



Value creation  
through **innovation**



## CCS – Capture Technology, Facilities, Process & Market issues

Oscar Fr. Graff, CTO

 **FORCE** - EOR Seminar

Stavanger, 7<sup>th</sup> November 2013

# Presentation - Highlights

- Background: Global warming, IEA outlook, EOR
- Technology overview:
  - Alternatives
  - Aker Solutions
- Aker Solutions activities (present & past):
  - R&D
  - Pilots
- Market today
  - Norway
  - Abroad
- TCM short movie
- Q&A

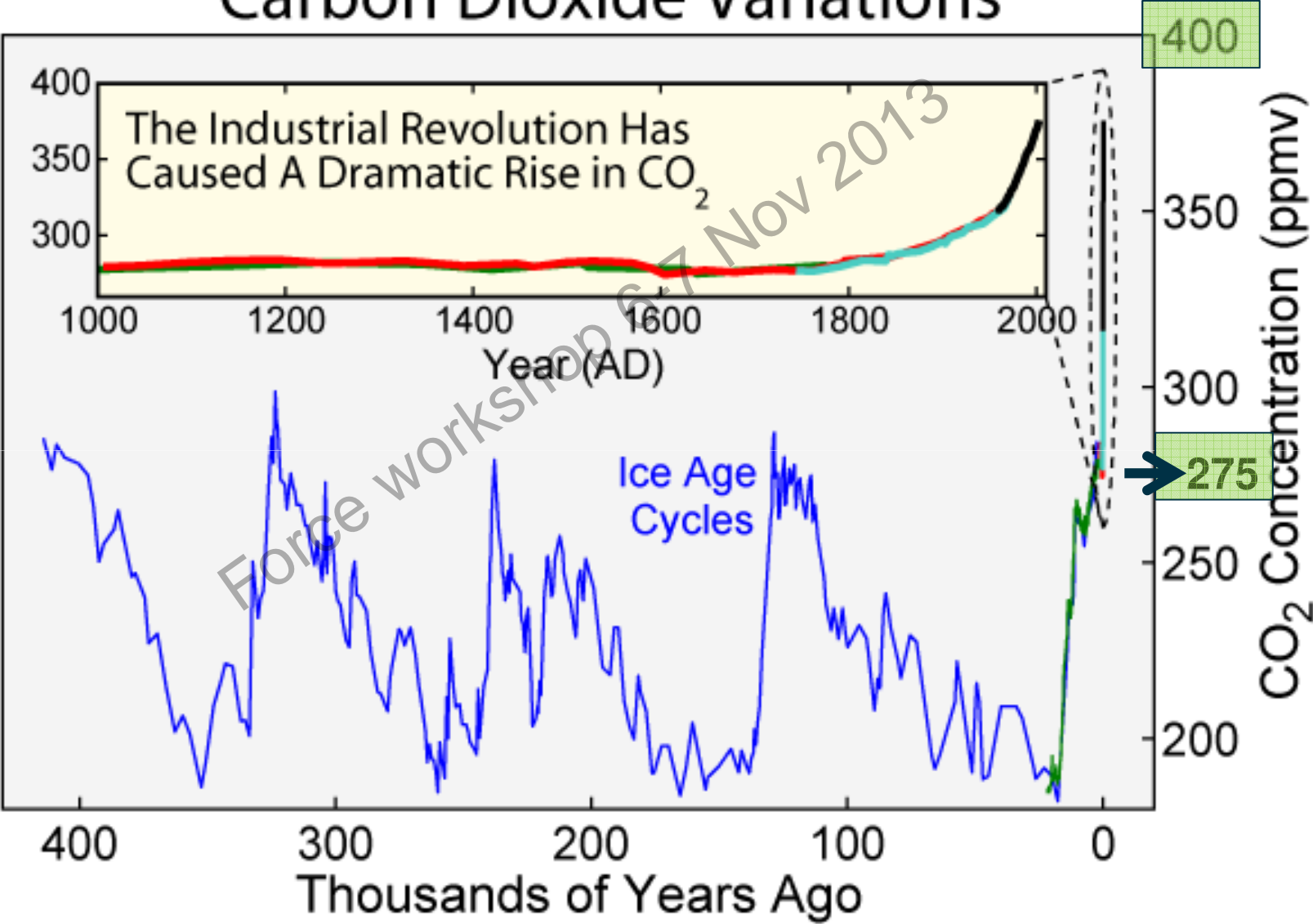
Force workshop 07 Nov 2013

# 400 ppm



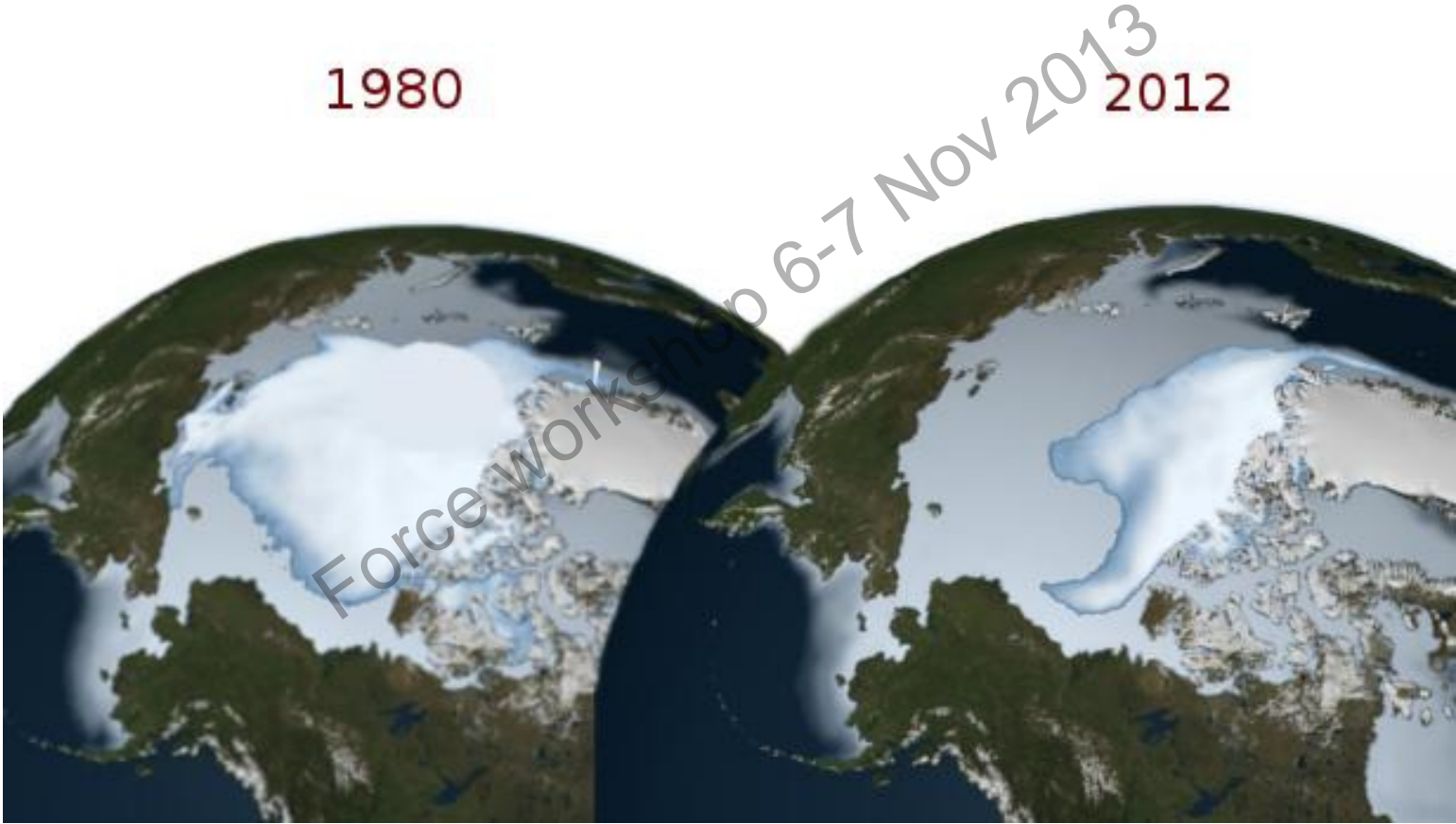
On May 9 this year, the daily mean concentration of carbon dioxide in the atmosphere of Mauna Loa, one of the volcanoes on the Big Island of Hawaii, surpassed 400 parts per million for the first time since measurements began in 1958, when CO<sub>2</sub> concentrations averaged 318 ppm.

# Carbon Dioxide Variations





# Ice melting - a visible indicator of global warming





# More extreme weather 1



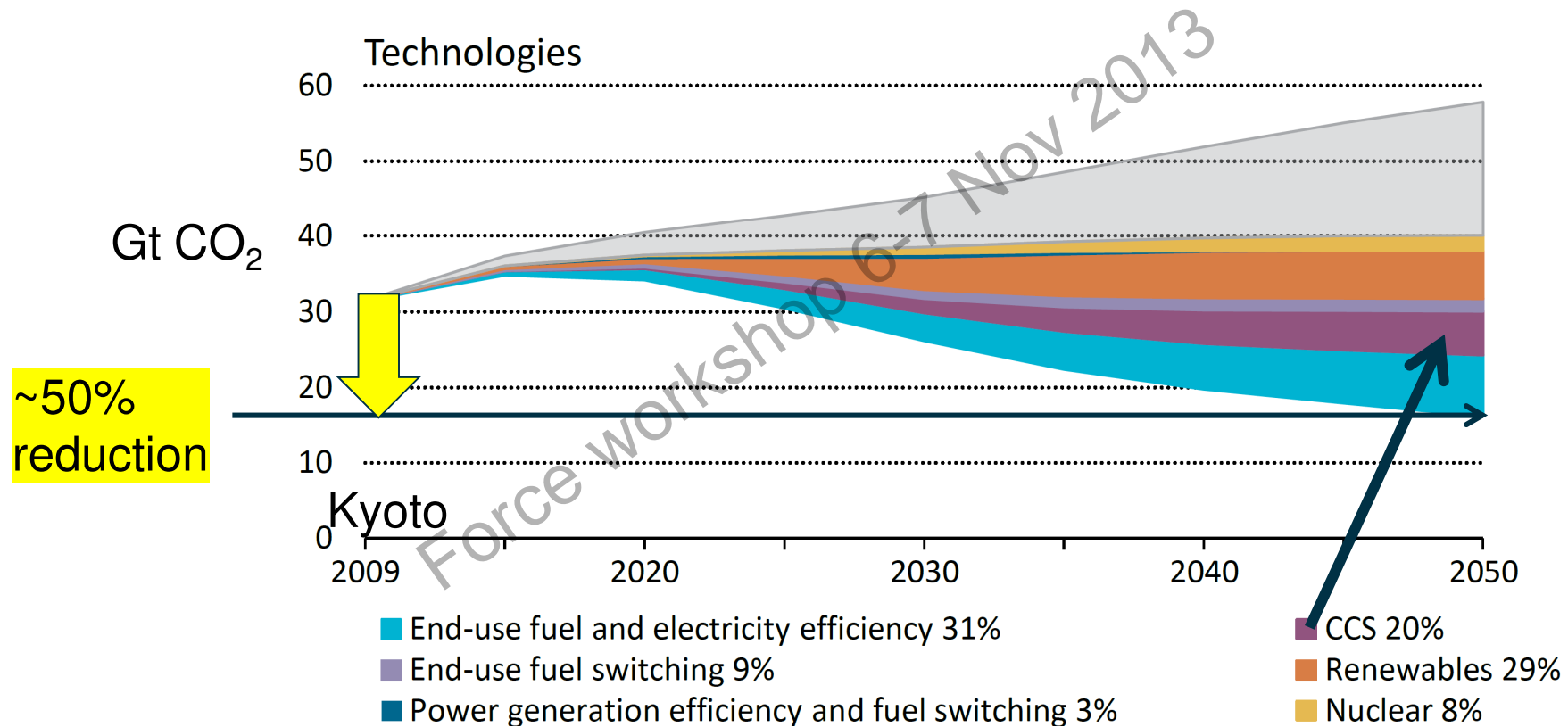


# More extreme weather 2



New term in Norwegian: “monster regn”

