5. Heating and Current Drive Systems
6. Theory and Numerical Simulation
7. Reactor Core Plasma Physics
8. Fuel Systems
9. Material Development and Code/Standards/Criteria
10. Safety of DEMO Reactor and Safety Research
11. Availability and Maintainability
12. Diagnostics and Control Systems

We need to find a solution for all the issues in the key technological elements by the time to start DEMO construction in 2030s.

➔ How to bridge a gap?

How to bridge a gap between ITER and DEMO?

Japanese Strategies to bridge a gap are the following activities:

(1) ITER (already mentioned)

(2) Broader Approach (BA) Activities (2007-2020: Phase I)

(a) Satellite Tokamak **JT-60SA** Program: high-β_N SC Tokamak

(b) Engineering Validation and Engineering Design Activities for the International Fusion Materials Irradiation Facility (**IFMIF/EVEDA**):

- Develop prototype accelerator for International Fusion Materials Irradiation Facility (IFMIF)

(c) International Fusion Energy Research Center (**IFERC**):

- DEMO Design and DEMO R&D
- Computer Simulation Center

Discussion of BA Phase II (2020 - 2025)

In order to solve all the issues for DEMO completely,

(3) New Strategy toward DEMO

– Japan’s Strategy to promote R&D for a fusion DEMO reactor – was formulated, and is now being carried into action (2018-):

- Check and Review through the 2020s-2030s
- Action Plan for DEMO and Roadmap including Domestic Programs

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Japanese Strategy toward DEMO

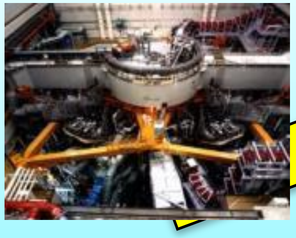
Scientific Feasibility

JT-60

Core Plasma Research

Q=1.25

Ti(0)=45keV



Scientific & Technological Feasibility

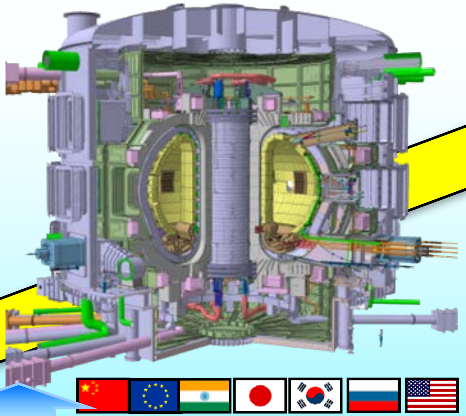
ITER

Fusion Power of 0.5GW

Q=10

DT Burning

@France



Technological Demonstration & Economic Feasibility

DEMO

Fusion Power Plant

Supplement ITER toward DEMO

Support ITER

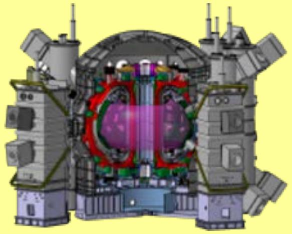
Academic Research

Helical Device LHD

Laser FIREX

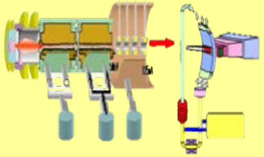
Broader Approach (BA) Activities

Establish Basis for DEMO



JT-60SA
@Naka

IFERC
@Rokkasho

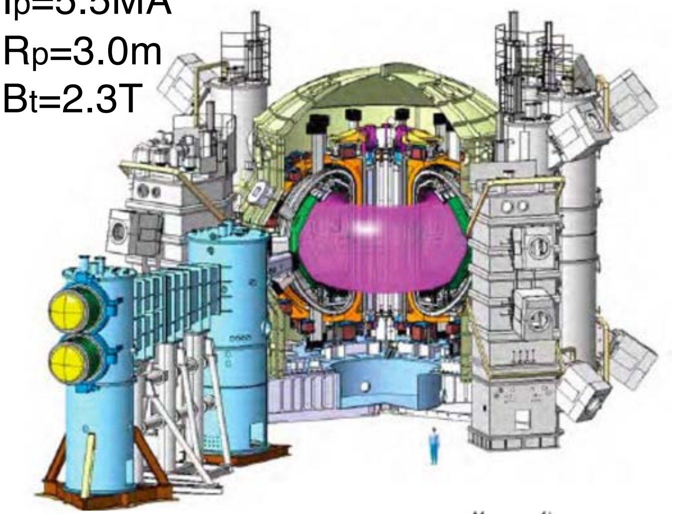


IFMIF/EVEDA
@Rokkasho

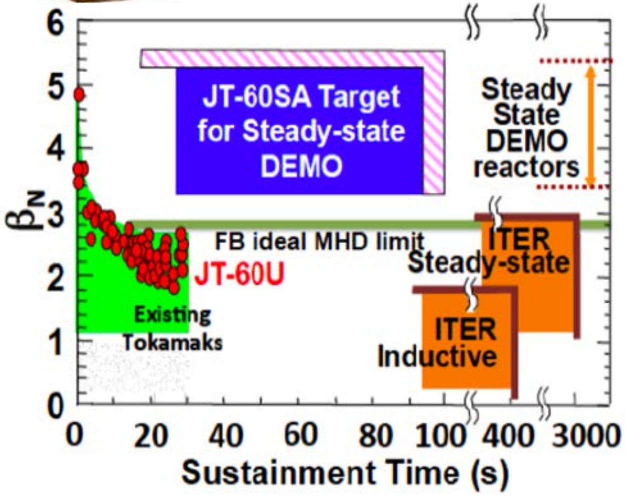
Total BA cost:
Approx. 900 M$, shared by JA and EU

(a) BA Satellite Tokamak JT-60SA *(Super Advanced)*

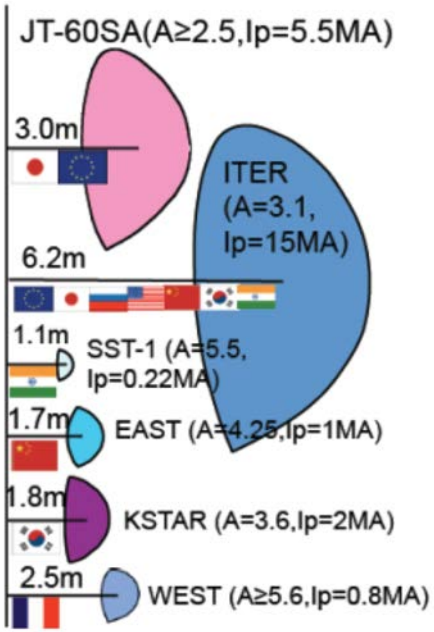
I_p=5.5MA
R_p=3.0m
B_t=2.3T



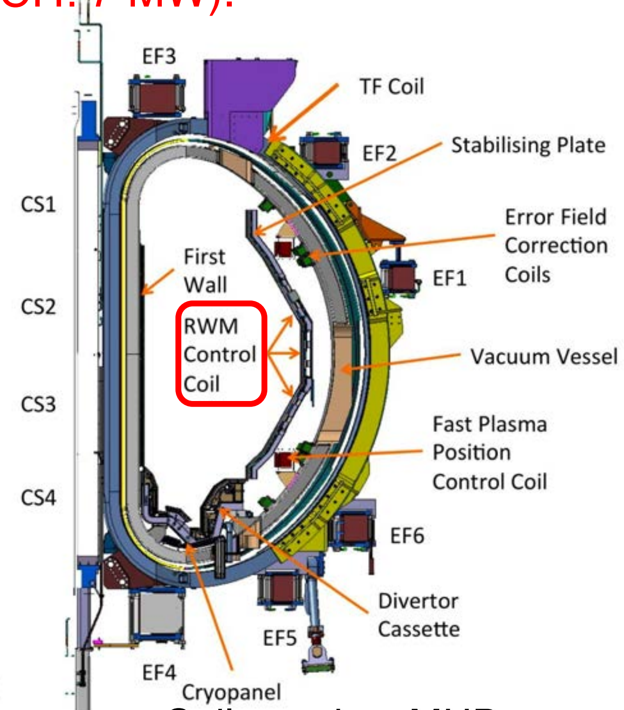
JT-60SA: a highly shaped ($S=q_{95}I_p/(aB_t)\sim7$, A~2.5) SC tokamak confining a deuterium plasma with I_p=5.5 MA for typically 100s longer than the timescales of the key plasma processes such as current diffusion with high heating power of 41MW (PNB: 24, NNB: 10, ECH: 7 MW).



