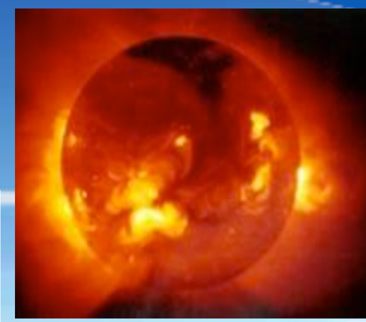
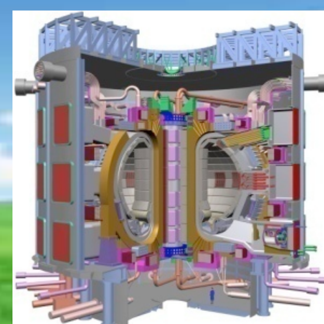
The Future of Fusion





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Institute of Plasma Physics, CAS, Hefei, China

38th International Conference on Plasma Science and 24th Symposium on Fusion Engineering , Chicago, Illinois • 26-30 June, 2011

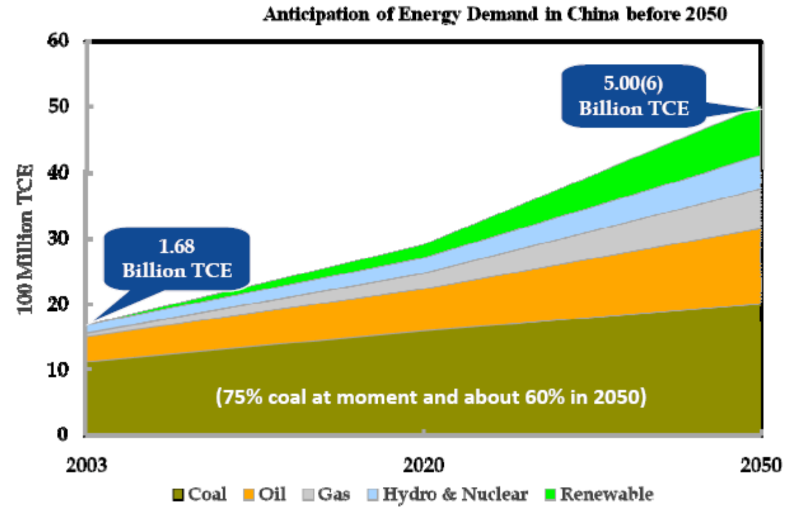
Contents

- Energy Needs in 21st Century
- Lessons learned from past
- Possible approaches for Accelerating Fusion Energy
- Summary

Energy Needs over the World

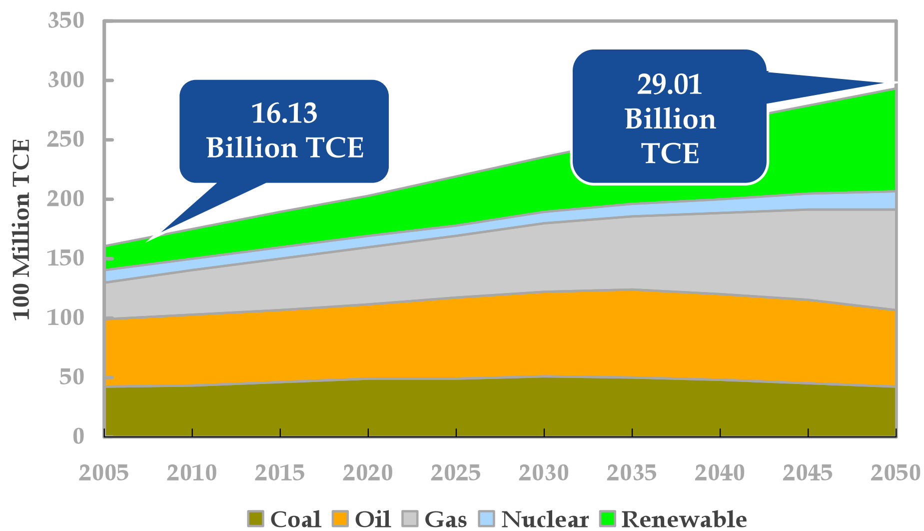
World average 2.4 kW per person
USA : 10,5k W
UK: 5,2kW
JP: 6.3kW
China:1.5kW (growing 10% /y)
India: 0.7kW
Bangladesh: 210 Watts

Energy Needs in China



IEA2005

Anticipation of Energy Demand over the World before 2050



Renewable and nuclear energy were promoted significantly in China for reducing CO_2 of 40% in 2020.

Fukushima Nuclear accident make a strong impact to nuclear energy

More urgent need for fusion energy.

IEA2005

2005—2050，average annual growth rate is 1.3%

Can Fusion Play a Role in This Century

How?

5 % of total primary energy

Fusion power plant in 2100

China : 150

India : 150

EU : 50

US : 50

Japan : 30

KOREA: 20

Total: 450 GW plant

When?

