Karlsruhe Institute of Technology

EUROfusion POWER PLANT PHYSICS & TECHNOLOGY DEPARTMENT

Long and winding road to the Grid – challenges and obstacles on the way to the FPP

Workshop on DEMO Physics and Technology R&D

5.-6. February 2018

Wolfgang Hering, E. Bubelis, S. Perez-Martin, Francisco Hernandez

Institute for Neutron Physics and Reactor Technology

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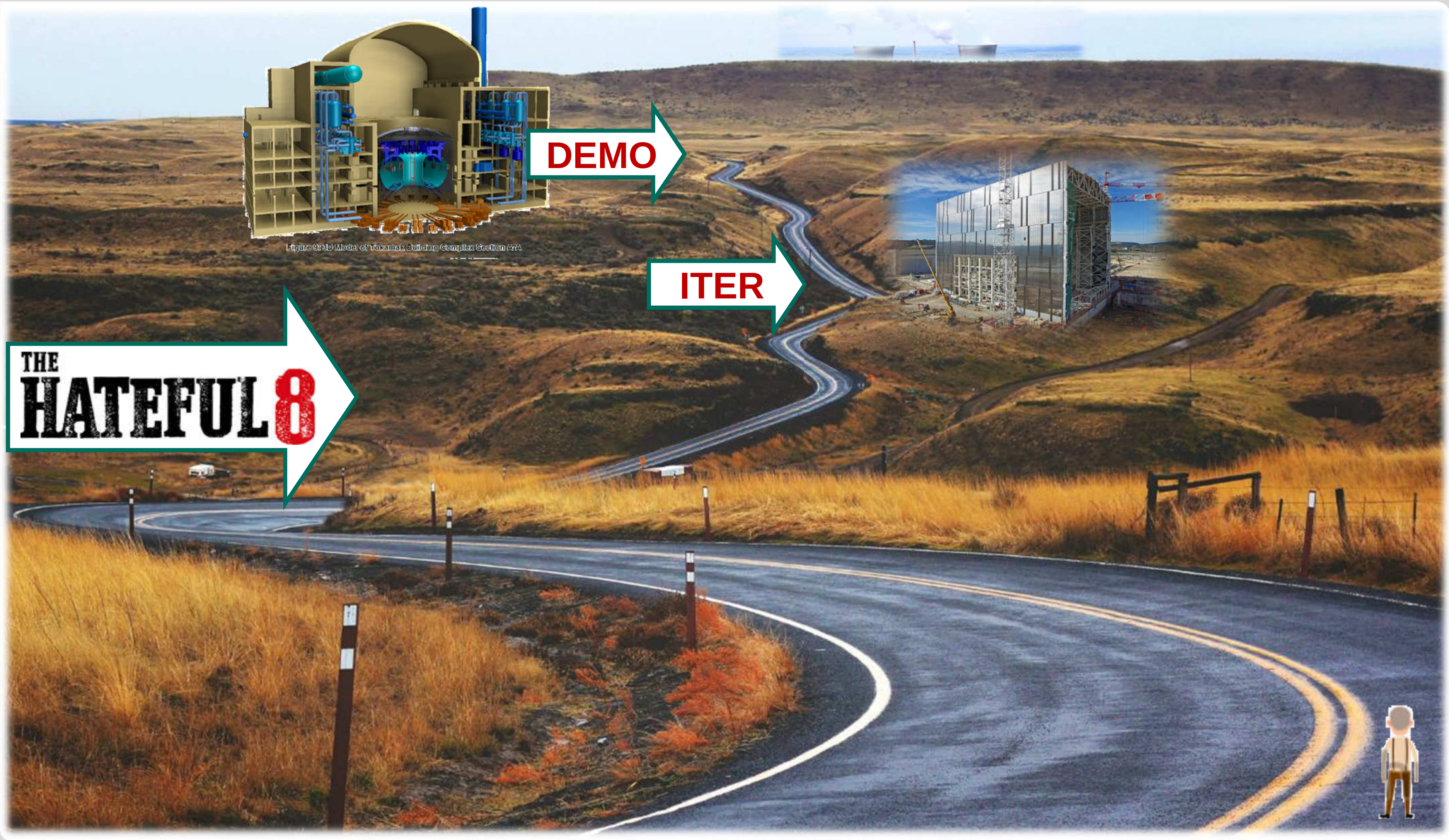


Figure 9: 3D Model of Tokamak Building Complex Section A-A
DEMO
ITER
THE
HATEFUL 8

Big open issues

- THE HATEFUL 8 — Req. by G. Frederici, PMU EUROfusion — What does it mean for DEMO BoP?
- What should DEMO be?
  1. Demonstrator to prove that Fusion is ready for grid support or
  2. Component test machine
- Can ITER be an ideal for DEMO?
- Can DEMO answer questions for FPP?
- What should an FPP deliver to grid?

Step by step!

THE HATEFUL 8 of PMU means:

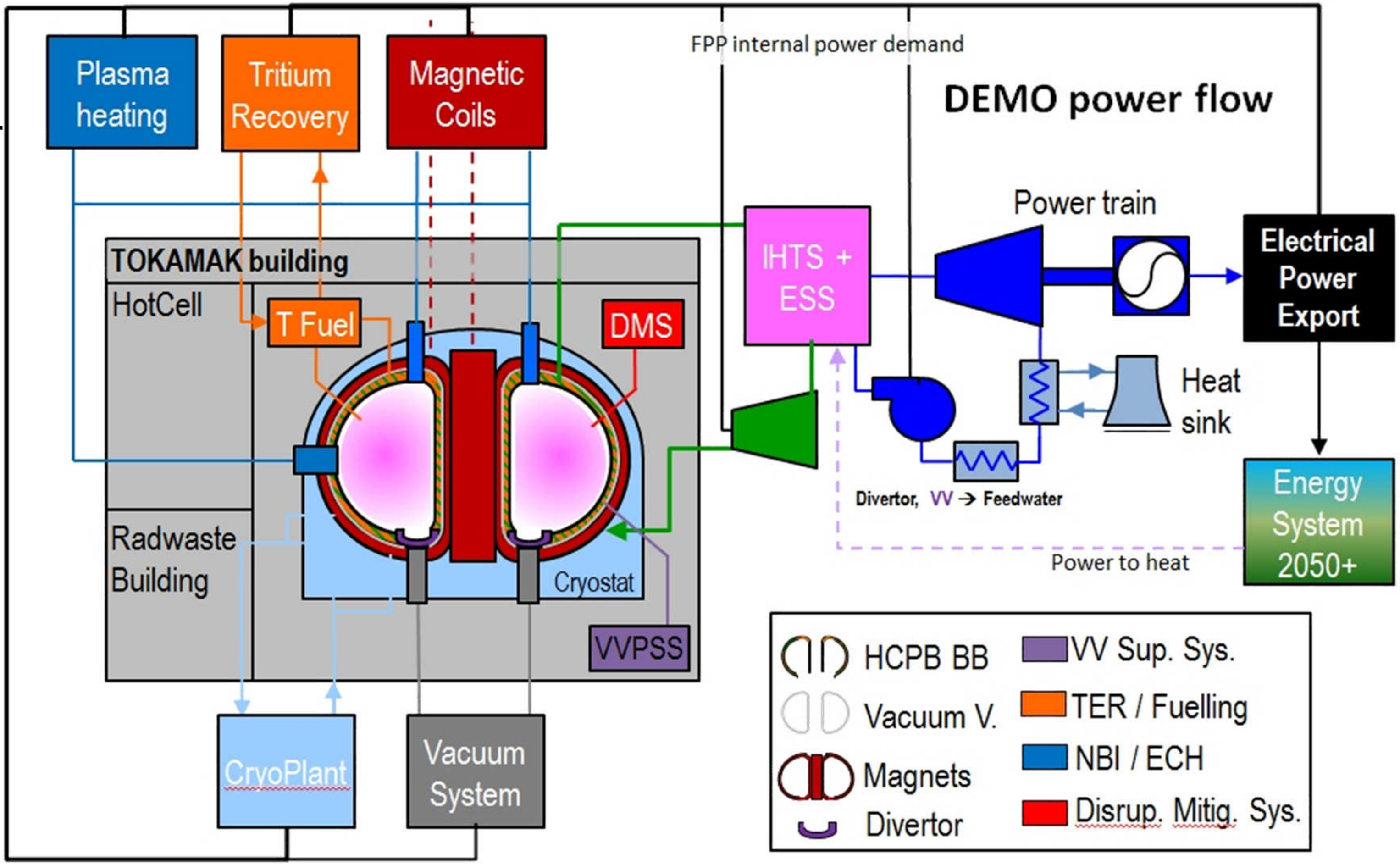
1. **RUs: Find solutions for Pulsed PCS (WCLL/HCPB)**
2. **Industry: Pulsed PCS for WCLL**
3. **Industry: Pulsed PCS for HCPB**

   } to provide operating experience, calculation models tuned on operating plants and special thermo-mechanical calculation on steam turbine useful to assess feasibility of the solutions

4. **HCPB PHTS&BOP design on DEMO-16**
5. **Internal Design Review of PHTS&BOP+ESS DEMO-18** (End of 2018)
6. **Completion of design activity on WCLL Pulsed PCS in 2018**
7. **Internal Design Review of PHTS&BOP without ESS** (End of 2019)
8. **Pre-gate Review in June 2020**

DEMO Systems connected to BoP

Main Power consumers connected to DEMO BoP



Status of DEMO BOP

Pulsed Tokamak with 120 min pulse and 10 min dwell time:

1. **Indirect coupling (IHTS plus a thermal energy storage ESS):**
   Today:
   - HTF technology from Concentrating Solar Power (CSP)
   - Helium technology (circulator, HX,…) checked and manufactural
   - Database for PHTS, IHTS and PCS established (not yet complete)
   → allows flexible plant operation

2. **Direct coupling (without IHTS):**
   steam generator inside Tokamak, steam line penetrates confinement, req. additional heating for boiler, turbine and steam generator
   → in development boosted by PMU allowing small ESS

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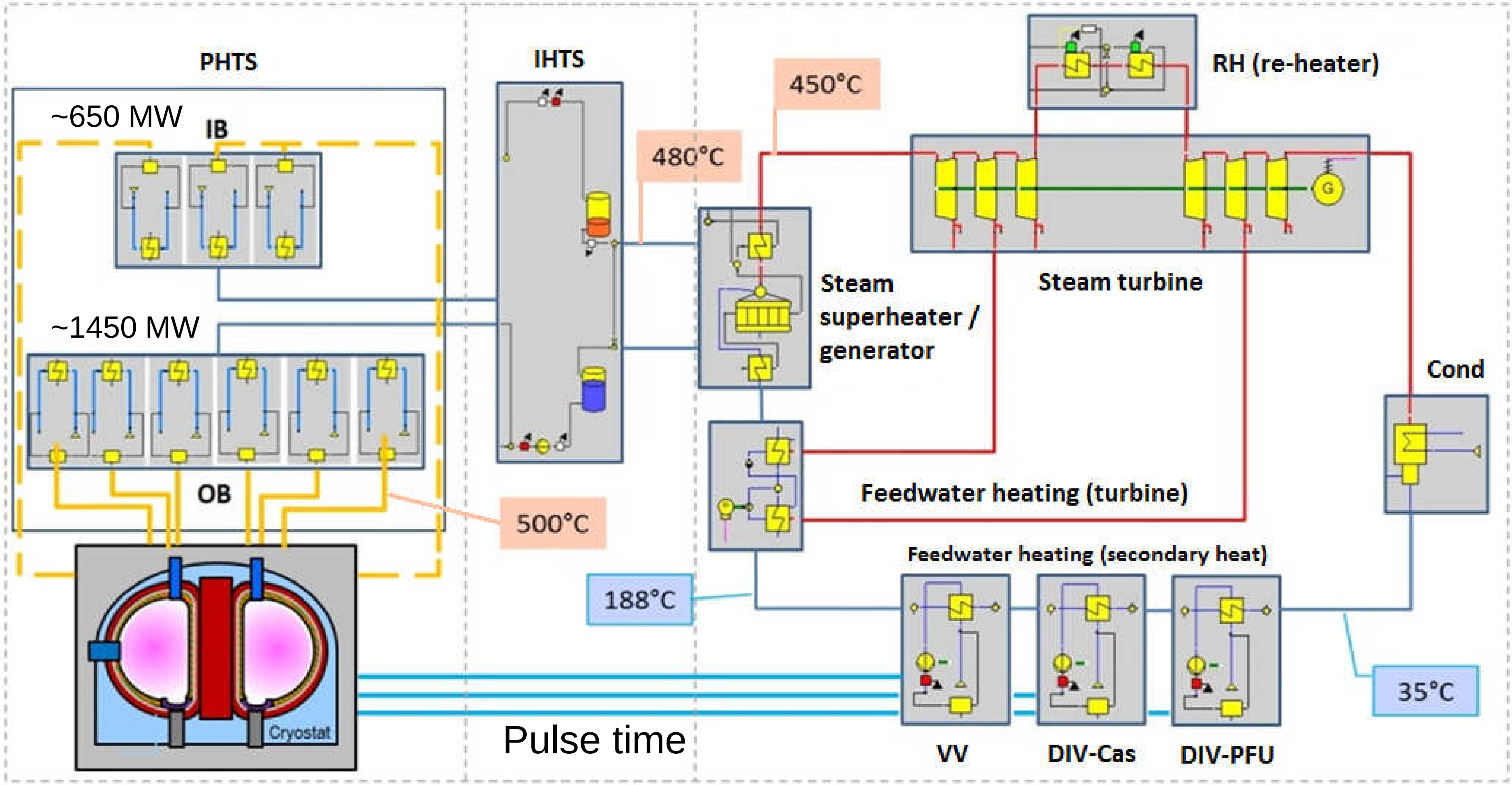
Energy transfer BB → PCS (DEMO-18)



