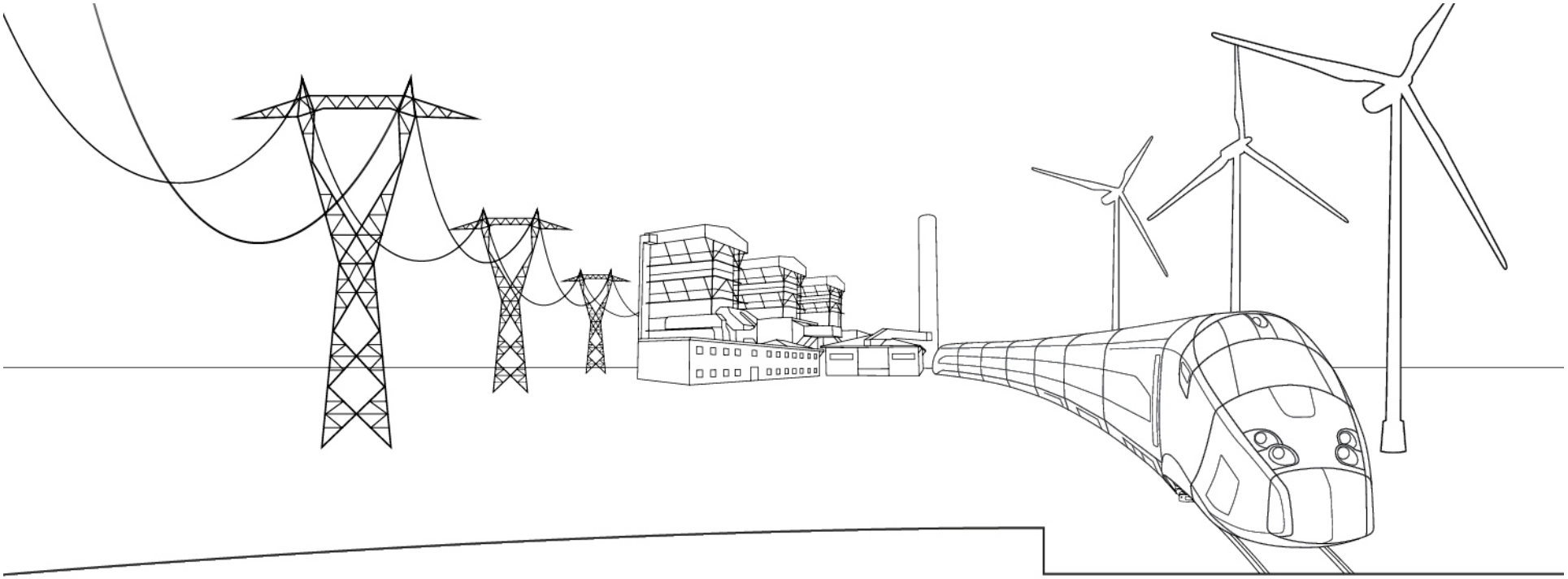


Alstom's Oxy-Combustion technology

Frank ENNENBACH

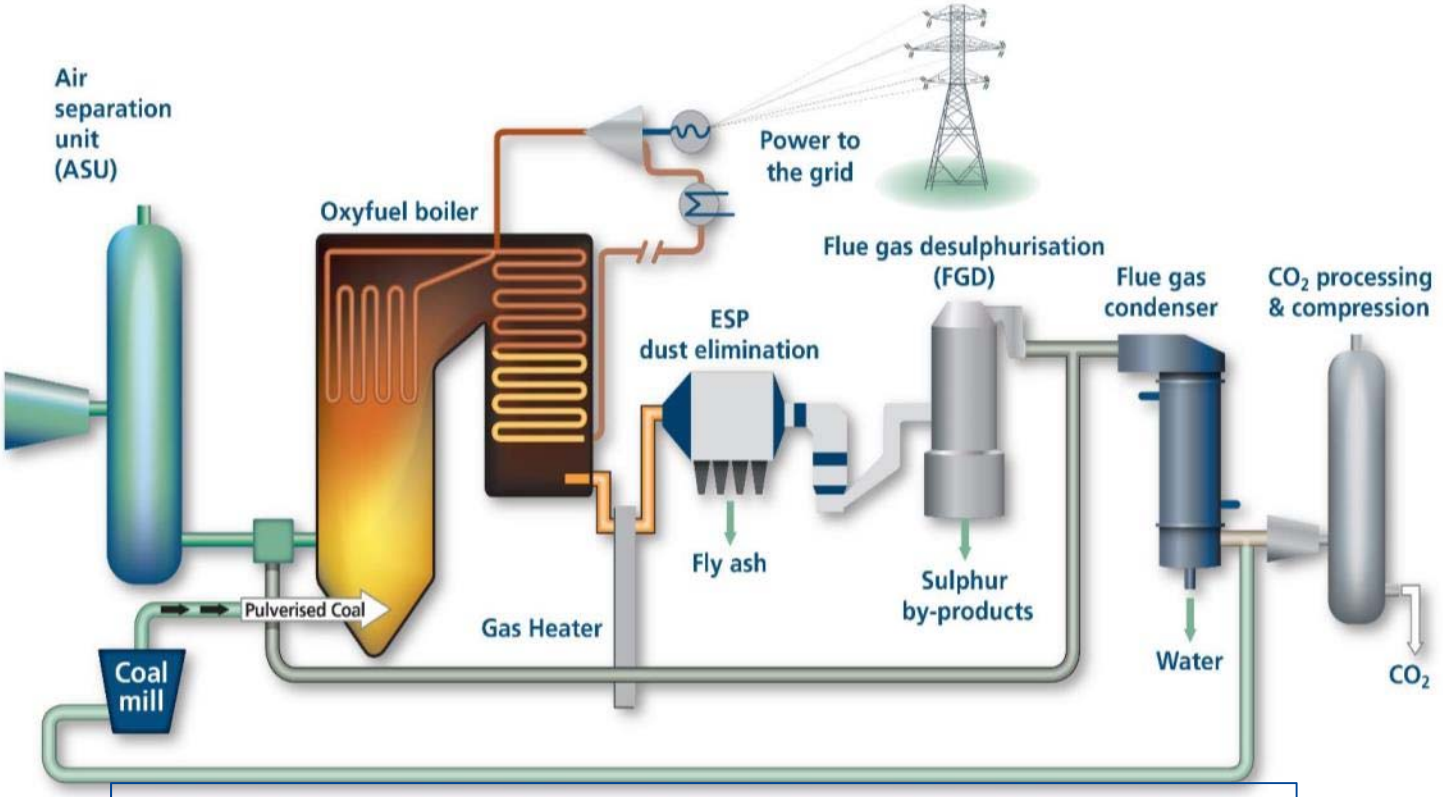
Riyadh, Saudi Arabia

2/11/2015

ALSTOM

Shaping the future

Oxy-fuel technology



Proven Reliable Fuel Flexibility

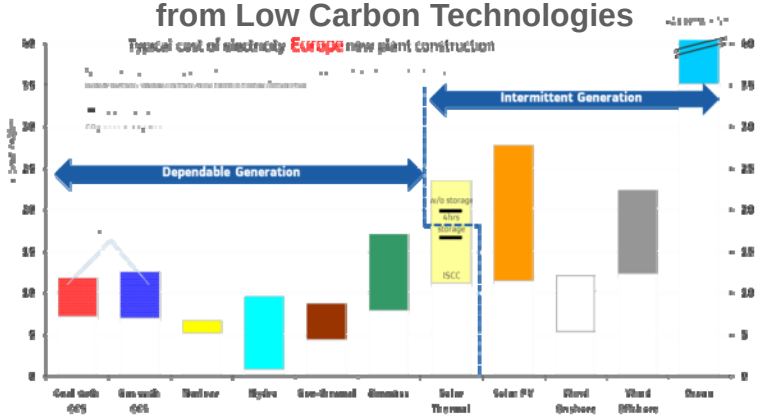
Alstom offers all major Oxy-Fuel Power Plant components [Boiler, AQCS, GPU] and integrated turnkey power plants and power blocks