2019-2038 ITER

2030-2050 DEMO

2040-2060 Proto-Type

2050-- First Power Plant

2060: 5-7 GW power plant

2070: 35

2080 70

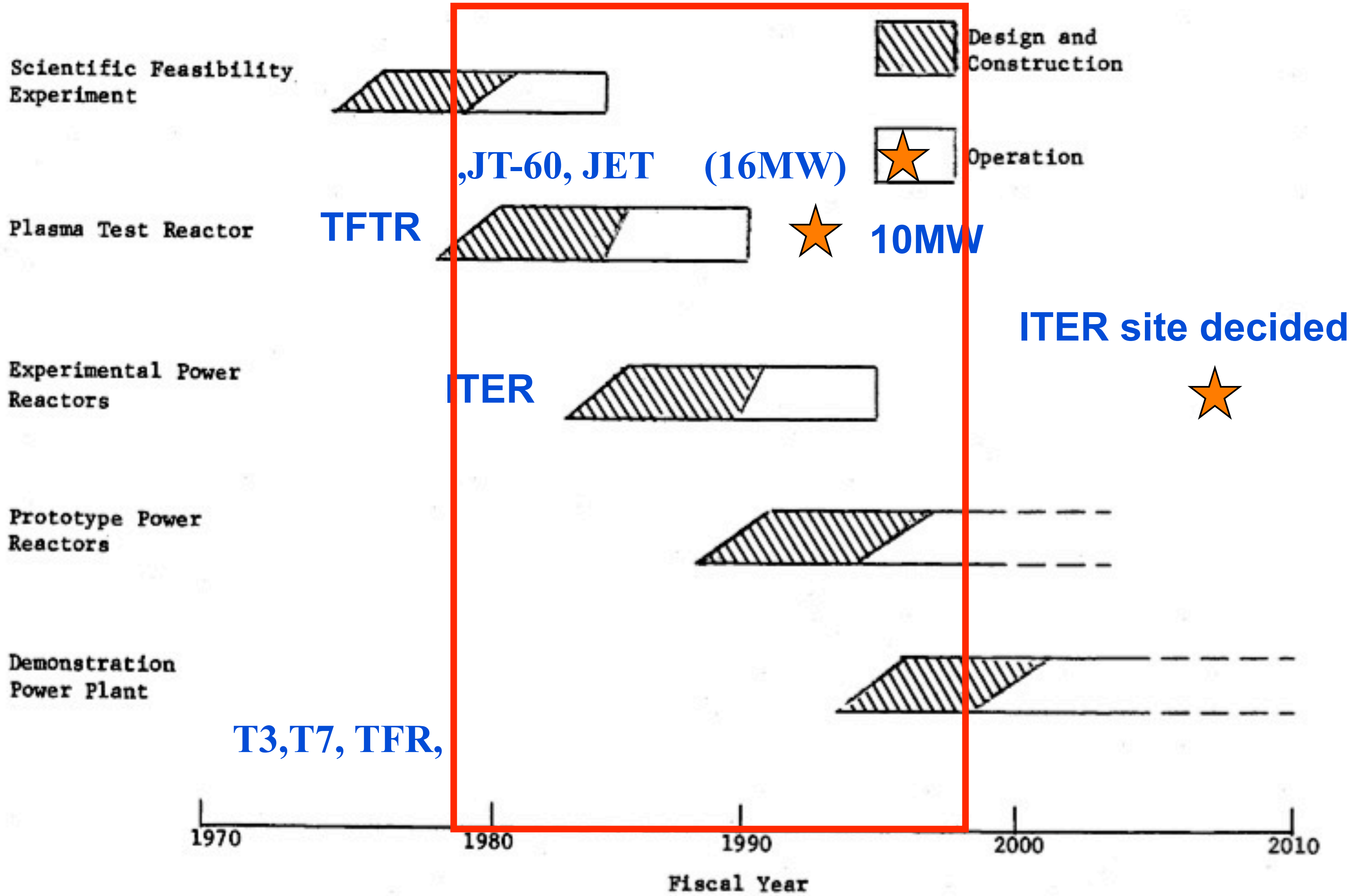
2090 150

2100 300 (x3=450!)

Lessons learned from past

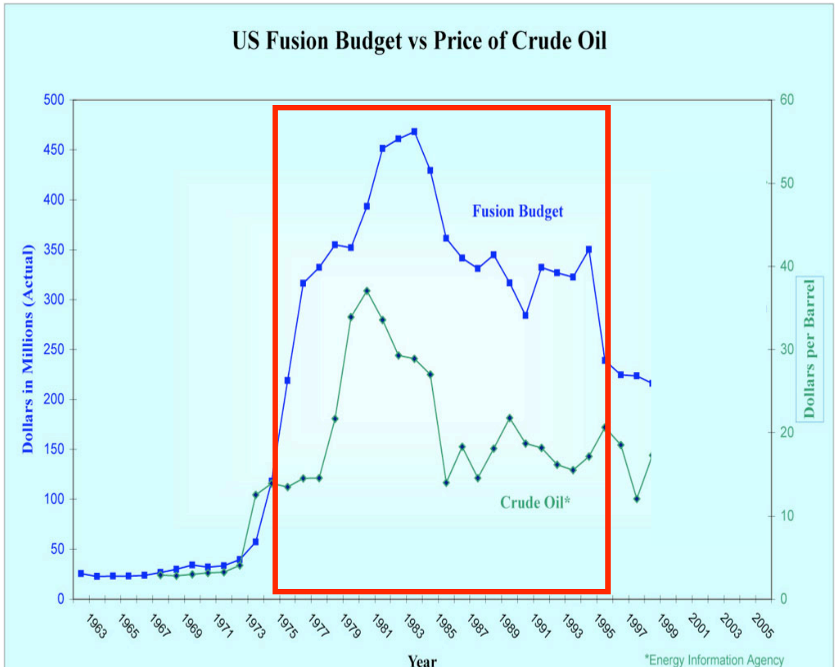
With Courtesy from D. Meade

Lessons learned from past



Projected Fusion-Reactor Development Program
Wash-1267, July 1973

Lessons learned from past



J. Willis, MacFusion

- TFTR construction began in1976, 4.5 years
- JET 1977, 5.5 y
- JT-60 1978,4.5
- T-15 1979,

