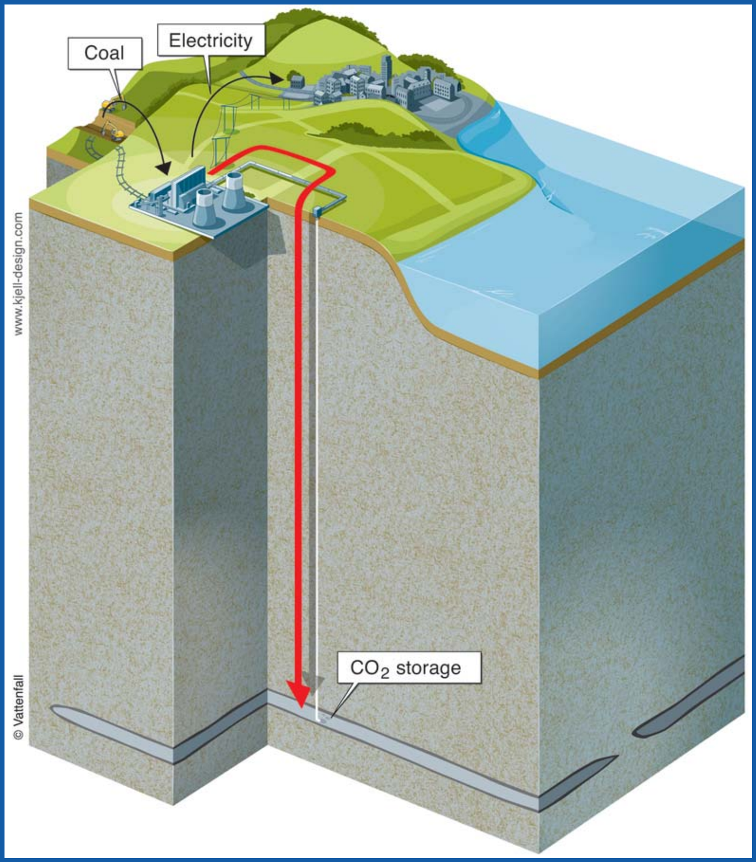
Characteristics of the captured CO_2 gas stream

Workshop On Sub-Seabed Carbon Dioxide Storage

Umweltbundesamt, Berlin, 17th of June, 2008



Sara Eriksson

Vattenfall Research and Development

Presentation outline

- Introduction
- Capture technologies
- Gas quality
- Technical issues
- Health, safety and environment
- Concluding remarks

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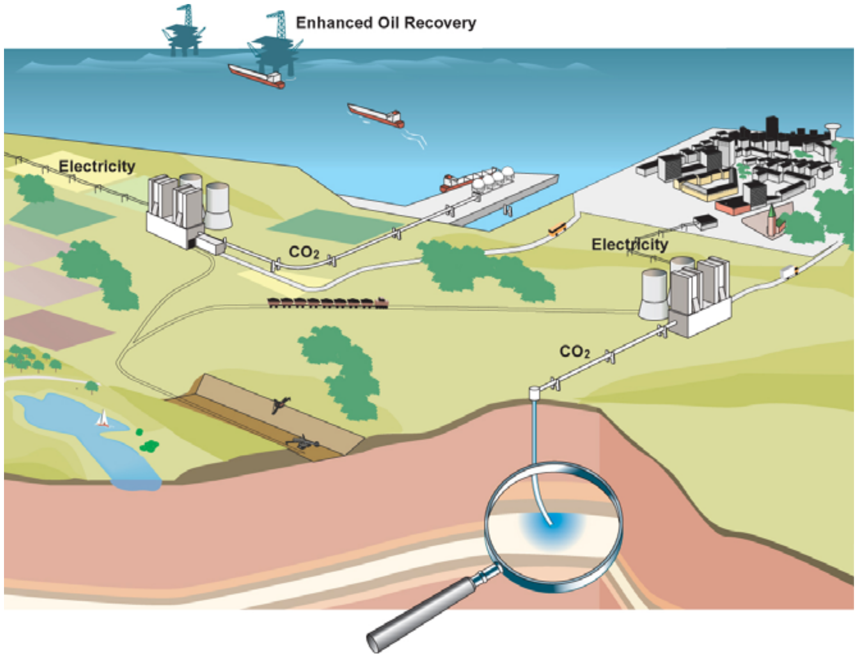
Introduction

- When capturing CO_2 streams from coal-fired power plants for geological storage, the gas stream also contains small amounts of other substances.

