Up-scaling CCS
– In Salah Lessons

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Disclaimer

- Iain Wright is giving this presentation in a personal capacity
  - To say "thank-you" for Japanese contributions to the In Salah Project
- Views expressed may not be the same as BP's

Agenda

- **Context & Overview**
  - **Up-scaling CCS**

- **In Salah JIP Key Learnings**
  - **CO_2 Storage: Planning and Operation**
  - **Monitoring**
    - Data Acquisition
    - Integration
    - Quantified Risk Assessment
    - Informing Regulation

- **Summary and Discussion**

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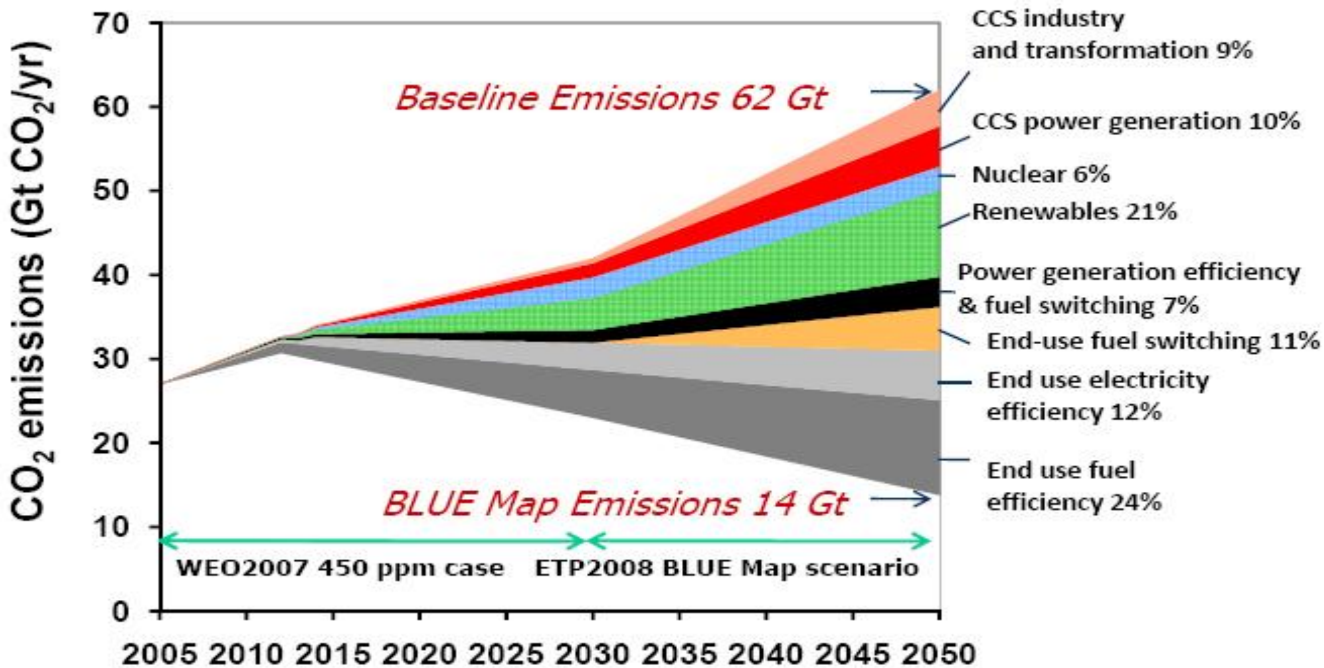
GHG Mitigation: CCS Contribution (IEA)

A New Energy Revolution: Cutting Energy Related CO_2 Emissions



In support of the G8 Plan of Action

Large-Scale Integrated Projects (GCCSI: 2013)

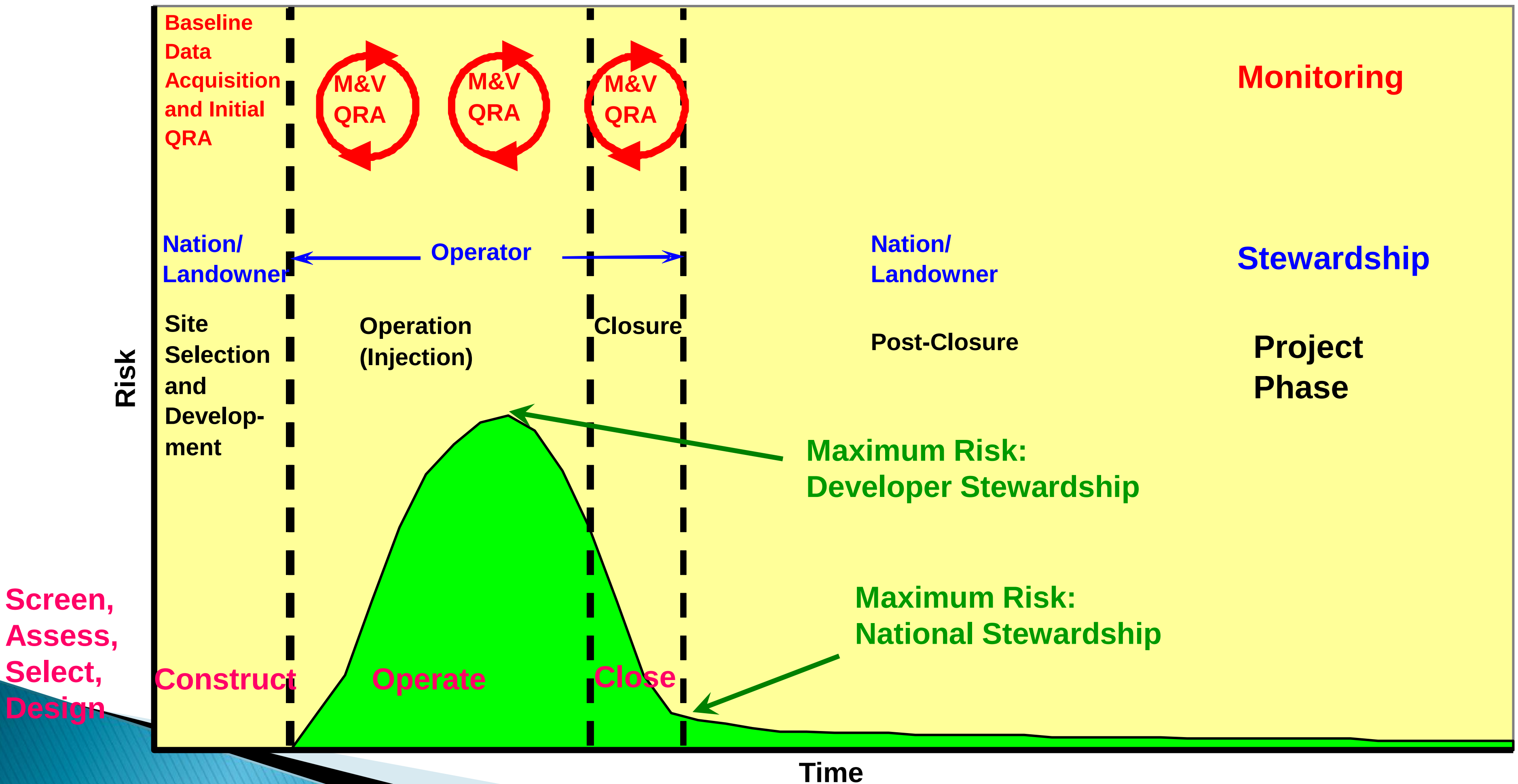
Project	Country	Start	Storage	MMTPA
Sleipner	Norway	1996	DSF	0.8
In Salah	Algeria	2004	DSF	0.7
Snohvit	Norway	2008	DSF	0.6
Val Verde	USA	1972	EOR	1.3
Enid	USA	1982	EOR	0.6
Shute Creek	USA	1986	EOR	7
Great Plains (Weyburn)	USA	2000	EOR	3
Century	USA	2010	EOR	8
Air Products SMR	USA	2013	EOR	1
Lula CCS	Brazil	2013	EOR	0.7
Coffeyville	USA	2013	EOR	1
Lost Cabin	USA	2013	EOR	1

For CCS to Make its Contribution:

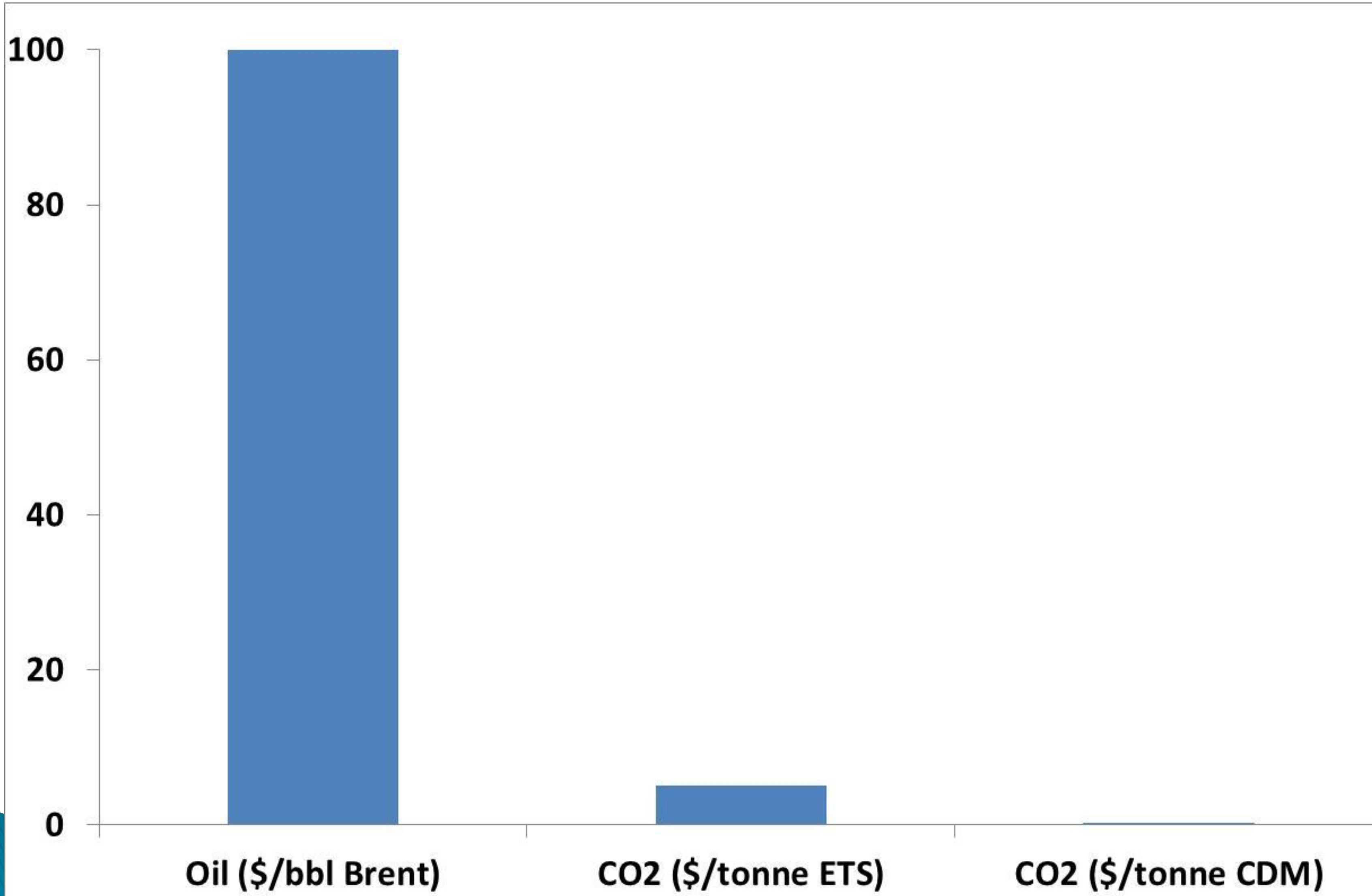
- Regulatory Framework
  - Clear allocation of liabilities
- Policy Framework
  - Investor confidence that investments will be recovered
  - ie a long-term (20-year) CO_2 price
- Public Confidence
  - Balance global benefits with local costs and risks
- Demonstration Projects
  - In Salah and Tomokomai

Regulatory Framework

Risk Profile of a CGS Project



Policy Framework: Commodity Prices (January 2014)



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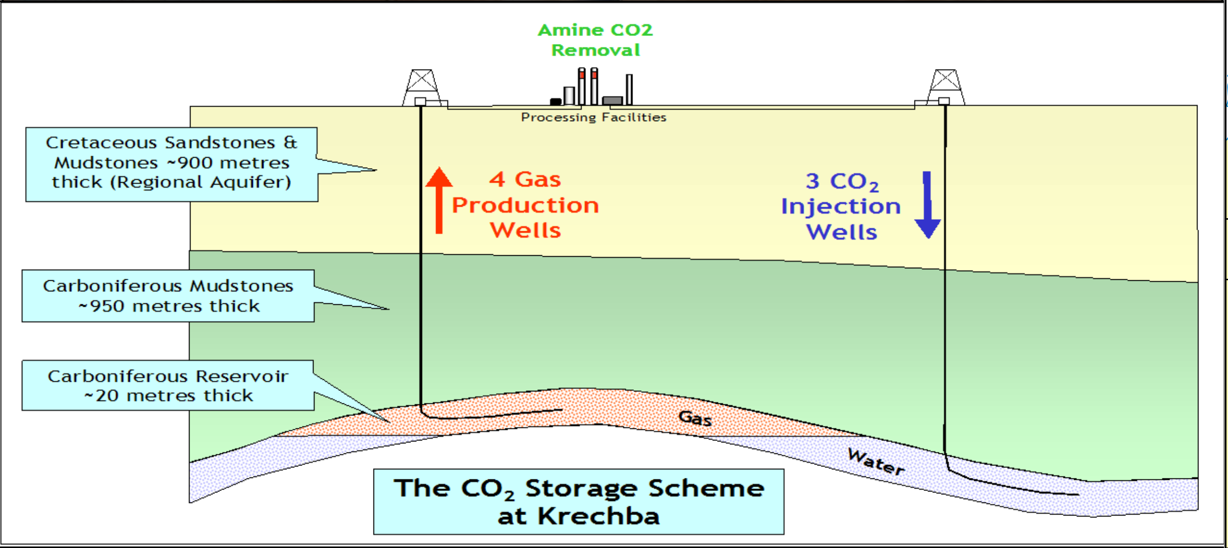
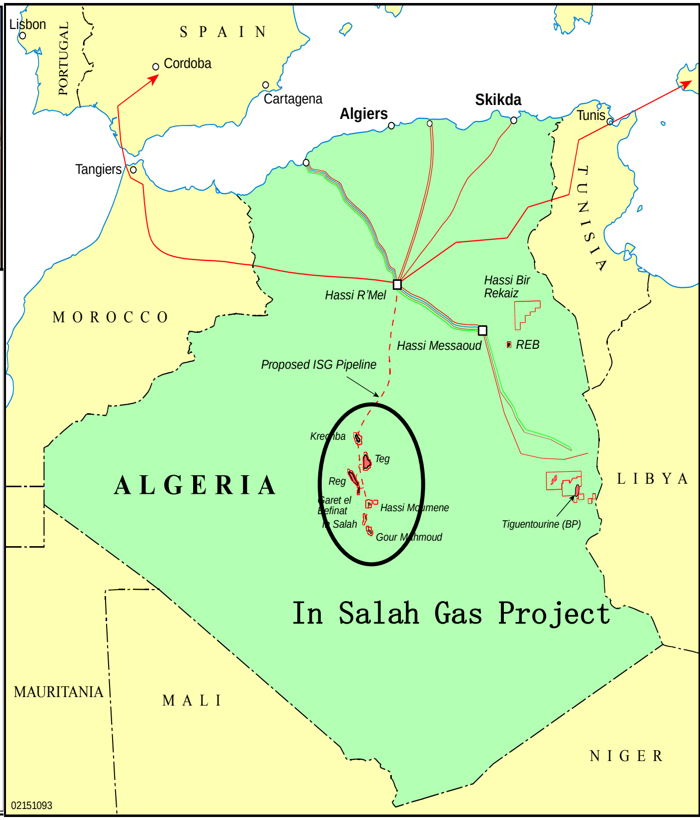
In Salah Summary

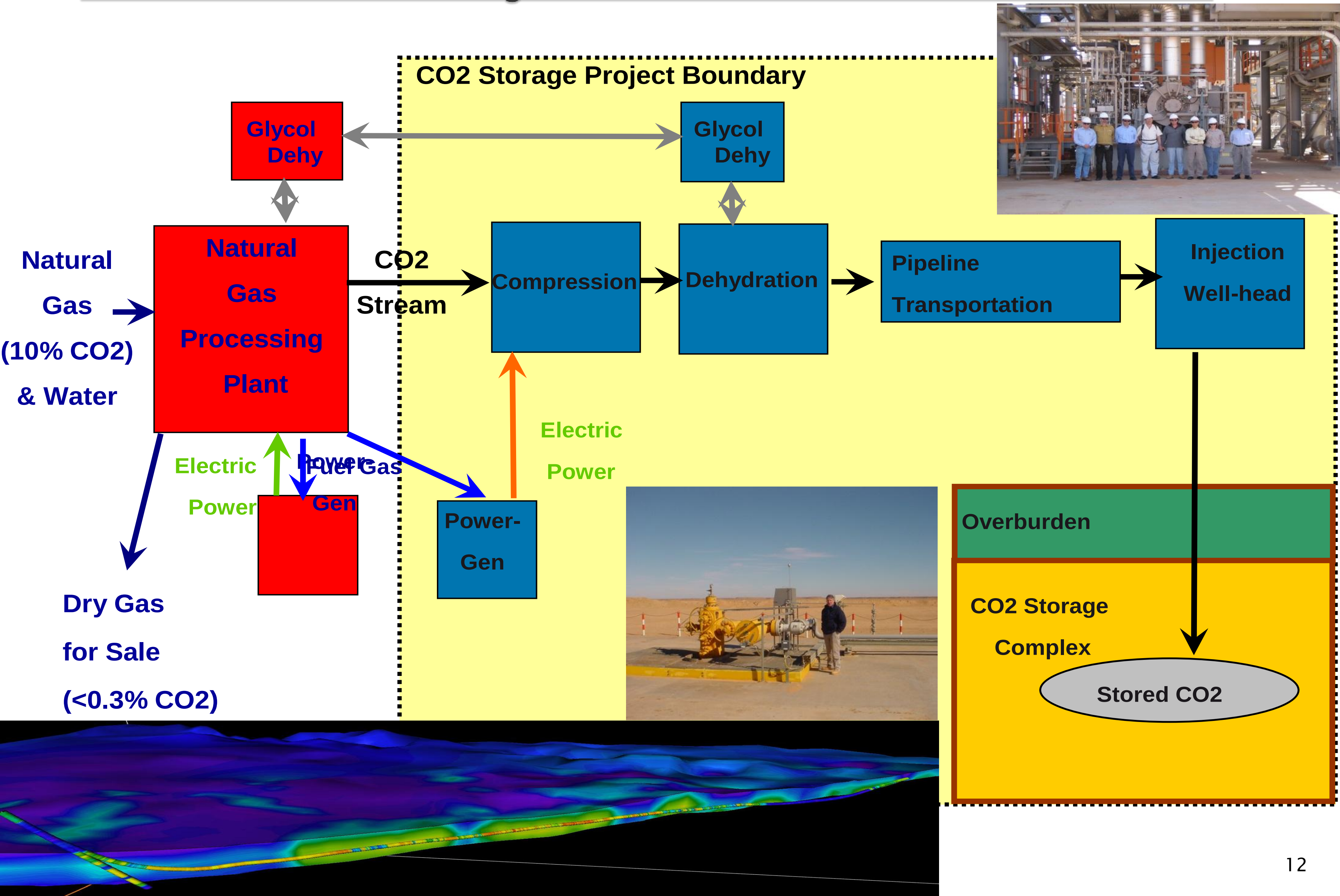




Project Summary

- 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, 3.85 mmt CO_2 stored
- $100mm Incremental Cost for Storage No commercial benefit
- Test-bed for CO_2 Monitoring Technologies: $30mm Research Project