Single party efforts

ITER
1986, start
1986-1998, 4 parties
1999-2005, 7 parties
2005-2007, site decision,
2007.10.24, ITER-IO
2007.10-2019.11, construction

GAP Analysis: > 50 years to power Plant

	Issue	Approved devices	ITER	IFMIF	DEMO Phase 1	DEMO Phase 2	Power Plant
Plasma performance	Disruption avoidance	2	3		R	R	R
	Steady -state operation	2	3		r	r	r
	Divertor performance	1	3		R	R	R
	Burning plasma (Q>10)		3		R	R	R
	Start up	1	3		R	R	R
	Power plant plasma performance	1	3		r	R	R
Enabling technologies	Superconducting machine	2	3		R	R	R
	Heating, current drive and fuelling	1	2		3	R	R
	Power plant diagnostics & control	1	2		r	R	R
	Tritium inventory control & processing	1	3		R	R	R
	Remote ha ndling	1	2		R	R	R
Materials, Component performance & lifetime	Materials characterisation			3	R	R	R
	Plasma -facing surface	1	2		3	4	R
	FW/blanket/divertor materials		1	1	3	4	R
	FW/blanket/divertor components		1	1	2	3	R
	T self sufficiency		1		3	R	R
Final Goal	Licensing for power plant	1	2	1	3	4	R
	Electricity generation at high availability				1	3	R

10 year	10 years	10 years	10 years	10 years
Build ITER	Run ITER	Build	Run	Build
+ IFMIF	+IFMIF	DEMO	DEMO	proto-type

Lessons learned from past

- – How long will it take? Next 50 years
- – Why's it taking so long?

Technical difficulties, limited financial and human resources, risk, politics..

- Do we really need another (moving) 50 years?

It took only 8 years for US landing on moon in 60s!

ITER is on the right track now

Do we make things more simple or more complicated

It is time from the Era of Fusion Science to Fusion Energy

Next step: European Union

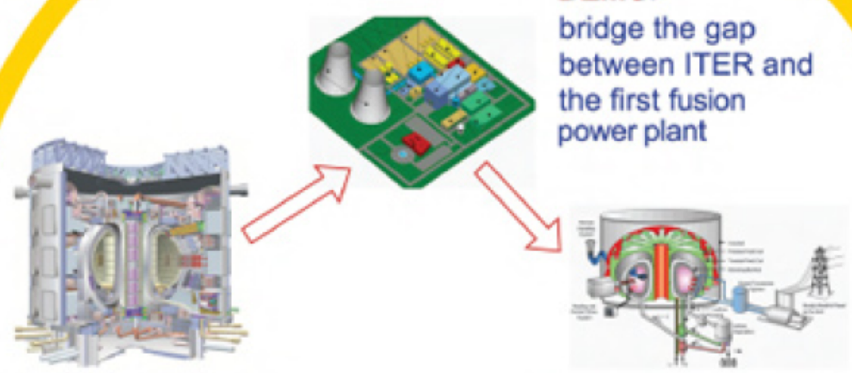
Towards a demonstration fusion reactor (DEMO)

ITER is not an end in itself: it is the bridge toward a first demonstration fusion power plant that produces electrical power.

The strategy to achieve this long-term aim includes a number of different elements: firstly, the development of ITER, research into special materials, development and use of existing fusion devices.

This will be followed by a demonstration fusion reactor (DEMO).

The expectation is that after DEMO, the first commercial fusion power stations can be constructed.