ALSTOM

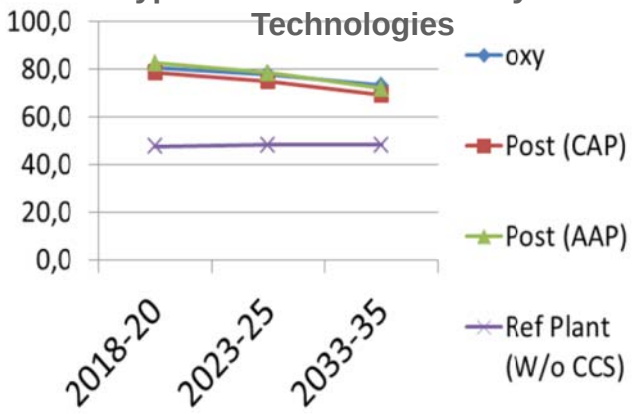
Why Oxy-Combustion:

- **Robust:**
  - ✓ developed from existing components
- **Flexible :**
  - ✓ All types boilers, firing systems, fuels
  - ✓ Options for operational flexibility
  - ✓ Retrofit and “Oxy-Ready” can be addressed
- **Scale-up:**
  - ✓ No constraints anticipated for large commercial units up to 1000 MWe, high efficiency with ultra-supercritical steam cycles
- **Cost competitive:**
  - ✓ With other CCS & other low carbon generation
- **Environmentally-friendly:**
  - ✓ Near Zero Emissions
  - ✓ No new chemicals introduced to plant
  - ✓ High CO_2 capture rates (>90%)

Typical CoE for Generation from Low Carbon Technologies



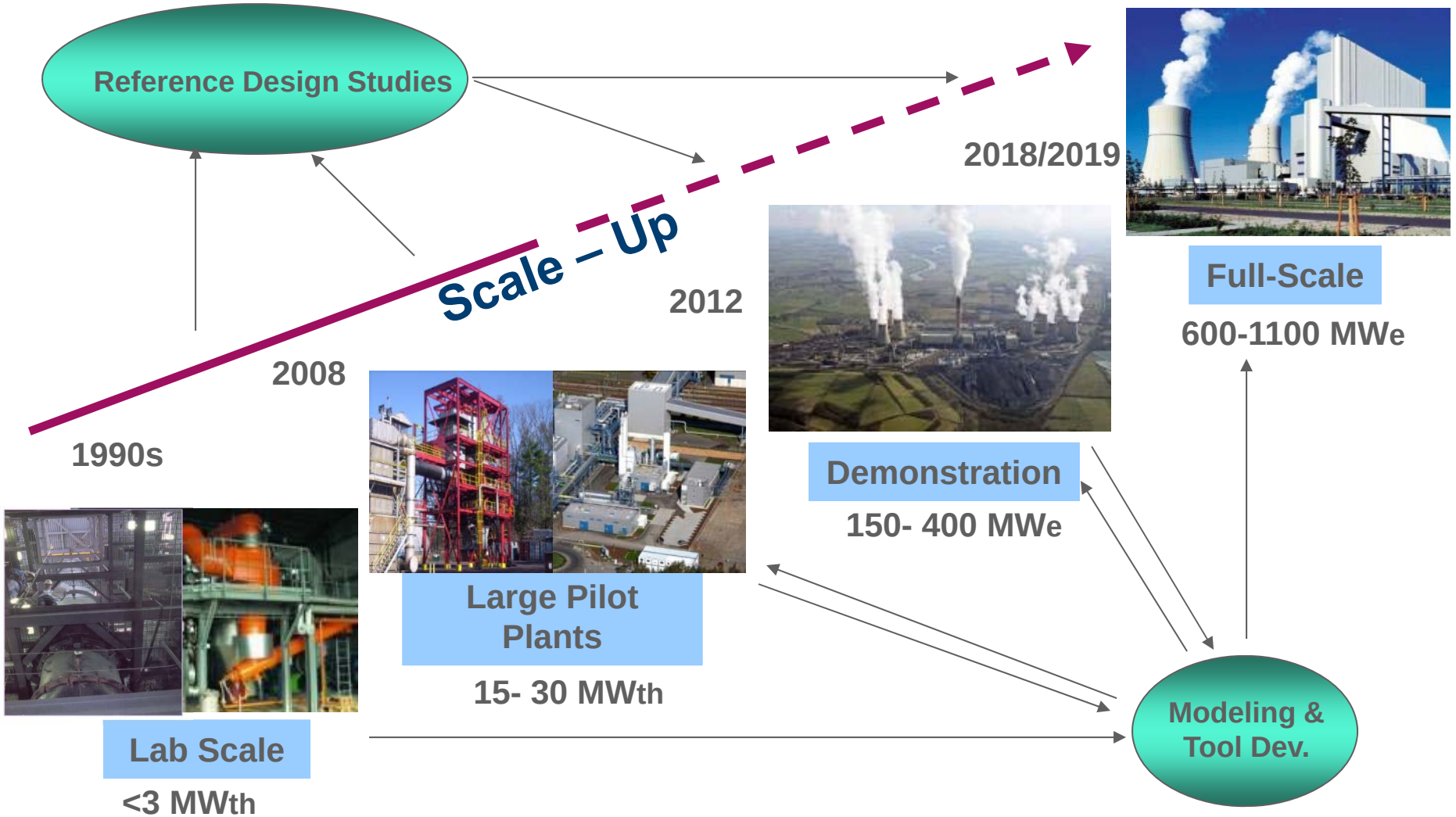
Typical CoE for Post & Oxy CCS Technologies



