ZEP Task force on Technology
First meeting: Plan work and discuss report content

Stockholm February 23, 2007

Lars Strömberg

Vattenfall AB

Corporate Strategies

Berlin / Stockholm

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Task Force 3 Technology
Proposal for Agenda

Lunch will be served at about 1230

1.	Opening of meeting	1000
2.	Introduction of participants	1010
3.	Approval of Agenda	1020
4.	Set the target for the work of the task force	1030
5.	Set the time plan	1050
6.	Discussion of the structure of the report	1110
7.	Discussion of the work process 1. Lead Authors 2. Editor 3. Contribution from the group	1330
8.	Next steps	1440
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The Task Force formalities

The following taskforces have been formed:

Taskforce Policy and regulation

Taskforce Technology

__Co-leads of TF Technology :__

Lars Strømberg, Vattenfall
Dirk Goldsmidth, Siemens
Niels Peter Christensen, GEUS

Taskforce Demonstration and implementation

Taskforce Public communication

Secretariat
General activities

Project organization Task Force ??

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The Task Force Terms of reference

The task Force is asked to do the following:

1. Organize R&D
   1. Map R&D needs and R&D landscape. Identify and specify the gaps and priorities
   2. Induce a higher level of activities & expertise from the R&D side
   3. Improve coordination between national programmes and FP7
   4. Maintain SRA & Working Group papers, possibly through a technology assessment group
2. Ensure public funding
   1. By mapping the need for additional finace for R&D
   2. Through public bodies (EC member states, jointly with task force Policy & Regulation
   3. By initiating public-private-partnerships
3. Network and disseminate
   1. Organize technical days aimed at networking researchers and industry

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The Task Force formalities

The first task is formulated by:

- ***TF Technology***

A meeting is planned on 23rd February 2007 where the aim of the meeting is to update the SRA and formulate specific topics for the FP7 Energy Work Programme 2008 (deadline is start of May 2007)

The report outline

- The report shall be of the typical size 10 pages
- The report *shall not* be a new report, but an update of the SRA (Startegic research agenda) and the underlying WG1 and WG2 reports
- The layout and wording of the report shall be such that the Commission can "cut and paste" when writing the work programme for the remaining calls of the FP7

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– Two weeks for the group to give input	
• **1st draft ready**	**19th March**
– 10 days for the group to respond	
• **Final draft ready**	**10th April**
– 1 week for minor adjustments	
• **Final editing**	**18th April**
• **The work shall be ready**	**30th April**
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Strategic Research Agenda

- CO_2-The Global Challenge
- The Key Questions
- SRA-key points
  - Technology Options
  - Storage & Transport
  - Environment and the Public
- The R&D Roadmap
- Key Recommendations
- The Way forward

The Key questions

- Can CO_2 from fossil plant be captured effectively?
- How can captured CO_2 be safely transported?
- Can the capture and long term storage of CO_2 be achieved at reasonable cost?
- Is CO_2 storage safe?

The SRA proposes RD & D priorities
and a technology roadmap to address these issues

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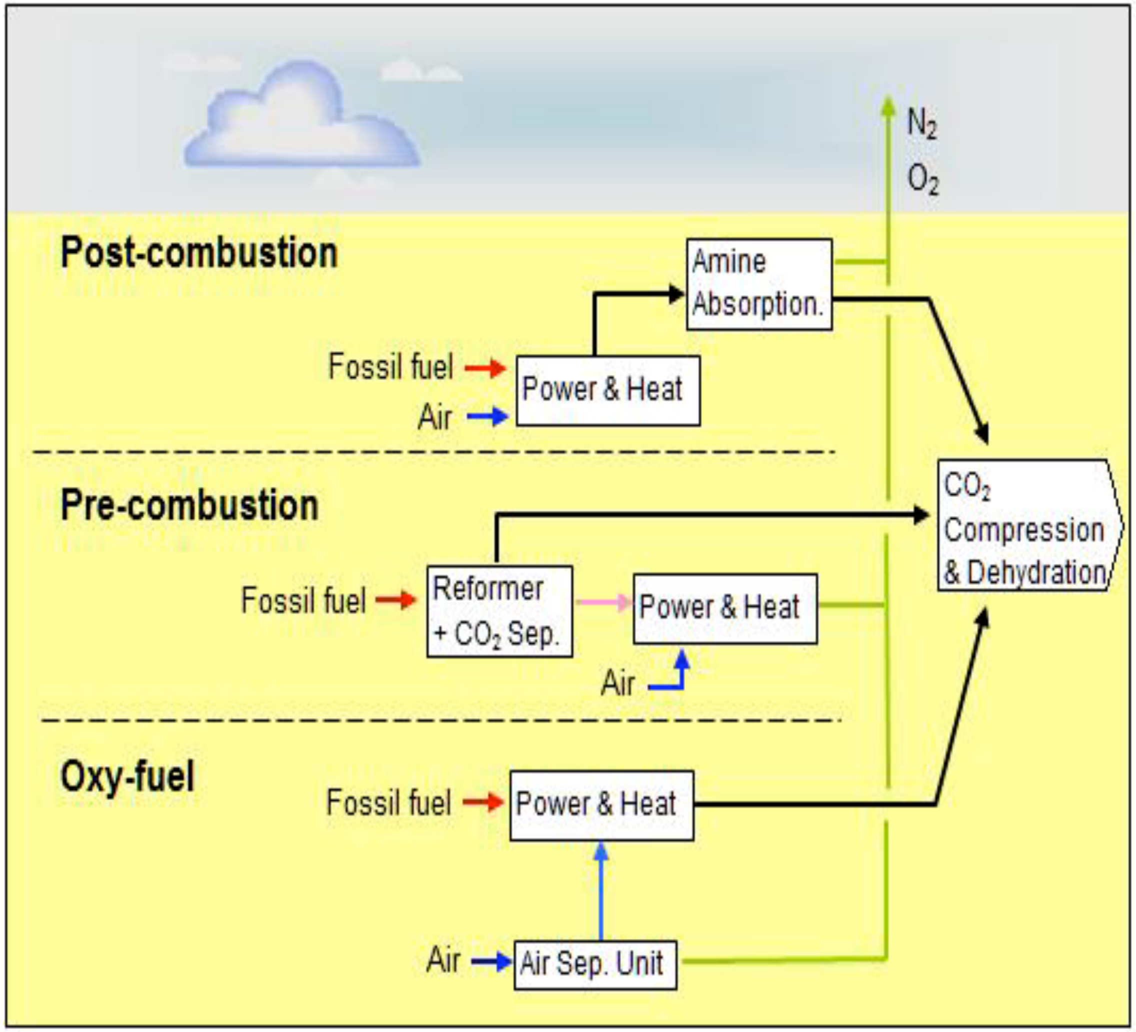
Key points - Technology Options

