CFD ACTIVITIES AT EDF CHINA R&D CENTER – FOCUS ON THE SUPPORT TO LOCAL THERMAL PLANTS

EDF CHINA R&D CENTER

- General presentation of EDF China R&D center
- CFD related activities in China
- Technical supports to local EDF assets in China:

Laibin B, SanMenXia, Liaocheng thermal plants

April 2nd, 2014

EDF GROUP 法电集团 - A WORLDWIDE LEADER IN ENERGY 世界能源领域领跑者

EDF GROUP IN ASIA 法电集团在亚洲

EDF (China) Holding Limited
Support China Division
EDF : 100%

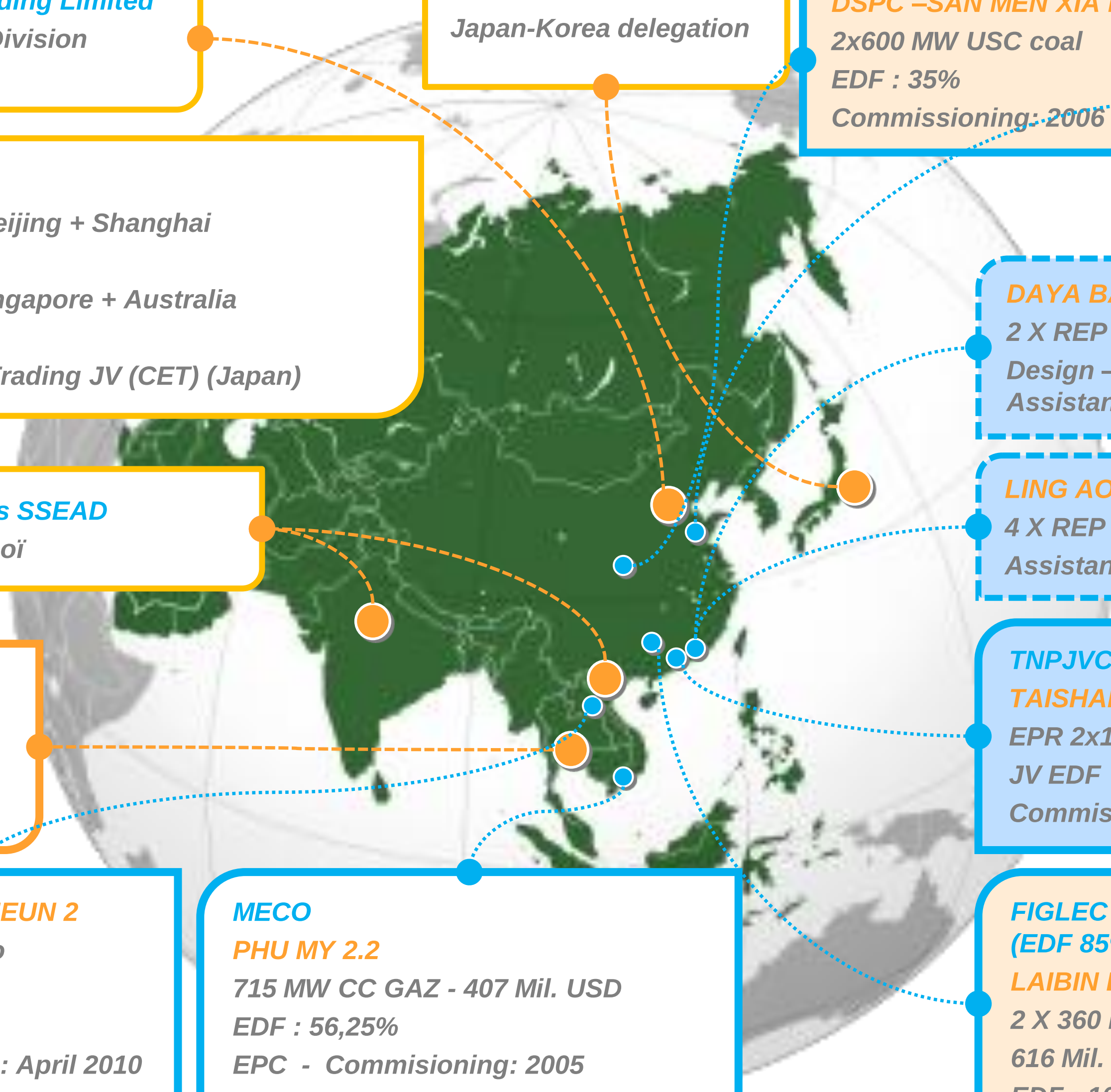
Japan-Korea delegation

DSPC –SAN MEN XIA II
2x600 MW USC coal
EDF : 35%
Commissioning: 2006

SZPC
6 X 300 MW coal
2 X 600 MW coal
2,16 Mds USD
EDF : 19,6%
Commissioning: 2005

EDF Trading
ESI (China) - Beijing + Shanghai

- Thailande + Singapore + Australia
- ChubuEnergyTrading JV (CET) (Japan)



DAYA BAY
2 X REP 985 MW Nuclear
Design – Construction - Assistance

LING AO 1 and 2
4 X REP 1000 MW Nuclear
Assistance

Regional Offices SSEAD
New Delhi + Hanoï

SEA (Thayland)
Support SSEAD
EDF: 100%
Net = 830 MW

TNPJVC
TAISHAN 1/2
EPR 2x1700 MW Nuclear
JV EDF 30% , CGN 70%
Commissioning2013 & 2014

NTPC - NAM THEUN 2
1 070 MW Hydro
1,25 Bil. USD
EDF : 40%
Commissioning: April 2010
Construction – operation

MECO
PHU MY 2.2
715 MW CC GAZ - 407 Mil. USD
EDF : 56,25%
EPC - Commisioning: 2005
Operation

FIGLEC (EDF 100%) & SYNERGIE (EDF 85%)
LAIBIN B
2 X 360 MW coal
616 Mil. USD
EDF : 100% Comissioning 2000

EDF R&D IN BRIEF 法国电力研究院

Working for all business units and subsidiaries of the group, the R&D sets as a priority:

- **Consolidate the low carbon energy mix** along with nuclear, renewable energy and CCS
- **Adapt the electrical system** with asset management and intermittency management
- **Manage the energy demand** through sustainable cities, energy in buildings and eco-efficient technologies using electricity