# To meet +2 °C in 2050, CCS can contribute with about 1/5 of the total required CO2 reductions (IEA)



**CCS= Carbon Capture and Storage**

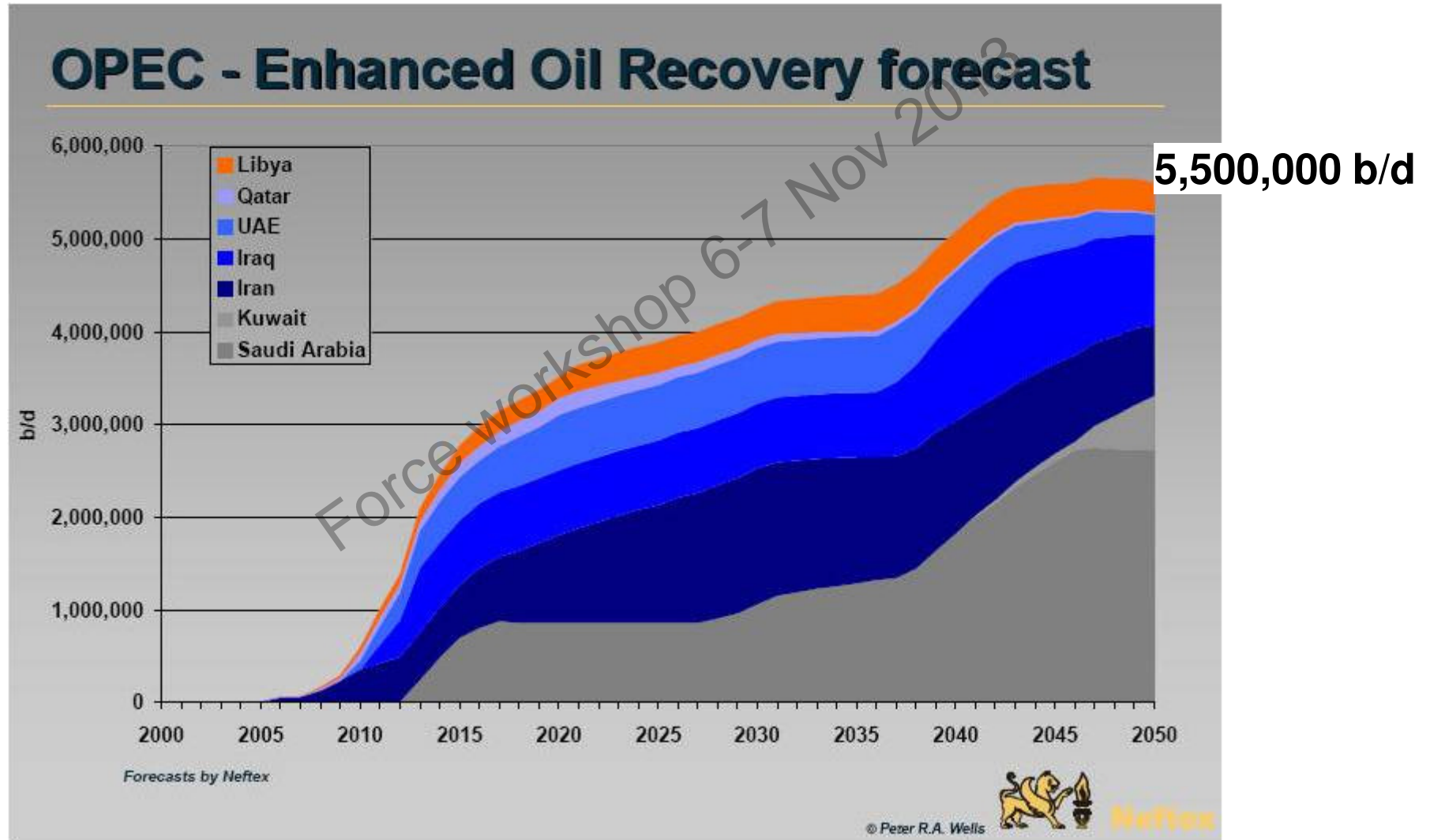
# Carbon Capture Journal: 12 EOR projects (in USA & Canada) out of 18 identified CCS projects globally

| State / District  | Country       | Volume CO <sub>2</sub>                | Operation Date | Facility Details       | Capture Type                    | Transport Length | Transport Type               | Storage Type                    | Project URL   |
|-------------------|---------------|---------------------------------------|----------------|------------------------|---------------------------------|------------------|------------------------------|---------------------------------|---|
| Texas             | UNITED STATES | 8.4 Mtpa                              | 2010           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 256 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.oxy.com/">http://www.oxy.com/</a>                               |
| Oklahoma          | UNITED STATES | 0.68 Mtpa                             | 1982           | Fertiliser Production  | Pre-Combustion                  | 225 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.kochfertilizer.com/">http://www.kochfertilizer.com/</a>         |
| Saskatchewan      | CANADA        | 3 Mtpa                                | 2000           | Synthetic Natural Gas  | Pre-Combustion                  | 315 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.oenovus.com/">http://www.oenovus.com/</a>                       |
| Wilaya de Ouargla | ALGERIA       | 1 Mtpa                                | 2004           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 14 km            | Onshore to onshore pipeline  | Onshore Deep Saline Formations  | <a href="http://www.insalahco2.com/">http://www.insalahco2.com/</a>                 |
| Wyoming           | UNITED STATES | 7 Mtpa                                | 1986           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 190 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.exxonmobil.com">http://www.exxonmobil.com</a>                   |
| North Sea         | NORWAY        | 1 Mtpa                                | 1996           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 0 km             | Direct injection             | Offshore Deep Saline Formations | <a href="http://www.statoil.com/en/">http://www.statoil.com/en/</a>                 |
| Barents Sea       | NORWAY        | 0.7 Mtpa                              | 2008           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 152 km           | Onshore to offshore pipeline | Offshore Deep Saline Formations | <a href="http://www.statoil.com/en/">http://www.statoil.com/en/</a>                 |
| Texas             | UNITED STATES | 1.3 Mtpa                              | 1972           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 132 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.exxonmobil.com/">http://www.exxonmobil.com/</a>                 |
| Texas             | UNITED STATES | 1 Mtpa                                | 2013           | Hydrogen Production    | Post-Combustion                 | 101 – 150 km     | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.airproducts.com/">http://www.airproducts.com/</a>               |
| Alberta           | CANADA        | Up to 0.59 Mtpa (initially 0.29 Mtpa) | 2014           | Fertiliser Production  | Pre-Combustion                  | 240 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.agrium.com/">http://www.agrium.com/</a>                         |
| Alberta           | CANADA        | 1.2 Mtpa                              | 2015           | Oil Refining           | Pre-Combustion                  | 240 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.northwestupgrading.com/">http://www.northwestupgrading.com/</a> |
| Saskatchewan      | CANADA        | 1 Mtpa                                | 2014           | Power Generation       | Post-Combustion                 | 100 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.saskpower.com/">http://www.saskpower.com/</a>                   |
| Western Australia | AUSTRALIA     | 3.4 - 4.1Mtpa                         | 2015           | Natural Gas Processing | Pre-Combustion (Gas Processing) | 7 km             | Onshore to onshore pipeline  | Onshore Deep Saline Formations  | <a href="http://www.chevronaustralia.com/">http://www.chevronaustralia.com/</a>     |
| Illinois          | UNITED STATES | 1 Mtpa                                | 2013           | Chemical Production    | Industrial Separation           | 1.6 km           | Onshore to onshore pipeline  | Onshore Deep Saline Formations  | <a href="http://www.adm.com/">http://www.adm.com/</a>                               |
| Mississippi       | UNITED STATES | 3.5 Mtpa                              | 2014           | Power Generation       | Pre-Combustion                  | 75 km            | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.mississippipower.com/">http://www.mississippipower.com/</a>     |
| Wyoming           | UNITED STATES | 1 Mtpa                                | 2013           | Natural Gas Processing | Pre-Combustion (Gas Processing) | Not specified    | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.oconocophillips.com/">http://www.oconocophillips.com/</a>       |
| Alberta           | CANADA        | 1.08 Mtpa                             | 2015           | Hydrogen Production    | Pre-Combustion                  | 84 km            | Onshore to onshore pipeline  | Onshore Deep Saline Formations  | <a href="http://www.shell.ca/">http://www.shell.ca/</a>                             |
| Kansas            | UNITED STATES | 0.85 Mtpa                             | 2013           | Fertiliser Production  | Pre-Combustion                  | 112 km           | Onshore to onshore pipeline  | Enhanced Oil Recovery           | <a href="http://www.cvrenergy.com/">http://www.cvrenergy.com/</a>                   |

Sleipner  
Snøhvit

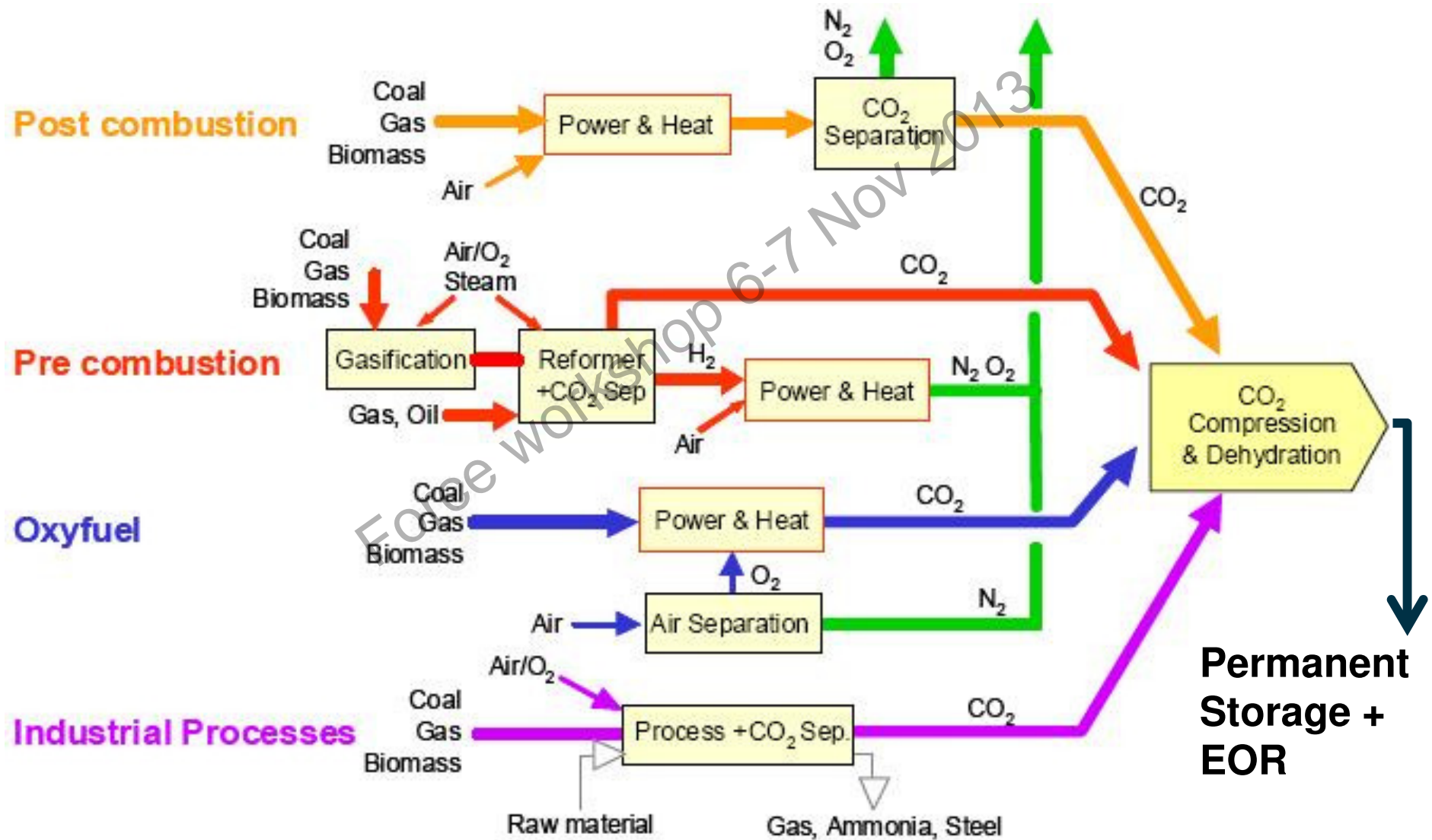
EOR is a commercial driver for CCS projects

