Improving the Protocols for CO_2 Leakage Monitoring with Attribution

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Expert Meeting on Carbon Dioxide Removal Technologies and Carbon Dioxide Capture, Use and Storage

Vienna, Austria

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1-3 July 2024

Where We are Now?

- Since 2006 IPCC Guidelines we have two decades of operational CCS experience with Monitoring Measurement and Verification
- Currently 41 Projects storing ~ 41 MMTPA
- No environmental impacts or reversal of storage
- A new understanding of how to implement environmental monitoring

First Accounting Protocol for CCS

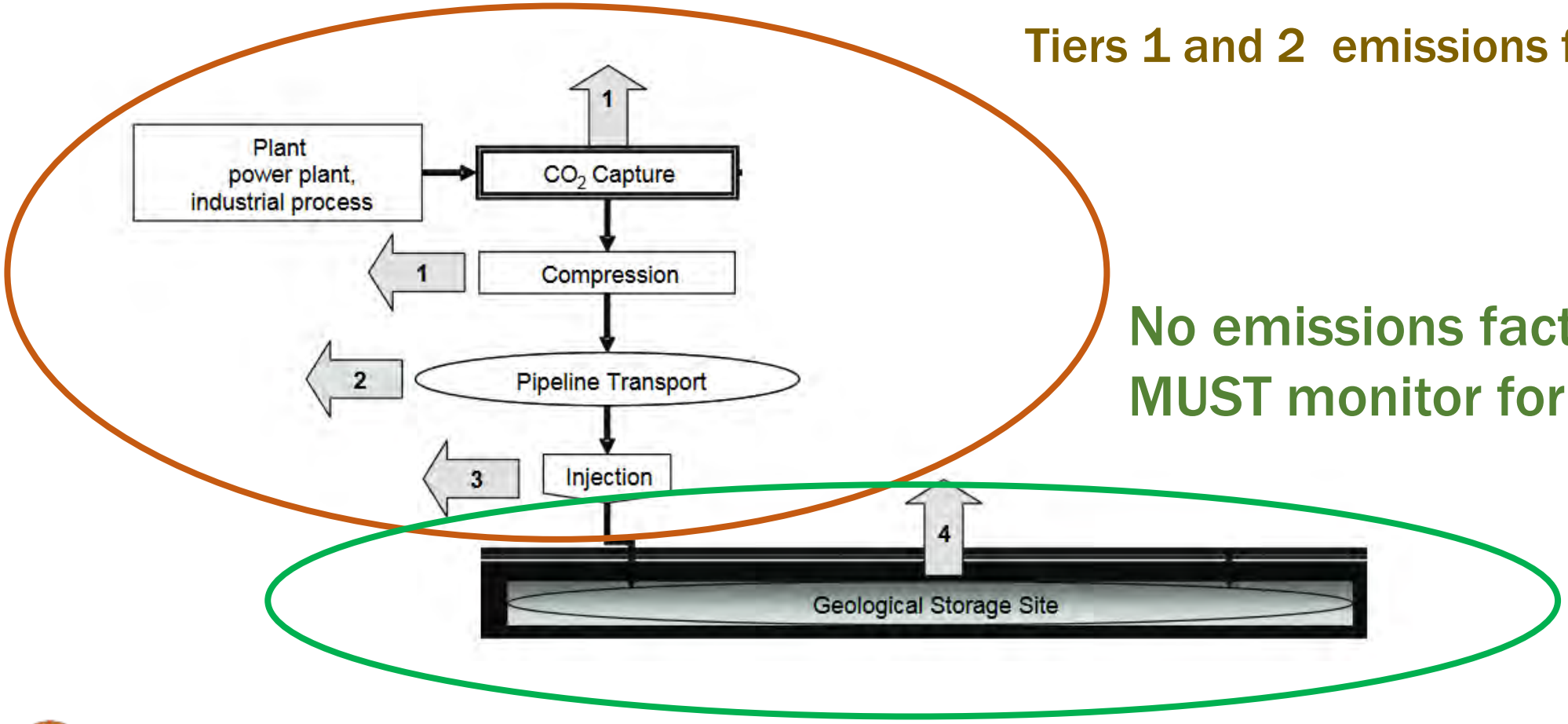
2006 IPCC Guidelines for National Greenhouse Gas Inventories

Volume 2

Energy

Chapter	Chapter Name
-	Cover Page of Volume 2
1	Introduction
2	Stationary Combustion *1
3	Mobile Combustion *4 *11
4	Fugitive Emissions *2 *10 *11
5	Carbon Dioxide Transport, Injection and Geological Storage
6	Reference Approach

