Proceedings of the 2nd IAEA Technical Meeting on First Generation of Fusion Power Plants: Design & Technology

PPCA.O-4

Conceptual study of Indian Fusion Power Plant

R. Srinivasan and the Indian DEMO team

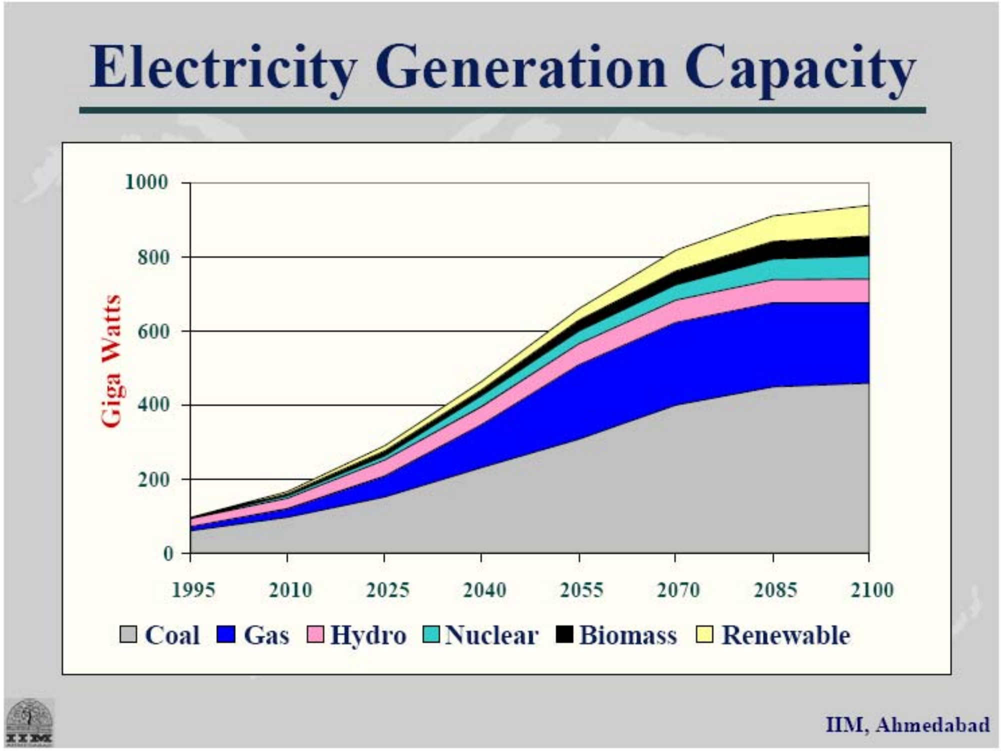
Institute for Plasma Research,
Bhat, Gandhinagar – 382 428,
India

Plan of the talk

- Energy scenario in India
- IFPP – design objectives
- Physics model
- Application to ITER-FEAT
- IFPP – base line design
- Various sub-systems requirement
- Required fusion technology development
- Optimization of IFPP
- Conclusions

Energy Scenario : INDIA

- By 2100 India needs about 900 GWe (9 times todays requirement)
- Most of them has to be produced with coal and the carbon emission increases by 5 times
- If fusion power reactor is available by 2050, by 2100 it can give 67 GWe