- The composition of the captured gas depends on several factors:
  - Fuel characteristics
  - Choice of capture technology
  - Level of flue gas cleaning



- The presence of other components in the CO_2 stream may change the stream characteristics

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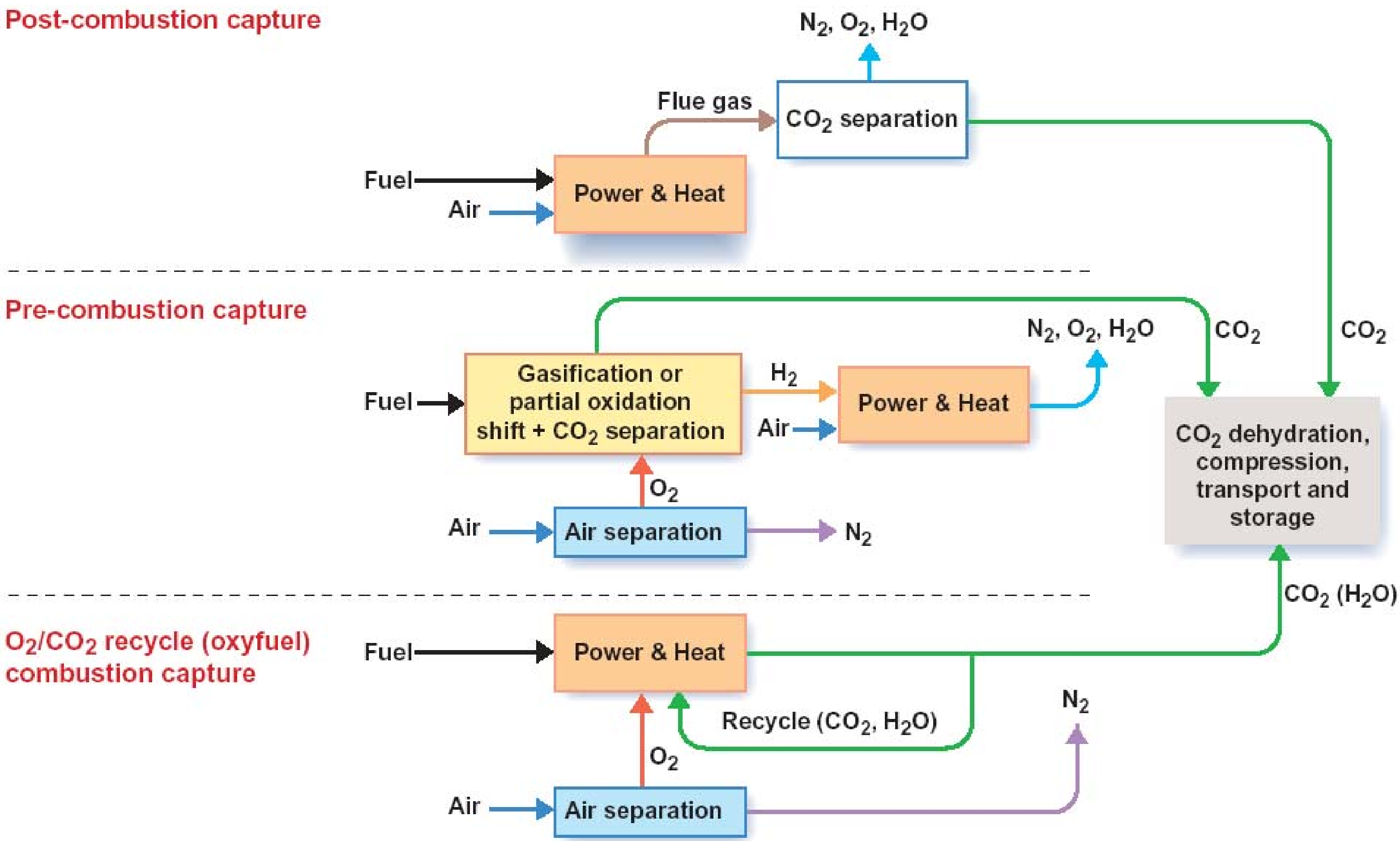
CO_2 capture technologies



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Where do the other substances in the CO_2 come from?

The sources of impurities in the CO_2 stream are:

1. Fuel
   - H_2O, CO, SO_x, NO_x, H_2S, HCl, HF, H_2, CH_4, heavy metals, hydrocarbons, particulates
2. Air or oxidant used for combustion of the fuel
   - O_2, N_2, Ar
3. Entering of air into the CO_2 capture system when it is operating at sub-atmospheric conditions
   - O_2, N_2, Ar
4. The CO_2 capture or CO_2 clean-up process
   - NH_3, solvents

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Gas composition and different capture technologies

- The composition of the CO_2 stream after compression (and before flue gas cleaning) depends on the capture technology

- For oxyfuel the CO_2 quality is a strong design parameter
  – Inert components from penetration of O_2 and air into the system
  – SOx, NOx removal level
  – Trace elements
  – Corrosive elements

- For precombustion the process selection and design requirements strongly influence the quality
  – Reducing components H_2S, CO, H_2
  – hydrocarbons

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Can a stream of high purity CO_2 be produced?

