Enabling technologies for pre-combustion

TCCS-6

June 14-16 2011, Trondheim

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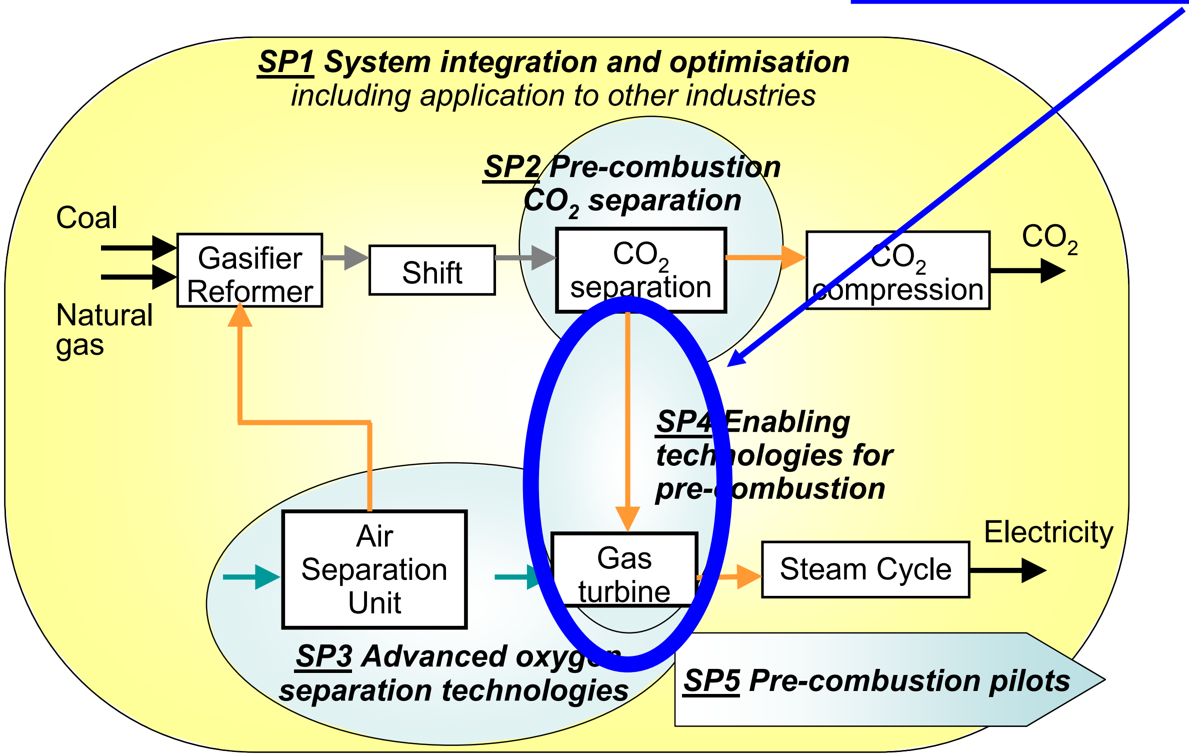
Enabling technologies for pre-combustion

Hydrogen rich fuel supply and combustion



Outline

- Numerical methods for hydrogen combustion modeling — SINTEF
- Development of a lean premixed hydrogen gas turbine re-heat combustor — ALSTOM
- Optimization of hydrogen rich fuel supply system — SIEMENS