Accounting for Full-Chain Emissions



Tiers 1 and 2 emissions factors

No emissions factors
MUST monitor for leakage

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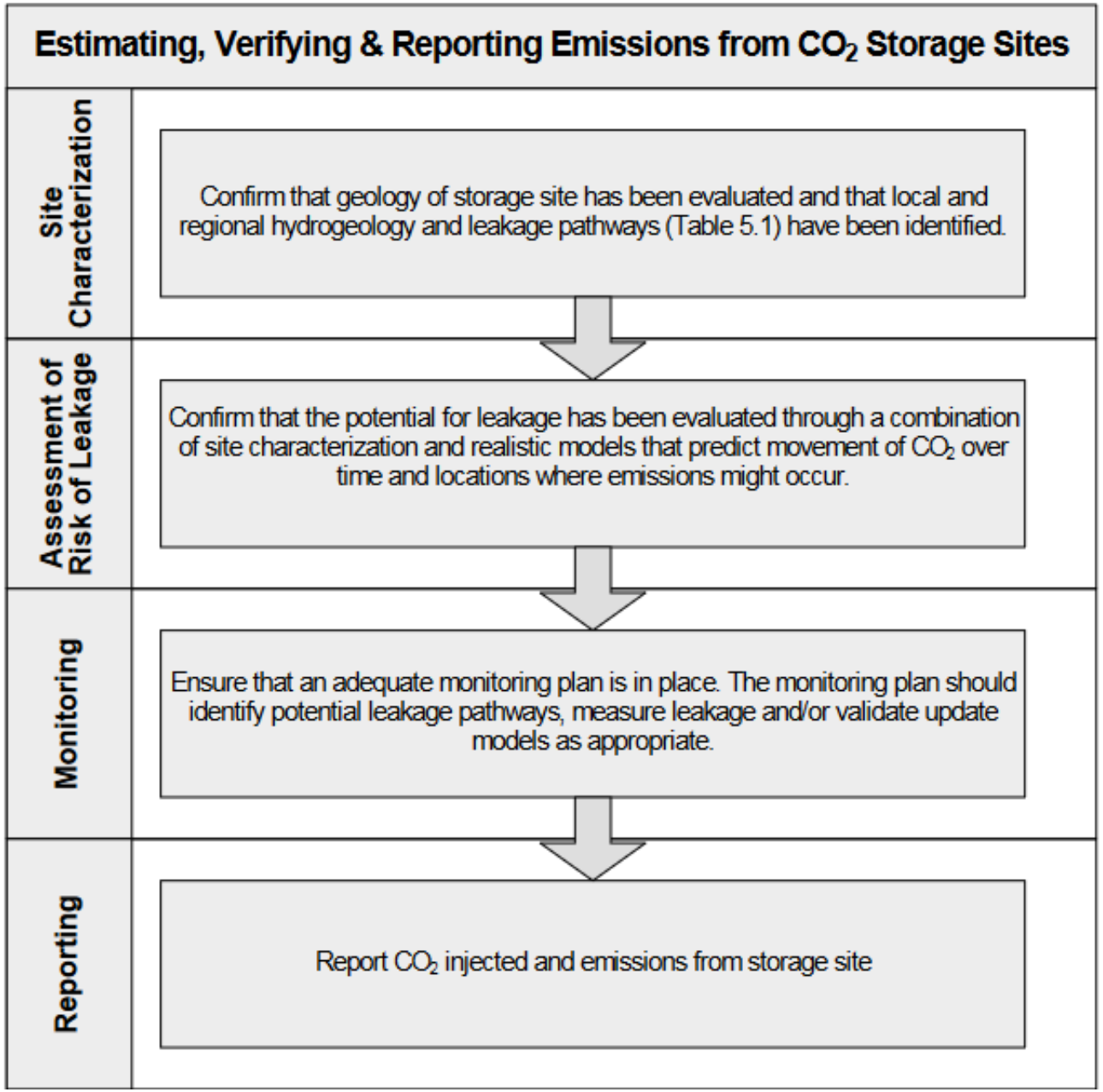
The Seed that Grew CO_2 Storage Regulations



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Safe and Secure CO_2 Storage Regulations

Regulatory Body / Monitoring Objectives:	IPCC GHG Guidelines	London Convention and Protocol	OSPAR	EU		US EPA		UNFCCC Clean Development Mechanism
				CCS Directive	ETS Directive	UIC Class VI well regulation	GHG reporting Subpart RR	
Overall Objectives	GHG accounting	Protection of the marine environment	Protection of the marine environment	Protection of the environment	GHG accounting	Protection of the environment (underground sources of drinking water)	GHG accounting	GHG accounting and protection of the environment

Dixon and Romanak, 2015, International Journal of Greenhouse Gas Control

ISO TC-265 – standards on Capture Performance, Pipeline Transport, Geological Storage, Storage in EOR, Vocabulary

Slight differences but the general workflow is similar among regulations

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In summary - Protocols for Leakage Monitoring:

- Monitoring to assess CO_2 storage performance in the reservoir
- Monitoring to acquire baseline measurements
- Monitoring to detect leakage at the surface

and, if leakage is detected or suspected, then

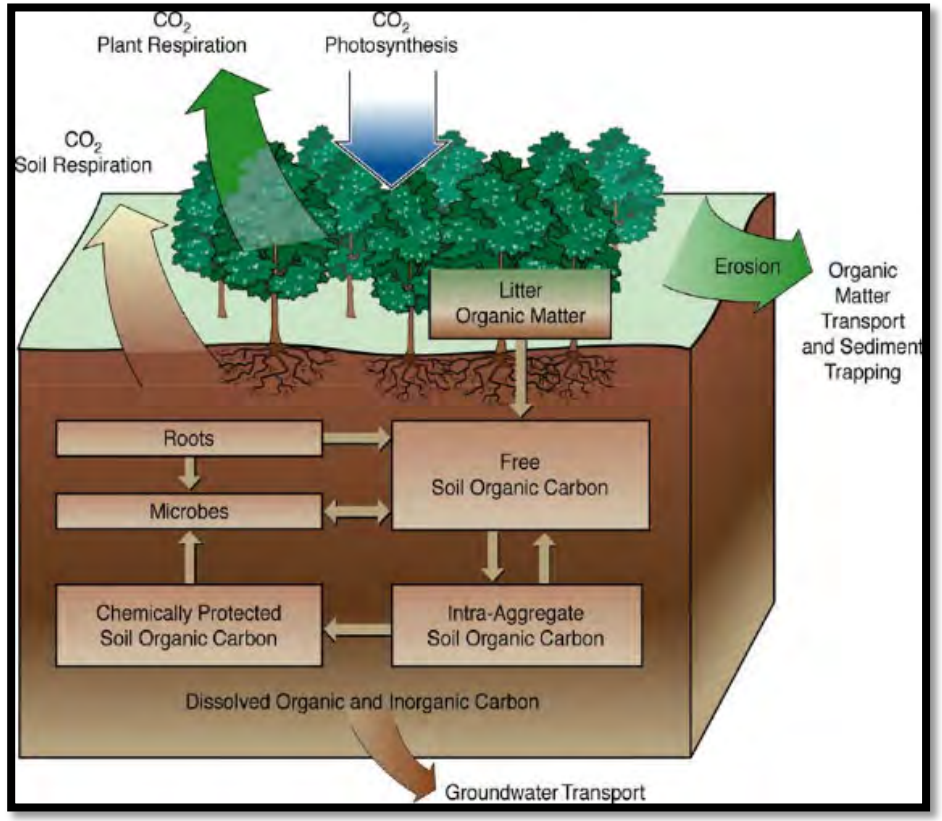
- Monitoring to quantify for leakage amounts

