In Salah CO_2 Storage Project: Monitoring Experience

Allan Mathieson JIP Programme Manager

CGS Conference – Ankara, Turkey, 14 June 2012

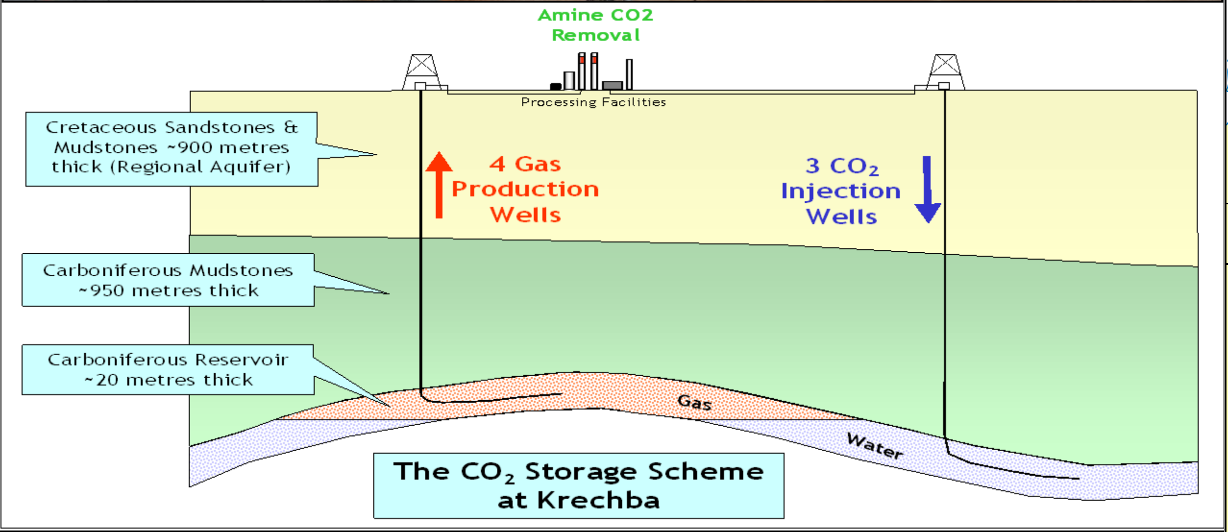
Agenda

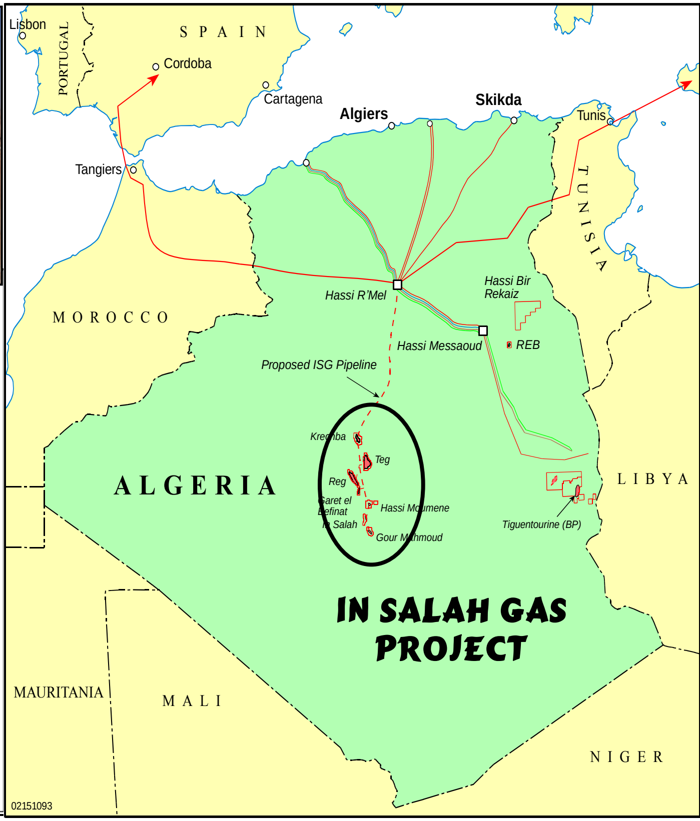
- **In Salah CCS: Context & Overview**

- **In Salah JIP Phase 1 Lessons:**
  1. **Site Selection**
  2. **Project Boundaries and Accounting**
  3. **Monitoring**
  4. **Risk Assessment**
  5. **Informing Regulation**

- **Summary & Discussion**

In Salah CCS Project: Overview





PROJECT SUMMARY

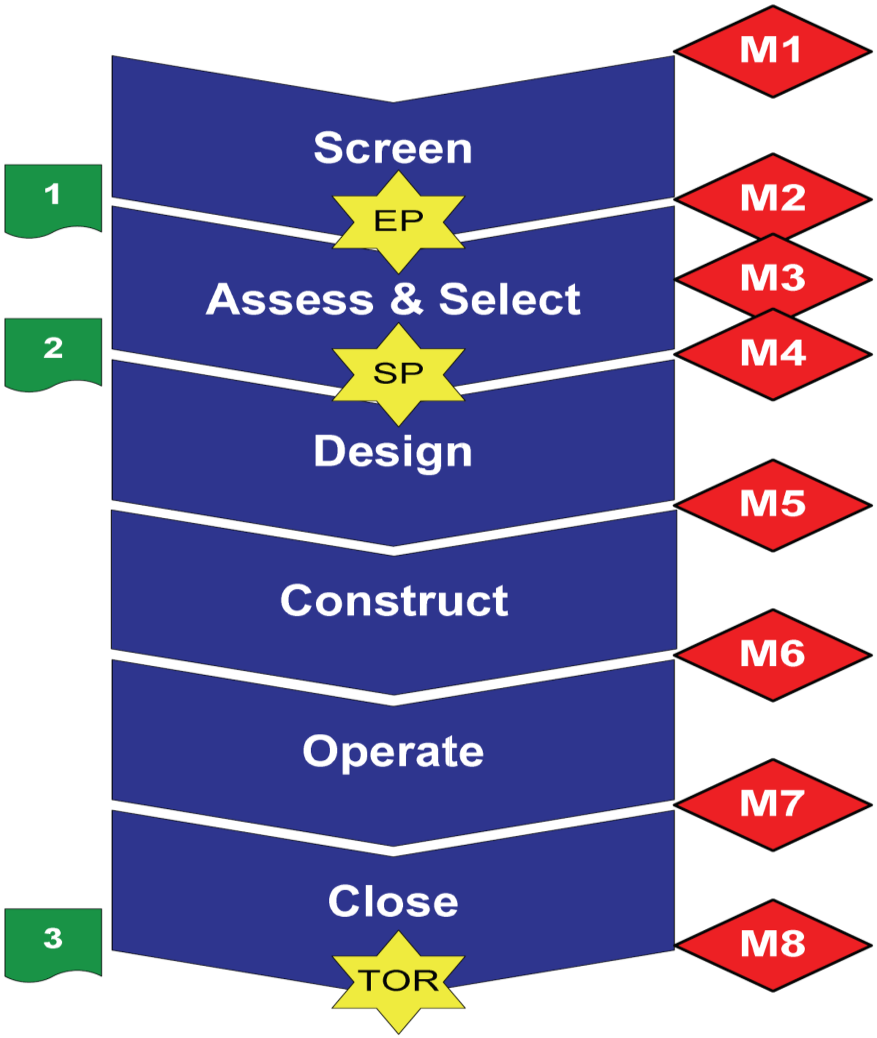
- Industrial Scale Demonstration of CO_2 Geological Storage (Conventional Capture)
- Storage Formation is common in Europe, USA & China
- Started Storage in August 2004 at 1mmtpa. 3.86 mmt CO_2 stored at end 2011
- $100mm Incremental Cost for Storage. No commercial benefit
- Test-bed for CO_2 Monitoring Technologies: $30mm Research Project