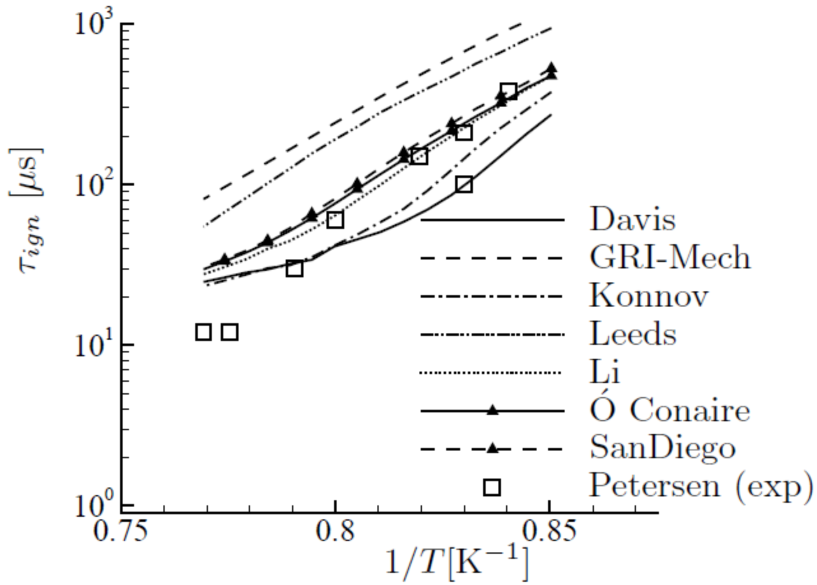
The Pencil-Code

- High order Direct Numerical Simulation (DNS) code
- Open source
  - http://www.nordita.org/software/pencil-code/
- Detailed chemistry combustion implemented
- No libraries required
  - Unix/linux
  - Fortran compiler
- *Journal of Computational Physics 230, 1-12 (2011)*
  - http://arxiv.org/abs/1005.5301

[Accepted publ: *Int. J. Hydrogen Energy*. http://arxiv.org/abs/1104.4925](http://arxiv.org/abs/1104.4925)

Chemical kinetics combustion model validated at LPM and SEV conditions

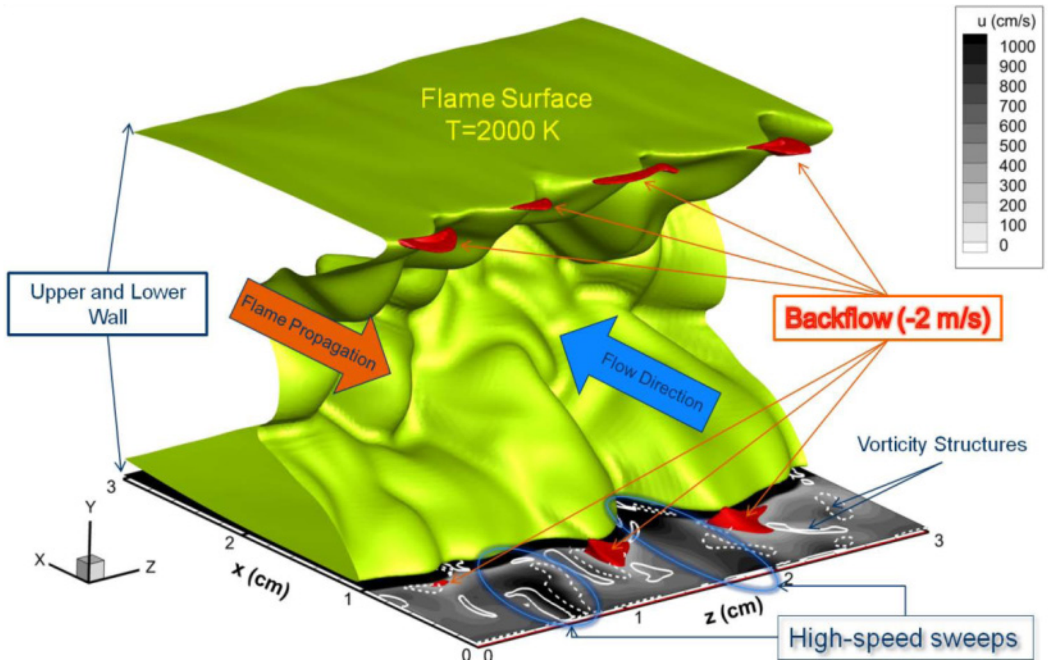
- **Background**: “Operation of SEV burners involves accurate knowledge and monitoring of both flame speed and ignition delay time.”
- **Results**:
  - H2 chemical kinetic models have been compared and partly validated at the high temperature and pressure conditions (up to 30 bar) relevant to LPM and SEV conditions.
  - At these conditions the mechanisms that are thoroughly validated for hydrogen at lower pressures, predict a factor 3 different ignition delay times.
  - To reduce the uncertainties in predictions with hydrogen mechanisms at the high temperature and pressure condition more experiments are needed.