Target Region of Pressure



SC Tokamaks

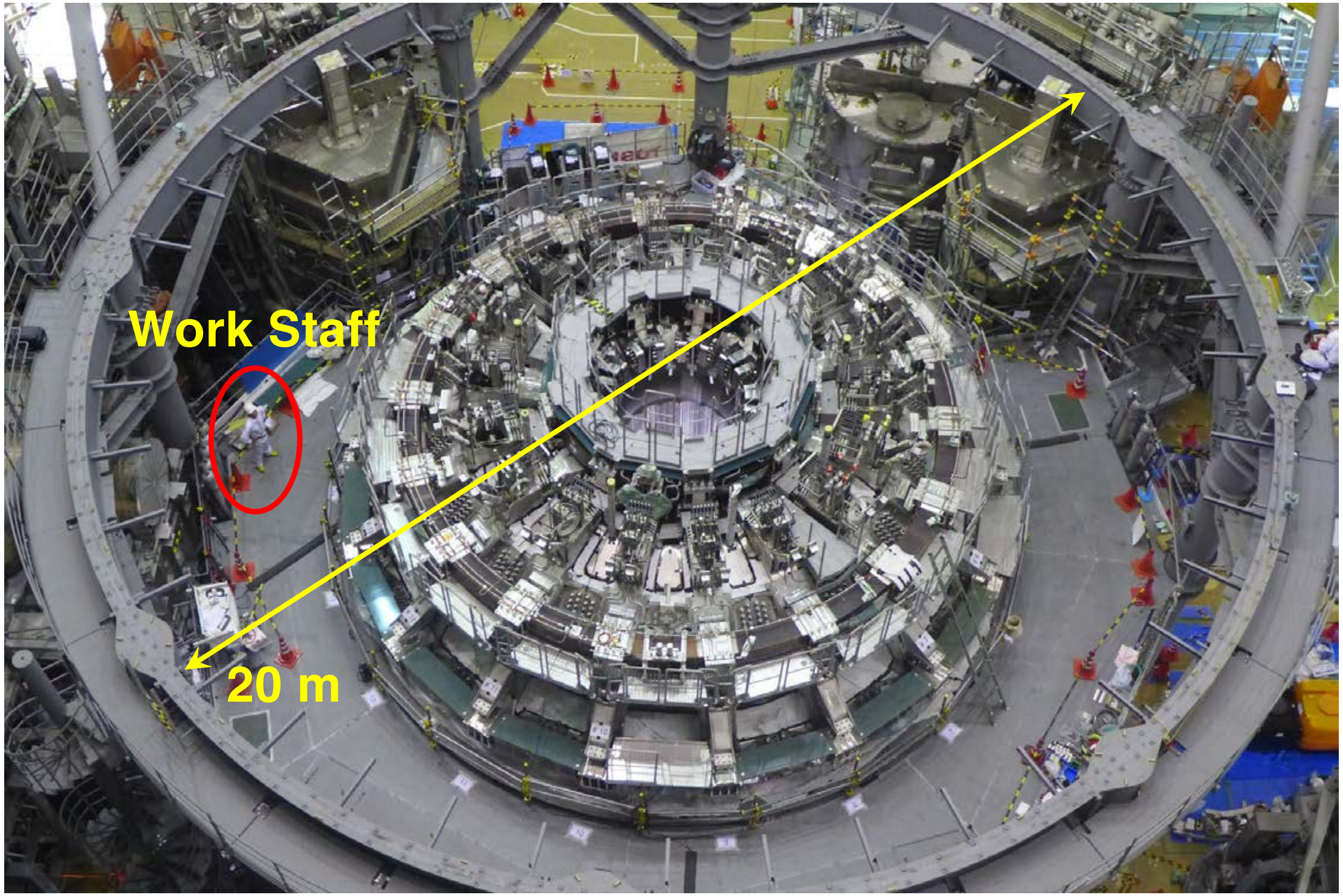


Coils against MHD Instabilities

(a) BA Satellite Tokamak JT-60SA (*Super Advanced)*

Current Status of Assembly (Nov. 30, 2018)

18 TF coils, 6 EF coils, and 360-deg VV have been all set at the right position.



(a) BA Satellite Tokamak JT-60SA (*Super Advanced)*

JT-60SA Assembly Is Going on Schedule.

Cryostat Base

Lower Poloidal Field Coils

Vacuum Vessel

VV thermal shield

TF Coils

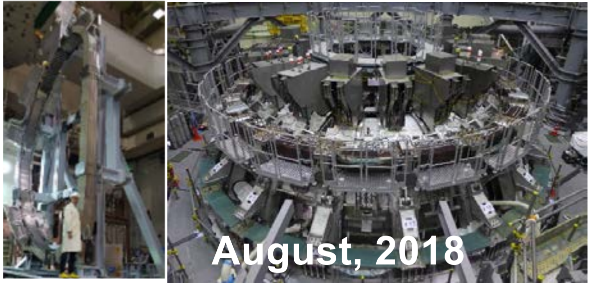
Upper Poloidal Field Coils and Central Solenoid

Cryostat

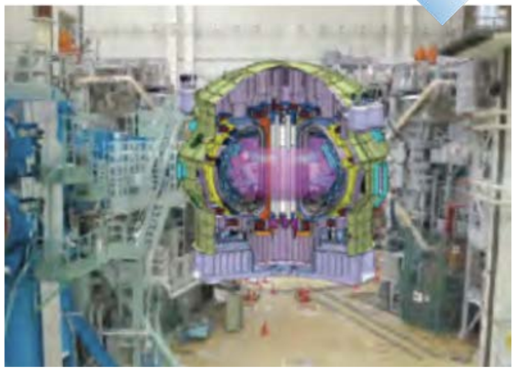
TF Coil Cold Test Facility

Current Lead

TF Coils



Completion of Tokamak Assembly: March, 2020



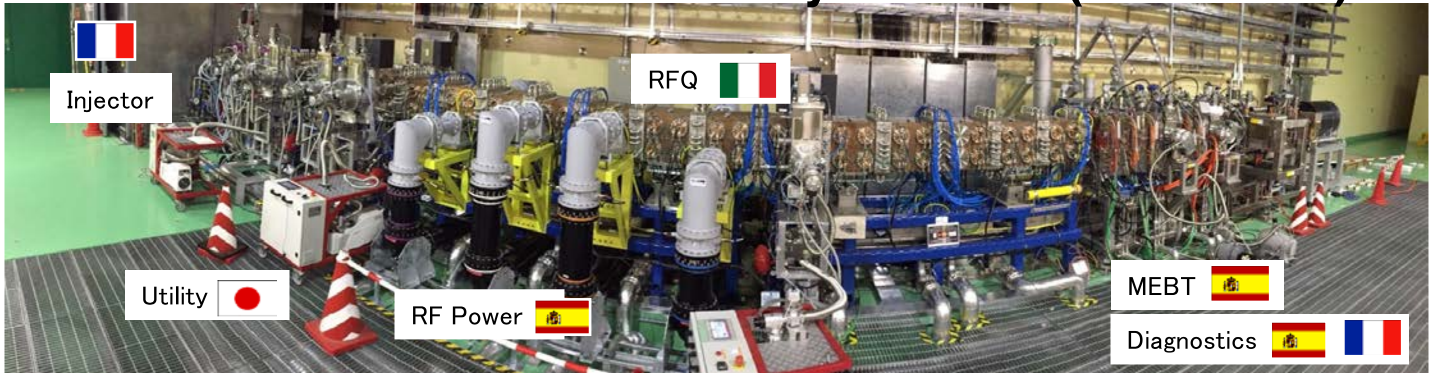
First Plasma: Sep. 2020

power supplies cryoplant NBI ECRF diagnostics, etc.

QPC **MG-set** **SCMPS** **SNU**

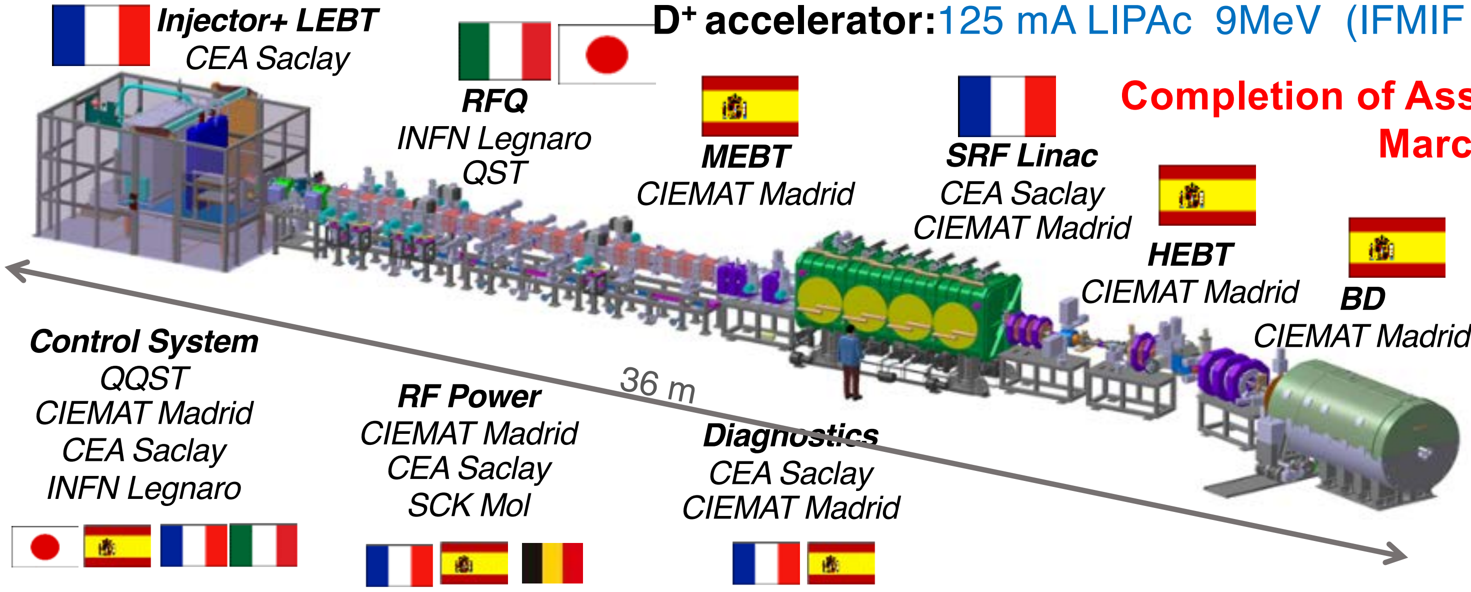
(b) BA IFMIF/EVEDA Project

Current Status of Assembly of LIPAc(Nov. 2018)