In Salah CCS Project: Additional Investment



In Salah Timeline

- 1960s: Krechba gas field discovered (Total)
- 1996: Krechba lease acquired by BP
- 1998: Kyoto Protocol & BP GHG trading
- 2000: In Salah development approved (with CCS)
- 2002: CO_2 Injection wells drilled
- 2004: CO_2 storage starts
- 2008: EU CCS Directive
- 2011: CO_2 Storage suspended
- 2013: In Amenas Tragedy

In Salah JIP Objectives

- Provide assurance that secure geological storage of CO_2 can be cost-effectively verified and that long-term assurance can be provided by short-term monitoring.
- Demonstrate to stakeholders that industrial-scale geological storage of CO_2 is a viable GHG mitigation option.
- Set precedents for the regulation and verification of the geological storage of CO_2, allowing eligibility for GHG credits

Summary: JIP Lessons Learned

1. **Monitoring should be part of the Field Development Plan (FDP) and routine field operation**
   - **In service of risk assessment**: designed to address site-specific risks
   - Acquisition, modelling and integration of a full suite of initial **baseline data is essential**

2. **QRAs should be carried out prior to injection and periodically throughout the operation**
   - Several methodologies are available

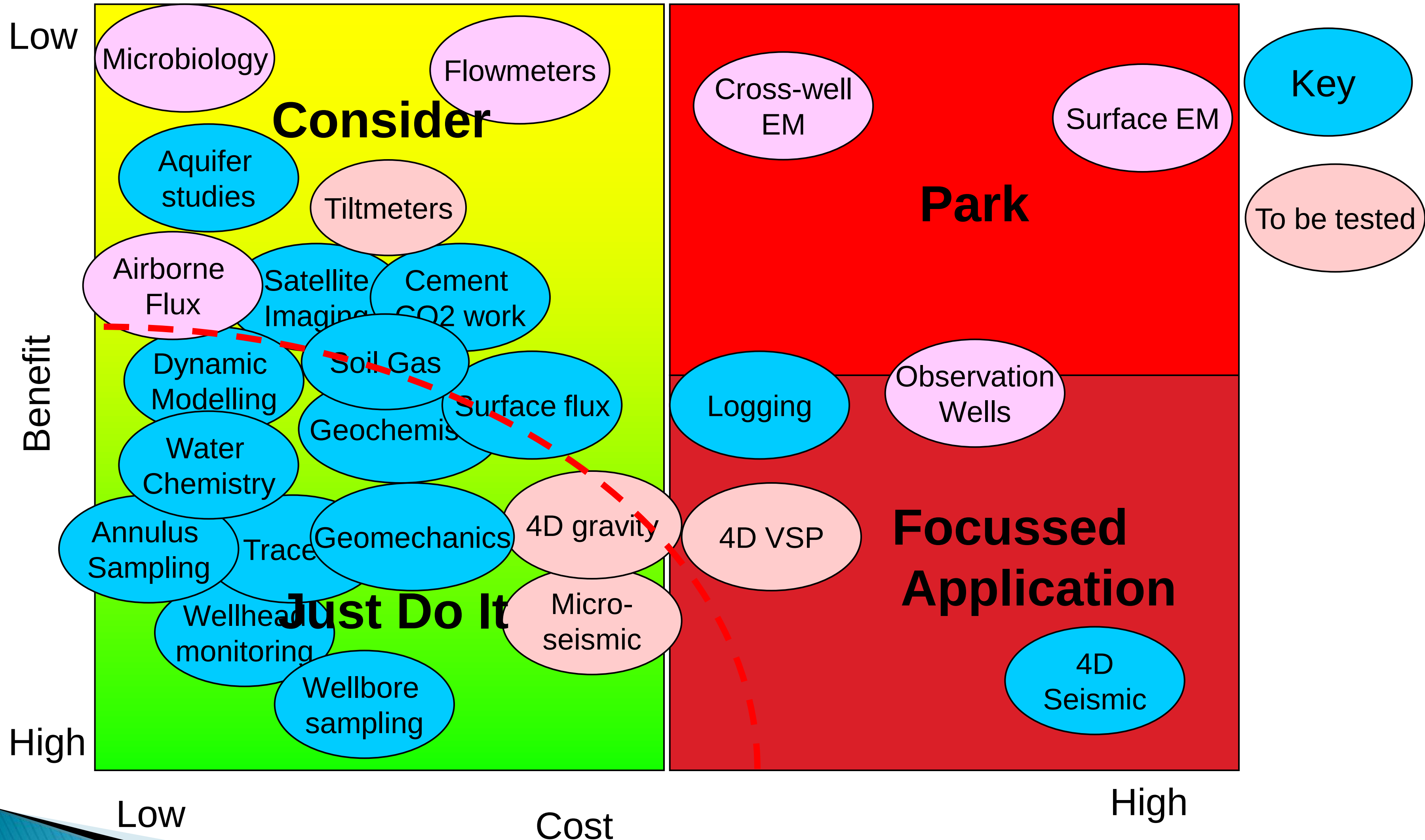
3. **The main seepage risks are driven by:**
   - Legacy well-bore integrity
   - Cap-rock integrity
   - CO_2 plume migration direction

4. **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**
   - A diverse suite of technologies should be deployed and integrated

5. **Injection strategies, rates and pressures need to be linked to geomechanical modelling**
   - Of both the storage formation and **caprock**

6. **CO_2 plume development is not homogeneous**
   - Reservoir characterization and modelling requires high-resolution data

Monitoring Technologies: Evaluation



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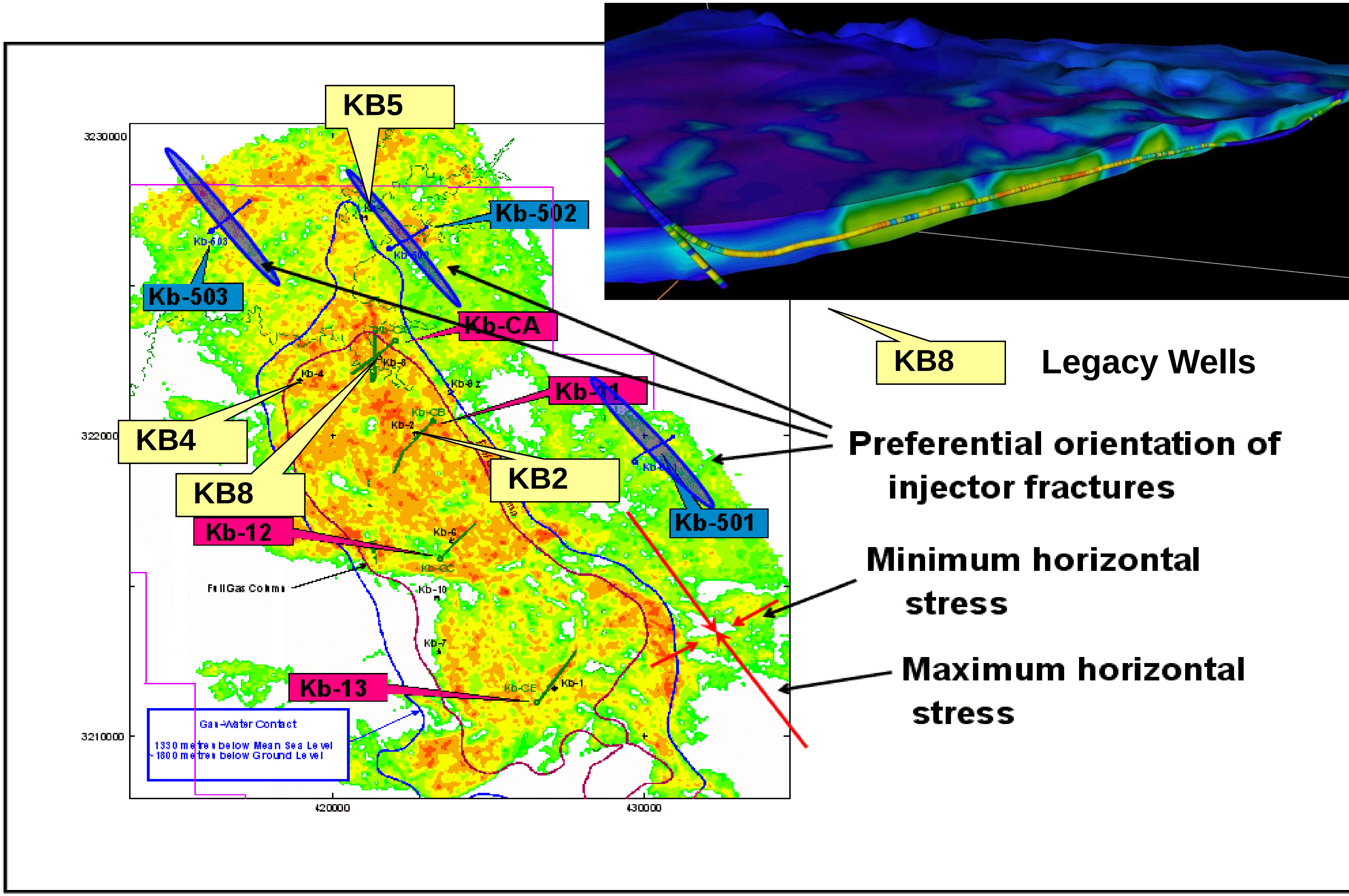
Krechba Field & Expected CO_2 Migration