P. R. Shukla et al., IIM, Ahmedabad

India should have Fusion Power Reactor by 2050

INDIAN FUSION ROAD MAP

Power Plant **2050**

Fusion Power Reactor

DEMO **2035**

- Qualification of Technologies
- Qualification of reactor components & Process

SST-2 **2020**

Indigenous Fusion Experiment

ITER Participation **2005**

scientific and technological feasibility of fusion energy

SST-1 **2004**

Steady State Physics and related technologies

1986

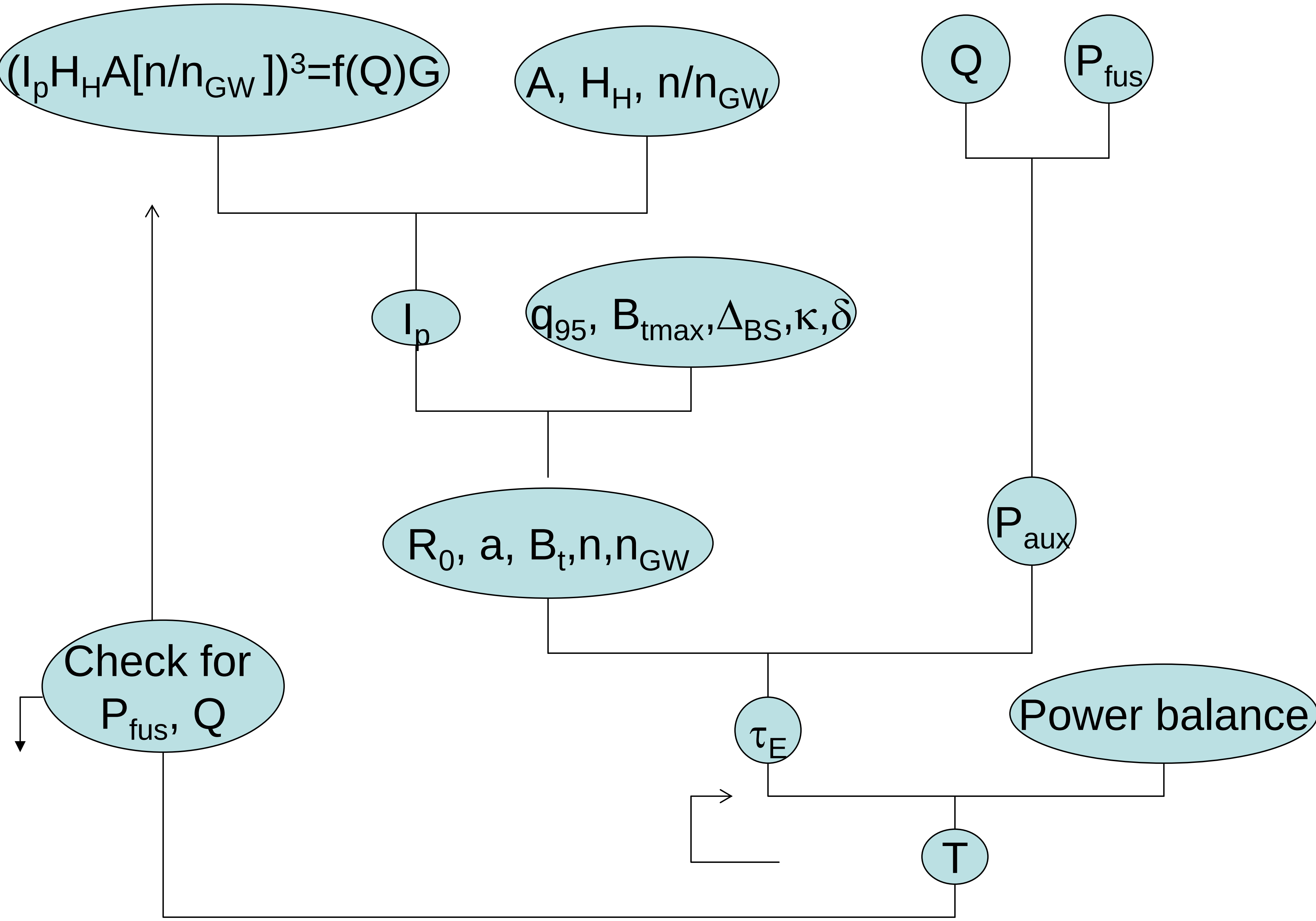
ADITYA Tokamak

IFPP Design :Objectives

- Production of more than 1 GW net electricity
- Power plant should operate atleast for 25 FPY
- Availability of the plant should be minimum 60 %(40 yrs@60 % ~ 25 FPY)
- Cost of the electricity should be either comparable or little higher than the available one
- Environmental safety should be safe guarded
- Base line design should be
  - Conservative (any improvement will be a boost)
  - Try to use the known technologies
  - Try to use the available materials
- Design should indicate the possible directions to improve the design further