  and

- Monitoring to assess impacts of leakage

CO_2 Variability

- CO_2 is naturally everywhere
- Dominant source is biological respiration
- Dynamic over space and time (temperature, rainfall, pressure…)
- CO_2 is reactive
- Very difficult to discern leakage from natural variability.
- Difficult to determine what is anomalous



Source: DOE, 1999: *Carbon Sequestration Research and Development*

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Determining Anomalies Using Baselines

- Measure "baseline" CO_2 for 1 year before project starts to document seasonal variability.
- Monitor CO_2 during project and compare to baseline.
- Significant increase from baseline during a project signals a leak anomalous CO_2

http://www.sustaenable.eu/?page_id=932

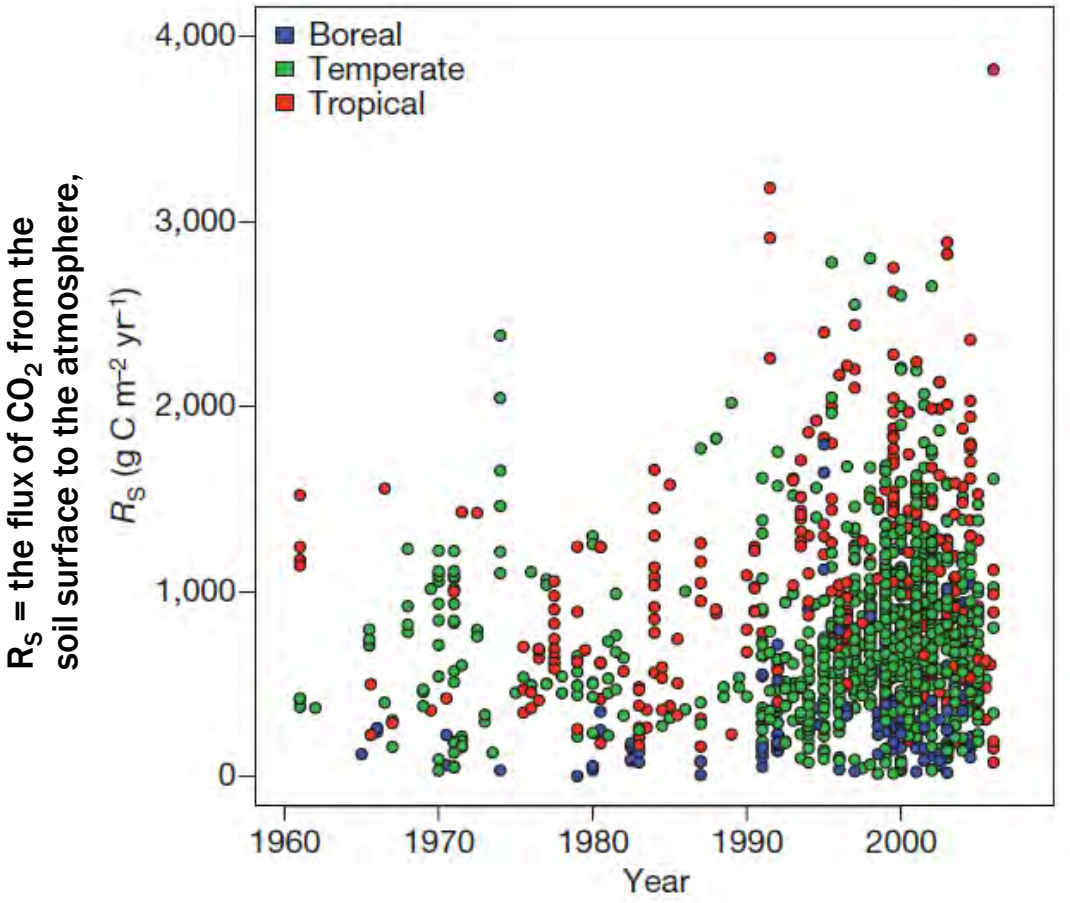
- Did the storage project cause the anomaly?
- "Attribution" is a missing step