Field Development Plan and Operations

- CO_2 monitoring should be part of the Field Development Plan (FDP) and routine Field Operations

- Quantified Risk Assessments (QRA) should be carried out pre-injection and during Operation and used to manage leakage risk
  - Several methodologies are available
  - There is no regulatory agreement on acceptable levels of risk

- The CO_2 storage monitoring programme should be designed around an early assessment of leakage 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 Krechba:

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

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  - CO_2 Storage: Planning and Operation
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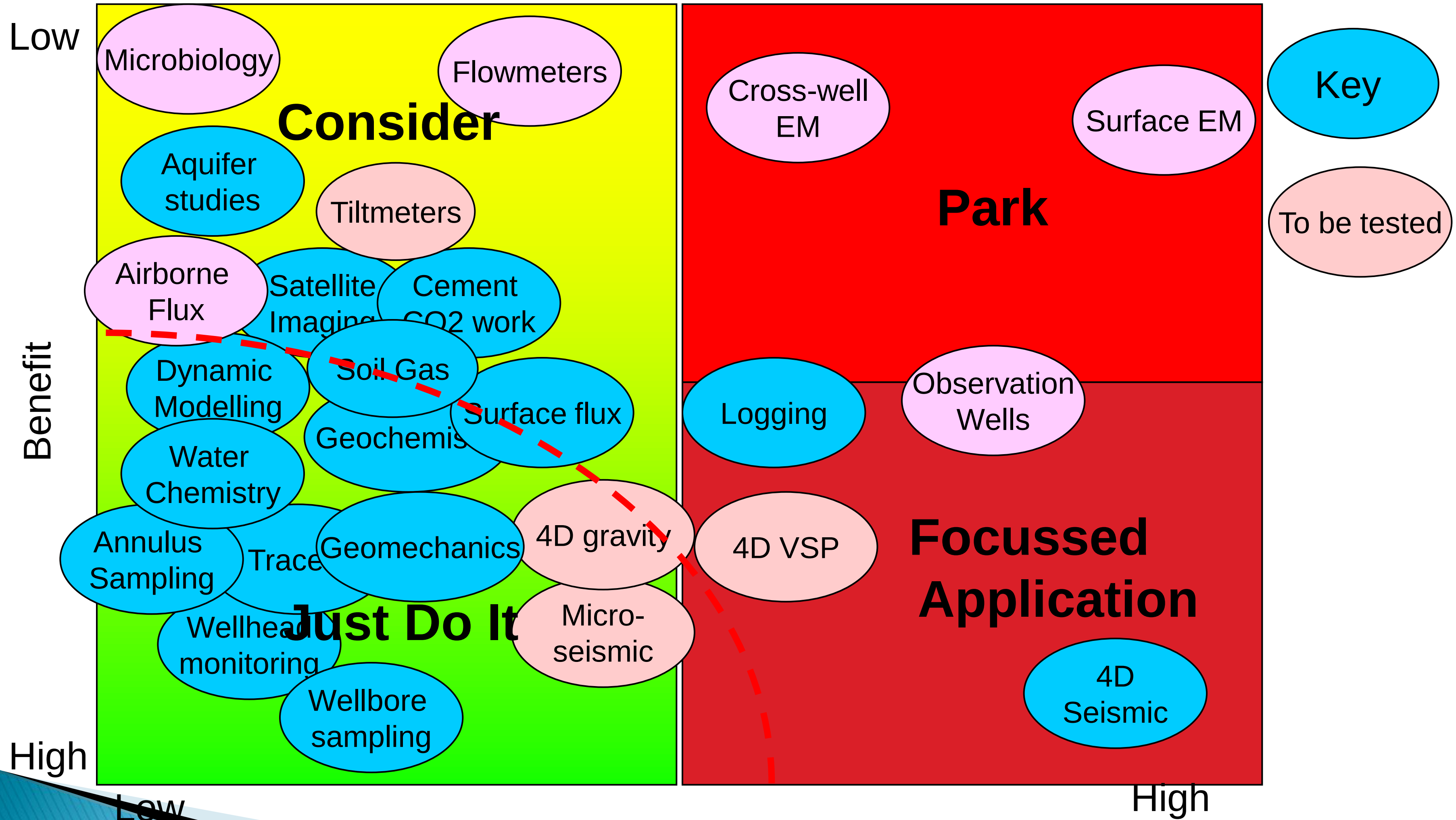
Monitoring Technologies: Evaluation

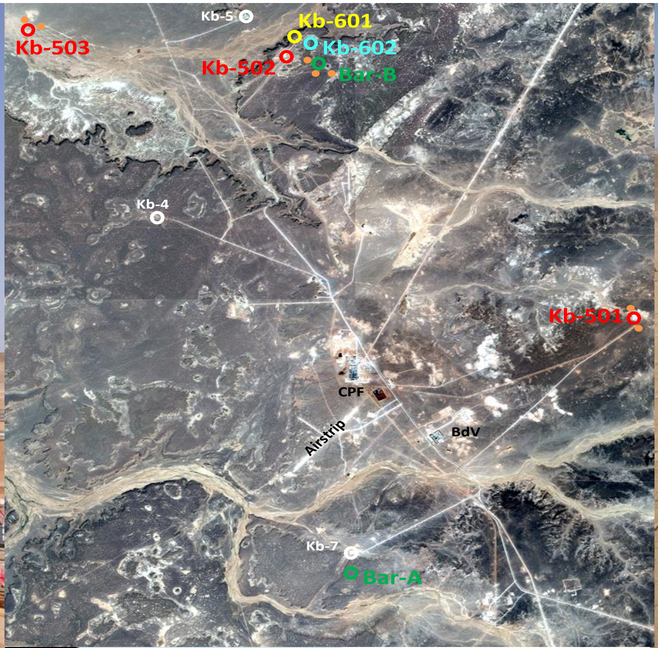


Data Acquisition: Low-cost Options

- Low-cost technologies can be very effective tools

At Krechba: 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*



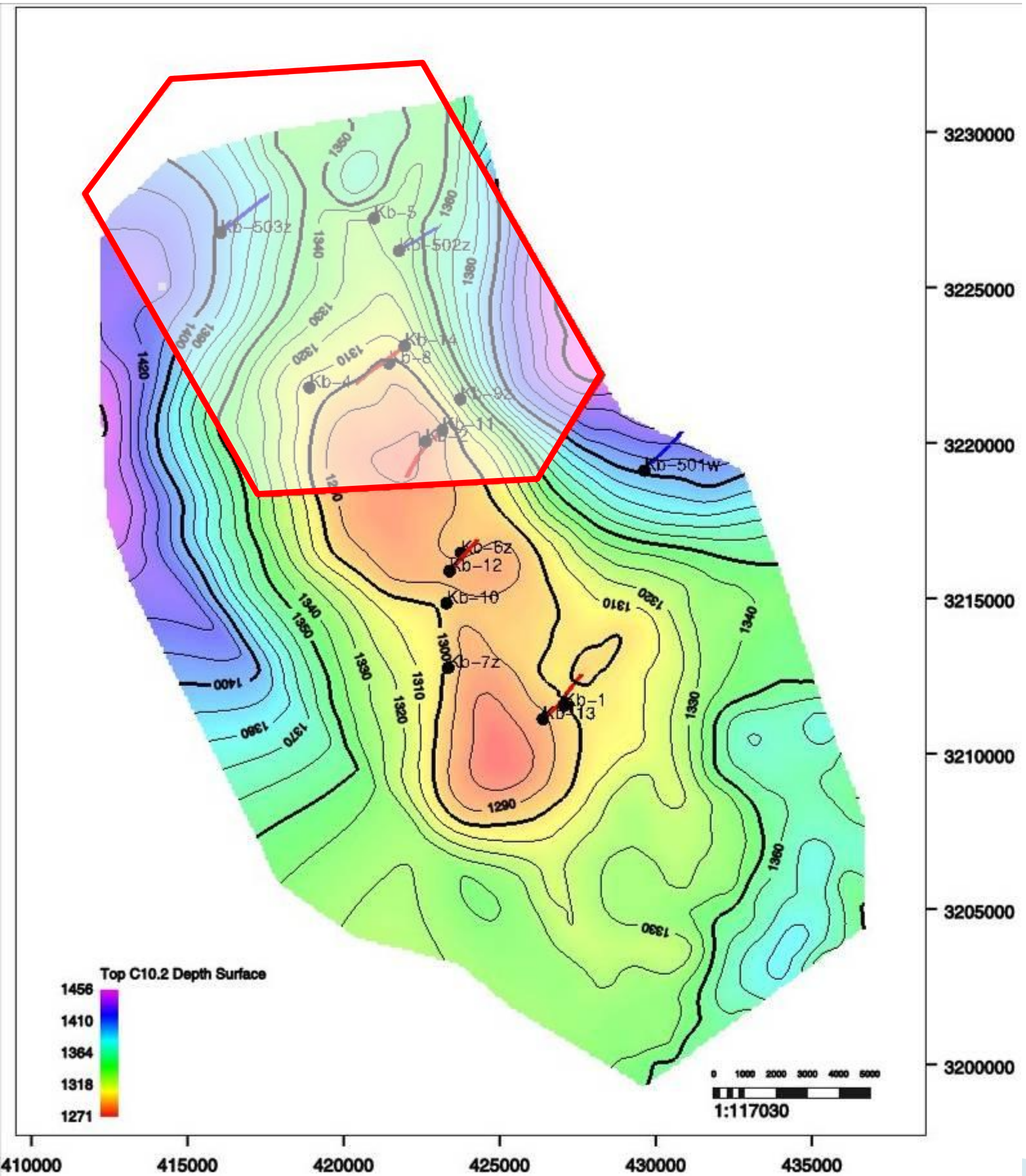
Data Acquisition: Seismic

- **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 density difference between in-situ fluids and injected CO_2**
- **Comprehensive understanding of the interaction of rock-physics, fluids and fractures is required to adequately model Seismic responses**