Agenda

- In Salah CCS: Context & Overview
- In Salah JIP Phase 1 Lessons:
  1. Site Selection
  2. Project Boundaries and Accounting
  3. Monitoring
  4. Risk Assessment
  5. Informing Regulation
- Summary & Discussion

Risk-Management Process (EU CCS Directive)

In Salah Gas
Stockage de CO_2



Milestones

1) Begin site screening
2) Shortlist storage sites
3) Select site & engineering concept
4) Storage permit application
5) Initiate construction
6) Initiate CO_2 injection
7) Qualify for site closure
8) Initiate decommisioning

Qualification Statements

1) Statement of storage feasibility
2) Certificate of fitness for storage
3) Certificate of fitness for closure

Permits issued by Regulator

EP – Exploration Permit
SP – CO_2 Storage Permit
TOR – Transfer of Responsibility

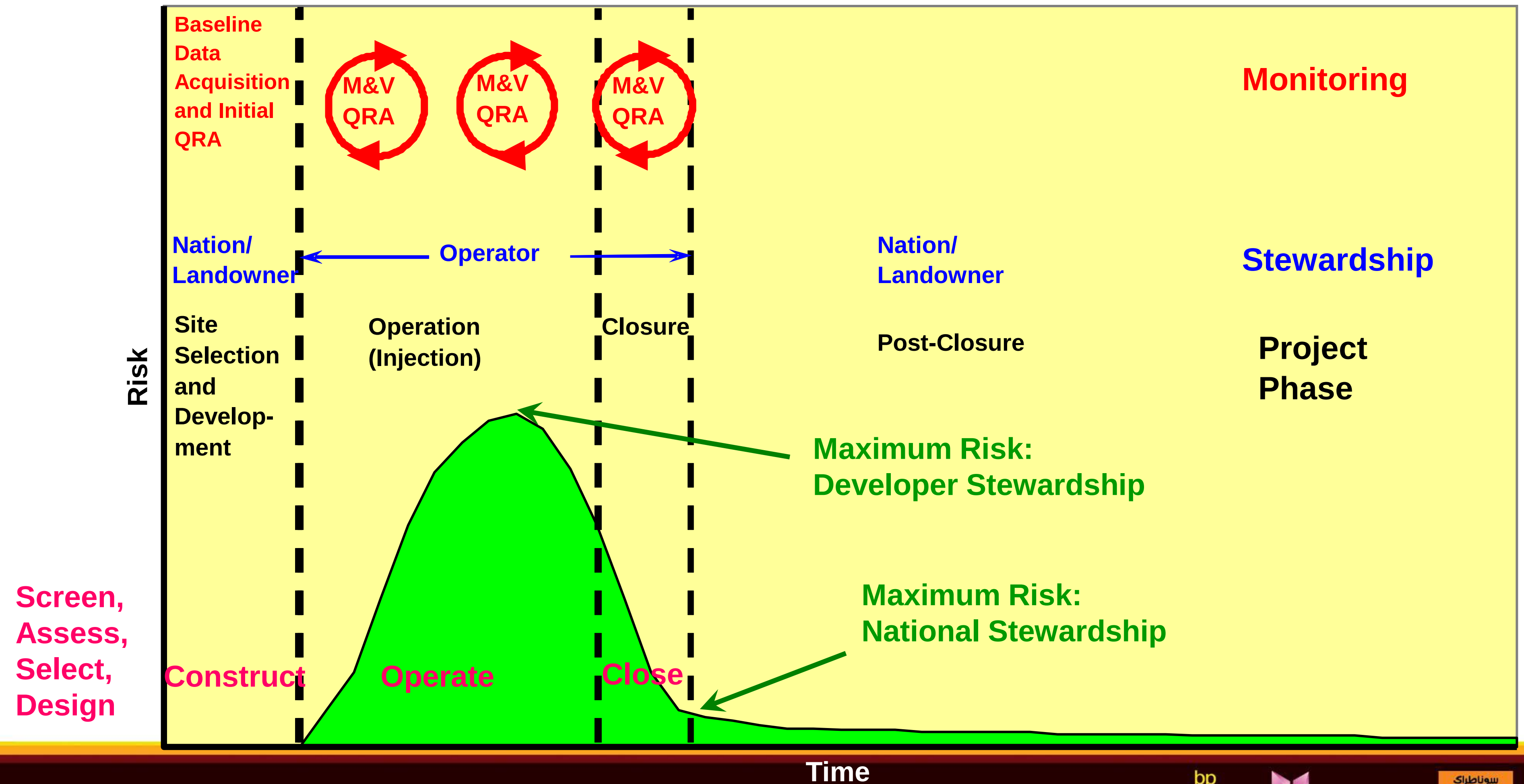
(Ref: CO2QUALSTORE, DNV 2009)