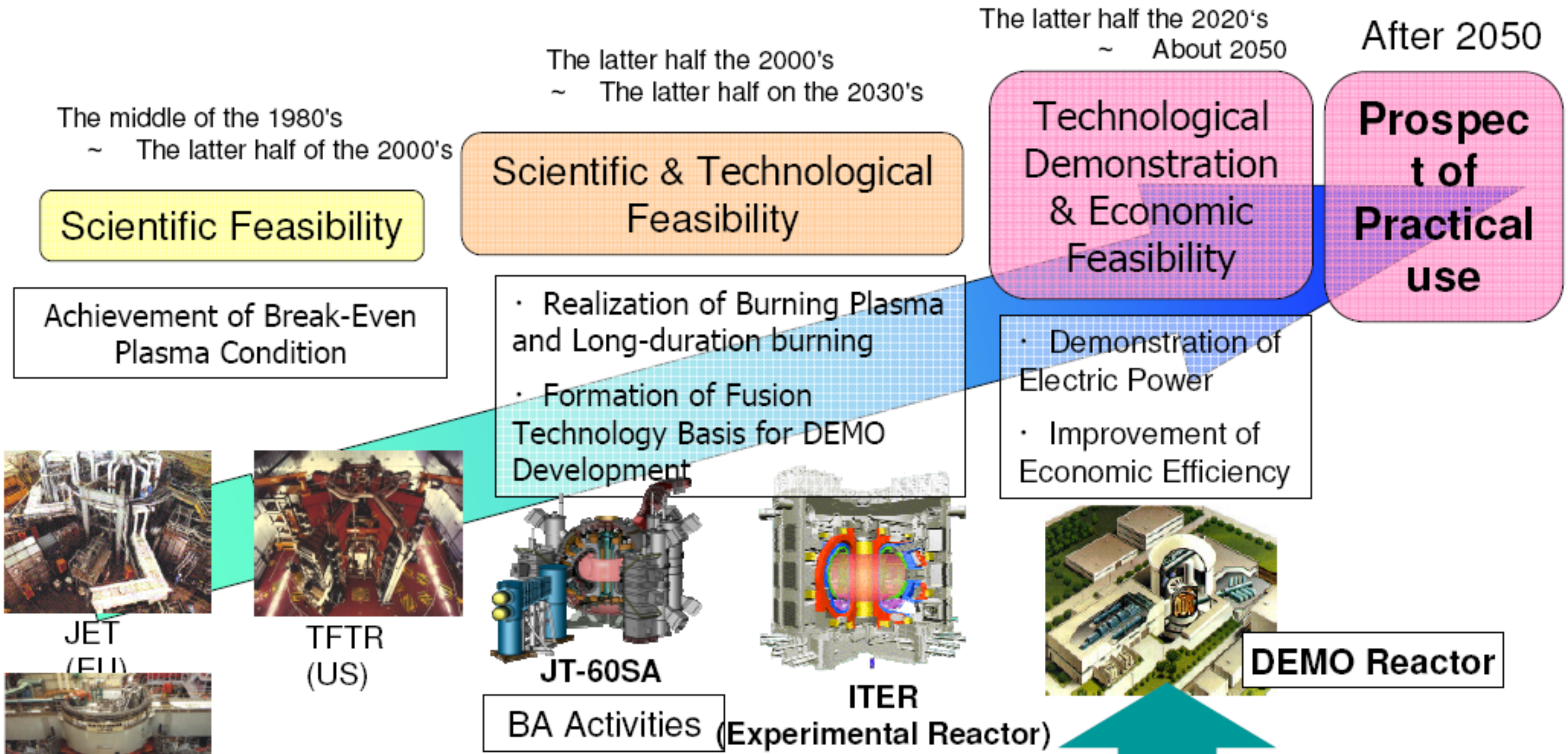
FAST TRACK SCENARIO

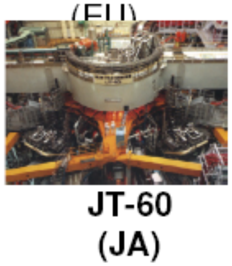
Safety & Environment

With Courtesy from EU-DA

Japan

Road Map to Fusion DEMO Reactor





< Issues addressed in ITER project >

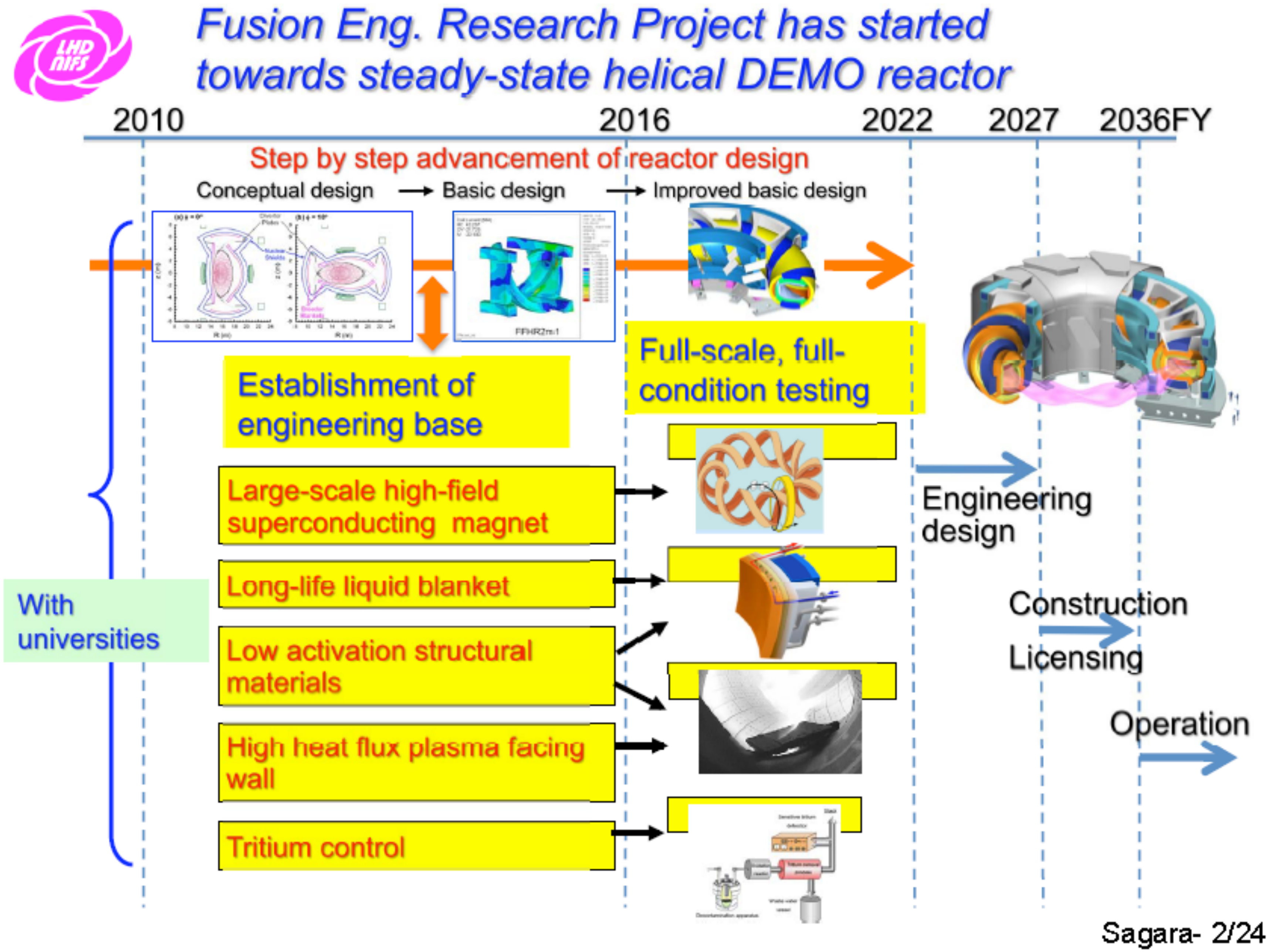
- Establishment of control technology towards steady-state sustainment of burning plasmas
- Demonstration of feasibility of fusion blanket for tritium breeding and collection, heat removal and generation of electricity