At Krechba:

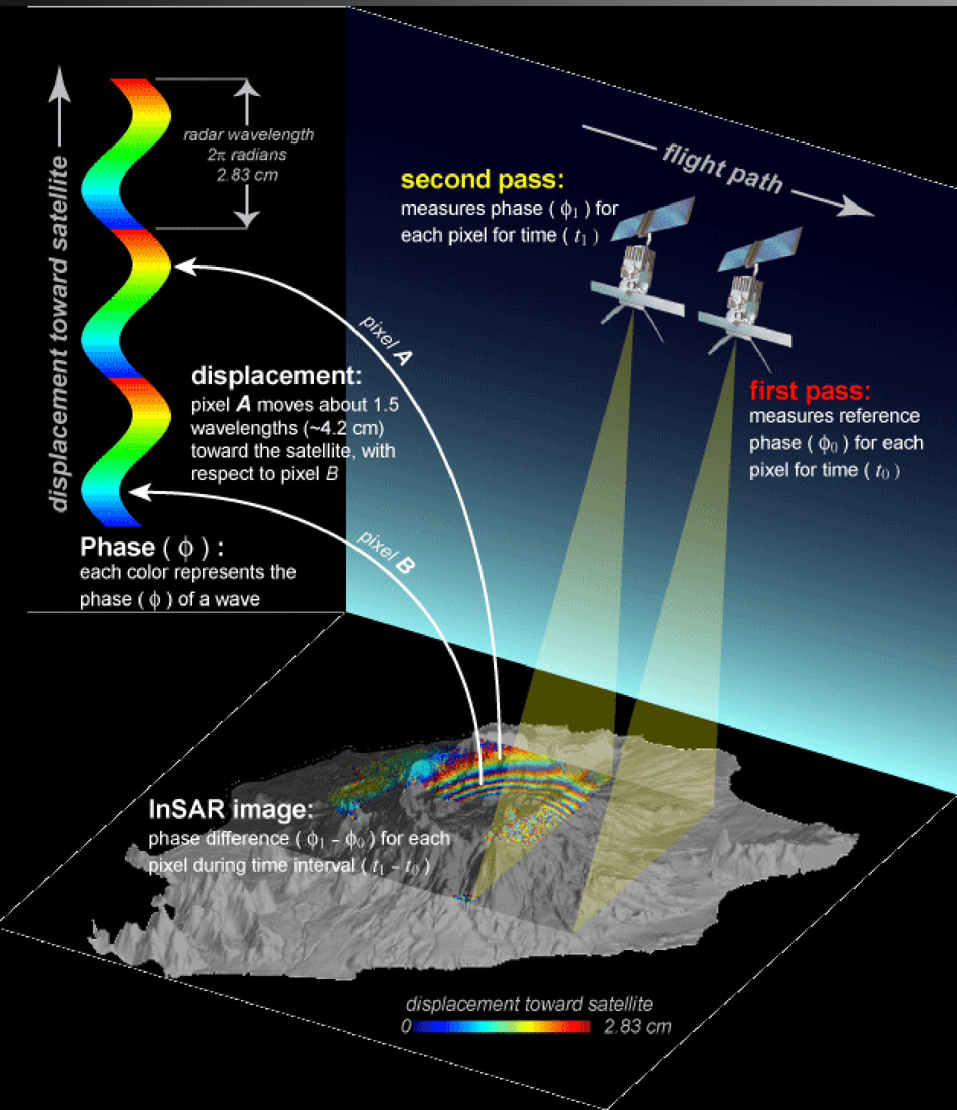
- *4D Seismic may never be a good option for CO_2 monitoring (due to poor rock quality and insufficient density contrast between fluids)*

Krechba 2009 Seismic Survey



- 2009 seismic acquired to improve overburden imaging
- Designed to provide wide angle multi-azimuth coverage to help identify fracture zones
- Focused on northern area with 3 injectors, 4 legacy wells and 2 producers
- 75% of CO_2 injected into northern area

Satellite Imagery: General

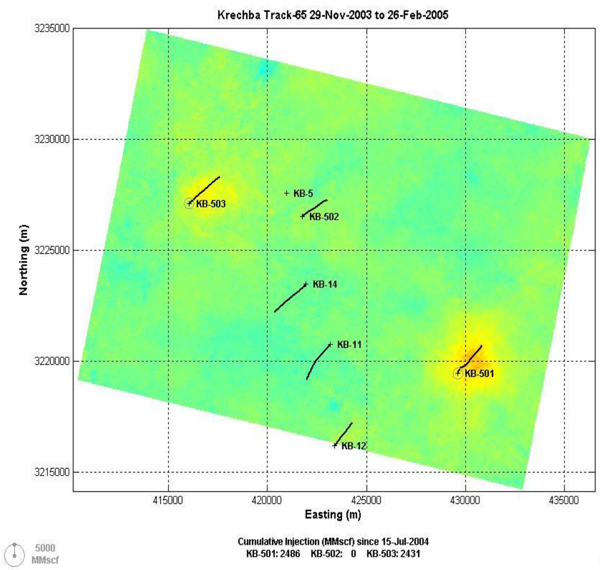


- Interferometric Synthetic Aperture Radar (InSAR)
- Technology developing rapidly due to:
  - Publicly available data
  - Better data resolution (satellite)
  - Improved processing capabilities
  - Competition between providers
- Provides accurate information on ground surface deformations over time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

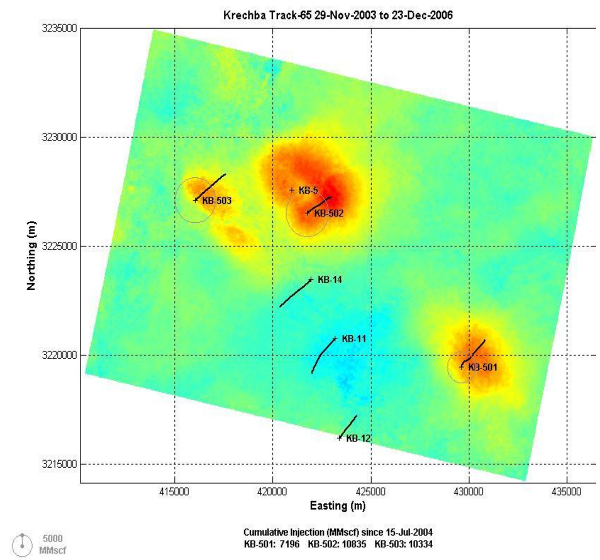
Satellite Imagery: At Krechba

- InSAR (with geo-mechanical modelling), was key to understanding the subsurface distribution of pressure fronts and CO_2 plumes
  - *Benchmarked by CO_2 observation at KB5*
  - *Influenced the 2009 seismic survey and Quantified Risk Assessment*
  - *Future value could be restricted as CO_2 moves into the depleted zone*
  - *Data available from2003 (pre-injection), C-Band (Envisat & Radarsat2)*
  - *Inversion using diversity of research partners and techniques*
  - *Used as an observation constraint for geo-mechanical modelling*

