South West Hub
Carbon Storage

Presented by

Dominique Van Gent

Agenda

Australian Government
Department of Industry, Innovation and Science

- Context for CCS
- Australian Approach towards CCS
- CCS in the South West
  - SW Hub Storage Concept
  - Performance Factors
  - Project Development Processes : Workflows and Technical Assurance
  - Static Model
  - Dynamic Model
- Uncertainties and Future Action
- Summary

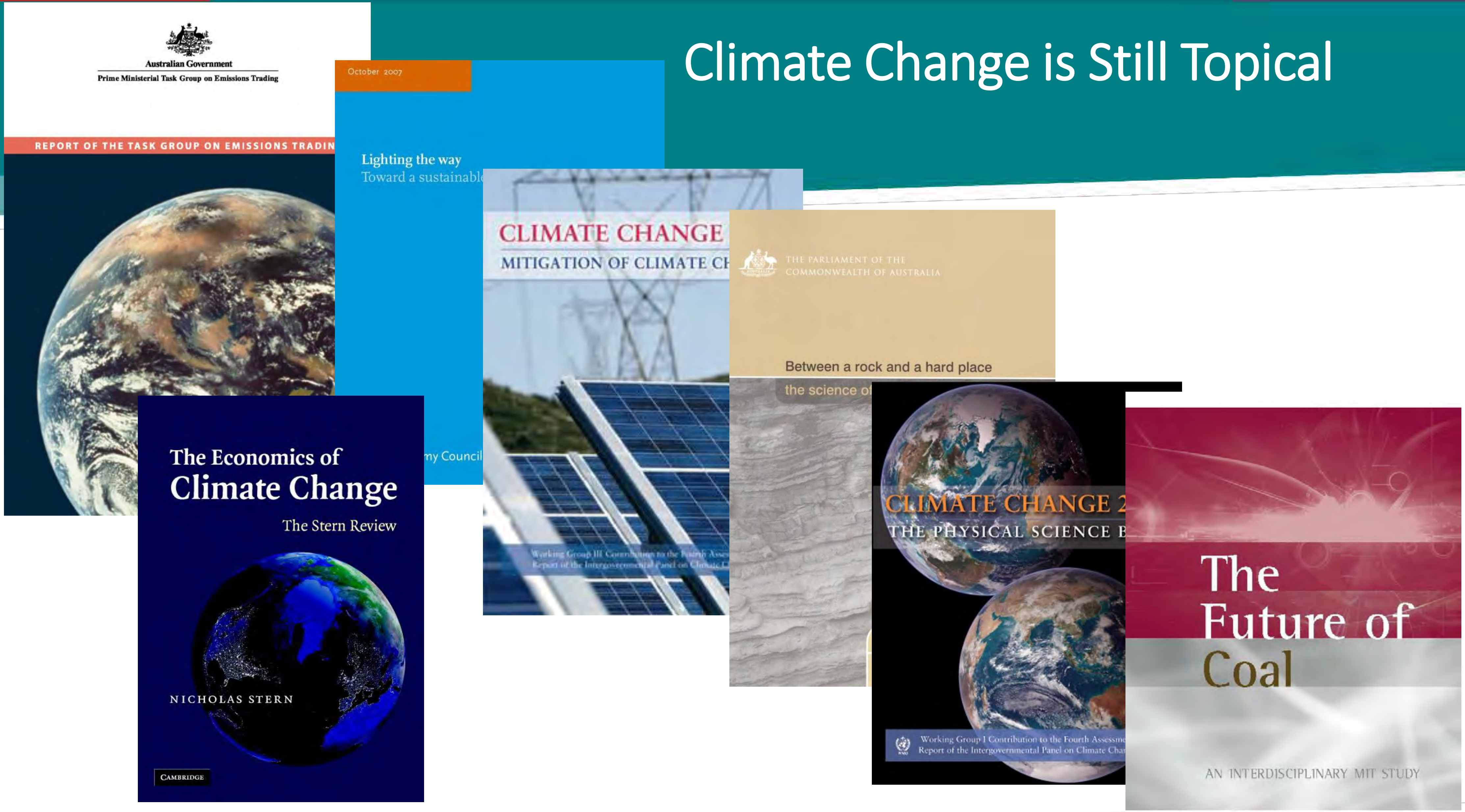
The project is supported through the Australian Commonwealth Government CCS Flagship Program through the Department of Industry, Innovation and Science (DOIIS);

The West Australian State Government through the Department of Mines, Industry Regulation and Safety (DMIRS);

The Australian National Low Emissions Coal R&D Program; and

The local community in the south west of Western Australia.

Climate Change is Still Topical



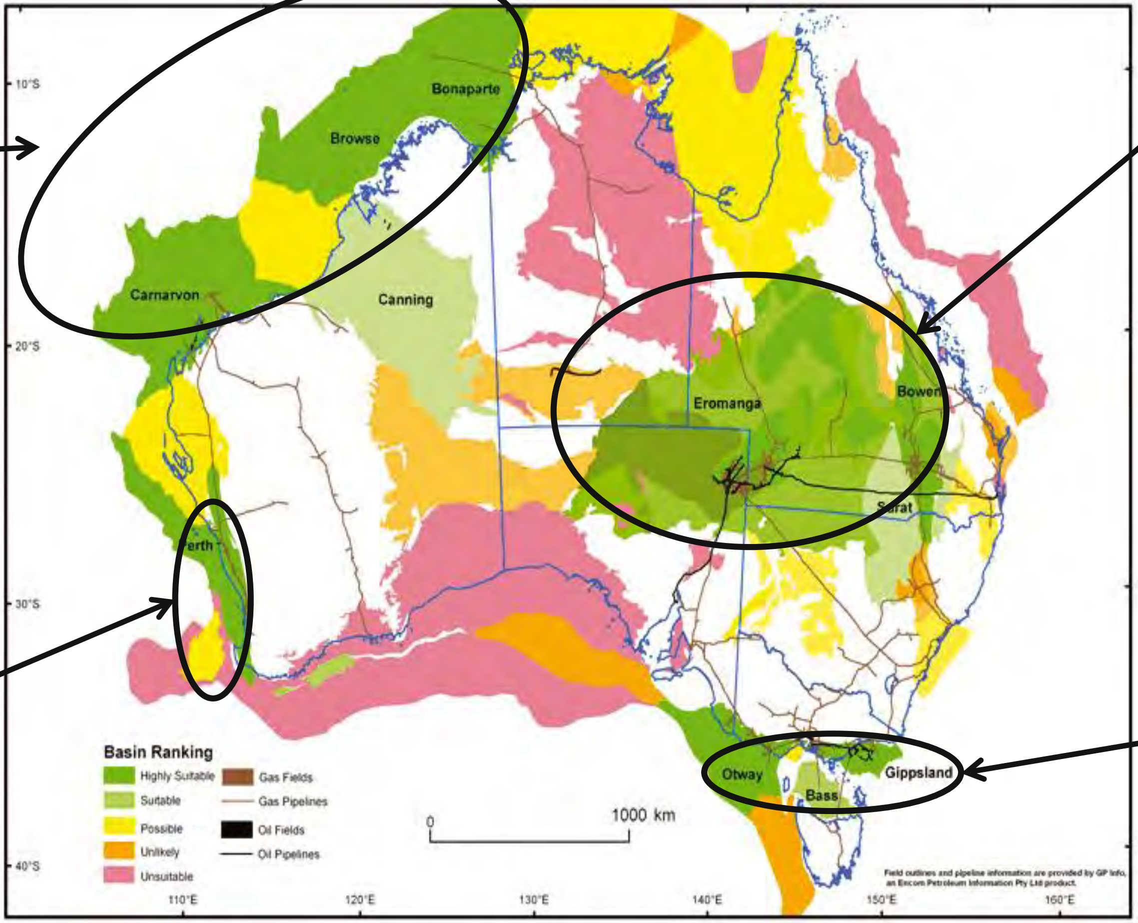
Why Carbon Capture and Storage ?

- CCS is an important part of the lowest-cost greenhouse-gas mitigation portfolio. Without CCS, overall costs to halve emissions by 2050 rise by 70%
- CCS is more than a strategy for "clean coal". CCS is effective for all fossil fuel power sources (gas, coal & oil)
  - CCS technology must be adopted by biomass and gas power plants, in the fuel transformation and gas processing sectors, and in emissions-intensive sectors like cement, iron and steel, and chemicals manufacturing including Alumina
- The effect of building coal with Carbon Capture and Storage (CCS): the initial steps are more expensive than renewables, but the abatement cost curve crosses over around 45%, after which renewables becomes a more expensive way of decarbonising the system. Of all the options explored, CCS offers the potential to go the furthest, achieving 80% emissions reduction

2009 Carbon Mapping Task Force: High level Identification of Potential Storage Sites

Large resource utilisation for gas-related storage other sources too remote

Moderate potential resource – limited occurrence of conventional seals



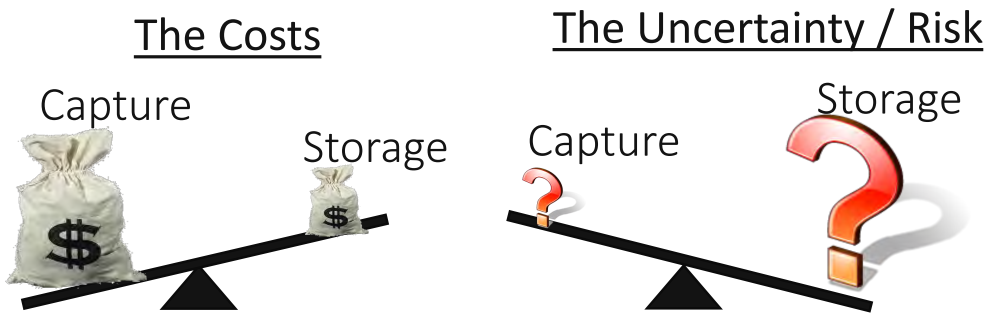
Large resource – access dependent on alignment of storage with groundwater extraction

Large resource – access dependent on alignment of storage with petroleum production

Source: Carbon Storage Taskforce Report

CCS In Australia – Key Themes established in the early 2000's

- Key elements of Capture, Transportation and Storage need to be considered differently
  - Capture: Engineering Challenge – Cost and energy penalty focused
  - Storage: Uncertainty Challenge – Need to identify structures
  - Transportation: Experience in the USA and gas pipelines in Australia
- Need for Legislation and Regulation
  - Oil and Gas Acts to be modified at Commonwealth and State Levels
- Community Confidence needs to be built
  - Best done through pilot projects in the country



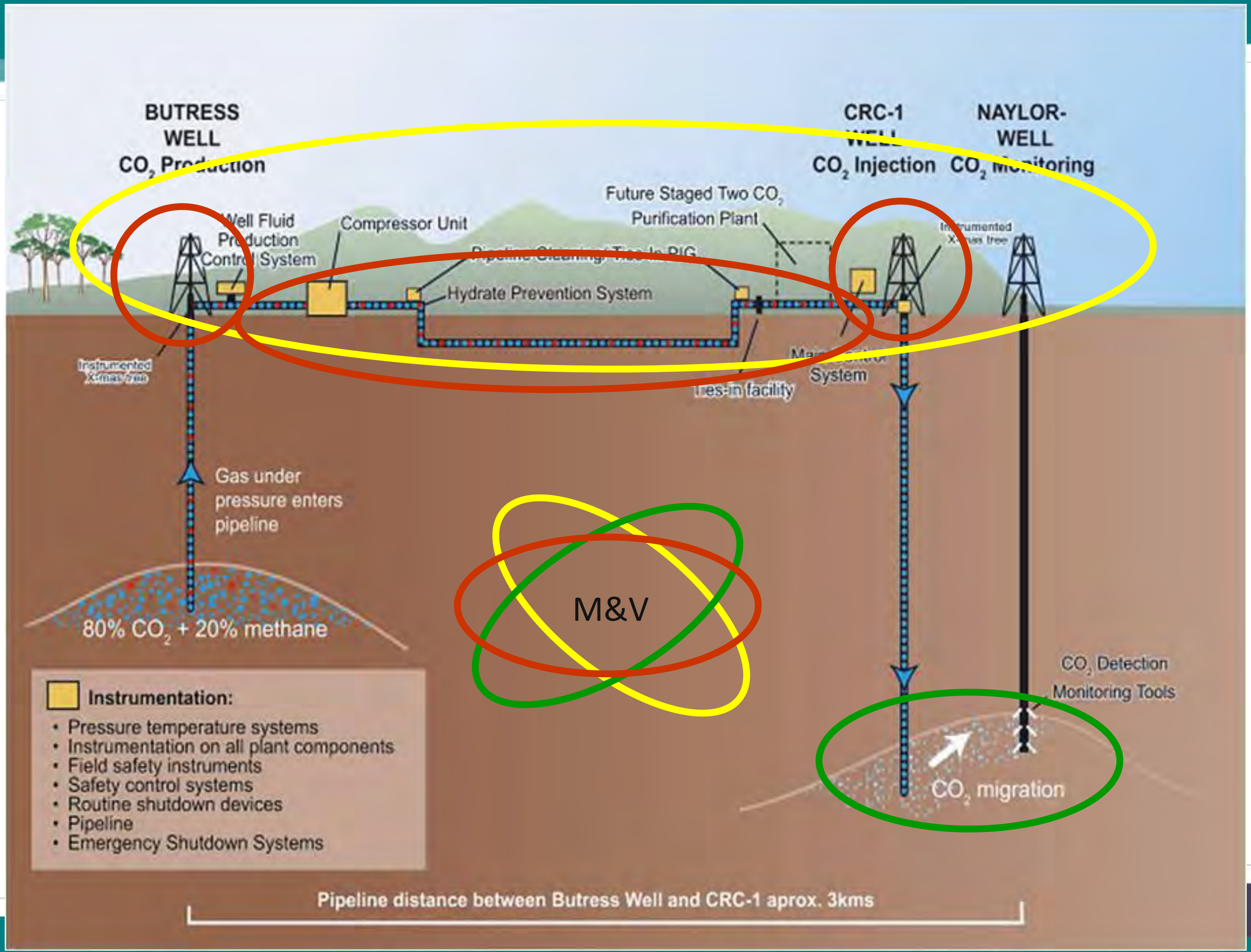
Our focus is on storage!

