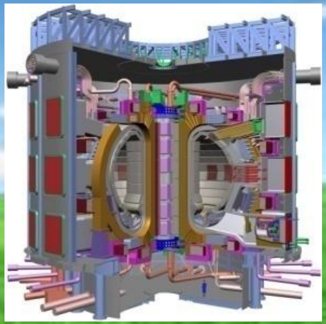
# The Future of Fusion

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

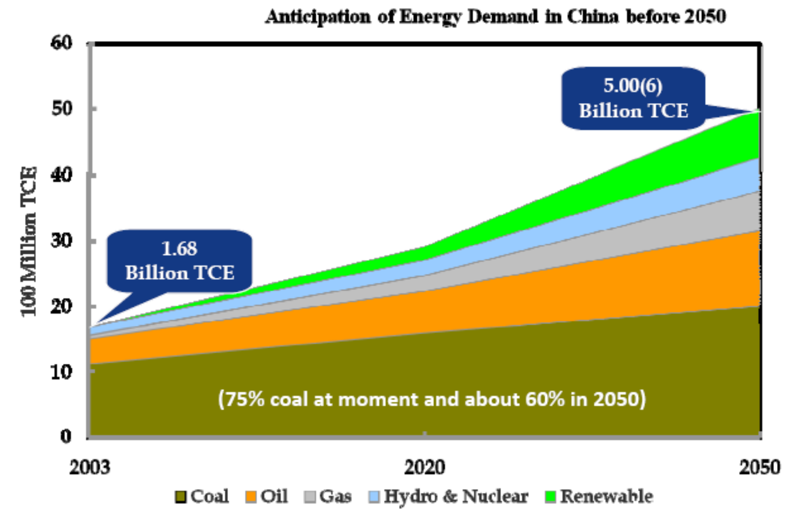
# Contents

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

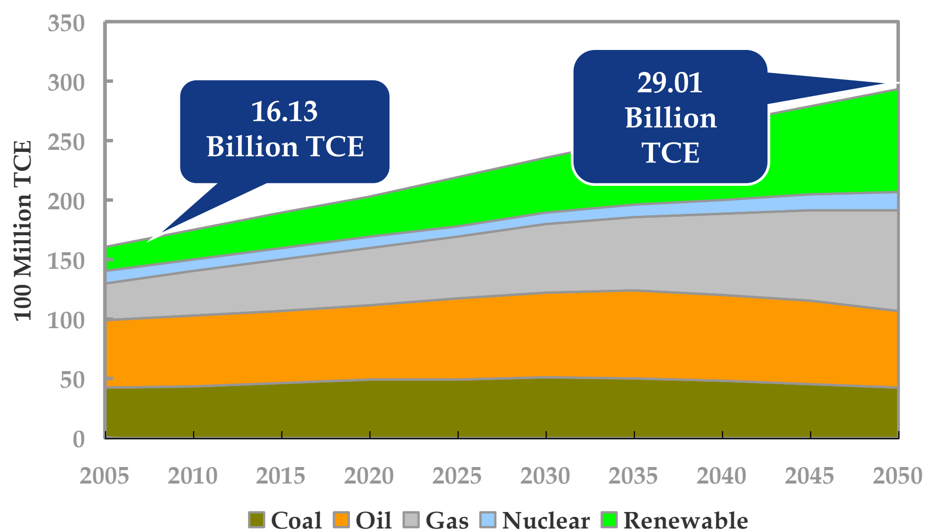
# Energy Needs over the World

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




**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**

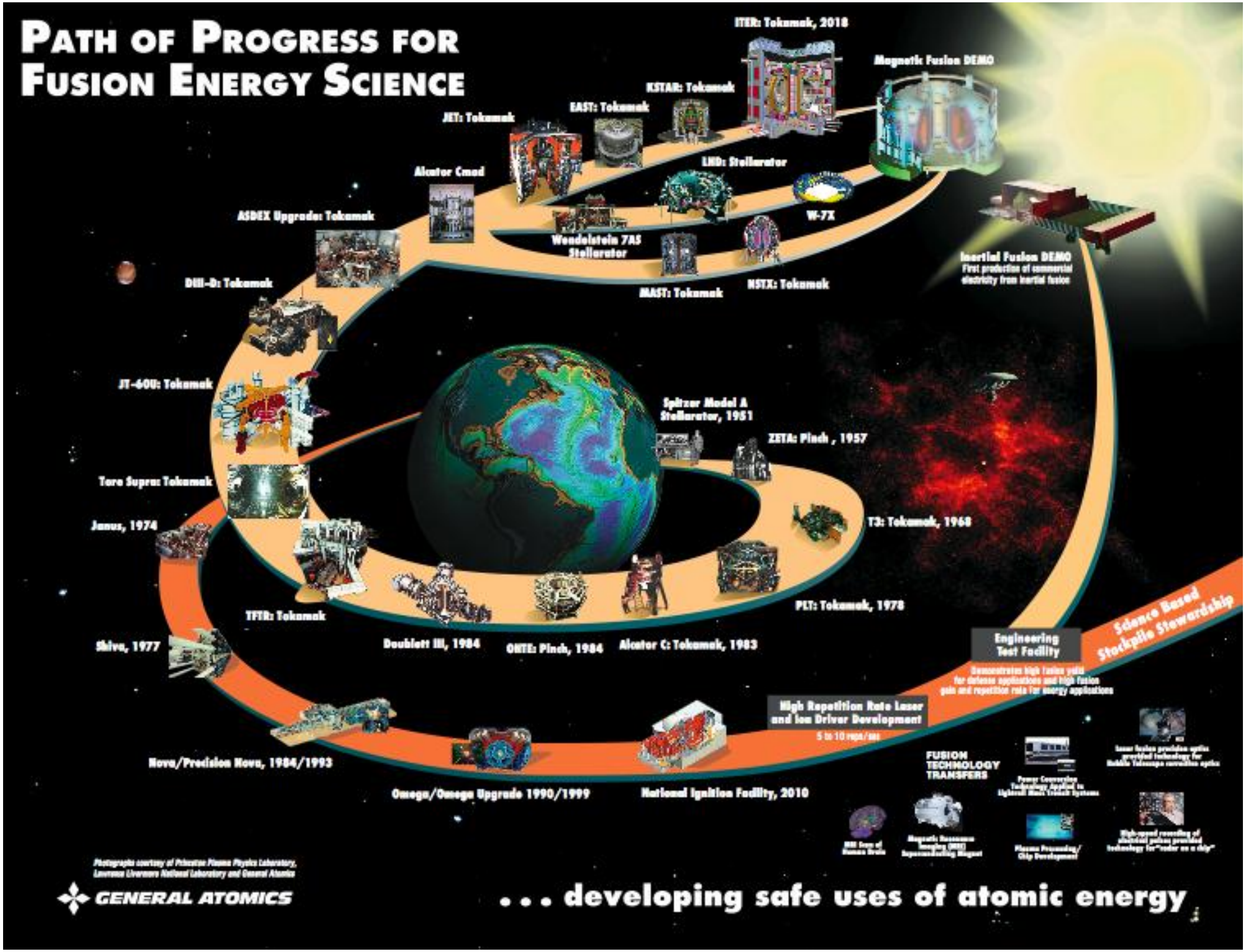
**2070: 35**

**2080 70**

**2090 150**

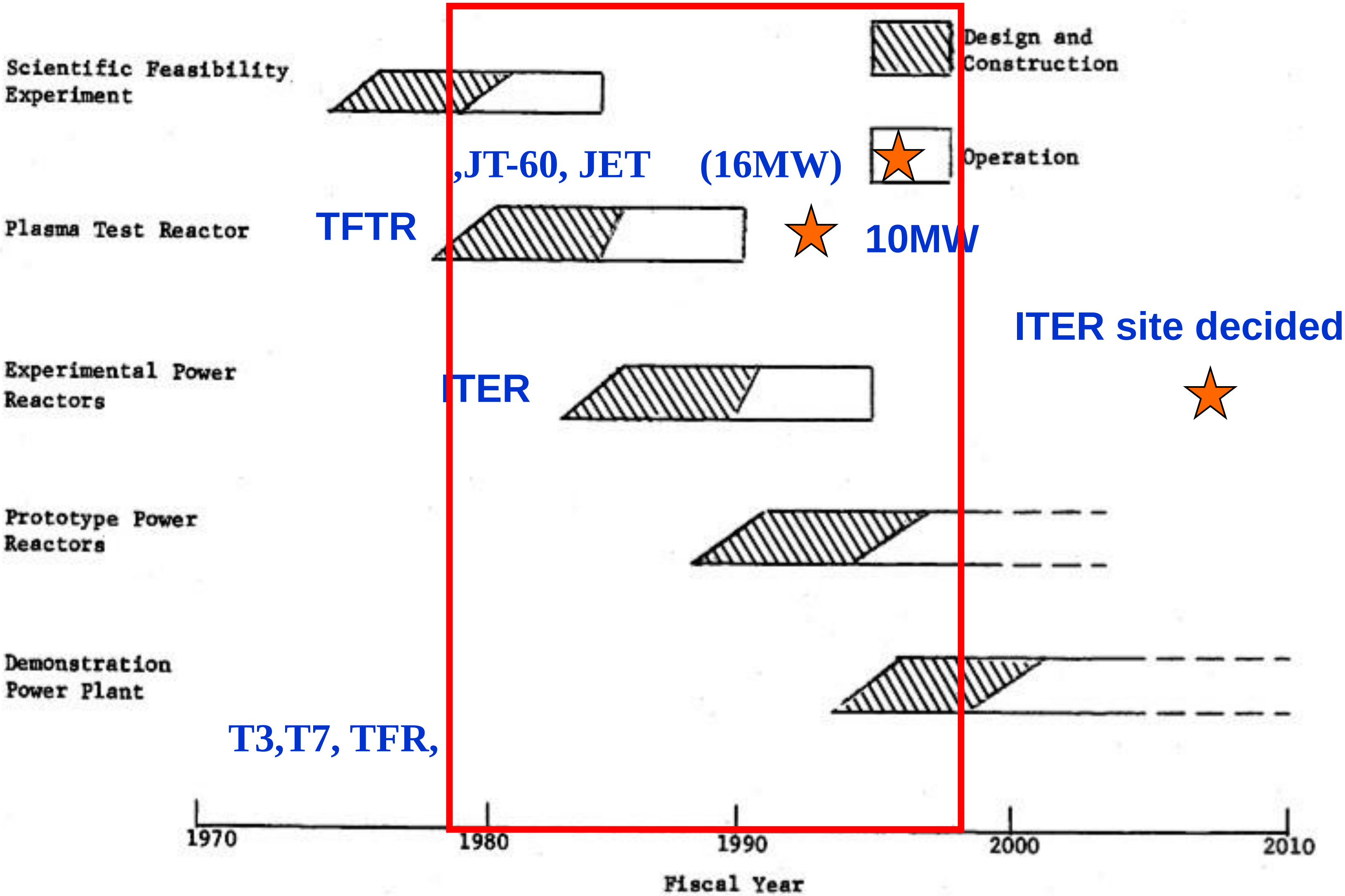