Source : Alstom analysis – 2013– New PC power plants with CCS including transport and storage . Europe

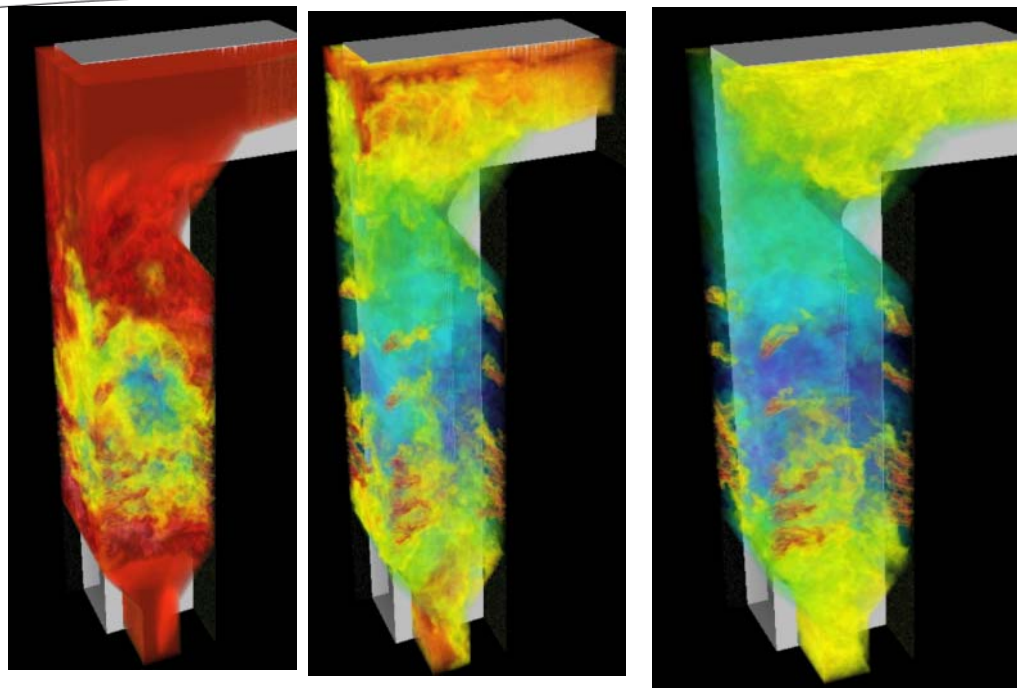
ALSTOM

Alstom Oxy-Combustion Development Steps-Combustion Technology

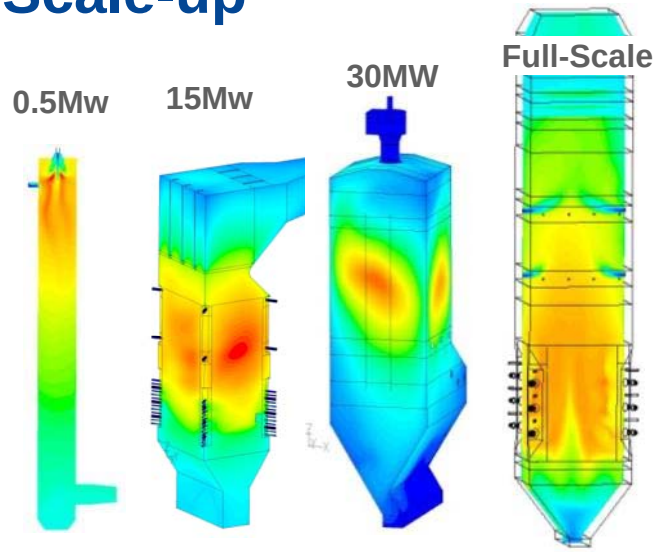


ALSTOM

Oxy CFD Model Development



Fluent Validation and Scale-up



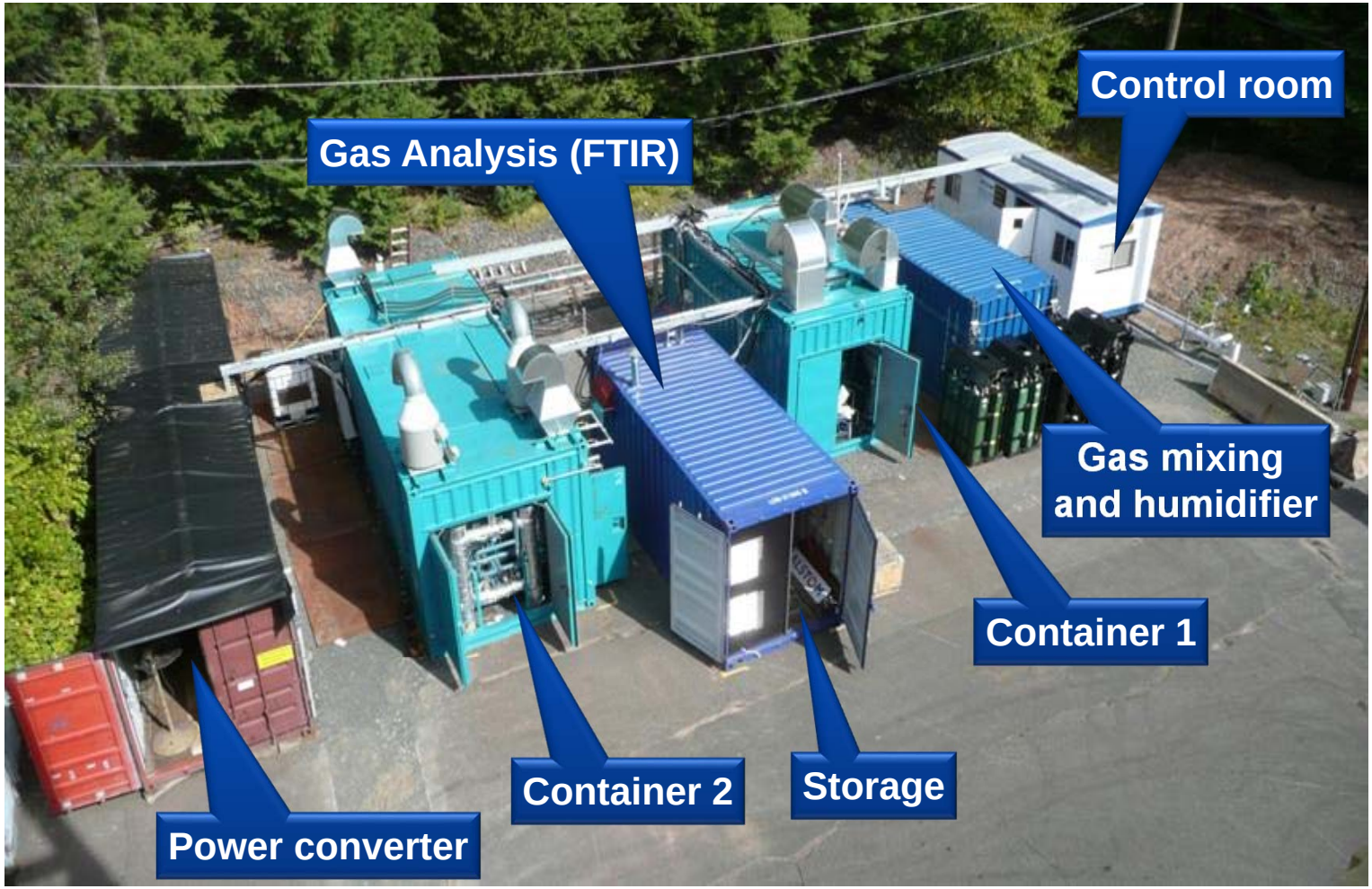
LES Modeling Evaluation

U of Utah Results and Animations of Unsteady Combustion (O2 conc.)

- Upgrade of Submodels
- Evaluation and Refinement Using Experimental Data
- Verification Analysis

ALSTOM

GPU Container Test Set-up



ALSTOM

White Rose OPP Commercialisation Project

- A new state of the art Oxy-Power Plant, up to 448 MWe (gross)
- Located Drax, North Yorkshire providing >300 MWe clean powe
- 100% of flue-gas treated, 90% CO_2 capture rate → 2 MTPA
- Biomass co-firing leading to zero - or near zero- CO_2 emissions
- CO_2 piped c.a. 100 miles to off-shore deep saline storage
- Anchor project for regional CCS cluster

- Preferred Bidder in UK Government CCS commercialization competition
  - Share in £1bn grant
  - Market support through Contract for Difference (CfD)
- €300m support from EU through NER300 programme

