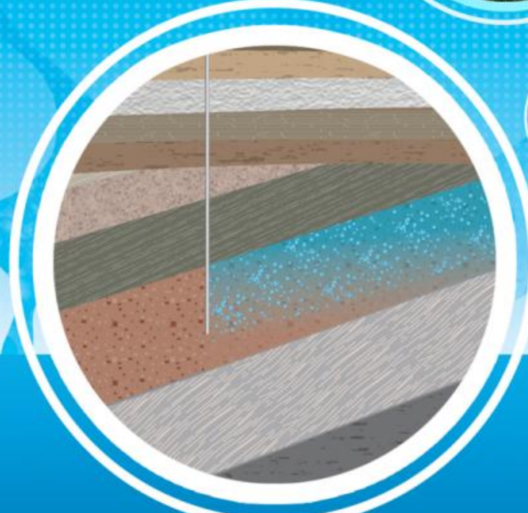
Feasibility of monitoring techniques for substances mobilised by CO_2 storage in geological formations – IEA GHG Project



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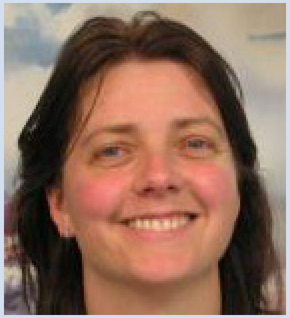
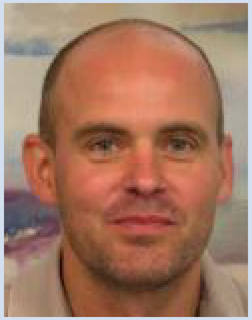
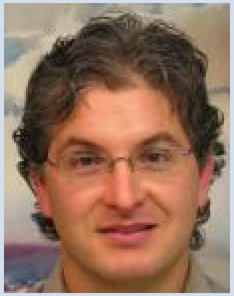
Presenting to
TCCS-6, Trondheim, 14-16th June, 2011

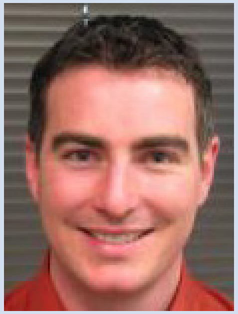
Acknowledgements

- Internal reviewers at CSIRO and CO2CRC
- IEA GHG for funding


Allison Hortle


Karsten Michael


Bobby Pejcic


Ryan Noble


Matthew Leybourne

Outline

- **Objectives**
  - Key points of the project
- **Looking at gaps**
  - Selected results
    - **Biosensing**
    - **Mobilising organics**
    - **Monitoring contaminants**
- **Conclusions**
- **Future work**

U-tube sampling facility at Otway.

Key points being covered in the project

- **Feasibility of Monitoring Techniques for Substances Mobilised by CO_2 Storage in Geological Formations**
  - Flow effects
    - Mixing of waters/changes in chemistry (via P/T)/pressure perturbations
  - Geochemical effects
    - Dissolution/diagenesis/chemical alterations (all formation types)/mobilisation of heavy metals
  - Shallow/surface effects
    - Toxicity on biosphere/microbial effects/scaling
  - Capture gas compositions
    - Power plants/LNG/industrial sources

- **Built on previous work "Downhole monitoring of chemical changes associated with CO_2 Storage" Ross et al, 2007, CO2CRC RPT07-0749**

Search Criteria

Analytes	Levels
CO_2	ppb to percent
pH	relative change
Hydrocarbons	ppb to percent
Anions	mMol
Cations	mMol
Tracers	ppb to ppm
Pressure/temp	kPa / °C
Geophysical properties	varies with methods employed
Biological changes	varies with methods employed
Contaminants	varies with contaminant

Considerations	Approx. Ranges
Depth	soil surface to km
Temperature	4°C to ~150°C
Aqueous environ.	yes
Power	240 V max.
Data transmission	wire or wireless
Lifetime	short to long-term
Self-calibration	drift
Redundant/robust	environ challenges
Relative cost	indicative costs

Methods Used

- **Literature Search**
  - ISI Web of Science
  - ISI Derwent Innovations Index
  - Google
  - others