bp Statoil sonatrach

CO_2 Storage: Generic Risk Profile

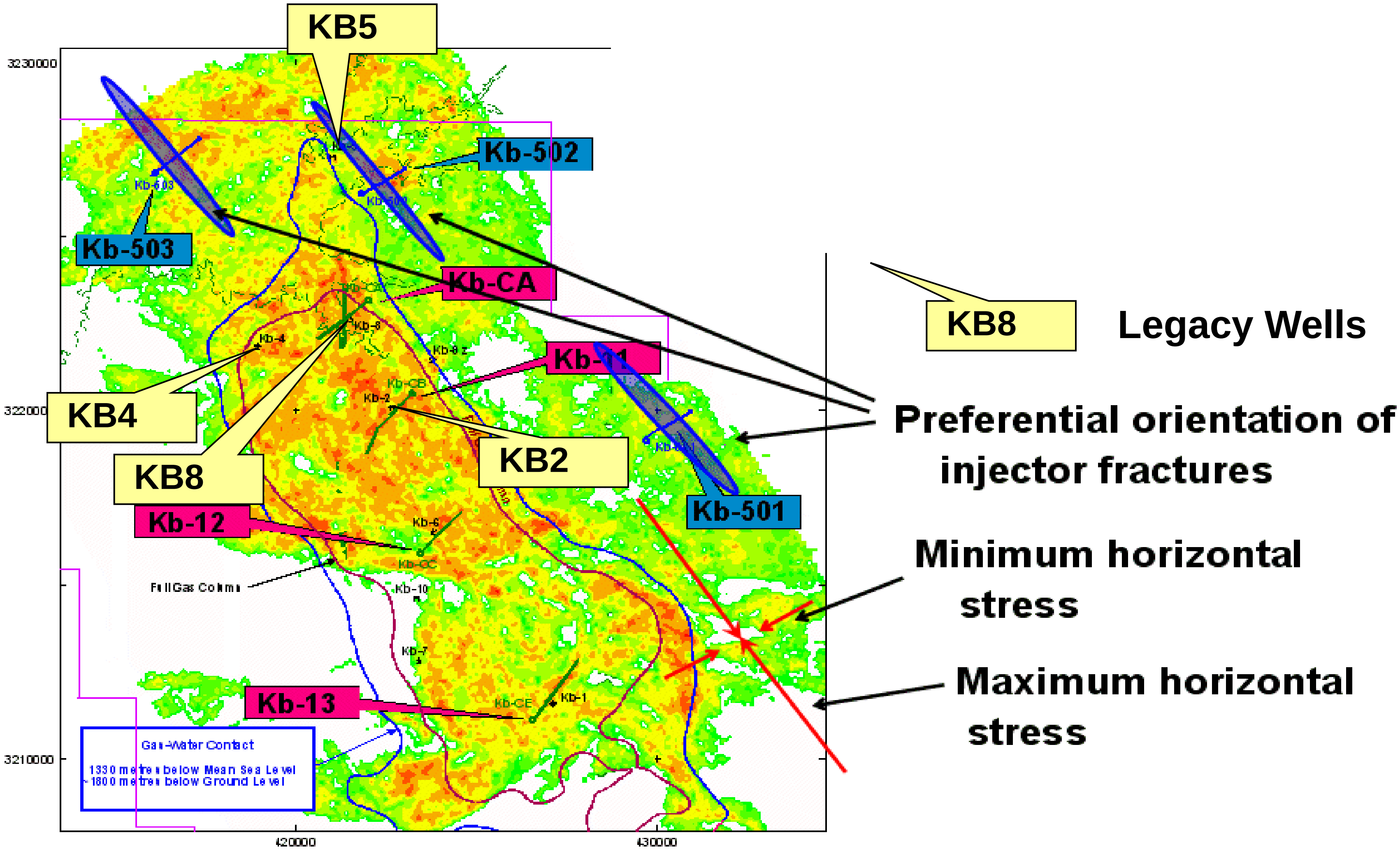
In Salah Gas Stockage de CO_2

Risk Profile of a CGS Project



bp Statoil sonatrach

Risk Management: Project Design



Site Selection and Operation

Quantified Risk Assessments (QRA) should be used to manage seepage risk

- During site selection, project design and updated periodically during operation
- Several methodologies are available

- Monitoring should be in the Field Development Plan (FDP) and Field Operations
  - Designed around an early assessment of seepage risks

- Initial appraisal and development of a CO_2 storage project should collect a comprehensive set of baseline data
  - To adequately characterise the Storage Complex / Area of Review

- At In Salah:
- ***Baseline data acquisition should have begun earlier & been more-comprehensive***
- ***Top Three risks were: Integrity of wells and caprock, plus CO_2 migration direction***

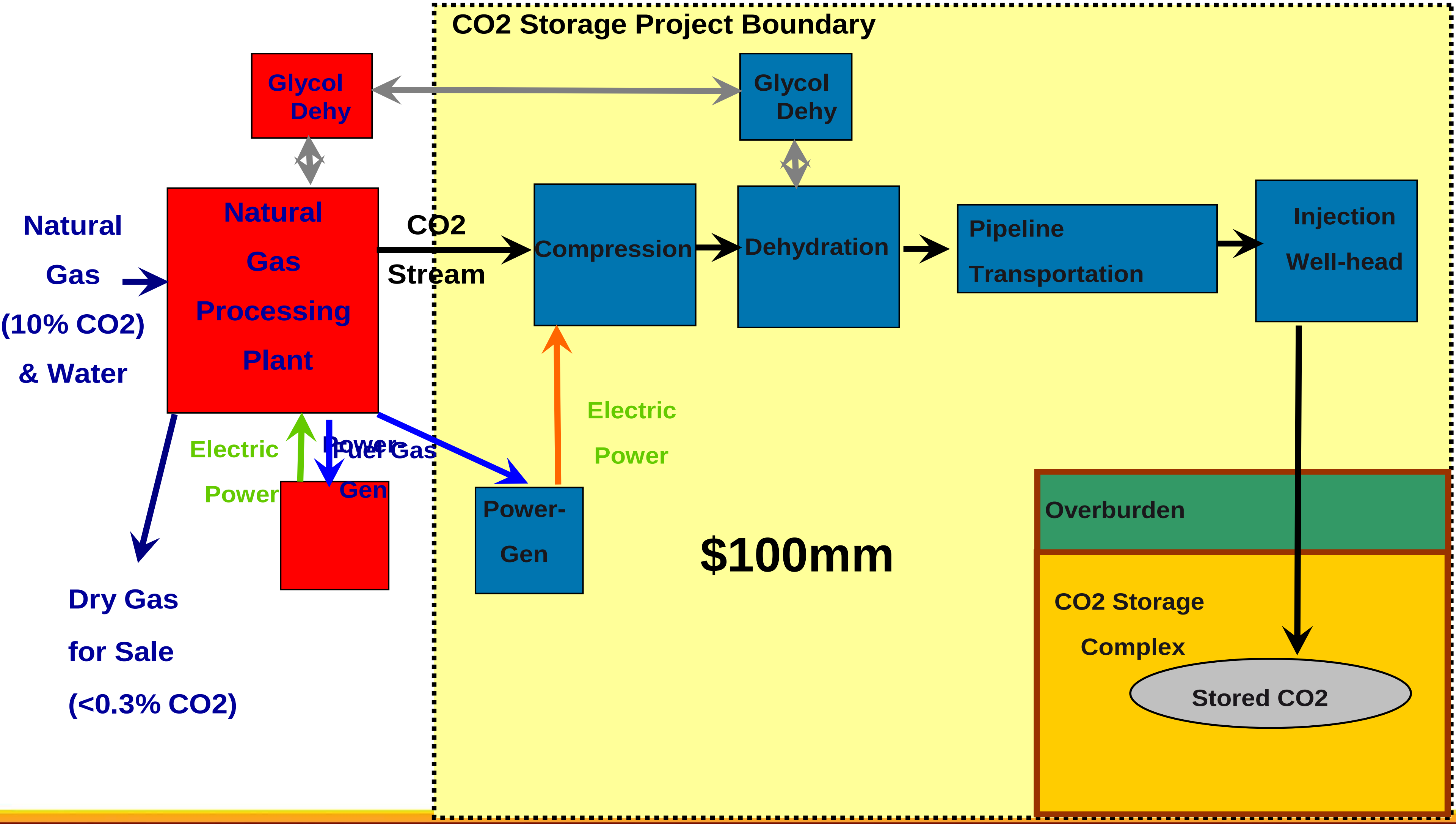
Agenda

- In Salah CCS: Context & Overview
- In Salah JIP Phase 1 Lessons:

1. Site Selection
2. **Project Boundaries and Accounting**
3. Monitoring
4. Risk Assessment
5. Informing Regulation

- Summary & Discussion

Project Boundaries and Accounting



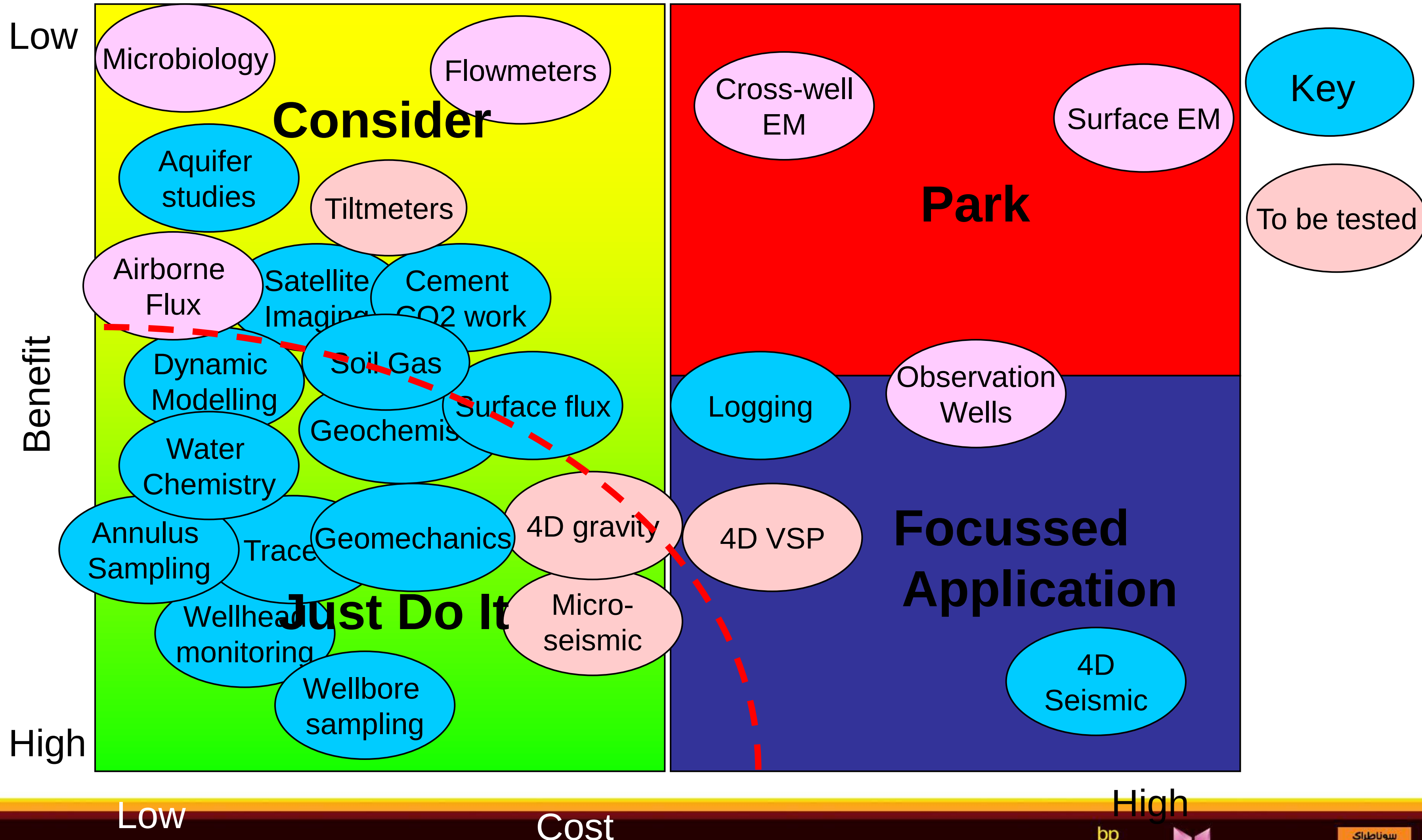
Agenda

- In Salah CCS: Context & Overview
- In Salah JIP Phase 1 Lessons:

1. Site Selection
2. Project Boundaries and Accounting
3. **Monitoring**
4. Risk Assessment
5. Informing Regulation

- Summary & Discussion

Monitoring Technologies: Evaluation



Monitoring Technologies Deployed at Krechba

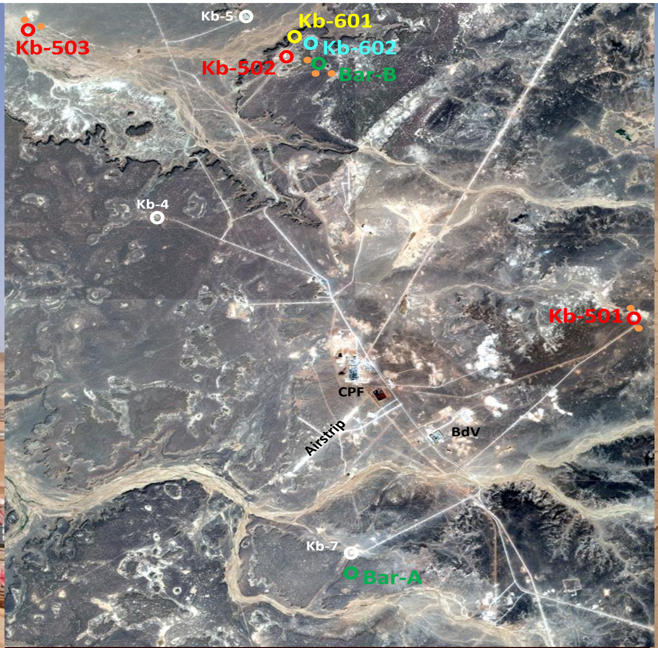
Monitoring technology	Risk to Monitor	Action/Status
Repeat 3D seismic	Plume migration Subsurface characterisation	➢ Initial survey in 1997 ➢ High resolution repeat 3D survey acquired in 2009 ➢ Initial interpretation complete. ➢ May show some time lapse (4D) effects
Microseismic	Caprock integrity	➢ 500m test well drilled and recording information above KB502 – encouraging results to date ➢ Need to replace surface recording equipment
InSAR monitoring	Plume migration Caprock integrity Pressure Development	➢ Images captured using X-band (8 days) and C-band (32 days) ➢ Used to develop time lapse deformation images ➢ Input to geomechanical modelling activities
Tiltmeters/GPS	Plume migration Caprock integrity Pressure Development	➢ Currently collecting data – 18 month collection period to end 2011 ➢ Use to calibrate satellite data
Shallow aquifer wells	Caprock Integrity Potable aquifer contamination	➢ 5 wells drilled to 350m – one beside each injector, one remote and one between KB5 and KB502. ➢ Two sampling programmes to date ➢ No anomalies noted to date
Wellhead/annulus samples	Wellbore integrity Plume migration	➢ 2 monthly sampling since 2005 ➢ No anomalies noted to date
Tracers	Plume migration	➢ Different perflourocarbon tracers into each injector ➢ Implemented 2006 ➢ Only tracer recorded in KB5 from KB502 (see section 4 for detailed discussion)
Surface Flux/Soil Gas	Surface seepage	➢ Initial survey pre-injection ➢ Two surveys in 2009 around key risk wells ➢ No anomalies to date
Microbiology	Surface seepage	➢ First samples collected in late 2009/early 2010 ➢ CO2 microfaunal assemblages recorded – may be of value for long term monitoring
Wireline Logging/sampling	Subsurface characterization	➢ Overburden samples and logs in new wells ➢ Geomechanical and geochemical modeling

Monitoring: Low-cost Options

- Low-cost technologies can be very effective CO_2 monitoring tools

At In Salah: these included:

- ***Wellhead (pressure & flowrate) annulus monitoring (including tracers)***
- ***Soil-gas surveys, permanent soil-gas detectors, microbiological sampling***
- ***Gas surface flux (using laser surveys),***
- ***Shallow aquifer sampling***