But…. "Baselines" in Soils are Shifting Upwards

Vol 464|25 March 2010|doi:10.1038/nature08930 nature

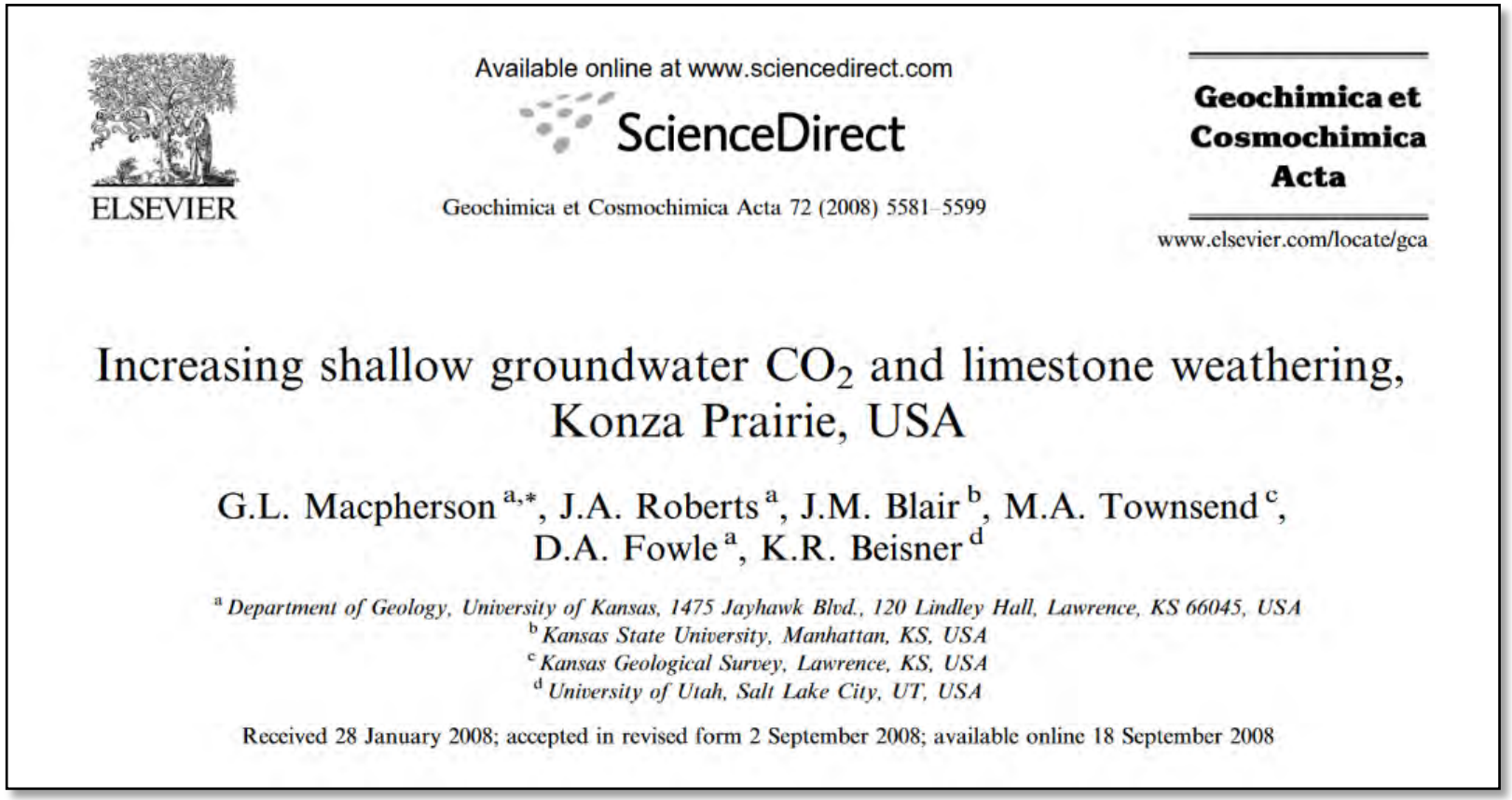
Temperature-associated increases in the global soil respiration record

Ben Bond-Lamberty[1] & Allison Thomson[1]



R_S = the flux of CO_2 from the soil surface to the atmosphere,

“Baselines” in Groundwater are Shifting Upwards



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www.elsevier.com/locate/gca

Increasing shallow groundwater CO_2 and limestone weathering, Konza Prairie, USA

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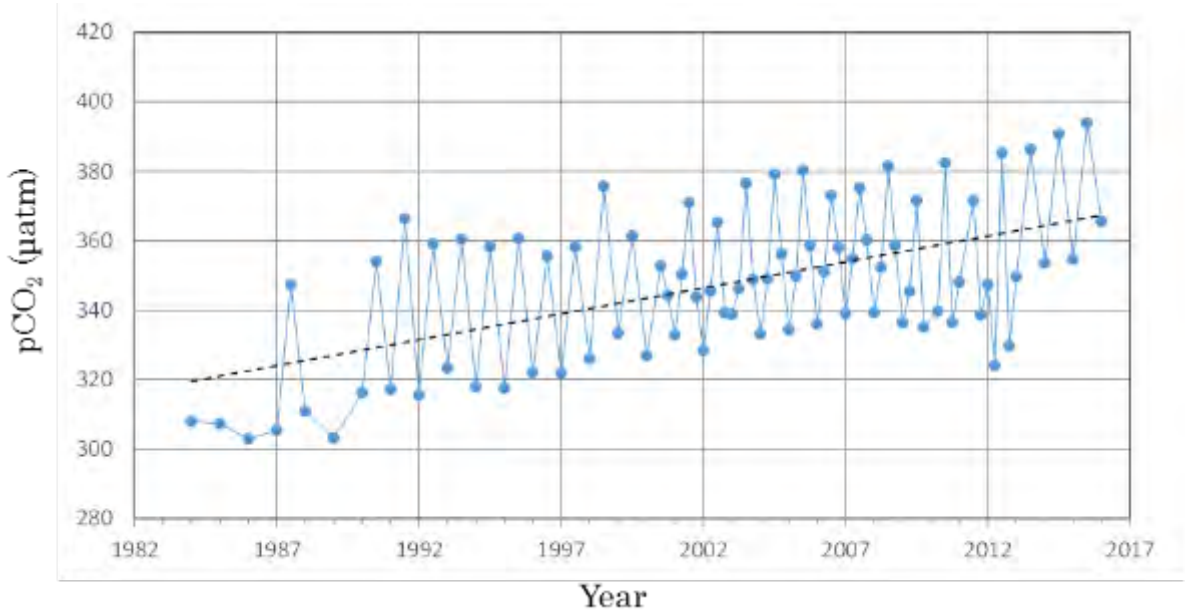
Received 28 January 2008; accepted in revised form 2 September 2008; available online 18 September 2008