D$^+$ accelerator: 125 mA LIPAc 9MeV (IFMIF 40MeV)

Completion of Assembly: March, 2020



Injector+ LEBT
CEA Saclay

RFQ
INFN Legnaro
QST

MEBT
CIEMAT Madrid

SRF Linac
CEA Saclay
CIEMAT Madrid

HEBT
CIEMAT Madrid

BD
CIEMAT Madrid

Control System
QQST
CIEMAT Madrid
CEA Saclay
INFN Legnaro

RF Power
CIEMAT Madrid
CEA Saclay
SCK Mol

Diagnostics
CEA Saclay
CIEMAT Madrid

Linear IFMIF Prototype Accelerator - **LIPAc**

RFQ: Radio Frequency Quadrupole

MEBT/HEBT: Medium/High Energy Beam Transport Lines

SRF Linac: SC RF Linac

(c) BA International Fusion Energy Research Center (IFERC)

DEMO Design

DEMO Task meeting
(Garching, Nov. 2017)

Scope of BA DEMO Design activity

- Gap study between ITER and DEMO regarding critical reactor design issues
- Analysis on the issues to find possible solutions to them and narrow down options or designs
- System design and design integration toward DEMO conceptual designs

Status

-Since 2011, 38 technical meetings were held for JA/EU joint design work on DEMO.

Highlights

-The 2nd Intermediate Report was developed as an internal report in April 2017.

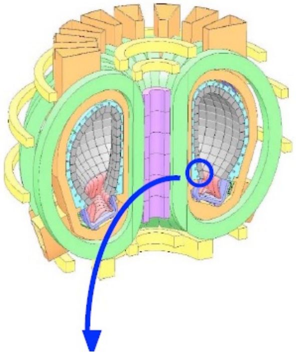
190 pages summarize JA/EU joint design activity.

2nd Intermediate Report

(c) BA International Fusion Energy Research Center (IFERC)

DEMO R&D

Five R&D subjects for DEMO Blanket from 2007 to 2017 (Database activity during June 2017- March 2020)



4. Tritium Breeder

Li_2TiO_3
1 mm diameter

$^6Li + n \rightarrow T + He$

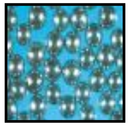
1. RAFM (Reduced Activated Ferric Martensite)

Structural material for DEMO Blanket

2. SiC/SiC

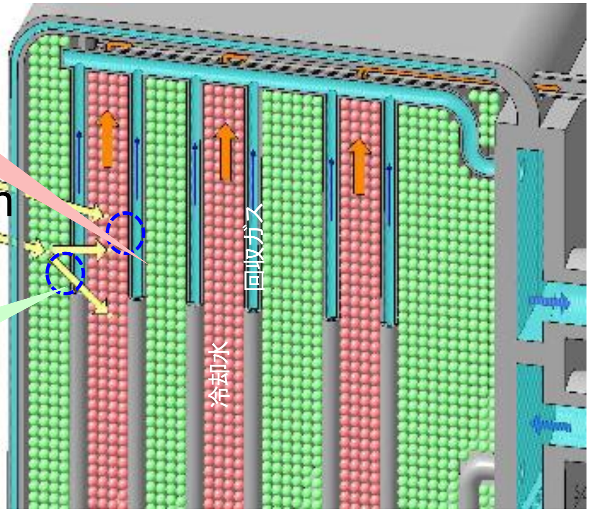
Advanced functional materials

5. Neutron Multiplier



$Be_{12}Ti$
1mm diameter

$Be + n \rightarrow 2He + 2n$



Recovery of tritium

3. Tritium Technology

(c) BA International Fusion Energy Research Center (IFERC)

Computer Simulation Center

Fusion-Dedicated Supercomputer

On the basis of success of BA IFERC Computer Simulation Center, QST introduced a new successor supercomputer and started its operation in June 2018.

1370 Computation Node/
Intel Xeon Gold 6148

4.208 PFLOPS(peak)
256TB MEM
HPLinpack 2.787PFLOPS
(the 61st in the world, June 2018)

This supercomputer is used for JA DEMO R&D including ITER, JT-60SA, neutron source & related research field, and **will be used to execute JA Action Plan for DEMO.**

Discussion of BA Phase Ⅱ

- BA Activities were launched under the BA Agreement between Japan and EU in 2007, and will finish in March 2020. The activities are (1) JT-60SA, (2) IFMIF/EVEDA, and (3) IFERC.
- BA Activities have been very well managed by both JA and EU, and now come to a mutual-trust-based collaboration.

- JA-EU recommends the following activities should be expected in the extended period of 5 years as BA phase II just after the current BA ones finish (April 2020 to March 2025).
  (1) To develop operation scenarios for the ITER and DEMO reactor by using JT-60SA.
  (2) To achieve the long-duration operation of Prototype Accelerator LIPAc (IFMIF/EVEDA).
  (3) To design a DEMO reactor, to execute necessary R&D, and to operate the computer simulation center (IFERC).

How to bridge a gap between ITER and DEMO?

Japanese Strategies to bridge a gap are the following activities:

(1) ITER (already mentioned)

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(a) Satellite Tokamak **JT-60SA** Program: high-β_N SC Tokamak

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- Develop prototype accelerator for International Fusion Materials Irradiation Facility (IFMIF)

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- DEMO Design and DEMO R&D
- Computer Simulation Center

  Discussion of BA phase II (2020 - 2025)

In order to solve all the issues for DEMO completely,

(3) New Strategy toward DEMO – Japan's Strategy to promote R&D for a fusion DEMO reactor – was formulated, and is now being carried into action (2018-):

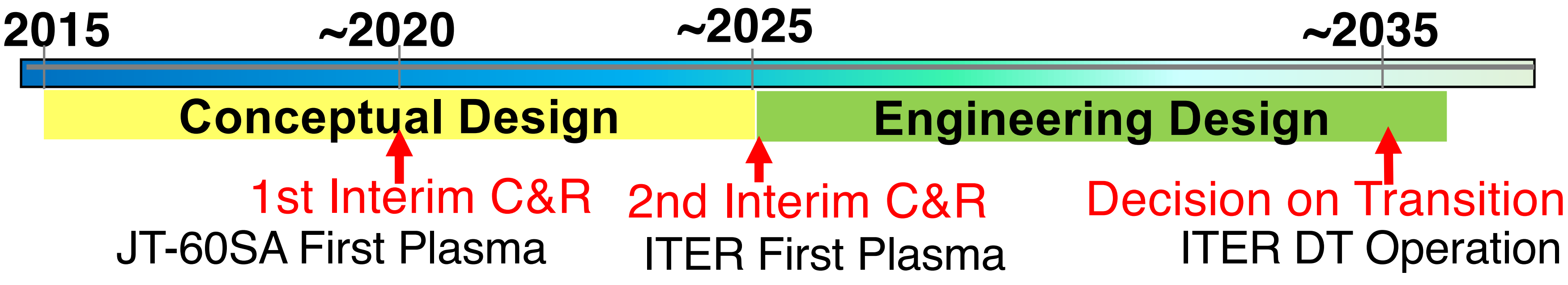
- Check and Review through the 2020s-2030s
- Action Plan for DEMO and Roadmap including Domestic Programs

New Strategy toward DEMO (1/2)

Japan's Strategy to Promote R&D for a Fusion DEMO Reactor

http://www.mext.go.jp/b_menu/shingi/gijyutu/gijyutu2/074/attach/1400127.htm

Check & Review's and Transition to DEMO through 2020s-2030s



C&R Items

(1) Validate burn control in the self-heating area by ITER.
(2) Establish an operational technique for stationary high-β plasma for operation of the DEMO reactor.
(3) Establish integrated technologies by ITER.
(4) Develop materials for the DEMO reactor.
(5) Develop reactor engineering for DEMO.
(6) Design the DEMO reactor.
(7) Establish public acceptance.