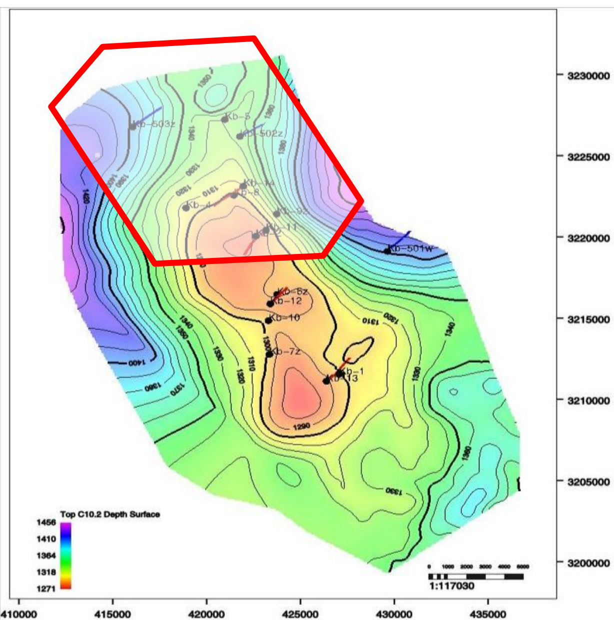


Monitoring: Seismic

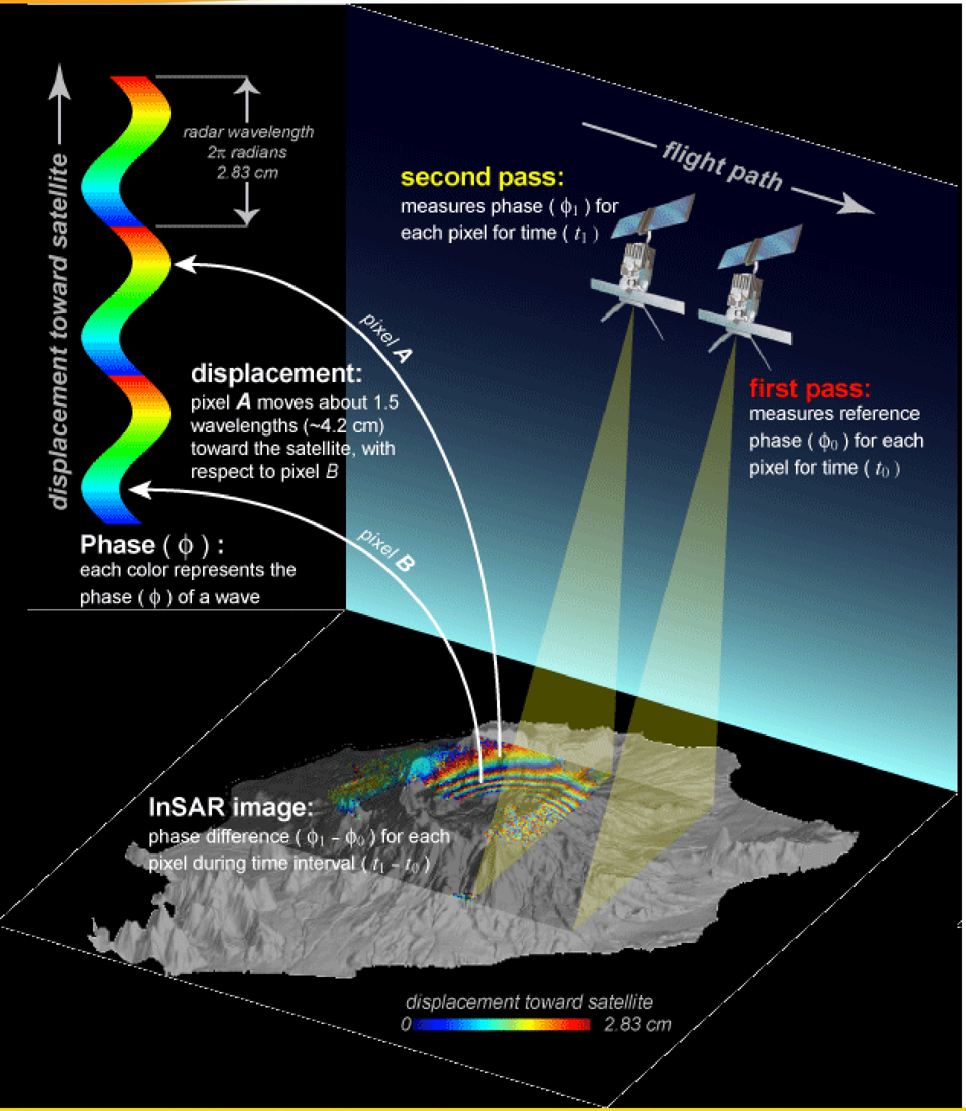
- **Acquisition of a high-quality, pre-injection 3D seismic baseline is a vital**
  - for characterising the overburden and the injection horizon
- **The value of subsequent (time-lapse) 3D surveys will depend on rock quality and the density difference between in-situ fluids and the injected CO_2**
- **A comprehensive understanding of the interaction of rock-physics, fluids and fractures is required to adequately model Seismic responses to CO_2 injection**

At In Salah:

- ***4D may never be a good option for CO_2 monitoring (due to poor rock quality and insufficient density contrast between fluids)***



Monitoring: Satellite Imagery - Generic

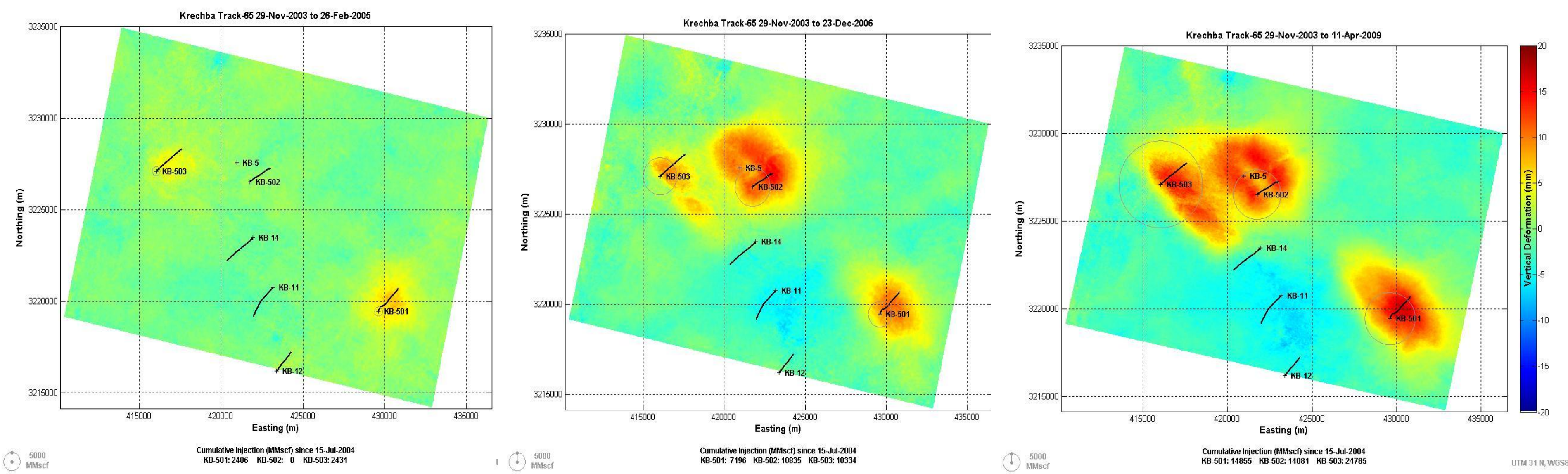


- Interferometric Synthetic Aperture Radar (InSAR)
- Technology developing rapidly due to:
  - Publicly available data
  - Better data resolution (satellite)
  - Improved processing capabilities
  - Competition between providers
- Provides accurate information on ground surface deformations over time
  - Surrogate for pressure (not CO_2)
- Not Specific to CO_2 Monitoring

Monitoring: Satellite Imagery - At In Salah

- **InSAR (combined with geo-mechanical modelling), has been key to understanding the subsurface distribution of pressure fronts and CO_2 plumes**
  - ***Benchmarked by CO_2 observation at KB5***
  - ***Significantly influenced the 2009 seismic survey and Quantified Risk Assessment***
  - ***Data is available since 2003 (pre-injection), C-Band (Envisat and Radarsat2)***
  - ***Use of new X-Band data allows observation every 8 days.***
  - ***Inversion using diversity of research partners and techniques***
  - ***Used as an observation constraint for geo-mechanical modelling***

2005 2007 2009



Agenda

- In Salah CCS: Context & Overview
- In Salah JIP Phase 1 Lessons:

1. Site Selection
2. Project Boundaries and Accounting
3. Monitoring
4. **Risk Assessment**
5. Informing Regulation

- Summary & Discussion

Risk Assessment

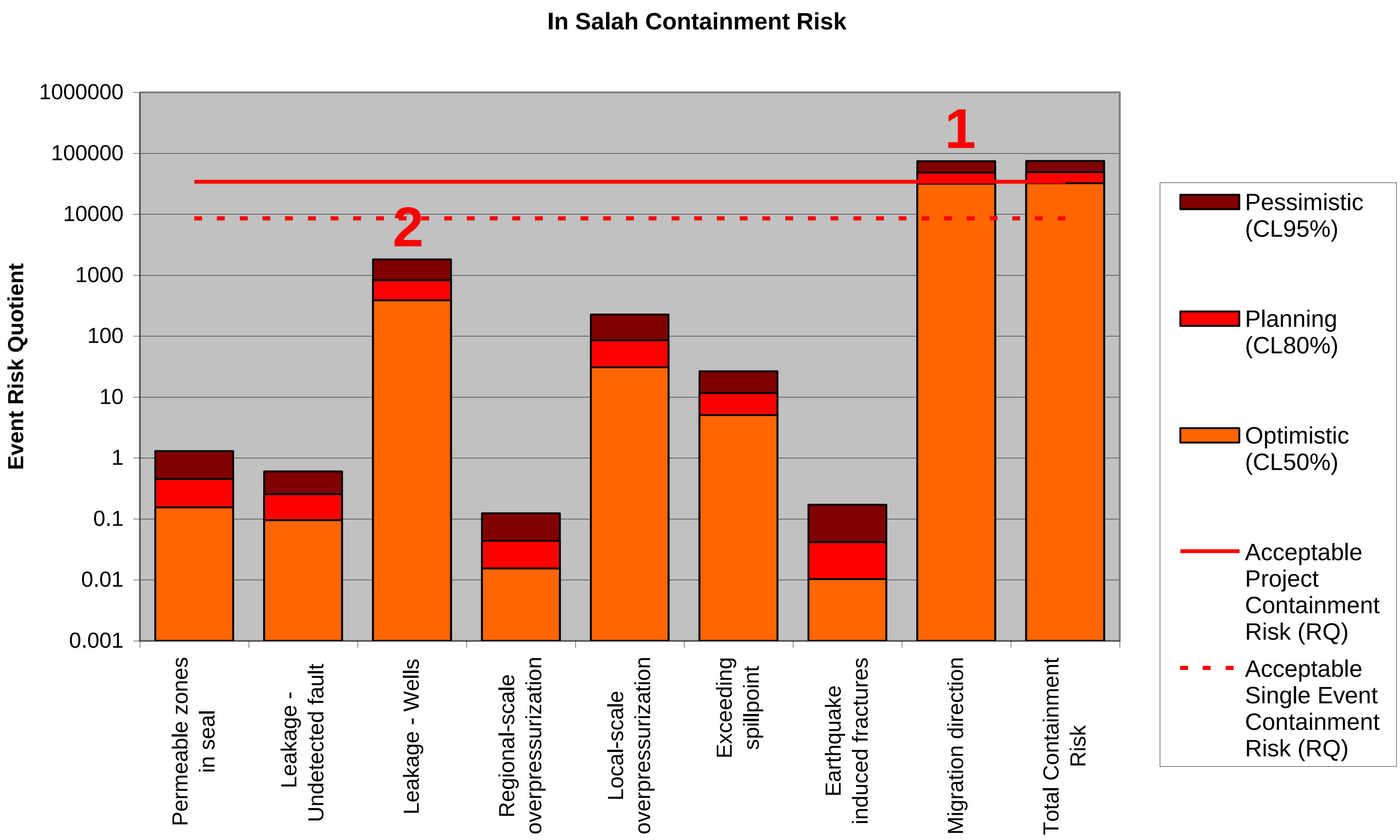
- **Quantified Risk Assessment (QRA) is an invaluable tool to understand, manage and communicate the performance of a CO_2 storage operation**
  - **Should be periodically repeated over the life of a CO_2 storage project**

- **Several methodologies are available**

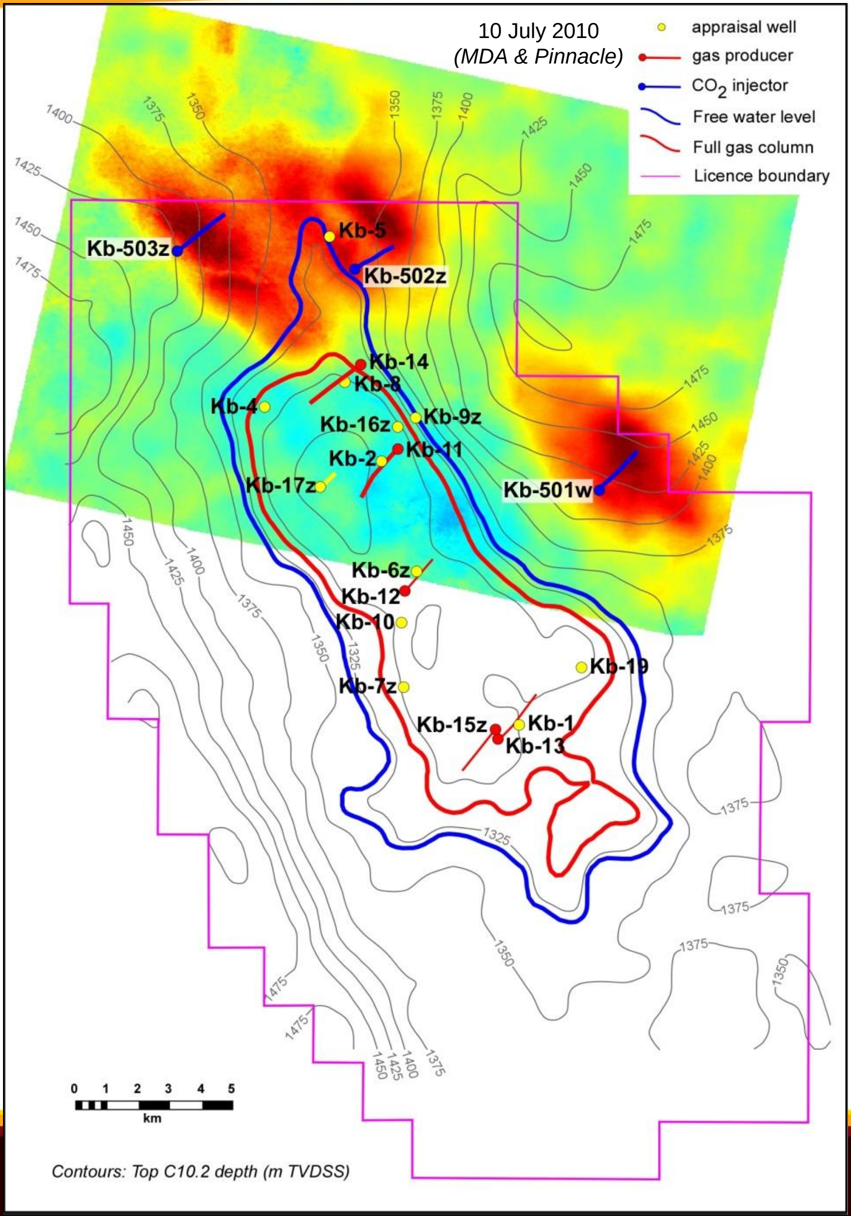
At In Salah:

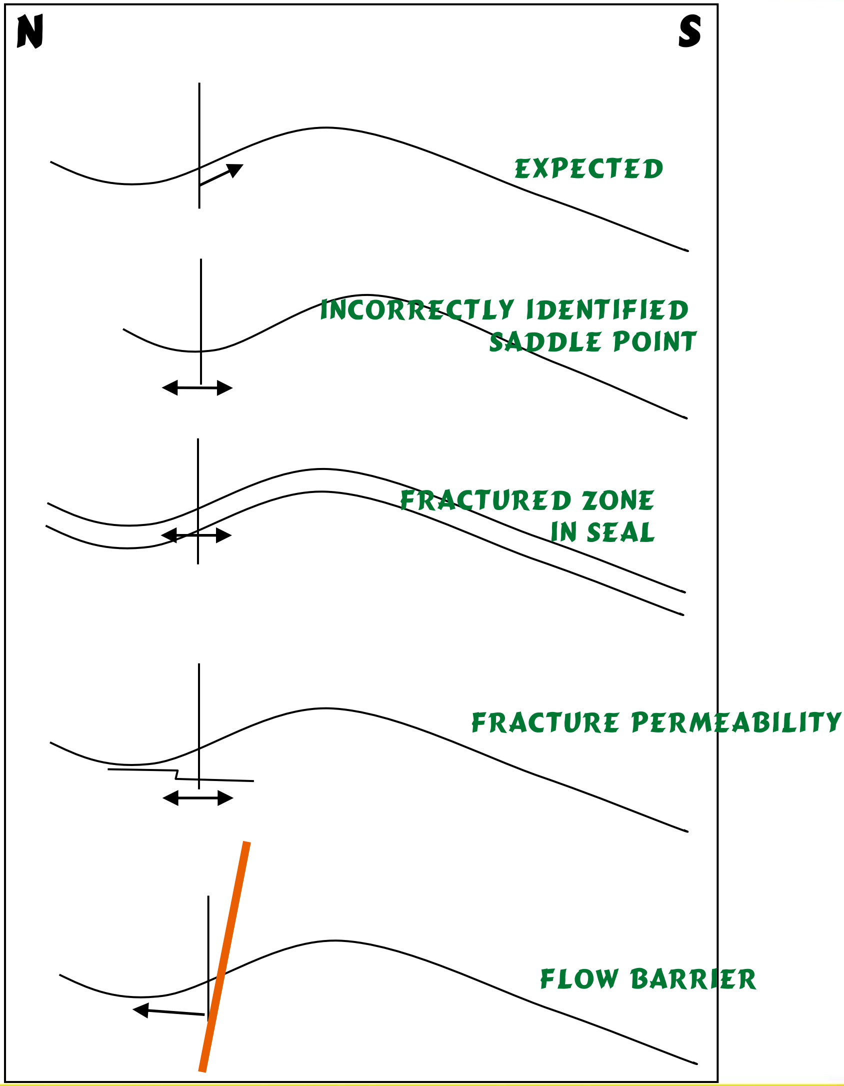
- ***Pre-injection risk assessment highlighted the key risks and informed the baseline data acquisition programme and early monitoring***
- ***Evaluated QRA methodologies: CCPCF, URS, FEP, Oxand***
- ***The QRA is updated regularly and used to inform injection and monitoring strategies***

In Salah Quantified Risk Assessment

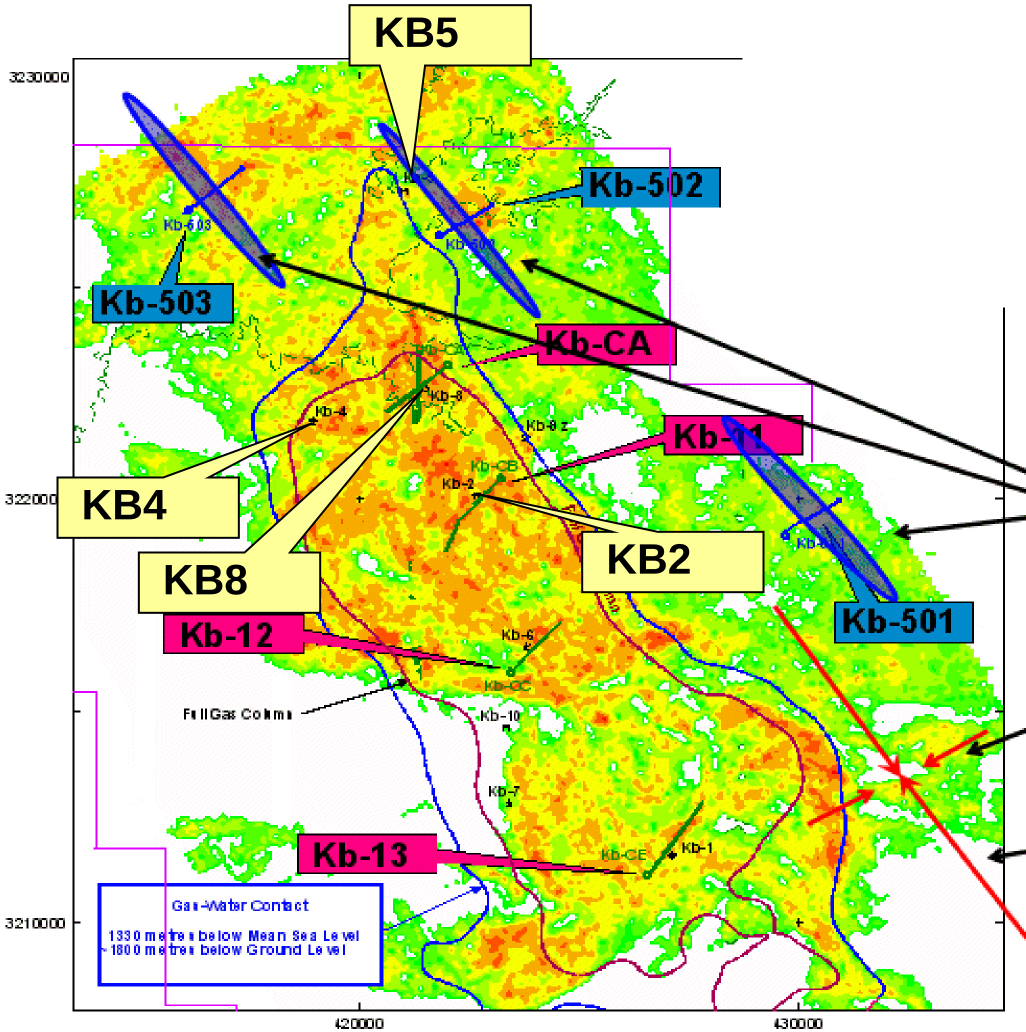


Key Risk #1: Migration Direction Risk





Key Risk #2: Legacy Wells



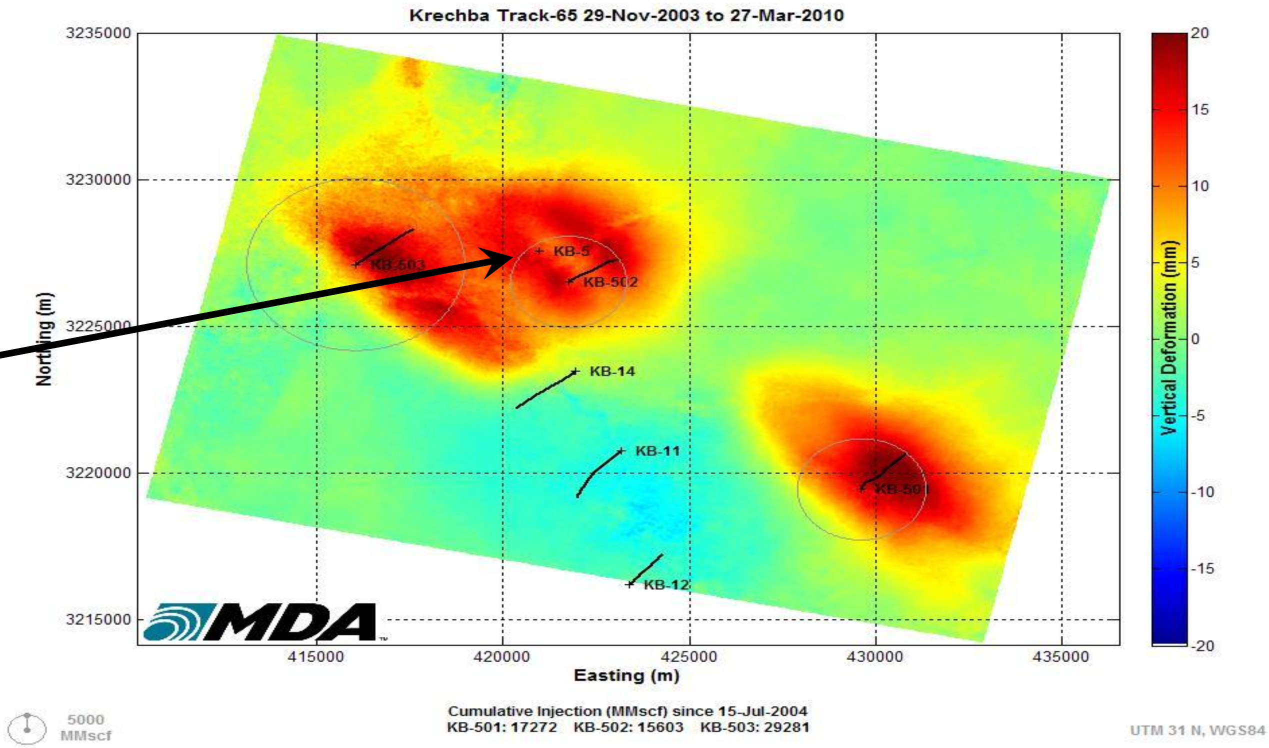
KB8 Legacy Wells

Preferential orientation of injector fractures

Minimum horizontal stress

Maximum horizontal stress

Legacy Well: KB-5



Drilled in 1980 and temporarily suspended (no integrity to gas)