“Baselines” in Seawater are Shifting Upwards



Time series of surface seawater CO_2 level near Japan. Source data by Japan Meteorological Agency, Courtesy of Jun Kita, RITE

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Katherine Romanak

Learning #1

- Naturally produced CO_2 in the biosphere is increasing due to climate change
- Use of “concentration-based” or “baseline” methods will result in false positives for leakage
- **The risk of false positives is greater than the risk of actual leakage**
- False positives put projects at unnecessary risk

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Tomakomai Project

- Tomakomai Offshore demonstration project Hokkaido Japan
- Derived leakage thresholds from 1 year of baseline data
- Injection began April 2016 with routine environmental monitoring plan
- May, 2016, operations were halted after 7,163 ton CO_2 was injected
- High CO_2 levels observed in the routine monitoring
- February 2017 operations resumed

Shifting baselines cause false positives and project shutdowns

Slide courtesy of Jun Kita, MERI

Learning #2

- If we actively look for “leakage” (e.g. via routine monitoring) we will find an abundance of natural anomalies
- We will need to attribute the source of these anomalies.
- Baseline methods are not effective or accurate.
- So how do we adequately assure environmental safety?

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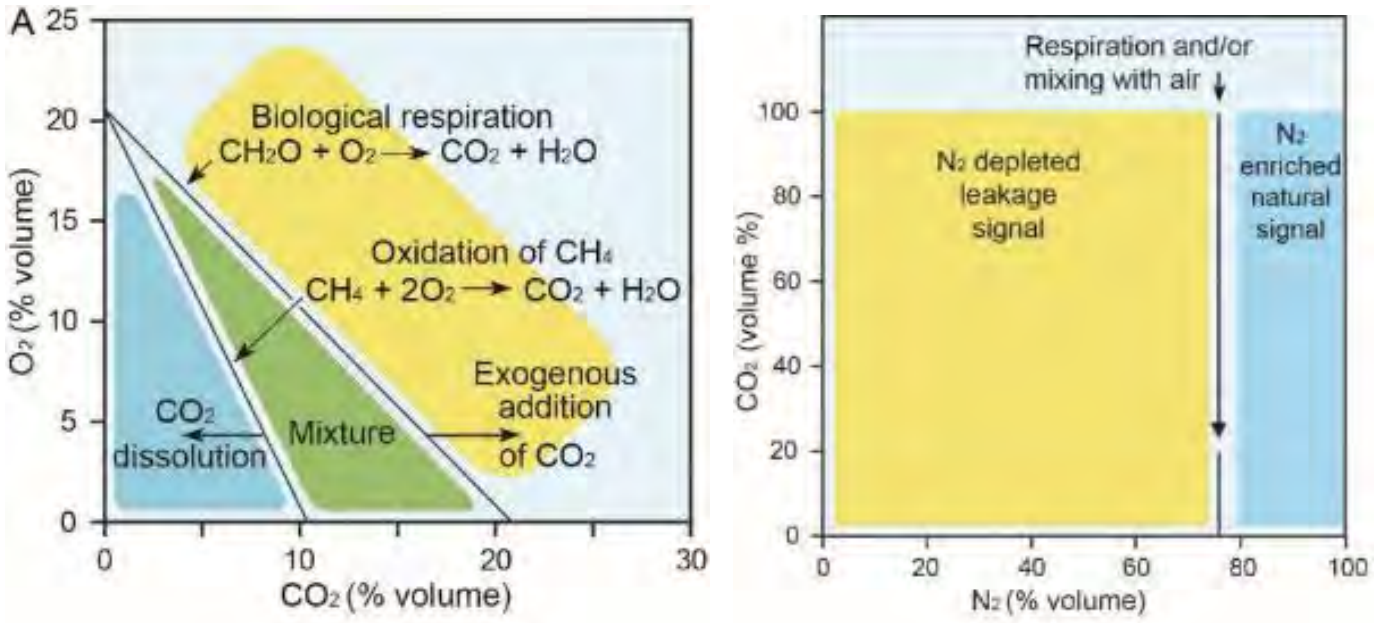
Process-Based Attribution Approach in Soil Gas

- Uses simple gas relationships to identify **processes.**
  - Biologic respiration
  - Methane oxidation
  - Dissolution
  - Leakage
- No need for years of background
- One time characterization
- Method can be applied in any environment regardless of variability



Romanak et al., 2014, International Journal of Greenhouse Gas Control, 30, 42-57
Romanak et al., 2012, Geophysical Research Letters, *39* (15).