< Issues addressed in Broader Approach activities >

- Development of high performance plasmas for reducing electricity cost
- Development of fusion reactor materials used under high neutron flux environment

etc

With Courtesy from JA-DA



SPL2-4 A.Komori Tuesday 14:15

With Courtesy from Prof. Sagara

Korea

Fusion Energy Development Roadmap in Korea

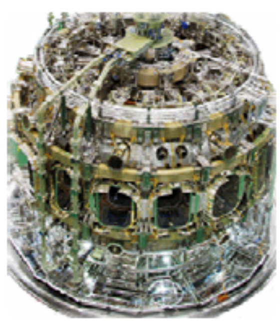
Role of KSTAR and ITER

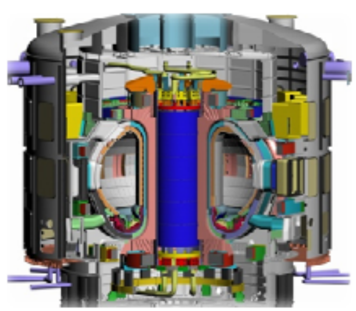
2010' KSTAR
- High-Beta, Steady-state
- Integrated Control
- Optimum Fusion Reaction
- ITER Operation Scenario Study & Component Test
  - ITER Pilot Plant

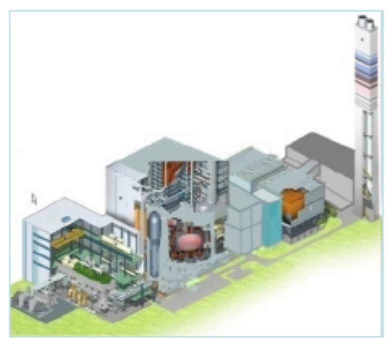
2020' ITER
- Tritium Fuel Cycle
- Reactor Engineering
- DT Burning Plasma
- Blanket, Divertor
- Joint Big Science Experiment

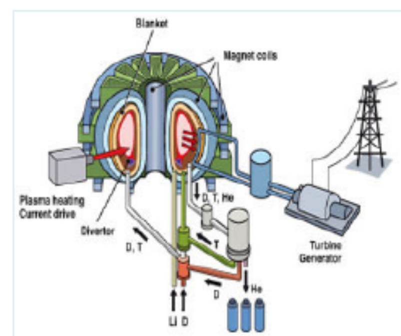
2030' DEMO
- Reactor System Optimization
- Socio-economic Studies
- Based on Results of KSTAR & ITER Operation
- Electricity Production

2040' Fusion Plant
- Completion of Fusion Plant Engineering
- Commercialization of Fusion Energy
- Massive Electricity Production