Check & Review Items, Works, and Criteria (1/4)

Items	1st C&R (~ 2020)	2nd C&R (~ 2025)	Criteria for transition to DEMO (2030s)
(1) Validate burn control in the self-heating area by ITER	- Create a technical target achievement plan for ITER.	- Conduct collaborative research based on the ITER technical target achievement plan.	- Maintain fusion power of Q=10 or higher (for over several hundred seconds) and validates burn control in ITER.
(2) Establish an operational technique for stationary high-beta plasma for operation of the DEMO reactor	- Proceed with ITER collaborative research and preparatory studies on stationary high-beta plasma and start JT-60SA research.	- Achieve a high-beta plasma by non-inductive current drive in JT-60SA. - Have integrated simulations including the divertor verified by JT-60SA and other projects. - Create a plan for JT-60SA divertor research compatible with the DEMO reactor's plasma-facing walls.	- Gain prospects for non-inductive steady operation by achieving non-inductive current drive in ITER, and integrated simulations based on ITER knowledge of burn control. - Validates the stationary operation of a high-beta (βN = 3.5 or higher) collisionless plasma in JT-60SA compatible with the DEMO plasma-facing walls.

Check & Review Items, Works, and Criteria (2/4)

Items	1st C&R (~ 2020)	2nd C&R (~ 2025)	Criteria for transition to DEMO (2030s)
(3) Establish integrated technologies by ITER	- Establish manufacturing technologies for SC coils and other key components and build an integrated technological foundation through the construction of JT-60SA.	- Launch ITER operation. - Acquire integrated technologies to manufacture, install and adjust the ITER apparatus.	- Establish integrated technologies through ITER operation and maintenance and confirm the safety technology.
(4) Develop Materials for the DEMO reactor	- Obtain reactor irradiation data of low activation ferrite steel (LAFS) up to 80 dpa and finalize the materials for testing under a neutron irradiation environment similar to nuclear fusion. - Complete the concept design of the nuclear fusion neutron source.	- Complete the validation of heavy irradiation data by fission reactor irradiation of LAFS up to 80 dpa. - Evaluate the initial irradiation behavior of blanket and diverter materials by reactor irradiation and validate the principles of Li-securing technology. - Start the construction of a fusion neutron source and create a plan for collecting material irradiation data.	- Draw up the structural design criteria. - Establish Li-securing techniques on a pilot-plant scale. - Collect initial irradiation data on low activation ferrite steel and blanket and divertor functional materials with a nuclear fusion neutron source.

Check & Review Items, Works, and Criteria (3/4)

Items	1st C&R (~ 2020)	2nd C&R (~ 2025)	Criteria for transition to DEMO (2030s)
(5) Develop reactor engineering for DEMO	- Formulate divertor development strategies. - Create technical development plans for reactor engineering requiring early preparation, including SC coil technology. - Collect the necessary data for blanket design from the cold testing facilities.	- Collect the necessary data relevant to the divertor, including the properties of the plasma-facing materials in JT-60SA, LHD, etc. - Create development plans for the SC coil, divertor, remote maintenance, heating/current drive, fuel system, measurement/control, etc. for the engineering technology of a medium- or plant-sized reactor, and complete the concept designs of these items for the development test facilities. - Establish basic technology for the power generation blanket, build the first ITER-TBM, and complete the safety verification tests on the actual device.	- Establish reactor engineering technologies that support DEMO reactor design, including such items as the SC coil, divertor, remote maintenance, heating/current drive, fuel system and measurement/control, based on the outcomes of the development test facilities and the performance results from ITER, JT-60SA, etc. - Evaluate tritium recovery in ITER and validate the evaluation technique for tritium behavior using the fusion neutron source.

Check & Review Items, Works, and Criteria (4/4)

Items	1st C&R (~ 2020)	2nd C&R (~ 2025)	Criteria for transition to DEMO (2030s)
(6) Design the DEMO reactor	- Formulate the overall objectives for the DEMO reactor. - Draw up a basic concept design of the DEMO reactor. - Submit requests regarding reactor core and reactor engineering developments.	- Complete the DEMO reactor's concept design that ensures high safety standards and economic feasibility by incorporating reactor core and reactor engineering developments. - Identify issues in developing reactor core and reactor engineering to establish a technological foundation for engineering design and create a development plan.	- Acquire social acceptability, confirm economic feasibility at the stage of practical use, and complete the DEMO reactor engineering design by coordinating reactor core and reactor engineering developments. - Draw up policies on safety laws and regulations.
(7) Establish Public Acceptance	- Establish a headquarters for promoting social awareness. - Draw up an awareness activity promotion plan.	- Promote social awareness initiatives and conduct social relations activities.	- Proceed with social relations activities toward the construction and operation of the DEMO reactor.

New Strategy toward DEMO (2/2)

New Strategy toward DEMO indicates the following points to solve technological issues:

- Development plan should contain construction cost, operation scenario, etc., with technical consistency.
- **Technological issues are classified into 15 elements (12 issues (Slide 9) and 3) below** as "**Action Plan.**"
    - 1. DEMO design, 2. SC Magnets, 3. Blanket, 4. Divertor, 5. Heating and CD, 6. Theory and Numerical Simulation, 7. Core Plasma Physics, 8. Fuel Systems, 9. Material Development and Code/Standards/Criteria, 10. Safety, 11. Availability and Maintainability, 12. Diagnostics and Control Systems, 13. Social Relation, 14. Helical, and 15. Laser
- Action Plan provides Work Breakdown that leads to solutions for 15 R&D issues along with the R&D timeline of 3 periods of now-2020, 2020-2025 and 2025-2035.
- Framework covering industry, academia and government should be reorganized.
- Human resources for long-term R&D should be cultivated.

An Example of Action Plan – DEMO Design (1/2)

Black: Kick off of Items

Red : Close of items

2015 2020~ 2025~ 2035~

DEMO Design	Conceptual design Establish phys.& eng. guideline Definition of safety policy Database(DB) of physics, engineering & materials	Prepare for licensing	Engineering design Site asses. Const. design Decision of site assess. for site safety DB update w/JT-60SA & irrad. results
Concept & Construct. Plan	(15)S: Phys.& eng. Guideline (19) (15)S: Basic design of concept (19) (16)S/TF: Fuel cycle strategy ------ (17)Q/N/U/S: Integrated simulator (18)S/D: Cost evaluation -------------	(20)S/D: Conceptual design(26) --------------------------------> (26) --------------------------------> (26) (23)S/Q/F: Rev. of target plasma (26) -------------------------------------->	(27)D/S: Design of Demo core parts (35) ------------------------------> (31) (29)G/TF: Candidate site (31) (32)G: Site assessment (35)
Equipment Design	(15)S/Q: Basic design of SC (19) (19)S/Q: Demo TBM targets (19) (17)S/D: Equip. config. w/ BOP (19)	(21)S/D: Conceptual Design of BOP (26)	**(for site asses.)** (27)D/S: Plant design,(31) (27)A/S: Reg & stand (31) **(after site candidates)** (32)D/S: Design plant (35)

Responsibility: S - Special Design Team, Q – QST, N – NIFS, U – universities, D – manufacturing companies, G – Japan. Gov.

An Example of Action Plan – DEMO Design (2/2)