Development of HCPB DEMO (2014→2017)

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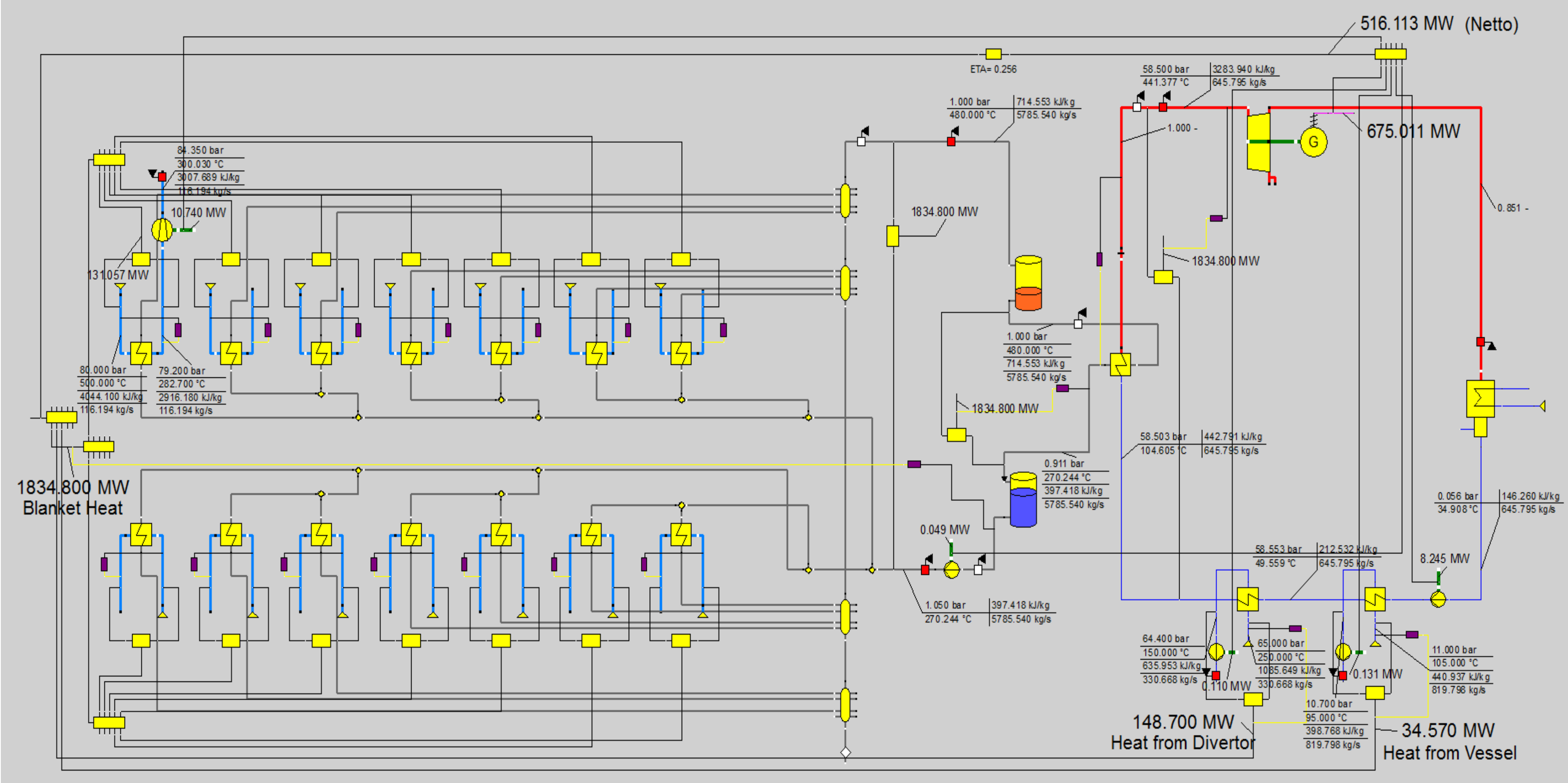