2004-2008 CO2CRC – Otway Stage 1 Demonstration Project : Insight into Legislation

Petroleum Act
DPI

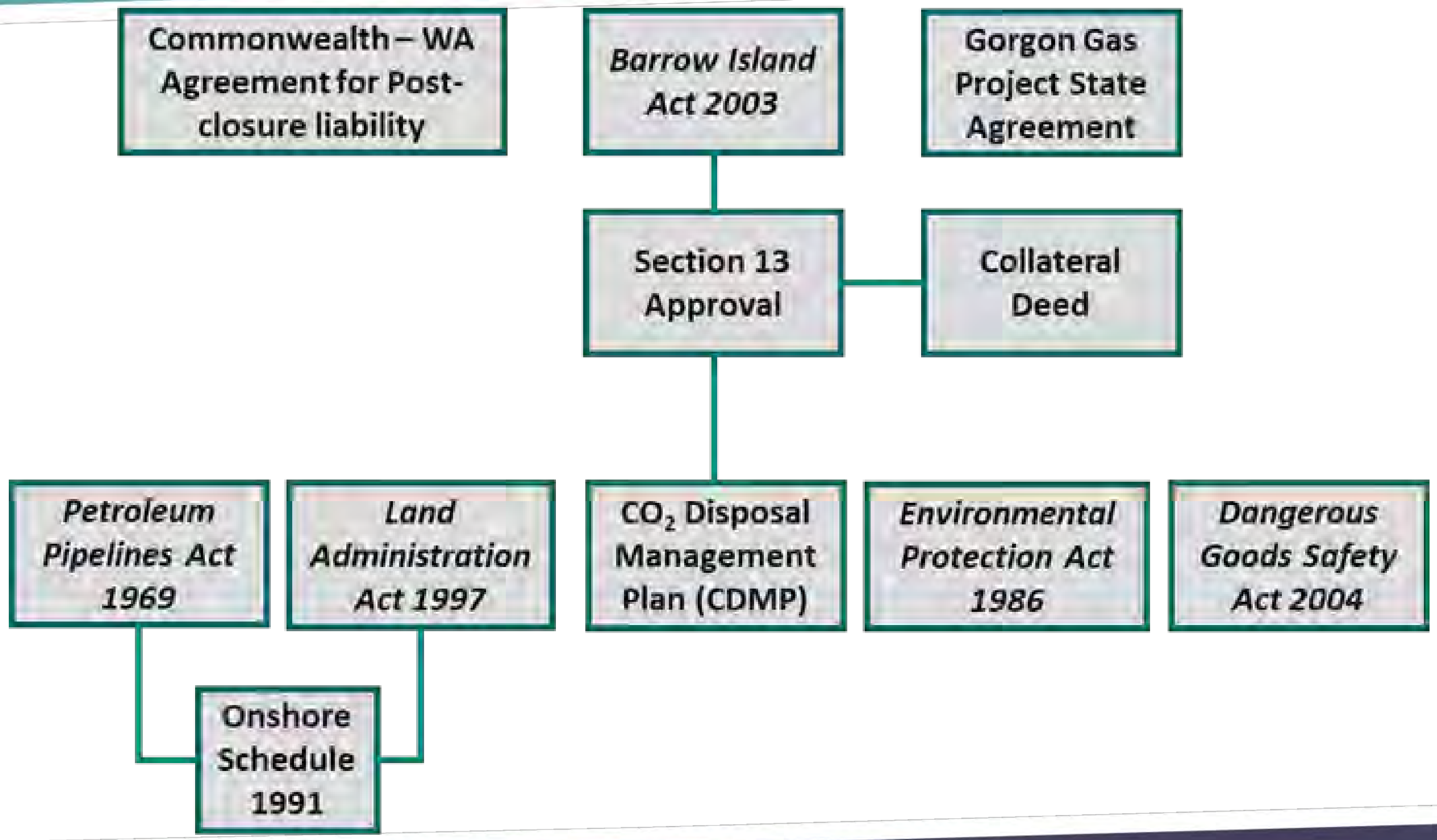
EPA
SRW

Planning Act
– DSE/Shire



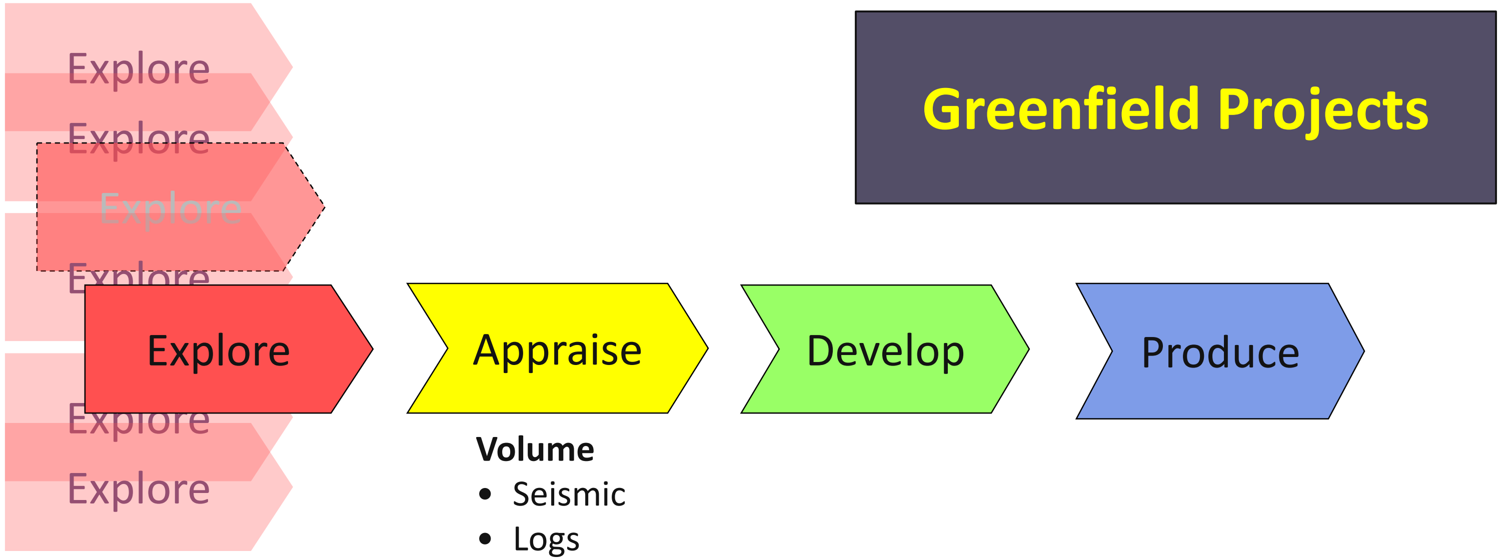
CO2CRC Ltd

Gorgon regulatory arrangements



Storage : Learn from the Oil and Gas Industry Diversify Front End Risks

Find & Develop a combination of specific sub-surface conditions
Studies, models, risk assessment and campaign **drilling**

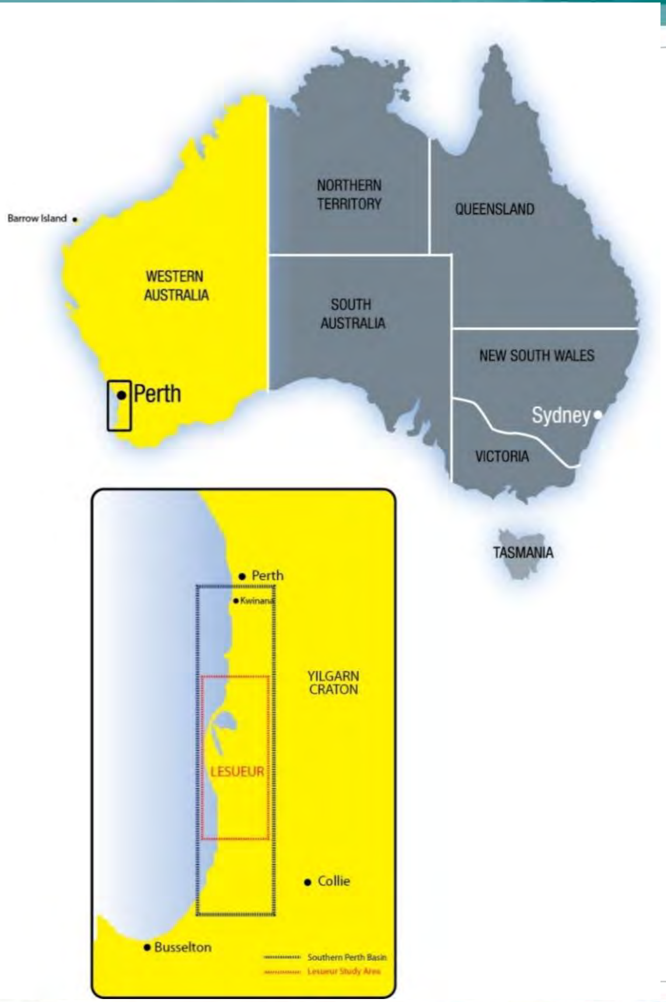


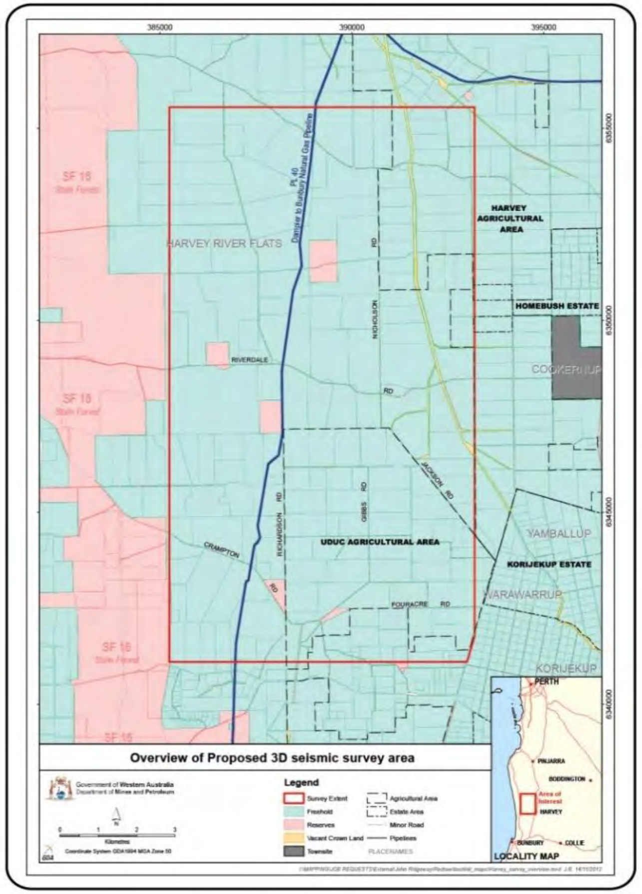
Diverse Risks Across
- Plays & Prospects
- Joint Ventures
- Technology / Costs
- Scale

Volume
- Seismic
- Logs
- Pressures

Rate
- Logs
- Samples
- Tests
- Extended Well Tests

SW Hub LOCATION : Near Industrial Centres



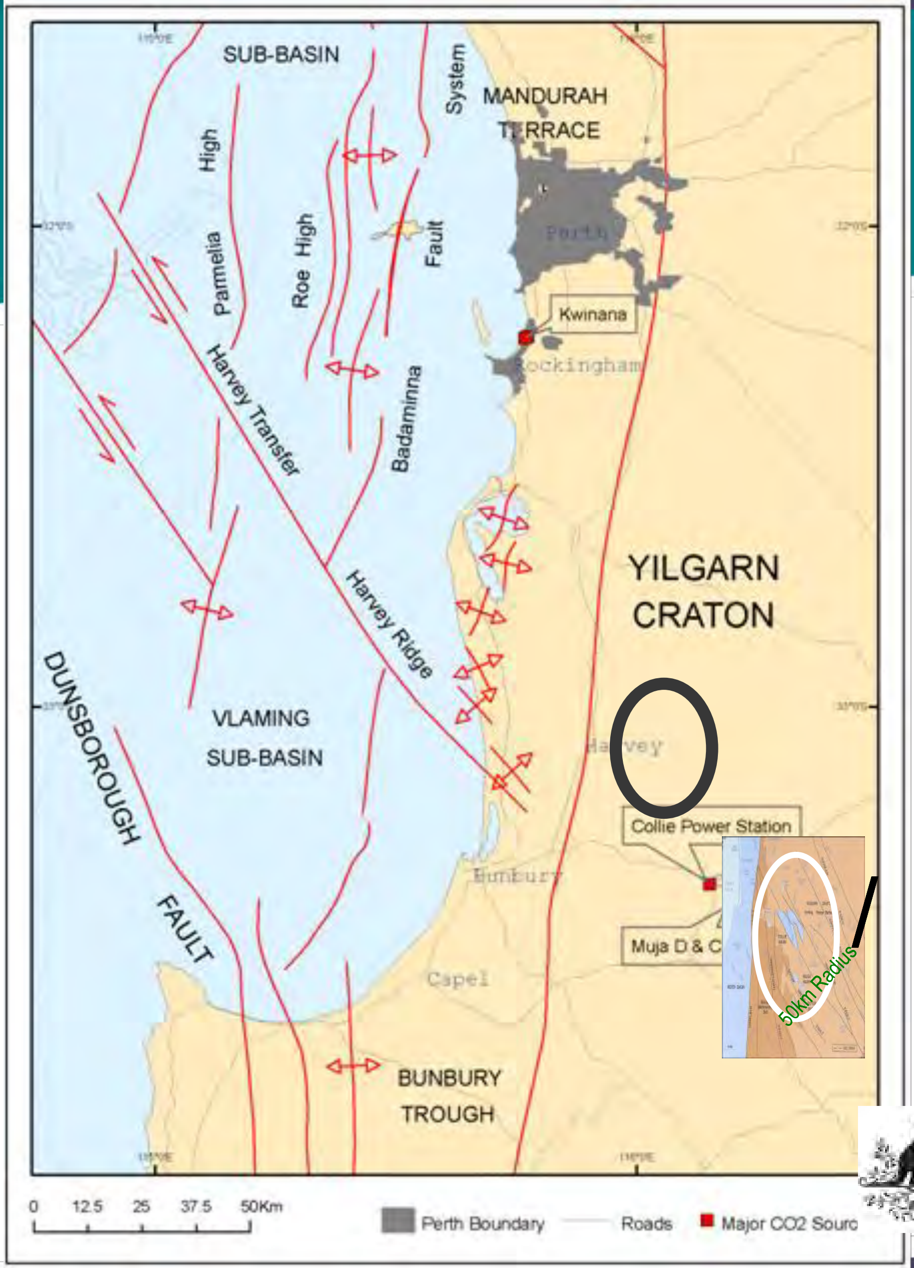


- In the heart of South West industry
- Agricultural and lifestyle area
- Project does not compete with potable water

Screening Studies : 1998 – 2007

S. Varma, T. Dance, J. Underschultz, R. P. Langford and K. Dodds

- APCRC Studies in 2000 identified potential areas in State
  - Collie Basin screened out
  - Southern Perth Basin identified as a possible area of interest
- CO2CRC study (2007) looked closer at this area for potential options :
  - Lightly explored: limited well and seismic data
  - **Harvey Ridge "Lesueur" identified as a potential area of interest**
  - 2,200 metre thick (800m to 3,000m+)
  - Wonnerup target injection Member over 1,500 m thick
  - Major aquifer "Yarragadee" absent