Three technologies seems capable to fulfil the primary target to 2020

- All largely contain known technology and components
- All need optimization, scale up and process integration
- Power process efficiency increase is always a supporting activity



Year

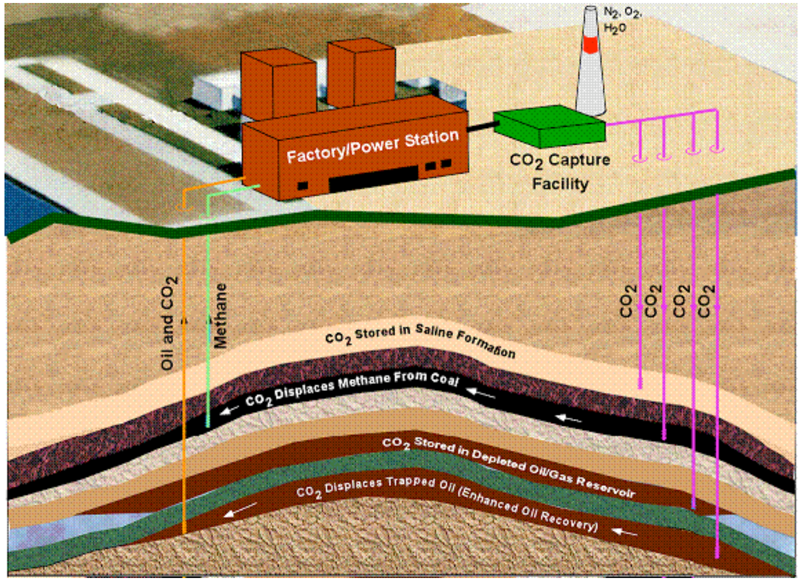
Parallel R&D routes needed

- Development of the three main technologies for the 2020 target
  - Several large scale pilot and demonstration plants, optimized, with full process integration
  - Supporting R&D to reach lower costs, increase process efficiency and achieve better availability
- R&D for new and emerging technologies for deployment after 2020
  - Many routes to examine
  - Assessment to prioritize the technologies capable to overtake the leading role from any of the three main candidates.

Storage & transport -key points

1. Demonstration of long term safety and monitoring is vital for CO2 storage.
2. Numerous storage options exist-but room for more innovation and better mapping of capacity in EU.
3. Optimise the benefits & use of CO2 (EOR,NGPS)

4. Transport options are well understood, but safe, efficient & cost effective routes must be identified



The Key Recommendations

1. Implement 10-12 integrated, large-scale CCS demonstration projects Europe-wide
2. Develop novel underpinning concepts for demonstration by 2010-2015 and implementation beyond 2020.
3. Support long-term exploratory R&D in advanced, innovative concepts for implementation of next-generation technology by 2050
4. Maximising co-operation at national, European and international level
5. Strengthen and accelerate R&D priorities to support the Strategic Deployment

Content of the WG1 report

- Capture and Power plant technology overview
- Benchmarking the technologies
- Market potential for different technologies
- Overall development goals by 2020 and after 2020
- The R&D Gaps
  - Power plant efficiency increase
  - Post combustion capture
  - Pre combustion capture
  - Oxyfuel combustion
  - Emerging and new capture technologies
- The way forward. Route Map and time frame
- Barriers for deployment and actions to remove them
- Conclusions and recommendations for action

