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

Ian Duncan

University of Texas

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 20-22, 2013

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).***

PROJECT GOALS and OBJECTIVES

- Employing Bayesian inference to evaluate sequestration risks
- Utilize the safety record of the CO_2 based Enhanced Oil Recovery industry (CO_2-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 CO_2 (and the dissolution of CO_2 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 CO_2 from deep brine reservoirs.

Comprehensive Risk Study of CCS: Risks of Transporting CO_2 by Pipeline

Ian Duncan

University of Texas

Lets 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 CO_2 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

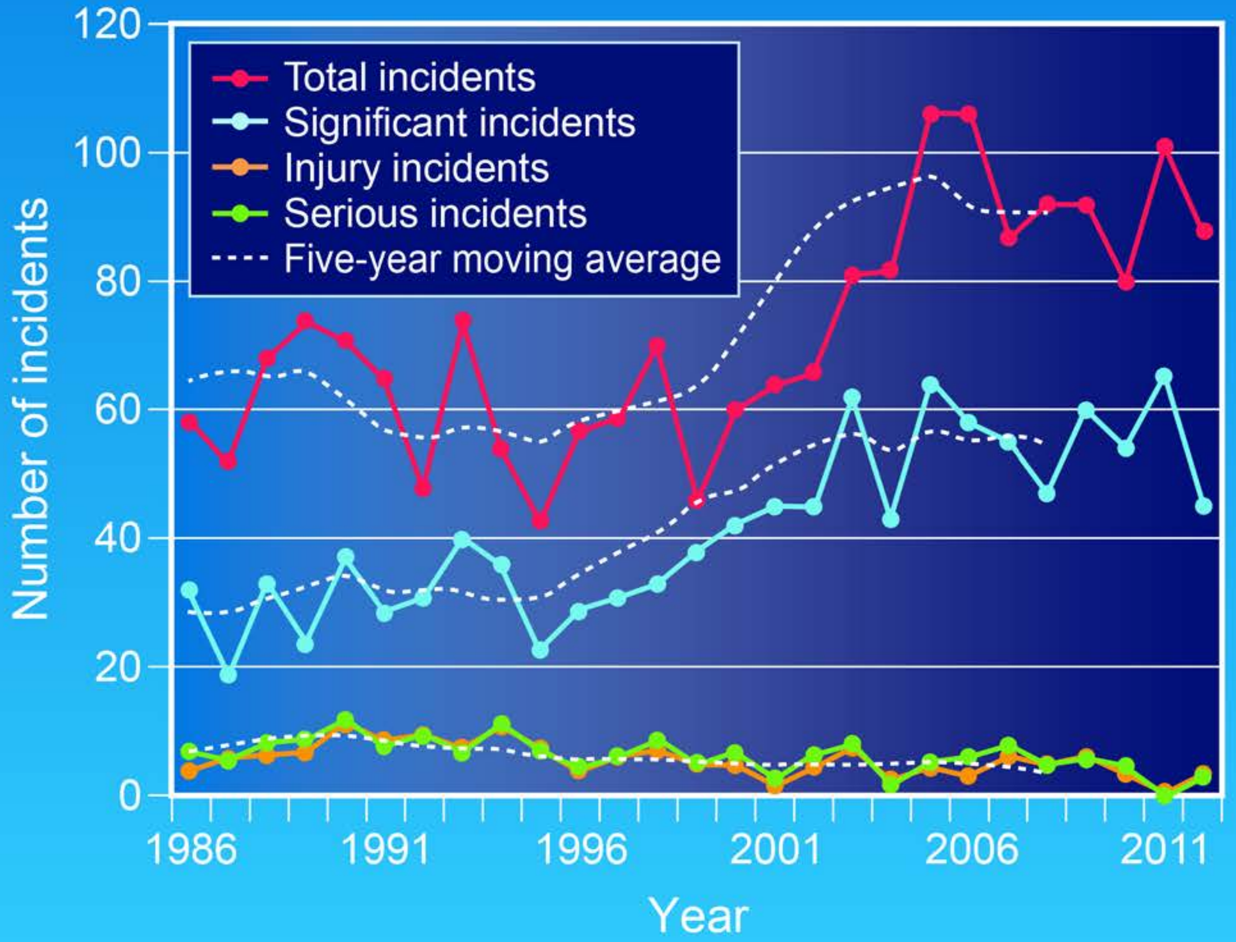
"pipelines are time bombs" and that "2 million miles of them deliver **potential catastrophe everyday**".

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***".