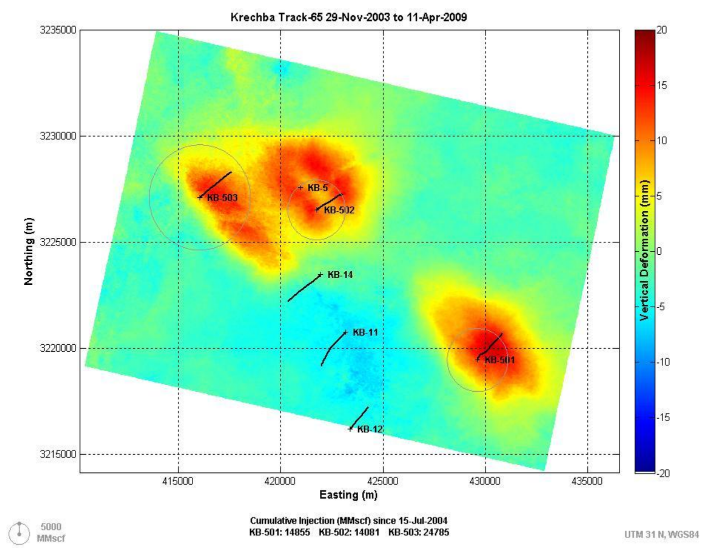
2005



2007



2009



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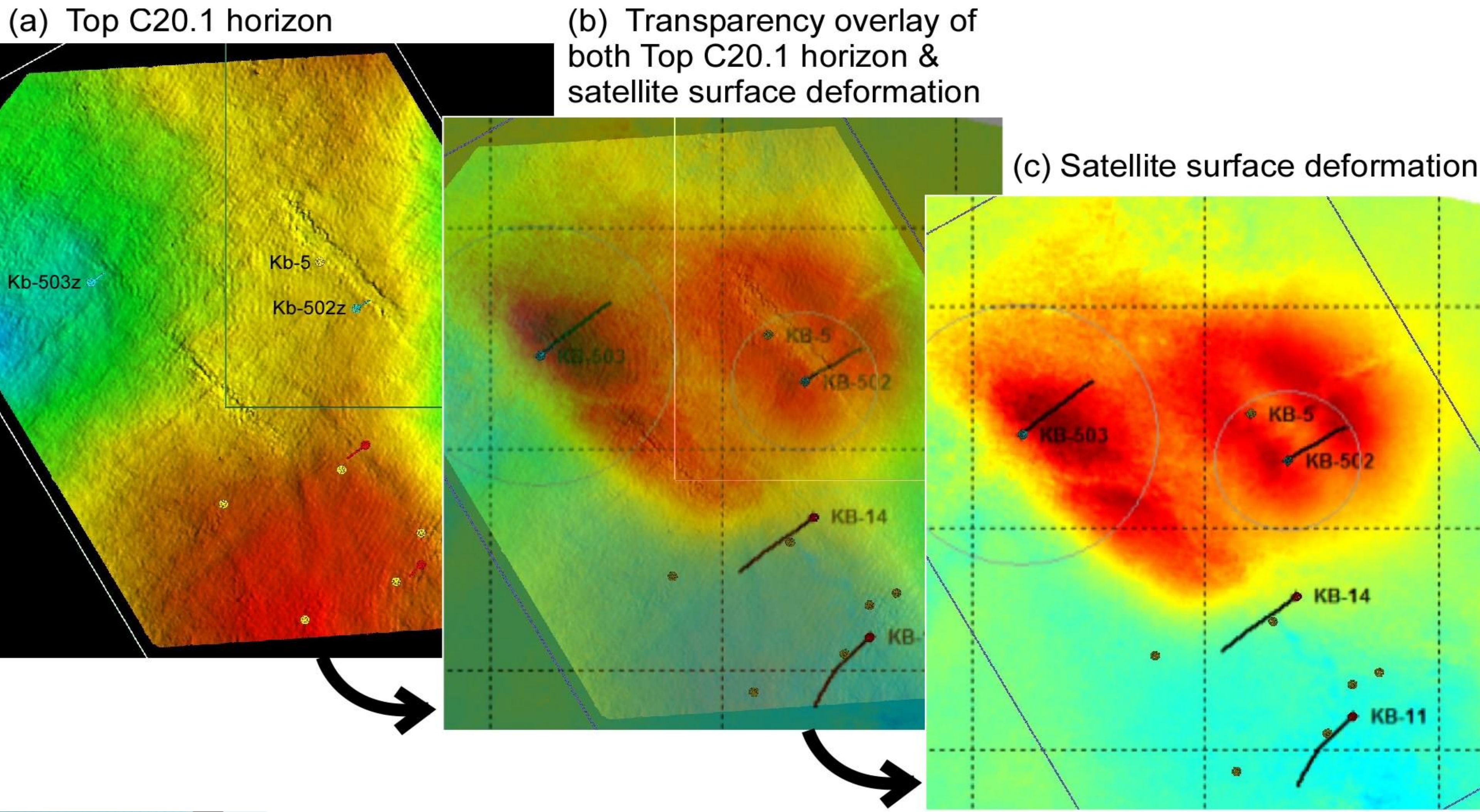
Integration

- CO_2 plume development is far from homogeneous
  - Requires high resolution data for reservoir characterization and modelling

- Effects that require advanced, coupled modelling are:
  - fluid-dynamics,
  - rock mechanics
  - temperature
  - geochemical reactions

- At Krechba:
  - *Faults and fractures play a key role in the subsurface migration of CO2*
  - *This was not sufficiently well-understood before injection started.*
  - *The JIP undertook a significant amount of work to understand the control that these features have on CO2 plume flow and implications for long-term storage*

Seismic Features Align with Satellite Imagery



Krechba: Integrated Suite of Models

Error/uncertainty in modelling parameters → **flow of CO_2 from well head to sandface**

PROSPER – WH P&T to BH P&T

↓

Error/uncertainty in modelling parameters → **from sand face to storage volume**

PIE – dynamic, analytical model

↓

Error/uncertainty in modelling parameters → **storage volume**

Irap RMS + Wellwhiz - static description

↓

Error/uncertainty in modelling parameters → **dynamic evolution of CO_2 plumes**

STARS – dynamic behaviour of CO_2 & other components

↓

Set of possible outcomes

How are these to be created & assessed?
What has been achieved so far?

Workflow

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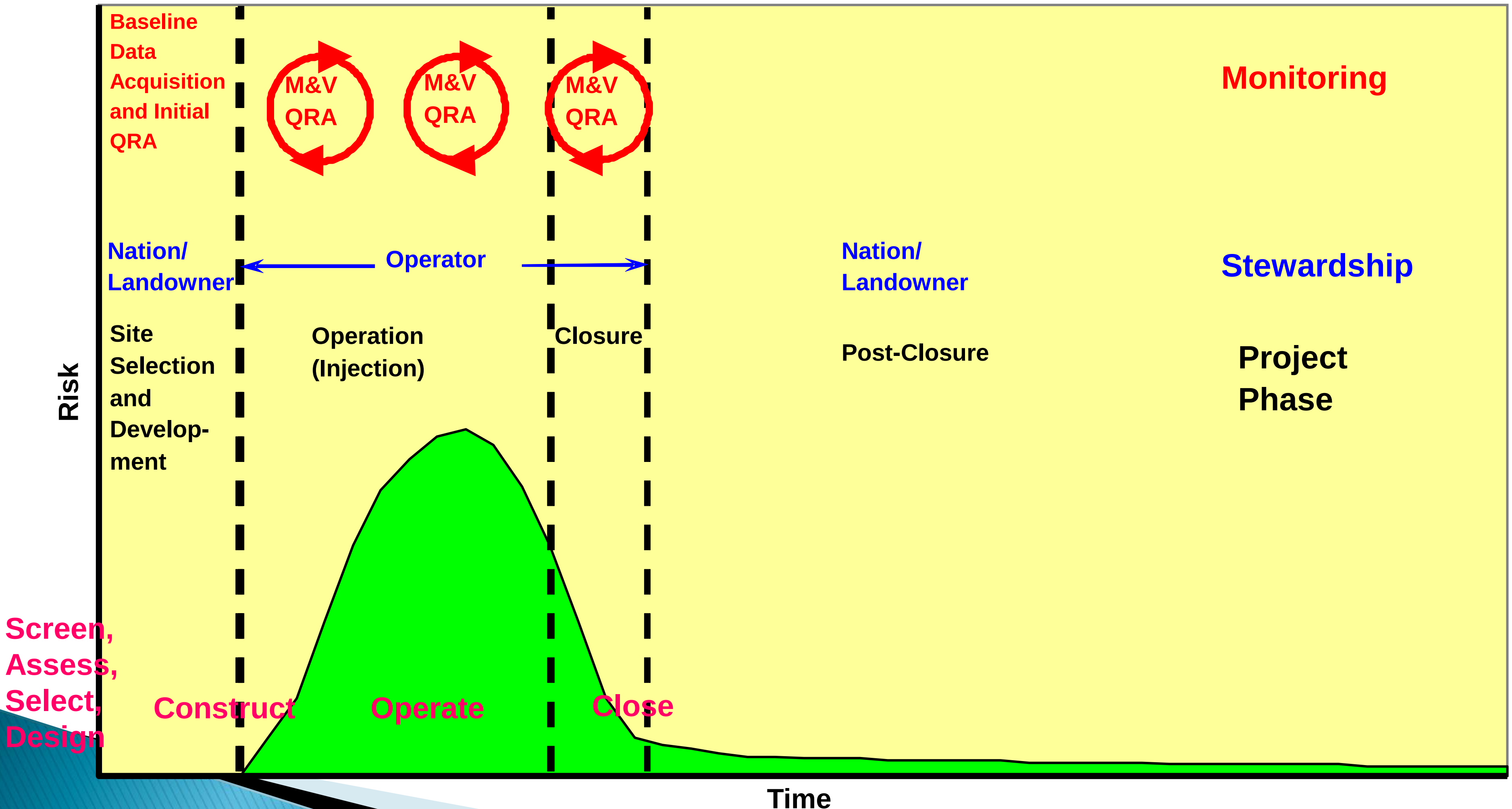
Quantified Risk Assessment (QRA)

- Quantified Risk Assessment (QRA) is an invaluable tool to understand, manage and communicate the performance of CO_2 storage
  - Should be periodically repeated over the life of a CO_2 storage project
- Several methodologies exist:
  - CCPCF, URS, FEP, Oxand
- There is no regulatory agreement on acceptable leakage risk

At Krechba:

- *Pre-injection risk-register highlighted the key risks and informed the initial (minimal) baseline survey data and early monitoring programme*
- *The 2008 QRA highlighted changes to the risk profile of the project and the injection and monitoring programmes were amended to address that*
- *Without a proper QRA conducted on a regular basis, these changes to the monitoring or operational strategies may not have been implemented in a timely manner*