IFPP : Physics design

- Fusion performance or fusion gain (Q) has to be maximized
- Q depends on plasma performance
  - Confinement time
  - Impurity level
  - n/n_{GW}
  - β_N
  - Normalized power crossing the separatrix
- In-directly depends on the geometry of the system
  - Maximum toroidal field at the TF conductor
  - Area available for the neutron load (breeding and damage)
  - Area available for the heat removal



$(I_p H_H A[n/n_{GW}])^3 = f(Q)G$
$A, H_H, n/n_{GW}$
Q
P_{fus}
I_p
$q_{95}, B_{tmax}, \Delta_{BS}, \kappa, \delta$
R_0, a, B_t, n, n_{GW}
P_{aux}
Check for P_{fus}, Q
τ_E
Power balance
T

Model : ITER-FEAT

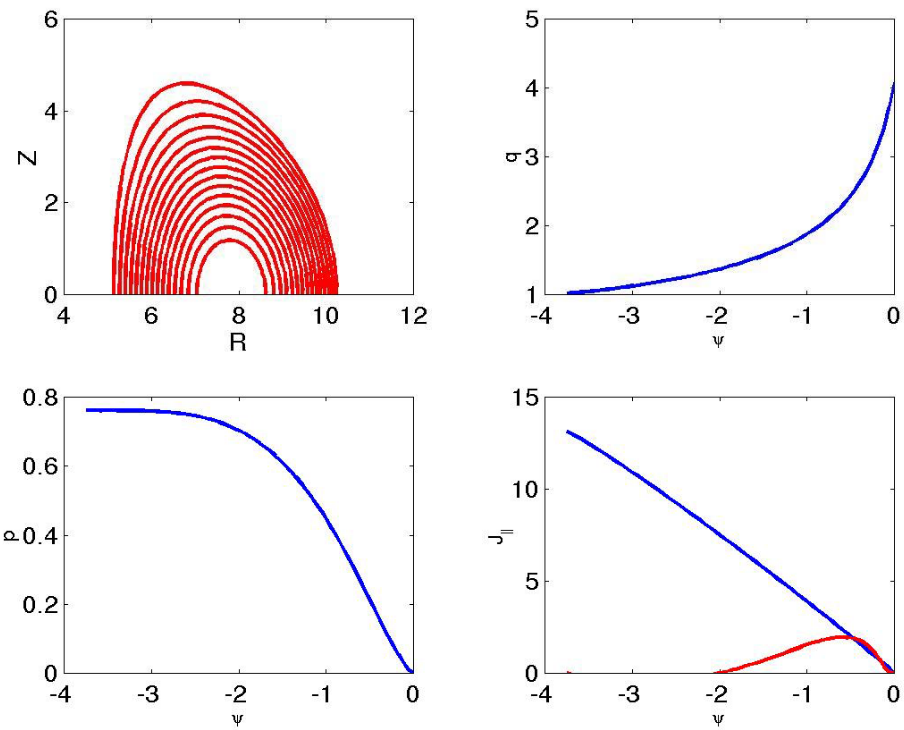
Plasma parameters	ITER-FEAT	Model prediction
R_0	6.2	6.13
a	2.0	1.98
B_t (T)	5.3	5.4
I_p(MA)	15.0	15.1
P_{loss}/P_{LH}	2.5	2.1
P_{fusion} (MW)	500	500
P_{aux}(MW)	50	50
$\langle n_{20} \rangle$	1.1	1.1
$\langle T \rangle$ keV	8.9	8.9
β_N	2.0	1.9