Lets look at some Real Information

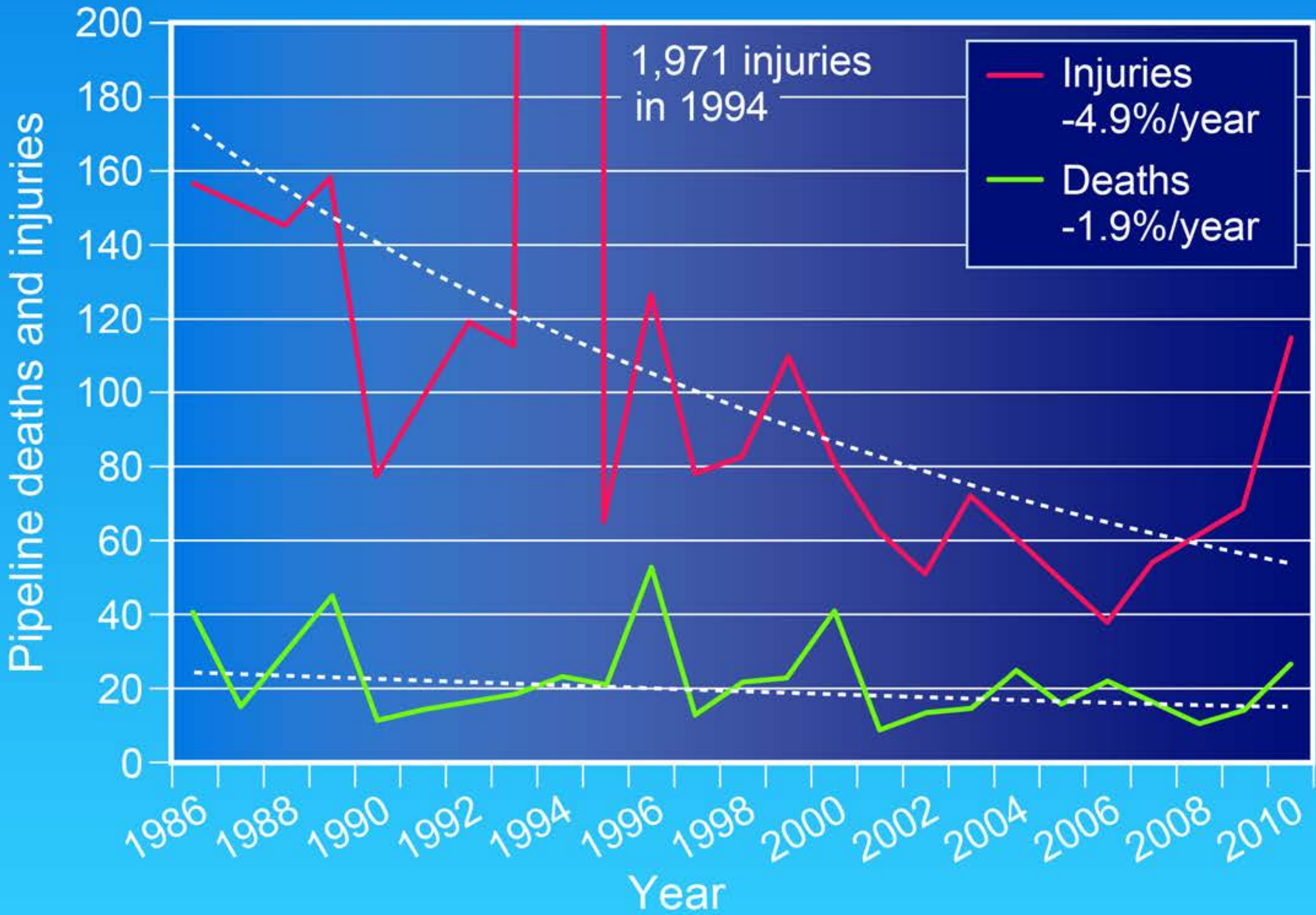
Natural Gas Transmission Pipeline Incidents