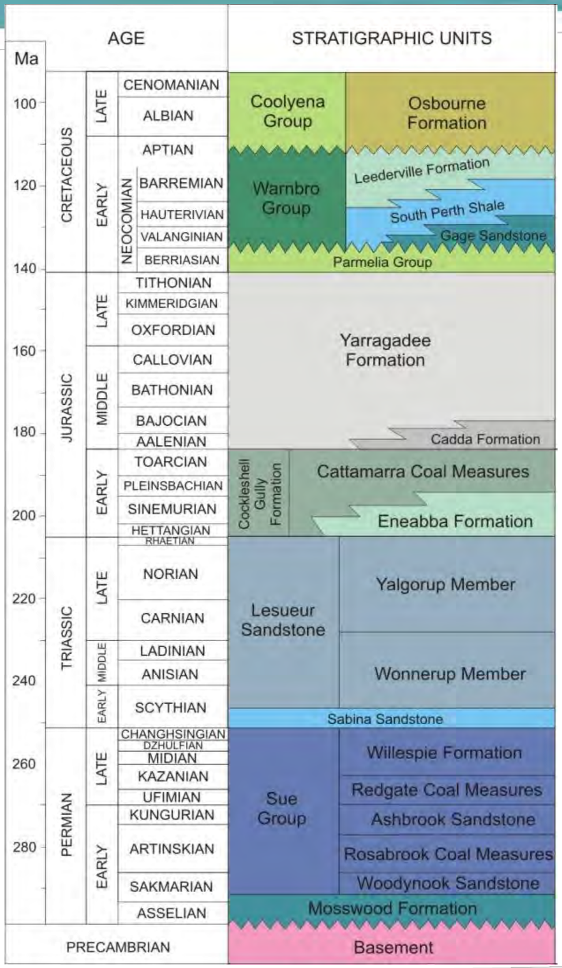
CSIRO

CO2CRC

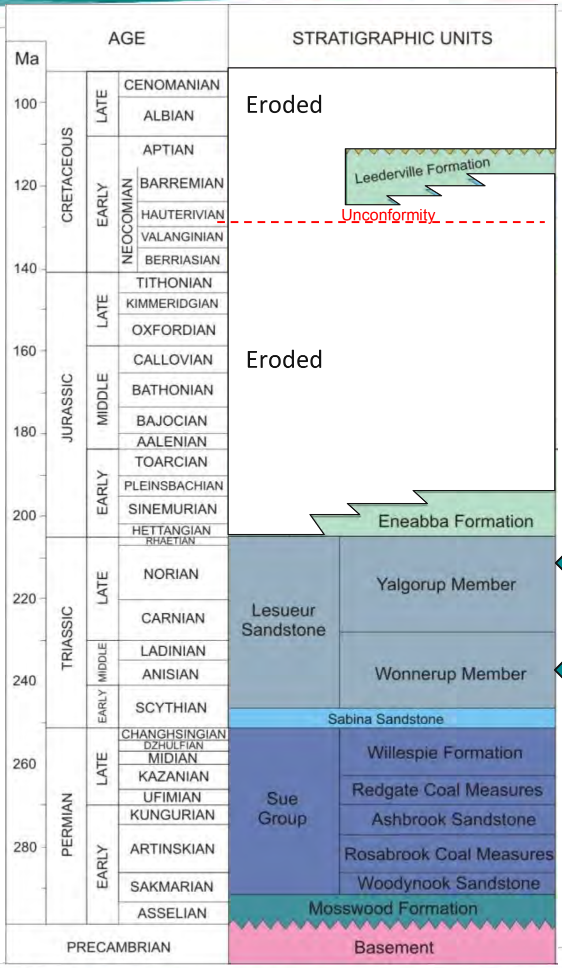
Australian Government
Geoscience Australia

SW Hub Stratigraphy: Regional and in the Area of Interest (AOI)

Perth Basin



AOI



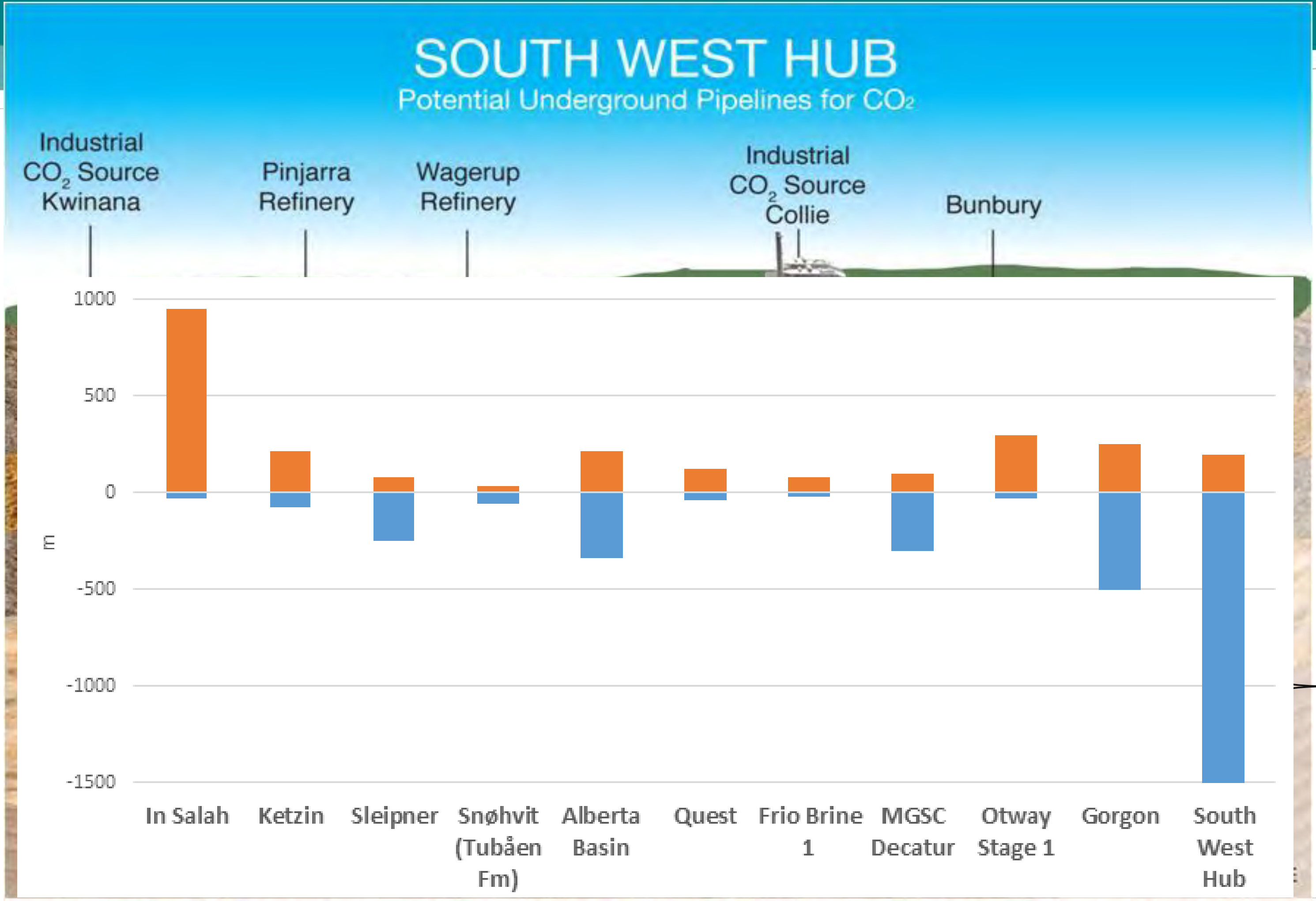
No basin resource conflict - absence of Yarragadee freshwater aquifer is critical to site selection

Lesueur Sandstone

Yalgorup Member 800 meters thick

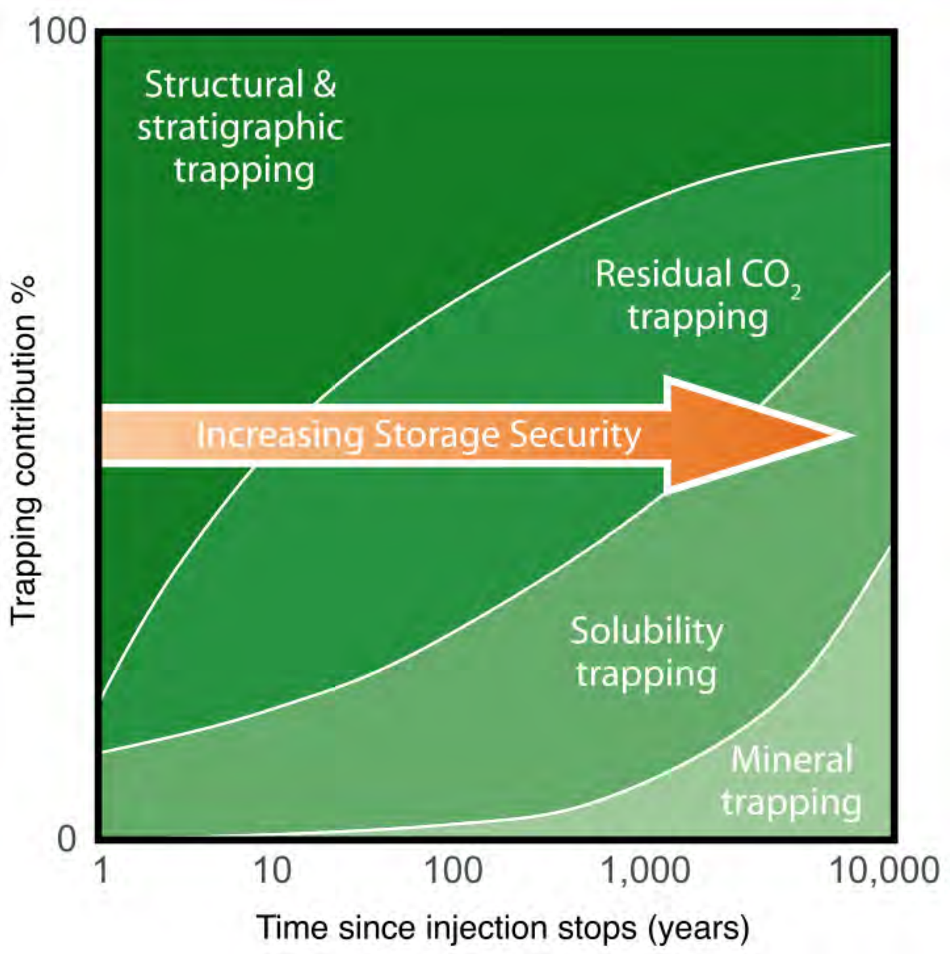
Wonnerup Member 1500 metres thick

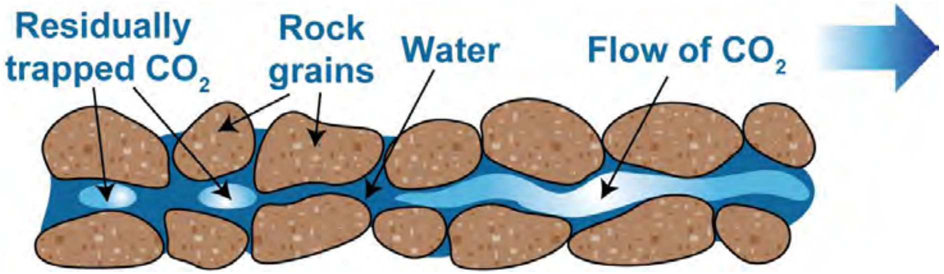
South West Hub Project Concept: Containment in a Thick Reservoir

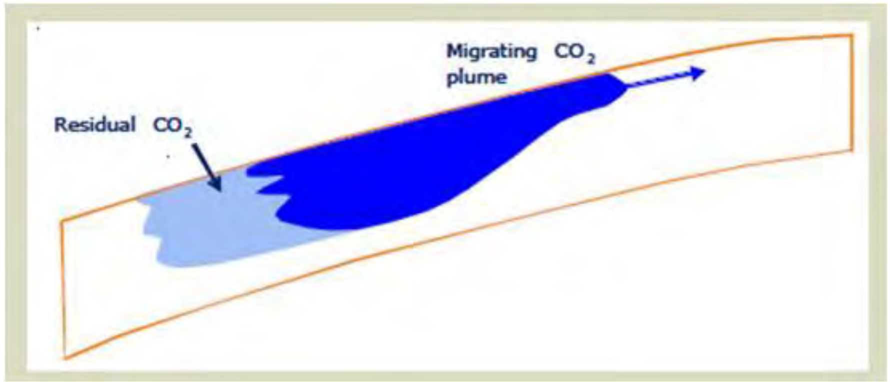


Storage Concept:
Containment through **residual trapping and dissolution within Storage Complex**

SW Hub : First Project aiming for Containment Without a Traditional Structural Seal.

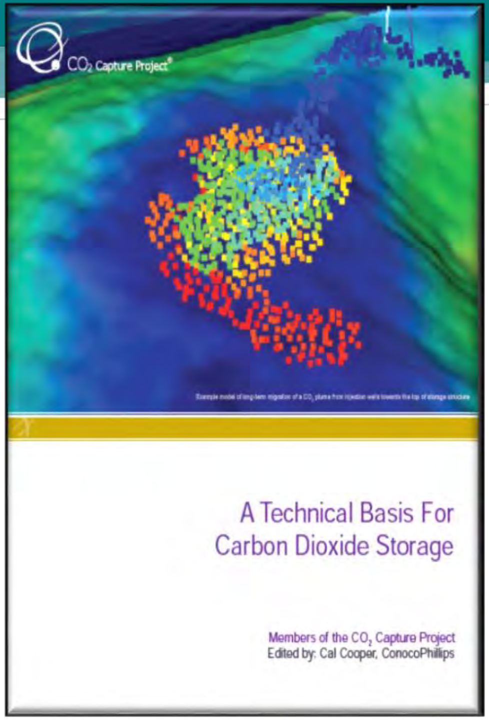


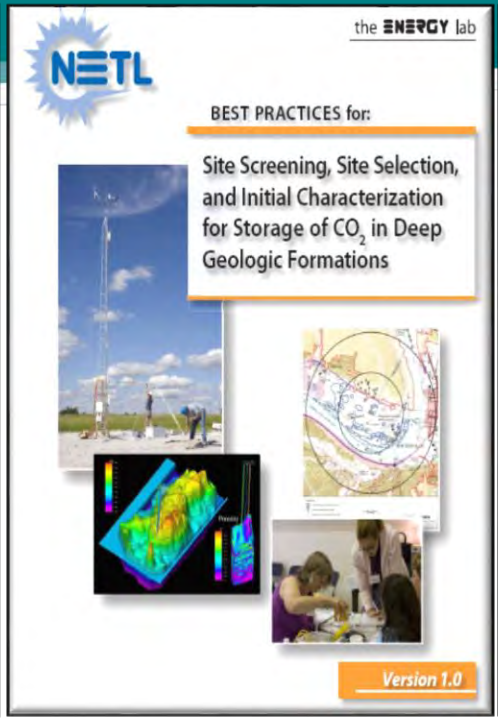


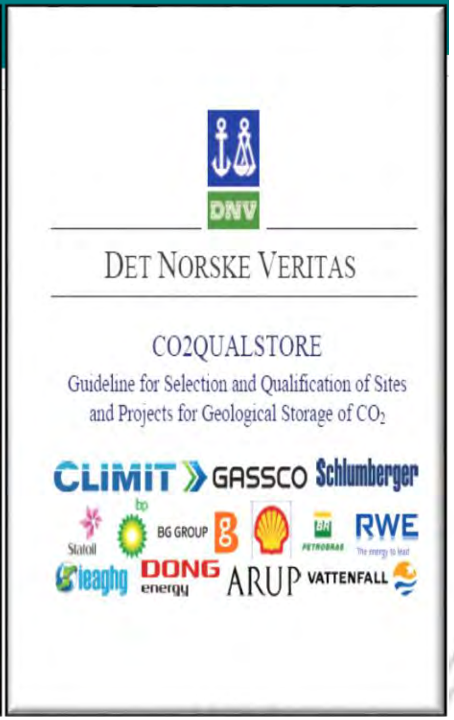


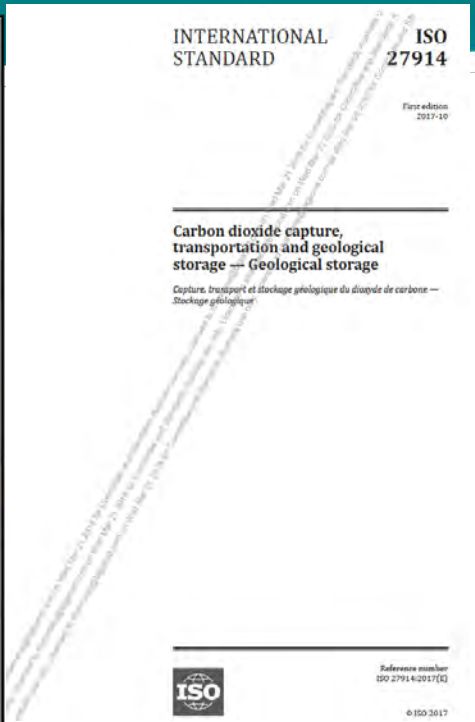
IPCC 2005, CO2CRC, CCP 2009

Seeking CCS Solutions - Focus on Process and Good Practices









Suitable Geology becomes a key determinant for storage.