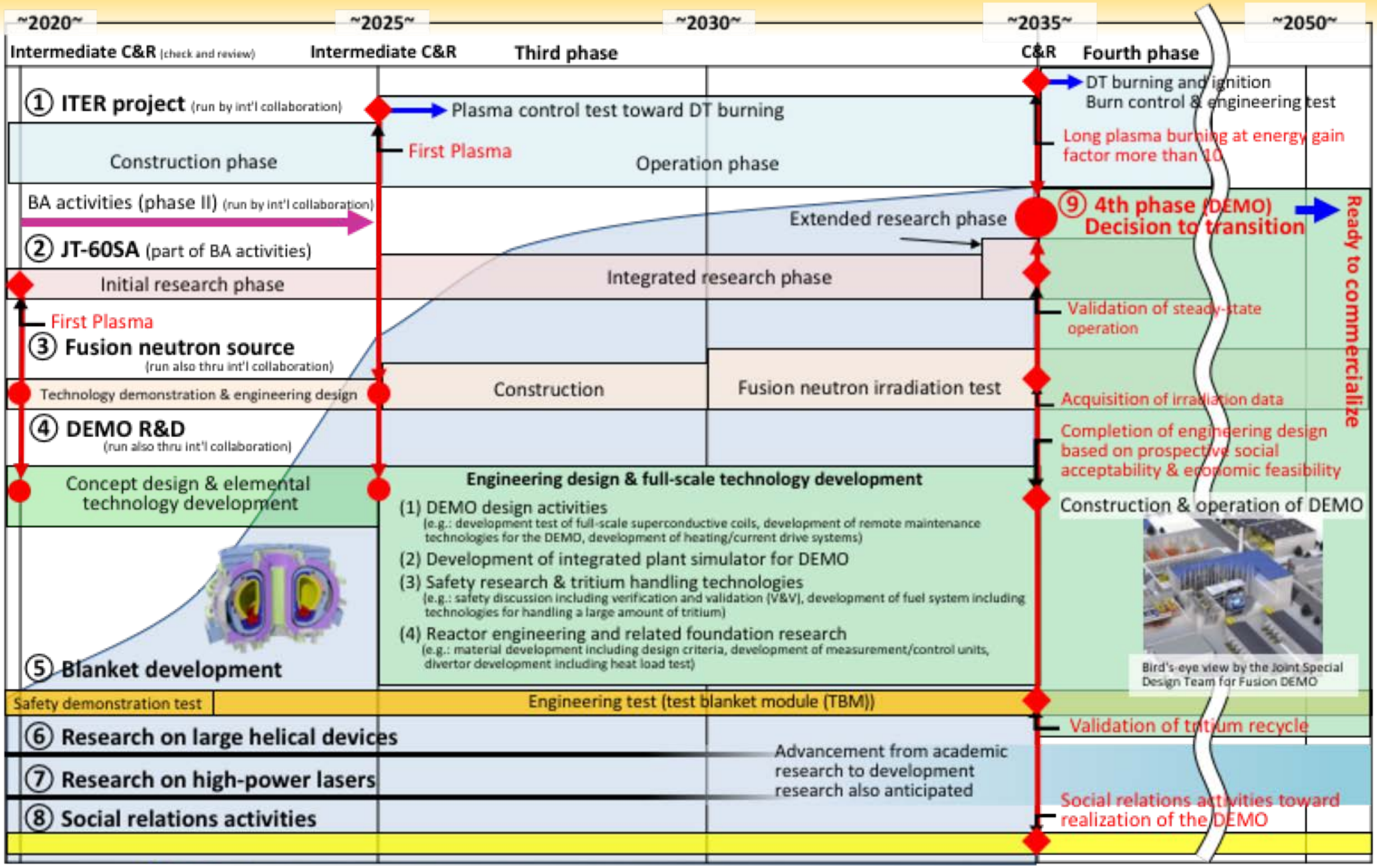
Black: Kick off of Items

Red : Close of items

	2015	2020~	2025~ 2035~
DEMO Design	Conceptual design Establish phys.& eng. guideline Definition of safety policy Database(DB) of physics, engineering & materials	Prepare for licensing	Engineering design Site asses. Const. design Decision of site assess. for site safety DB update w/JT-60SA & irrad. results
Safety Policy	(16)S/D: Draft safety policy (19)	(20) S/D: Asses. of Safety aspect -------------- (20)S/D: Asses. of Safety aspect (26) (20)TF/S: Draft for safety regulation (26)	--------------------------------> (31) (27)G/TF: Safety regulation (35) (32)G: Safety assess (35)
Database of Physics, Enginrg & Materials	(16)Q/U/F/S: Demo Phys. DB ------- (16)Q/U/F/S: Eng. & Materials DB-	---------------------------------->(26) ---------------------------------->(26)	(27)Q/S: Update Eng.& materials DB (31) **w/ results of JT-60SA** (32)Q/S: Update material DB (35) **w/ 14MeV heavy irrad data**

Responsibility: S - Special Design Team, Q – QST, N – NIFS, U – universities, D – manufacturing companies, G – Japan. Gov.

Japanese Roadmap toward DEMO



~2020~ ~2025~ ~2030~ ~2035~ ~2050~

Intermediate C&R (check and review) | Intermediate C&R | Third phase | C&R | Fourth phase

① **ITER project** (run by int'l collaboration)

Construction phase

Plasma control test toward DT burning

First Plasma

Operation phase

DT burning and ignition
Burn control & engineering test

Long plasma burning at energy gain factor more than 10

BA activities (phase II) (run by int'l collaboration)

② **JT-60SA** (part of BA activities)

Initial research phase

Integrated research phase

Extended research phase

Validation of steady-state operation

First Plasma

③ **Fusion neutron source** (run also thru int'l collaboration)

Technology demonstration & engineering design

Construction

Fusion neutron irradiation test

Acquisition of irradiation data

④ **DEMO R&D** (run also thru int'l collaboration)

Concept design & elemental technology development

Engineering design & full-scale technology development

(1) DEMO design activities
(e.g.: development test of full-scale superconductive coils, development of remote maintenance technologies for the DEMO, development of heating/current drive systems)

(2) Development of integrated plant simulator for DEMO

(3) Safety research & tritium handling technologies
(e.g.: safety discussion including verification and validation (V&V), development of fuel system including technologies for handling a large amount of tritium)

(4) Reactor engineering and related foundation research
(e.g.: material development including design criteria, development of measurement/control units, divertor development including heat load test)

Completion of engineering design based on prospective social acceptability & economic feasibility

⑨ **4th phase (DEMO) Decision to transition**

Ready to commercialize

Construction & operation of DEMO

Bird's-eye view by the Joint Special Design Team for Fusion DEMO

⑤ **Blanket development**

Safety demonstration test

Engineering test (test blanket module (TBM))

Validation of tritium recycle

⑥ **Research on large helical devices**

⑦ **Research on high-power lasers**

Advancement from academic research to development research also anticipated

⑧ **Social relations activities**

Social relations activities toward realization of the DEMO

Legend

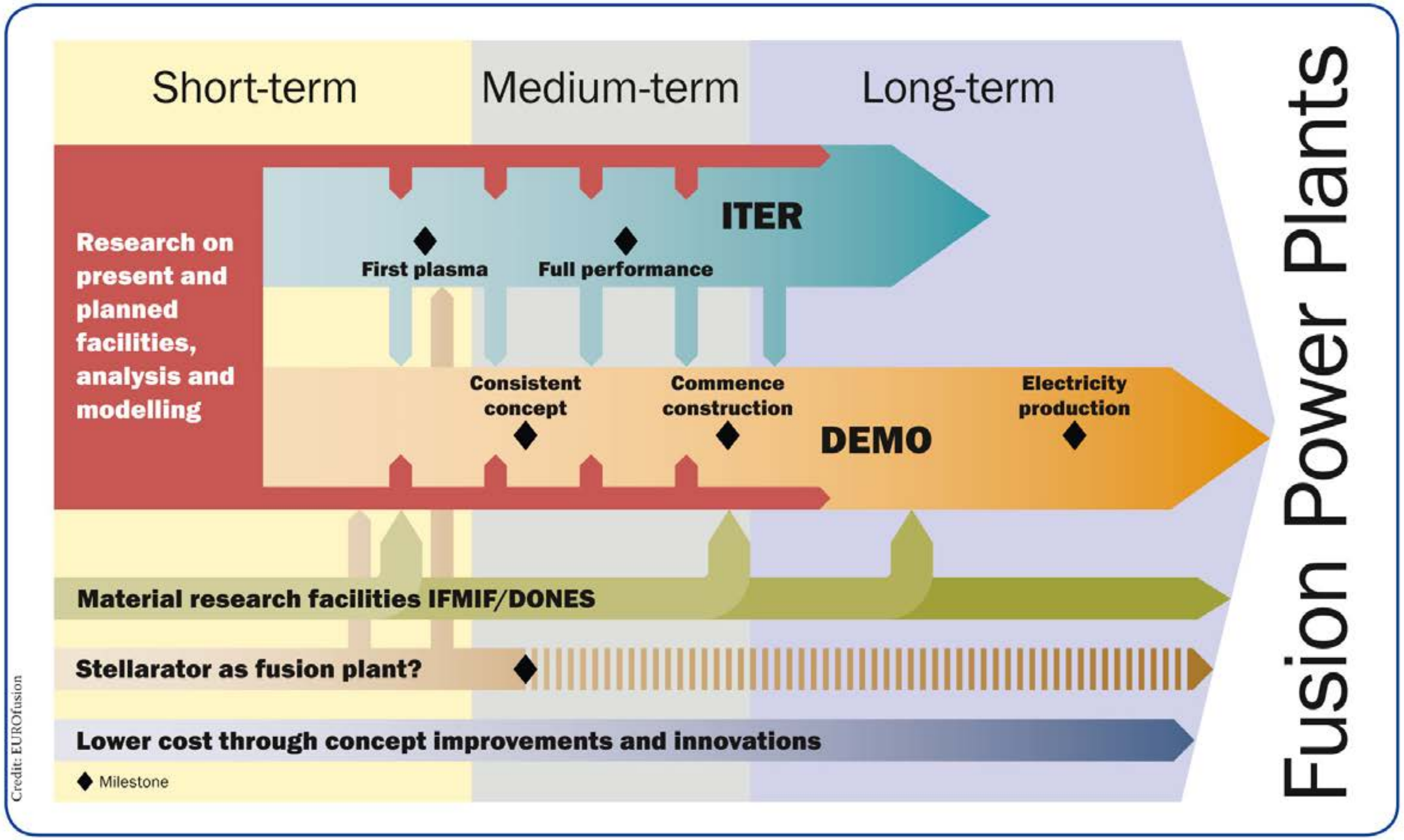
◆ When to achieve the target ⮤ Target to achieve

● When to decide transition to the next phase

⌂ Figure of activities required

Survey of Roadmaps and Plans toward DEMO

European Roadmap toward DEMO



Credit: EUROfusion

The contents of this slide are described in "European Research Roadmapto the Realisation of Fusion Energy (Long/short Version)," by EUROfusion, Sept. 2018

With the Permission of
Dr. Tony Donne, Programme
Manger EUROfusion

European Roadmap toward DEMO

The road to fusion electricity: Three stages to design fusion power plants

Near term
- Construction of ITER
- Research & Development in support of ITER
- Deuterium-tritium operation of JET
- Concept Design phase of DEMO
- Research & Development for DEMO
- Construction of a fusion materials testing facility, IFMIF-DONES
- Scientific and technological exploitation of the stellarator concept