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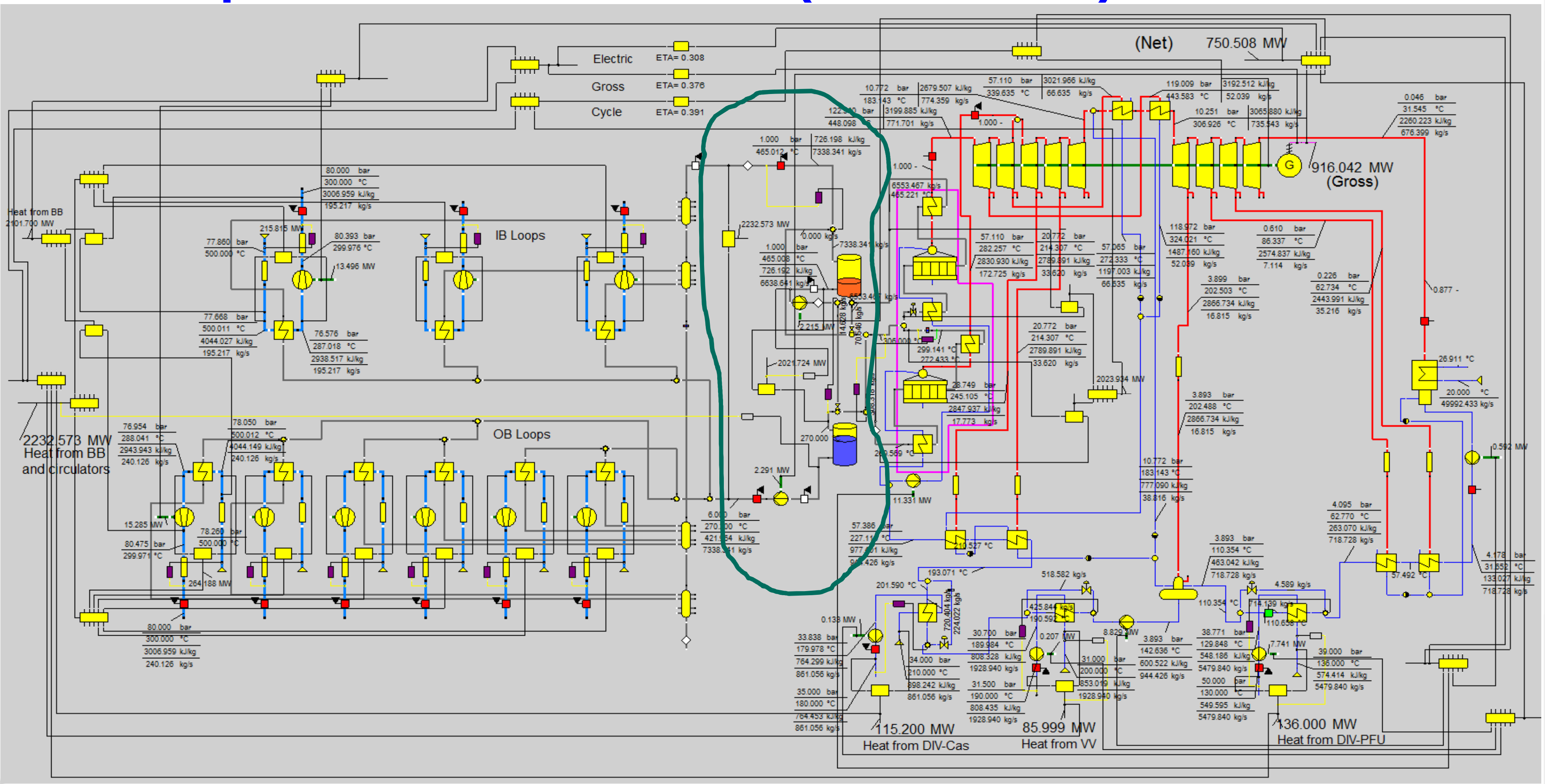
INR

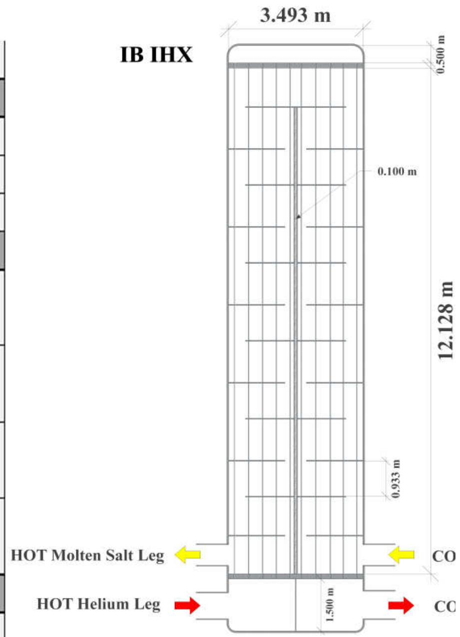
Development of HCPB DEMO (2014→2017)



Examples: Heat exchanger: He – MS

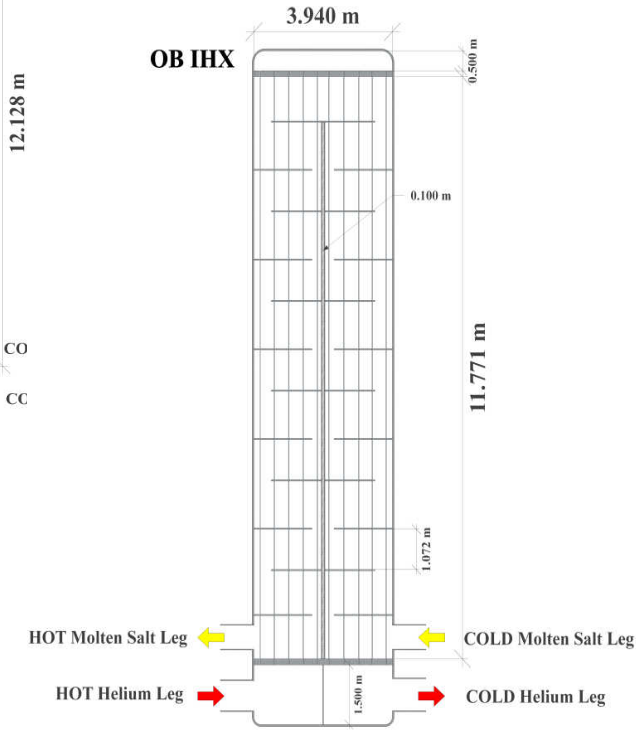
Inboard IHX			
Boundary/Input conditions at EOL			
$T_{in/out\ He}$ [°C] = 500/287.84		$T_{in/out\ MS}$ [°C] = 270/465	
G_{He} [kg/s] = 188.866		G_{MS} [kg/s] = 683.332	
$v_{He\ max}$ [m/s] = 35.000		$v_{MS\ max}$ [m/s] = 1.030	
Main geometric parameters			
HX layout TEMA F shell - 2 tube/shell passes		Tubes layout Square	
$D_{e\ tubes}$ [mm] 19.050	P/D_e [-] 1.341	$L_{active\ per\ pass}$ [m] 12.128	$D_{i\ shell}$ [m] 3.493
t_{tubes} [mm] 1.651	$S_{ext\ active\ (EOL)}$ [m^2] 8416.610	H_{baffle} [m] 0.933	$N_{active\ tubes\ (EOL)}$ [-] 5798
$V_{MS\ in\ shell}$ [m^3] 63.640	$V_{He\ in\ Bundle}$ [m^3] 30.133	$V_{He\ in\ Heads}$ [m^3] 19.164	$N_{tubes\ (BOL)}$ [-] 6378
Thermal-Hydraulic parameters			
$\Delta P_{He\ total\ (bundle+heads)}$ [bar] 0.862		$\Delta P_{Salt\ total}$ [bar] 1.042	
U_{Avg} [W/m^{2}K] 970.015			

Data from Ivo Moscato (Ansaldo)