Capacity

The amount of CO_2 that can be safely stored

Injectivity

The rate at which the CO_2 can be injected

Containment

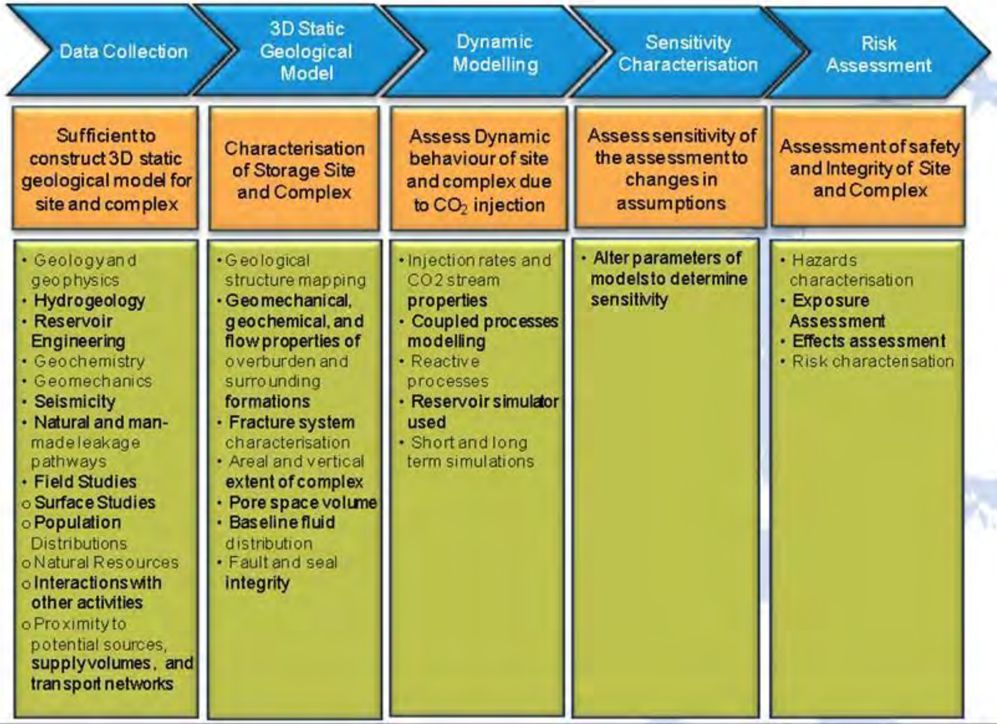
The ability to store CO_2 safely and permanently

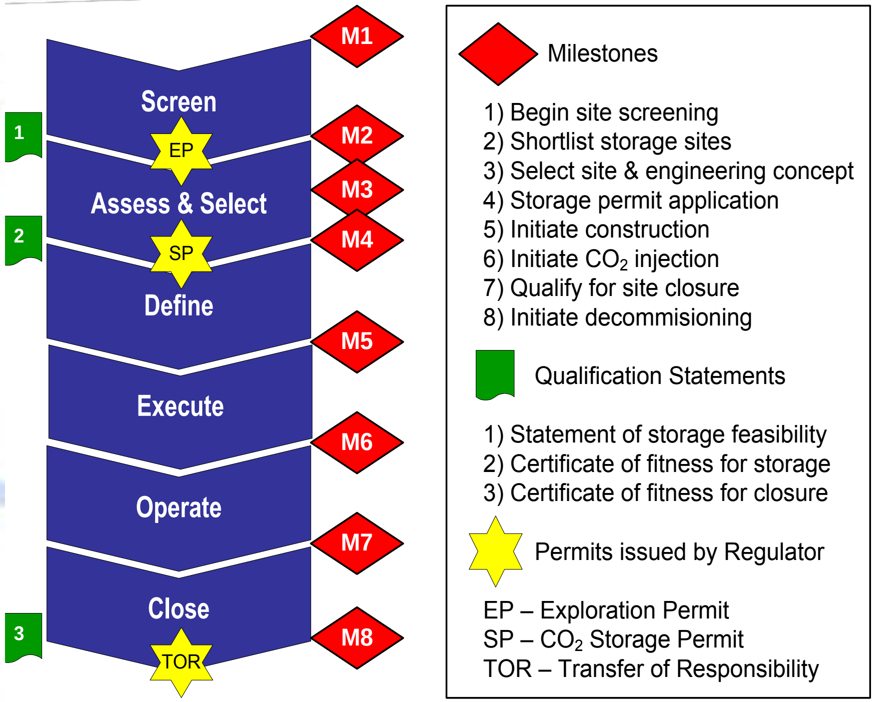
Other Criteria

- Environment
- Infrastructure
- Legal
- Public opinion
- Economics

MONITORING and VERIFICATION

SW Hub: Project Approach consistent with CCS Development Workflows





DNV CO2QualStore

EU Directive 2009/31/EC
and Australian Legislation have similar structures

New Data Acquisition with Extensive Community Consultation

2011 - 2D Seismic

2012 - Harvey-1 Well

2013 - 3D Seismic

2015 - Harvey 2, 3 & 4

Extensive Core and Log Data/Analyses

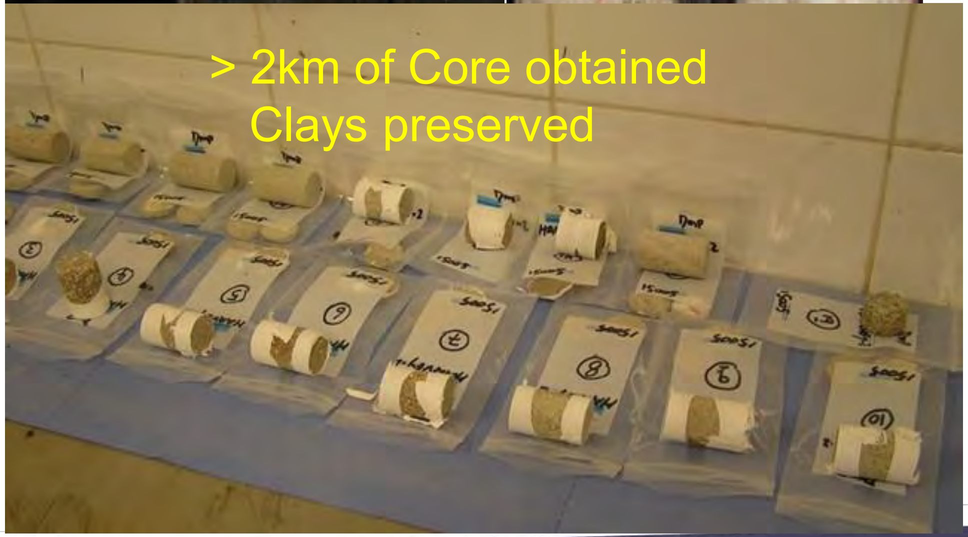
Routine Core Analysis (RCA)

- Grain volume and grain density
- Porosity and Permeability
- Permeability to brine
- Threshold Pressure to Carbon Dioxide

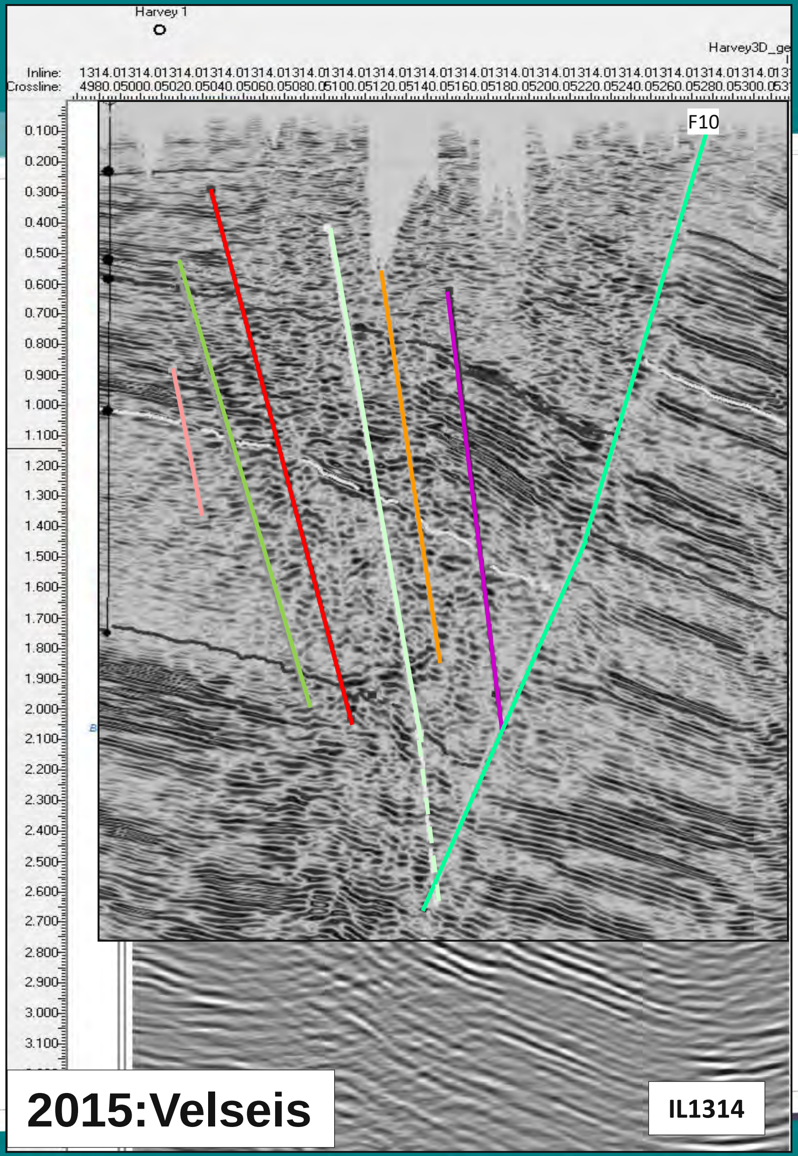
Special Core Analysis (SCAL)

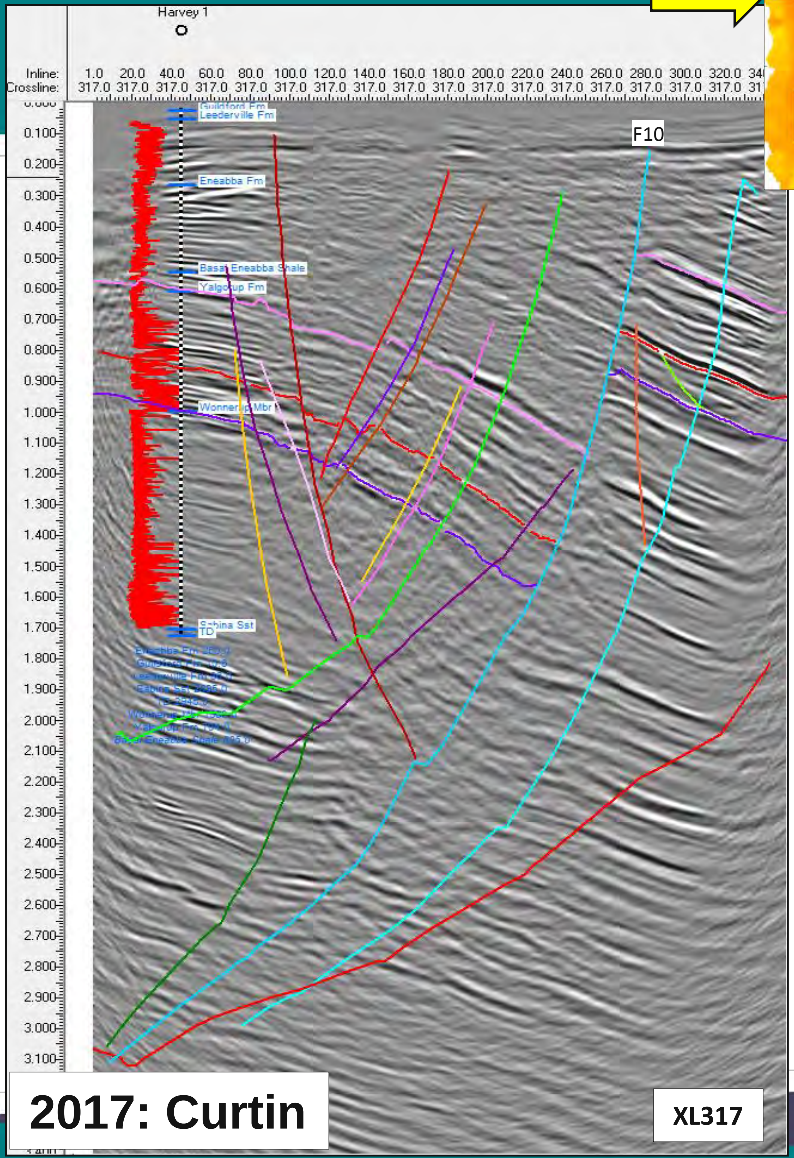
- Flow studies
- Mercury Injection Analysis
- Geomechanical Analysis

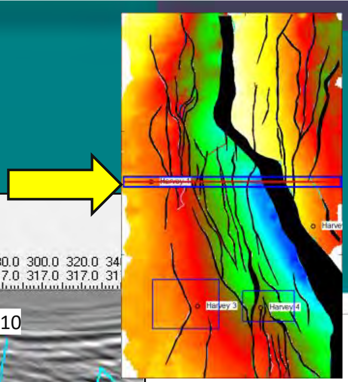
Well	Run	Services
Harvey-2	1	Gamma-Resistivity-Dipole Sonic
	2	Seismic VSP
Harvey-4	1	Gamma-Resistivity-Dipole Sonic-Neutron-Density
	2	XRMI Image
	1	Gamma-Resistivity-Dipole Sonic-Neutron-Density
	2	XRMI Image
		CSNG Compensated Spectral Gamma
	3	MRIL Nuclear Magnetic Resonance
	4	RDT Reservoir Description Tool
	5	Seismic VSP
Harvey-3	1	Gamma-Resistivity-Sonic-Neutron-Density
	2	Gamma-Resistivity-Sonic-Neutron-Density
	1	Gamma-Resistivity-Sonic-Neutron-Density
	2	HSFT Formation Tester
	3	Seismic VSP