# EOR – Potential in the Middle East





# Alternative processes for CC & CO2 production



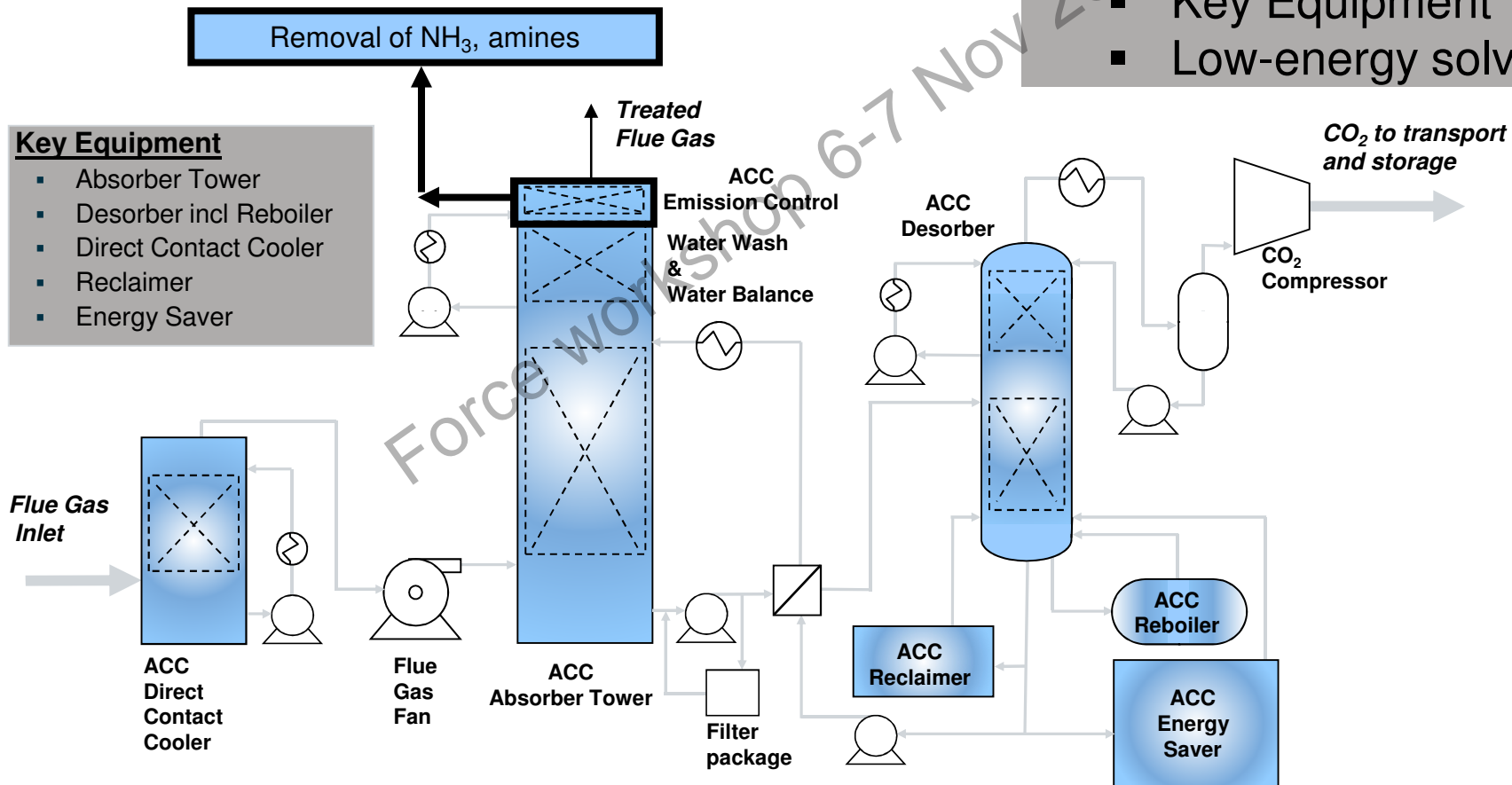
# Aker Solutions – Amine Post Combustion Process

Strategy:

Technology license and key equipment package

**Focus on improvements:**

- Key Equipment
- Low-energy solvents



- Key Equipment**
- Absorber Tower
  - Desorber incl Reboiler
  - Direct Contact Cooler
  - Reclaimer
  - Energy Saver

# Main differences between gas sweetening and CCS?

| Gas sweetening                        | CCS  |
|---------------------------------------|--|
| High pressure – low volumes           | Low pressure – large volumes                               |
| Compact equipment and piping          | Large equipment and piping/ducts                           |
| No oxygen – no oxidation              | High oxygen – high oxidation                               |
| Limited impurities and a. degradation | SO <sub>2</sub> , NO <sub>x</sub> , ashes = a. degradation |
| Limited pre-treatment of gas          | Pre-treatment required                                     |
| CO <sub>2</sub> at high pressure      | CO <sub>2</sub> at atmospheric pressure                    |
| Treated gas to consumer               | Treated gas to atmosphere                                  |

CO<sub>2</sub> content in flue gas (vol-%):

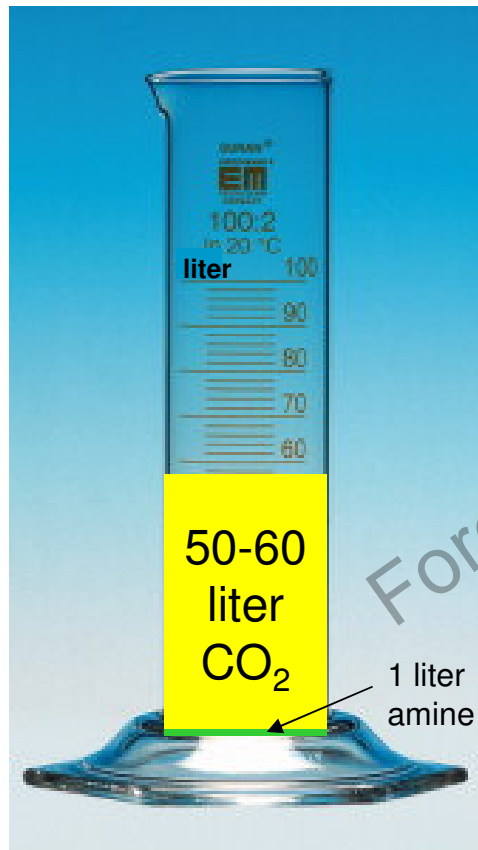
Gas power= 3

Coal power= 12-15

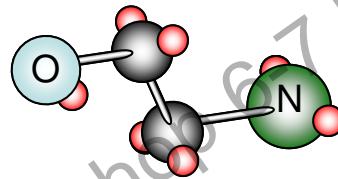
Cement industry= 20

# What is an amine?

## How much CO<sub>2</sub> can be absorbed in 1 liter amine solution?



It's a liquid normally diluted in water (30-50%)



Typical amine (MEA)  
Primary amine

### Typical properties of amines:

- high solubility in water
- capture large volumes of CO<sub>2</sub>
- CO<sub>2</sub> is released again by adding heat



# Aker Solutions partner in substantial R&D&Q programmes:

Total Projects = ~ €110M (~750 mill. NOK)

## Study & FEED



## CCS Coal



## TCM/CCM



### R&D Programmes:

- SOLVit
- BigCO2
- CASTOR
- Plastic Liner/Mat.
- Reclaiming
- BigCCS
- Emissions
- Cleo

### Technology Qualification:

- DNV (DNV-RP-A203)
- CCM Project

### Lab facilities:

- NTNU / SINTEF / IFE / Norner / NILU

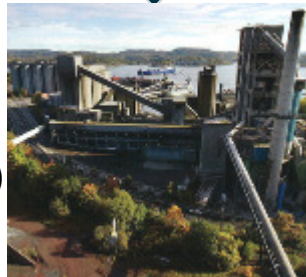
### Pilot Testing:

- Tiller Pilot, Trondheim
- Mobile Test Unit (MTU)
- EnBW in Heilbronn

## CCS Gas



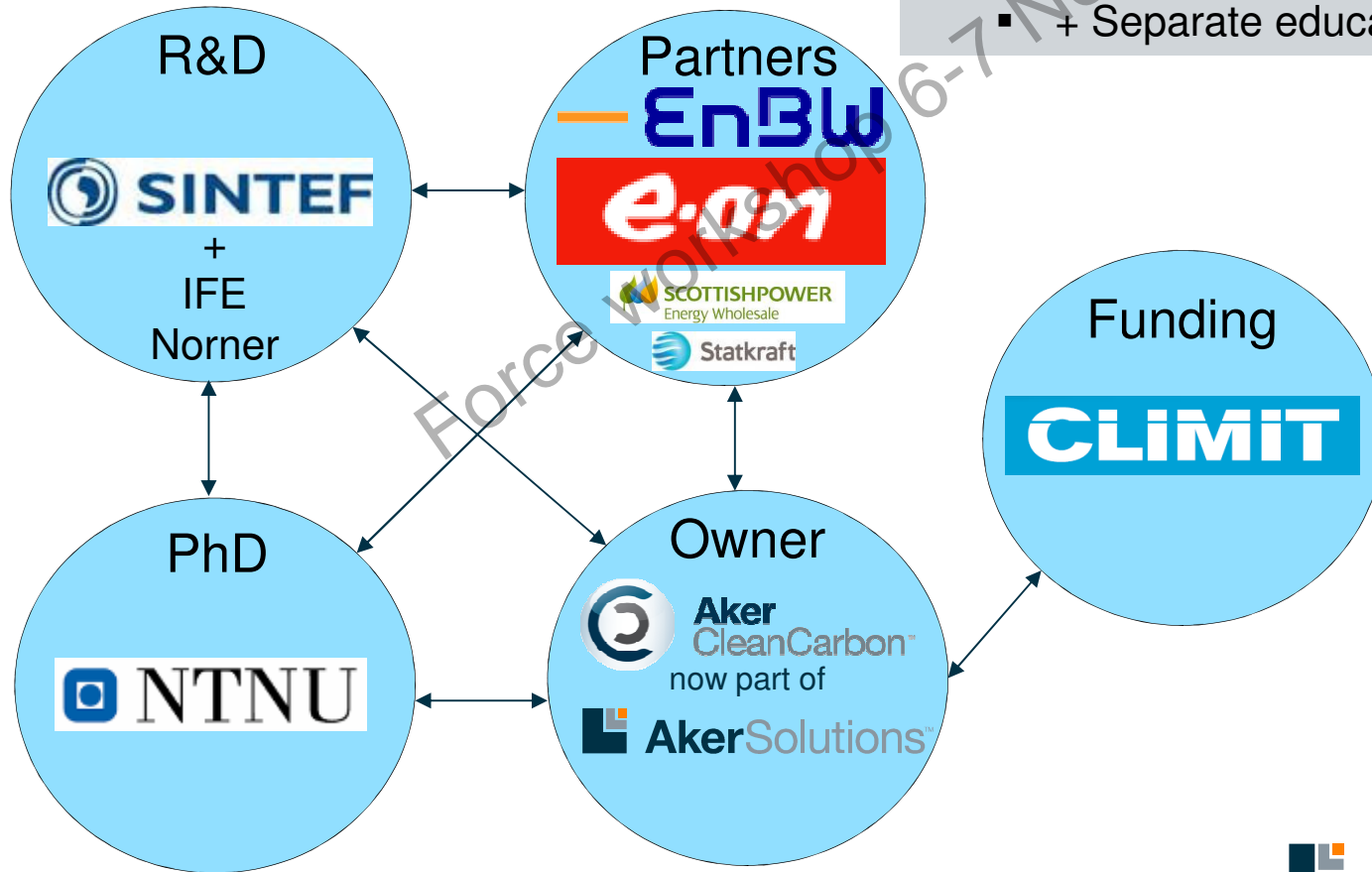
## Industrial emissions (cement, etc.)





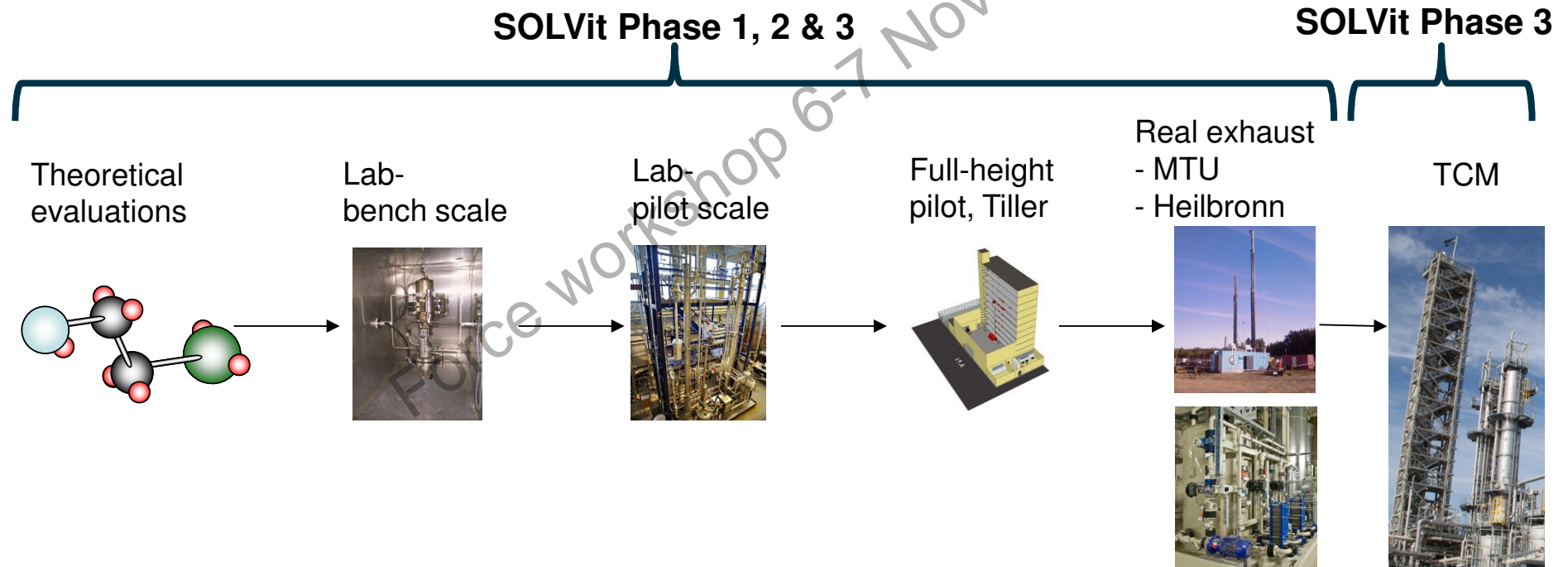
# SOLVit – Solvents for the next generation of post combustion CO<sub>2</sub> capture systems

- Unique European R&D Programme**
- 7 years programme (2008-2015)
  - Fundamental R&D
  - Extensive testing in pilots
  - Heavy industry involvement
  - 332 MNOK (phase 1,2 & 3)
  - + Separate educational programme



# SOLVit – main objectives

- Develop and demonstrate solvents with minimum energy consumption and lowest possible environmental impact. This is done step-wise and systematic:



Develop demonstration program to transfer experimental data to **cost-effective process and plant design**

# Trondheim: Two test pilots for SOLVit



Gløshaugen Pilot



## Tiller R&D Pilot Established in SOLVit

- Official opening: 29. April 2010
- Flue gas: from propane burner
- CO<sub>2</sub> content: 2-14 vol%
- Absorber diameter: 0.2 m
- Extensive monitoring
- Access via 11 floors
- Laboratory facilities
- Several SOLVit campaigns

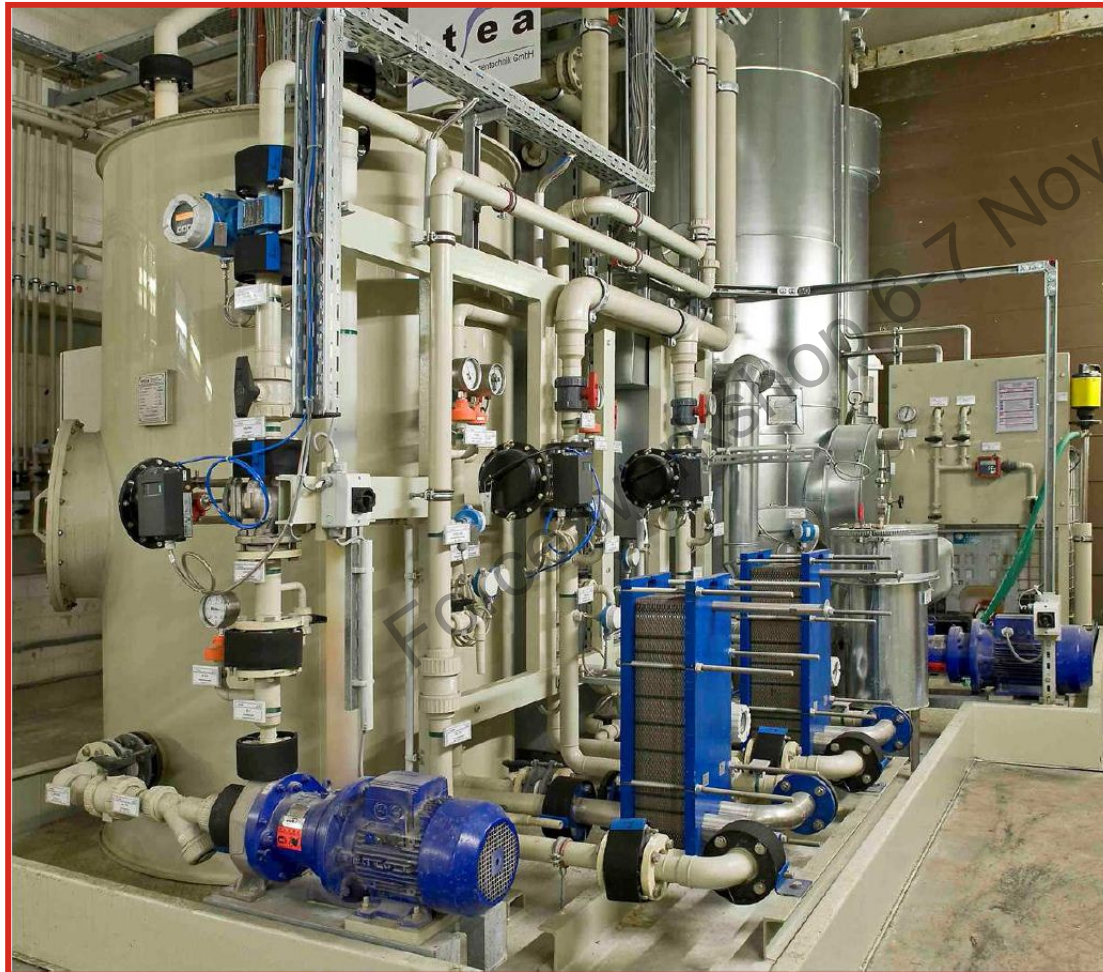


Tiller Pilot



# Several test campaigns at EnBW's pilot plant in Heilbronn, Germany

## Part of SOLVit Phase 2 & 3 testing

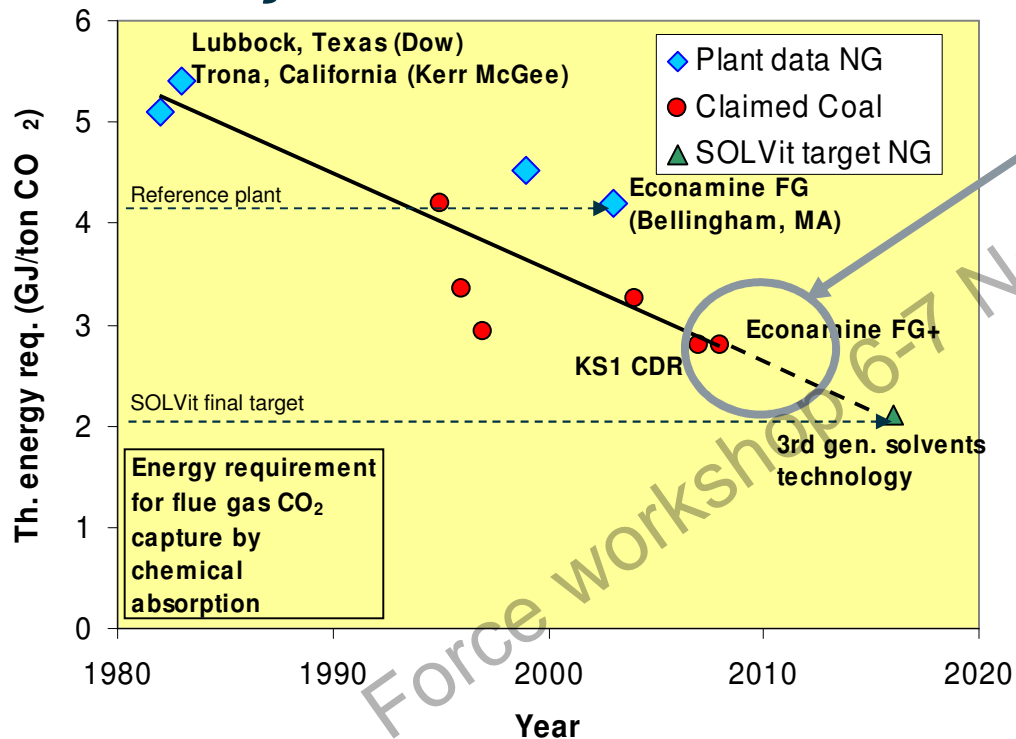


- Official opening: July 2011
- Flue gas: from coal/biomass
- CO<sub>2</sub> content: 13 vol%
- Absorber diameter: 0.6 m
- Absorber height: 37 m
- Extensive monitoring
- Extensive use of PP
- Access via several floors
- Several campaigns - SOLVit



# SOLVit - Sintef & Aker Solutions

## - Summary & Achievements



### SOLVit Phase 1 & 2 results:

#### MTU test results

- Screening of about 80 blends
  - Identified 45 degradation prod.
  - Seven emission campaigns
  - Five reclaiming campaigns
  - “Green solvents”
  - Selected 3<sup>rd</sup> generation system
  - Approx. 35% energy reduction
- +
- 5 PhD's at NTNU (part of ed.)