2 100 people / 370 doctors / 150 doctoral students

200 research fellows from Universities and other higher education establishments

90 % Success rate

For annuel contracts signed with EDF Group entities and business units

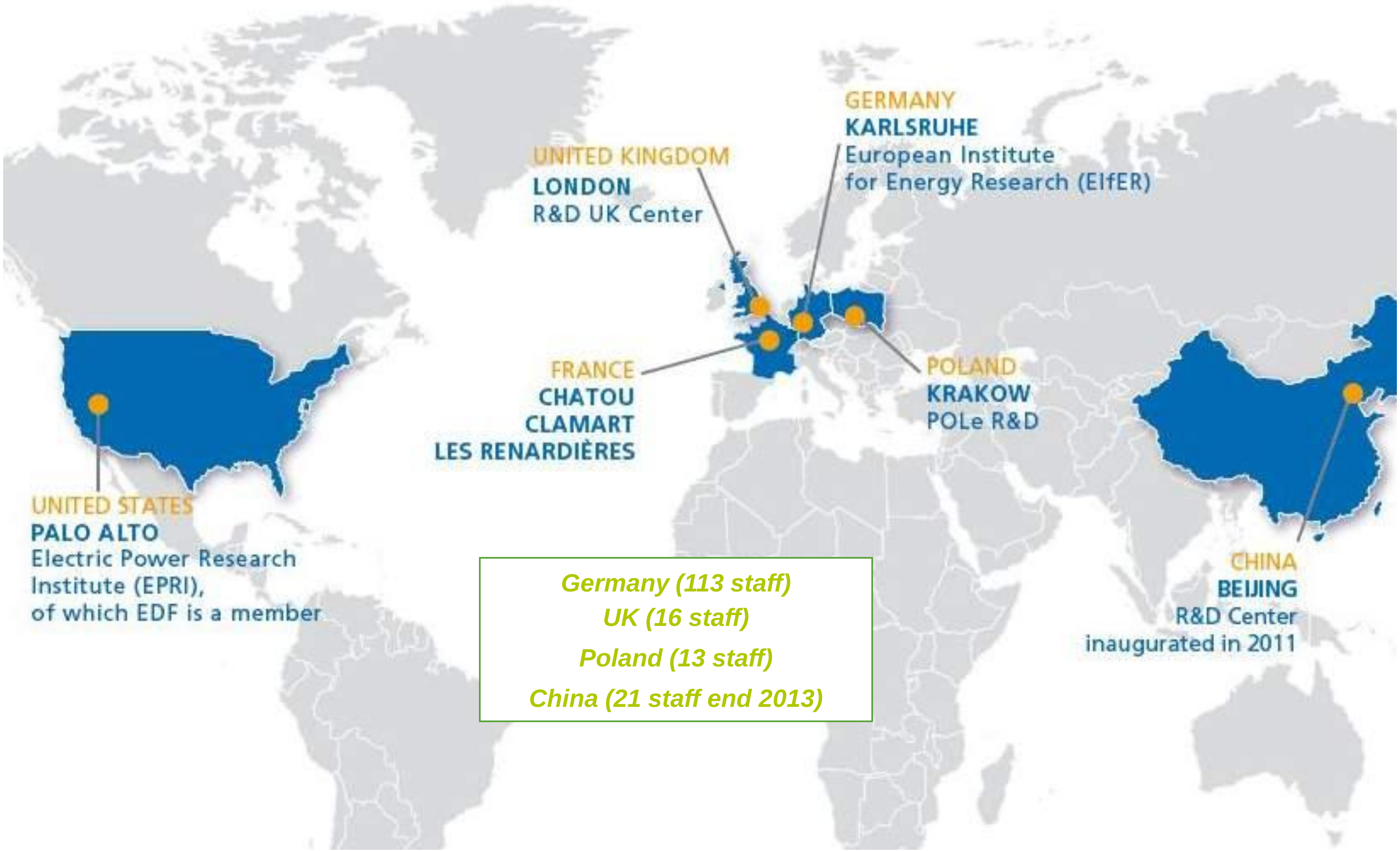
15 departments

12 common laboratories

7 Research centers of which
3 in France / 1 in Germany
1 in the UK / 1 in Poland
<u>1 in China</u>

500 major research projects per year

EDF R&D IN BRIEF 法国电力研究院



Germany (113 staff)

UK (16 staff)

Poland (13 staff)

China (21 staff end 2013)

Our mission

- ***Strengthen cooperation between EDF and the Chinese scientific and industrial R&D actors in the energy sector***
- ***Provide R&D support to EDF and its partners in China***

EDF China R&D Center, created in June 2011, belongs to the R&D direction of EDF and works jointly with experts located in its R&D centers in France, Germany, UK and Poland.

我们的使命

- *加强法国电力集团和中国科研机构在能源领域的合作*
- *为集团及集团在中国的合作伙伴提供有强力的技术支持*

*法国电力集团中国研发中心创立于**2011**年**6**月，隶属于集团研发总部，与集团在法国、德国、英国和波兰的研发中心保持着紧密的合作关系*

Aiming for excellence of research

追求卓越研发

Main R&D activities

Clean Coal Power Generation: boiler coal combustion optimization, CCS

Renewable Energies: CSP, PV, wind, biomass

Numerical Simulation for Power Generation Systems: solid mechanics, thermo hydraulics, hydraulics, numeric power plant

Electrical engineering: smart grid, smart meters, integration of renewable, energy storage, EV charging

Sustainable urban development: based on numerical city model, dealing with energy, density, population, water, land use, providing quantitative basis for urban planning

Energy Efficiency: building and industry

主要合作研发领域及技术咨询服务

化石能源清洁化：煤电锅炉燃烧优化，碳捕捉技术

可再生能源：光热聚焦发电技术，光伏、风能、生物质技术研发

数字仿真技术：依托法国电力自主研发的软件平台，在设备、土建结构力学、热工水力，水力学，数字电厂领域对工程实际问题实施分析研究，服务于核电、火电、水电及环评项目。

电气配电工程：智能电网，微网，智能电表应用，配电自动化，储能技术，间歇式可再生能源并网技术，电动车充电入网等技术研发

可持续城市规划：围绕能源问题建立城市数字模型，在时间上和空间上对人口、密度、能源、水务、土地使用予以综合模拟，为市政决策及市政规划部门提供量化的参考依据。

节能：建筑节能及工业节能研发及应用咨询

ADVANCED SIMULATION FOR ADVANCED POWER GENERATION ENGINEERING (1/3)
先进数字仿真技术：固体力学，热工，水力学，数字电厂

Advanced Simulation for Advanced Power Generation Engineering

先进数字仿真技术

Smart grid, Renewable Energies, Storage and Electric Vehicle

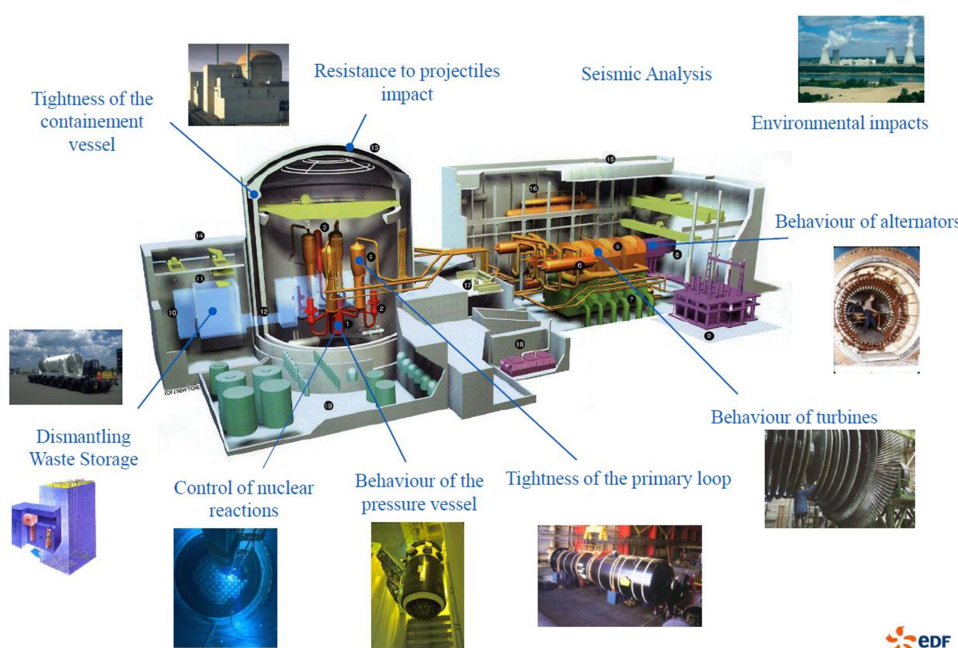
智能电网，可再生能源，电动车充电系统

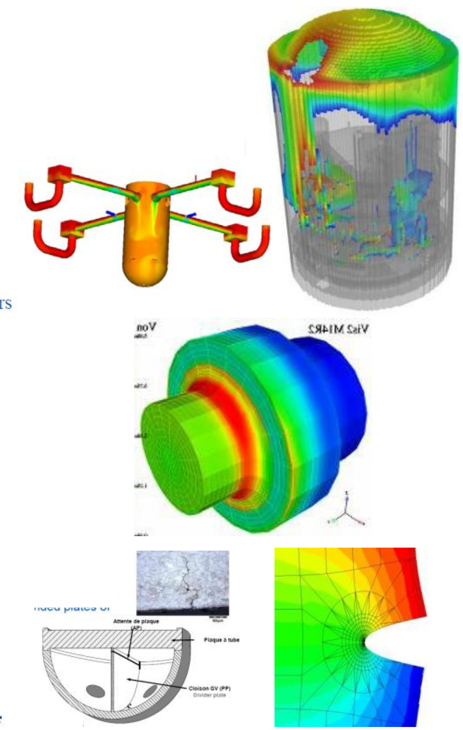
Sustainable Urban Development

可持续性城市数字模型

EDF R&D has computer power that puts it ***amongst the top industrial research centers in the world***. Its supercomputers and in-house codes as well as its experts represent important capabilities in support of EDF and its partners activities in the following sectors:

- **Nuclear power (thermo-hydraulics and solid mechanics related issues)**
  - identification of new safety margins allowing the extension of plants lifetime,
  - analysis of accidental situations non reproducible by experiments,
  - better understanding of physics or system response concerning ageing of materials and installations,
  - qualifying and optimizing processes and materials





ADVANCED SIMULATION FOR ADVANCED POWER GENERATION ENGINEERING (2/3)

先进数字仿真技术：固体力学，热工，水力学，数字电厂

Advanced Simulation for Advanced Power Generation Engineering

先进数字仿真技术

Smart grid, Renewable Energies, Storage and Electric Vehicle

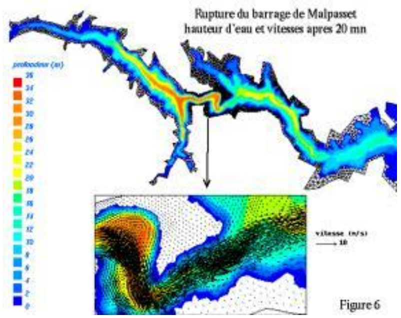
智能电网，可再生能源，电动车充电系统

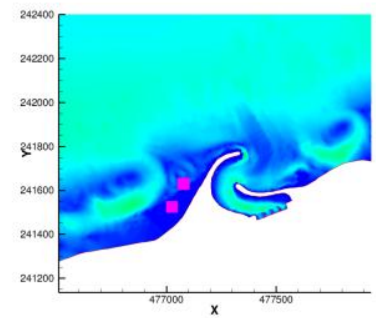
Sustainable Urban Development

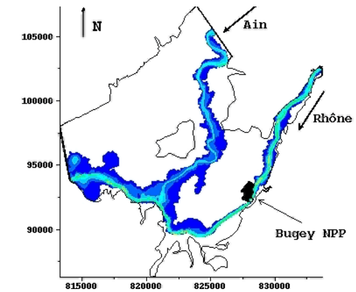
可持续性城市数字模型

Hydraulic issues in nuclear and hydro power

- evaluation of the environmental impact of hydro power plants
- assessment of the impact of the environment on hydro power plants

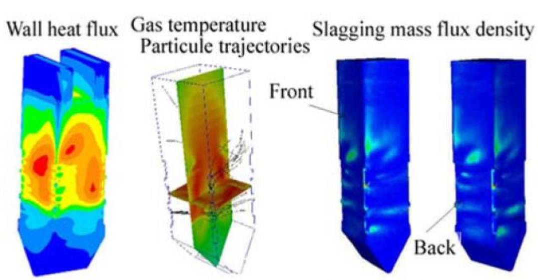




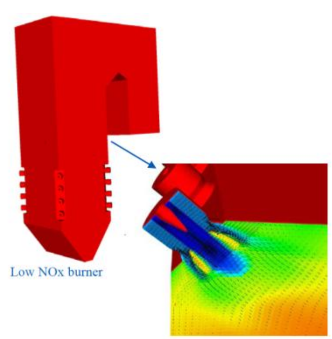


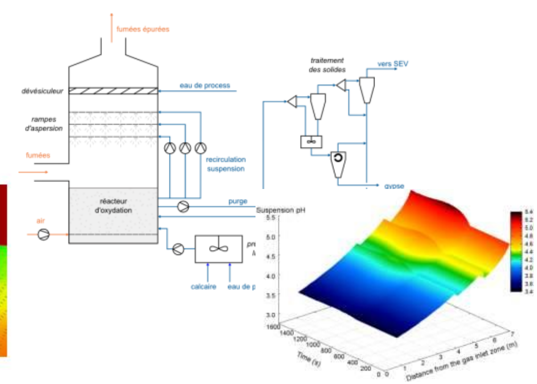
Fossil generation

- optimization of combustion in terms of unburned coal, pollutant emissions and boiler efficiency for different as-burned coals
- flue gas cleaning system optimization (FGD, SCR, ESP)
- verification of plant performances and identification of improvement potential



Ash deposit on shell plates and exchangers reduces the **efficiency** of **Q600**-type pulverized coal-fired boilers.





ADVANCED SIMULATION FOR ADVANCED POWER GENERATION ENGINEERING (3/3)

先进数字仿真技术：固体力学，热工，水力学，数字电厂

Advanced Simulation for Advanced Power Generation Engineering

先进数字仿真技术

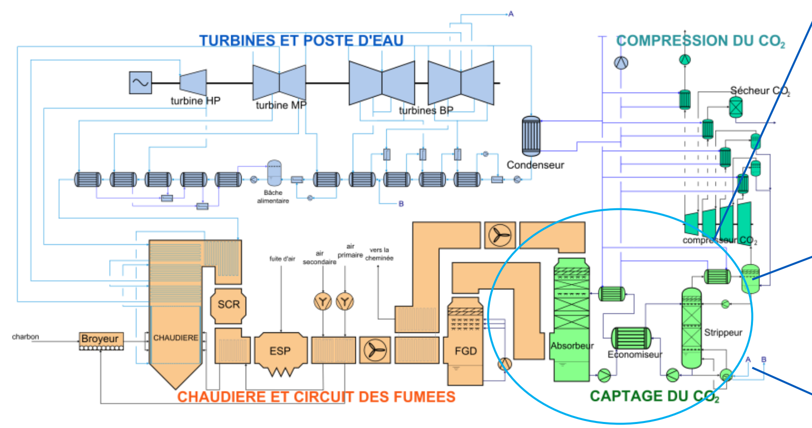
Smart grid, Renewable Energies, Storage and Electric Vehicle