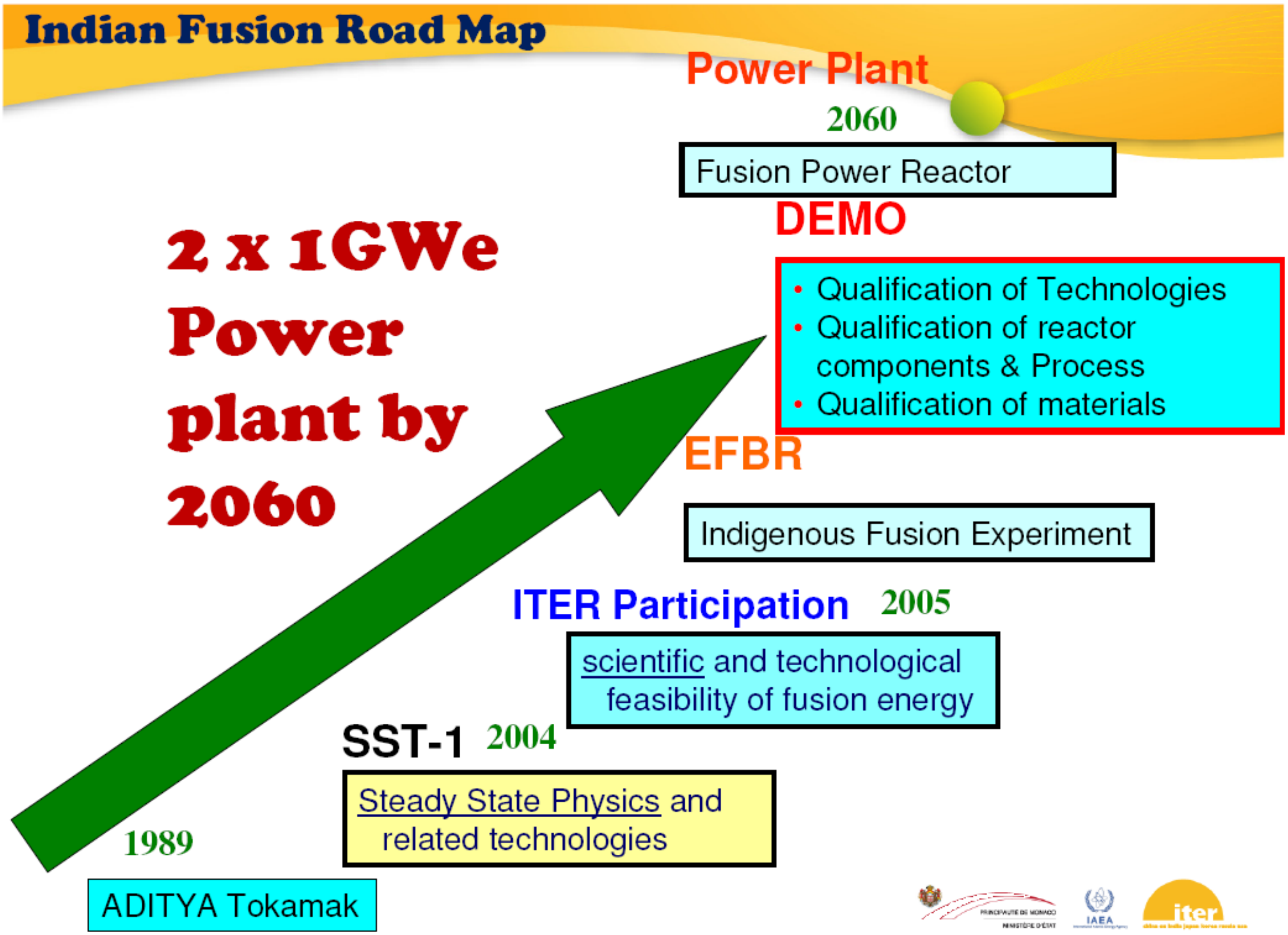
With Courtesy from H-C-Kim

DEMO R&D Facilities for Design Validation Test

R&D and Test Facilities Plan to be Proposed

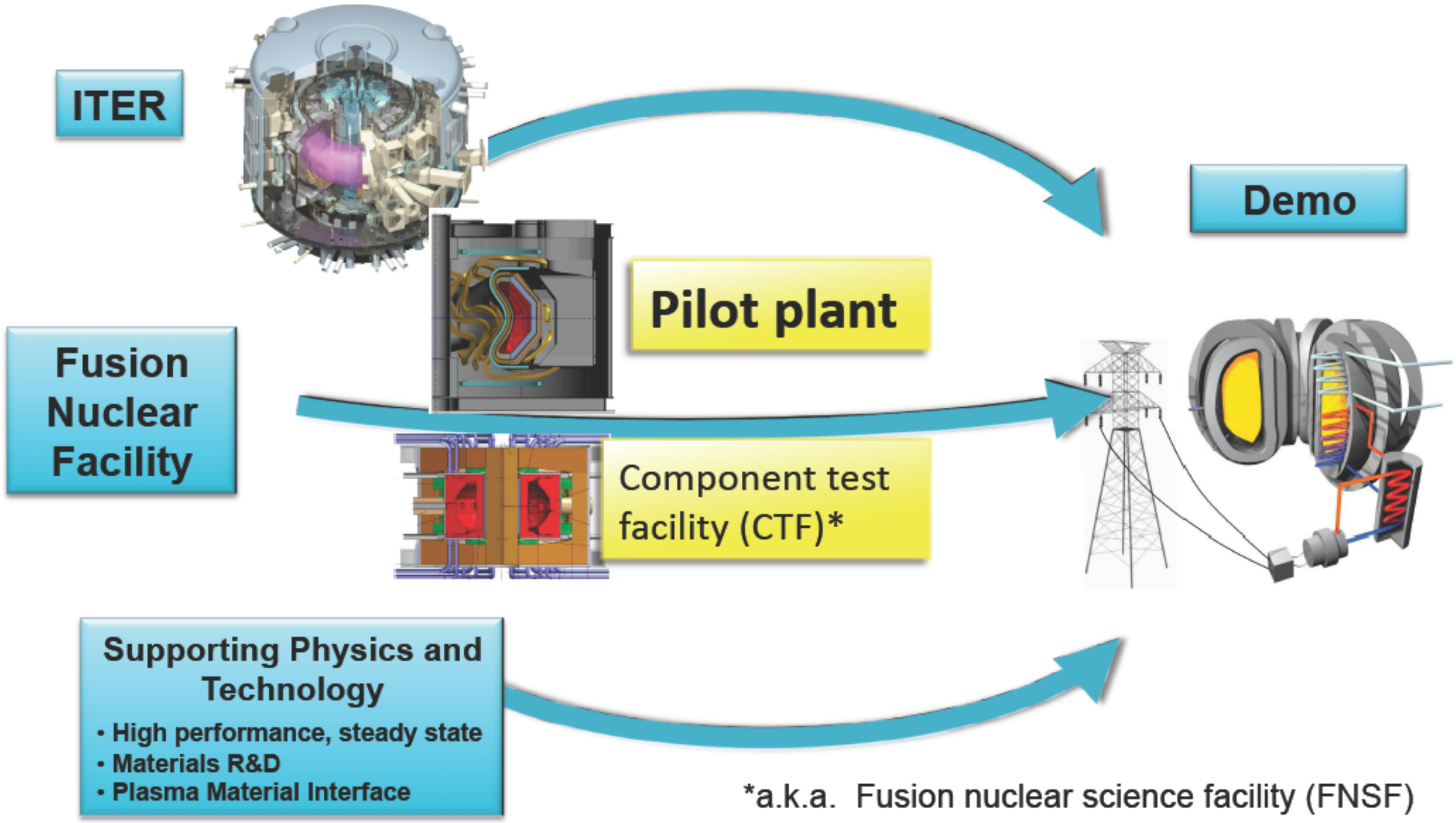
With Courtesy from H-C-Kim

Indian



With Courtesy from IN-DA

Charting the Roadmap to Fusion Energy: Options for a Nuclear Next Step



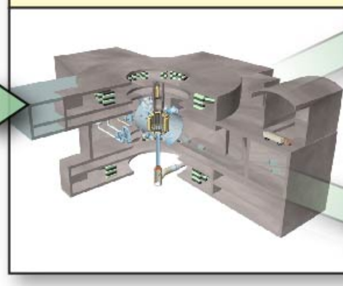
Requires a technical evaluation of missions, requirements, and prerequisites for Demo and next-step facilities.

10:00 SO4A-1, G. H. Neilson, Thursday **SO4A-2, M.Peng** **SO4A-4, S. Konishi**

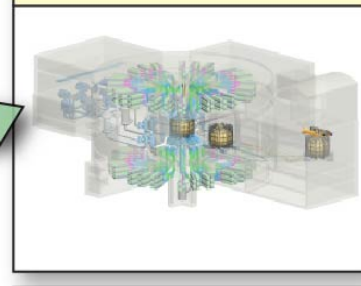
Development Path -

NIF

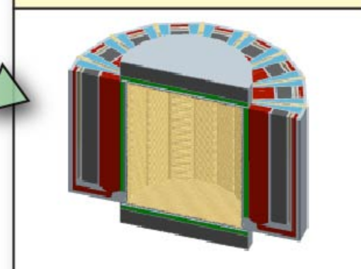
LIFE.1



LIFE.2 Pure Fusion



LIFE.2 Fusion/Fission



Full-system demonstration, "LIFE.1" in 2020s

- Conservative design maximizing use of near turn solutions
- Fully integrated development and vendor readiness program
- Steady state, integrated fusion operations ($\sim$500 MW_{th})
- Define the plant availability growth program
- Materials / structure qualification for commercial plant

Commercial GWe plants, "LIFE.2" from 2030s

- Deliver baseload power to grid at relevant size (~ 1GWe)
- Uses systems and materials qualified on LIFE.1
- Defines capital and operating costs for rollout

 SPL1-2 E. I. Moses Monday

With Courtesy from M.Dunne

Options for next step-Important issues

ARIES-Team:

- ARIES-I first-stability tokamak (1990)
- ARIES-III D-^{3}He-fueled tokamak (1991)
- ARIES-II and -IV second-stability tokamaks (1992)
- Pulsar pulsed-plasma tokamak (1993)
- Starlite study (1995) (goals & technical requirements for power plants & Demo)
- **ARIES-RS reversed-shear tokamak (1996)**
- **ARIES-AT advanced technology and advanced tokamak (2000)**