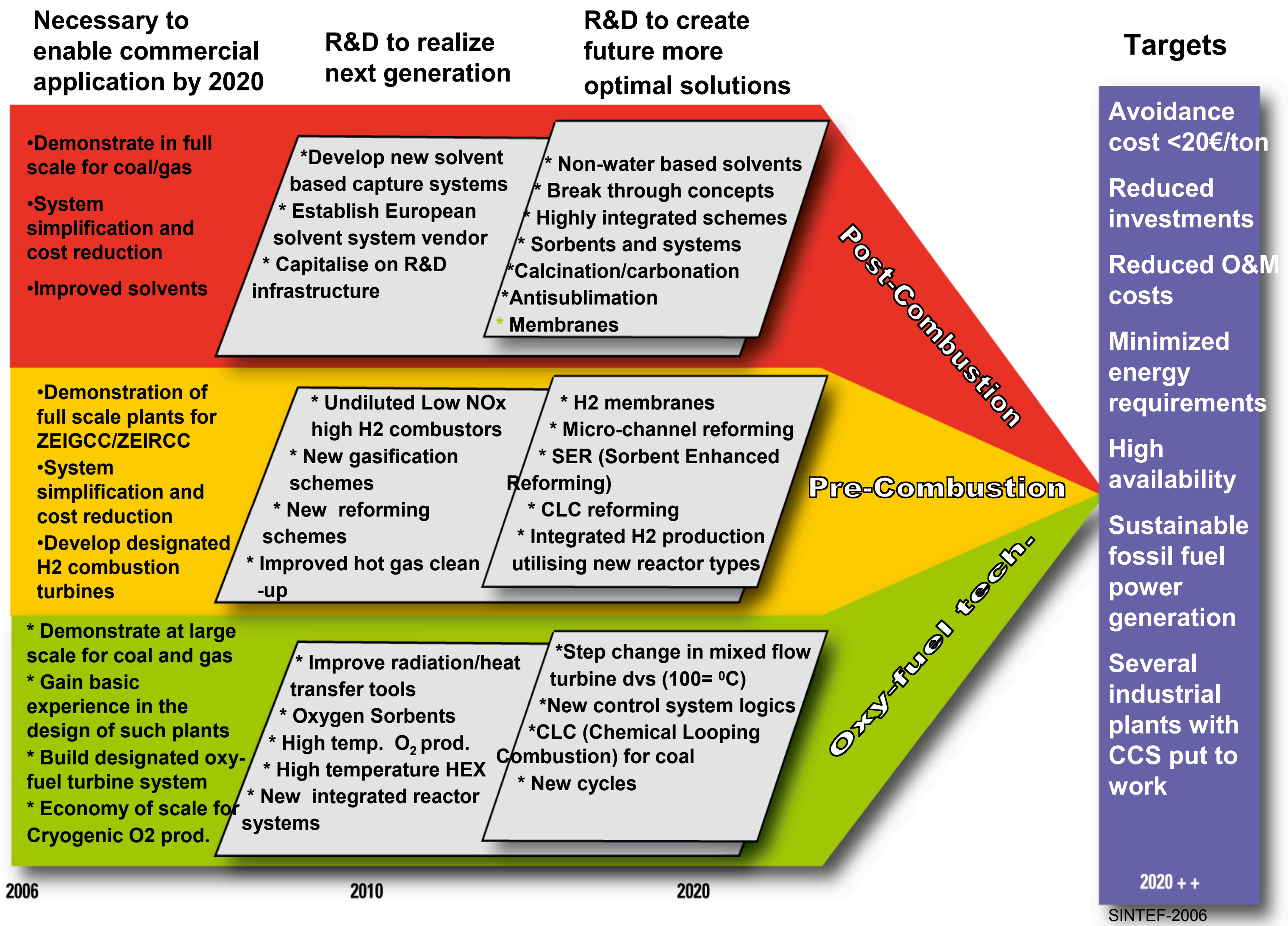
Barriers

- General barriers
  - Create a worldwide market for CCS
  - Commercial availability to storage facilities
  - Availability of educated people, in universities, administration and industry
- Technical barriers
- Infrastructural barriers
- Institutional and organizational barriers
- Regulatory and legal barriers
  - Permissions and acceptability
  - ETS

Action to remove the barriers

- Facilitate research and development work in identified areas.
  - Concentrated efforts on prospective technologies, both on an integrated level and basic R&D for support
- Create a level playground concerning market, and commercial framework for the industry
- Create a unified legislation, update regulations, standards, guidelines and permission processes to include CCS
- Make the individuals involved in legislative activities, permission processes, and the public, knowledgeable about the technology.