1.5 km NW of KB502 CO_2 injector (expected CO2 migration direction)

0.1 tonne CO_2 seeped in 2007 (valve leak – not pressure on gauge)

Caused by lack of well & wellhead integrity (physics not chemistry)

KB5 now fully decommissioned with CO_2 resistant cement

Agenda

- In Salah CCS: Context & Overview
- In Salah JIP Phase 1 Lessons:
  1. Site Selection
  2. Project Boundaries and Accounting
  3. Monitoring
  4. Risk Assessment
  5. **Informing Regulation**
- Summary & Discussion

CO_2 Storage: Generic Risk Profile

In Salah Gas
Stockage de CO_2

bp Statoil sonatrach

In Salah and EU Directive

In Salah Gas Stockage de CO_2

Colour Key

- **Compliant**
- **Compliance possible**
- **Non or difficult compliance**

In Salah CO2 Storage vs. EU CCS Guidelines

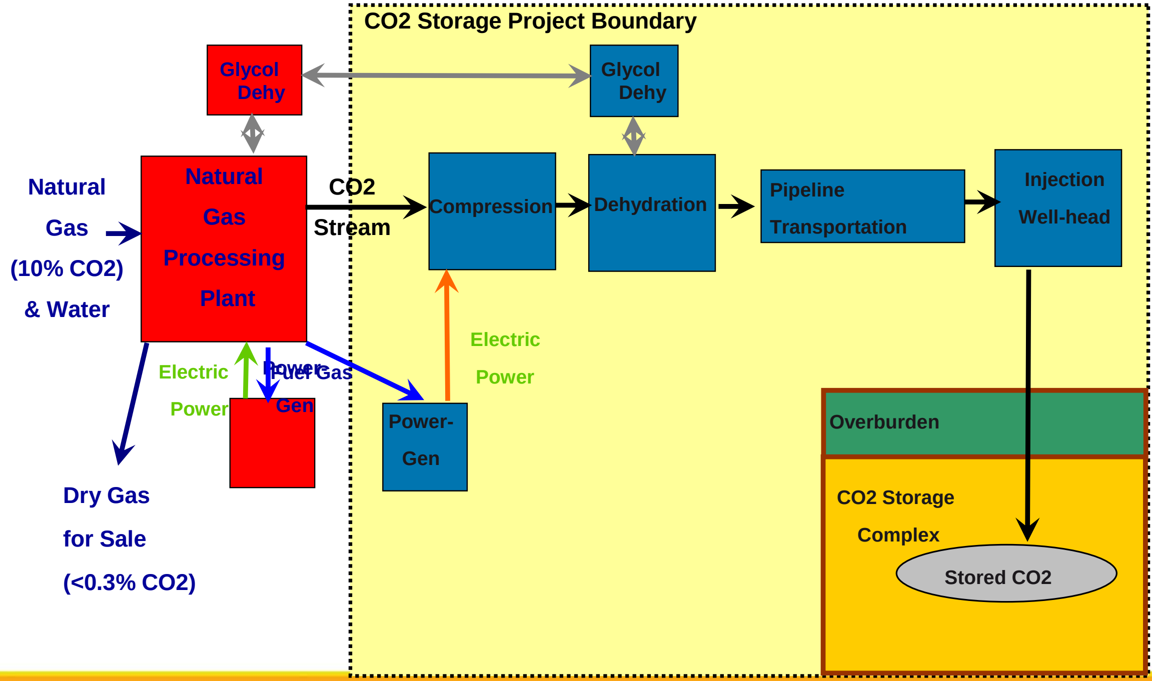
ectio	Category	Activities	Directive MPCP	Storage Project Stages: Assessment / Appraise	Characterisation / Select/Define	Development / Execute	Operation / Operate	Closure / Decommission
GD1 Life Cycle Risk Managem								
2.1	Life Cycle Risk Management	Periodic Risk Assessment and Management						
		Model and performance Uncertainty assessment						
3.3	Life Cycle Phases							
	Characterisation	Characterisation/assessment of storage complex						
		Detailed Risk Assessment						
		Develop injection, monitoring, corrective measures plans						
	Development	Detailed engineering design of the storage scheme						
		Baseline pre-injection monitoring						
	Operations	Reporting of monitoring results to Competent Authority (CA)						
		Development of Corrective measures plan						
		New data used to update models and risk assessment						
		Monitoring plans to be updated and verified						
		Notify CA of any leakage or significant irregularities						
	Closure	Develop monitoring plan with targets and methods						
		Conduct post closure monitoring						
		Updated site characterisation and risk assessment						
		Inspections by CA post closure						
	Pre-Transfer to CA	Prove long term containment of CO2						
		Monitor and assess for **20 years**						
		Site sealed and facilities removed						
6	Risk Management for Geological Storage	Use CO2Qualstore risk assessment methodology (DNV 2010a)						
		Dialogue on Risk management with CA						

bp Statoil sonatrach

In Salah and Kyoto Protocol: CDM

New Methodology for CCS was submitted in 2009

Publicly available at: www.insalahco2.com



Agenda

- Context & Overview
- In Salah JIP Phase 1: Key Learnings
  - CO_2 Storage: Planning and Operation
  - Monitoring
    - Data Acquisition
    - Integration
    - Quantified Risk Assessment
    - Informing Regulation
- JIP2 Plan
- **Summary & Discussion**

Top Ten Lessons Learned

1. Monitoring should be part of the Field Development Plan (FDP) and routine field operations.
2. QRAs should be carried out prior to injection and periodically throughout the operation
   - Several methodologies are available, but there is no regulatory agreement on acceptable levels of risk
3. The main leakage risks are driven by:
   - Legacy well-bore integrity
   - Cap-rock integrity
   - CO2 plume migration direction
4. Monitoring should be in service of risk assessment: designed to address site-specific risks
5. Acquisition, modelling and integration of a full suite of initial baseline data (specifically caprock cores and geo-mechanical logs) is essential for evaluating long-term integrity.
6. Compared to hydrocarbon developments, CO_2 storage projects require the integration of a wider-scope of datasets (InSAR, soil gas, seismic) over a greater aerial/vertical extent (overburden and area of possible migration).
7. A diverse suite of different technologies should be deployed and integrated.
8. Injection strategies, rates and pressures need to be linked to geomechanical modelling of the reservoir and the overburden and continuously monitored and managed.
9. CO2 plume development is not homogeneous and requires high-resolution data for reservoir characterization and modelling.
   - Effects that require advanced, coupled modelling are: fluid-dynamics, rock mechanics and temperature
10. The regulation of CO_2 storage projects is immature, but In Salah could retrospectively comply with the EU CCS Directive and the requirements of the Clean Development Mechanism.
    - In Salah can inform emerging CCS regulatory frameworks around the world.

Questions?

www.insalahco2.com