QAe1941

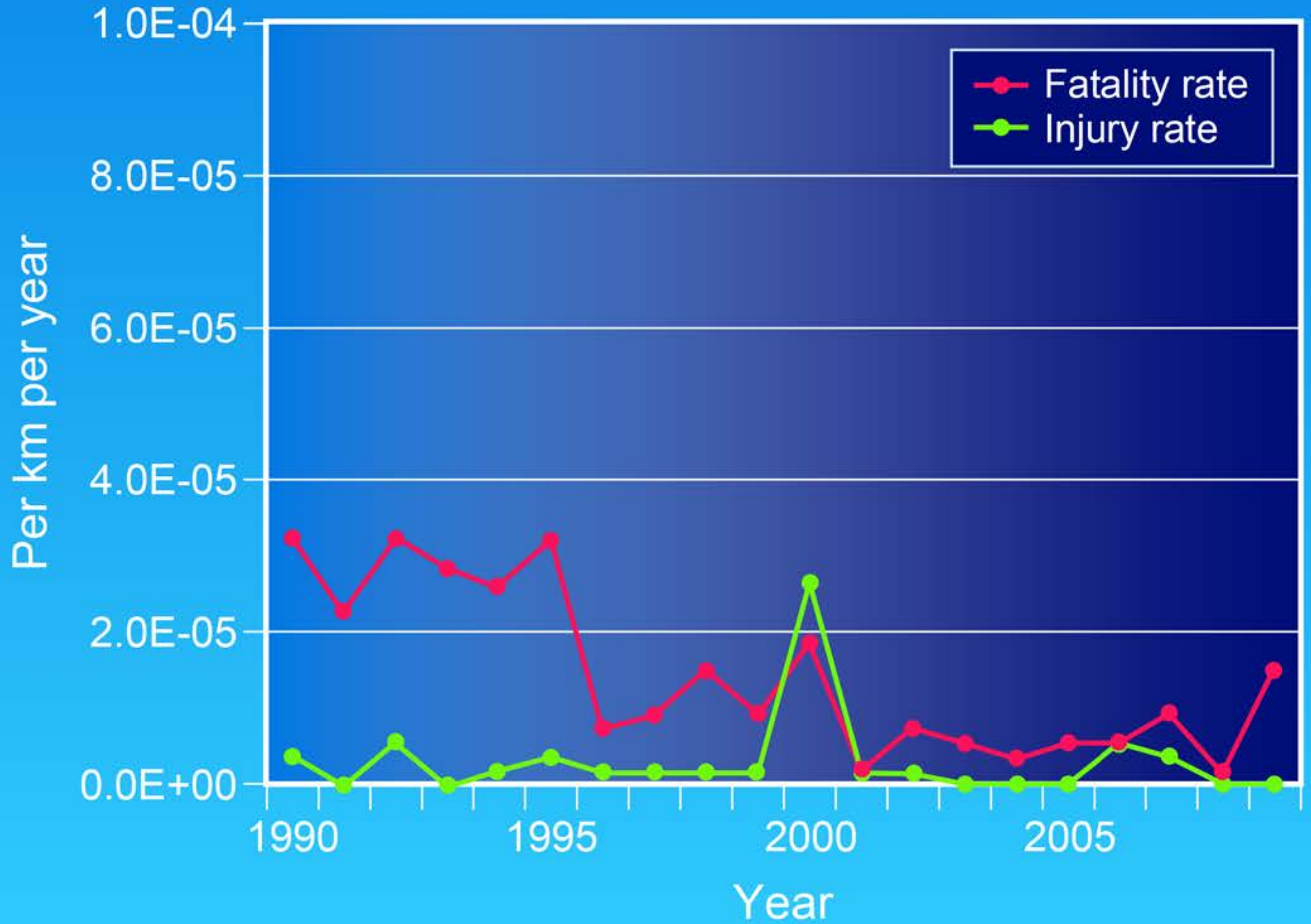
But Pipelines are Getting Safer!

Pipeline Deaths and Injuries
(1986-2010)



Data: DOT/PHMSA Incident data (May 2, 2011)

Fatality and Injury Rates
Natural Gas Transmission Pipelines



QAe1943

Transmission Pipeline Explosion
San Bruno, California

Bureau of Economic Geology

The Scene after the San Bruno Event

Bureau of Economic Geology

Why are Natural Gas Pipeline Incident Rates of Interest?