- **Case Study Reviews**
  - Pembina, Canada
  - Ketzin, Germany
  - Cranfield, USA
  - Frio, USA
  - Otway, Australia

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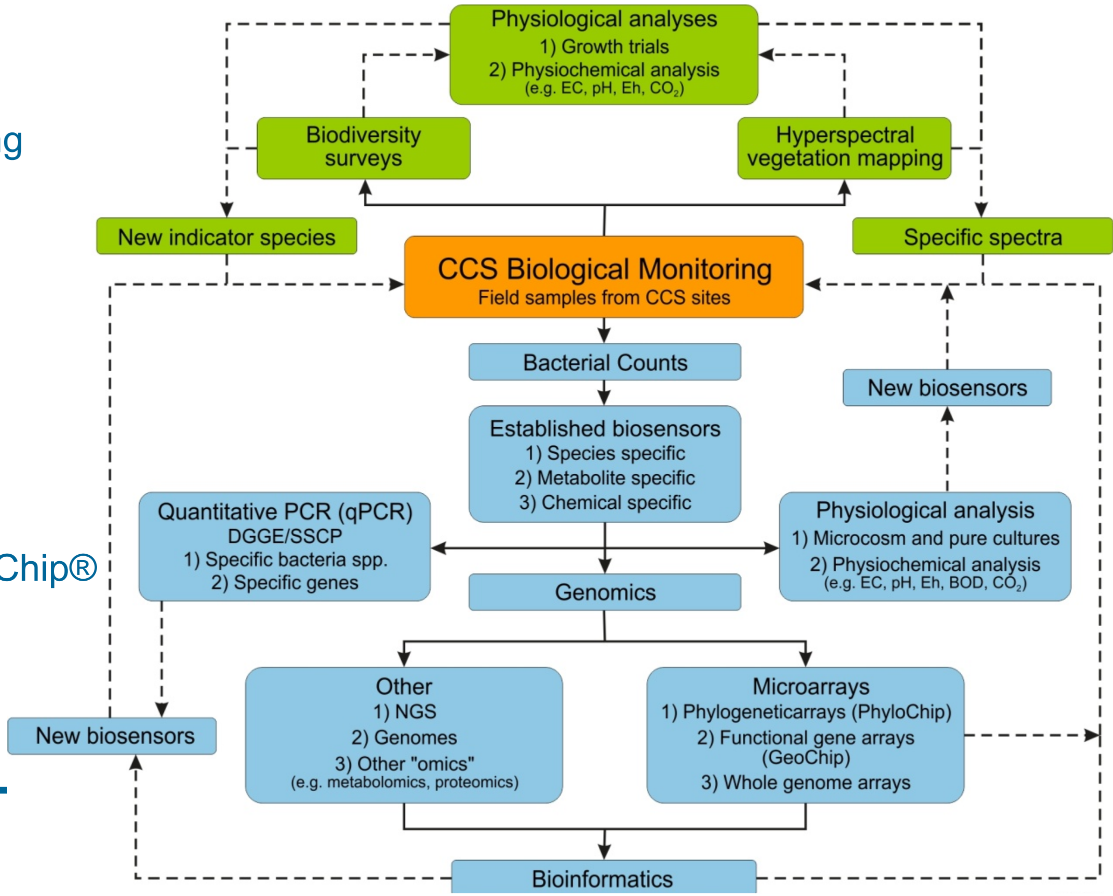
Biological technology for monitoring CO_2

- **The challenges**
  - Identifying new tools
  - Understanding and characterising the changes in these domains caused by CO_2 increase or displacement of O_2
- **The tools**
  - Ecosystem – Botanical Monitoring
  - Microbiological monitoring
  - Bacterial counts
  - Microbiological/metabolic activity
  - Selected enzyme/shift sensors
  - PCR/DNA fingerprinting
  - Microarrays - PhyloChip® & GeoChip®
  - Next Generation DNA (NGS)
  - Ecogenomics



