Project Title: DEVELOPING A COMPREHENSIVE RISK ASSESSMENT FRAMEWORK FOR GEOLOGICAL STORAGE OF CO2

Ian Duncan
University of Texas
Presentation Outline

1. Benefit to the Program
2. Goals and Objectives
3. Technical Status Project
4. Accomplishments to Date
5. Summary
Benefit to the Program

The research project is developing a comprehensive understanding of the programmatic (business), and technical risks associated with CCS particularly the likelihood of leakage and its potential consequences. This contributes to the Carbon Storage Program’s effort of ensuring 99 percent CO$_2$ storage permanence in the injection zone(s) (Goal).
• Employing Bayesian inference to evaluate sequestration risks

• Utilize the safety record of the CO2 based Enhanced Oil Recovery industry (CO2-EOR) and pilot sequestration projects to identify and evaluate potential risks

• Identify and quantify the nature of programmatic risks

• Utilize diverse, highly qualified expert panels drawn from industry and nongovernmental organizations (NGO) to evaluate changing perceptions of programmatic risks

• Develop an understanding and quantify the role that a pressure field generated by injected CO2 (and the dissolution of CO2 from the plume into the brine phase) may play in risk

• Assess the possible consequences to water ecology and energy resources from potential leakage of CO2 from deep brine reservoirs.
Comprehensive Risk Study of CCS: Risks of Transporting CO$_2$ by Pipeline

Ian Duncan
University of Texas
Let's talk about individual risks that we face:

Why don’t we all live in concrete bunkers?
What is the probability that something, like a jet engine, will fall from the air and kill us?
Is it safe?

“because nothing can be absolutely free of risk, nothing can be said to be absolutely safe”

Lowrance (1976)
“A thing is safe if its risks are judged to be acceptable.”

Lowrance (1976)
“establishing acceptable levels of risk, particularly for those in proximity to a pipeline, will always be a difficult task.”

Williams (2012)... Report to Parliament of Canada
Estimating Level of Acceptable Risk

Analysis of actuarial risk/benefit information could reveal the magnitude of risk acceptable to the public. Starr (1969)

the “revealed preference approach” … Slovic (1987)
Why Study Risks Associated with CO_2_ Pipelines?

IPCC (2005):

“If CO2 is transported for significant distances in densely populated regions; the number of people potentially exposed to risks from CO2 transportation facilities may be greater than the number exposed to potential risks from CO2 capture and storage facilities”

“Public concerns about CO2 transportation may form a significant barrier to large-scale use of CCS”.
Why Study Risk of Natural Gas Transmission Pipelines

• Natural gas transmission pipelines follow same design codes, use same steel and installation techniques as CO₂ pipelines.

• Only data set on public risk large enough to make a robust analysis
What do the Newspapers Say about Risks of Natural Gas Pipelines?

USA Today, 2000

“pipelines are time bombs” and that “2 million miles of them deliver potential catastrophe everyday”.

USA Today, 2011

“A fiery natural gas explosion in Allentown, Pa., is the latest in a series of deadly accidents that have raised worries about a form of energy that had a good safety record until recently”.
Let's look at some Real Information
Natural Gas Transmission Pipeline Incidents

Number of incidents

Year


Total incidents
Significant incidents
Injury incidents
Serious incidents
Five-year moving average
But Pipelines are Getting Safer!
Pipeline Deaths and Injuries (1986-2010)

Data: DOT/PHMSA Incident data (May 2, 2011)
Fatality and Injury Rates
Natural Gas Transmission Pipelines

![Graph showing fatality and injury rates per km per year from 1990 to 2005. The graph indicates a decrease in both fatality and injury rates over the years.]
Transmission Pipeline Explosion
San Bruno, California
The Scene after the San Bruno Event
Almost all previous risk studies of CO$_2$ Pipelines have Used Incident Rates for Natural Gas Transmission Pipelines as Estimates of Individual Risk…
Natural Gas Pipeline Incident Rates used by Published CO2 Pipeline Risk Analyses

3.0 \times 10^{-3} \text{ to } 1.5 \times 10^{-4} \text{ (per kilometer per year)},
median of about 2.0 \times 10^{-4}

13 published CO2 pipeline risk analyses use these probability estimates

US rate for modern pipelines (last 30 years)
1.2 \times 10^{-5} \text{ per km per year}
Injury + Fatality Rates versus Number of Significant Incidents
If Incident Rates do not Correlate with Fatalities… what are they Correlated with?
Serious Incident Rate versus Gas Price

- Henry Hub natural gas price
- Failure rate of offshore transmission pipelines
- Failure rate of offshore gathering pipelines

Year:
- 1990
- 1995
- 2000
- 2005

Natural gas price (dollars per Million BTU):
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8