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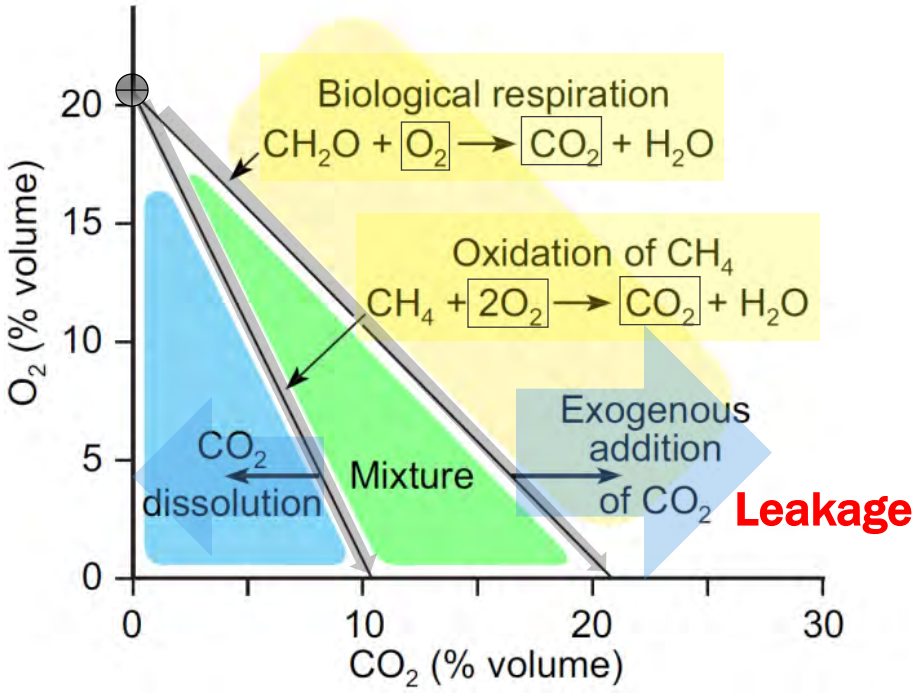
Process-Based Attribution Example

- Uses geochemical relationships to identify key processes rather than concentration comparisons



Application to a Leakage Allegation

- IEAGHG Weyburn CO_2 Monitoring and Storage project, Saskatchewan Canada
- Farmers perceived environmental change and blamed on the CO_2 storage project
- Attribution protocols for responding to stakeholder concerns were not in place
- Unexperienced consultant wrongly attributed the anomaly to leakage.


THE GLOBE AND MAIL

IN PICTURES

Carbon capture leak forces Saskatchewan couple to leave farm

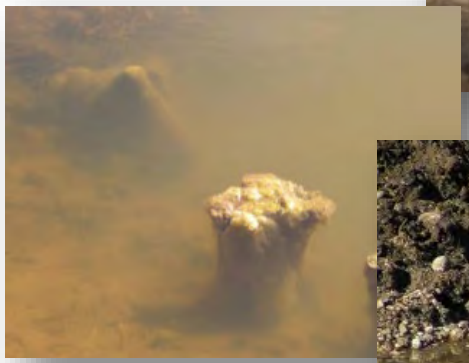
Published Tuesday, Jan. 11, 2011 6:12PM EST

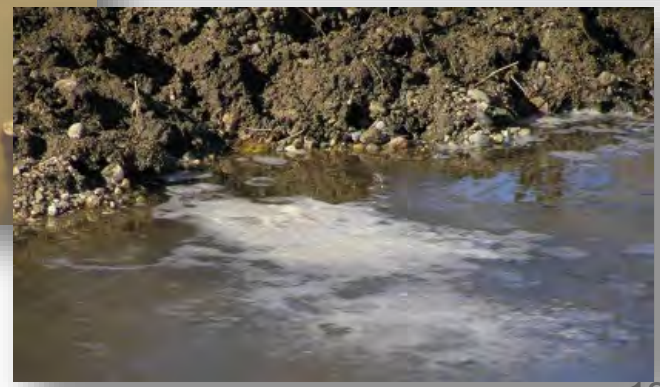
Pair abandon Saskatchewan farm because of blowouts, dead animals and algae