Adapted from Maphosa et al., 2010

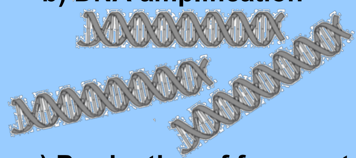
PhyloChip® - Workflow & Output

1. Sample collection

2. Sample preparation

a) DNA extraction

b) DNA amplification



c) Production of fragment target labelling and array hybrization

d) The labelled DNA fragments and a control mixture are inserted into the Chip

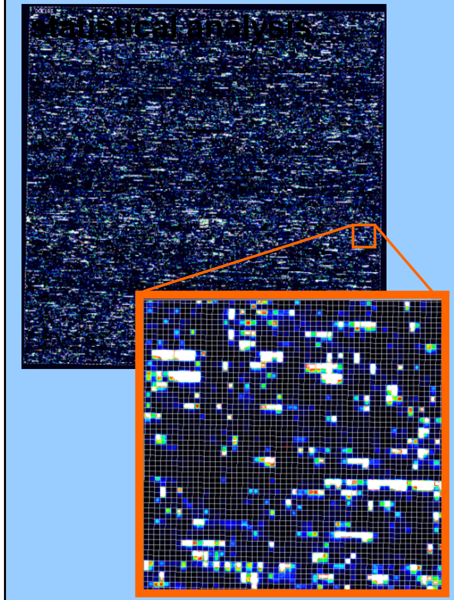
3. Sample analysis

a) The Chips are given a stringent wash under specified conditions in a fluidics station. Non-exact DNA 'matches' are eluted off

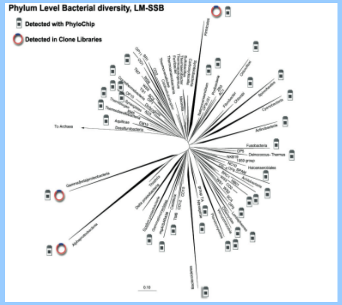
b) Chips read by laser scanner

Photos courtesy S. Wakelin, 2008

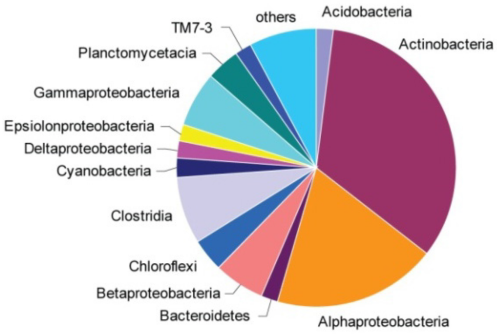
4. Data processing, normalization and statistical analysis



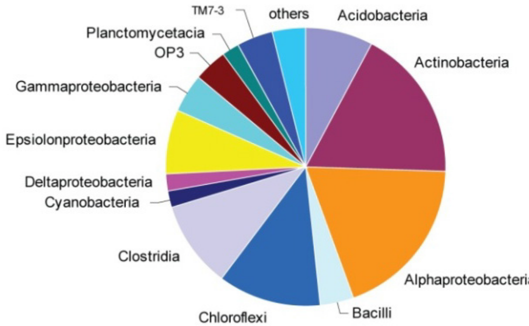
5. Data output



Sample 1



Sample 2



From Wakelin et al, in review

ieaghg GNS SCIENCE CSIRO CO2CRC

Biological

		High throughput	Cost	Deep CCS	Shallow CCS	Tested Deep	Tested Shallow	Tested Analogue
Plant species survey	Botanical	Y	L	X	suitable	X	tested	tested
Plant counts	Botanical	Y	L	X	less suitable	X	tested	tested
Hyperspectral plant monitoring	Botanical	Y	L	X	less suitable	X	tested	tested
Bacterial counts	Microbiological	Y	L	less suitable	less suitable	limited testing	tested	tested
Plating	Microbiological	N	L	less suitable	less suitable	limited testing	tested	untested
ATP activity	Microbiological	Y	L	less suitable	less suitable	limited testing	tested	tested
Metabolic profiles	Microbiological	N	L	less suitable	less suitable	tested	tested	limited testing
Biosensors	Microbiological	Y	L	suitable	suitable	untested	tested	untested
Phospholipid Fatty Acid	Microbiological	Y	L	less suitable	less suitable	limited testing	tested	limited testing
Microcosms	Microbiological	N	H	less suitable	less suitable	untested	tested	tested
PCR	Microbiological	N	M	suitable	suitable	tested	tested	tested
Microarrays	Microbiological	Y&N	M	suitable	suitable	limited testing	tested	untested
Pyrosequencing	Microbiological	Y&N	M	less suitable	less suitable	untested	tested	untested
Ecogenomics	Microbiological	N	H	less suitable	less suitable	untested	tested	limited testing