Ignition delay results with 2% H2, 1% O2, 97% Ar at 33atm. Comparison of predictions with various chemical mechanisms and shock tube data of Petersen et al.

Provide fundamental combustion data for H2-rich fuels at high temperature and high pressure

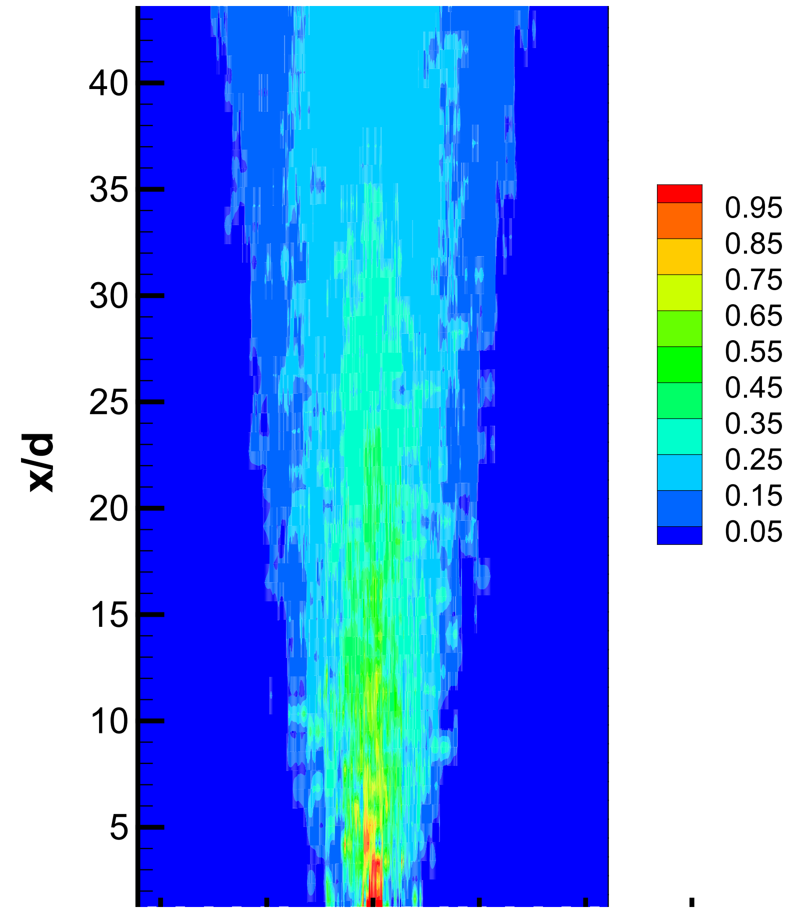
- **Background**:"Direct Numerical Simulations (DNS) may be seen as a numerical experiment as nothing except the chemical kinetics is modeled"
- **Results**:
  - DNS of flames propagating in isotropic decaying turbulence have been performed to find the dependence of the turbulence on the turbulent flame velocity
  - DNS of flame propagating in a turbulent channel flow shows the mode of propagation.



Submitted for publication in J. Fluid Mech.