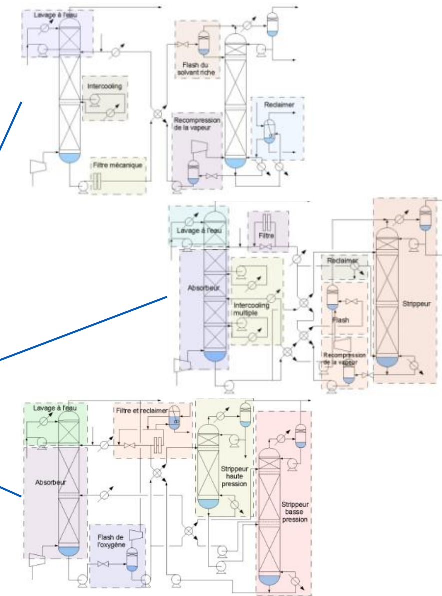
智能电网，可再生能源，电动车充电系统

Sustainable Urban Development

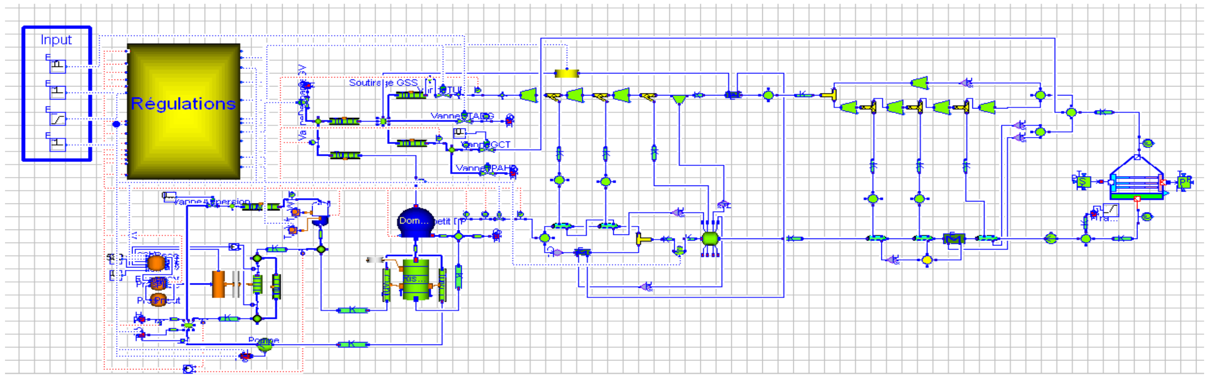
可持续性城市数字模型

- **New technologies for clean power generation (CCS, CSP, biomass,…)**
  - flow-sheet optimization and energy integration
  - assessment of innovative solutions





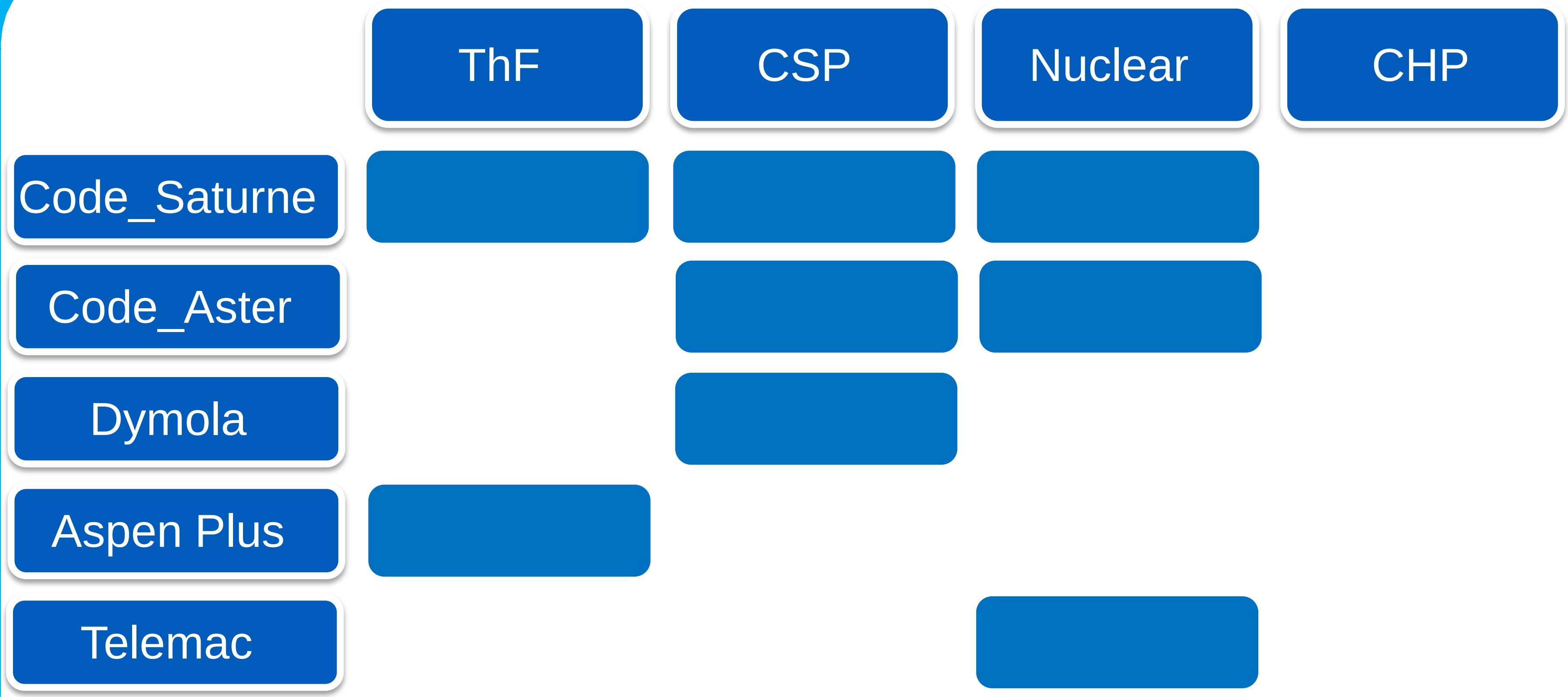
- **For all power generation sectors:**
  - numerical power plant model development
  - other solid mechanics, thermo-hydraulics and free surface flow related issues



THE SOFTWARES USED IN EDF CHINA R&D CENTER

Code_Saturne	EDF's general purpose **CFD software** handling incompressible or expandable flows with or without heat transfer and turbulence, combustion
Code_Aster	EDF's software for ***analysis of structures and thermomechanics*** for studies and research
Dymola	Commercial engineering software with open Modelica® modeling language. For ***numerical power plant modeling***, EDF R&D has developed ThermoSysPro library
Aspen Plus	Market-leading ***process modeling*** tool for conceptual design, optimization, and performance monitoring. Includes world's largest database of pure component and phase equilibrium data
Telemac	CFD code dedicated to ***free surface flows*** initially developed at EDF

POWER GENERATION ACTIVITIES



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- Technical supports to local EDF assets in China: Laibin B, SanMenXia, Liaocheng thermal plants

Nuclear: hydrogen and steam dispersion inside the containment

In link with MFEE

Context:

Severe accidents in nuclear power plant generate hydrogen and steam inside the containment:

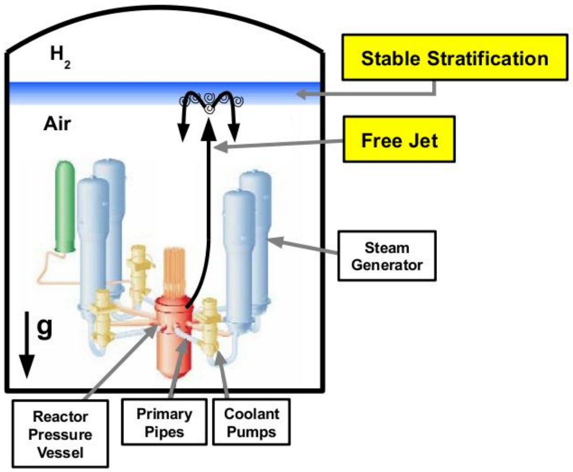
- due to hydrogen dispersion, its local concentration may exceed the fast combustion limit;

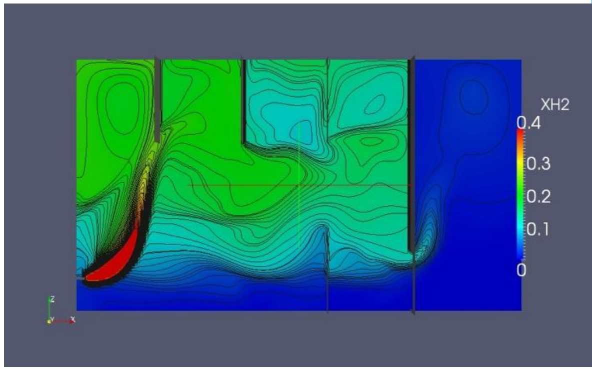
- steam release increases containment pressure which is controlled by active/passive steam condensation process.