Failure rate (per km per year):
- 0
- 0.0005
- 0.001
- 0.0015
- 0.002
- 0.0025
Onshore Incident rate versus Gas Price
Offshore Natural Gas Pipeline Incident Rate Versus Gas Price

![Graph showing incident rate versus gas price for offshore natural gas pipelines. The graph displays data points for offshore gathering pipelines (red dots) and offshore transmission pipelines (yellow dots).](image-url)
How can we use Natural Gas Pipeline Data .... to Understand Likelihood of failure of Future CO2 Pipelines?
Failure Mechanism versus NG Pipeline Age
Failure Pressure to MAOP versus Pipeline Age

![Graph showing the relationship between Failure Pressure to MAOP and Pipeline Age](image)
Rupture Rate Versus NG Pipeline Age

![Graph showing the rupture rate versus NG pipeline age.](image)

**Y-axis:** Failure rate (per km per year)

**X-axis:** Installation years

- **1940~1950**
- **1950~1960**
- **1960~1970**
- **1970~1980**
- **1980~1990**
- **1990~2000**
- **2000~2009**
Most Ruptures are Small

Ocurrence probability of different ruptures

Per km per year

Rupture length (inches)
Public versus Company Injury/Fatality Rates

- Public injury rate
- Public fatality rate
- Non-public injury rate
- Non-public fatality rate
U.S. Approach

- Pipeline design and construction must meet ASME Design Standards
- Pipeline operators must do proactive risk management on pipelines in High Consequence Areas (HCAs)
High Consequence Areas

Class 1 Rural 10 or fewer houses within 150 meters

Class 2 Village or outer suburban area with more than 10 and less than 46 buildings intended for human occupancy within 150 meters.

Class 3 Town with 46 or more houses or any area within 100 meters of a building or a playground, recreation area, outdoor theatre, etc.

Class 4 Urban/ city buildings with four or more stories
Public versus Non-Public Risks

Public fatality risk = $7.2 \times 10^{-7}$

Non-Public fatality risk = $4.8 \times 10^{-7}$
Natural Gas Transmission Pipeline Failure near Elyria, Ohio, August, 2012

Consequence:

Four serious injuries to members of general public
Member of general-public kills pipeline...
What Happened?

The vehicle ... attempted to jump over railroad tracks at a high rate of speed

... went air born at least 40 feet

... went thru a chain link fence and crashed into a cinder block building

... Four people were in the car.
What is the Significance of High Consequence Area Regulations for Predicting CO2 Pipeline Safety?

No previous study has examined the effect that HCA rules have on pipeline risk...

“accidents [associated with CO₂ pipelines] in densely populated areas represent a greater risk both in terms of probability and severity.” (Esteves and Morgado, 2012)
High Consequence Areas

Class 1 Rural 10 or fewer houses within 150 meters

Class 2 Village or outer suburban area with more than 10 and less than 46 buildings intended for human occupancy within 150 meters.

Class 3 Town with 46 or more houses or any area within 100 meters of a building or a playground, recreation area, outdoor theatre, etc.

Class 4 Urban/ city buildings with four or more stories
Design Factors for HCAs

ASME B31.8S specified minimum yield strength (SMYS) as key design factors:

Class 1 72% of SMYS
Class 2 60% of SMYS
Class 3 50% of SMYS
Class 4 40% of SMYS

For constant pipeline pressure, the design factor is accommodated by increasing the wall thickness thus increasing the SMYS.
Pipeline Wall Thickness Versus Diameter

- Wall thickness for natural gas pipelines
- Suggested wall thickness for CO₂ pipelines (DF=0.72)
- Suggested wall thickness for CO₂ pipelines (DF=0.6)
- Suggested wall thickness for CO₂ pipelines (DF=0.5)
Safety Factor versus Injury Rate

The diagram illustrates the relationship between safety factor and injury rate. It shows data points for different classes labeled as Class 1, Class 2, Class 3, and Class 4. The x-axis represents the safety factor, while the y-axis represents the injury and fatality rate. The data points are distributed across the graph, indicating varying levels of safety factor and injury rate for each class.
Safety Factor Versus Fatality Rate

- **Class 1**
- **Class 2**
- **Class 3**
- **Class 4**
Safety Factor vs. Rupture (>10 in) Rate

- Class 1
- Class 2
- Class 3
- Class 4

Rupture rate (per km per year)

Safety factor
Public Fatality Rate

Safety factor

Class 1
Class 2
Class 3
Class 4

Public fatality rate
Safety Factor vs. Rupture (>10 in) Rate

- Class 1
- Class 2
- Class 3
- Class 4

Safety factor vs. Rupture rate (per km per year)
Public Fatality Rate

- Class 1
- Class 2
- Class 3
- Class 4
But do Design Factors Effectively Manage Risk of Fatalities?
Let's Talk about the Nature of Risk
Voluntary Versus Imposed Risks

• Voluntary risks are taken on under informed consent.... (examples: mountain climbing, working for a pipeline emergency response team)

• Imposed risks (a pipeline gets built next to my house, a gas well is drilled near my water well)
EXAMPLES OF INDIVIDUAL RISKS:

North Sea offshore oil and gas production
1 in 1000 or $1 \times 10^{-3}$ per year. Equivalent to a rate of just above 30 fatal accidents per $10^8$ exposure hours.