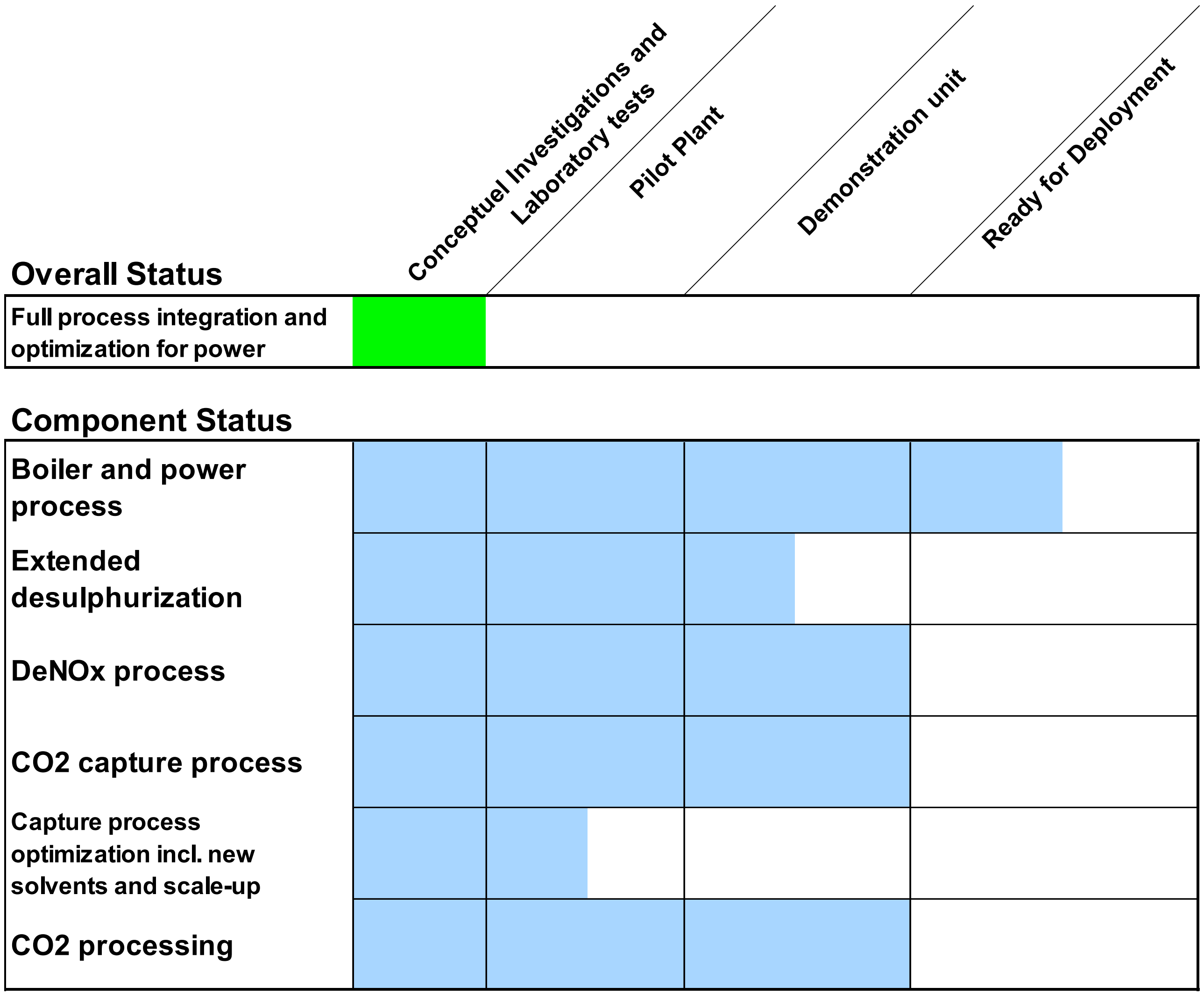
WG1 Roadmap



Necessary to enable commercial application by 2020
R&D to realize next generation
R&D to create future more optimal solutions
Targets
•Demonstrate in full scale for coal/gas
•System simplification and cost reduction
•Improved solvents
*Develop new solvent based capture systems
* Establish European solvent system vendor
* Capitalise on R&D infrastructure
* Non-water based solvents
* Break through concepts
* Highly integrated schemes
* Sorbents and systems
*Calcination/carbonation
*Antisublimation
* Membranes
Post-Combustion
•Demonstration of full scale plants for ZEIGCC/ZEIRCC
•System simplification and cost reduction
•Develop designated H2 combustion turbines
* Undiluted Low NOx high H2 combustors
* New gasification schemes
* New reforming schemes
* Improved hot gas clean -up
* H2 membranes
* Micro-channel reforming
* SER (Sorbent Enhanced Reforming)
* CLC reforming
* Integrated H2 production utilising new reactor types
Pre-Combustion
* Demonstrate at large scale for coal and gas
* Gain basic experience in the design of such plants
* Build designated oxy-fuel turbine system
* Economy of scale for Cryogenic O2 prod.
* Improve radiation/heat transfer tools
* Oxygen Sorbents
* High temp. O_2 prod.
* High temperature HEX
* New integrated reactor systems
*Step change in mixed flow turbine dvs (100= ⁰C)
*New control system logics
*CLC (Chemical Looping Combustion) for coal
* New cycles
Oxy-fuel tech-
Avoidance cost <20€/ton
Reduced investments
Reduced O&M costs
Minimized energy requirements
High availability
Sustainable fossil fuel power generation
Several industrial plants with CCS put to work
2006
2010
2020
2020 + +
SINTEF-2006

Key Points – Development need

Post-combustion



Post Combustion Capture

Key research issues

- Insufficient experience for power plant application on a large-scale and special requirements due to flue-gas conditions

- High energy demand/penalty for regeneration of the solvent and energy requirements for CO_2 compression

- Full process integration and optimisation for power generation

- Absorption system with high-throughput under oxygen environment is unavailable today

Post Combustion Capture

- **CO_2 capture and conditioning processes**
- General areas include:
- New and less energy-intensive solvents which exhibit stable performance in flue gases
- Process optimisation for large-scale plants
- New and less energy-intensive solvents which exhibit stable performance in flue gases
- Demonstrating long-term operational availability and reliability on a full-scale power plant, using relevant fuels
- Retrofittable concepts

Post Combustion Capture

- **Emerging technologies**
- Materials research to improve the performance and lower the costs of the separating agents, such as adsorbents, membranes
- Component development, e.g. membrane modules and novel reactors addressing issues such as scale-up, methods of fabrication
- Improving the efficiency of supporting technologies, e.g. vacuum pumps and CO_2 compressors
- Process development to demonstrate technical feasibility of the process or a particular component on a small scale and/or in a realistic environment
- Laboratory-based pilot plant activities

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Key Points – Development need

Pre-combustion

Overall Status

	Conceptuel Investigations and Laboratory tests	Pilot Plant	Demonstration unit	Ready for Deployment
Full process integration and optimization for power				

Component Status

	Conceptuel Investigations and Laboratory tests	Pilot Plant	Demonstration unit	Ready for Deployment
Air separation unit				
Coal Gasification				
Natural gas reforming				
Syngas processing				
CO2 capture process				
CO2 processing				
High efficiency, low emission H2 Gas Turbine				