### SOLVit Phase 1 & 2 (2008-2013): 56 mth's

#### Main Target:

- 35 % reduction in energy consumption
- Minimum HSE impact

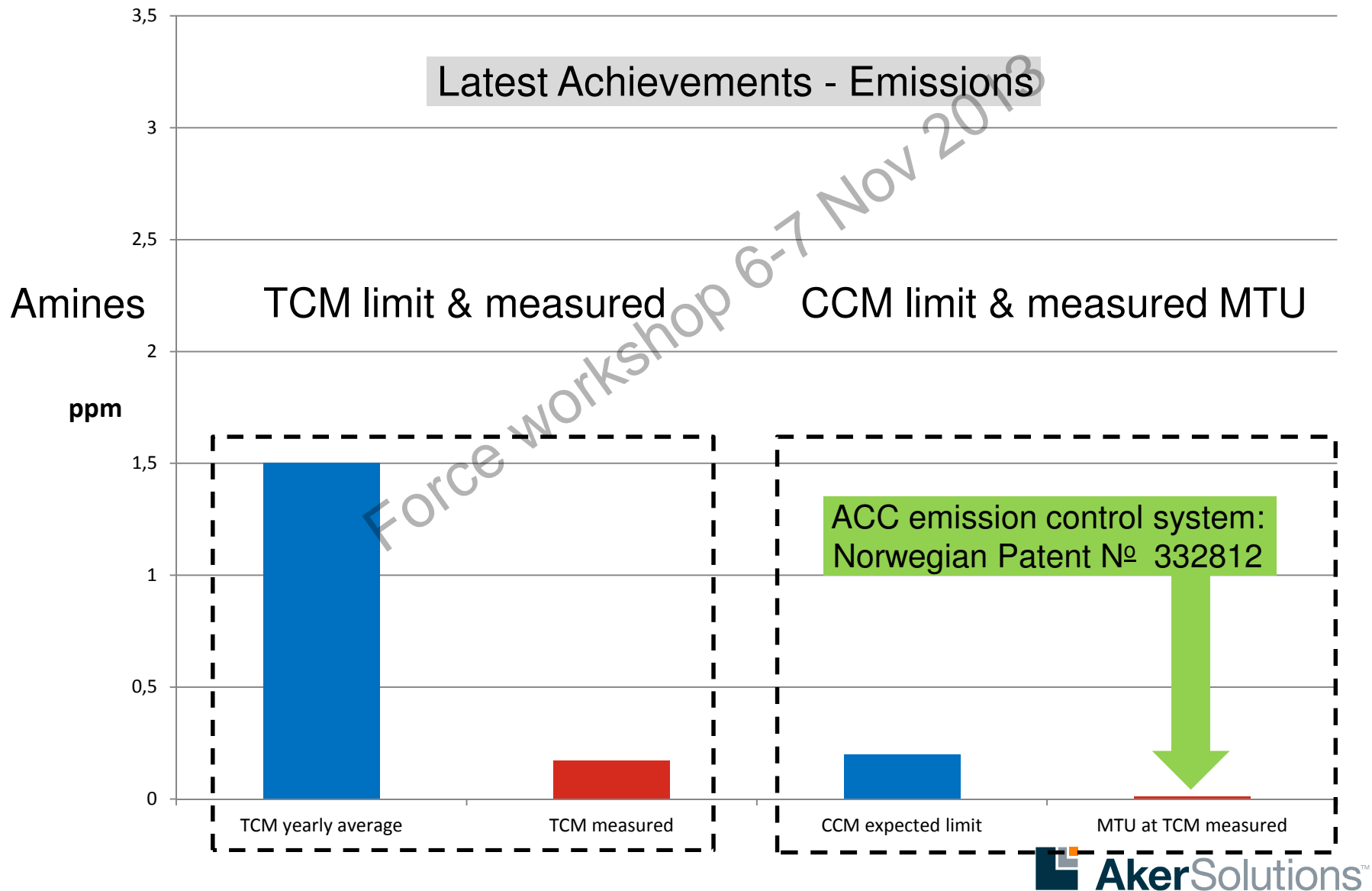
### SOLVit Phase 3 (2013-2015): 27 mth's

#### Main Targets:

- 50 % reduction in energy consumption
- Demonstrate 3<sup>rd</sup> generation system



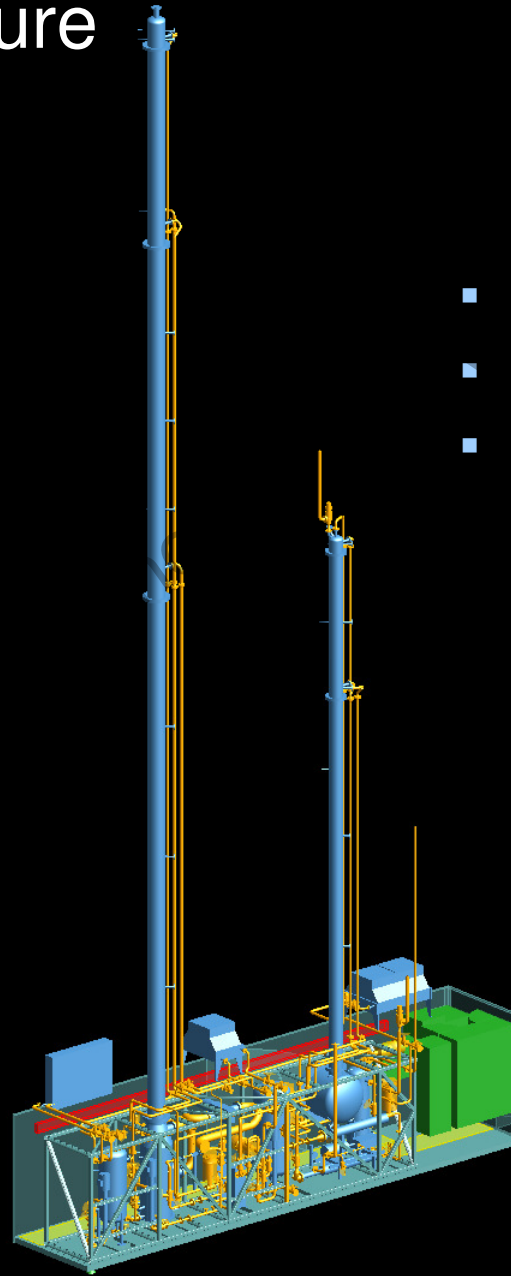
# Aker Solutions has measured extremely low amine emissions at TCM - ACC's innovative emission control system





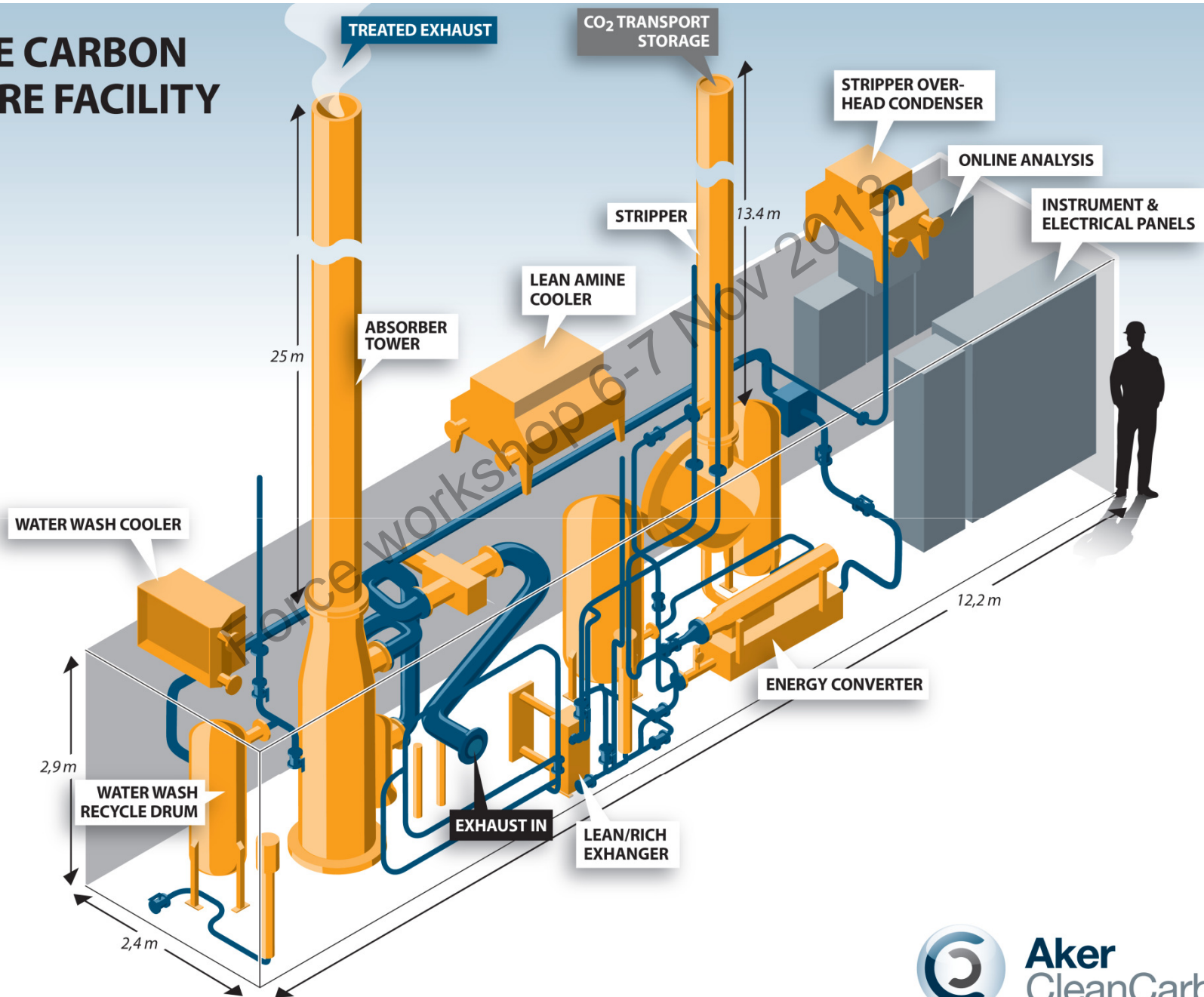
# Mobile Carbon Capture Facility

- Safe operation
- Easy transport & h-up
- Standard container
- Lorry & ship transport
- Industrial flue gases
- Amine flexibility
- Verify design data
- Verify solvent
- Long term testing
- Easy modifications
- Extensive monitoring & analysis