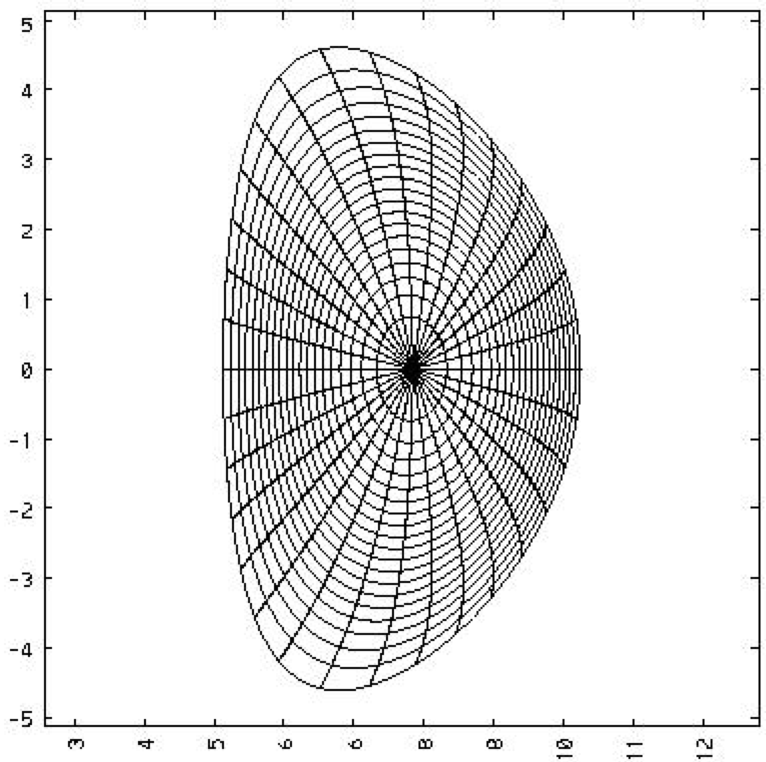
Model : IFPP

Plasma parameters	IFPP-base line
R_0	7.7
a	2.6
A	3.0
B_t (T)	6.0
I_p(MA)	21.4
f_{bs}(%)	25
P_{loss}(MW)	522
P_{fusion} (MW)	2500
P_{aux}(MW)	83
Q	30
n/n_{GW}	0.93
<T> keV	15.5
β_N	2.3

Plasma parameters	IFPP-base line
R_0	7.7
a	2.6
A	3.0
B_t (T)	6.0
I_p(MA)	17.8
f_{bs}(%)	50
P_{loss}(MW)	720
P_{fusion} (MW)	3300
P_{aux}(MW)	110
Q	30
n/n_{GW}	0.93
<T> keV	21.5
β_N	3.3