The one parameter that has the main influence of the composition of the captured CO_2 gas stream is the designed cleaning level – We can steer and optimise the gas quality.

- Conventional flue gas cleaning equipment can be used to clean the CO_2 gas stream to ”air emission levels”
- A CO_2 stream of very high purity can be produced in theory, but there are consequences:
  - Increased energy consumption for the purification process. More fuel has to be used to produce the same amount of electricity
  - Increased investment and operational costs. The cost of CCS will increase
  - Decreased CO_2 recovery. CO_2 may be lost as a consequence of the clean-up process

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Technical issues

Other factors besides health, safety and environmental considerations place restrictions on the gas stream quality.

Technical requirements relating to transport and storage of CO_2 are also important for good operations.

Using the CO_2 gas stream for Enhanced Oil Recovery (EOR), will impose concentration restrictions on some components for technical reasons

Transport related aspects of gas quality

- Corrosion of the pipeline must be minimised
  - Done as part of risk management
  - Important to avoid negative impacts on operation
  - Increased maintenance costs

  Solution: Limiting the concentration of corrosive components/water content and use low-corrosion materials

  Relevant components: H_2O, CO_2, SO_x, NO_x, O_2, H_2S, HCN, HF, HCl

- Hydrate formation
  - Operational problems
  - Risk of plugging

  Solution: Technical issues can be resolved by
    - Operating the system within defined thermodynamic boundary conditions
    - Limiting the content of hydrate forming components

  Relevant components: H_2O, CO_2, H_2S, CH_4

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Transport related aspects of gas quality

- Two-phase flow
  - Operational problems

  Solution: Operating at appropriate thermodynamic conditions will avoid this

  Relevant components: Ar, O_2, H_2, H_2S

Other technical aspects of gas quality relating to pipeline transport,

Examples:

- Pipeline fouling by particulates
- using the transport volume efficiently/economically (Ar, N_2, O_2)

The technical issues relating to CO_2 transport can be **resolved** by limiting and optimising the concentrations of relevant components and through appropriate process and pipeline design.

Storage related aspects of gas quality - injection

- The injection well shall be designed to minimise risks during both the operation and the after closure phase:
- Minimise risk of corrosion:
  - Difficult to replace damaged parts on the well

  Solutions:
  - High-quality steel for exposed parts, limit water content, maintain a good operation regime
- Avoid the formation of hydrates (and potential damage):
  - Hydrates form at low temperatures and high pressures, and presence of other gas stream components may also have an influence (hydrates may form at higher temperatures)
  - With H_2S and CH_4, hydrates can form without presence of free water.

  Solutions:
  - Good operating and thermodynamic conditions will help to avoid the formation of hydrates

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Storage related aspects of gas quality – storage formation

- Other gas stream components take up volume in the reservoir, which may to some extent lead to increased storage costs.
  - …to be compared with the additional costs of CO_2 processing at the power plant.
- Other components may to a limited extent have effects on chemical reactions in the reservoir (precipitation/dissolution reactions). (These are however present in much lower concentrations than CO_2.)
- The potential and extent of chemical reactions involving other components than CO_2 should be assessed (modelling, experiments, sampling etc.) as part of risk management on a site-specific basis – based on local geology/site conditions
- No impacts on the integrity of the seal due to presence of low concentrations of other gas mixture components than CO_2 in the gas stream is expected.
- Other gas components may increase the viscosity of the gas stream – easier to inject – positive effect

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The leakage issue

For capture of CO_2, the main environmental impact - apart from the **positive** effect of the decrease in CO_2 emissions to the atmosphere - is mainly associated with the increased use of energy and resources.

For CO_2 transport and storage, concerns for environmental impacts are to a large extent associated with potential leakage scenarios and risks.

The no-action, or slow-action, alternative is guaranteed to have adverse environmental consequences such as ocean acidification.

Natural leakage of CO_2, from volcanic processes, into a river. (Ribeira Grande, Lombardos Valley, the Azores, Portugal).
Photographed by Sara Eriksson

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Health, Safety and Environmental aspects

HSE characteristics of other gas stream components:

- Acidification
  - components that form stronger acids than CO_2 (SO_2, NO_x, H_2S etc.)
- Components with toxic properties
  - H_2S, SO_2, COS, CO, NO_x, heavy metals (Hg), organic compounds (solvents, mercaptans).
- flammable compounds
  - such as H_2, CH_4
- Nutrients (eutrophication),
  - Some components present are nutrients (such as NO_x, N_2) (In the context of a leakage into the marine environment, this is not considered to be a major issue.)