**2100 300 (x3=450!)**

# Lessons learned from past



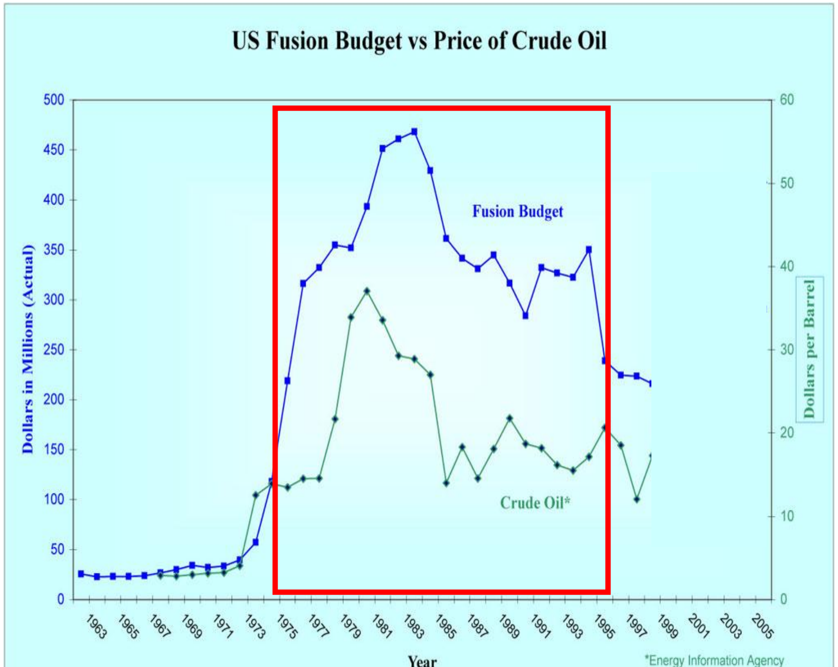

**With Courtesy from D. Meade**

# 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 + IFMIF | Run ITER +IFMIF | Build DEMO | Run DEMO | Build 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

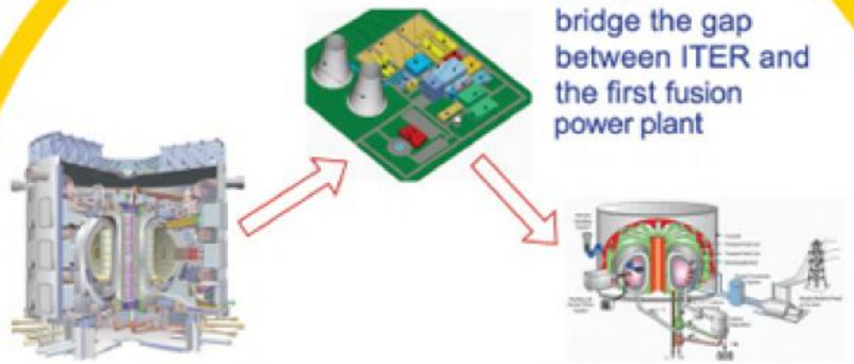
## Towards a demonstration fusion reactor (DEMO)

### 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.



DEMO: bridge the gap between ITER and the first fusion power plant