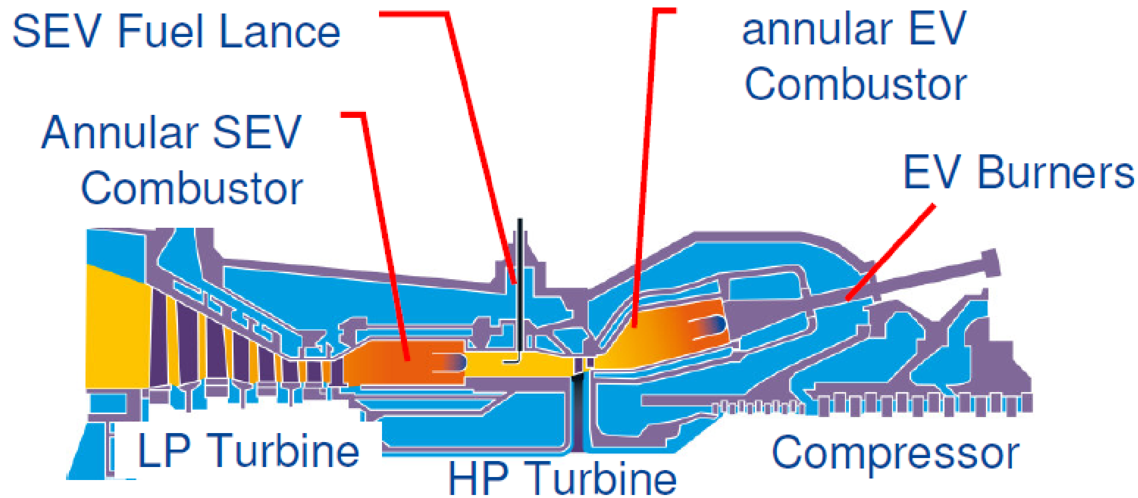
Improved combustion model: Linear Eddy Model (LEM3D) integrated with RANS

- **Background:** “LEM3D provides high fidelity resolution at a significantly lower cost than Direct Numerical Simulation (DNS)”
- **Results**:
  - The LEM3D mixing-reaction model has been coupled to the in-house CFD-code SPIDER and with FLUENT through User Defined Functions (UDFs)
  - The coupled model LEM3D-RANS has been verified against experimental data for the turbulent non-premixed jet flame denoted DLR A.

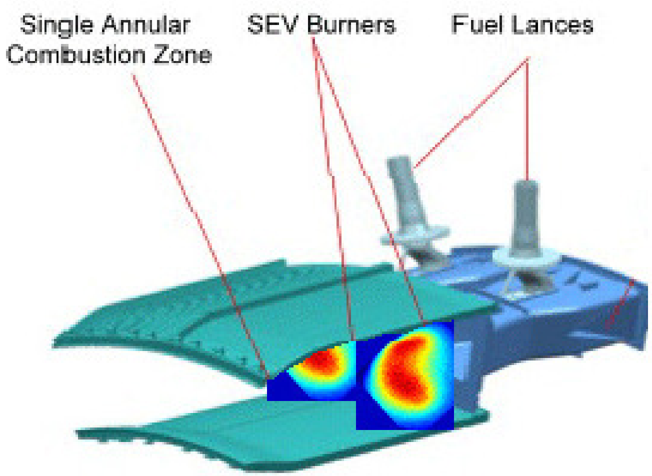


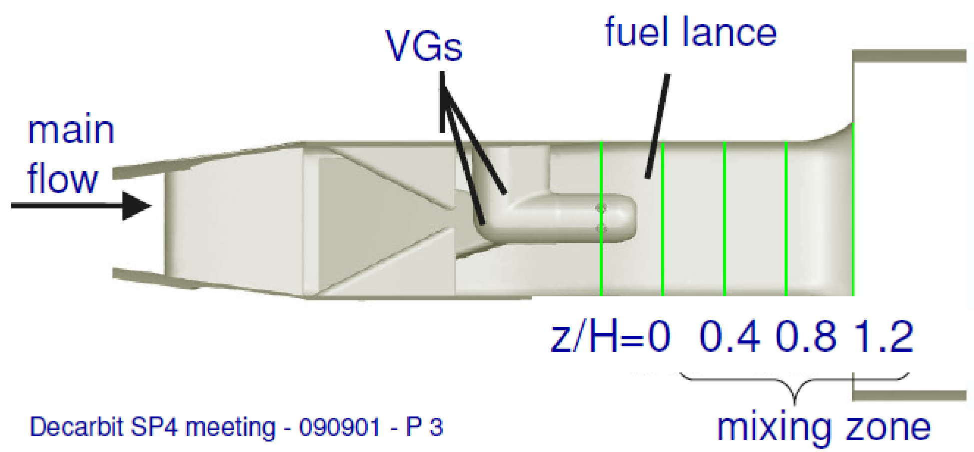
Snapshot of LEM3D-RANS simulation: Mixture fraction contours in a non-premixed turbulent jet flame (DLR-A)