- L= 40 ft, H= 2.6 m
- Weight= 22 tonnes
- Capacities:
  - Flue Gas: 1000 Am<sup>3</sup>/h
  - CO<sub>2</sub> capture:
    - Coal Power: 180 kg/h
    - Gas Power: 60 kg/h
    - Composition: 3 -14 %
    - Rate: ~ 85 – 90 %

# MOBILE CARBON CAPTURE FACILITY

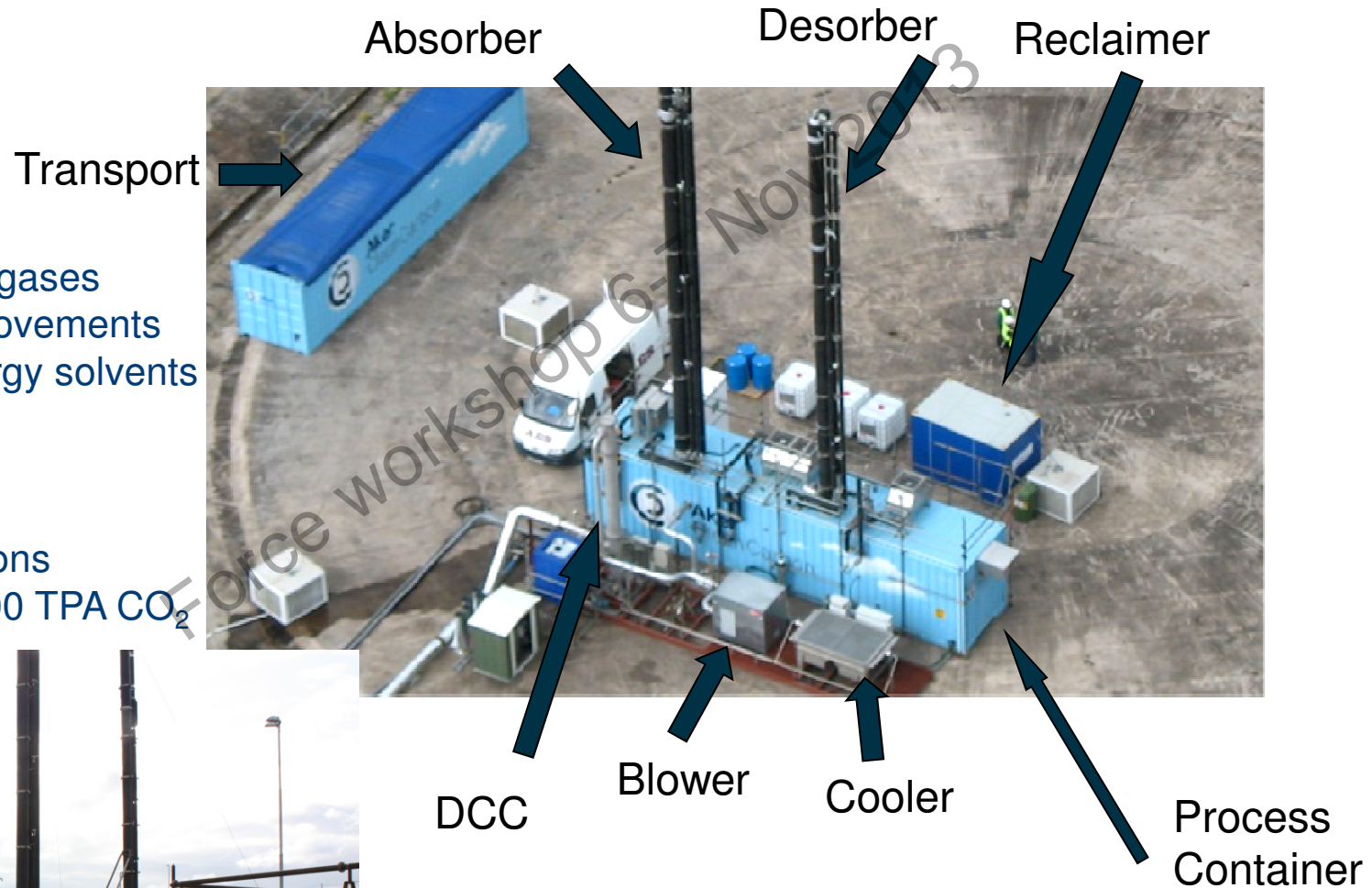


Testing with clients actual flue gas at their site

## MTU – Mobile Test Unit – a complete capture plant in 2008

### MTU:

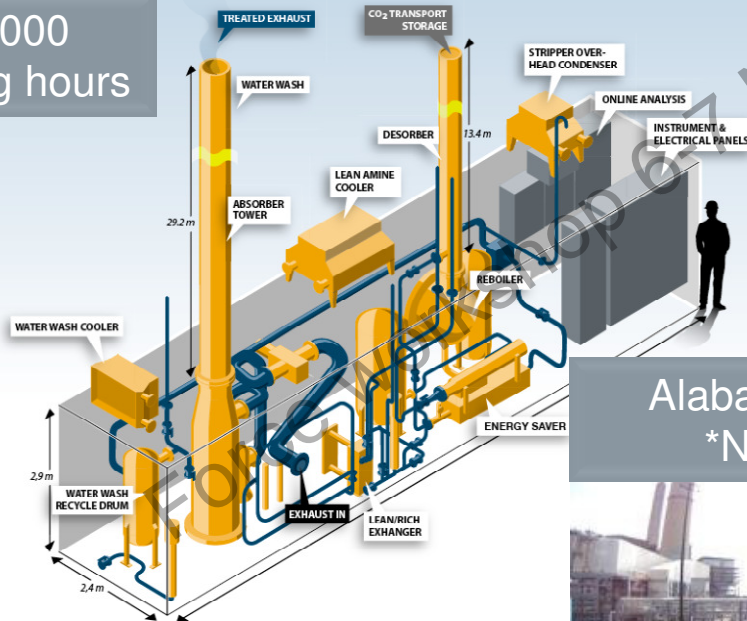
- Different flue gases
- Process improvements
- New low-energy solvents
- Reclaiming
- Degradation
- Corrosion
- LCC evaluations
- Capacity: 2000 TPA CO<sub>2</sub>



# MTU, Mobile Test Unit - Advanced CO<sub>2</sub> capture pilot

## Test campaigns in industrial environment since 2008

Over 15 000  
operating hours



Alabama, US  
\*NCCC

MTU in operation at  
Longannet Power Plant

2009



ACC 1<sup>st</sup> in UK

Picture: Scottish Power

Risavika & TCM  
2008 Norway 2012



ACC 1<sup>st</sup> at NCCC

\* NCCC: National Carbon Capture Centre

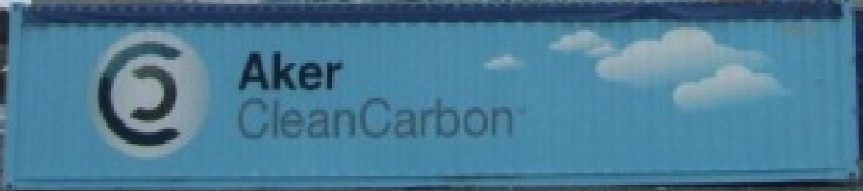


# SOLVit: Strong HSE focus: 7 emission campaigns

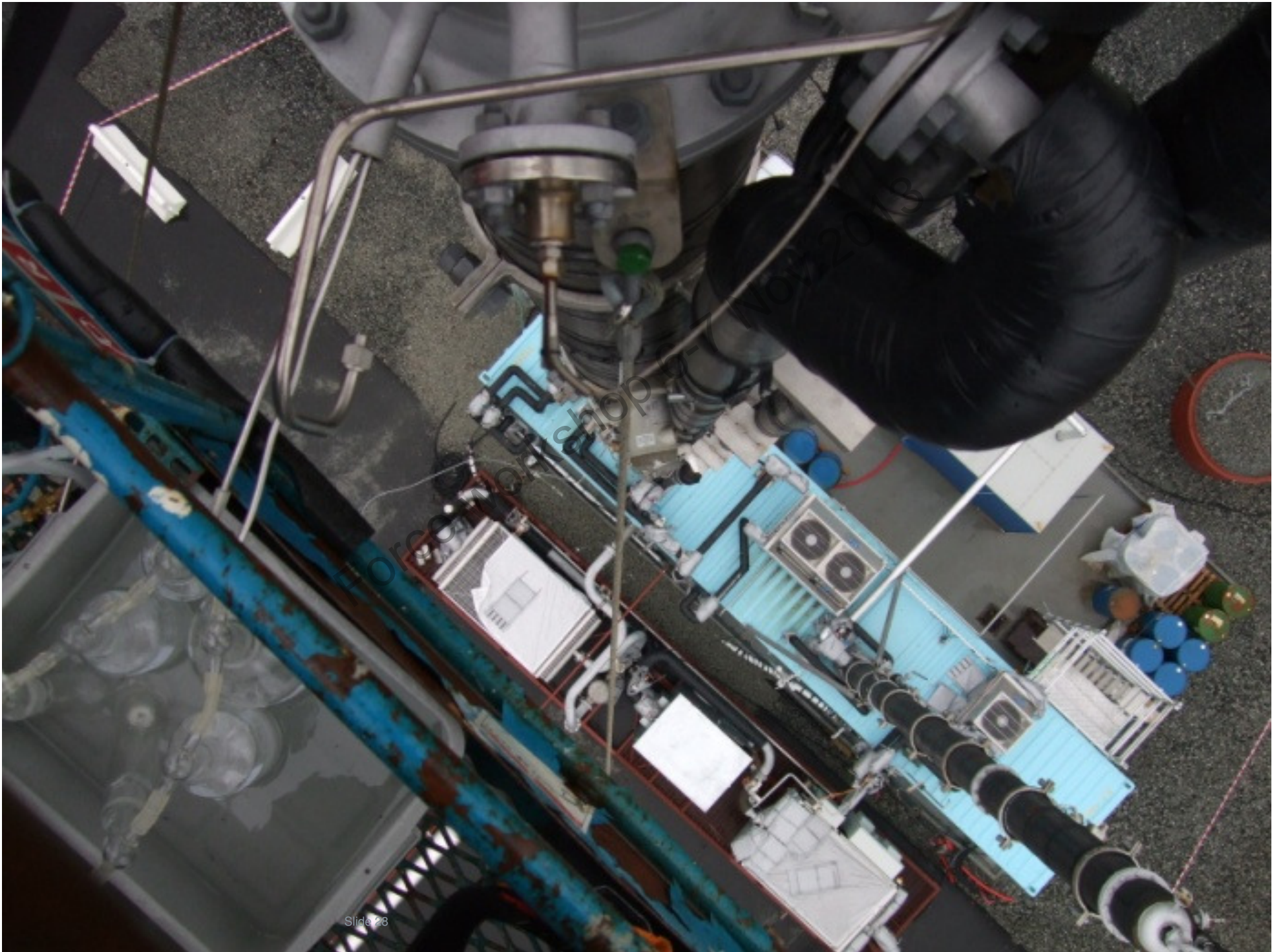
30 m



Tests in Valencia



1<sup>st</sup> Emission Campaign at Risavika March 2009





## Flexible amine plant (start up August 2012) **CO<sub>2</sub> Technology Centre Mongstad – TCM**

- ACC has designed and built the world's most advanced CO<sub>2</sub> amine capture plant
- Mechanical Complete July 2011
- ACC actively involved in commissioning, start-up and performance test
- ACC shall test proprietary amines during 15 month's
- ACC shall test in MTU in parallel