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Health, Safety and Environmental aspects – cont.

- Potential effects on health, safety and environment are **concentration dependant**
- We determine the concentrations and design the CO_2 gas stream according to desired specifications, by deciding on the level of cleaning
- Vattenfall's approach is that presence of other components can not lead to significant or unacceptable risks for health, safety and environment.

  The CO_2 stream will consist overwhelmingly of CO_2 . When considering HSE risks and CO_2 gas stream design - no other component in the gas stream should be present at concentrations that makes it a greater hazard than CO_2 itself.

  → CO_2 should be the limiting component from a HSE perspective!
- This is the same approach used in the study of CO_2 gas quality specifications in the Dynamis EU project.

Assessing the HSE effects in case of a leakage

- In case of a leakage to the marine environment, the impacts will mainly relate to the change in pH levels (due to dissolved CO_2, and to some extent other components).
- The rate at which leaked CO_2 stream is diluted will influence the degree of impact - depends on local factors such as depth, underwater currents, diffusion rate etc.
- Organisms under pH stress may be more susceptible to other forms of pollution.
- Little specialised research is done on impacts on the marine ecosystem in case of leakage of a CO_2 stream containing low concentrations of other compounds.
- There are however locations on the sea floor where naturally occurring seeps of CO_2 mixed with other gases at various proportions occur. These seeps can be seen as natural analogues to a CO_2 leakage, and information can be learnt from studying them.

Natural CO_2 reservoirs occur in the earth crust

- Large CO_2 reservoirs occur natural in the earth crust, and are used as CO_2 sources for enhanced oil recovery in the American oil industry.
- Typical other components that may occur in these natural CO_2 reservoirs are methane, nitrogen, other lighter hydrocarbons and H_2S.
- Such large CO_2 reservoirs can be found in Western U.S., eastern Europe and Indonesia, and in various fields in the mountainous regions of Central and South America.
- There are also several areas in the world where CO_2 of volcanic origin leak to the surface.

Abandoned factory for carbonated water, Lombardos valley, the Azores (Portugal) Carbonated water from underground natural sources are pouring out of a broken pipe.

Reference: Practical aspects of CO_2 flooding. P.M. Jarrel et al. SPE Monograph volume 22. USA 2002.

Photo: Sara Eriksson

Experiences from natural analogues

- There are many extreme environments with highly specialised life forms and ecosystems, such as those surrounding deep sea gas vents.
- The marine ecosystem has been found to adapt to the environmental conditions in the vicinity of a gas vent
- There are natural sources of H_2S in the marine environment in many places → anoxic sulphide-containing sediments
- Marine ecosystems have evolved that are adapted to an environment with sulphide, and sulphur-oxidizing bacteria are common in the oceans. Presence of H_2S may result in a lowering of local dissolved oxygen levels (impact on organism respiration. (Source: IPCC special report)
- The effect of the gas leaks on the marine environment is very local - limited to the areas surrounding the vents

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Conclusions I

- We determine the quality of the captured gas stream
  - the composition is mainly dependent on the designed cleaning level
- CO_2 of high purity can be produced in theory – but at a very high cost
- Co-capture and storage of other components are associated with effects and costs - to be compared to the costs (economical and environmental) of processing and cleaning the CO_2 gas stream at the power plant.

Photo: Sara Eriksson

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Conclusions II

- CO_2 is the main gas stream component by far. In case of a leakage, CO_2 rather than the co-contaminants are expected to be the main environmental issue in case of a leakage.
- A site-specific assessment should form the basis for HSE requirements on gas quality
- Local environmental impacts resulting from a release of CO_2 depend on the nature of the release and the ambient conditions, rather than the amount of CO_2 released.

Photo: Sara Eriksson

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Conclusions III

- The best way to avoid a leakage and negative environmental consequences is to select a site that will not leak – should be focus
- Providing well-documented site knowledge and studies together with plans for monitoring and safety programmes is essential
- Technical aspects affects the design specifications (minimising corrosion, use for EOR applications, etc.)
- Since we are storing CO_2, it makes sense that CO_2 should be the limiting component from a HSE perspective – no single other substance should pose a greater risk.
- Technical and HSE issues that relate to the quality of the gas stream can all be managed through good process design, site-selection and project management.

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Thank you!

Sara Eriksson
Vattenfall Research and Development
sara.eriksson@vattenfall.com

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