Medium term
- First scientific and technological exploitation of ITER
- First exploitation of IFMIF-DONES
- Engineering Design phase of DEMO with industrial involvement
- Development of power plant materials and technologies
- Possible further development of the stellarator concept

Long term
- High performance and advanced technology results from ITER
- Qualify long-life materials for DEMO and power plants with IFMIF-DONES
- Finalisation of the design of DEMO
- Construction of DEMO
- Demonstration of electricity generation
- Commercialisation of technologies and materials
- Deployment of fusion together with industry

The contents of this slide are described in "European Research Roadmapto the Realisation of Fusion Energy (Long/short Version)," by EUROfusion, Sept. 2018

With the Permission of
Dr. Tony Donne, Programme
Manger EUROfusion

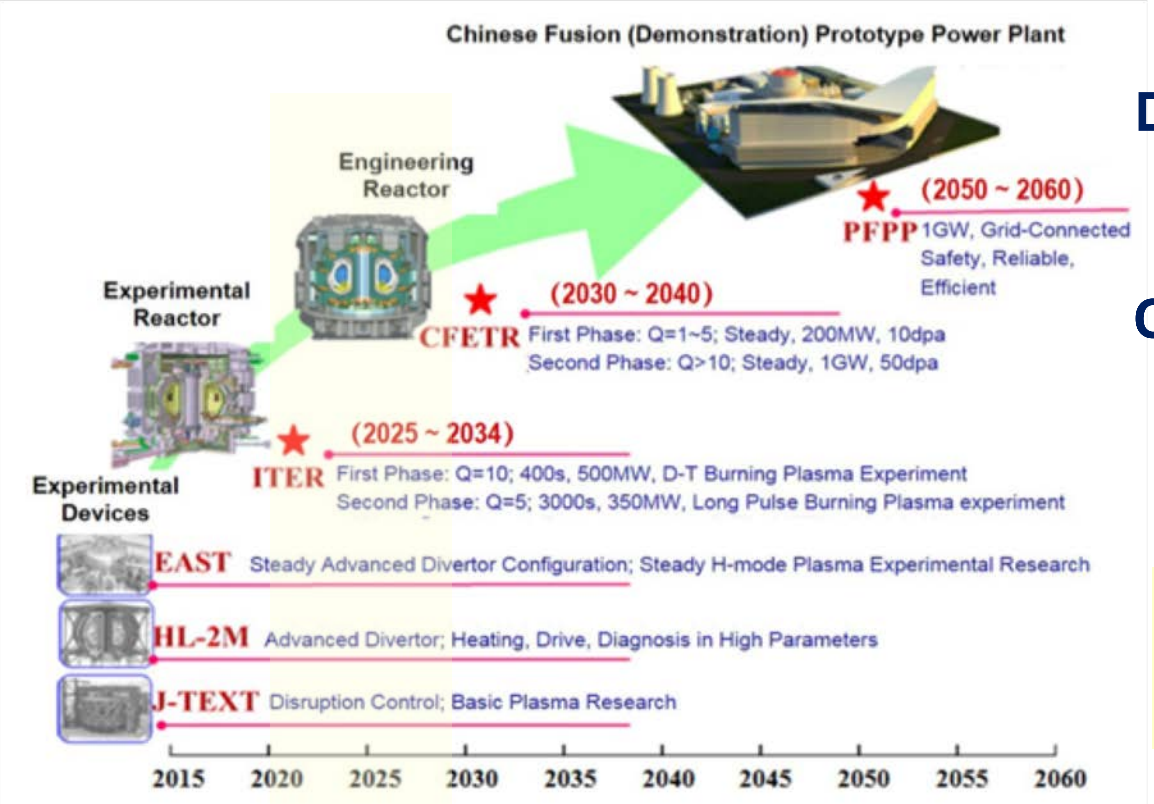
Chinese Roadmap toward DEMO

ITER CHINA

中国国际核聚变能源计划执行中心

China International Nuclear Fusion Energy Program Execution Center

Tech roadmap of development of China's MCF(draft)



PFPP (2050 ~ 2060) 1GW, Grid-Connected Safety, Reliable, Efficient

CFETR (2030 ~ 2040) First Phase: Q=1~5; Steady, 200MW, 10dpa
Second Phase: Q>10; Steady, 1GW, 50dpa

ITER (2025 ~ 2034) First Phase: Q=10; 400s, 500MW, D-T Burning Plasma Experiment
Second Phase: Q=5; 3000s, 350MW, Long Pulse Burning Plasma experiment

EAST Steady Advanced Divertor Configuration; Steady H-mode Plasma Experimental Research

HL-2M Advanced Divertor; Heating, Drive, Diagnosis in High Parameters

J-TEXT Disruption Control; Basic Plasma Research

DEMO

CFETR

ITER

With the Permission of
Dr. Luo Delong,
Director-General,
ITER China Domestic
Agency, MOST, China

Chinese Roadmap toward DEMO

Some Parameters of CFETR (Engineering Reactor)