Exhaustive Data Processing to Improve Definition



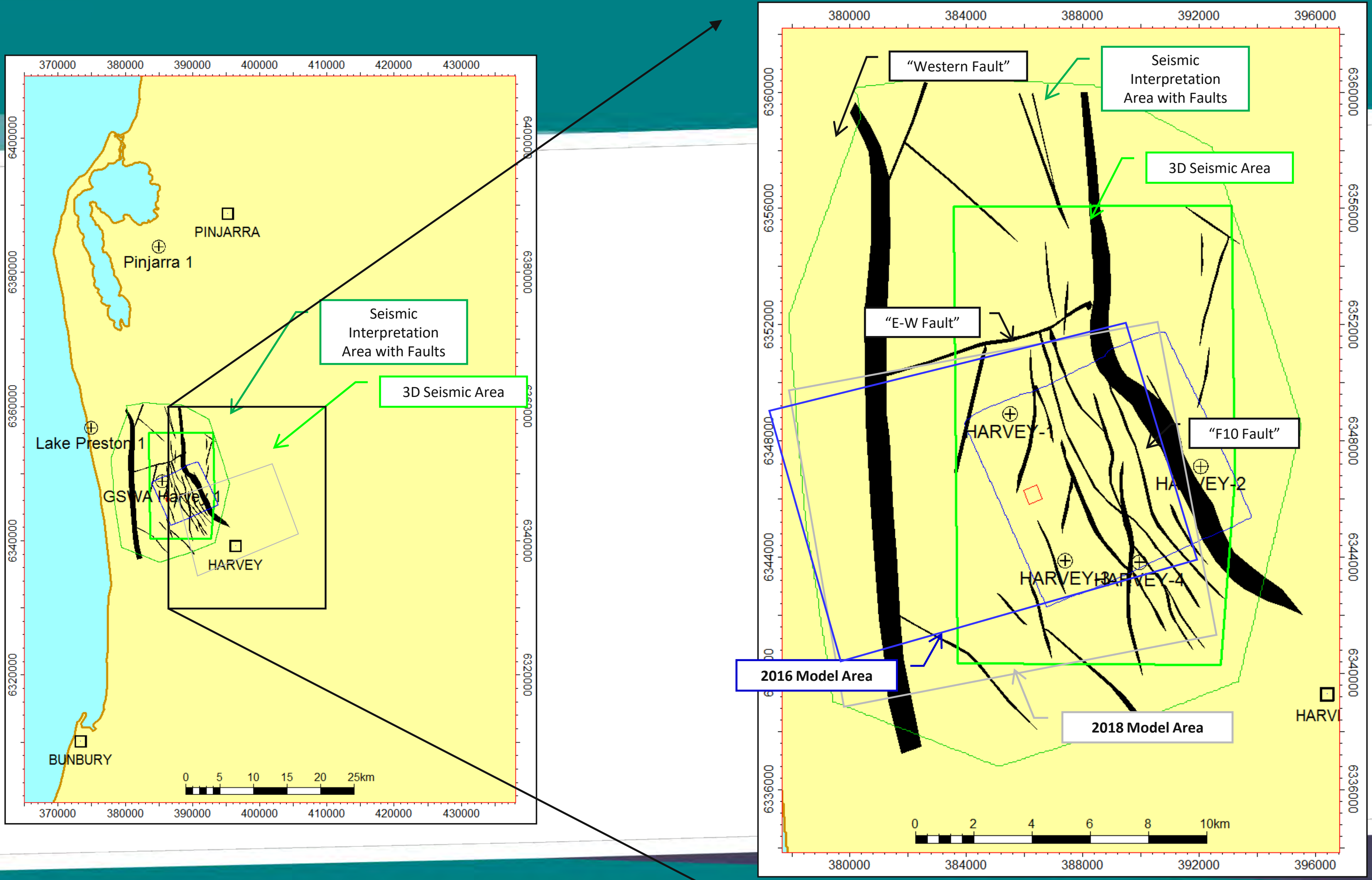


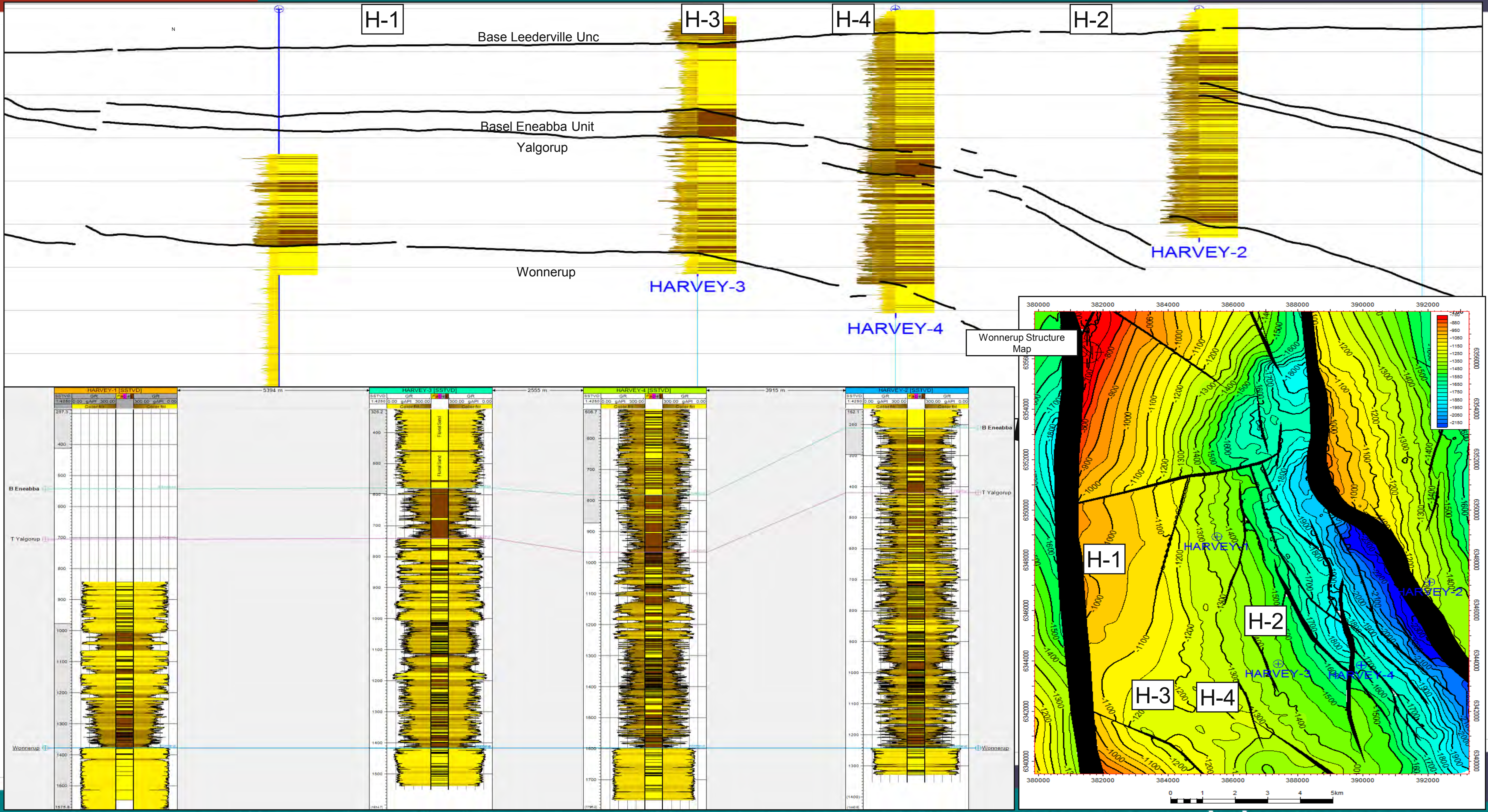


Velseis Proc Datum = 0m

Curtin Proc Datum = 40m
XL and IL reversed c.f. Velseis

SW Hub : Model Area



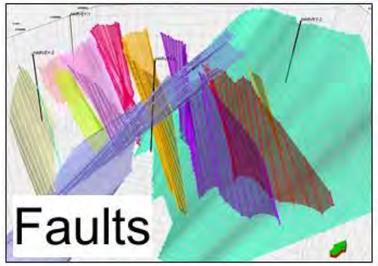


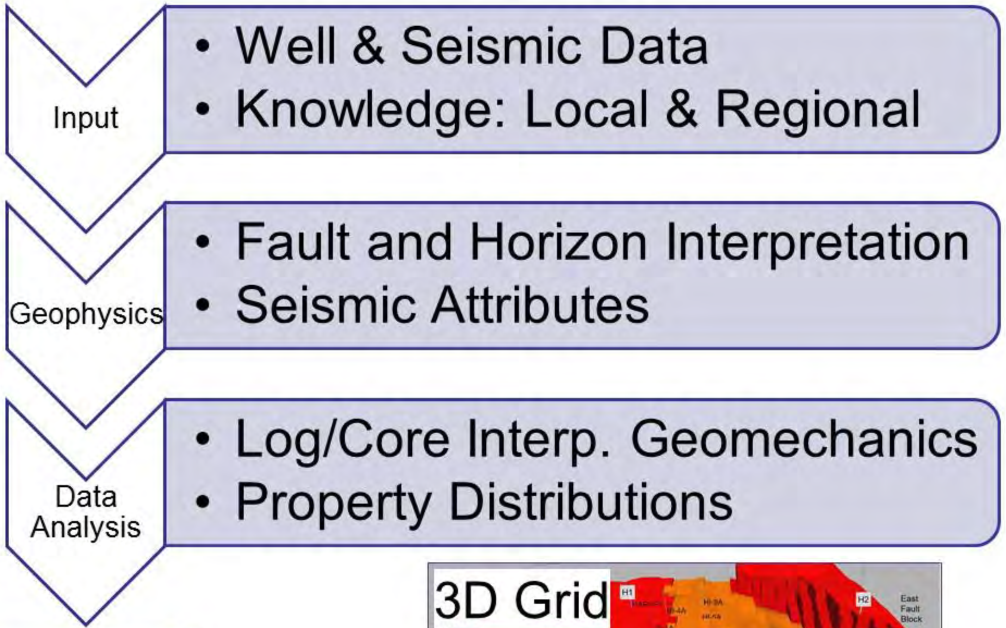
Structural Cross Section

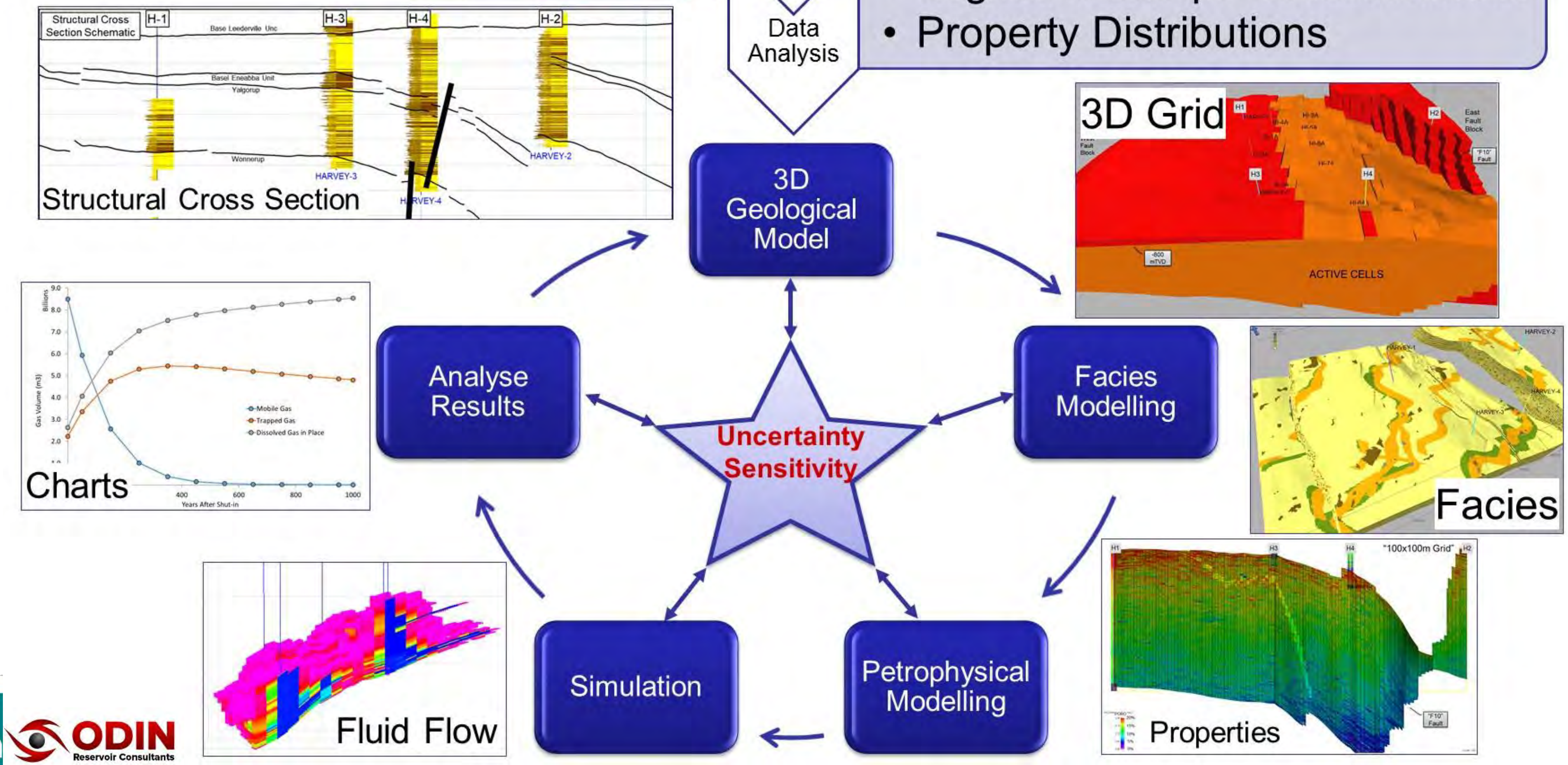
MODELLING WORKFLOW

Focus on uncertainty impacts on Performance Factors

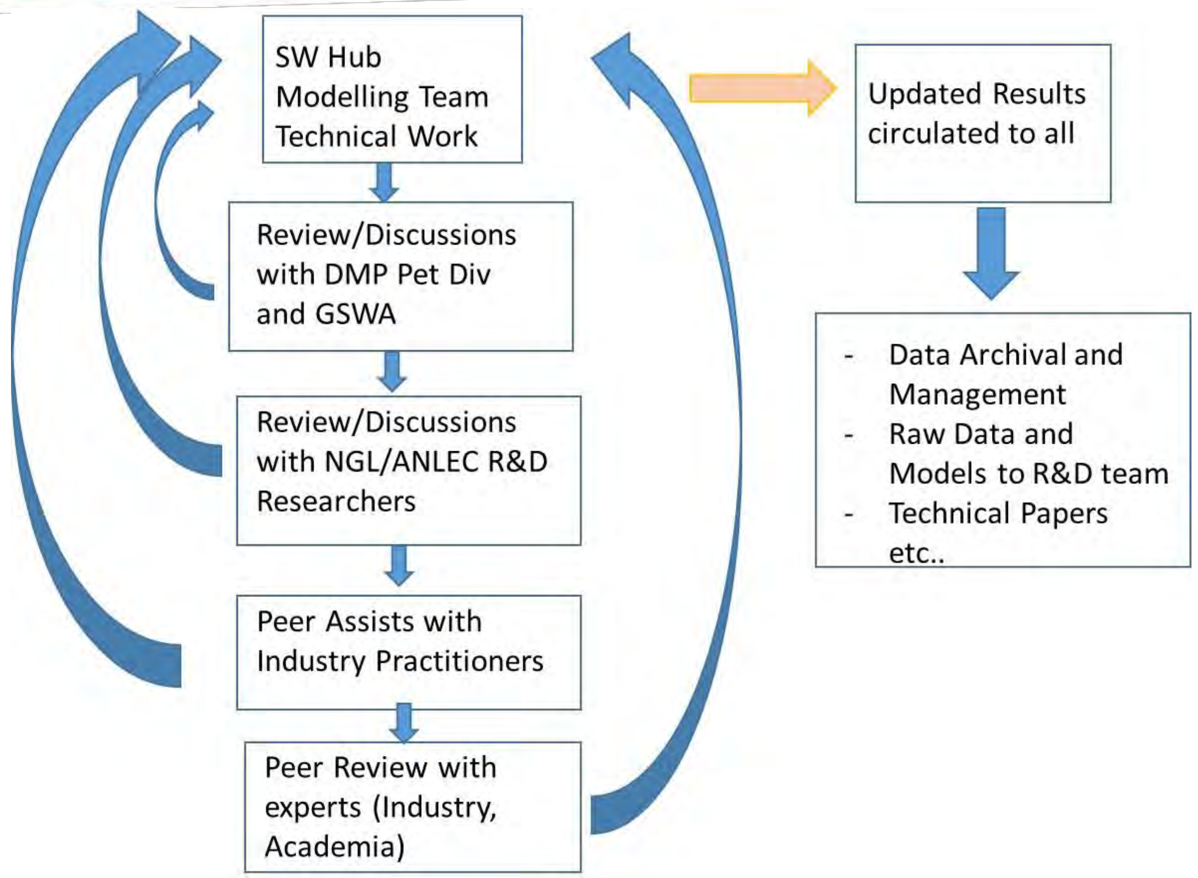
- Capacity
- Injectivity
- Containment







Peer Reviews for Technical Assurance

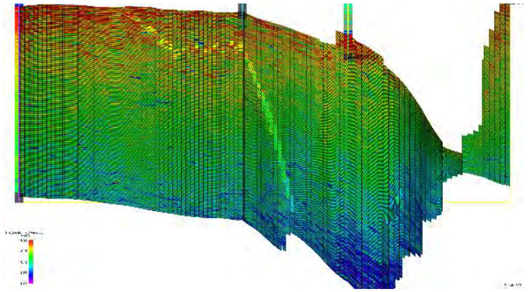


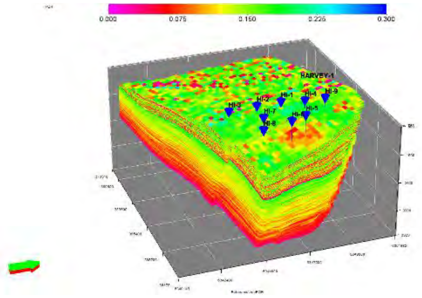
Date	Peer Assists/Reviews
2/12/2015	Introduction Meeting with Garnett and McKenna
17/12/2015	Workstation Review of seismic interpretation
25/02/2016	Review of Input Data and Static Model
28/04/2016	Injectivity modelling and upscaling
18/05/2016	Static Model Scenarios and Uncertainties
8/06/2016	Full Field modelling and Plume Movement
8/12/2017	Peer Assist: Review of Updated Interpretations
14/12/2017	Peer Review: Updated Interpretations
17/04/2018	Peer Assist: Static and Dynamic Modelling
23/04/2018	Peer Review: Static and Dynamic Modelling
14/06/2018	Peer Review: Modelling Outcomes and Data Options

Date	Researchers Review
3/12/2015	GeoMechanics, Geophysics, Image Log Interpretation, Static Model
13/01/2016	Static Model Update
2/03/2016	Static Model
29/04/2016	Injectivity modelling and upscaling
6/09/2017	Introduction Meeting with Researchers
14/09/2017	Technical Discussions with Researchers
18/04/2018	Static and Dynamic Modelling
12/06/2018	Present Model Outcomes to Researchers

Four Generations of Models

As more information became available, so did the level of sophistication and intensity of the models:





Generation 1 - >100 layers - 10 million cells

Generation 2 - 357 layers - 30 million cells

Generation 3 - >1,100 layers - 214 million cells

Dynamic model - 1.1 million cells

Generation 4 - current - 256 million cells

Dynamic model - 1.96 million cells