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

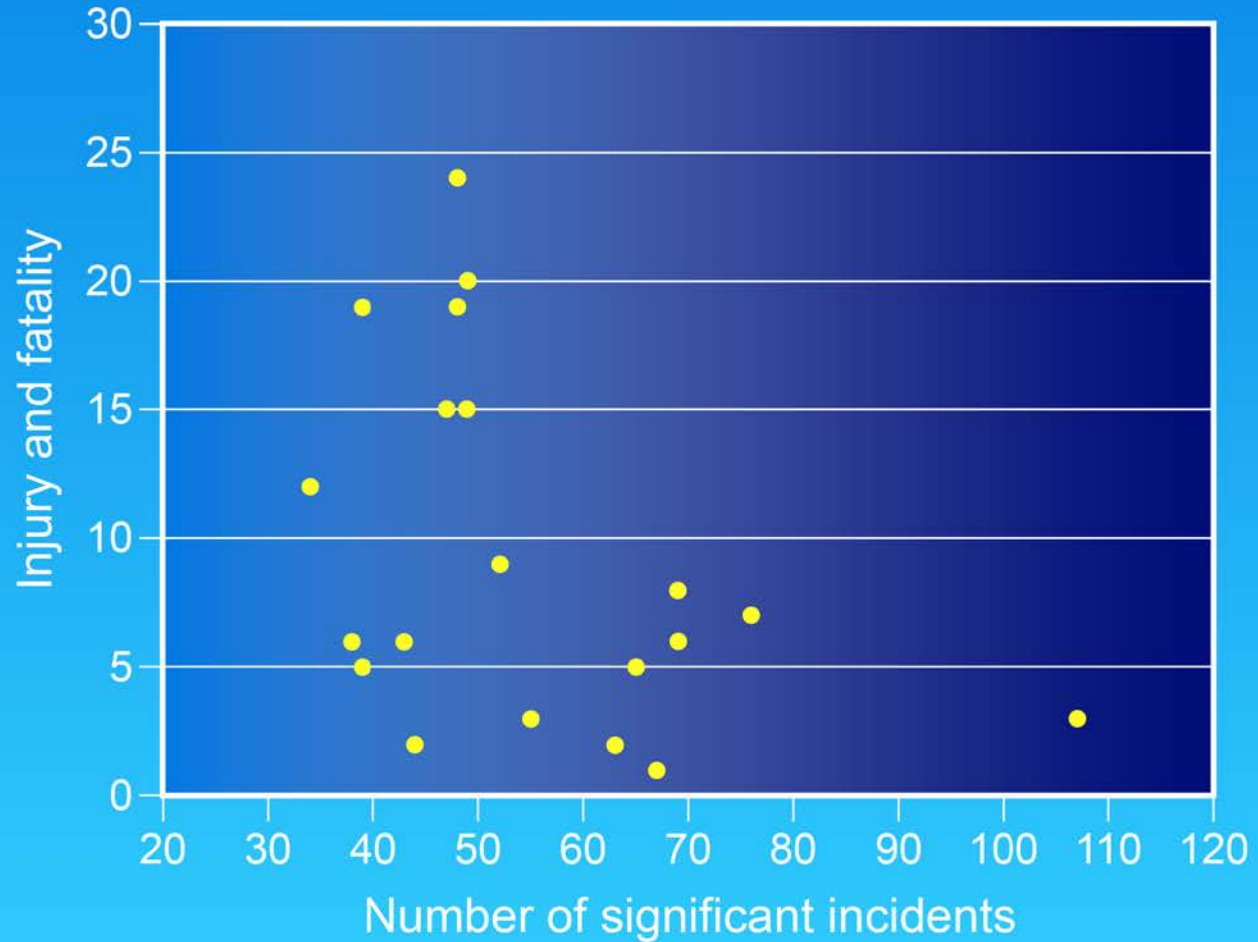
3.0×10^{-3} to 1.5×10^{-4} (per kilometer per year), median of about 2.0×10^{-4}

13 published CO2 pipeline risk analyses use these probability estimates

US rate for modern pipelines (last 30 years)