Mountain climbing: risk of $10^{-3}$ per year

Driving an automobile: risk of $1 \times 10^{-4}$ per year

Flying: risk of $5 \times 10^{-5}$ per year.
# Exposure to $10^{-3}$ Risks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Number of activities in one year that equals and IRPA of $10^{-3}$ per year</th>
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<tbody>
<tr>
<td>Hang-gliding</td>
<td>116 flights</td>
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<td>Surgical anaesthesia</td>
<td>185 operations</td>
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<tr>
<td>Scuba diving</td>
<td>200 dives</td>
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<tr>
<td>Rock climbing</td>
<td>320 climbs</td>
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</table>
At what risk level do we loose interest?

- Risk of something falling from sky and killing us is $10^{-9}$
- Risk of death from the sky within 2 Km of an airport is $10^{-8}$
- But we don’t live in concrete bunkers so most of us are not concerned about risks at this level...
FATALITY RATE VERSUS CLASS

Total Fatalities
Class 1 = $4.0 \times 10^{-6}$
Class 2 = $1.0 \times 10^{-6}$
Class 3&4 = zero

Public Fatalities
Class 1 = $1.0 \times 10^{-6}$
Class 2,3,&4= zero
UK HSE Acceptable Risk

Frequency (N or more) per year

N (Fatalities)

Unacceptable risk

ALARP zone

Acceptable risk
Cost Benefit Analysis
Cost of Lowering Risk

- Acceptable risk
- Total cost
- Minimum project cost
- Capital and construction cost
- Cost of pipeline failure

Risk: $10^{-5}$ to $10^{-8}$
Cost: $10^{-6}$
CONCLUSIONS: NG Pipeline Risk

• Real risk data from US pipelines suggest that the risk to the general public from natural gas transmission pipelines shows that risk of fatalities is two orders of magnitude smaller than that set as acceptable in Europe.....

• Acceptable Level of Risk Revealed?
UK HSE Acceptable Risk

- Frequency (N or more) per year
- N (Fatalities)

- Unacceptable risk
- ALARP zone
- Acceptable risk
CONCLUSIONS: CO₂ Pipeline Risk

- Likelihood of CO₂ pipeline failure significant enough to cause deaths at least 3 orders of magnitude less than assumed in previous risk studies.

- Individual risk of CO₂ pipelines is likely in the range of $10^{-6}$ to $10^{-7}$ or lower

- Fatality risk of a well designed, appropriately mitigated CO₂ pipeline in an urban area is even lower
Risk of US Pipelines versus other Countries?

In the US lack of strong land-use zoning enables urban development to encroach on pipelines.

Most major pipeline accidents with fatalities have occurred in unmonitored pipelines not up to code, and with critical defects.

Pipelines in most countries meet or exceed ASME design codes.
Final thought...

For pipelines, dams, for earthquake safety, for unconventional natural gas development etc.

….. how safe do we want it to be and are we prepared to pay the cost?
Appendix
# Organization Chart

**Project Director**  
Ian Duncan  
Phone: 512-471-5117  
Cell: 512-923-8016  
ian.duncan@beg.utexas.edu

<table>
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<tr>
<th>Task 1 Management</th>
<th>Task 2 Development and application of Conceptual Framework for Risk Assessments for CO2 Sequestration Projects in Deep Brine Reservoirs</th>
<th>Task 3 Development of protocols for risk assessment for geologic sequestration in brines</th>
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| **Task Leader:** Ian Duncan | **Task Leader:** Eric Bickel  
512 232 8316  
ebickel@mail.utexas.edu | **Task Leader:** Ian Duncan |

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<td>2.2 Compilation of information on operational risks from CO2-EOR industry and identification of linkages between programmatic and technical risks</td>
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<td>2.3 Development of prototype risk analysis methodologies</td>
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<td>2.4 Implementation and testing of proposed risk analysis methodologies</td>
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<td>2.5 Refinement of risk analysis methodologies</td>
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<td>2.8 Identification of realistic, fact based, scenarios for leakage from geologic reservoir containment</td>
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<td>2.13 Modeling risks associated with seal leakage</td>
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<td>2.15 Identification of risk associated with injection pressure inducing earthquakes</td>
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<td>2.16 Development of site-specific risk protocols for pressure induced earthquakes</td>
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<td>2.17 Modeling and analysis of risks associated with injection pressure induced earthquakes</td>
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<td>2.18 Evaluate risk related to CO2 dissolution into brine and entering regional flow systems</td>
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Bibliography