ITER: scientific and technological (partially) feasibility of fusion

Fusion Power Plant: economically acceptable, safe and environmental friendly

**FAST TRACK SCENARIO**

## Safety & Environment

**With Courtesy from EU-DA**

Japan

# Road Map to Fusion DEMO Reactor

The middle of the 1980's
~ The latter half of the 2000's

**Scientific Feasibility**

Achievement of Break-Even Plasma Condition

The latter half the 2000's
~ The latter half on the 2030's

**Scientific & Technological Feasibility**

- Realization of Burning Plasma and Long-duration burning
- Formation of Fusion Technology Basis for DEMO Development

The latter half the 2020's
~ About 2050

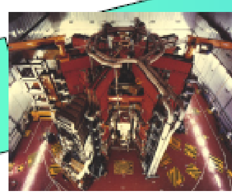
**Technological Demonstration & Economic Feasibility**

- Demonstration of Electric Power
- Improvement of Economic Efficiency

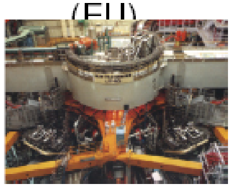
After 2050

**Prospect of Practical use**

JET
(EU)



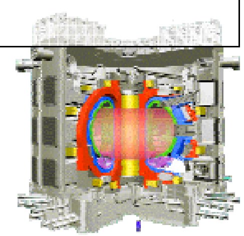
TFTR
(US)