Pre Combustion Capture

Key research issues

- Scale-up issues in designing and developing a highly reliable n industrial-scale power plant with CO_2 capture

- Scale-up of gasifiers

- Highly efficient gas turbines for hydrogen combustion

- Energy losses by shift-reaction and CO_2 capture process must be compensated

- Full process integration and optimisation for power generation

Pre Combustion Capture

Gasification, reforming, gas cooling and cleaning

- Develop large up-scaled gasifiers with 1200-1500MW_{th} for a single train configuration, together with an effective heat recovery/quench system
- Develop improved coal feeding systems
- Improve slag and fly ash removal systems
- Develop conversion technologies with O_2 membrane production

Pre Combustion Capture

Gas conditioning in CO_2 capture

- Further develop the shift catalyst - specifically in durability, reduction in costs and admission of high concentrations of CO
- Develop optimised solvents to separate CO_2 and H_2S. Improve selectivity and reduce investment, and operations and maintenance (O&M) costs
- Develop membranes to separate CO_2 and H_2S. Improve selectivity and reduce investment and O&M costs
- Achieve the cost-effective cryogenic separation of CO_2 and H_2
- Develop membranes for separating CO_2 and H_2
- Determine admissible specifications of impurities for CO_2 geological storage
- Develop new or improved physical or chemical solvents for gas treatment under pressure
- Remove sulphur at high temperature level on a dry basis
- Investigate CO_2 hydrates

Pre Combustion Capture

Gas turbine and water steam cycle

- Optimise plant concepts with reduced auxiliary consumptions
- Develop 300MW+ gas turbines capable of burning H_2-rich gases with the highest efficiencies
- Further develop high temperature water steam cycles
- Optimise unit control system of the overall plant
- New cycles for higher efficiency, e.g. hybrid combining fuel cells and gas turbines

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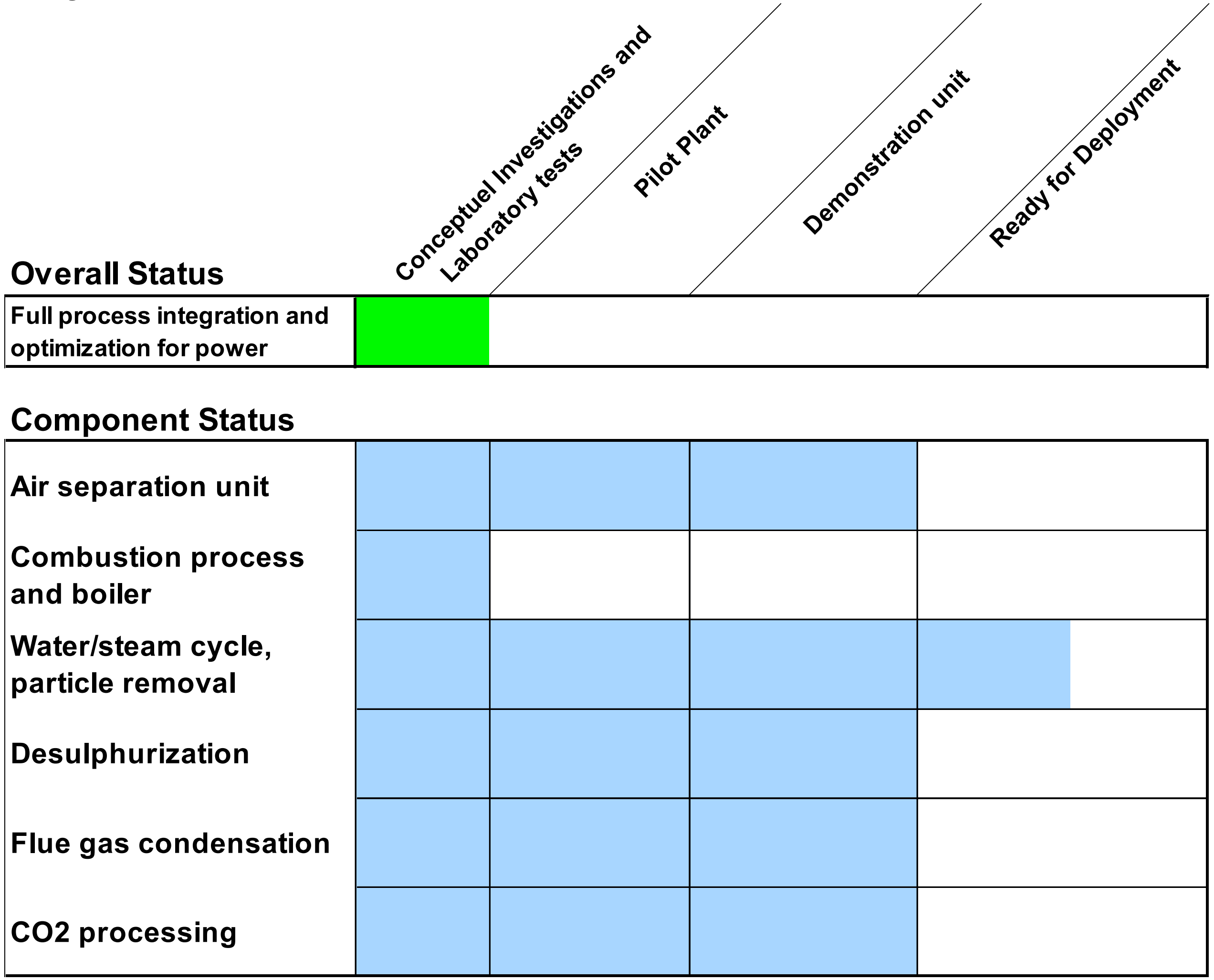
Pre Combustion Capture

- **Air Separation Unit (ASU)**
- Optimise process integration, depending on air extraction and N_2 dilution requirements
- Improve adsorbents for removing contaminants prior to distillation, tailored for high pressure adsorption and regeneration cycles
- Develop high efficiency packings for distillation fluids close to supercritical conditions
- Develop mixed conducting ceramic membrane technology for oxygen production
- Undertake process studies to evaluate the various schemes needed to provide oxygen at high pressure, upstream the gasifiers.