- **ARIES-CS Compact Stellarators(2007)**

With Courtesy from Farrokh Najmabadi

- **SS operability of a fusion energy facility, including plasma control, reliability of components, availability, inspectability and maintainability of a power plant relevant device.**
- **Net electricity generation.**
- **Complete T fuel cycle.**
- **Power and particle management.**
- **Necessary date for safety & licensing of a fusion facility.**
- **Large industrial involvement.**
- **Cost**

Road Map

US: ITER—IFMIF+CTF(FNF)--DEMO-Power Plant

EU&JP: ITER—IFMIF-- DEMO-Power Plant

KO: ITER— DEMO---Power Plant

Risks are always there. No single device can solve all S&T problems.

Learning by Doing.

Make Next Step forward is most important.

How to Speed up fusion energy development

- Decision

Technical solution

Cost (size)

World political and economic environments

International cooperation

- Construction

Availability of technology

Personnel

Financial resources

Structure of management

- Operation

Scientific mission

Structure of management

ITER

- Decision

1985-2007

8m→ 6 m→cheaper?

By full agreement

- Construction

R&D still needed

No enough expertise

IC-IO-DA

~10 years?

- Operation

Q=10

20 years

Decision+ Technical solution + Personnel

Wide International Cooperation

Take full advantage by using existing facilities

JET, JT-60U, JT-60SA

ASDEX-U, DIII-D, HL-2A(M), C-Mod

EAST, KSTAR, Tore-Supra

MAST, NSTX,

SST-1, HT-7,

TCV, TEXTOR, FTU

LHD, W7-X

ITER

Facilities for engineering:

ST magnets

H&CD facilities

Remote Handling

T-plant

IFMIF (?)

14 MeV neutron Source

Build Necessary test facilities for next step in different countries, such as CTF.