ALSTOM

Oxy-combustion of Oil Heavy Residues

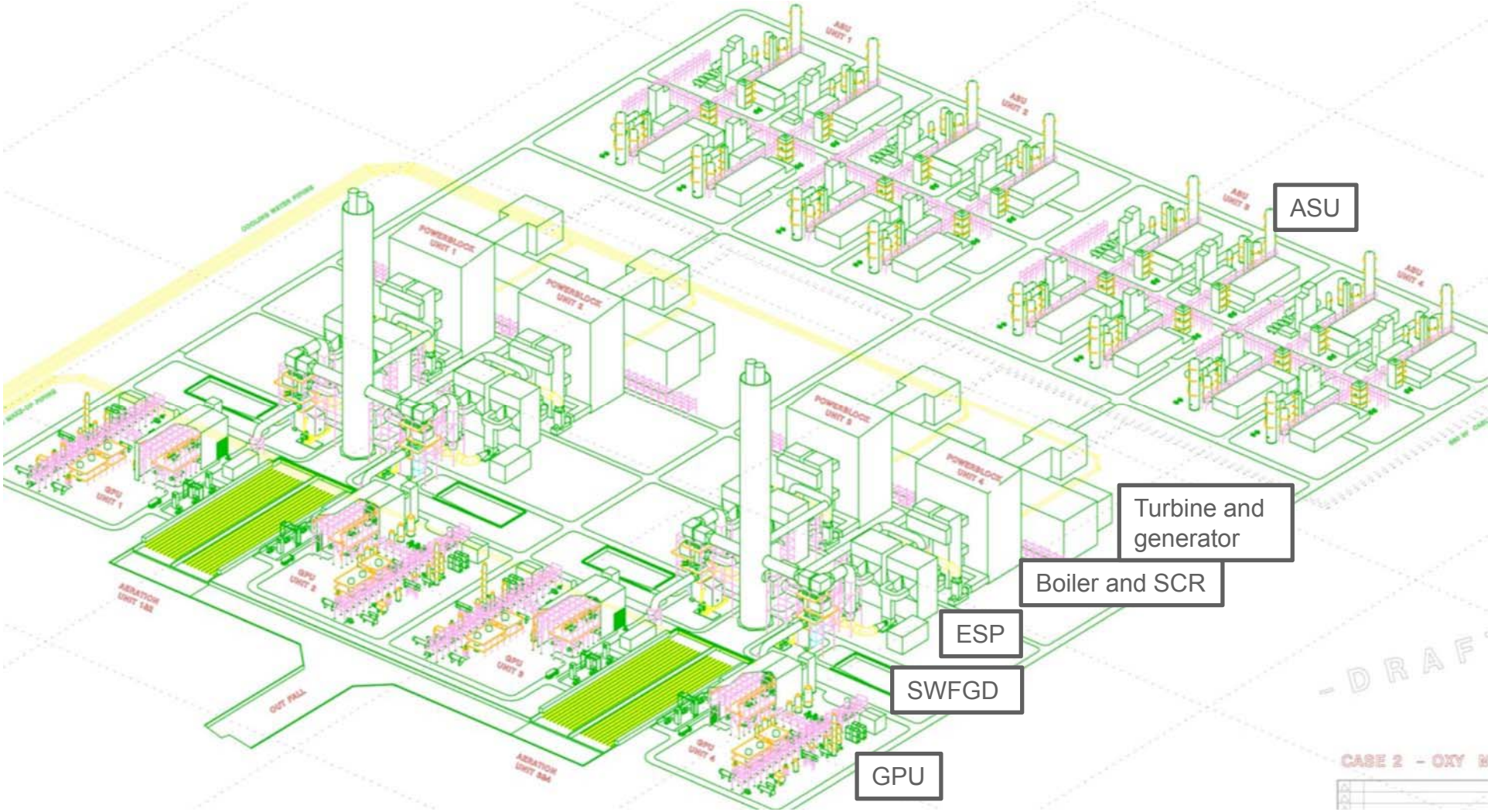
Joint Saudi Aramco – Alstom development

- Combustion tests of OHR at Alstom's facilities
  - 3 weeks testing in both oxy and air mode
  - Detailed information:
    - OHR handling
    - atomization
    - combustion
    - thermal performance
    - Emissions
- Feasibility study of oxy-firing scale-up
  - Base Case Plant Design
  - Oxy-burner Design and Experimental Works
  - Economic Evaluation
  - Pilot Plant Definition and Costing

Increased thermal efficiency with oxy-firing

ALSTOM