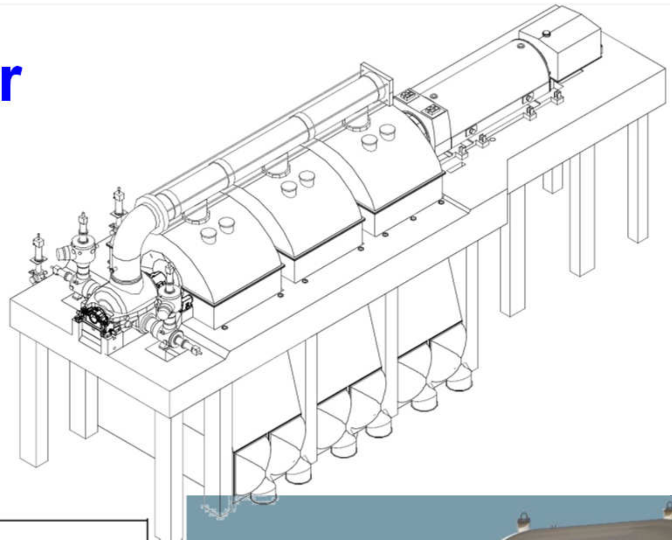


IB: 216 MW

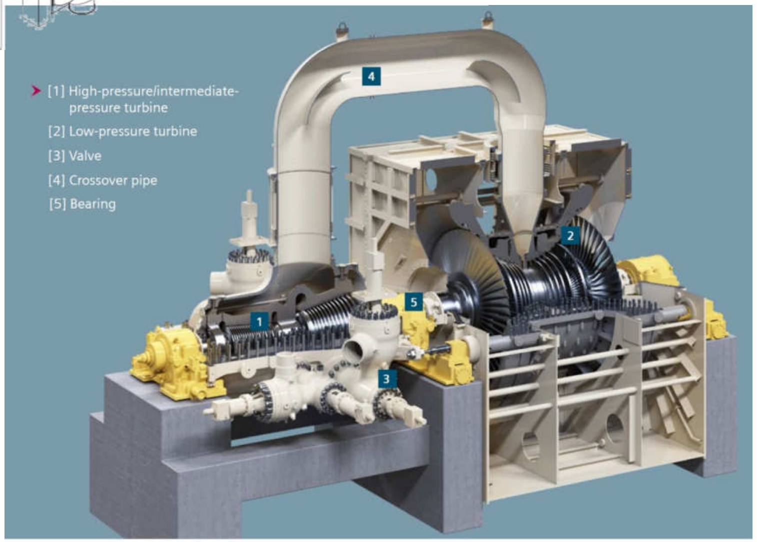
OB: 264 MW



Examples: Turbo-Generator



Turbogenerator (PCS ST)	
Live steam pressure	130 bar(abs)
Live steam flow rate	842 kg/s
Live steam temperature	447 °C
Max. PCS Output	≈ 1009 *MW*
Turbogenerator weight	Approx. 1285000 kg
Turbine manufacturer	Siemens
Turbine type	SST5-6000: I50 / 6x12.5m²
No. of turbine stages	1 IP turbine stage; 3 LP turbine stages
Turbine rated speed	3000 rpm
Electrical generator manufacturer	Siemens
Electrical generator type	SGen5-3000W
Electrical generator rating	965 MVA
Condenser cooling water quantity	35184 kg/s
Condenser cooling water inlet temperature	20 °C
Condenser cooling water outlet temperature	29.5 °C
Turbogenerator space reservation	L=52m;H=24m;W=19m



www.siemens.com/steamturbines

Summary indirect coupling

- Solutions for all initial “show stoppers” found
  - not perfect ideal but accepted by industry for further development
- Circulation power still high (~150 MW)
- Helium inventory still too high:
  → segmentation
  → size reduction necessary

BoP interacts from the beginning with:

- Breeding blanket (BB):
  optimize interface and design, operation and emergency conditions
- Safety (SAE)
  such as: Plasma instability, Disruptions, Emergency shut down,…
  → Safety provisions

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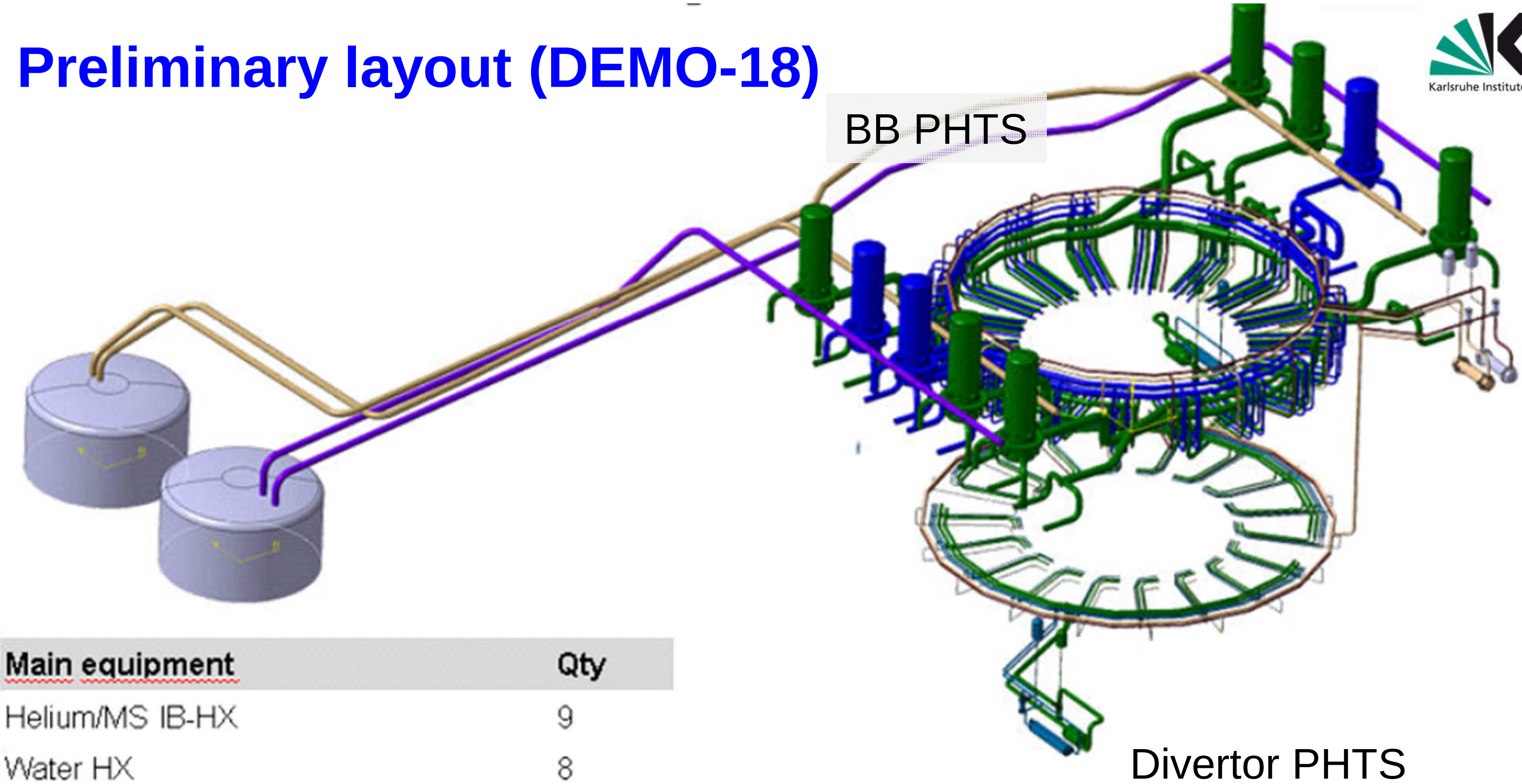
Preliminary layout (DEMO-18)