With **each iteration more data** is acquired and **uncertainties reduced**

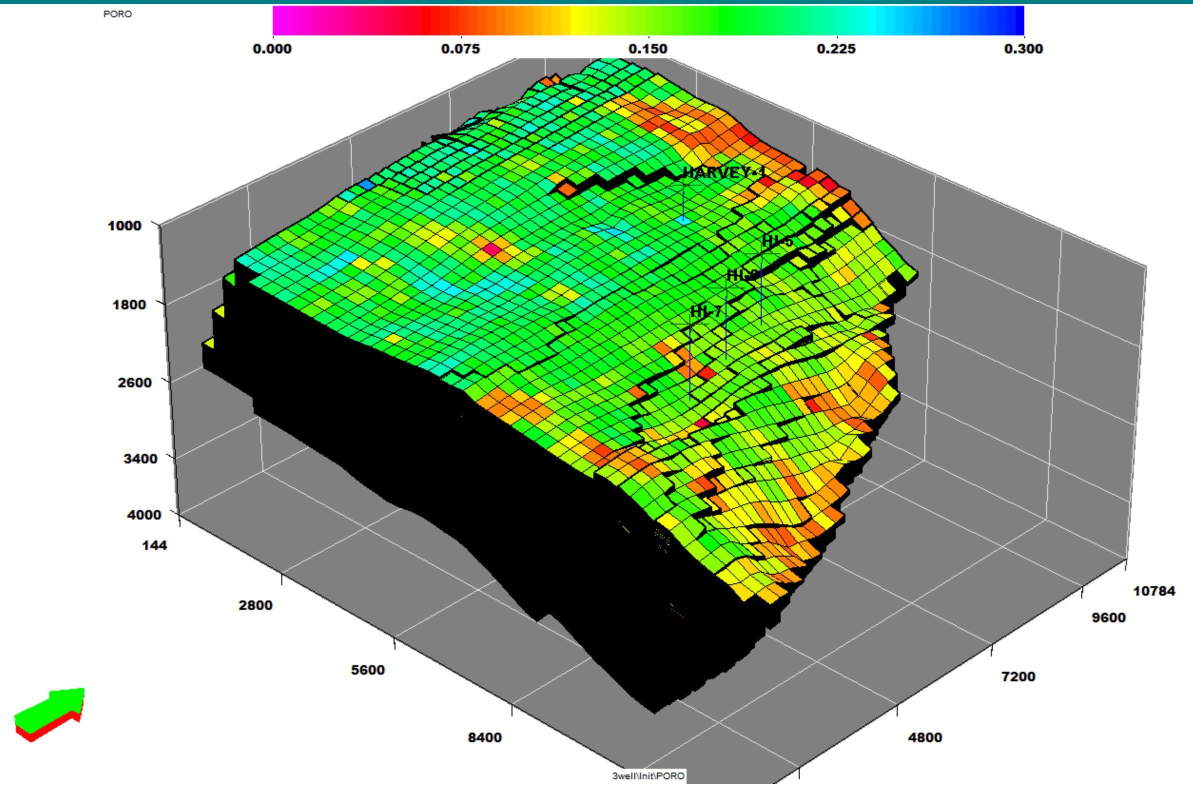
Decision Criteria and Impacts of Uncertainties

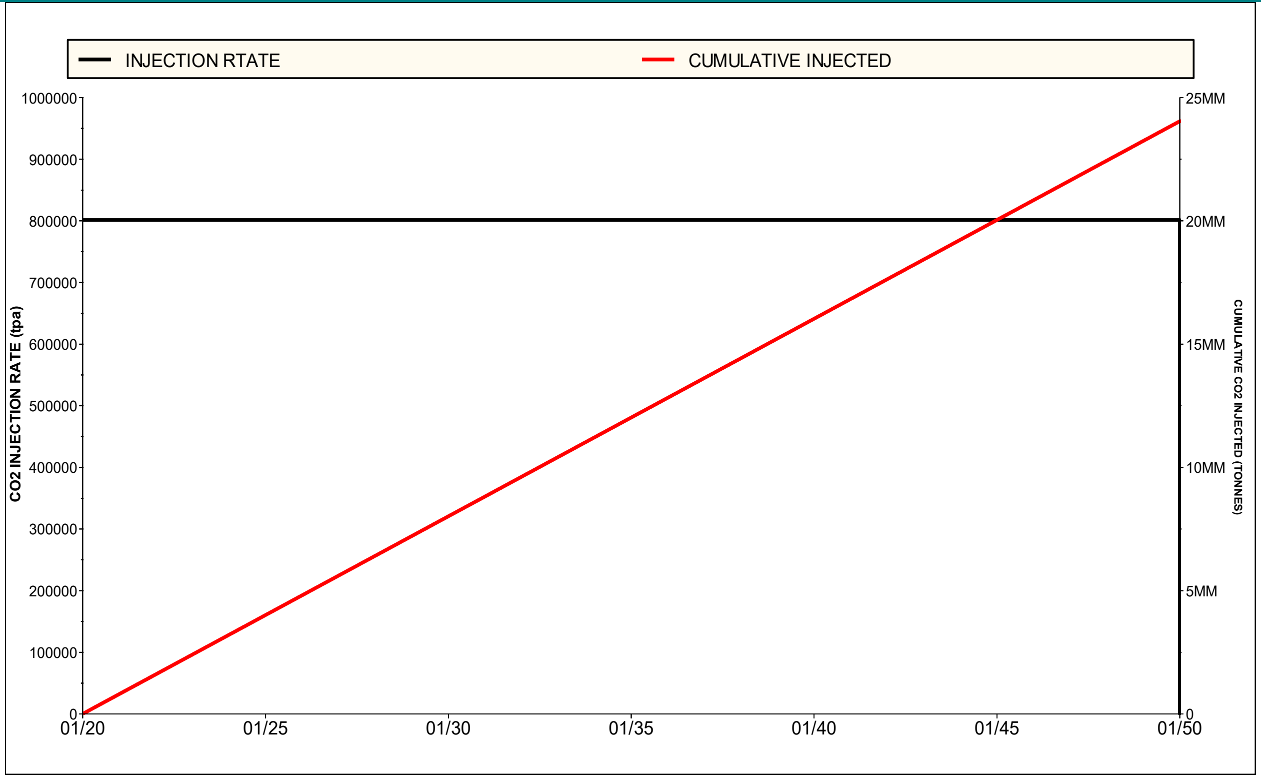
- **Decision Criteria:**
  - Site can accept injection rates of **800,000 tonnes per annum of CO2 over 30 years** and the plume will remain contained for **1000 years**
  - To be achieved through a **well count of 9 or** less.
- **Modelling: Focus on Uncertainties**
  - Extensive modelling of injection rates with varying parameters
  - Multiple scenarios defined to map plume profiles
  - Industry standard modelling tools used
  - Uncertainty impacts tested against Decision Criteria
- **Results**
  - Very encouraging – defined rates can be achieved with 3 wells.
  - Injected volumes remain within storage complex

Black Oil and Compositional Modelling

- Dynamic modelling of the CO_2 sequestration process in the Harvey area was conducted in two ways:
  - "Black Oil" Modelling – A simplified description of the physics of the fluids based on simple interpolation of PVT properties as a function of pressure.
  - Compositional modelling - Using a "compositional" approach based on a thermodynamically-consistent model such as a cubic equation of state (EOS).
- Evaluations using Black Oil models can be done, in many instances, a few orders of magnitude faster than compositional models. In the Harvey area, most of the modelling is conducted using the "Black Oil" formulation. Specific cases are tested in a compositional model as a sense check.

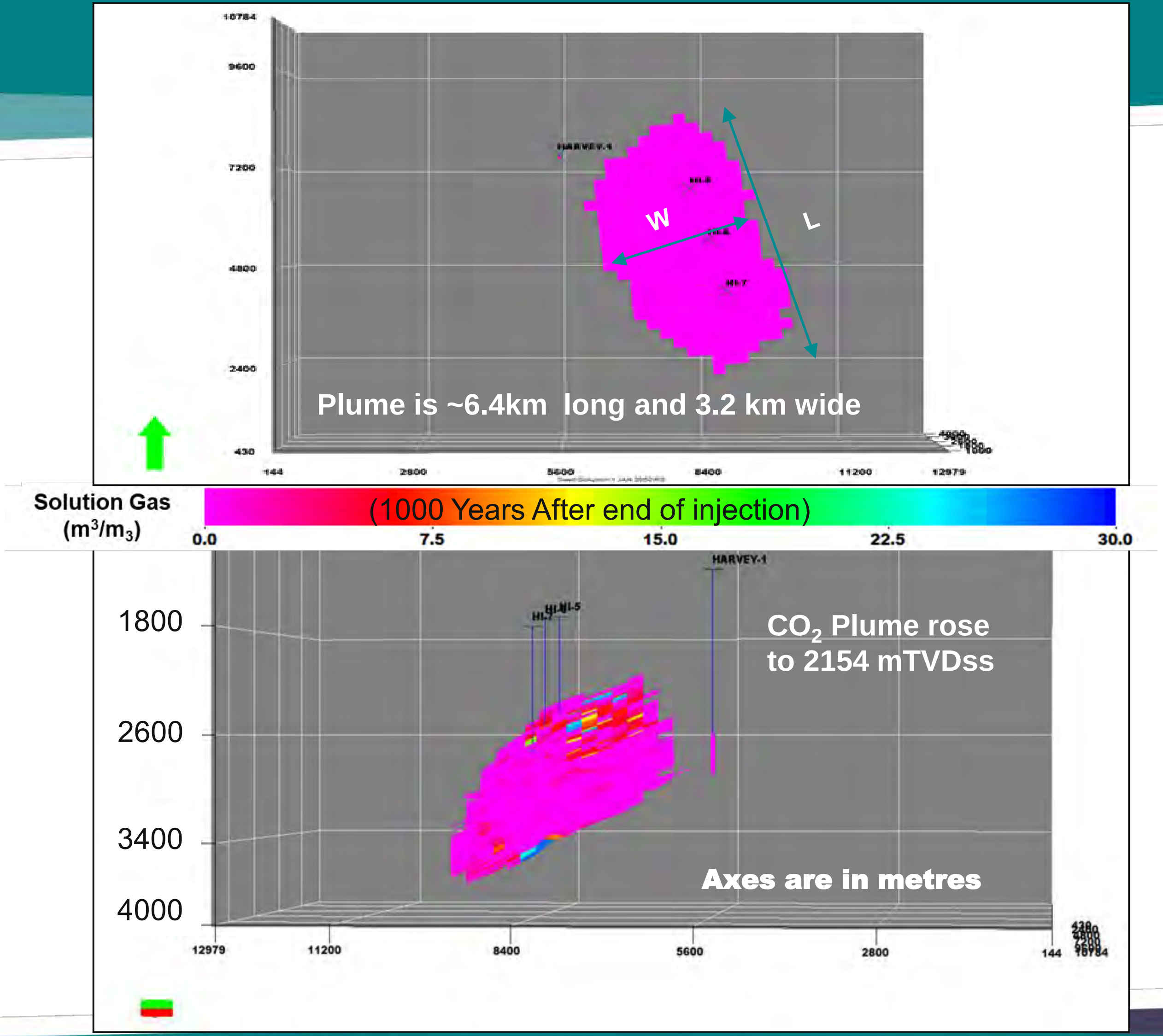
Conceptual Development Plan and Injection Profile





- The conceptual plan envisages 3 gas injectors plans had 9 injectors.
- All injectors are completed at depths of almo

Reference Case – Black Oil Model

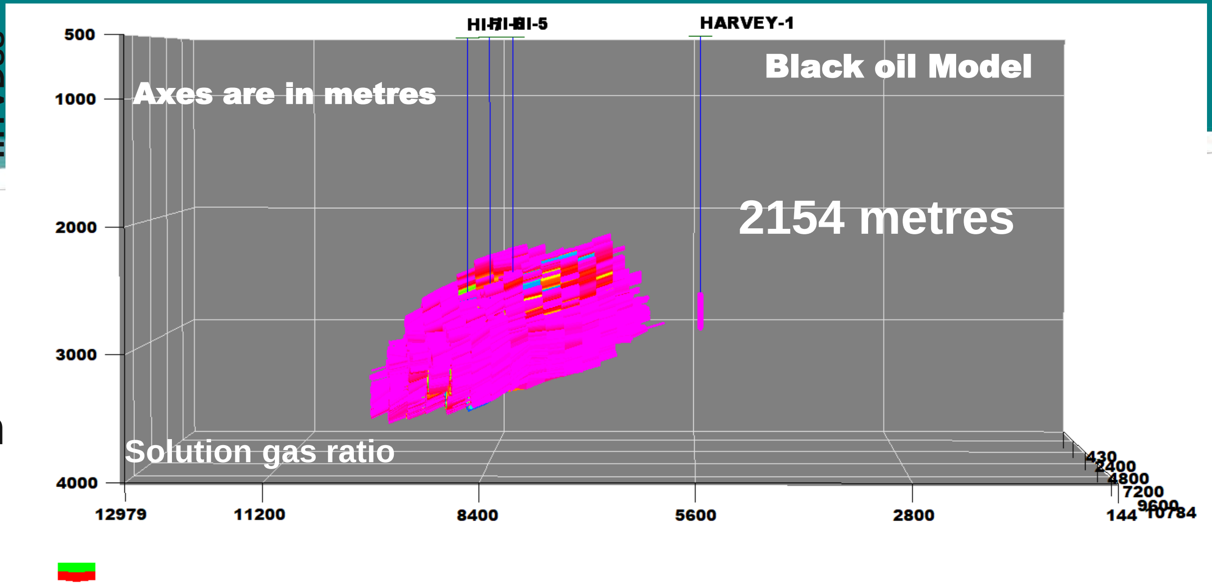


- CO_2 plume is compact and remains within the Area of Interest (AOI).
- The CO_2 stays within the Wonnerup.
- These results are consistent with the Phase 1 studies.
- The CO_2 plume stabilises about 600 years after the end of injection.