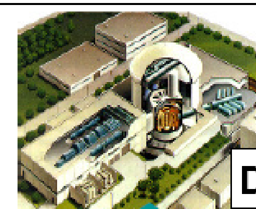
**JT-60**
**(JA)**

**JT-60SA**

BA Activities



**ITER**
**(Experimental Reactor)**



**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

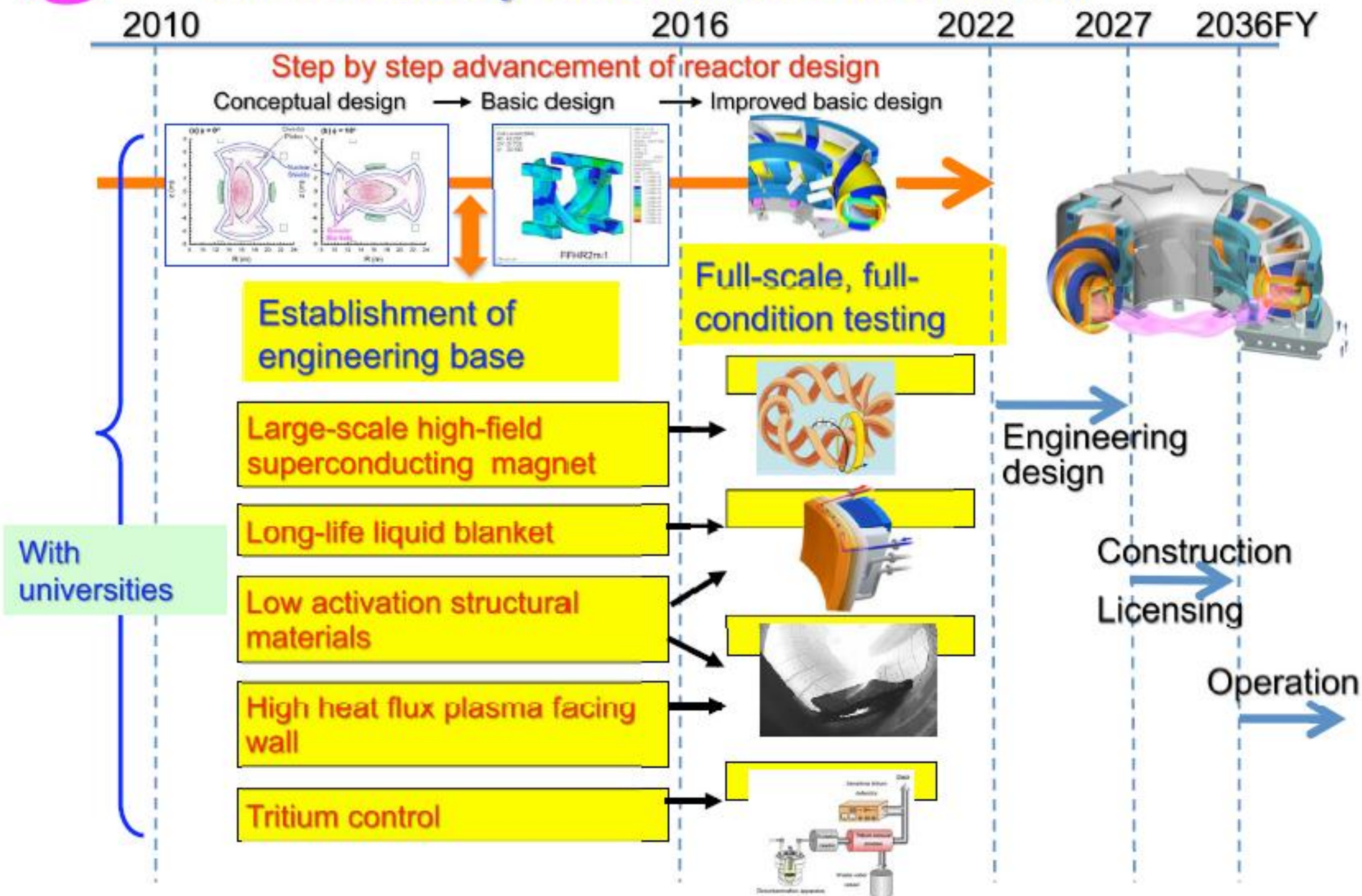
< Issues addressed in Broader Approach activities >