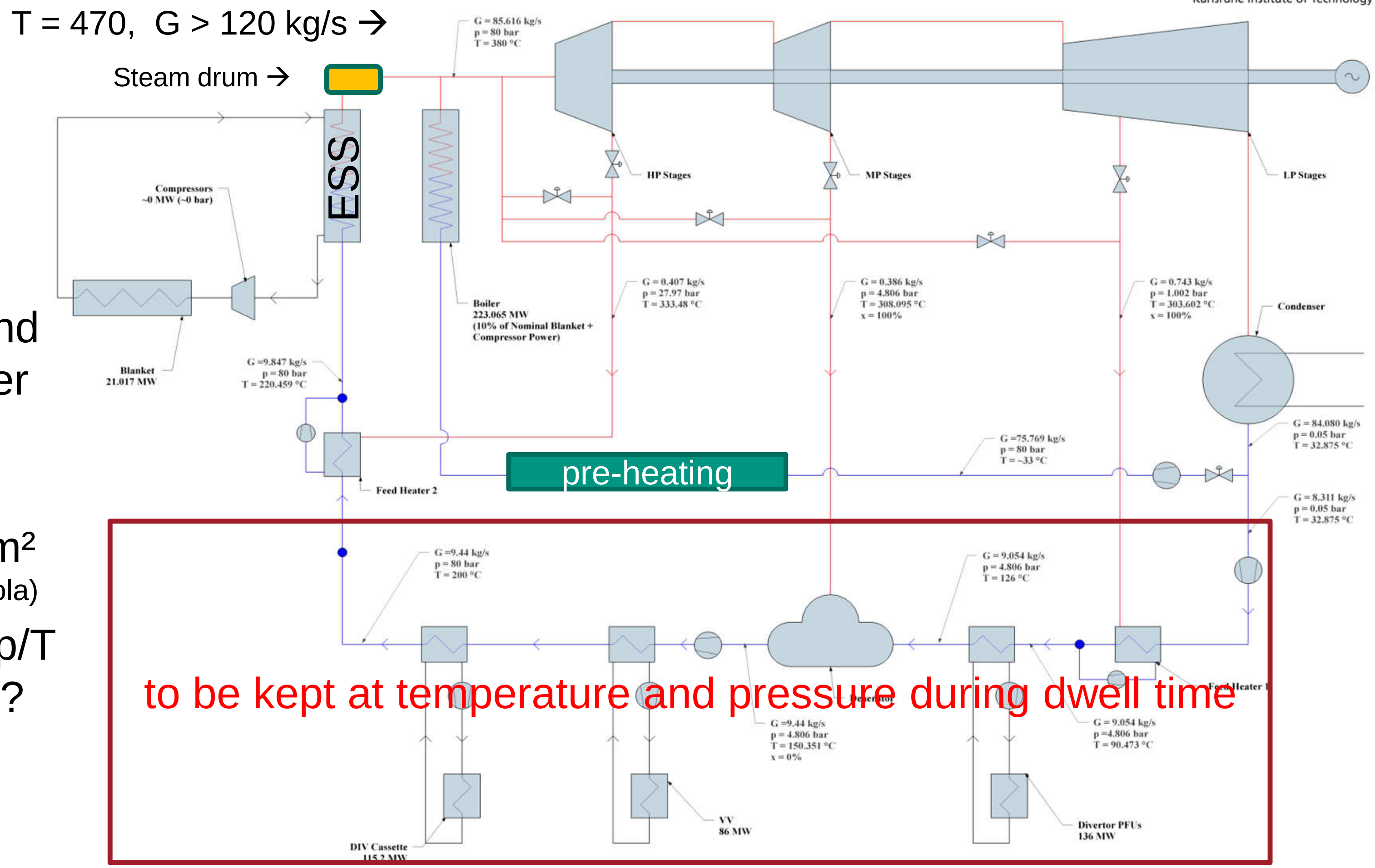
Main equipment	Qty
Helium/MS IB-HX	9
Water HX	8
MS Tanks (3000m³)	2
Piping PHTS	**≈3.5 km**
Piping MS system	**755m**

A. Tarallo, CREATE

Analysis of direct coupling

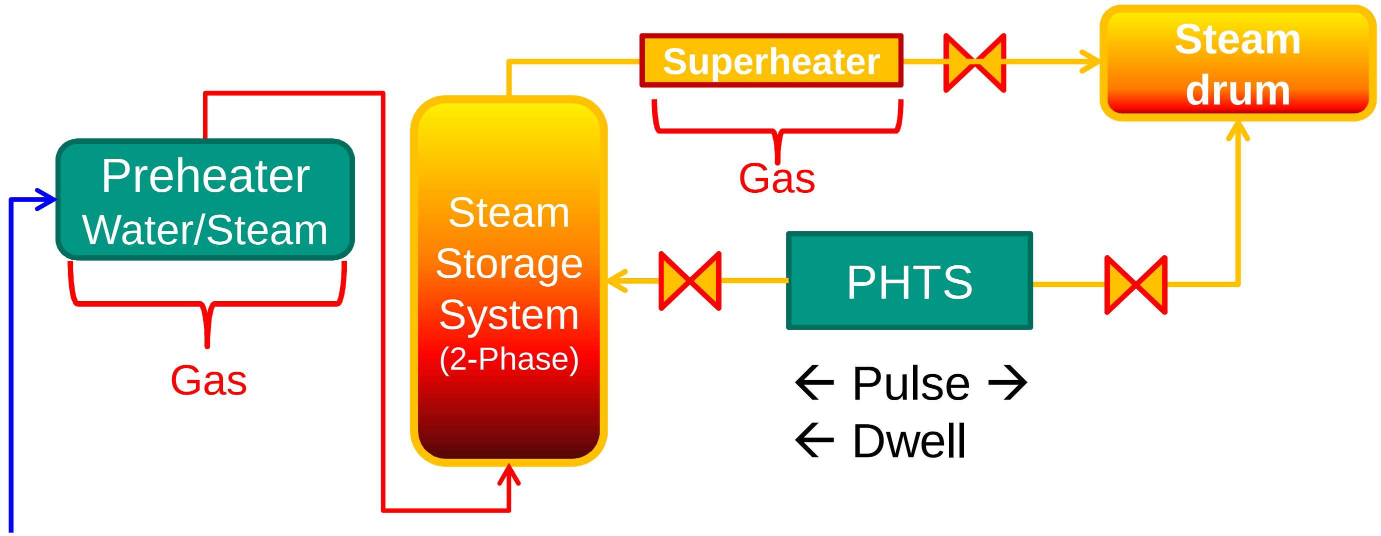
Upshot:

- Transition times
- Values?
- Flow 7% and Boiler power 10%?
- Boiler: HT area ~650m² (0,3 MW/m²Merola)
- Deaerator p/T oscillations?



Advanced concept to reduce costs

- Problem of boiler: fast temperature and pressure transients



- Solution Boiler + 2-phase steam storage (+ superheater)
- But ineffective for higher pressures and energy capacities
  (no industrial experience at DEMO size)

Challenges to be solved

- Keep steam turbo-generator, feedwater-system, steam generator and pumps alive
- Transition between dwell and pulse risky due to fast power increase
- Limit temperature (<2K/min) and pressure changes (0,5 bar/min)
- Obey limitations in turbo-generator speed to stay synchronized
- Keep an eye on additional investment and operating costs:
  - Full power boiler ~ 120 Mio €
  - Energy storage for water (innovative - never build so far, cost?)
  - High capacity gas pipeline ~1 Mio €/mi (depending on gas grid)
  - Infrastructure investments ?
  - Maintenance costs at boiler: corrosion due transient gas burning
  - Costs of fuel (gas)?

Summary and Outlook

Direct coupling

- Turbine no manufacturer:
  (SIEMENS: indirect coupling, ANSALDO max change rate: ~10%/min)
- Buffer system ESS: additional boiler expensive
- Steam generator ramp up/down ~15 min (comp to Benson boiler)

Indirect coupling

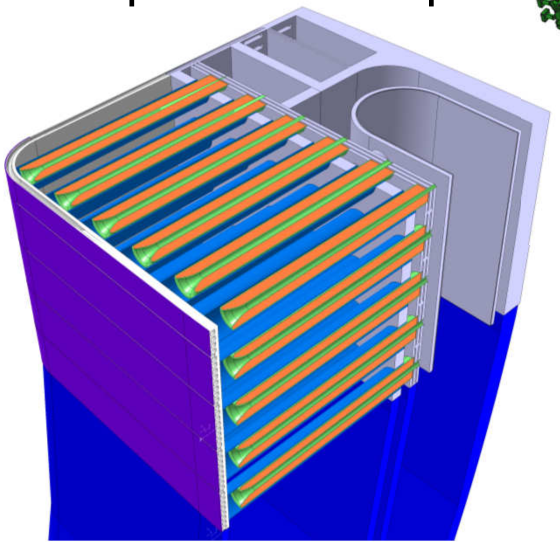
- Follow DEMO tokamak change from 18 to 16 sectors (DEMO-16)
  → Modify design and simulations to 16 sectors
  → Incorporate new BB design
  → Industry involvement to address component feasibility
- Dynamic simulations for transitions pulse to dwell required (RELAP5-3D)
- BoP knowledge applicable to Stellerator

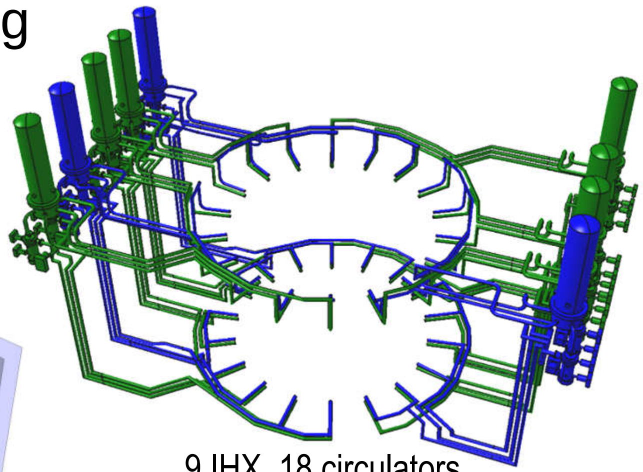
New hope from new BB design

- New design of BB (Francisco Hernandez)

  + higher FW cooling capability

  + significant lower pressure drop



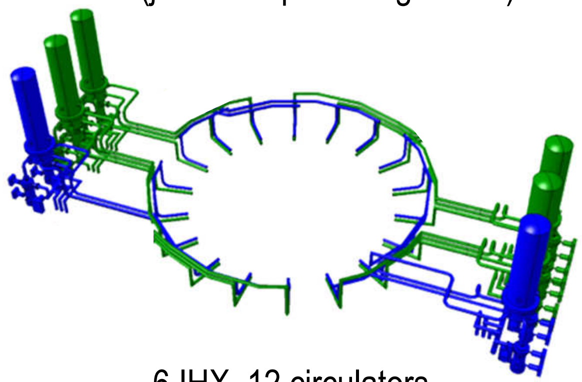


9 IHX, 18 circulators

P_{circ} ≈ 10MW/circ.

P_{pump}≈150MW

(just example configuration)