IFPP : MHD





MHD Equilibrium

Ideal MHD stability with PEST-2

IFPP : Sub-systems

S. Pradhan et al.

For base line design

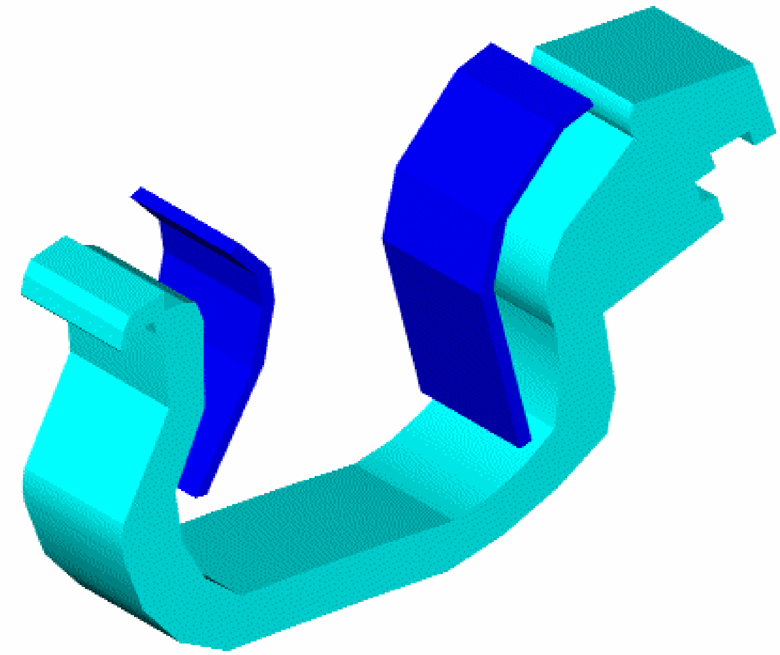
TF system

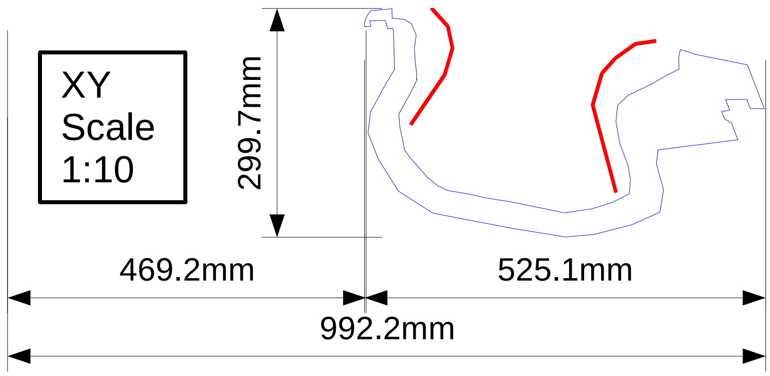
- B_{tmax} is 12 T (Nb_3Sn)
- D-shaped (width of D-shape = 11.4 m, height = 12.4 m), Coil width is 0.6 m radial and 1.37 m toroidal, Current density is 25 Amp/mm^2
- 16-18 TF modules, Electro-magnetic stress of 750 MPa
- Central solenoid with radial width of 1.4 m and radius 1.9 m, 12 m height can provide about 100 V-s
- Cooling requirement is around 20 kW @ 4.2^o K

IFPP : Sub-systems

Divertor

- Expected heat load is 10 – 15 MW/m^2 (for single null)
- Double null case for 10 mm SOL, angle 20^o , it is about 5 - 8 MW/m^2
- In board div. area 30 m^2 and out board div. area 50 m^2
- Number of modules has to be decided by the available port size





Sameer et al.

IFPP : Sub-systems…

P. K. Sharma et al.

Auxiliary power

- 80 MW –ve NBI will sustain the required plasma current
- Boot strap fraction is only 25 - 50% considered
- Additional RF power of 70 MW needed for controlling the plasma, CD and heating
- P_{ICRH}~30 MW (additional heating)
- P_{EC}~20 MW (Startup, ECCD to suppress MHD activity)
- P_{LH}~ 20 MW (for advanced scenario)

IFPP : Sub-systems…

Blanket system

Shishir et al.

- LLCB (structural 30 %, Pb-Li 40 %, Ceramic breeder 30 %)
- Inboard blanket thickness ~ 0.85 m and outboard thickness ~1.14 m
- Port size →2.4 m tor., 5.12 m height, blanket module size ~2x2x1.2, available area for breeding is 75%
- Structure material is ferritic steel
- Neutron wall load ~1.69 MW/m^2
- TBR ~ 1.1
- Gain ~ 1.2
- Thermal efficiency ~ 0.3

Materials for IFPP

- High heat flux materials

First Wall — Tungsten on LAFMS

Diverter — Tungsten (W) H_2O / He cooled

- Structural Materials
  - LAFMS
- Blanket Materials
  - Tritium breeding materials (Li_2 TiO_3 and Pb-Li)
  - Neutron Multiplier (Pb)
  - Flow channel inserts (SiC_f /SiC composite)
- Coolant
  - He , Pb-Li
- Shielding Material
  - WC
- Coatings
  - Trtium Permeation barrier (Al_2O_3)