Methodology

Calculation of concerned physical phenomena (dispersion of hydrogen and steam, steam condensation) via *Code_Saturne*, to

- validate numerical results with exhaustive experimental results on velocity, mass concentration and pressure;
- autoVnV tests of different physical and numerical parameters;
- assess the impact of different dilatable models for buoyancy-driven flow in *Code_Saturne* via different test cases;
- improve existing condensation model for low Mach flow in *Code_Saturne* under different passive condensation scenario;
- Test of existing condensation model (homogenous approach) and possible implementation of improved scheme.





Helium distribution diagram of gas dispersion test case

CSP: Tube deformation inside molten salt receiver

In link with STEP – MFEE

Context:

In the frame of the collaboration with CAS-IEE on demonstration CSP project (1MW), EDF R&D participate in the understanding of physical phenomena during the operation of CSP plant:

- impact of thermal hydraulic behavior of molten salt inside superheaters due to the **external conditions**, such as day-night alternation, weather change, and season variation, and to the **internal conditions**, such as the heat exchanger design and working fluid properties.

Badaling 1MW CSP demo plant, China

Methodology:

Determine **the thermal hydraulic behavior** of **molten salt** and tube surface temperature in the heat exchanger under several typical **normal and extreme** external scenario, and carry out coupled ***Code_Saturne*/Syrthes** calculations in complex heat exchanger geometry,

- to determine the molten salt temperature inside the tubes,
- to check that no freezing point of molten salt will be reached in the whole tube system under different scenarios,
- to provide temperature distribution inside the tubes used as input data for the mechanical stress calculation with *Code_Aster* => evaluate & check the possible **thermal stress-induced deformation** of tubes.

ThF: Combustion optimization - high temperature corrosion - NO_x reduction

In link with MFEE

Context:

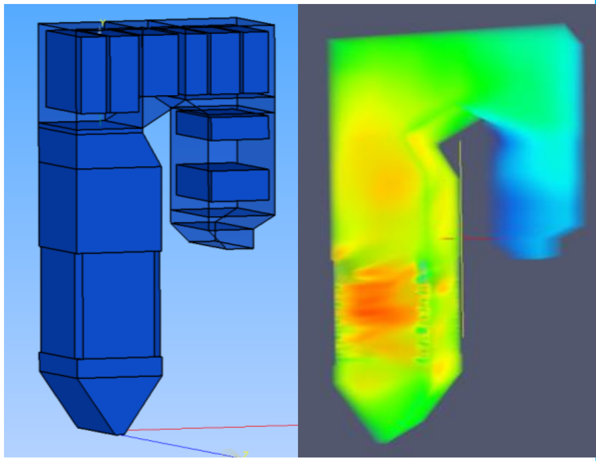
Support to EDF local assets – coal-fired power plant in China for different purposes:

- improvement of coal combustion behavior due to low quality supplied coals [**Laibin B**];

- assessment of high temperature corrosion risk [**Laibin B**];

- in-furnace combustion performance evaluation [**SMX**];

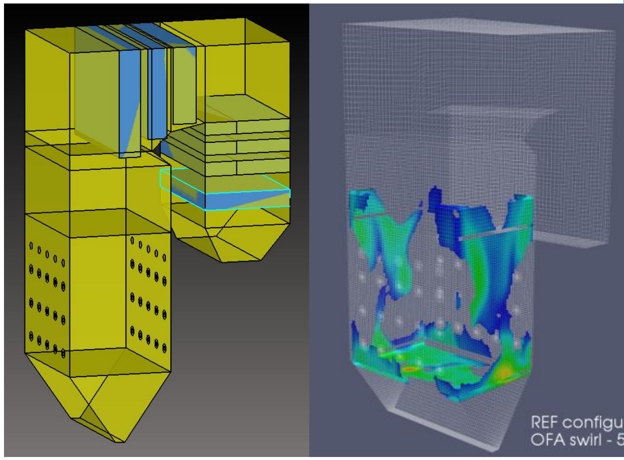
- NO_x reduction analysis via in-furnace combustion [**Liaocheng**];



Laibin B: geometry & temperature field

Methodology:

- On-site data collection (operation data & geometry sketch);
- Experimental investigation on coal properties, including size distribution, ultimate analysis, proximate analysis, devolatilisation and char oxidation experiments inside drop tube furnace;
- Numerical simulation of coal combustion:
  - Pre-processing [**Salomé**]: geometry and mesh creation;
  - solver [*Code_Saturne*]: calculation via user script with adopted physical models;
  - Post-processing [**Paraview**]: visualization & data processing.



SMX: geometry & corrosion risk

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Laibin B, SanMenXia, Liaocheng thermal plants

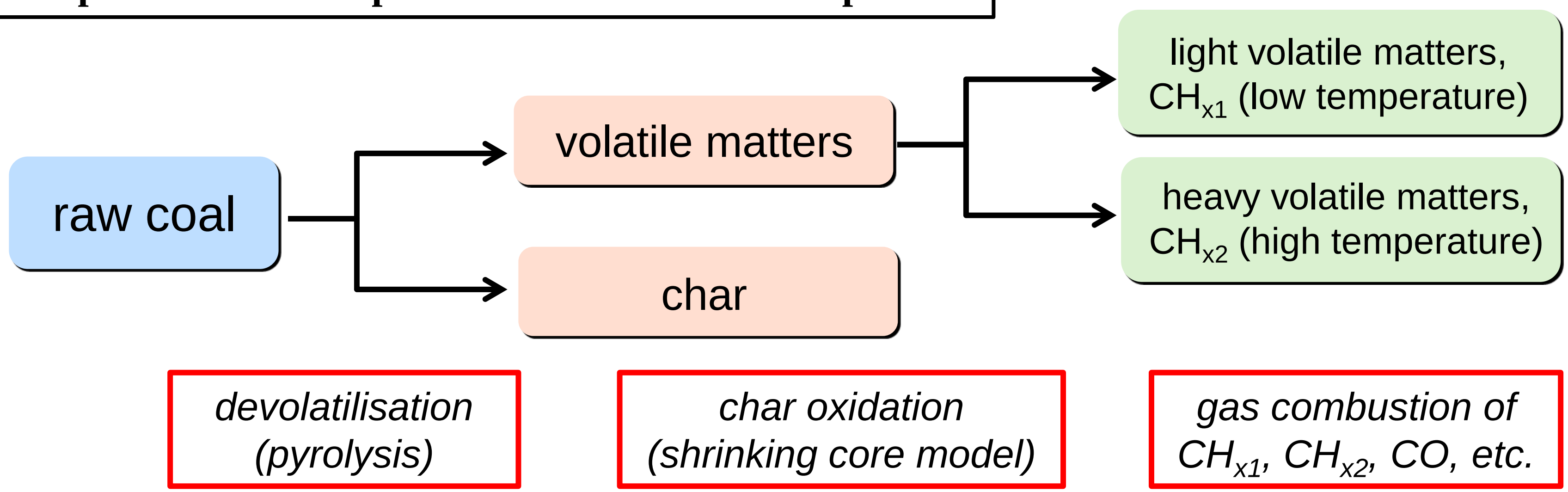
CODE SATURNE

CFD modelling for pulverized coal combustion

- Blend coal utilization
- Radiative heat transfer of gas and walls
- Chemistry/Turbulence
- Complex cola size distribution (up to 10 classes) based on Rosin-Rammler law
- **Coal devolatilisation, volatile gas combustion and heterogeneous combustion**
- NO_x formation mechanism: Fuel-NO, Thermal-NO and Prompt-NO
- Additional chemistry for oxy-combustion and gasification