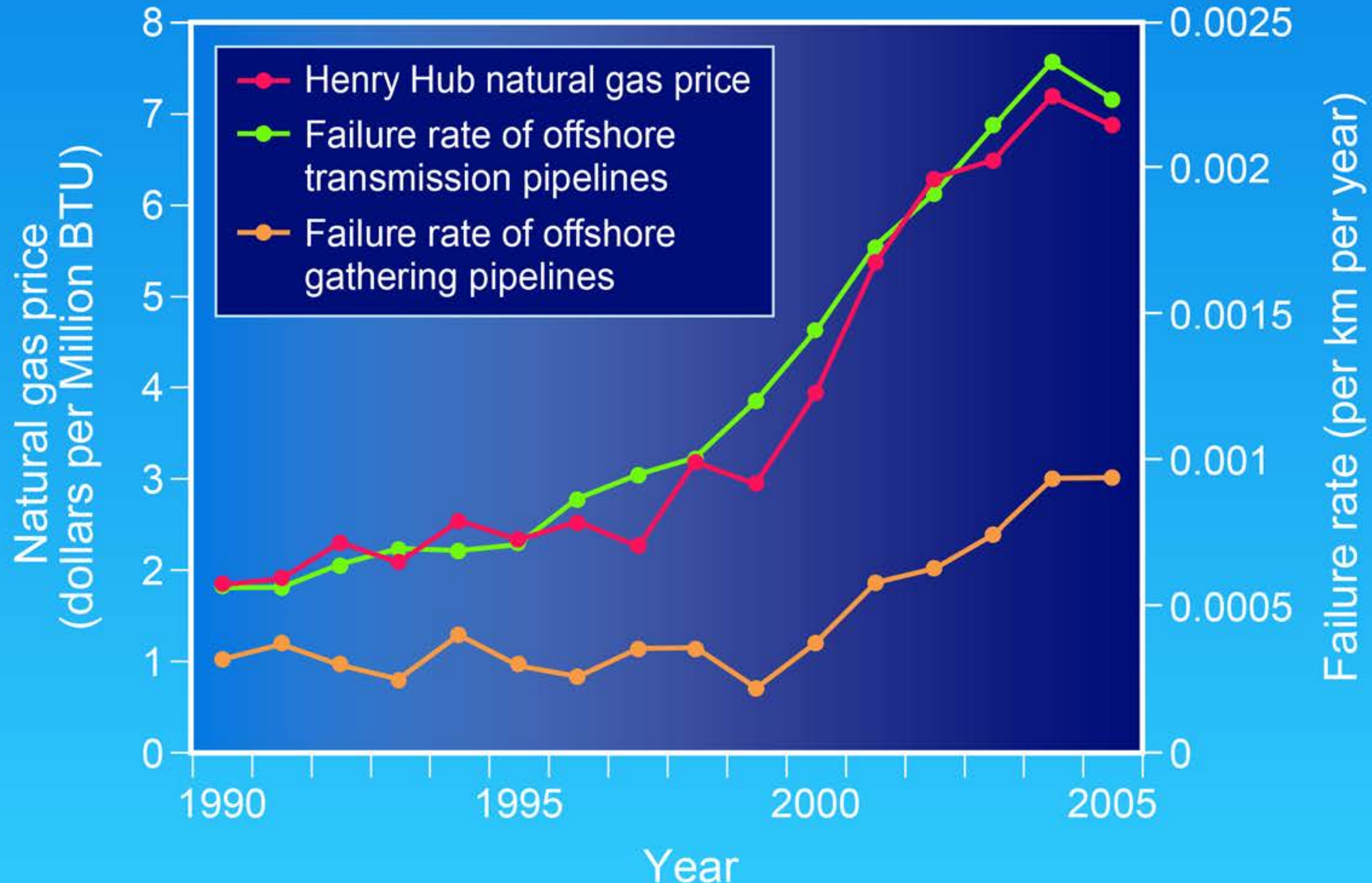
1.2×10^{-5} per km per year

Injury + Fatality Rates versus Number of Significant Incidents



If Incident Rates do not Correlate with Fatalities… what are they Correlated with?