P. M. Raole et al.

Tritium breeding calculations

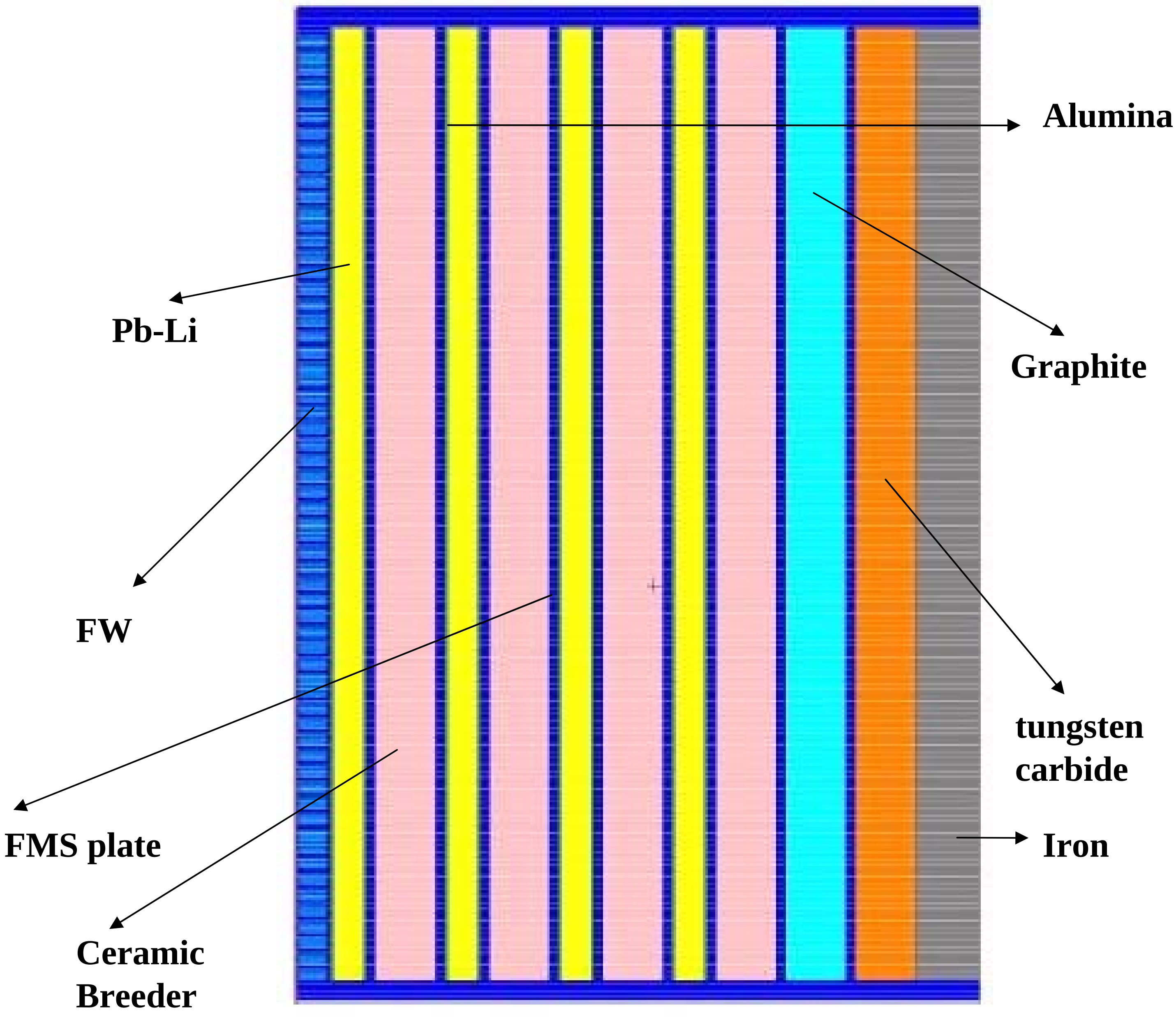
Two separate BUs has been modeled

14.1 Mev Planar source is used

Breeder material: Li_2TiO_3 (90 %)