- 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**

# Fusion Eng. Research Project has started towards steady-state helical DEMO reactor




Sagara- 2/24

**SPL2-4 A.Komori Tuesday 14:15**

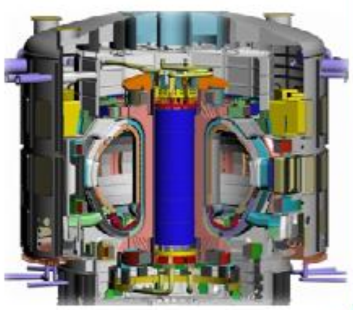
**With Courtesy from Prof. Sagara**

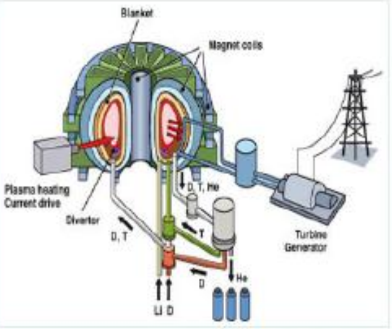
# Korea

## Fusion Energy Development Roadmap in Korea

### Role of KSTAR and ITER

| 2010' KSTAR | 2020' ITER | 2030' DEMO | 2040' Fusion Plant |
|---|---|---|---|
| High-Beta, Steady-state<br>Integrated Control<br>Optimum Fusion Reaction<br>ITER Operation Scenario Study & Component Test<br>- ITER Pilot Plant | Tritium Fuel Cycle<br>Reactor Engineering<br>DT Burning Plasma<br>Blanket, Divertor<br>Joint Big Science Experiment | Reactor System Optimization<br>Socio-economic Studies<br>Based on Results of KSTAR & ITER Operation<br>Electricity Production | Completion of Fusion Plant Engineering<br>Commercialization of Fusion Energy<br>Massive Electricity Production |