Arrangement planning 4x700MW$_{el}$ Oxy fired



ALSTOM

Acknowledgements and Disclaimer

THANKS TO MANY PARTNERS WHO HAVE SUPPORTED AND/OR WORKED WITH ALSTOM ON THE EFFORTS PRESENTED. PARTICULAR ACKNOWLEGEMENT TO UK DECC, US DOE NETL, EU NER, EU RFCS,

Acknowledgement

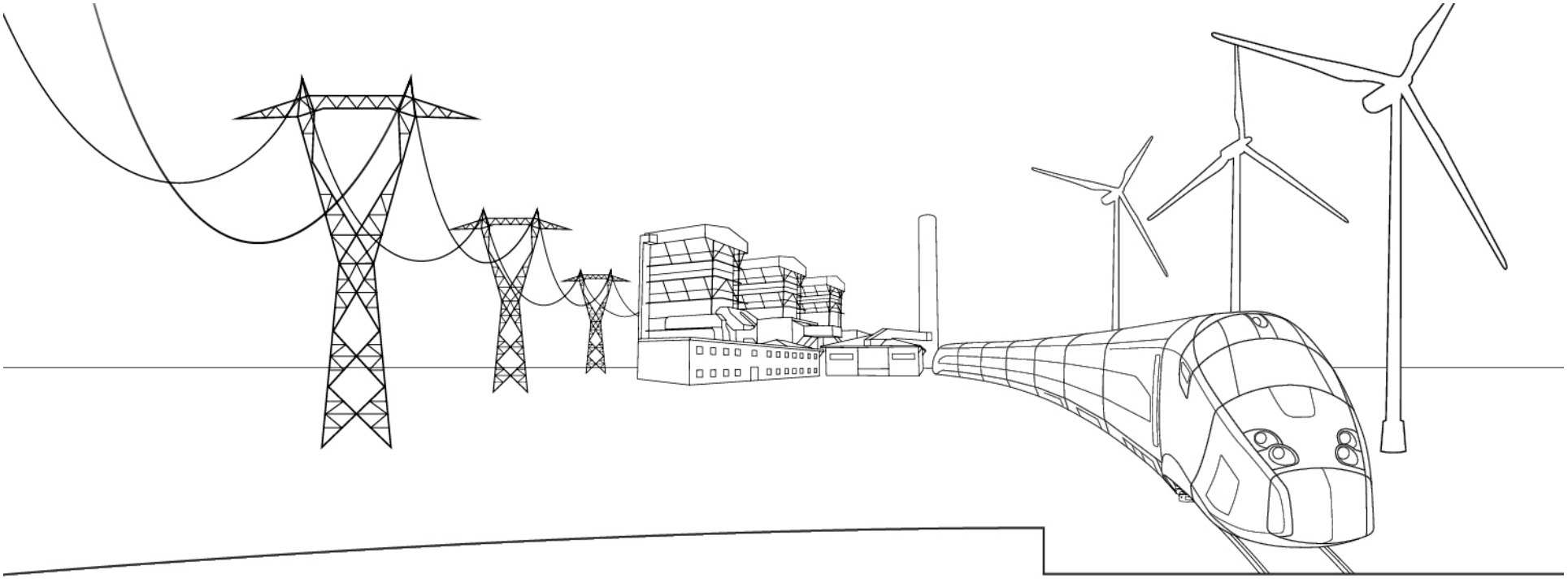
Some of work presented was supported by the U S Department of Energy through the National Energy Technology Laboratories under Agreement DE NT-0005290. The guidance and direction of NETL Project Managers Steve Mascaro and Tim Fout is acknowledged and appreciated.