Key Points – Development need

Oxy-fuel



Oxyfuel combustion

Research issues

- No commercial gas- or coal-fired power plants currently exist which operate under oxy-fuel conditions
- Only tests being performed are in laboratory-scale rigs and experimental boilers up to a size of a few MW_{th}
- There are uncertainties as to what are acceptable impurities in the CO_2 rich flue gas
- CO_2 rich flue gas treatment is not yet developed

Oxyfuel combustion

Developing and implementing oxy-fuel combustion for boilers

- Laboratory research into combustion, heat transfer, formation of pollutants, ash compositions, slagging, fouling and corrosivity of flue gases. For circulating fluidised bed (CFB), also bed material behaviour and in-situ sulphur removal
- Develop design tools for scale-up, based on research results
- Pilot plant tests (10s of MW_{th}) of full oxy-fuel pulverised fuel (PF) process and oxy-fuel CFB
- Large-scale demonstrations (100s of MW_{th}) of complete oxy-fuel PF and oxy-fuel CFB power plants
- Oxy-fuel combustion for CFB boilers: specific design and scale-up issues include strong heat extraction to solid bed material circulation loop

Oxyfuel combustion

Emerging technologies

- Oxy-fuel gas turbines and combined cycles - establish a sound engineering basis for these turbines through basic R&D, possibly with some pilots within the next 5 years
- Development and implementation of Chemical Looping Combustion (CLC)
- R&D on emerging technologies, including lower flue gas recycle in oxy-fuel PF boilers, CFBs and new large-scale oxygen production concepts using ceramic transport membranes or ceramic autothermal recovery (CAR) technology
- General R&D as basis for new oxy-fuel based systems, i.e. high temperature steam cycles (up to 1000–1200˚C, gas turbine derived technology); high temperature heat exchangers; condenser operation and heat transfer characteristics for high CO_2 content mixtures; dynamics of power cycles with high degree of integration; cost-effective membrane modules; and combustion in near surface conditions (membranes)

Oxyfuel combustion

Material selection and R&D

- Investigate long-term operational properties of materials for flue gas environment in oxy-fuel processes, including testing new advanced materials expected to be used in future Ultra Critical Code (USC) 700°C power plants. Research materials for both coal-fired boilers and gas turbine application

CO_2 capture, compression and conditioning process for oxy-fuel combustion

- Develop flue gas cleaning technologies for implementation in the CO_2-compression train
- Optimise CO_2 processing and compression system to remove inert gases from the CO_2-product
- Establish themophysical properties of high concentration CO_2-mixtures
- Improve the efficiency of CO_2 compressors and scale-up

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Oxyfuel combustion

Air separation unit (ASU)

In addition to R&D actions for pre-combustion capture:

- Further increase in the single-phase and two-phase cryogenic heat-exchangers to reduce power consumption due to pressure drops and temperature differences
- Develop very large air compressors, potentially of the adiabatic type, to lower the cost of these units and develop new integration possibilities within the heat system of the power plants

Power Plant Efficiency

Steam power plants - achieve over 50% efficiency

- Develop and qualify new materials for high-temperature-loaded areas in steam generators, piping, valves and turbine for 700°C+
- Research component adapted design and integrity concepts
- Develop new protective coatings
- Improve welding methods, cost-cutting measures for manufacturing and certification, safeguarding of properties, manufacturing large components and measures for detecting defects and flaws
- Investigate corrosion under oxy-coal atmosphere
- Develop novel steam turbine designs with steam cooling, ceramic coatings, improved clearance control, new sealings and improved aerodynamics
- Improve water/steam cycles
- Enhance design tools and codes in order to calculate heat transfer, aerodynamics and components
- Conduct experimental validation and rig tests as required for successful implementation

Power Plant Efficiency

Gas turbine plants - achieve over 63% efficiency

- Harmonise optimisation of gas turbines, steam turbines, generators and boilers, while reducing losses in auxiliary equipment
- Improve aerodynamic performance, materials and cooling systems. Design ultra high-strength materials for gas turbine rotors, production technology for large components, assessment methods for material properties and new materials for blades of low density
- Develop thermomechanical models and simulation tools for evaluating material properties
- Research high temperature coating systems
- Improve rubbing, sealing and combustion systems
- Investigate low-emission technology
- Achieve longer lifetime, combined with cost-efficient operation
- Enhance lifetime modelling
- Fuel flexibility (different natural gas compositions, syngases, H_2-rich gases and low heating value fuels, such as bio-fuels and industrial gases)