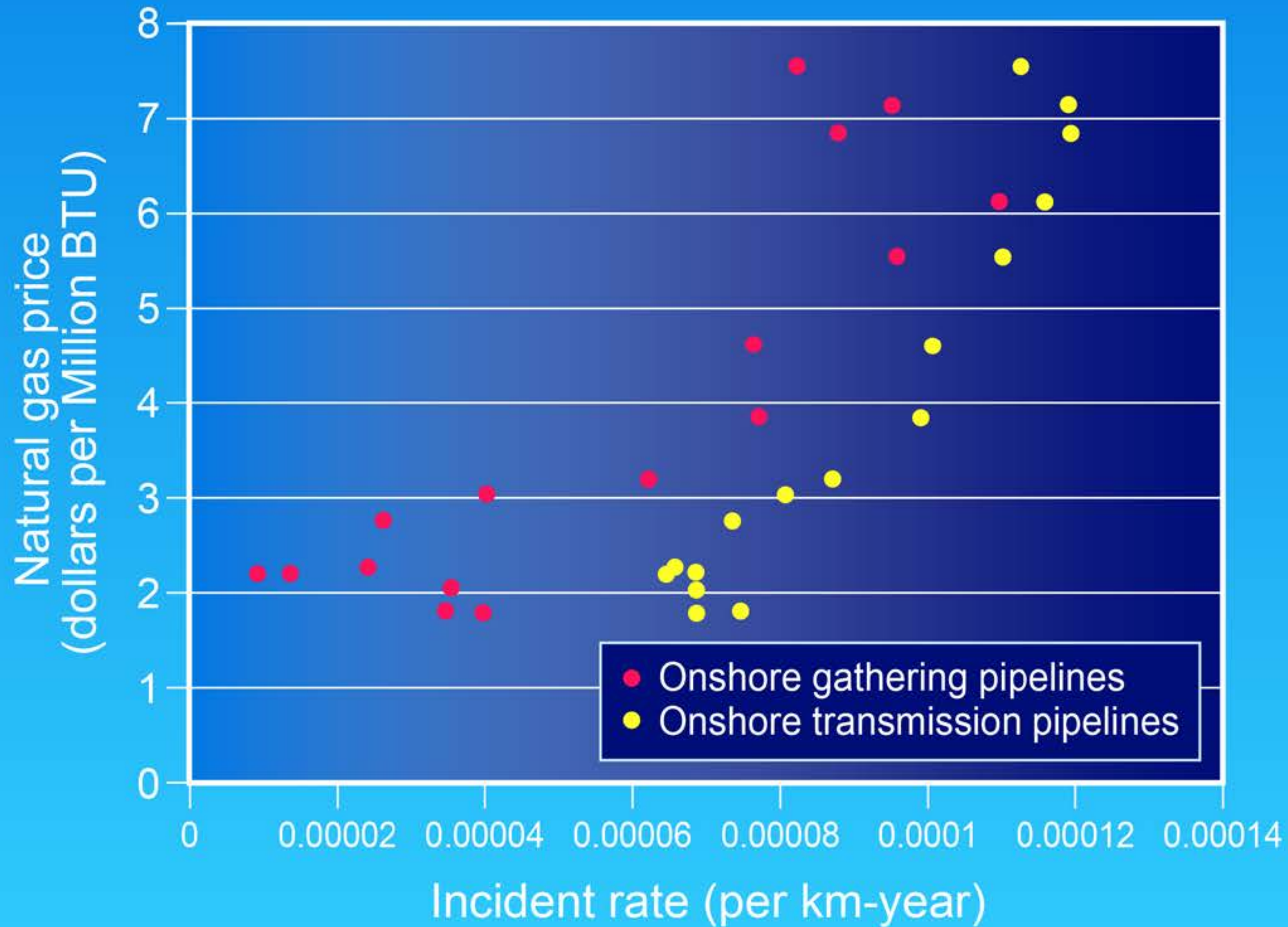
Serious Incident Rate versus Gas Price



Bureau of Economic Geology

QAe1947

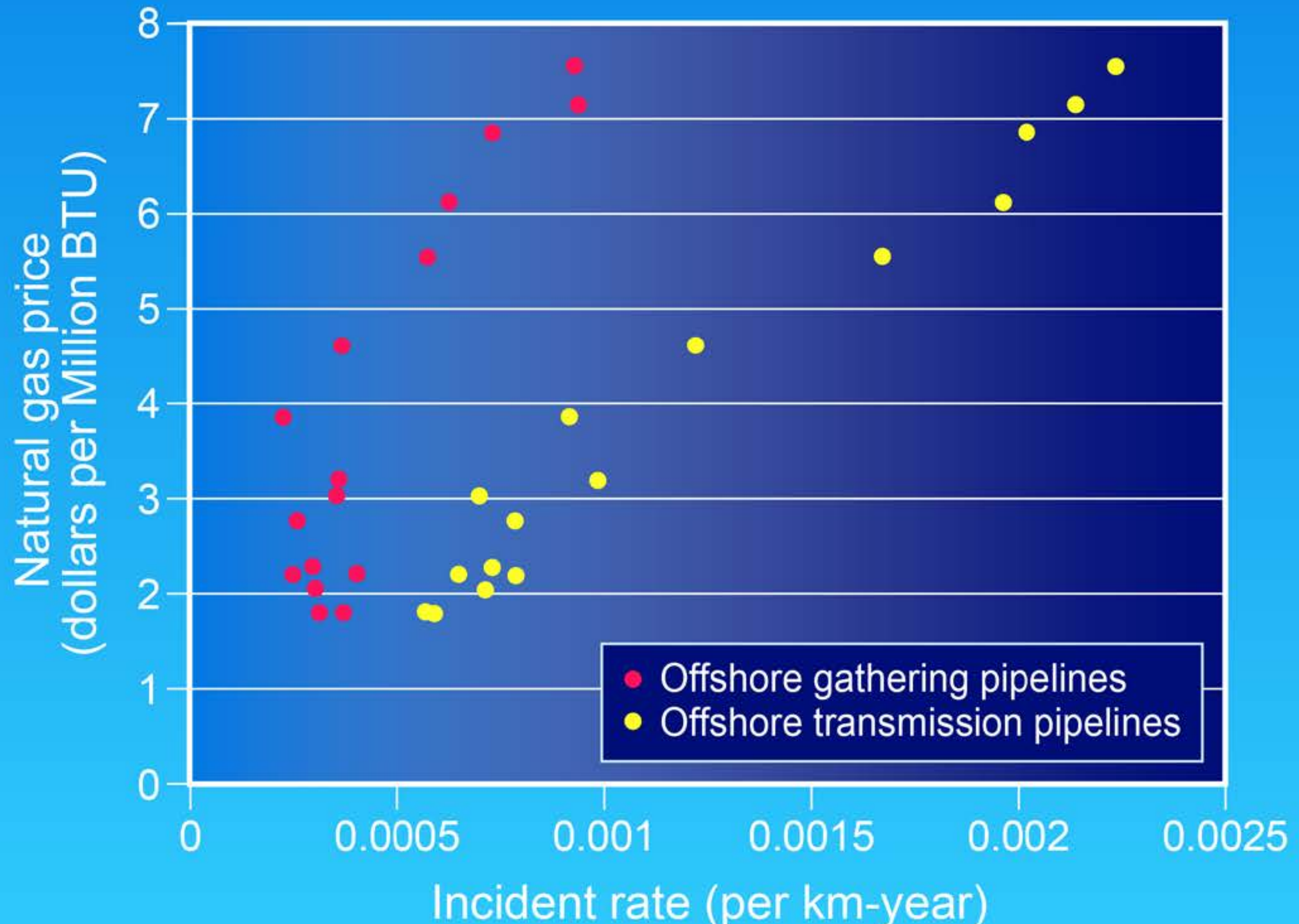
Onshore Incident rate versus Gas Price