### **Owners TCM DA:**

- Gassnova
- Statoil
- Sasol
- Shell

# CO<sub>2</sub> Technology Center Mongstad – amine plant

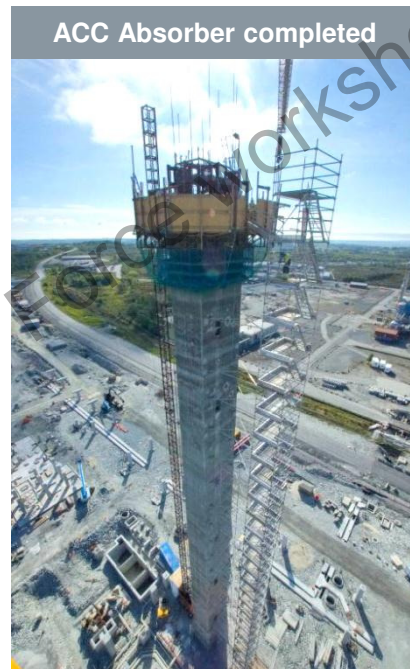
## Construction method

### Construction of ACC Absorber Tower:

- Completed in 20 days
- 3.5 x 2 x 62 m
- Concrete w/liner (new liner with Norner)
- Slip-form construction

### Plant construction method:

- Modularization of Pre-Assembled Units (PAU) and prefabrication
- Construction of auxiliary and piperack (PAR) at Kvaerner Stord, transport to Mongstad and installed



**Delivered on time!**

 **Aker Solutions™**



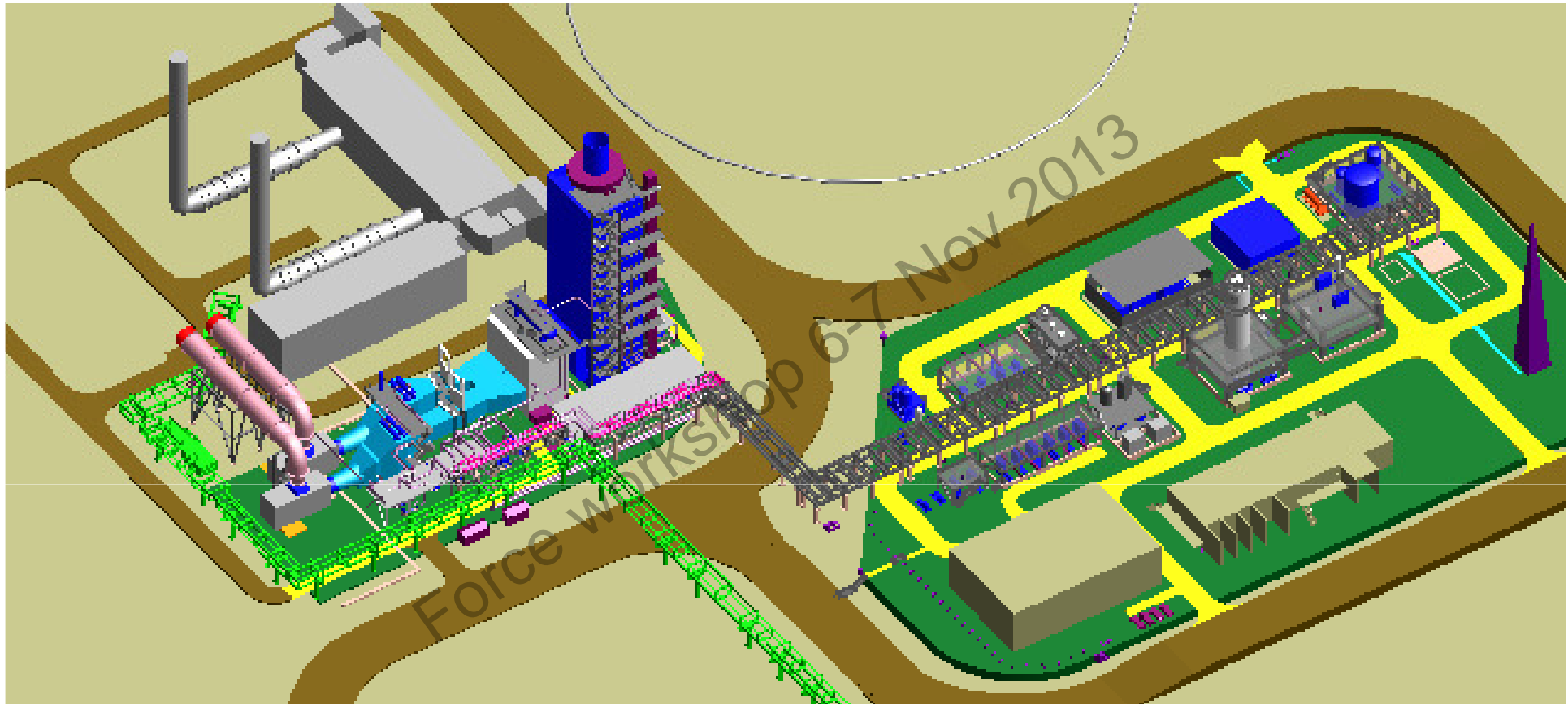








# Carbon Capture Mongstad Project – CCM



- Gas fired CHP plant – 3.3 vol. % of CO<sub>2</sub>
- Full-scale capture, transport and storage of 1.2 M TPA CO<sub>2</sub>
- Aker Solutions involved in several Technology Qualification Programmes and Conceptual Engineering
- About 50 engineers have been engaged





# Norway has been a front runner within CCS for over 20 years

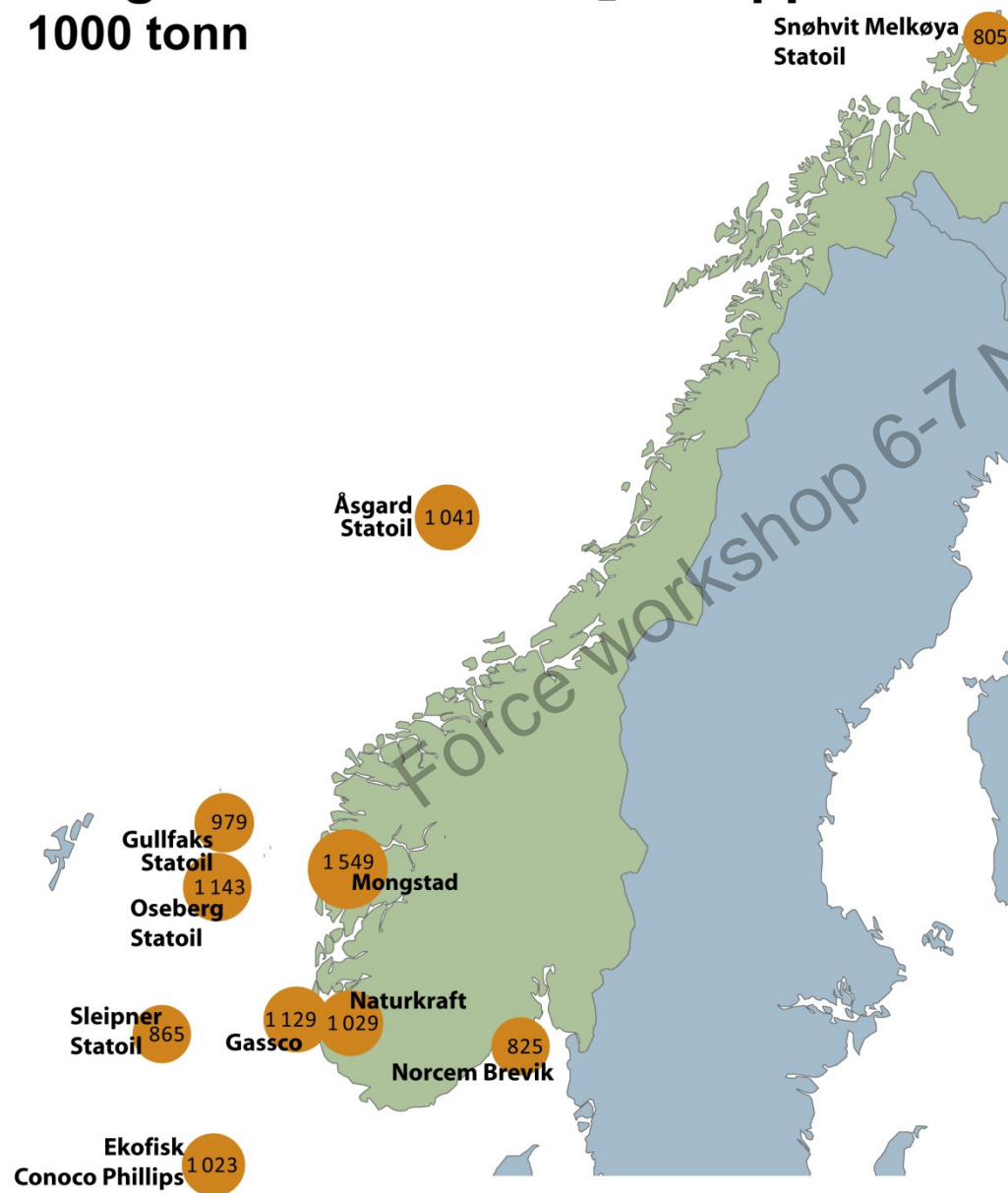
- CO2 tax (1991)
- CO2 injection at Sleipner (1996)
- Klimatek, R&D programme, Forskningsrådet (1997)
- CLIMIT, R&D, projects & 40 PhD (2005)
- Gassnova, pilot & demo (2005)
- Mongstaagreement (2006):
  - Stage 1: Technology Centre (TCM)
  - Stage 2: Full-scale demo (CCM)
- Aker Clean Carbon AS, ACC (2007), now Aker Solutions
- Mobilt Test Unit (MTU), Aker Solutions (2008)
- Tiller R&D pilot, SINTEF (2010)
- Opening TCM (2012):
  - Amin plant (Aker Solutions)
  - Chilled ammonia (Alstom)
- Developed considerable CCS competence in Norway; capture and storage

20.09.2013: Termination of Mongstad full-scale plant (stage 2)

Klimaforliket in Stortinget: Full-scale CCS within 2020

# Norges 10 største CO<sub>2</sub>-utslipp i 2009

1000 tonn



9 of the 10 largest emissions are related to our O&G activities

Kilde: Klima- og forurensningsdirektoratet, 2010

# CCS prospects in Norway 2013

| Longyearbyen               | +                 | ÷                     |
|----------------------------|-------------------|-----------------------|
| 0,05 Mt/år                 | Kraftforsyning    | Liten global effekt   |
| Nytt moderne kullkraftverk | Lokal miljøeffekt | Størrelse: 50% av TCM |
|                            | FoU (UNIS)        |                       |
|                            | CCS kjeden        |                       |
|                            | Landbrønner       |                       |



| Hammerfest E              | +              | ÷            |
|---------------------------|----------------|--------------|
| 1,1 Mt/år                 | Kraftforsyning | Nytt utslipp |
| Nytt 450 MW gasskraftverk | Snøhvit lager? |              |

| IKM                       | +              | ÷            |
|---------------------------|----------------|--------------|
| 0,75 Mt/år                | Kraftforsyning | Nytt utslipp |
| Nytt 250 MW gasskraftverk |                |              |