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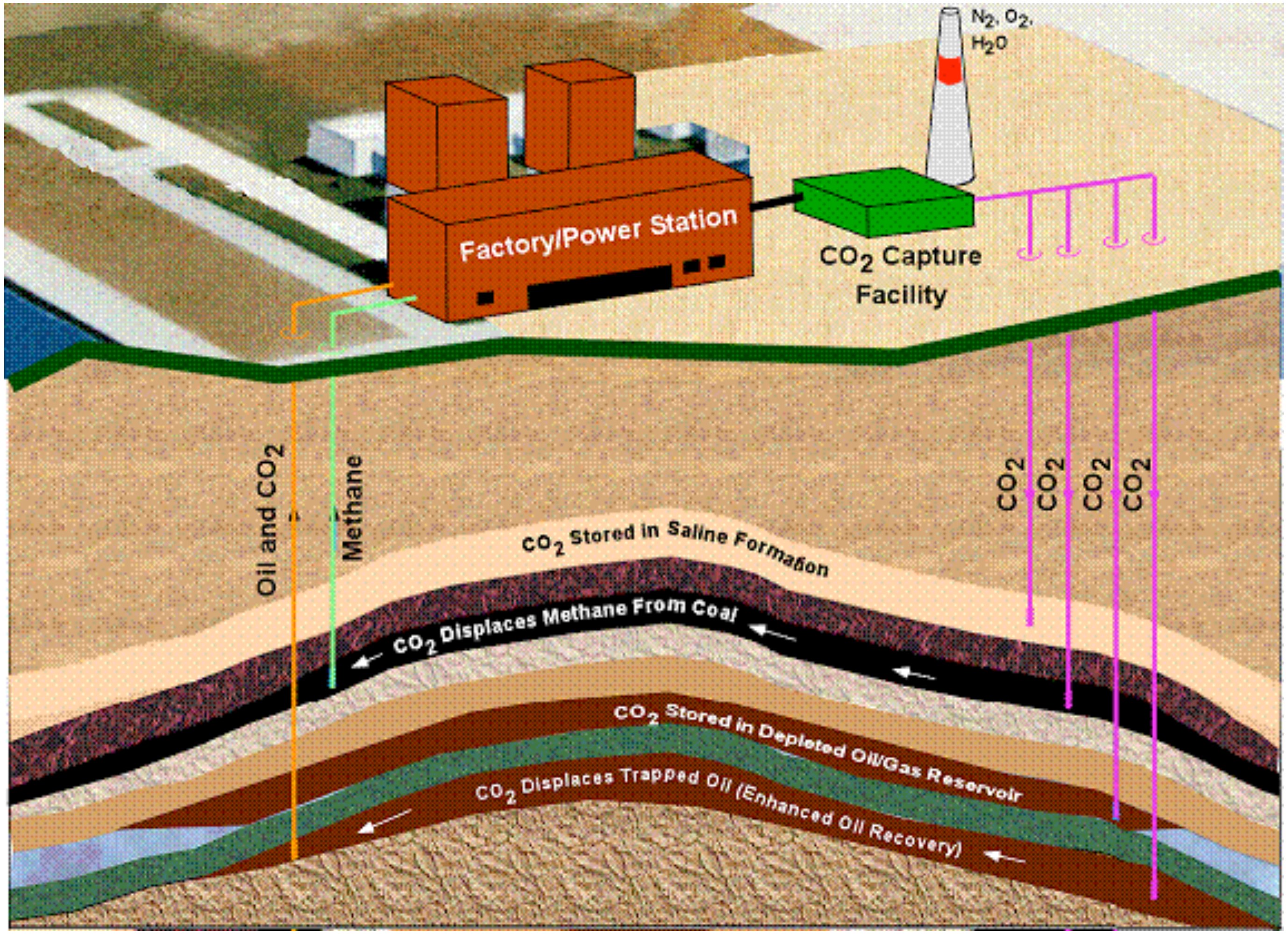
Research needs Storage

Assessing storage capacity

There is currently a lack of hard data on storage capacity, requiring a tool for predicting spatial reservoir characteristics. The best way to fill gaps and evaluate potential storage capacity is to start with well-characterised saline aquifers and establish clear qualifying and quantifying criteria.

- Establishing standards for improving the assessment of storage capacity
- Analysing and assessing capacity for storage, relative to geology and trapping mechanisms

Research needs Storage



Research needs Storage

- **Proving the trapping concept**
- Understand physical, chemical and biological processes in the subsurface involving CO_2.
- Identify expected fluid–rock interactions at variable fluid chemistry
- Verify different in-situ geological conditions.
- Rock-fluid interactions from reservoirs in which CO_2 has been injected.
- Explore seal integrity for injecting large amounts of CO_2
- Develop dynamic models of CO_2 over time and migration
- Constraints on the fate of CO_2 by geophysical and geochemical monitoring.
- Study cap rock integrity, seal classification and prediction of seal characteristics
- Up-scale experimental data (e.g. gas breakthrough experiments) with CO_2 for low permeable samples.
- Tools for predicting spatial reservoir properties, coupled to the burial history.
- Glacial influence and other late tectonic movement of the sedimentary strata – vital for evaluating the overburden integrity.

Research needs Storage

Modelling the storage reservoir

- Design field and well systems,positioning injection and production wells and monitoring systems.
- Determine the evolution of CO_2 stored underground for long periods
- Describe migration paths
- The main mechanisms for CO_2 propagation, during operation and long-term storage.
- Static geological modelling to predict accurately the short- and long-term safety and reliability of CO_2 geological storage.
- Calibrate parameters by dynamic modelling of laboratory and field test data.
- Model long-term transport processes through clay-rich sediments and other cap rocks.
- Geochemical modelling of reactions and transport of species.
- Coupled phenomena of chemical reactions, caprock permeability, mechanical properties, and geochemical factors.
- 3D modelling of reservoirs lacks several sub models
- The complex structure and behaviour of faults.