Cost:
H= High, M=Moderate, L=Low

For CCS applications:
- (red) = suitable,
- (orange) = less suitable

For method development:
- (dark) = tested,
- (grey) = limited testing,
- (white) = untested
- X= not applicable

- (green) = Botanical
- (blue) = Microbiological

Hydrocarbons and Organics

- **EOR/EGR relevance - CO_2 as a solvent**
- **Increased awareness of BTEX mobilisation**
- **Many tools out there**
  - Piezoelectric
  - Chemiresistors
  - IR
  - Small scale sensors
- **Tools are often non-selective**
  - More selective tools are less robust (e.g. membranes)
  - Drift and longevity are untested

Hydrocarbon	Transducer	Analytical range	Detection limit	Comments
Various aliphatic and aromatic compounds	Resistance	NA	~100 ppmv (gas)	Relatively cheap and has a temperature control feature. Portable. Very little information available of selectivity
Various aliphatic and aromatic compounds	Surface acoustic wave	NA	ppb	Portable and compact. Low power. Excellent selectivity
Methane	Near infrared	10 ppm - 100 vol%	~ppm	Portable. Fast response time. Highly selective
Methane	Near infrared	NA	~100 ppm	Portable, rugged and fast response time. Highly selective
Various aliphatic hydrocarbons	Potentiometric and Resistance	NA	~ppm	Portable, rugged and rapid response. Poor selectivity.
Benzene, toluene, xylene	Resistance	1-10 ppm	0.5 ppm (toluene)	Portable and compact. Low power. Affected by humidity.

Hydrocarbons and Organics

Cost:
H= High
M=Moderate
L=Low

Y = Yes
N = No

= has been tested
= has potential but requires further testing
= untested

X= not applicable

	High throughput	Cost	Suitability at high tempera-ture & pressure	Down-hole monitoring	Groundwater monitoring	Shallow CCS	Deep CCS
Chemiresistor	Y	L	Y				
Potentiometer	Y	L	Y				
Quartz crystal microbalance	Y	M					
Surface acoustic wave	Y	M					
Mid-infrared		H					
Near-infrared		H					
Fluorimeter	Y	H	Y				
Gas chromatography	Y	H	X	X	X	X	X
Mass spectrometry	Y	H	X	X	X	X	X

Monitoring Contaminants

- **Literature review**
- **"Effects of Impurities on Geological Storage of Carbon Dioxide*" IEA/CON/09/172 by CanmetENERGY**
- **Identified quantitatively significant contaminants**
- **Contaminants as tracers**

- **Impacts on**
  - Injectivity
  - Storage capacity
  - Cap rock integrity
  - Corrosion and fouling
  - Mixing of different effluent streams

Component	Pre-combustion		Post-comb	Oxyfuel		
	Selexol	Rectisol	Average$^{(n=3)}$	Comp 1	Comp 2	Comp 3
CO_2 (vol%)	97.95	99.7	99.89	85.0	98.0	99.94
O_2 (vol%)			0.02	4.70	0.67	0.01
N_2 (vol%)	0.9	0.21	0.06	5.80	0.71	0.01
Ar (vol%)	0.03	0.15		4.47	0.59	0.01
H_2O (ppm)	600	10	266.67	100	100	100
NO_x (ppm)			20.0	100	100	100
SO_2& SO_3 (ppm)			13.3	50 & 20	50 & 20	50 & 20
CO (ppm)	400	400	13.3	50	50	50