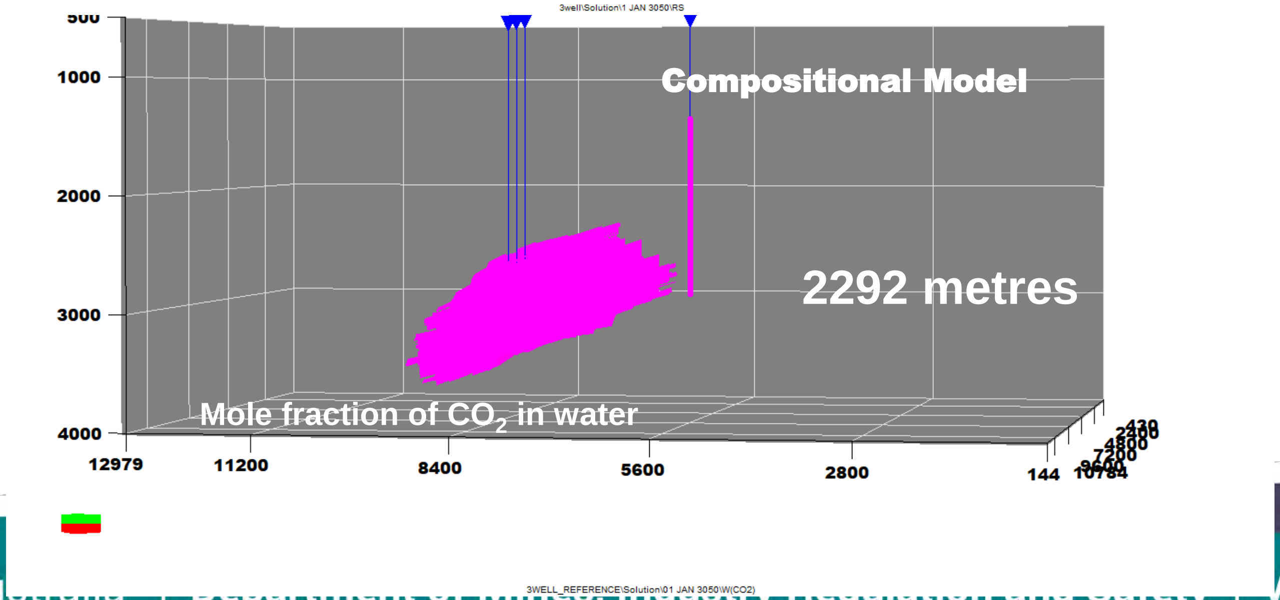
Reference Case - Comparison of Plume Shape and Movement Looking South

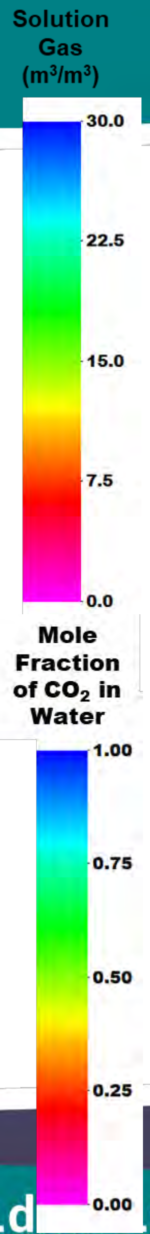
Black Oil

1000 years after injection stops.

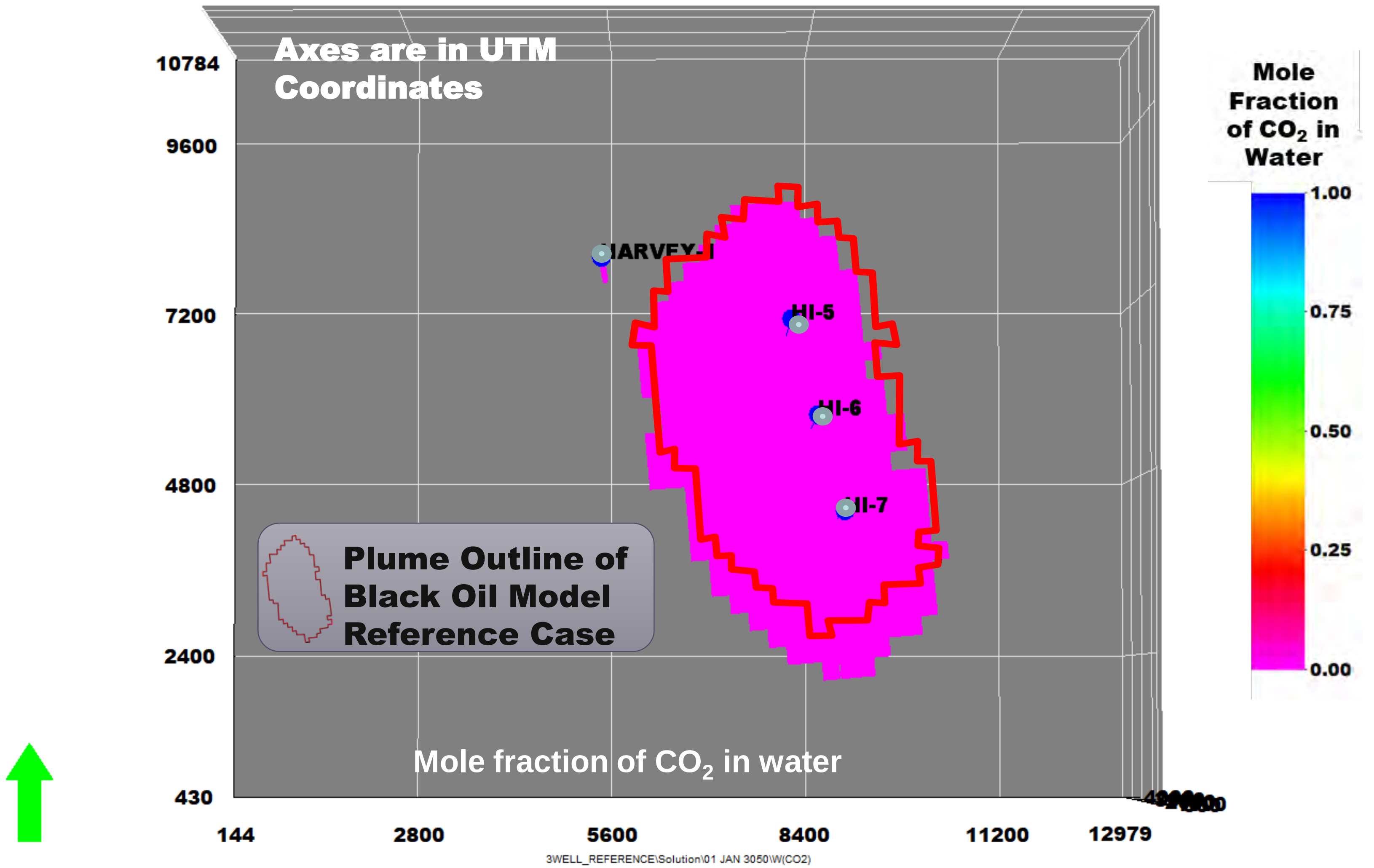


Compositional





Reference Case - Comparison of Plume Outline (Top View) Black Oil and Compositional Model



CO_2 Material Balance (1000 Years After Shut-in)

(Reference Case - Compositional Model)

	Supercritical CO2			
	Trapped Gas (moles)	Mobile Free Gas (moles)	Total CO2 Dissolved (moles)	Total CO2 (moles)
Gas Material Balance	3.54E+11	2.37E+08	2.13E+11	5.68E+11
% of Injected	62.4%	0.0%	37.5%	100.0%

Modelling – Scenarios to test Uncertainty Impacts

Objective: To test under what conditions the success criteria can be breached

- Multiple Cases (Scenarios) Modelled
- Ranges of uncertainties considered
- Combination of uncertainties considered as “stress” cases.

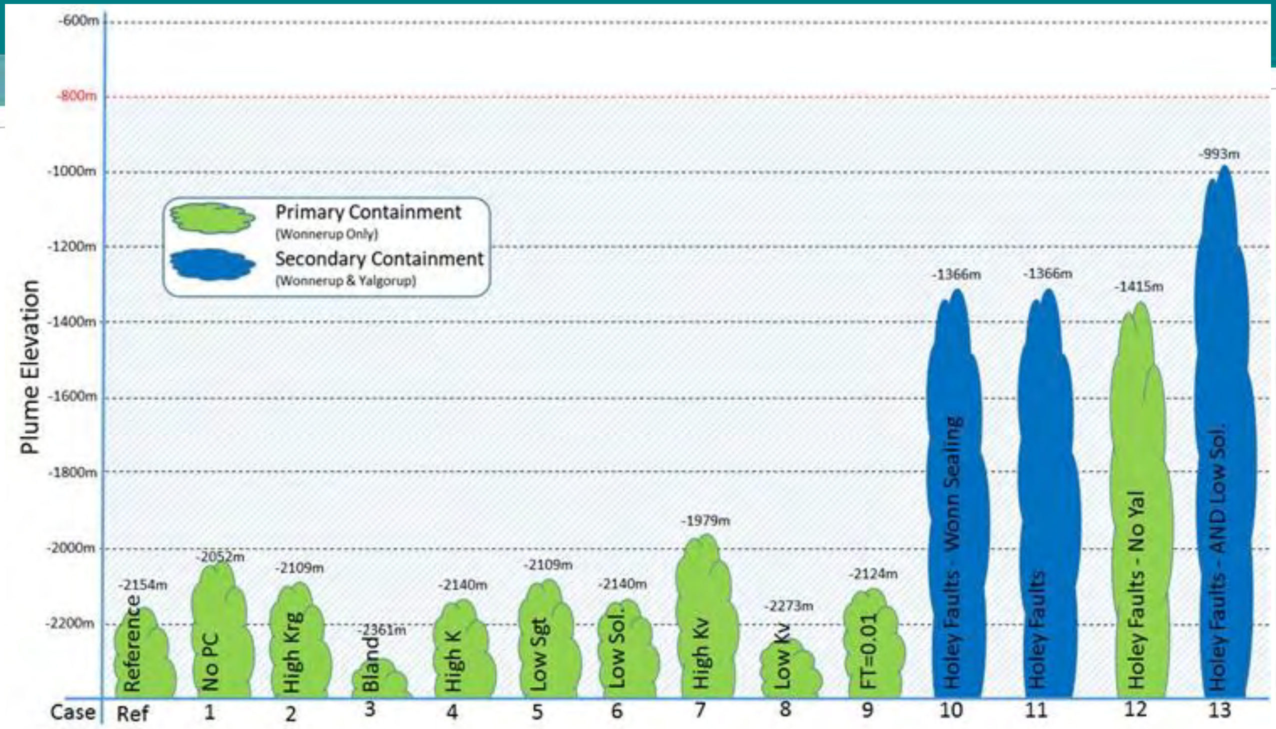
Case	Case Name	Geological Model	Description
Reference	3Well	Reference	800,000 tpa. Brine salinity=45600 ppm (NaCl Equivalent) SgT based on Land Correlation C=1.95
1	3Well_NoPC	Reference	800,000 tpa. Brine salinity=45600 ppm (NaCl Equivalent) No capillary pressures SgT based on Land Correlation C=1.95
2	3Well_highkrg	Reference	800,000 tpa. Brine salinity=45600 ppm (NaCl Equivalent) Krg=0.25 SgT based on Land Correlation C=1.95
			alent)
			alent)
			alent)
			valent)
			alent)
			alent)
			alent)
1			alent)
1			alent)
1			alent)
13	3Well_holey_wonnseal_lowsol	Cells adjacent to faults have the vertical permeability increased by 10 times. Wonnerup and Yalgorup in communication through the faults.	800,000 tpa. Brine salinity=200000 ppm (NaCl Equivalent) SgT based on Land Correlation C=1.95

Uncertainties Modelled (Examples)

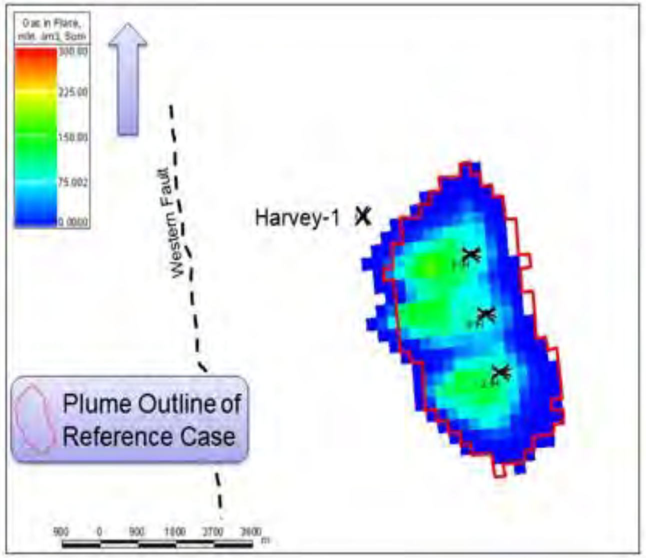
- **High mobility Upwards**
- **Poor trapping mechanism**
- **Low solubility of gas in the water**
- **Pessimistic scenarios of gas movement in the reservoir**
  - **Fault baffles.**
  - **Fractures which promote upward movement of gas**