One party dominate cooperation mechanism is better for next step

EDEMO /Pilot plant (20 years)
Electricity generation with reduced mission

Electricity generation

No need real steady state

Burning plasma control

Sufficient T Breeding

As a CTF

H_2 production

Testing tokamak system availability (reliability, buildability, operability and maintainability)

P_{fusion}~200MW, t = a few hours to weeks

16:20 SO2B-3 T. P. Intrator,Tuesday

Based on existing technologies:

Option 1: Pure Fusion

- A FDF-class with SC coils
- A ST-type compact device

Option 2: Fusion –Fission hybrid

- Fusion: Q=1-3, Pth=50-100MW
- Fission: M= 20-30, Pt = 0.3-1.5GW

Or:

ITER-type machine with different blanket: Pt =5GW, Pe=1.5GW

15:30 SO2B-1 A. Sykes Tuesday

Efforts Made in China

G-IV Reactor:

Fast Breeder

65MW (now)

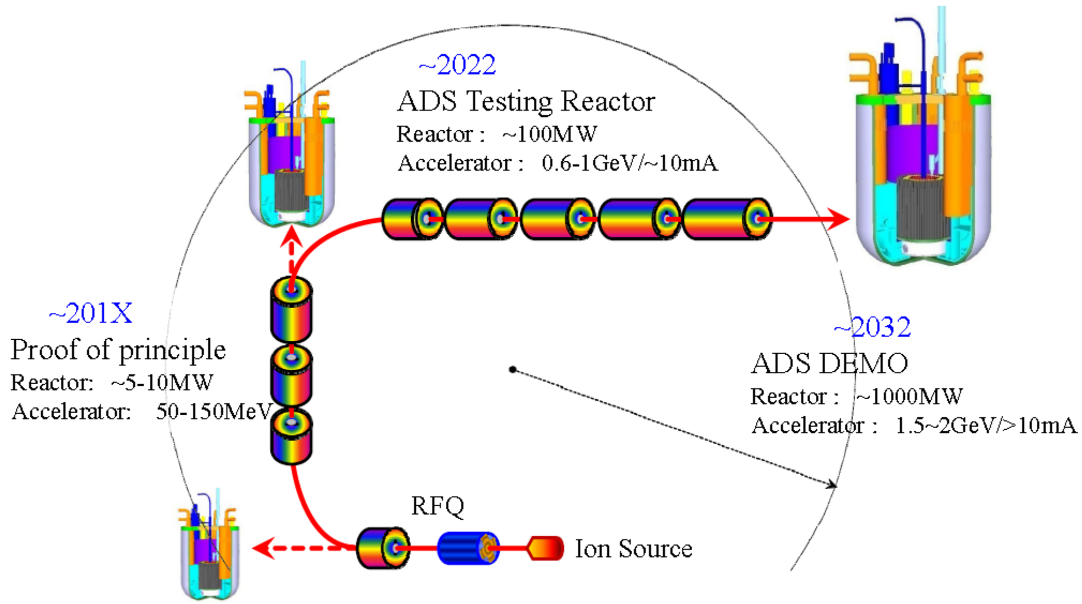
→800MW(2015)

HTGR

10MW (now)

→ 200MW (2015)

ADS-NWT Road Map



ADS starts for NWT

Z-pinch and Laser hybrid reactor configurations also proposed

DO WE FUSION HAVE ENOUGH ROOM

CN-MCF Near Term Plan (2020)

ITER construction

- ASIPP: Feeders (100%), Correction Coils (100%), TF Conductors (7%) , PF Conductors (69%), Transfer Cask System(50%), HV Substation Materials (100%), AC-DC Converter (62%)
- SWIP: Blanket FW (10%) &Shield (40%), Gas Injection Valve Boxes+ GDC Conditioning System (88%), Magnetic Supports (100%),
- Diagnostics (3.3%)

+

Enhance Domestic MCF

Upgrade EAST, HL-2M

ITER technology

TBM

University program

DEMO design (Wan)

DEMO Material

Education program(2000)

Decision ↓ Making

Can start construct CN next step device around 2020

Personnel: Education Program

Present state:

- ASIPP: HT-7/EAST (150 students), ITER (80 students)
- SWIP (60)
- School of Physics (USTC, 25)
- School of Nuclear Science (USTC-ASIPP, >50)
- CN-MOE-MCF center (10 top universities) 50

Total about 450 students, 150/y, 20-30% remain in fusion

Targets and efforts

- 2000 young fusion talents
- MOST, MOE, CAS, CNNC

have lunched a national fusion training program for next 10 years.

Basic training in 10 Univ.

Join EAST/HL-2A experiments

small facilities in Univ.

Foreign Labs& Univ.

Annual summer school, workshop

China Fusion Engineering Testing Reactor

R=5m；
a=1.5m；
k=1.75；
BT=5T；
Ip=8-10MA；
ne=1-4x10^{20}m^{-3}；
Beta N： 3-5
Pth: 100MW-1GW

TWO Steps in one machine

Step 1: ITER-SS-H mode

ARIES-RS

Step 2: AT H-mode
ARIES-AT

Main functions

Q=1-5

T> 8 hour, SSO

Component testing

T breading (TBR>1),

different TBM configuration

Qeng>1

T fuel recycling

RH validation

RAMI validation (weeks)

Hybrid blanket testing (spent fuel burner, transmutation)

Efforts from China

ASIPP

China needs fusion more urgent and would like to be the first user of fusion energy

I. Very Strong Supports from top leaders to public

II. Start MCF program with strong evolvement with industry

III. Finding possible near term application

Summary

- **Fusion development comes to a new era with significant progress during past 50 years.**
- **It is too long to wait for another 50 year to get electricity by fusion.**
- **A much more aggressive approach should be taken with better international collaboration towards the early use of fusion energy.**
- **Decision should be made quickly. A EDEMO/Pilot plant might be a better approach to start.**