Bureau of Economic Geology

QAe1948

Offshore Natural Gas Pipeline Incident Rate Versus Gas Price

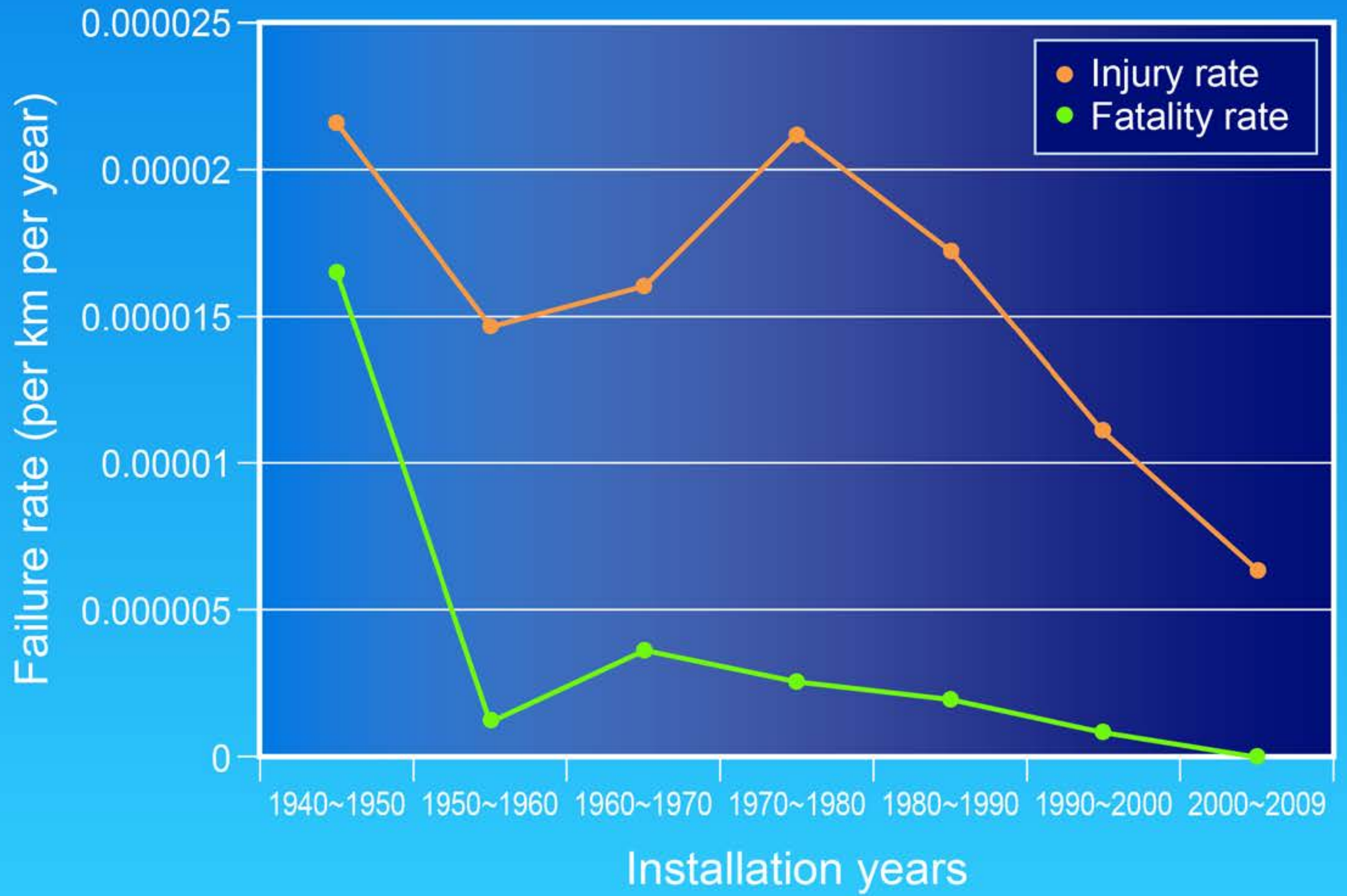


Bureau of Economic Geology

QAe1949