Multiplier material: Pb-Li

Structure material: EUROFER



IFPP : Fusion Tech. Development

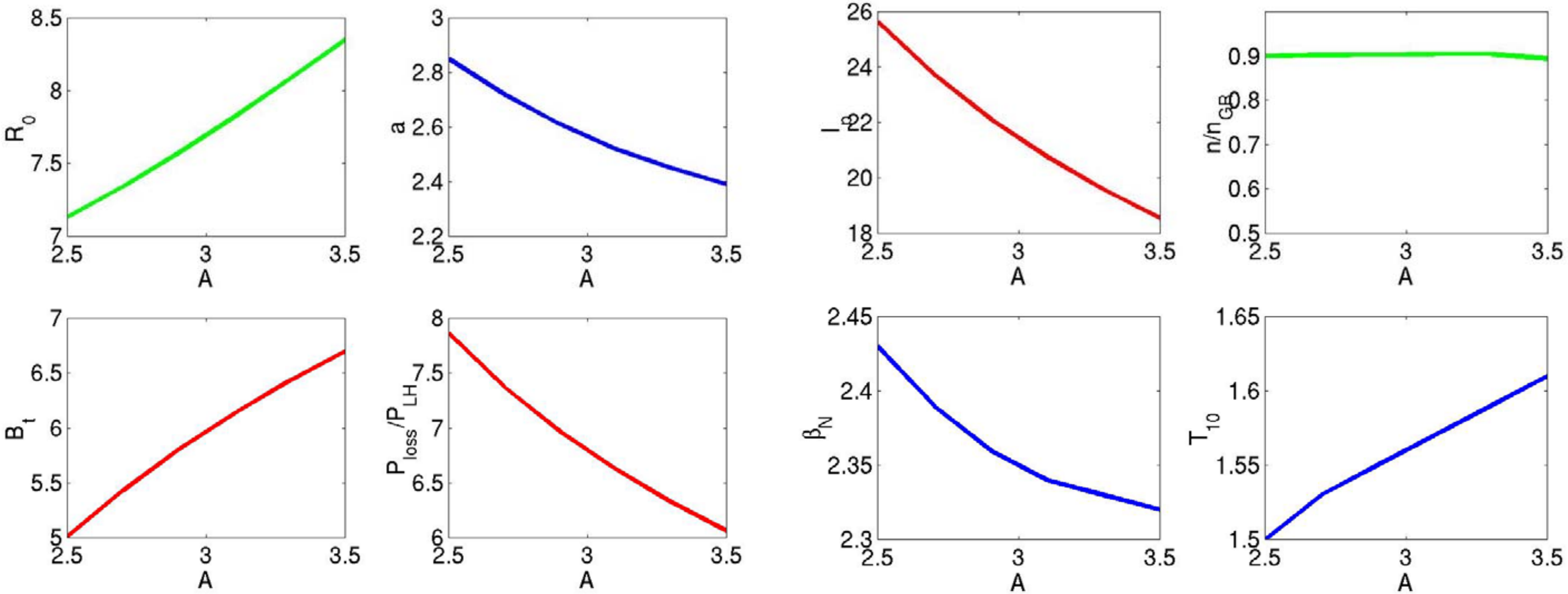
- Magnet system
  - High T_c superconducting magnet
  - High magnetic field at low temperature (Nb_3Al)
  - Reduced central solenoid
- Divertor system
  - Single or double null
  - Modify the magnetic topology near the divertor
  - Special materials for high heat flux
- Blanket system
  - Tritium breeding
  - Power gain
  - Operating temperature (for thermal efficiency)

Variation with aspect ratio

Q = 30, P_f = 2.5 GW

Physics optimization

- n/n_{GW} =1, H_H > 1, f_{bs} > 50 % and 30 < Q < 50



Conclusions

- Approximate estimate of CoE is about Rs 5 to 10 per kW-h (9 to 16 Eurocents)
- Physics optimization may increase the fusion power output
- Hybrid and RS have different requirements in CD, heating and control systems
- Fusion technology development in next 25 years will decide the optimization in terms of technology
- Maximizing thermal efficiency is essential to bring down the CoE

Thank you