Eulerian approach

Simplified scheme of pulverized coal combustion process



TECHNICAL SUPPORTS TO EDF LOCAL ASSETS IN CHINA

in close link with MFEE

EDF China R&D center references in combustion optimization

research unit	year	boiler	objective
EDF China R&D	2012 - 2013	Laibin B, 360 MW	combustion optimization for different coal blend
EDF China R&D	2013 - 2014	Sanmenxia II, 600 MW	wall-fired boiler, SC unit, combustion optimization
EDF China R&D	2014 - 2015	Liaocheng, 600MW	W-flame boiler, NO_x reduction via combustion

Laibin B - 360MW tangential fired boiler

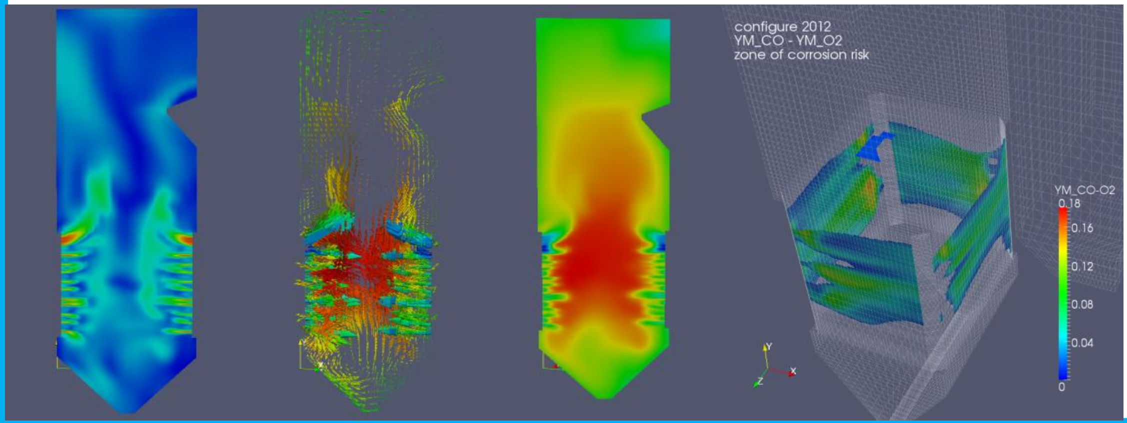
detailed parametric test (SA, OFA, titling, refractory belt, coal type, particle size) to achieve

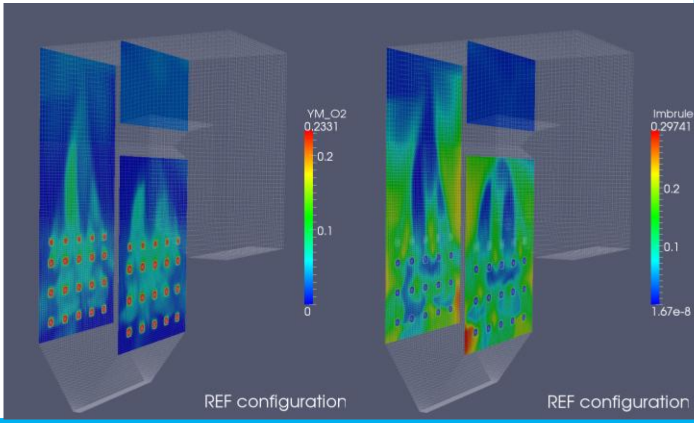
- optimum conditions for different coal blends;
- reduction of unburned coal;
- improvement of flue gas flow itinerary;
- evaluation of high temperature corrosion risks;

SMX II – 600MW supercritical wall-fired boiler

A number of tests on different parameters is done to

- identify potential improvements on NO_x reduction by modifying the location of SOFA burner;
- identify and evaluate prevention measures of high temperature corrosion;
- assess the impact of different coal blend for the performance of coal combustion;



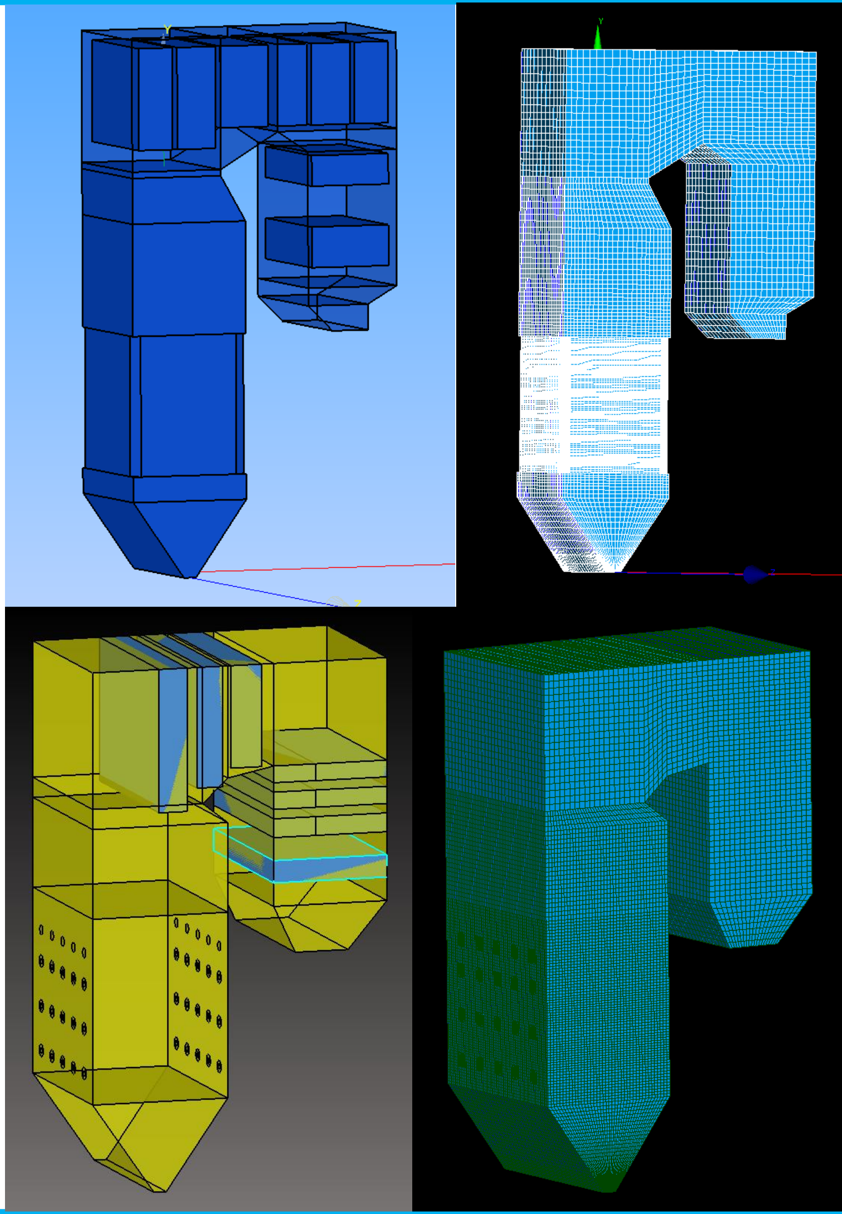


GEOMETRY and MESH generation with Salomé

- around 500 000 cells of structured hexa mesh; refinement at main combustion and injection zones;
- mesh joining for 3 separated mesh parts;

Calculation parameters

- Reynolds-Averaged Navier-Stokes;
- k-epsilon linear model;
- Parallel computation with 32 cores;
- time step: variable in time and in space
- reference time step = 0.001
- Courant number < 15
- Fournier number < 10



Context: poor combustion efficiency related to the coal quality

- Quality of current supplied coal
  - consists of several coal types: bituminous, lean coal, lignite and **anthracite;**
  - strongly variation in composition (no details), dependent on coal supplier;
  - increase in the percentage of **anthracite** in coal blend;

⇒ high unburned ratio and decreased thermal efficiency

  - reduction of thermal efficiency;