Risk Profile



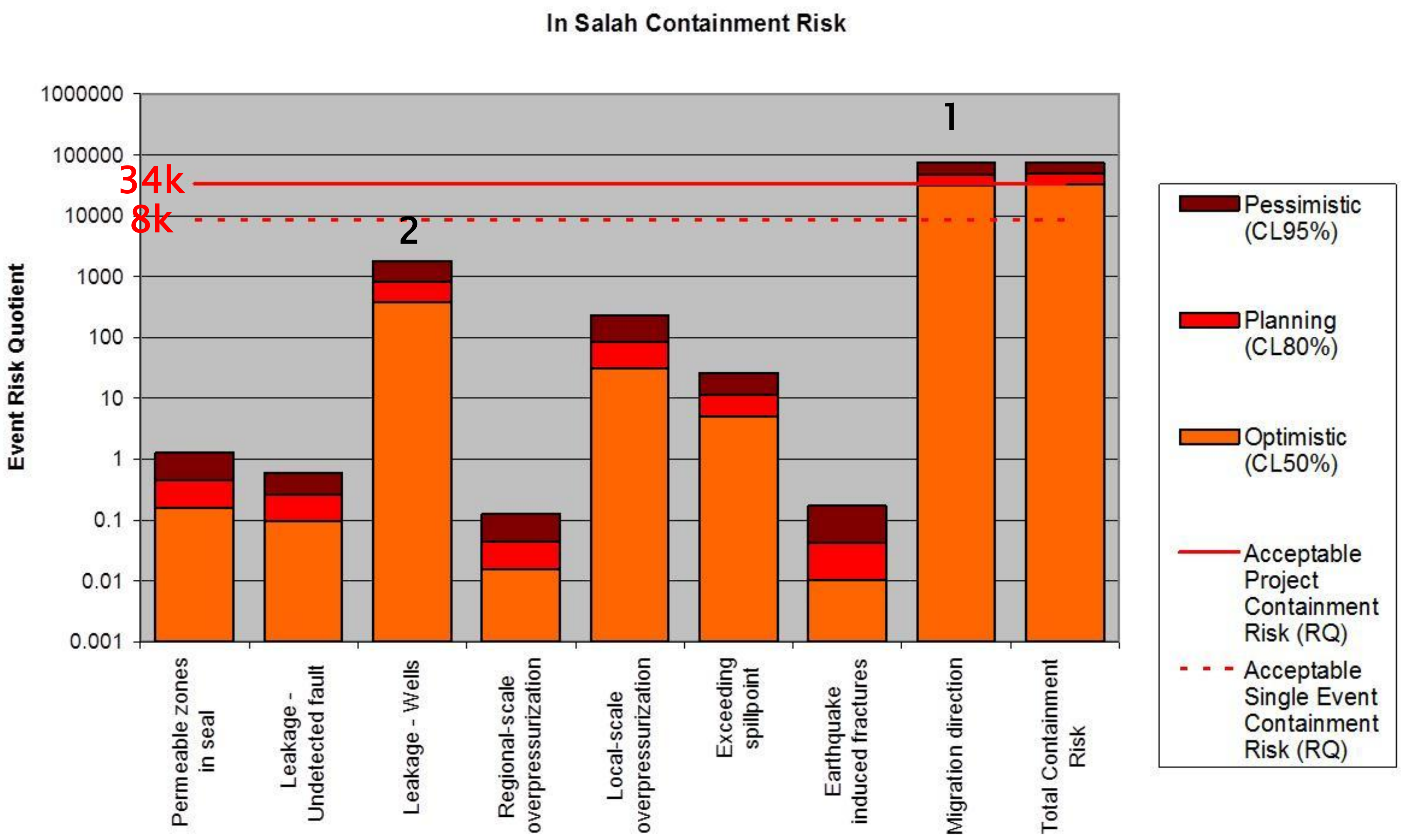
Acceptable Leakage Risk?

IPCC Special Report on CCS:

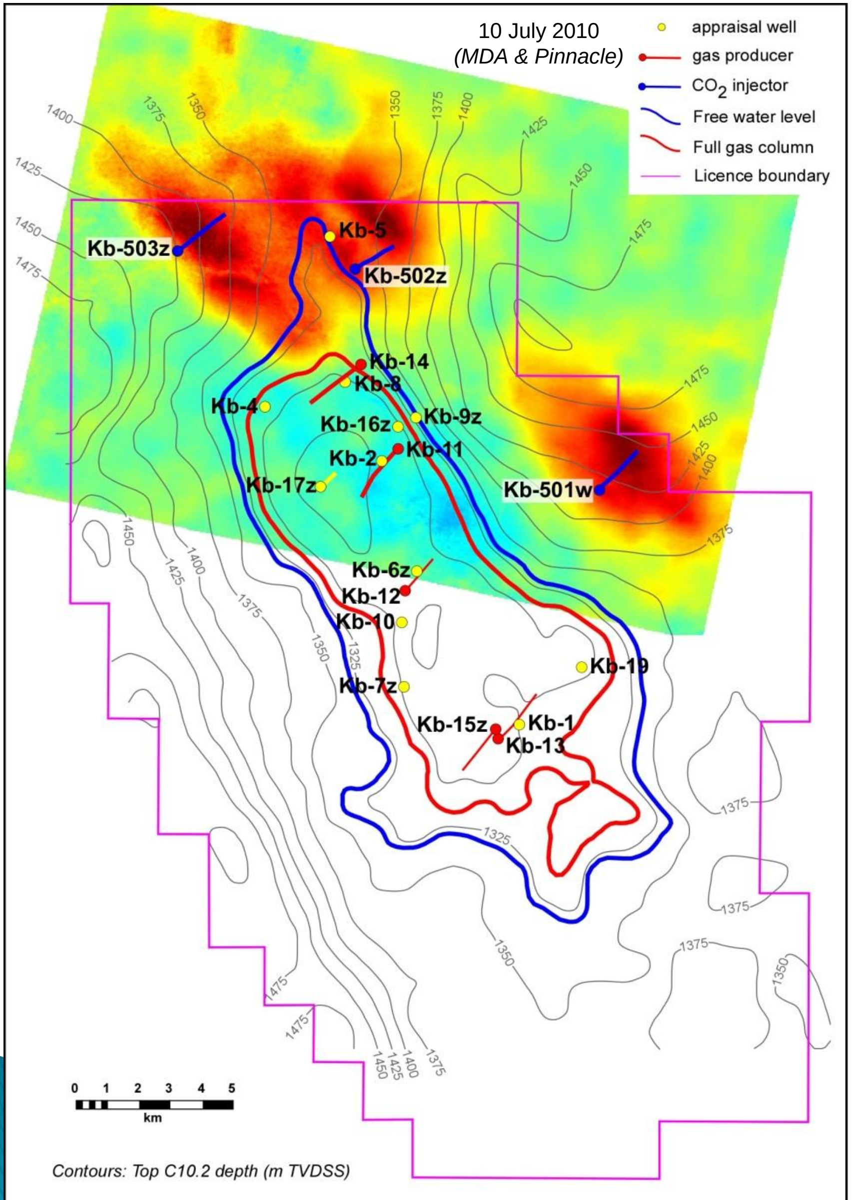
- "the fraction [of CO_2] retained in appropriately selected and managed geological reservoirs .....is likely to exceed 99% over 1,000 years"

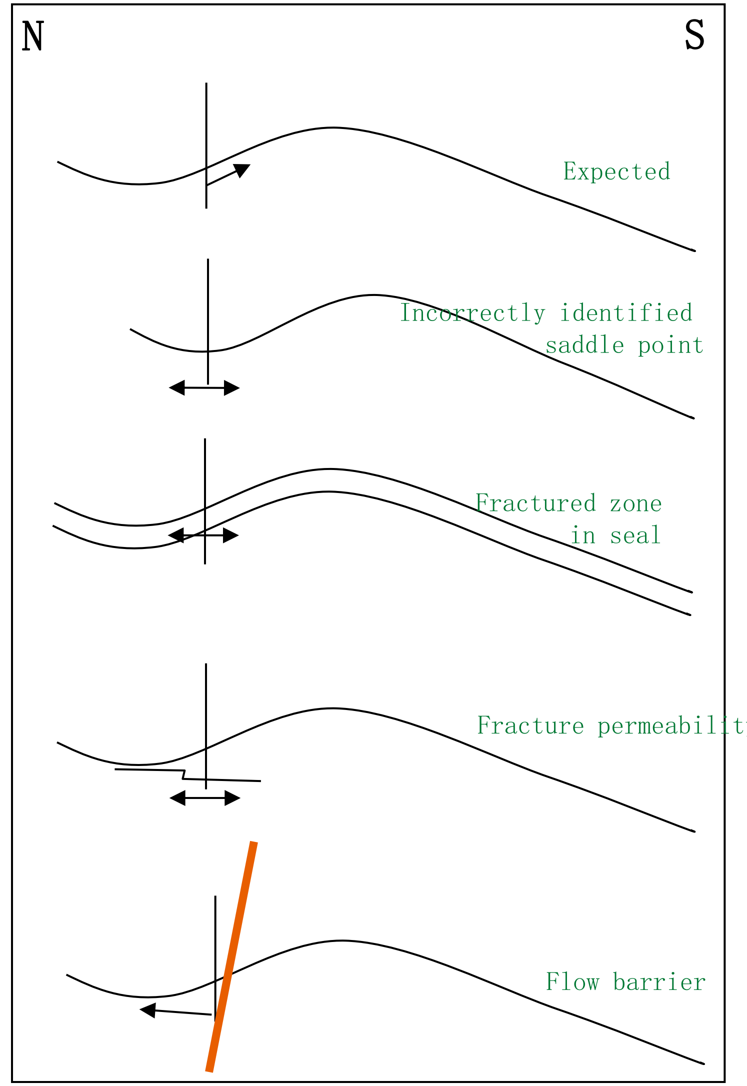
- 17mm tonnes x 0.01 x 0.2 = 34k tonnes
- " " 0.05 = 8k tonnes