Alstoms GT24/GT26



EV = **E**n**V**ironmental
SEV= **S**equential **E**n**V**ironmental

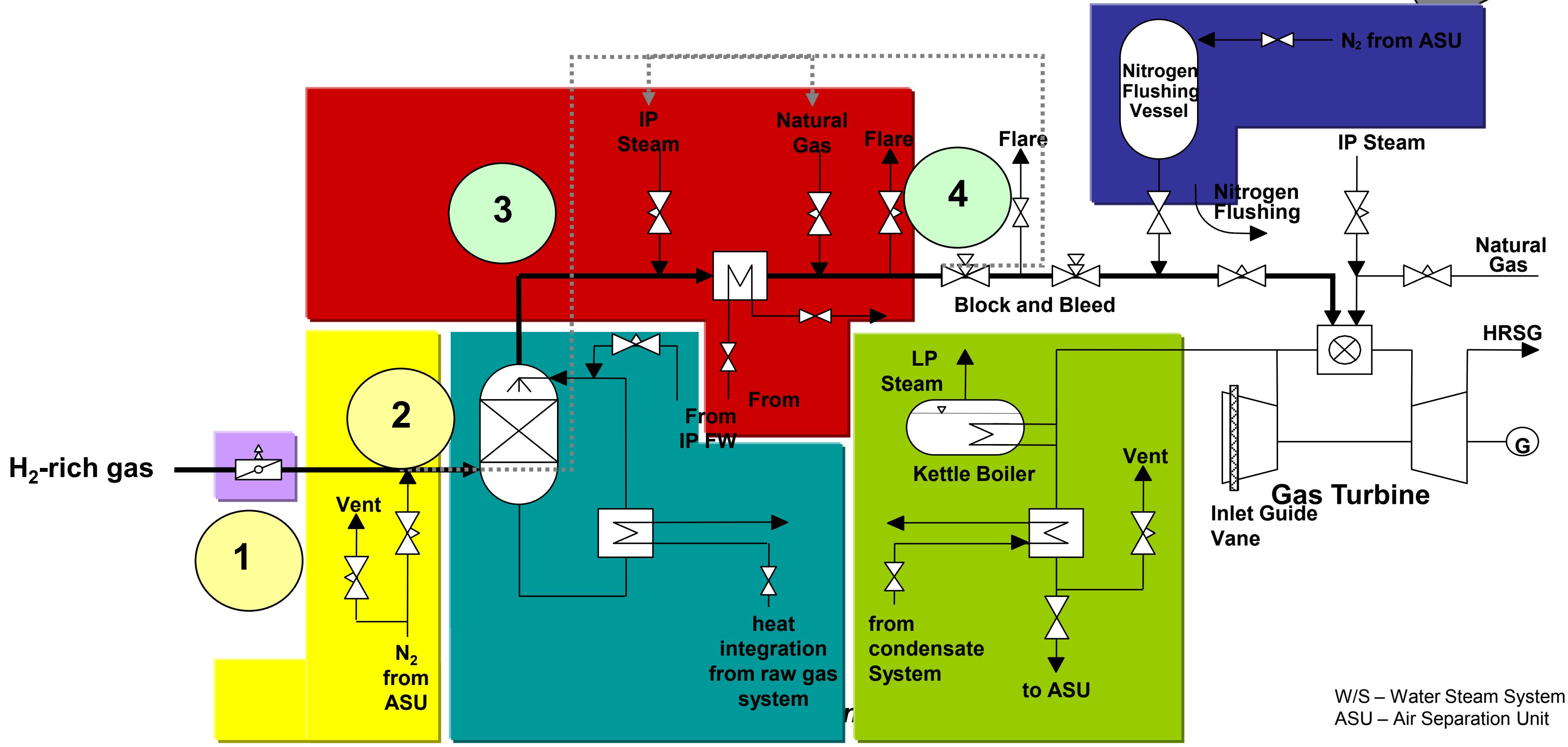




VG: Vortex generator

Modular Fuel System for IGCC-CCS

To avoid corrosion, plant has to be drained and conserved with inert gas after shut down.