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Research needs Storage

Investigating CO_2 thermodynamics

- Improved simulation tools are required to better represent CO_2 properties, especially in mixtures with impurities
- New tools to cover short-term detailed processes simultaneously at the reservoir scale as well as long-term, large-scale hydrological processes in the overburden.
- New improved models to include reactions of CO_2 with rock
- New simulation tools to be multi-phase and multi-component fluid flow models, including relative permeabilities, capillary pressures and thermodynamics. Heat and mass transfer between fluids should be taken into account by the transport model.
- Improve long-term predictions with coupled models that address several parallel phenomena, with geochemistry, geomechanics and multi-phase flows accounted for.
- Assess the impact of impurities injected with the CO_2 (*i.e.* O_2, N_2, NO_x, SO_x, CO, H_2S, etc) on fluid properties and geochemical reactions.

Research needs Storage

Designing new monitoring tools

- Monitoring the geological storage of CO_2 can be adapted from hydrocarbon exploration and development activities. However, second-generation solutions are required, including the development of new monitoring tools:
- Tool response functions should characterise measurement resolution, accuracy and sensitivity to changes in CO_2 saturation.
- Include multi-measurements and model-based interpretation in order to monitor CO_2 displacement and CO_2 in place.
- Develop methodologies for calibrating simulation models.
- Detailed tool response models calibrated on laboratory experiments to interpret measured data.
- Borehole seismic measurements to link surface seismic with other well measurements, focusing on accurate tiltmeters or satellite-based ground elevation measurement techniques. Micro-seismicity will also image re-activated faults planes. Interference testing and tracer injection could provide information about changes in fault transmissibility.

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Research needs Storage

Understanding wellbore integrity over the long-term:

- Characterise the completion component (casing, cement) degradation and leakage routes
- Characterise interfaces of formation-cement and cement-casing in terms of hydraulic isolation
- Quantitatively estimate leaks from integrity measurements
- Monitor wells after closure (plugs) and estimate fault transmissibility
- Optimise the monitoring system with regard to storage performance, risk control and monitoring cost.

Research needs Storage

Detecting and mitigating leaks, and tracking CO_2 in the reservoir:

- Improve measurement of fault-pathfinder trace gas concentration and fluxes to detect potential leakage routes, before and during CO_2 injection
- Develop methods and technologies for mitigating leaks in the unlikely event that they occur
- Define the measurement grid to get comprehensive coverage of an area
- Identify the correct and widespread use of tracers added to the injected CO_2 to differentiate anthropogenic input from natural
- Improve standards for the comparison and cross-use of different soil gas and infrared (IR) remote sensing techniques
- Evaluate geogas uprising velocity from the soil
- Develop ability to monitor precursors of large seismic hazards
- Use and analysis of multiple measurement techniques together. Both local direct measurements (sampling) and global, indirect measurements (seismic) should be addressed
- Establish a field laboratory for studying CO_2 migration in the overburden - this could also be used to calibrate models and study specific processes.

Research needs Storage

Ensuring new monitoring programmes:

- Control storage operation performance with respect to capacity, injectivity and containments
- Control risks associated with leakage, including the contamination of shallower formations, releases on surface and corrective action
- Estimate the evolution of the performance and risks as reliably as possible
- Establish a guide for performance and risk analysis, accounting for all potential leakage pathways
- Control the displacement and distribution of the CO_2 in the reservoir
- Benchmark the distribution of CO_2 and the behaviour of contaminants.

Research need for Transport

Materials

- The corrosive behaviour of CO_2 when wet is well known, but further research is necessary to determine how variations in temperature, flow rate, gas stream composition and pH influence the corrosion on different materials. .

Pipelines

- Validate any differences between transportation of hydrocarbons via offshore pipeline and that of CO_2. Define and optimise methodologies for underwater CO_2 pipeline technology. Develop accurate and verifiable monitoring systems.

Ships

- Optimise the efficiency of terminal storage, construction and safety, including load port and off load port applications. Identify the best storage medium and any environmental impacts where CO_2 might escape during trans-shipment. Ensure refrigerated CO_2 can be safely, environmentally and economically transhipped and mixed into a pipeline that carries super-critical CO_2.

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Task Force 3 Technology
The Work Process

- Lead Authors are appointed
  - Capture
    - Post combustion capture
    - Pre combustion capture
    - Oxyfuel combustion
    - Novel Technologies
  - Storage
    - Aquifers
    - Use and transport (EOR, EGR,ECBM……..)
- The Group members declare which part they would like to contribute to
- An Editor cooperate with the Lead authors to coordinate, align and edit the input
- All Group members are welcome to contribute, give views and to comment on the different versions of the material

Task Force 3 Technology
The Work Process

- The SRA and the WG1 and WG2 reports are the base for the work. Use them to comment and to update
- The paper will use the "bullet points" of the SRA as "Draft 0"
- There will be a first draft sent out
  - It will be a compilation of
    - The SRA base material
    - The contributions from the group
    - The balancing and aligning done by the Lead Authors
    - It will be compiled by the Editor
- The Group will respond to the First draft
  - Lead Authors will adjust the text
  - The Editor will bring a final draft together
- The Group will respond to the Final draft with proposals for minor changes
  - The report will be adjusted and sent to the AC

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5.	Set the time plan	1050
6.	Discussion of the structure of the report	1110
7.	Discussion of the work process 1. Lead Authors 2. Editor 3. Contribution from the group	1330
8.	Next steps	1440
9.	Next meeting	1500
10.	AOB	

VATTENFALL

Task Force 3 Technology
Proposal for Agenda

Lunch will be served at about 1230

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2.	Introduction of participants	1010
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Back up