ODIN Reservoir Consultants

Plume remains inside storage complex in all modelled cases

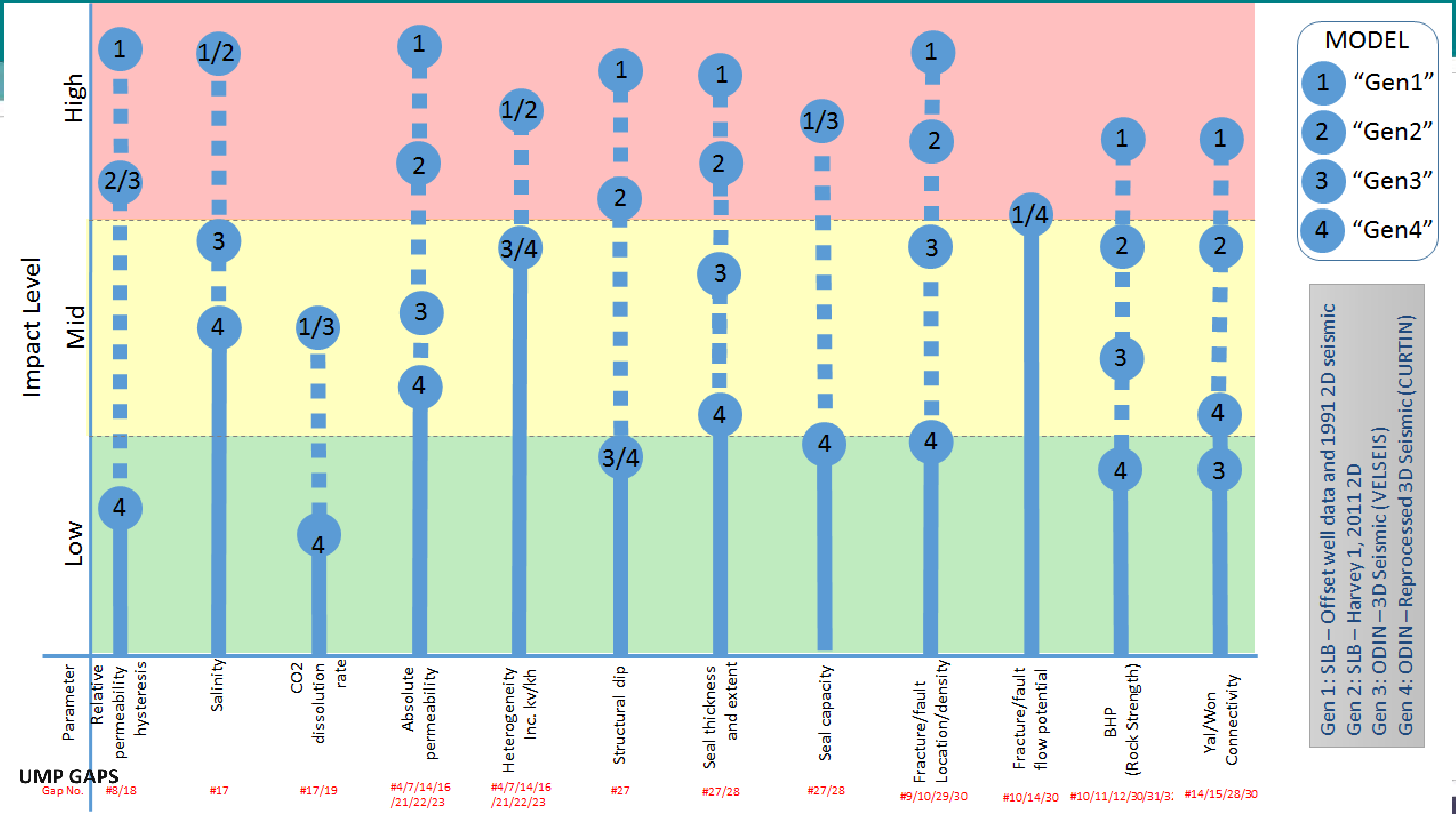


Only under few conditions the plume (< 2%) enters the secondary containment zone



Limited spread of plume compared to reference case: 6.5km X 3.5km

Visualising the Key Uncertainties over time



Uncertainty Matrix

Range of Uncertainty →

Impact of Uncertainty ↑

	1	2	3	4	5
5		• Paleosol Efficacy	• Deep Reservoir Properties and Diagenesis • Heterogeneity (Vertical and Horizontal) • Compartmentalisation		
4			• Vertical Migration through Faults • Yalg/Wonn Communication	• Dynamic Reservoir Response • Vertical Versus Horizontal migration of plume	
3		• Fault Interpretation			
2			• Formation Salinity • Rock strength parameters (LOT)		
1	• Structure/ Formation Dip • Compartments	• Dep. Environ. Interpretation			• Facies Prediction Using 3D Seismic

Need for New Data

Qualitative ranking by colour code.

Relevance of the SW Hub

- Our modelling shows that it could be feasible to inject and store **800,000 tpa of CO_2 over 30 years** in the Lesueur formations in the Harvey area.

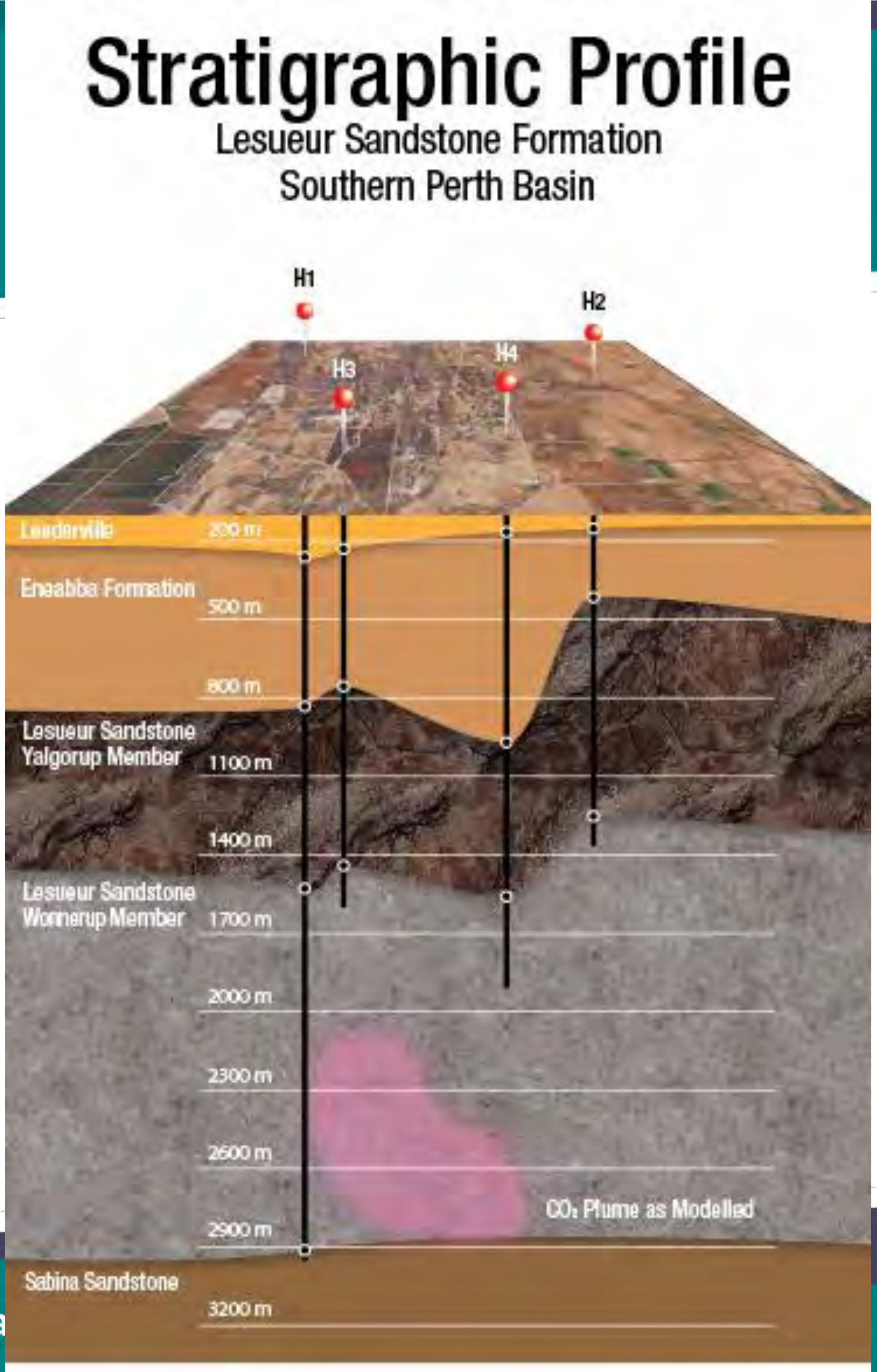
- Higher volumes can potentially be stored. **3 million tpa for 30 years have been modelled**

- **Main Remaining Gaps requires new well and test data**

- If proven , **absence of a traditional shale cover should not prematurely screen-out** reservoirs for CO_2 storage

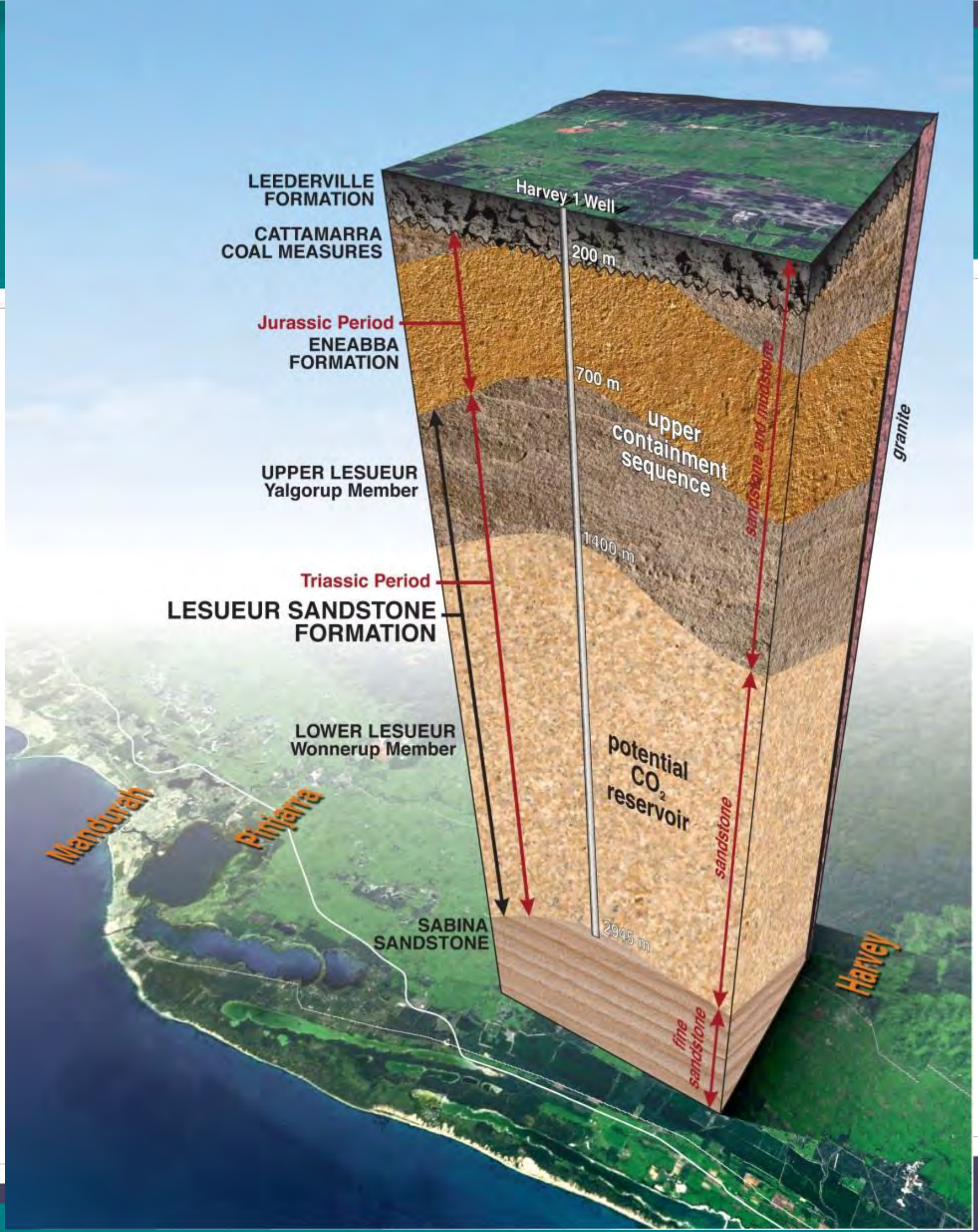
- **SW Hub can widen the available sites for CCS consideration worldwide**

- **Located in the heart of the S-W industrial belt proximal to multiple emissions sources**



In the South West

- The Lesueur represents the best opportunity for CCS in the South West
- The absence of the Yarragadee (potable water) is critical



CCS: Possibly the only mitigation option for some industries

LNG and Gas Processing to Remove Reservoir CO_2

- Minimal capture cost

Gasification for Chemicals or Liquids

- Minimal capture cost - higher capital cost than gas

Coal and Gas Power Projects

- High capture cost and capital cost

Steel and Cement Plants

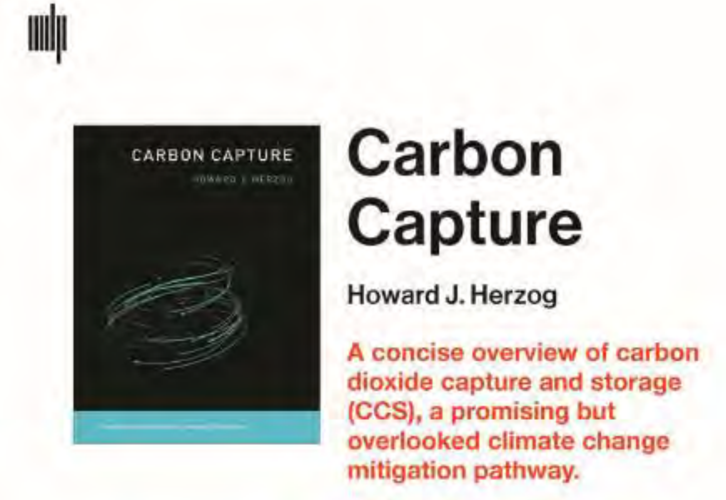
- High capture cost and capital cost

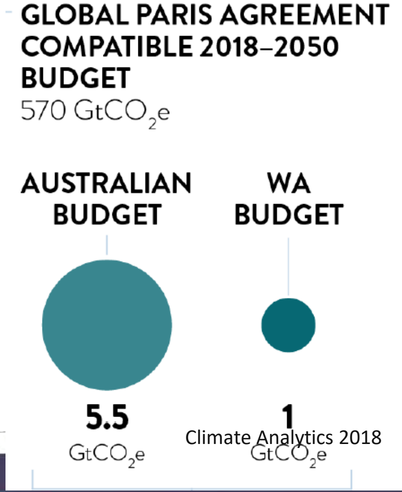
Bio-fuels plus CCS (Negative Emissions)

- Range of capture costs – current scale limitations

Concluding Thoughts …..

- Numerous studies have shown CCS helps achieve lowest cost mitigation options as part of a portfolio.
- CCS has potential – but often overlooked in the narrative
  - **Need continued Government support as no business imperative**
  - **Need industry to voice support for the technology – as they pursue decarbonisation.**
  - **Need to develop a narrative for the community**
- The only way to build confidence with the community is through demonstration
- **In reality – do we have a choice if we want to achieve 2DS? If not, why delay?**





Thank You

All data is publically available.

www.dmp.wa.gov.au/ccs

www.dmp.wa.gov.au/wapims

www.ngl.org.au

www.anlecrd.com.au