W/S – Water Steam System
ASU – Air Separation Unit

Selection of piping and sealing materials

- Material Selection for Section 1 and Section 2: carbon steel 1.5415 / 1.0425 / 1.0345. CO has no effect on carbon steel due to low T, no H2O.
- Section 3: Austenitic stainless steel necessary: 1.4571 / 1.4404 since condensed water can not be avoided (dissolution of CO2 in H2O)
- Section 4: Austenitic stainless steel favorable: 1.4571 / 1.4404. H2O condensation and formation of H2CO3 can occur at start up or shut down

		1	2	3	4
		CC-CCS			
		ll hard c			
		Clean syngas at entry Syngas Fuel System	after Waste-N2 admixing	after saturation by water	Diluted and saturated Syngas after overheating
Composition [vol %]	H_2	85,32	46,34	42,54	42,54
	N_2	8,37	49,45	45,40	45,40
	Ar	1,04	0,69	0,64	0,64
	H_2O	-	-	8,20	8,20
	CO	4,76	2,59	2,37	2,37
	CO_2	0,50	0,27	0,25	0,25
	CH_4	0,01	0,01	0,00	0,00
	O_2	-	0,65	0,60	0,60
	others	-	-	-	-
p [bar(a)]		25,25	25,25	25	24,5
T [°C]		28	86,4	119,1	200
m_punkt [Kg/s]		20,508	100,83	110,895	110,895
LHV [MJ/kg]		36,436	7,411	6,796	6,796

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Selection of piping and sealing materials (2)

- Hydrogen embrittlement is no substantial problem since H2 partial pressures and maximum temperatures are too low
- In the presence of CO, carbon steel (section 1&2) can suffer from Carbonyl formation (Fe(CO)5), S is catalyst, Carbonyls less problematic for IGCC-CCS
- Inconel Alloy 82 (or similar) as joining (carbon – austenitic)

Auto-oxidation effects and self ignition

- Auto-oxidation experiments with plug-flow reactor made of stainless steel 1.4517 (selected material) at atmospheric pressure
  - For residence times in a realistic modular fuel system (ca. 4 s) only 3% of the residual oxygen (3 vol%) will be consumed by auto-oxidation
  - Only traces of ammonia are found due to the presence of about 2 % carbon monoxide that acts as a catalyst poison for this reaction. Equilibrium composition of a typical syngas contains more than 9 % ammonia; cannot be neglected for pre-combustion concepts with very high rates of carbon capture.
- Experimental self ignition tests up to 50 bar for 3 vol%, 4 vol% and 5 vol% oxygen in the syngas
  - No risk of self-ignition if oxygen<3 vol% and T<400°C (for typical pressure and syngas composition)

Optimised design of the fuel system

- Redundant pumps at saturator recommended (“saturator failure”)
- High packing size in saturator recommended (“saturator failure”)
- Moving steam admixing upstream of heat exchanger recommended (“saturator failure”)
- Moving NG admixing closer to gas turbine (“gasifier failure”)
- Ensure fast-switch-back function of gas turbine (“waste N2 failure”)

Conclusion

- Two high fidelity simulation methods previously only used for academic applications; Direct Numerical Simulations (DNS) and the three dimensional Linear Eddy Model (3D-LEM), have proven useful for guidance in development of industrial applications
- SIEMENS has studied safety, availability and material issues for the Hydrogen fuel supply system and have used the results to design an optimized fuel supply system.

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The End

- Thank you for your attention!

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