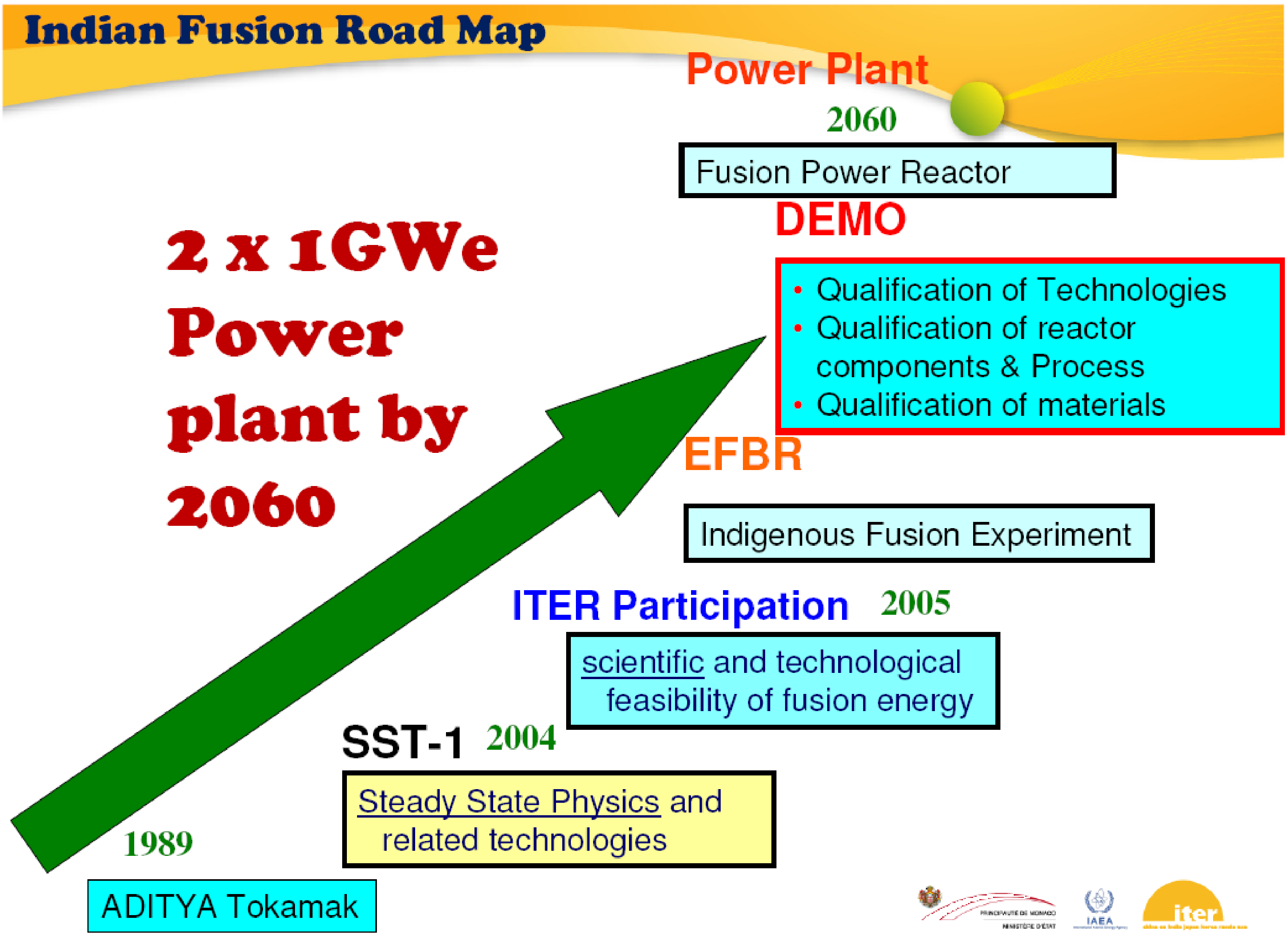

**With Courtesy from H-C-Kim**

# DEMO R&D Facilities for Design Validation Test

## R&D and Test Facilities Plan to be Proposed

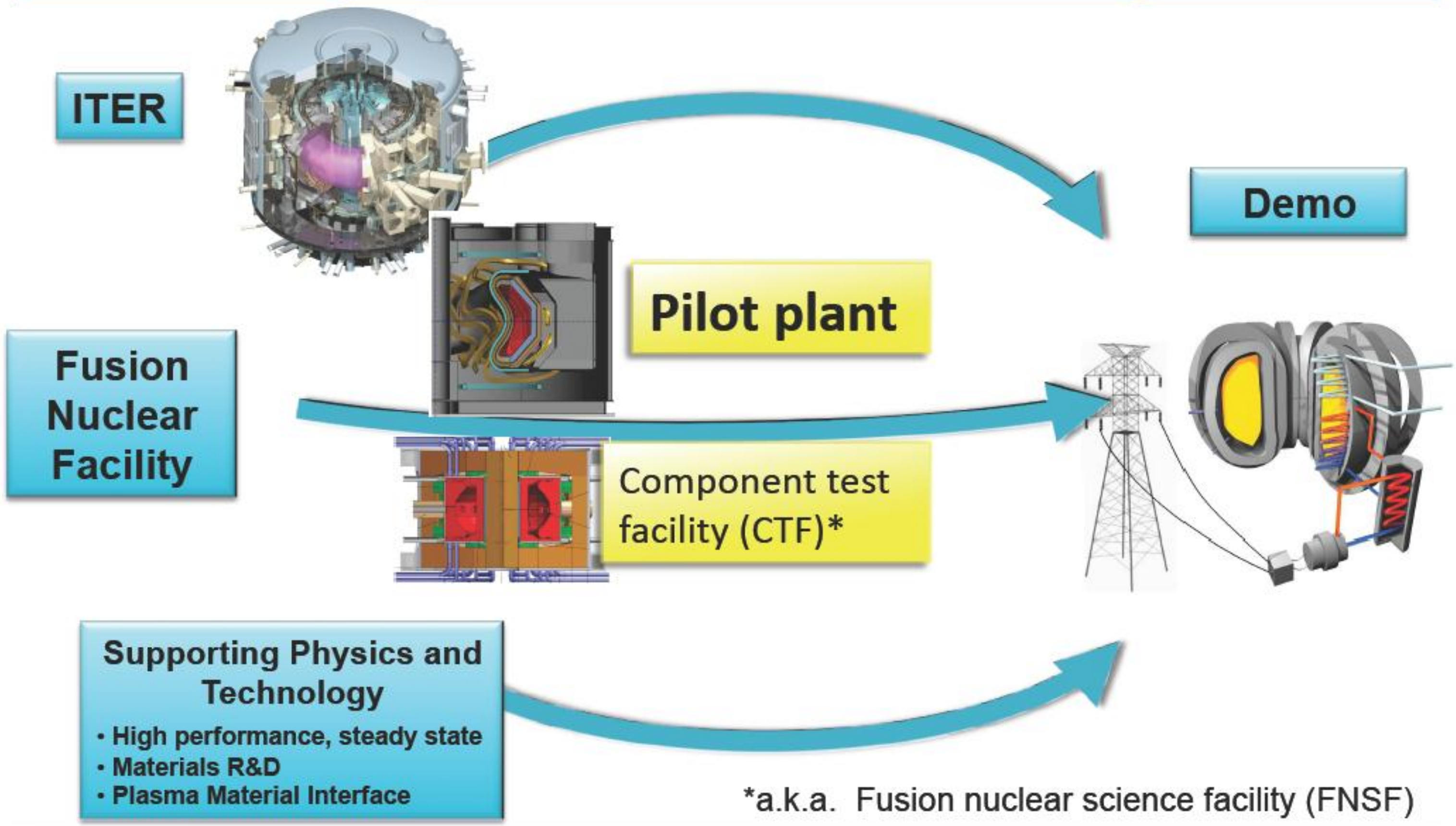

**With Courtesy from H-C-Kim**

# 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.

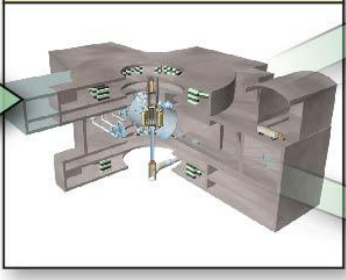


10:00 SO4A-1, G. H. Neilson, Thursday **SO4A-2, M.Peng** **SO4A-4, S. Konishi**

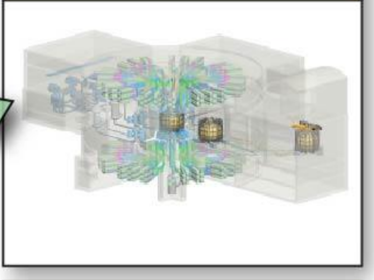