Quantified Risk Assessment

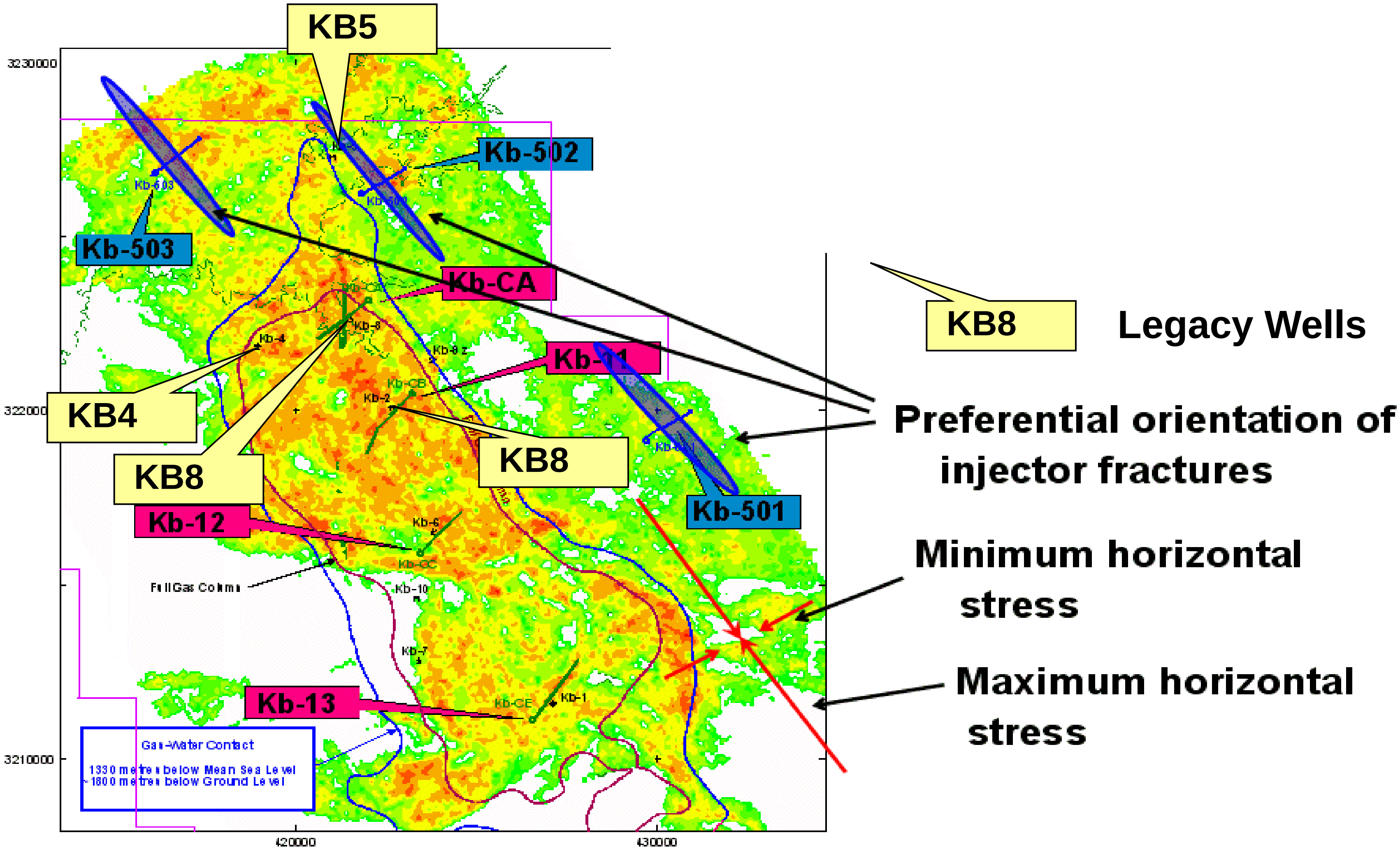


Key Risk #1: Migration Direction Risk

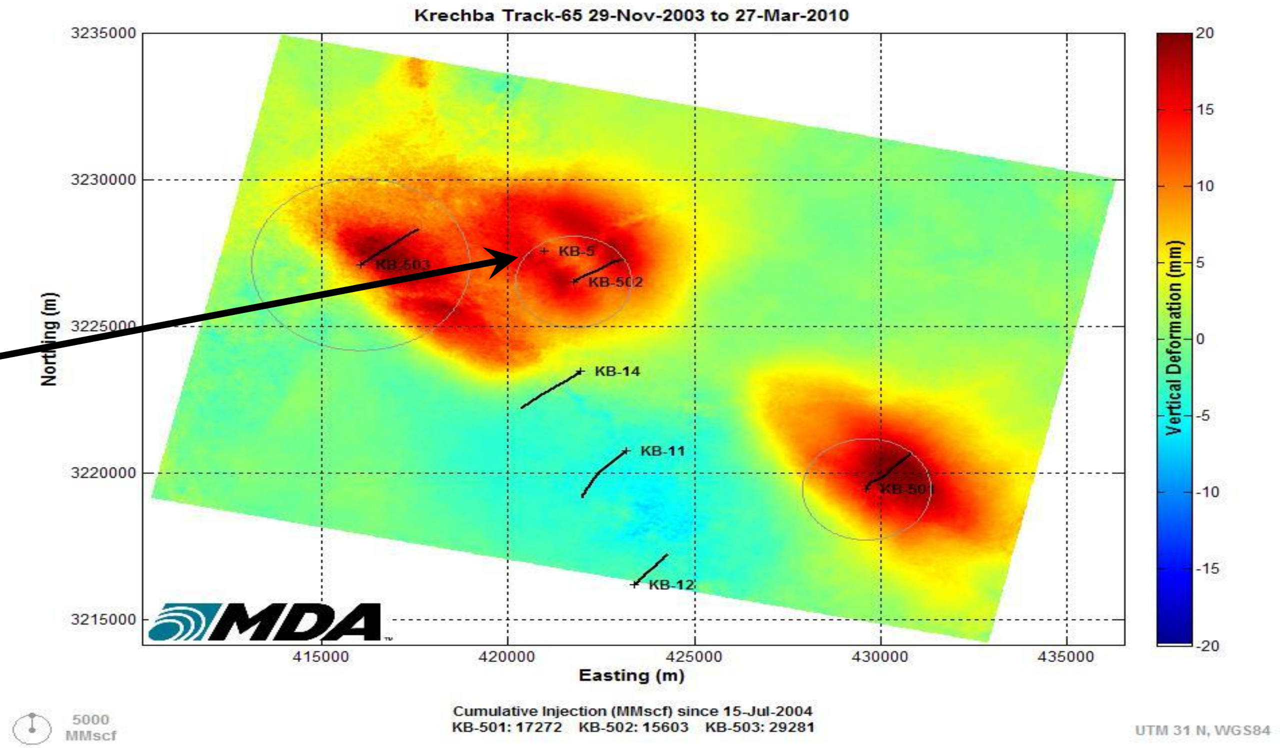




Key Risk #2: Legacy Wells



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

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In Salah and EU Directive

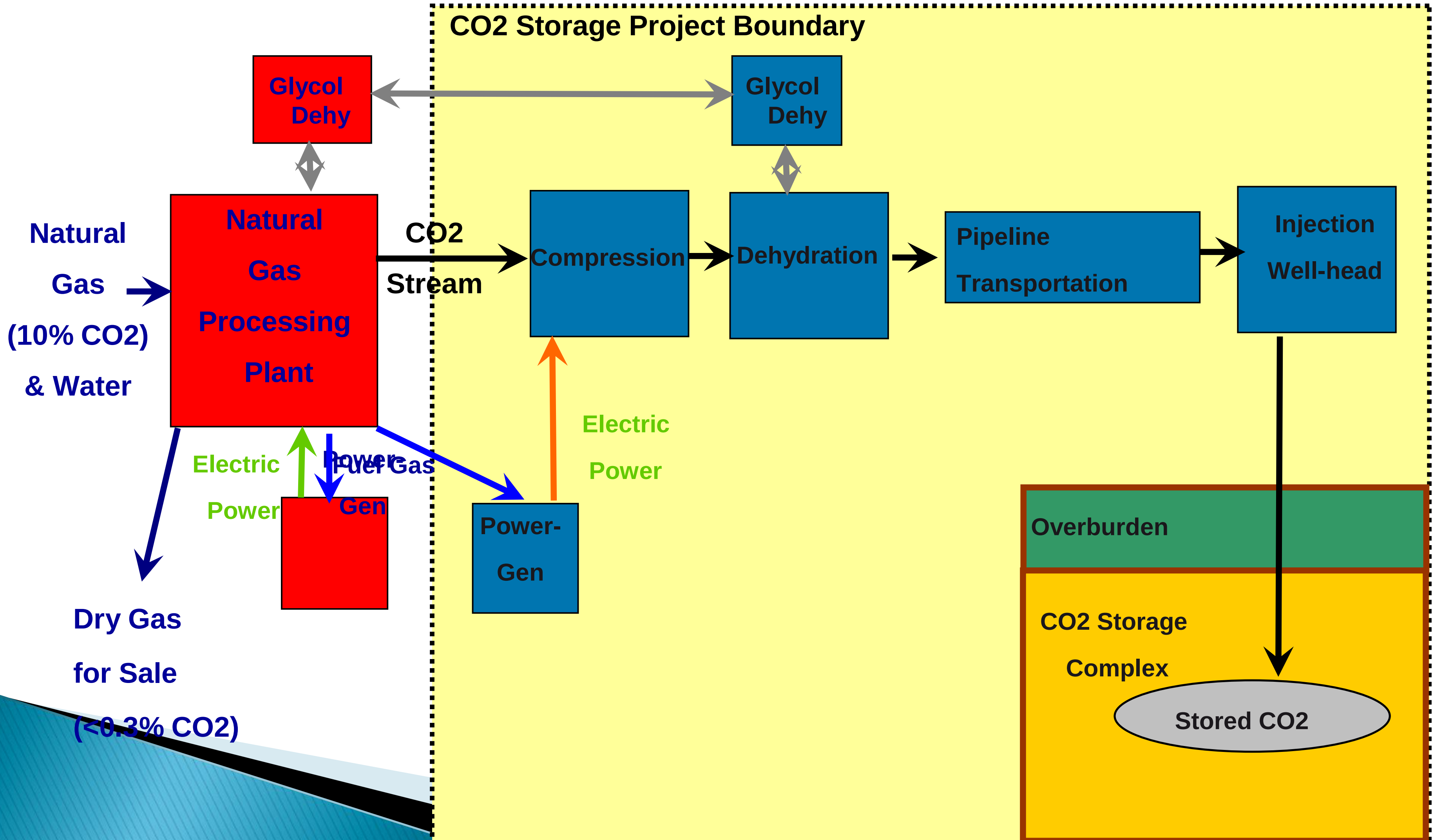
Colour Key

- 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 C... elstore risk assessment methodology (DNV 2010a)						
		Dialogue on Risk ma... with CA						

In Salah and Kyoto Protocol: CDM



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Thank-you! Questions?

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