1 of 10

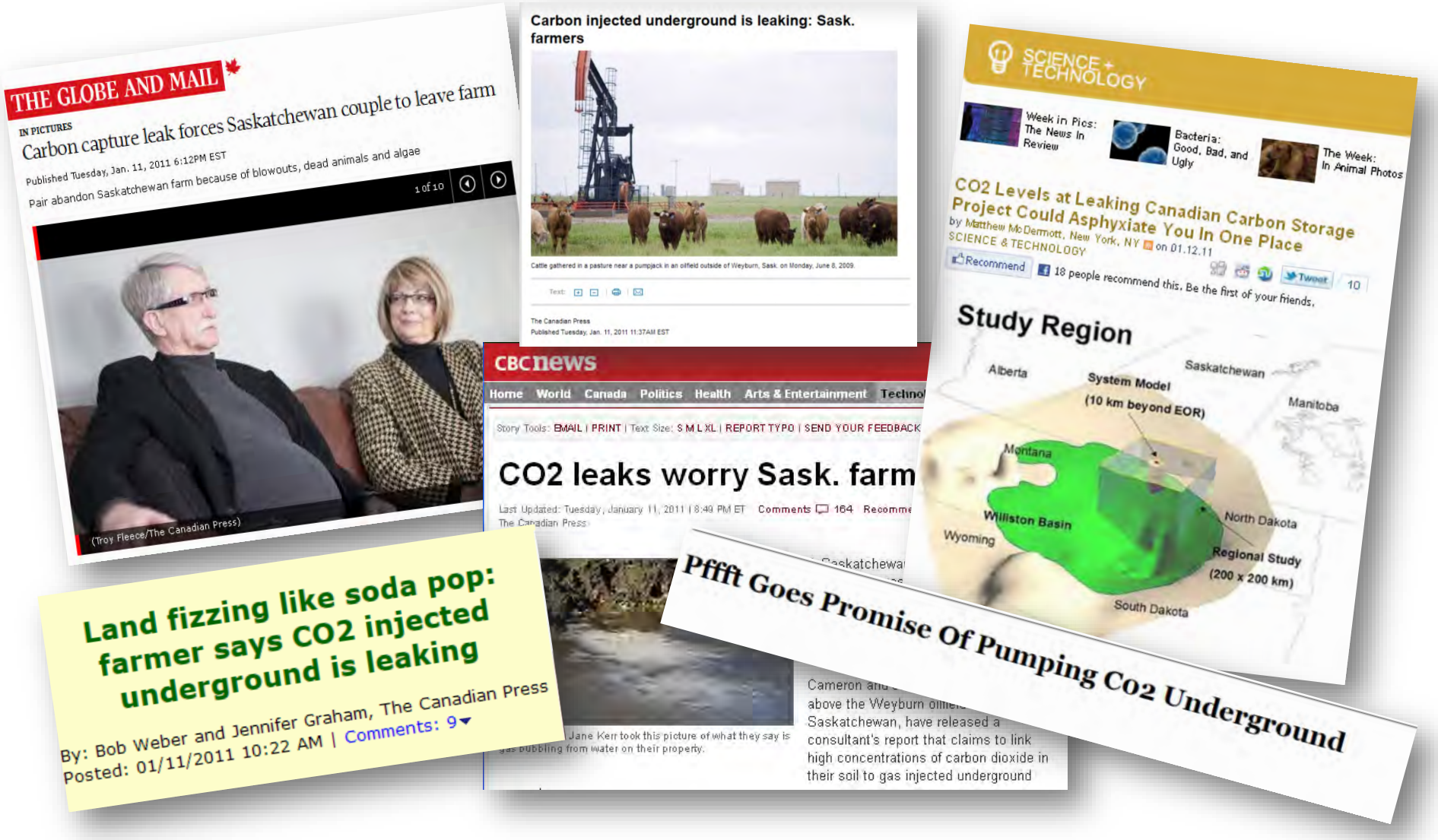
(Troy Fleece/The Canadian Press)

Show caption

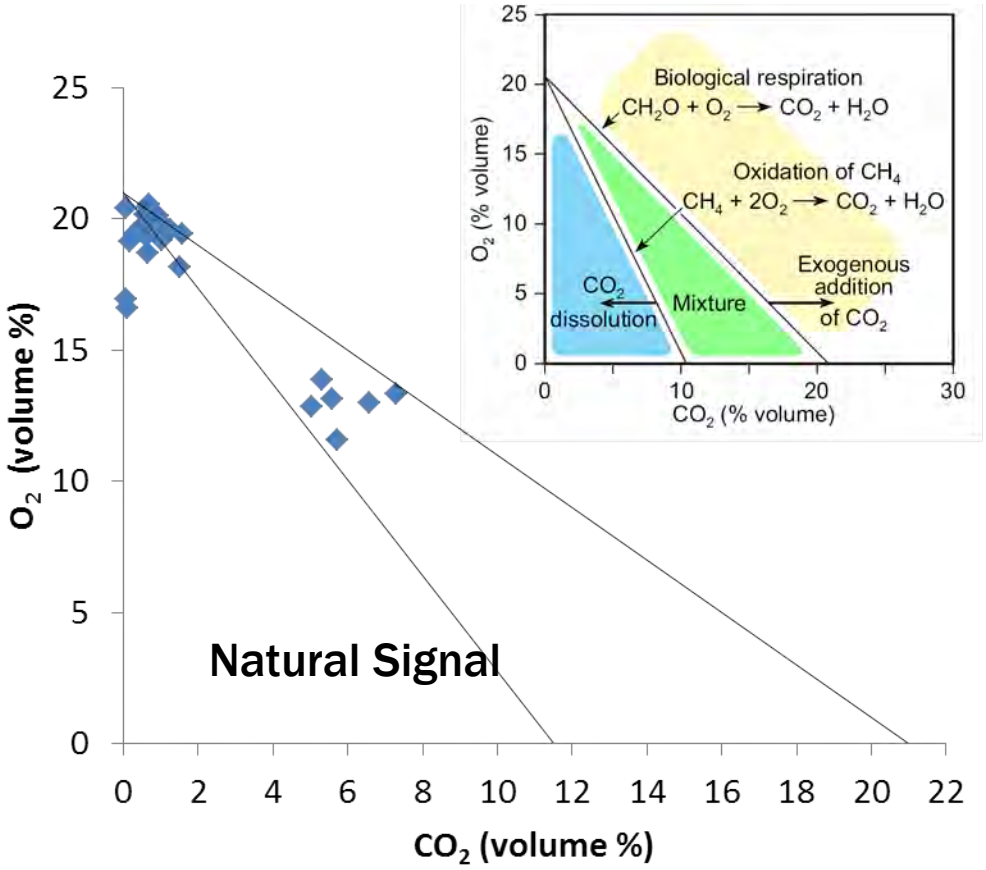




Wrong Attribution- Negative Media Storm



Process-Based Attribution Data from the Kerr Farm



Leakage Allegation Discounted

"the Kerrs, accepted the IPAC-CO2 study's findings while emphasizing its necessity, saying that "without a full scale investigation, it has been impossible until now to rule out CO_2 contamination."