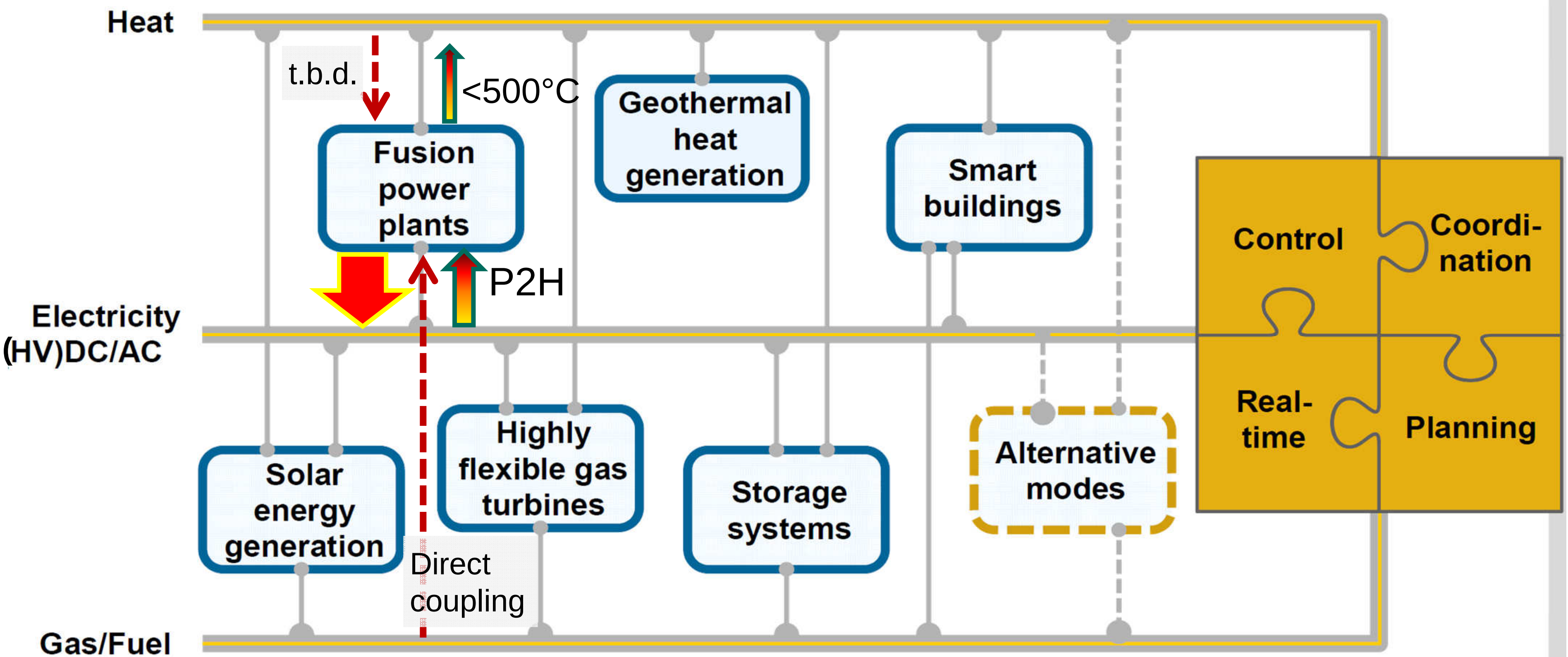


6 IHX, 12 circulators

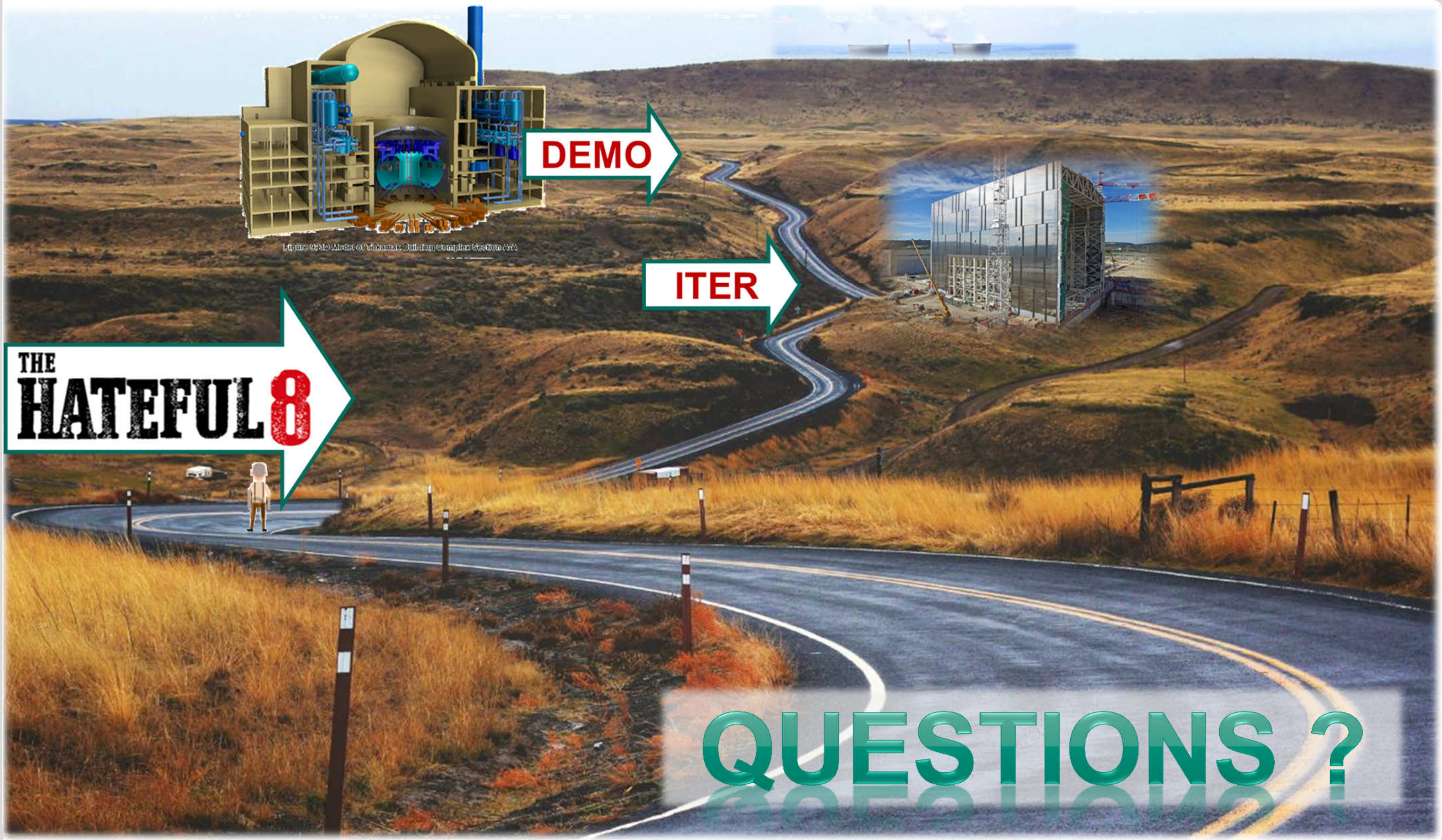
P_{circ} ≈5÷6MW/circ.

P_{pump}≈60÷70MW

And now to grid integration: ESI-2050+



- Electric power: In: (Startup, P2H) **AND** Out (FFP 2 grid: 30-110%)
- Thermal power: In: (???) **AND** Out (Process heat: <500°C)
- Gas/Fuel In: external heater for direct coupling and start-up


DEMO
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THE HATEFUL 8
QUESTIONS ?