Objectives

- ***Are all foreseen proposals efficient ?***
- ***Are there any other efficient modifications ?***

- Better understanding of coal combustion process in Laibin B boiler, in order to, from a physical point of view,
  - evaluate possible modifications proposed by the operator, not only for improvement of coal blend combustion, but also for verification with design coal;
  - identify potential improvement solution allowing to increase combustion efficiency, and further to enlarge coal spectrum range (boiler modifications, operation recommendations, innovative solutions);

Numerical model validation

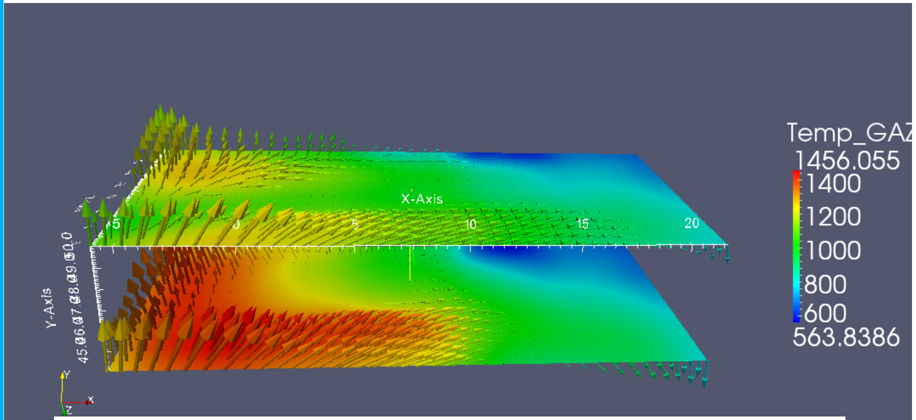
2007: **design coal** / 2012: **coal blend**

item	2007_exp.	2007_num.	2012_exp.	2012_num.
FG temperature (°C)	--	--	--	--
Y_{O2} in FG (%)				
unburned rate in ash	--	--	--	--

Good agreement between exp. and num.

Validation of numerical results by experimental observations

- heat disequilibrium between two sides of heat exchangers (left & right), due to the intense vortex structure even on the top of the boiler;
- offset of combustion zone to the front wall of furnace;



Temperature field of horizontal section for flue gas on the top of the boiler (44m & 50m)

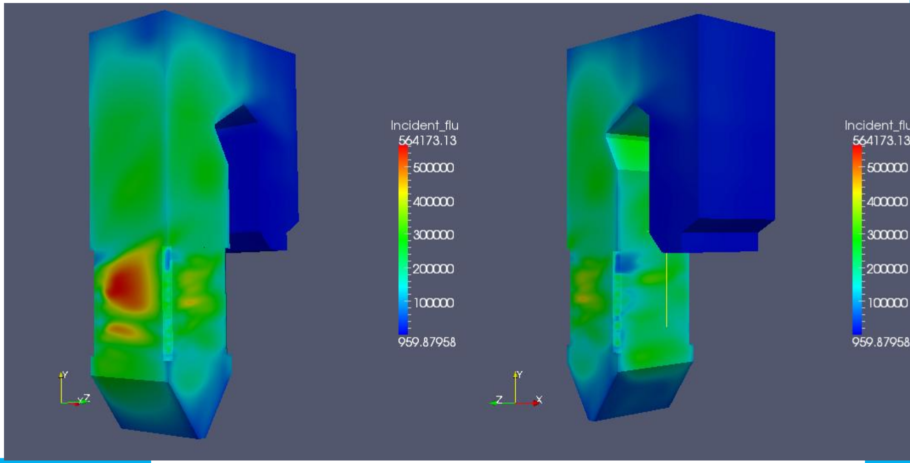


Diagram of incident flux to furnace walls

LAIBIN B STUDY (3)

Conclusion

further study on high temperature corrosion risk assessment

modification type	N°_MOD	brief description	efficiency for unburned rate improvement
re-arrangement of OFA/SA	LAIBIN-1	enlargement of bottom SA section	medium
	LAIBIN-2 LAIBIN-13	redistribution of SA mode	no
	LAIBIN-4	re-arrangement of VA containing fine coal particles	no
	LAIBIN-7	re-organization of OFA/SA; decrease OFA	medium
coal particle size	LAIBIN-5	improvement of milling system	high
	LAIBIN-12	reduction of coal particle size; adjustment of current sieves	high
geometry / supplementary installation	LAIBIN-3	installation of refractory belt	medium
	LAIBIN-6	lengthened boiler	medium
	LAIBIN-8	adjustement of burners' tilting angle	negative
coupled effect	LAIBIN-9	coupled effect: enlargement of bottom SA and re-organization of OFA/SA	high
	LAIBIN-10	coupled effect: enlargement of bottom SA, re-organization of OFA/SA and refractory belt	high
coal blend	LAIBIN-11	different coal blend composition	--

SMX STUDY (1)

Context

- Technical Service Agreement (TSA) signed between Datang Sanmenxia power generation Co., Ltd (DSPC) and EDF
  - EDF is the minor share holder of Datang Sanmenxia power plant II
  - Sanmenxia II is a 600MW super-critical (24.5 Mpa – 566 ºC) wall-fired power plant

Objectives

- Better understanding of coal combustion process inside the boiler, by
  - EDF in-house CFD numerical simulation tool, ***Code_Saturne***®
  - experimental analysis on coal reactivity (Drop Tube Furnace)
  - expert insight from R&D Dept. MFEE

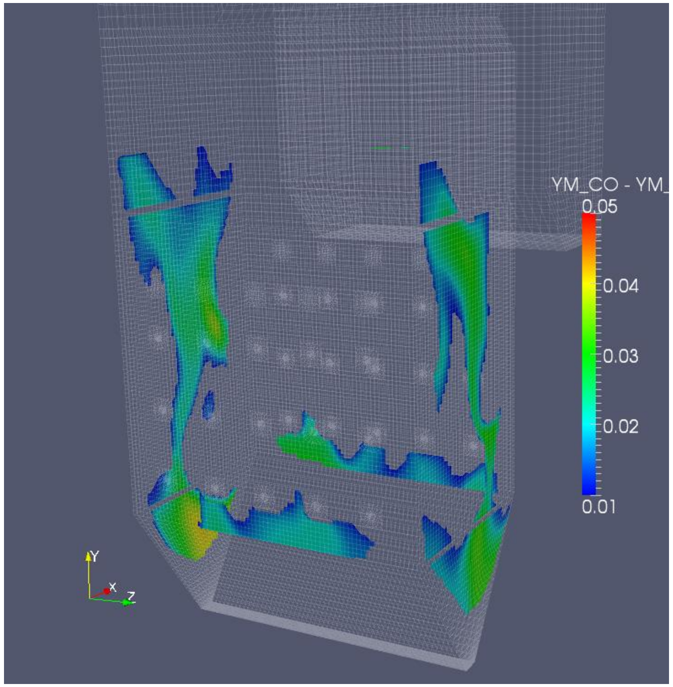
in order to, from a physical point of view,

- understand the combustion process inside the boiler;
- identify potential improvement solutions for combustion efficiency and low NO_x emission

Numerical model validation

item	Exp.	Num.
O_2 concentration	--	--
Flue gas temperature (°C)		
unburned rate		
NO (after FGD) (mg/Nm^3)	--	--

Good agreement between exp. and num.



Criteria for high temperature corrosion risk

Illustration of concerned walls having the corrosion risk by using defined criteria for reductive atmosphere. (do not consider the bottom part)

Color level indicates the intensity of YM_CO – YM_O_2.