a=2.2m,

R=7.2m,

k=2

B_T: 6. 5 T

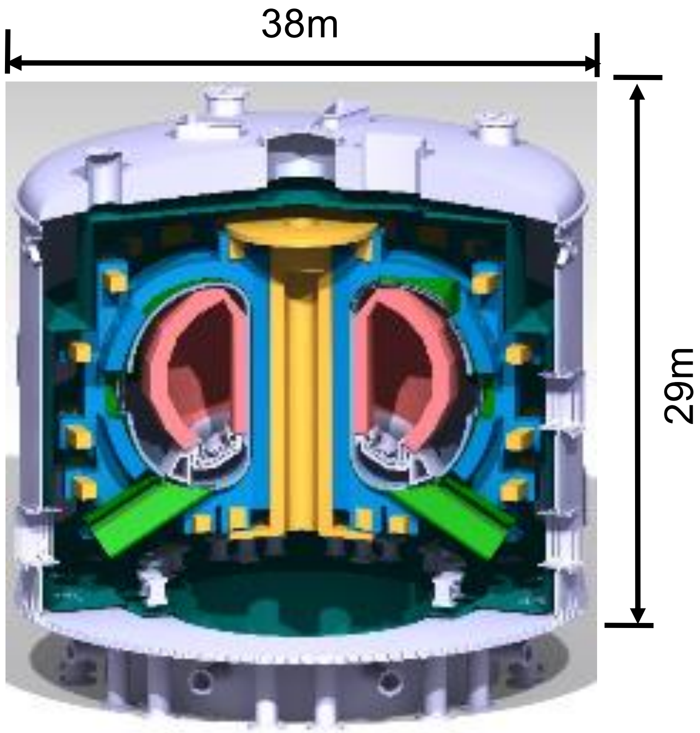
Ip: 8 -14 MA

12 TF coils for easy RH, H&CD

More reliable plasma targets

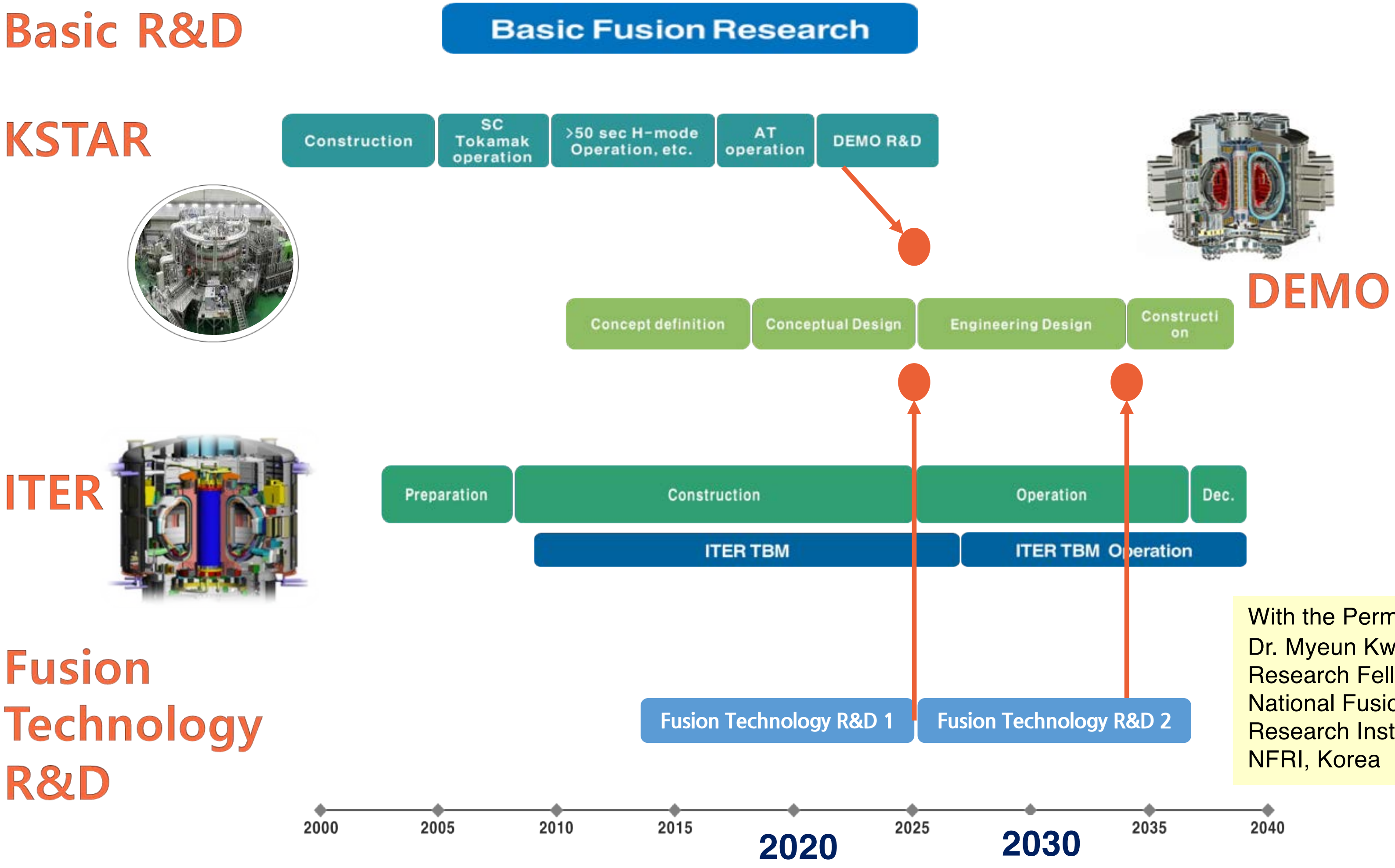
Higher confidence for STE goals

With the Permission of
Dr. Luo Delong,
Director-General,
ITER China Domestic Agency, MOST, China



(Design is expected to be completed around 2020.)

Korean Roadmap toward DEMO



Basic R&D

Basic Fusion Research

KSTAR

Construction | SC Tokamak operation | >50 sec H-mode Operation, etc. | AT operation | DEMO R&D

DEMO

Concept definition | Conceptual Design | Engineering Design | Construction

ITER

Preparation | Construction | Operation | Dec.

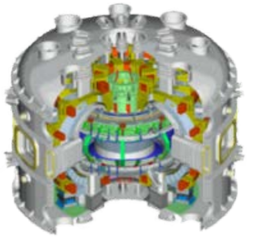
ITER TBM | ITER TBM Operation

Fusion Technology R&D

Fusion Technology R&D 1 | Fusion Technology R&D 2

With the Permission of
Dr. Myeun Kwon,
Research Fellow,
National Fusion
Research Institute,
NFRI, Korea

A Strategic Path to K-DEMO



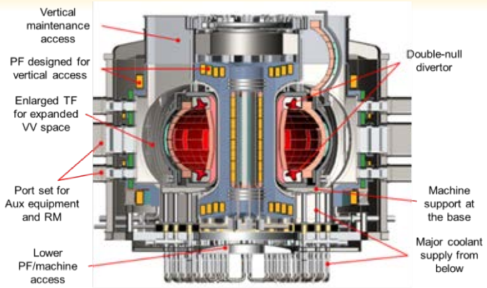
KSTAR

(β_N ~2, steady-state)

(β_N ~4, stationary)

($f_{bootstrap}$ > 50%)

Advanced operation
high β_N (~4) & high bootstrap current



K-DEMO

(Reactor-scale plasma volume)

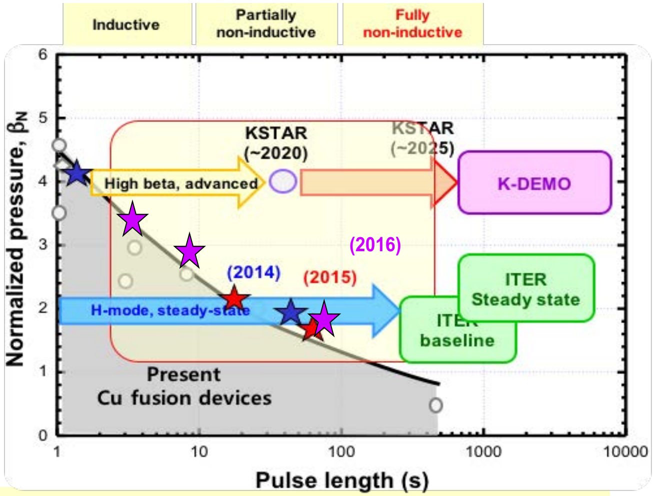
(β_N ~ 4 & D-T fusion)

(steady-state, by bootstrap)

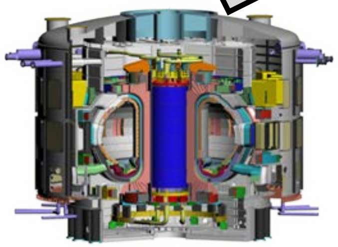
(alpha heating)

(Blanket, T-breeding)

Self-sustaining
D-T burning



With the Permission of
Dr. Myeun Kwon, Research Fellow,
National Fusion Research Institute, NFRI, Korea



ITER

(Reactor-scale plasma volume)

(β_N ~ 2 & D-T fusion)

(steady-state, external CD)

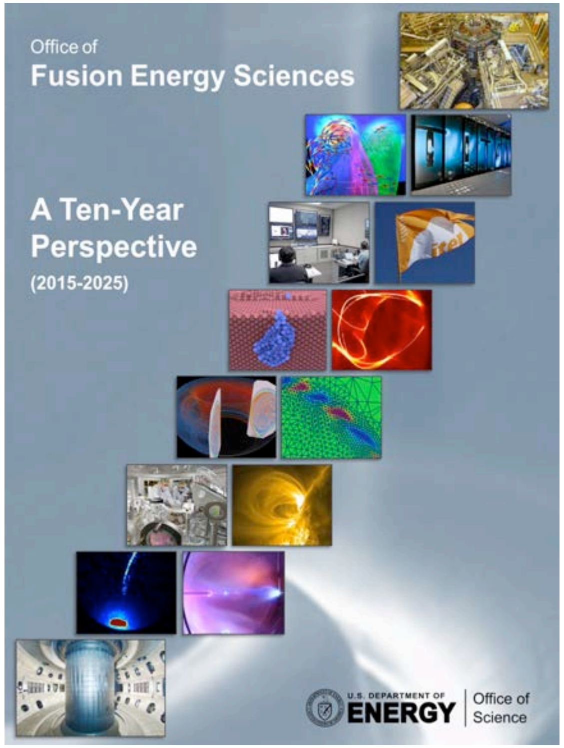
(alpha heating)

Fusion Engineering / others

- Material R&D
- Blanket
- System Eng. (Tritium, remote)
- Engineering optimization
- License & Codes
- Human resource
- Etc

A Strategic Plan for U.S. Burning Plasma Research

10-Year Perspective
2015-2025
By U.S. DOE (Dec. 2015)

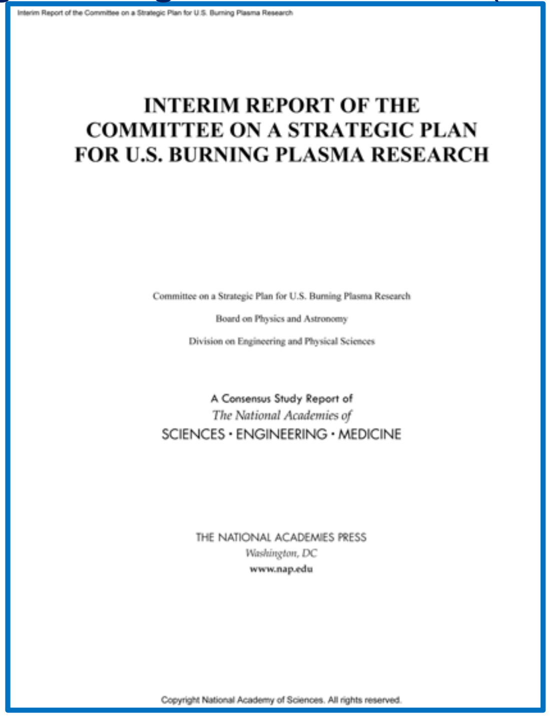


Office of
Fusion Energy Sciences

A Ten-Year
Perspective
(2015-2025)

U.S. DEPARTMENT OF
ENERGY
Office of
Science

Interim Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research
By National Academies of Science, Engineering, and Medicine (2018)



Interim Report of the Committee on a Strategic Plan for U.S. Burning Plasma Research

INTERIM REPORT OF THE
COMMITTEE ON A STRATEGIC PLAN
FOR U.S. BURNING PLASMA RESEARCH

Committee on a Strategic Plan for U.S. Burning Plasma Research

Board on Physics and Astronomy

Division on Engineering and Physical Sciences

A Consensus Study Report of
The National Academies of
SCIENCES · ENGINEERING · MEDICINE