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Learning #3

- Environmental change resulting from climate change will cause stakeholders to question the storage project
- When CCS is fully deployed, responding to stakeholders concerns may be our main activity.
- Need fast accurate stakeholder-friendly methods with clear thresholds
- Methods that are easily communicated to stakeholders are needed

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Attribution Methods

Method	Scientific Basis	PROS	CONS
Noble gas tracers (He, Rn)	• Fingerprinting technique • Assume conservative behavior • Low concentrations in the biosphere • Inherent to the CO_2 stream or reservoir • Can be added at cost	• Rigorously tested and proven in aqueous systems • Clear thresholds	• Not proven in soil gas • Conservative tracers may not directly represent reactive CO_2 concentrations • No continuous monitoring capability • Mostly proven for in-reservoir applications
Process-based soil gas ratios (CO_2, N_2, CH_4, O_2)	• Soil gas ratios indicate the processes that create the gases	• Easily measured • Instant simple graphical result • Universal threshold • Inherently includes seasonal and diurnal CO_2 fluctuations • Demonstrated at many project sites	• Used as a screening tool- if threshold is exceeded, additional attribution using carbon isotopes is required. • Continuous measurement technology is in development
Carbon Isotopes $\delta^{13}C$ versus ^{14}C	• Fingerprinting technique • Values are well-known in various media • Changes can easily predicted • Well documented and highly studied	• Easily measured • Continuous measurement currently available for $\delta^{13}C$ • Highly determinative when used together	• Significant overlap in $\delta^{13}C$ with majority of CO_2 sources • ^{14}C expensive analysis with no continuous measurement capability • Must be used together in most applications

Dixon and Romanak, 2015 recommended methods that: Rely on a one-time "characterization" rather than "baseline" methods

Revised Protocols for Leakage Monitoring

- Monitoring to acquire background measurements
- Monitoring to assess CO_2 storage performance in the reservoir
- Monitoring to detect leakage

and, if leakage detected or suspected, then

- **Monitoring for CO_2 attribution**

and only if CO_2 attributed to injected CO_2, then

- Monitoring to quantify leakage amounts
  and
- Monitoring to assess impacts of leakage

← Most of the time will not be needed at all

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Gap in the Global Regulations

Regulatory Body / Monitoring Objectives:	IPCC GHG Guidelines	London Convention and Protocol	OSPAR	EU		US EPA		UNFCCC Clean Development Mechanism
				CCS Directive	ETS Directive	UIC Class VI well regulation	GHG reporting Subpart RR	
Overall Objectives	GHG accounting	Protection of the marine environment	Protection of the marine environment	Protection of the environment	GHG accounting	Protection of the environment (underground sources of drinking water)	GHG accounting	GHG accounting and protection of the environment
Storage Performance	✓	Only in terms of retention	Only in terms of retention	✓		Only in terms of pressure and plume extent		✓
Detection of Leaks or Anomalies	✓	✓	✓	✓		✓	✓	✓
Baseline/ Background Measurements	✓			✓		✓	✓	✓
Attribution of Leaks and/or Anomalies	Mentions in the context of baseline isotopic ratios. Not included as a step						Mentions in the context of baseline CO_2 concentrations. Not included as a step	Not included as a step but accommodates a range of monitoring techniques
Environmental Impacts		✓	✓	✓		✓		✓
Quantification of GHG	✓				✓		✓	✓

Dixon and Romanak, 2015, Improving monitoring protocols for CO_2 geological storage with technical advances in CO_2 attribution monitoring *International Journal of Greenhouse Gas Control*, *41*, 29-40.

Recommend attribution be added as a step to the regulations.

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Conclusion and Implications

- Due to growing confidence in new monitoring techniques, we propose additional stage in monitoring protocols which will…
  - Increase monitoring efficiency
  - Respond to stakeholder concerns
  - Avoid false positives for leakage
  - Avoid unnecessary leakage quantification and impacts monitoring
  - Avoid significant unnecessary monitoring costs

Propose to be explicitly included for new protocols or when existing protocols are updated

2023 Updates Adding Attribution to the EU CCS Directive

Draft Zero for revised Guidance Document 2:

Characterisation of the Storage Complex, CO2 Stream Composition, Monitoring and Corrective Measures

Box 4: Attribution monitoring

Attribution monitoring aims to differentiate naturally occurring CO_2 from CO_2 that has originated from storage operations. Natural processes, such as decay of organic matter, dolomitisation, volcanic activity/ migration of magmatic CO_2 through dikes and sills, and wildfires, can generate CO_2. This is a key consideration in baseline monitoring, so that natural CO_2 can be distinguished from leaked CO_2. Geochemical monitoring methods can sometimes be used to attribute CO_2 to its source.

- Environmental monitoring for leakage out of the storage complex towards, at or near the surface, on land or offshore:
  - Detection of suspected leakage anomaly;
  - Attribution of leakage anomaly;
  - Quantification of leakage;
  - Accounting and quantification of emissions from the storage complex for surrender of emissions trading allowances for any leaked emissions under EU ETS Directive 2003/87/EC (see Section 4.2); Not all emissions are relevant to the EU ETS Directive.
  - Safety and Environmental impacts.

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