# Development Path -

**NIF**

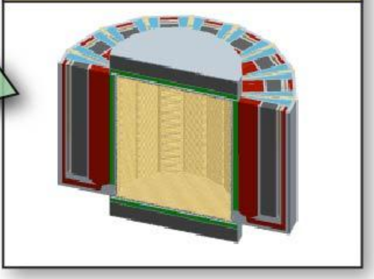
**LIFE.1**



**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 (~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)

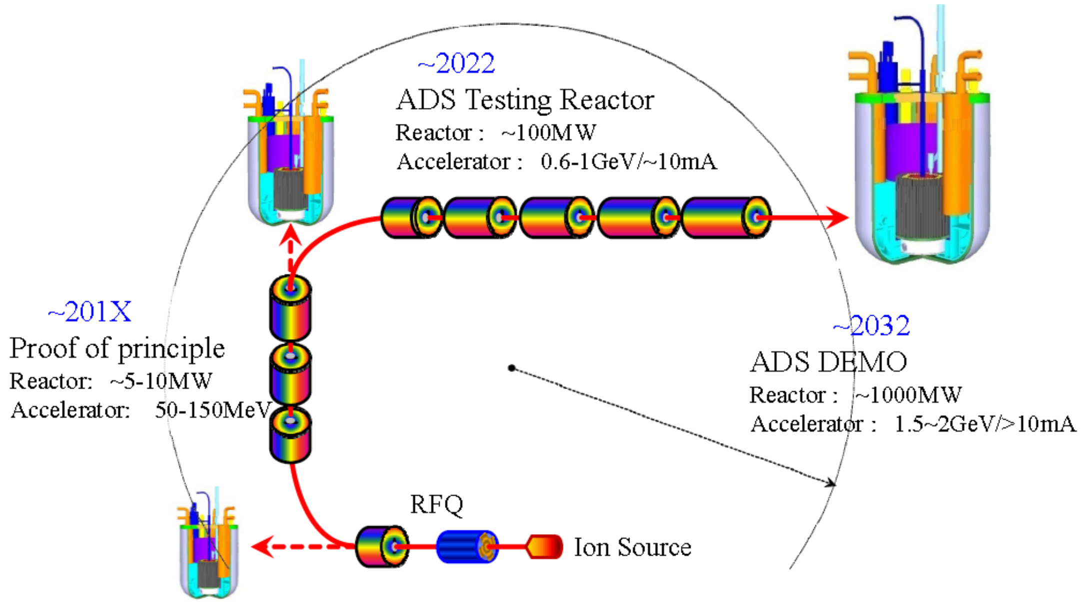
→800MW(2015)

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=1-4x$10^{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



## 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.**