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Washington, DC
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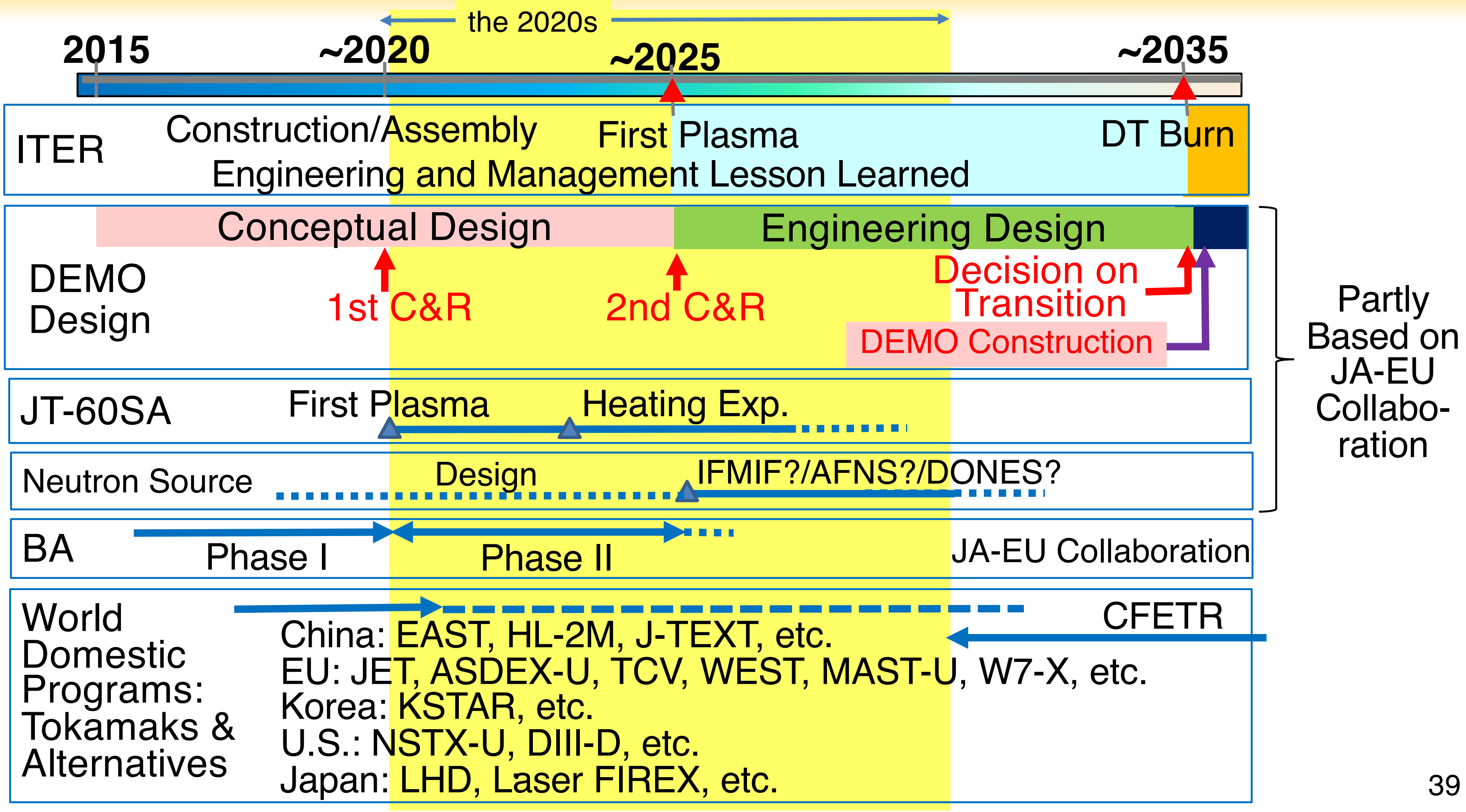
With the Permission of
Dr. James W. Van Dam, Acting Associate Director,
Office of Science, Fusion Energy Science, U.S. DOE

What will happen through the 2020s?



China: EAST, HL-2M, J-TEXT, etc.
EU: JET, ASDEX-U, TCV, WEST, MAST-U, W7-X, etc.
Korea: KSTAR, etc.
U.S.: NSTX-U, DIII-D, etc.
Japan: LHD, Laser FIREX, etc.

Summary

Strategies and Expectations through the 2020s

Japanese Strategies to bridge a gap between ITER and DEMO are:

(1) ITER: Procurement is basically going well by overcoming engineering difficulties.

(2) Broader Approach (BA) Activities (2007-2020: Phase I)

(a) In **JT-60SA** project (high-β_N SC Tokamak), construction/assembly is going well on schedule.

(b) In **IFMIF/EVEDA** project, assembly of prototype accelerator for International Fusion Materials Irradiation Facility (LIPAc) is being collaboratively conducted.

(c) In **IFERC**, DEMO Design and R&D are going well. New CSC started its operation.

BA Phase II (2020 - 2025): Under discussion by JA-EU.

In order to solve all the issues for DEMO completely,

(3) New Strategy toward DEMO was formulated:

C&R Items for 2020 and 2025, and Transition criteria for 2035 were decided.

Action Plan for DEMO and Roadmap including Domestic Programs are now being carried into action (2018-).

We expect to promote the Fusion R&D activities toward DEMO according to the strategic timechart through the 2020s.

Thank you for your attention!

Acknowledgments

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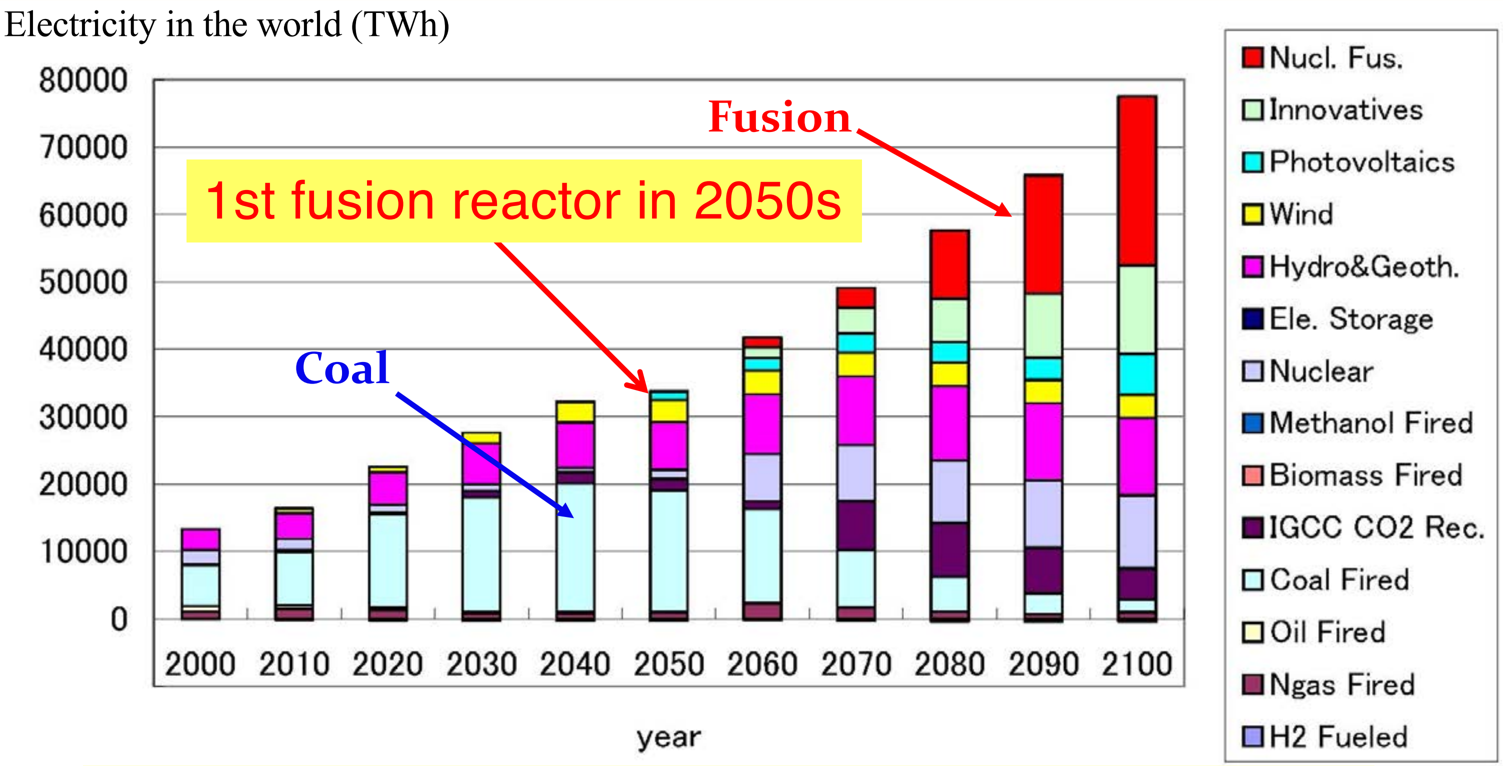
Dr. Luo Delong, Dr. Myeun Kwon,
Prof. Yuichi Ogawa, and Ministry of Education, Culture,
Sports, Science and Technology of Japan.

Introduction of Fusion Energy into the World Energy Market



@ In the case of 550 ppmv CO_2 concentration constraint.
@ Future energy demand is assumed to be the case of IS92a.
@ In nuclear fusion the cost of electricity (COE) in the introduction year (i.e., 2050) is assumed to be 65 mill/kWh,

TOKIMATSU, K., et al., Studies of breakeven prices and electricity supply potentials of nuclear fusion by a long-term world energy and environment model, Nuclear Fusion 42 (2002), 1289.