SMX STUDY (3)

Summary of proposed modifications

Positive feedback

		impact		
N° _MOD	**brief description**	**unburned rate**	**NO_x**	**corrosion**
SMX-1_REF	=> SA-swirl angle = 45° , SOFA-swirl angle = 5° ; => distance between SOFA and top level burners = 3.51m; => SOFA/(SA+SOFA+PA) = 0.215; => coal blend: Tongchuan-20%_Liulin-10%_Yima-70%;	--	--	--
SMX-2	**SA** swirl number: **swirl angle** = 30°	☺	😐	☹☹☹
SMX-3	**SA** swirl number: **swirl angle** = 60°	😐	😐	😐
SMX-4	**SOFA** swirl number: **swirl angle** = 25°	☹	☺	😐
SMX-5	**SOFA** swirl number: **swirl angle** = 45°	☹☹	☺	😐
SMX-6	**SOFA** swirl number: **swirl angle** = 45° /5° (alternate)	☹	😐	😐
SMX-7	**coal blend**: Yima-100% [LHV = 20763, S = 0.69]	☺	☺	☺
SMX-8	**coal blend**: Tongchuan-25%_Liulin-25%_Yima-50% [LHV = 22900, S = 0.995]	☹	😐	😐
SMX-9	**coal blend**: Tongchuan-25%_Liulin-50%_Yima-25% [LHV = 24185, S = 0.981]	☹	☺	☺☺
SMX-10	**coal blend**: Tongchuan-50%_Liulin-25%_Yima-25% [LHV = 23750, S = 1.315]	☹	☹	😐
SMX-11	**SOFA/(SA+SOFA+PA)** = 0.18	😐	😐	☺☺☺
SMX-12	**SOFA/(SA+SOFA+PA)** = 0.25	☹	☺	☹☹
SMX-13	reduction of **SOFA section** by 27.75% (radius reduction by 15%)	☹	😐	😐
SMX-14	**enlargement (x1.5) of the distance** between SOFA and top level burners	☹	😐	😐

Context

- Liaocheng Power Plant (phase I, 2x600MW W-flame coal-fired units) of Shangdong Zhonghua Power Company (SZPC) [ongoing]
  - EDF is the minor share holder of Shangdong Liaocheng power plant phase I (19.6%)
  - High NO_x emission (~ 1200 mg/Nm^3) at current operation condition; (improvements were achieved by removing partially refractory belt, **from 1500+ to 1200 mg/Nm^3**)

Besides, a number of studies was made on NO_x reduction via in-furnace combustion process:

[1] Miao et al. (2004) *The commissioning analysis on NO_x reduction in* ***600MW W-flame boiler***

[2] Guo et al. (2006) *Experimental investigation on the operation and combustion behavior of* ***W-flame boiler***

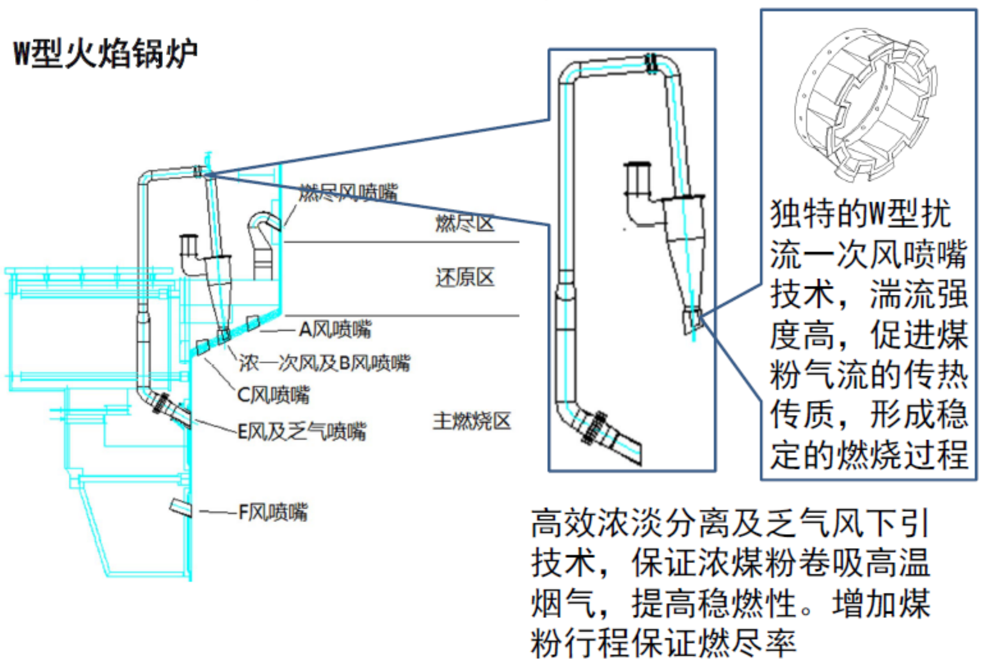
[3] Zhu et al. (2007) *Optimal combustion on* ***W-flame boiler in Liaocheng power plant***, Electric Power

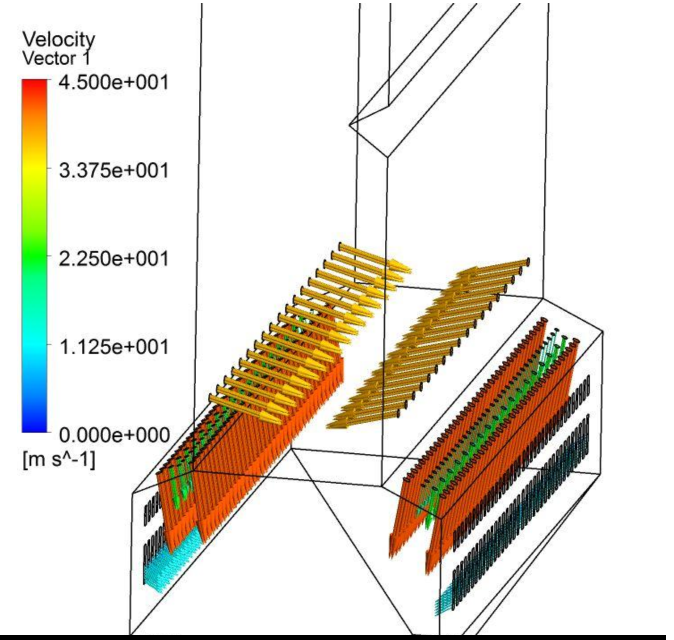
[4] Doosan Babcock (2011) *In-furnace Nox reduction feasibility study report for* ***Liaocheng power plant***

Objectives

identify potential improvement solution for **low NO_x emission (30%)** with less combustion efficiency degradation, based on a better understanding of coal combustion process inside the boiler via simulation with ***Code_Saturne***

Possible solutions for W-flame boiler





re-organization of flow structure inside the boiler

<u>Possible measures for NO_x reduction and maintain of boiler performance (EDF R&D):</u>

- relocation of SA & VA injectors and their injection angle => fully use combustion zone inside the furnace to reduce local temperature peak;
- Swirl burner configuration for PC => enhance flame stability close to the burner;
- Creation of OFA => staged combustion & to compensate increased unburned coal rate due to above measures;
- Coal blend configuration => improve flame ignition with new coal blend within minimized financial increase

CONCLUSION

Added values of these studies on ThF

- Technical supports to EDF local assets for plant performance improvement;
- Good way of obtaining REX from local operators (data collection, discussion with local engineers, validation Exp./Num.), in particular for plants that EDF is a minor share holder; and increase EDF technical implications in these plants;
- Application of *Code_Saturne* to EDF thermal plants in China with different boiler technologies, tangential firing (Laibin B), W-flame (Liaocheng) and super-critical wall-firing (SanMenXia) boilers;
- Identification of potential improvement of existing models, such as C_p & rho calculation via coal ultimate & proximate analyses;
- Promotion of *Code_Saturne* in China;
- Synergies between EDF R&D and local EDF business units through these local supports actions;

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