Disclaimer

Parts of this presentation were prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Information disclosed herein is furnished to the recipient solely for the use thereof as has been agreed upon with ALSTOM and all rights to such information are reserved by ALSTOM. The recipient of the information disclosed herein agrees, as a condition of its receipt of such information, that ALSTOM shall have no liability for any direct or indirect damages including special, punitive, incidental, or consequential damages caused by, or arising from, the recipient's use or non-use of the information

ALSTOM



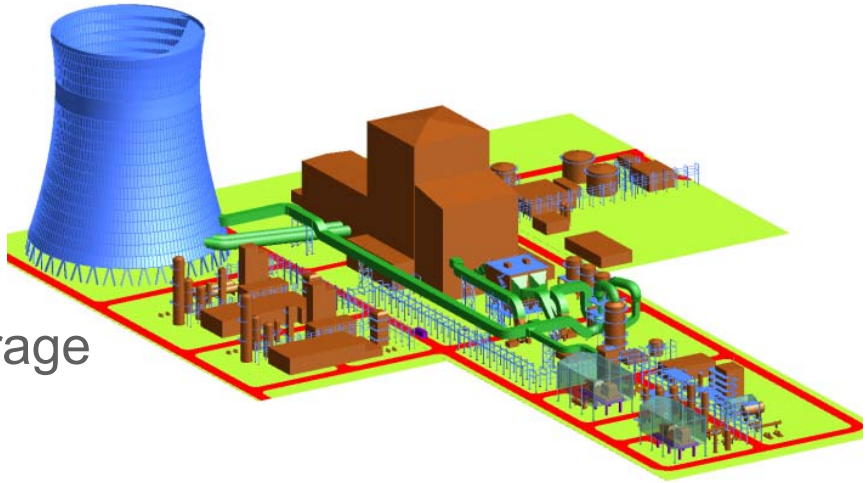
ALSTOM

Shaping the future

Oxy-firing Integrated Approach
Reference concept with integration

Design Basis

- Oxy-Combustion Power Plant 900 MW (Steam Cycle : 600°C / 620°C / 275 bar
- Bituminous Coal
- Direct cooling (power plant, ASU, GPU)
- 90% CO_2 Capture - Specification for Storage
- Base load operating regime
- Flexibility in oxy-mode down to 40%



Estimated Plant Performance

	Net Eff. (LHV)	Net Output
Conventional Air-Fired Plant (No Capture)	46.2%	836 MW
Oxy Capture Plant - Not Integrated	34.0%	618 MW
Oxy Capture Plant – Integrated	37.1%	673 MW

ALSTOM