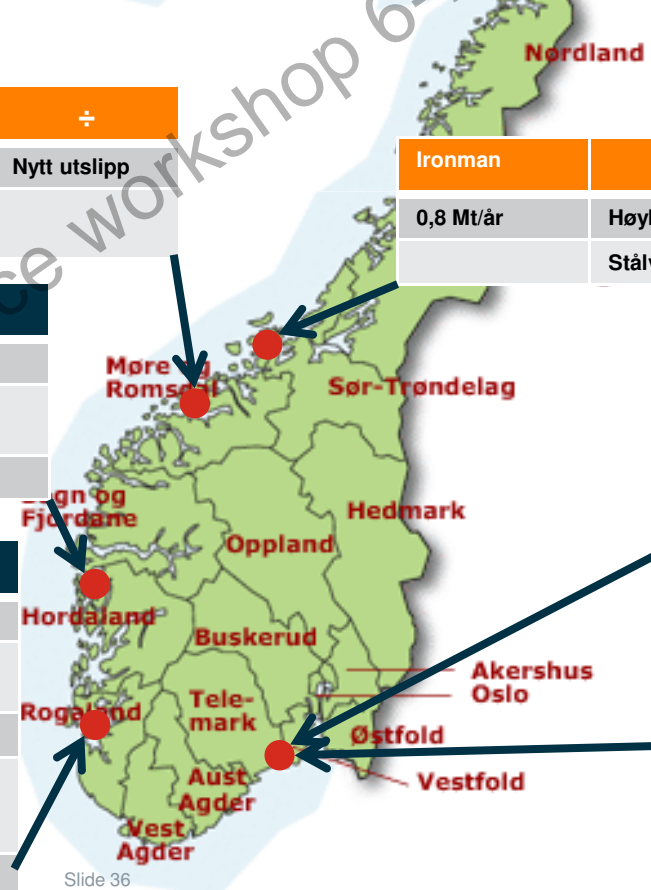
| Ironman   | +            | ÷            |
|-----------|--------------|--------------|
| 0,8 Mt/år | Høykons. CO2 | Nytt utslipp |
|           | Stålverk     |              |

| Mongstad         | +             | ÷          |
|------------------|---------------|------------|
| 2,2 Mt/år        | Stort utslipp | Komplisert |
| Raffineri og CHP | TCM           |            |
|                  | Restvarme     |            |

| Yara      | +             | ÷                 |
|-----------|---------------|-------------------|
| 0,8 Mt/år | Høy CO2 kons. | Lager & transport |
| Gjødsel   |               |                   |

| Kårstø                    | +   | ÷               |
|---------------------------|---|-----------------|
| 2,5 Mt/år                 | Stort utslipp                               | Drift gasskraft |
| Terminal og gasskraftverk | Eksisterende gasskraftverk                  |                 |
|                           | Gassterminal                                |                 |
|                           | Elektrifisering Utsirahøyden + Hydro Karmøy |                 |
|                           | Mulig EOR                                   |                 |

| Norcem    | +             | ÷                  |
|-----------|---------------|--------------------|
| 0,9 Mt/år | Høy CO2 kons. | Lager og transport |
| Sement    | Noe restvarme |                    |



## Norway - Norcem Industrial client - Cement plant

Scope: CO<sub>2</sub> capture for Cement plant  
– **first time world wide**

Long term relationship with Norcem:

- Cooperation agreement in 2011
- Concept study and a Pre-engineering Study in 2012
- Contract for long term use of ACC MTU at Brevik from 2013 to 2014, incl. solvent development program
- Supported by the European Cement Research Academy (ECRA) and Climit
- ECRA members (40 cement companies in Europe) have chosen Norcem Brevik as its site for CO<sub>2</sub> capture test projects.

**NORCEM**  
HEIDELBERGCEMENT Group



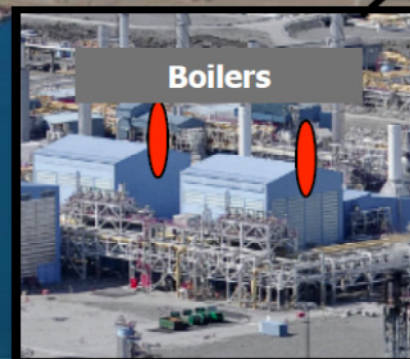
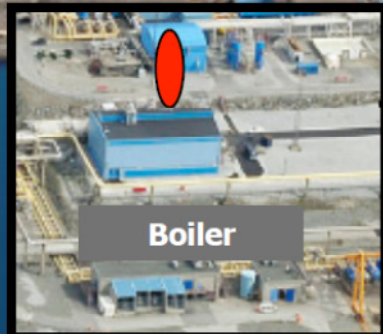
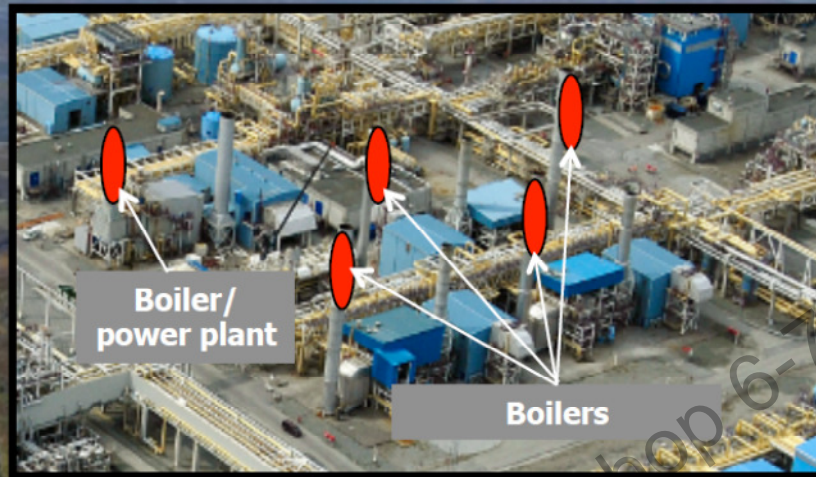
# Svalbard CCS

- Gassnova is asked by the parliament to investigate CCS at Svalbard.
- The existing coal fired power station is more than 30 years old, is unreliable and has too high emissions of soot, NOx and SOx
- The proposed activities will have a positive effect for Svalbard and the Norwegian CCS industry.
- Aker Solutions has been involved in the early evaluations.
- The size of the capture plant will be similar to TCM





# Kårstø gas terminal



Emission sources

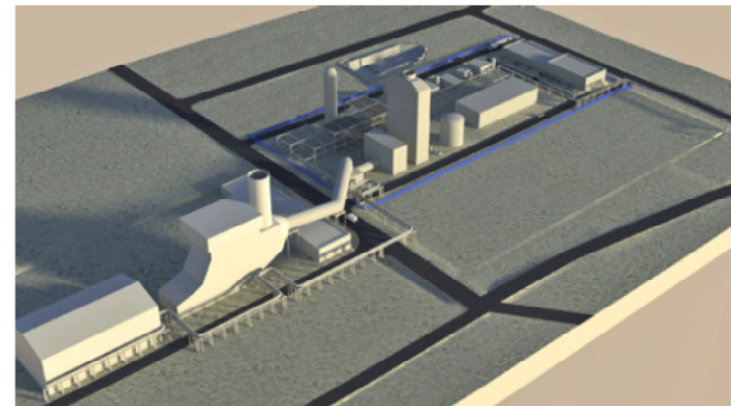
Total emissions: ~2.5 MT CO<sub>2</sub>/year

## The Kårstø full scale CCS project (2010)

- Capture of ~1,1 Mtonnes CO<sub>2</sub>/year\*
  - From Naturkraft gas fired power plant (~430 MW)
  - Post-combustion amine based capture process
- Pipeline transport to the Norwegian Continental Shelf for subsea storage
  - 240 km 12" pipeline
  - Geological storage in the Utsira formation, in the vicinity of the Draupner platform
- Project technically matured for an investment decision
  - Procurement process put on hold, due to uncertainties related to the operating pattern of the gas fired power plant
- CAPEX for capture, transport and storage ~10,4 BNOK



Transport and storage solution for the Kårstø CCS project



Example; gas fired power plant and CO<sub>2</sub> capture plant  
Source: [www.gassnova.no](http://www.gassnova.no)

[www.gassco.no](http://www.gassco.no)



\*: Assuming 8000 hrs annual operation



# 1<sup>st</sup> Full-scale CCS plant in the world. Coal power plant & EOR, Boundary Dam, Canada

## SaskPower Integrated CCS Demonstration Project SNC-Lavalin Scope and Status

### Project Status:

- Carbon Capture Plant FEED completed in 2009 (Competitive FEEDs)
- Start of detailed design: February 2010
- Start of construction : May 2011
- Mechanical completion: July 2013
- Hot commissioning and start-up completion: December, 2013
- Commercial operation: Q1, 2014



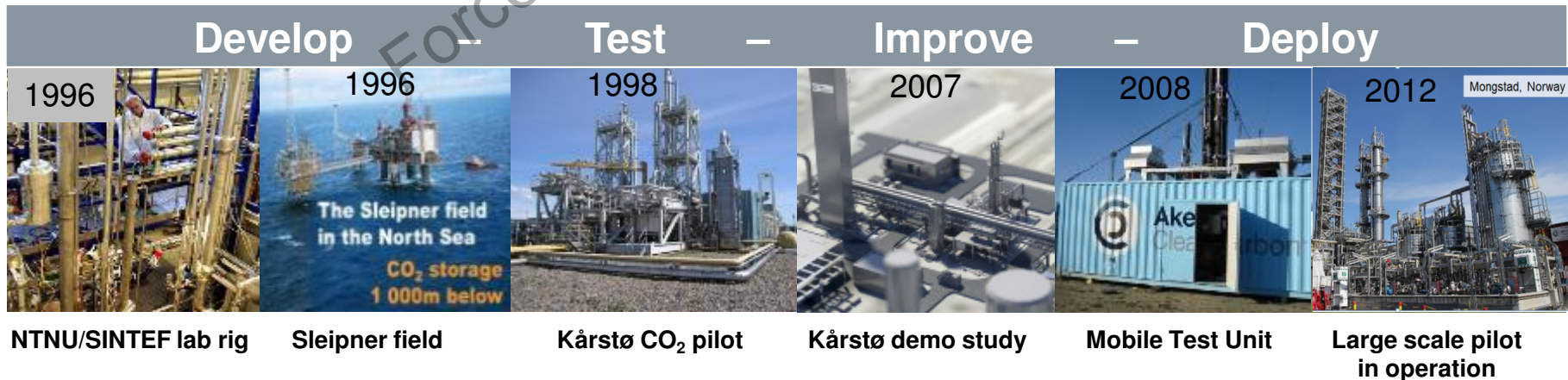
# Aker Solutions

***A global supplier of cost-effective CO<sub>2</sub> capture plants and technology***

**Ownership:** Aker Solutions (100%)

**Office:** Oslo, Norway

- A focused technology development
  - 20 years of CCS know-how and experience acquired via Aker projects
  - Core competence within flue gas treatment and CO<sub>2</sub> capture
  - Invested €50M in technology, leading one of the largest R&D programmes in Europe (SOLVit)
  - Operating a unique, advanced mobile test unit (MTU), engaged in several CCS projects.
  - 25 persons in ACC and about 300 employees in Aker have been engaged in CCS
  - License with delivery of key equipment
- Aker Solutions' step by step business approach:





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