Data from * and IEA GHG

Impact of Contaminants

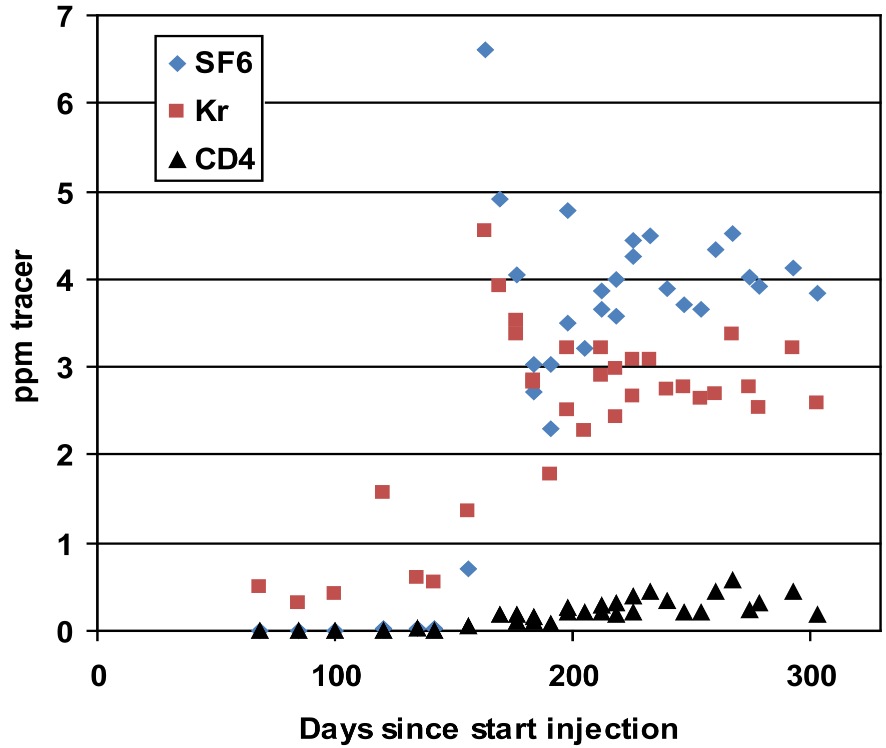
- **Contaminant sources**
  - Coal power plants (IGCC/oxy)
  - Oil refineries
  - Iron, steel or alumina processing
  - LNG/GTL plants
  - Coal to urea fertilizers & chemicals

- **High levels of impact on "Hub" style CCS Projects**
  - Collie SW CO_2 Hub in WA
  - Mixed sources of CO_2 proposed
  - Mixed contaminants = reactants
  - Monitoring at surface & subsurface to understand changes in composition, abundance over time, reactions and other processes.

Collie South West CO_2 Geosequestration Hub

Contaminants as Tracers

- **Contaminant quantities are of a similar ratio as many tracers used in CCS research**
- **Otway Stage 1 results show**
  - sulphur hexafluoride in range of < 1 to 6.6 ppm (atmospheric value 7 ppt)
  - Krypton ranging from < 1 to 4.5 ppm (atmospheric value 1.14 ppm)
  - CD_4 approx 1 ppm (not present in the atmosphere).
- **Effects of Impurities on Geological Storage of Carbon Dioxide study**
  - Argon in oxyfuel can be > 4% (atmospheric value 0.934%)



U-tube 2 tracer results from Otway Stage 1

Key Points

- **Bad news**

  - This statement from Ross et al (2007) still applies "few suitable sensing technologies … are available. … representing a significant gap in technology … for large scale implementation of carbon capture and storage"
  - Data management and handling will be more problematic

Conclusions

- **A range of maturity in different sensors and tools**
  - Geophysics is fairly mature – incremental changes to technology
  - Biosensing – tested in other environments, only now testing in CCS
- **The more rugged tools come from the petroleum industry**
- **Other tools are entering a ruggedization/miniaturisation phase for deployment**
- **There is scope for developing multi-analyte tools in the future**
- **Field trials of tools and a database of the conditions and performance is essential**
- **Data handling will be come a bigger issue due to volume of information**
- **What we do with the assurance data is most important**

CO2CRC Participants

Australian Government
Geoscience Australia

CSIRO

Curtin University

MONASH University

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THE UNIVERSITY OF MELBOURNE

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STANWELL CORPORATION LIMITED

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Government of South Australia | CANSYD Australia | Charles Darwin University | Simon Fraser University

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