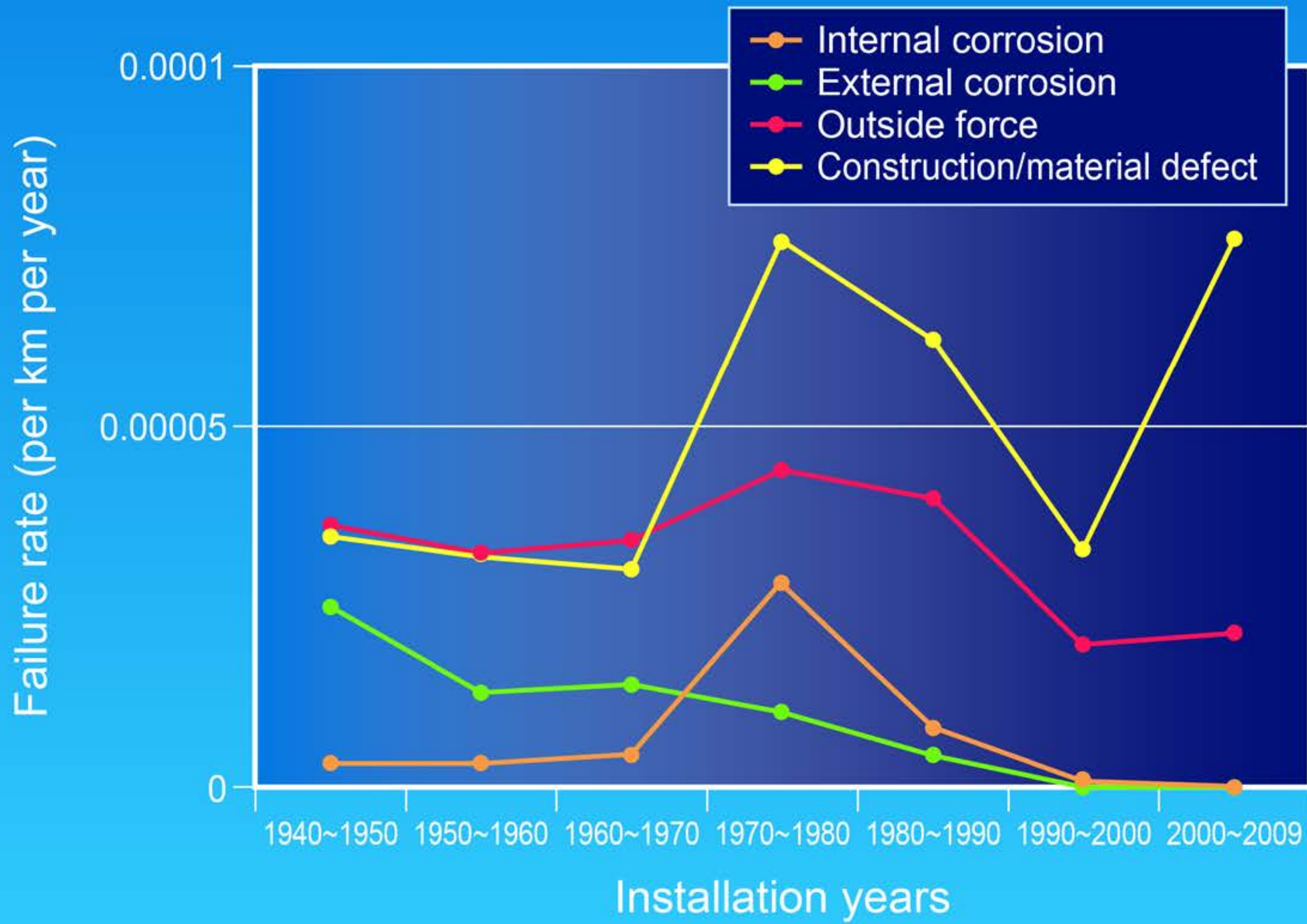
How can we use Natural Gas Pipeline Data …. to Understand Likelihood of failure of Future CO_2 Pipelines?

Injury and Fatality Rate Versus NG Pipeline Age

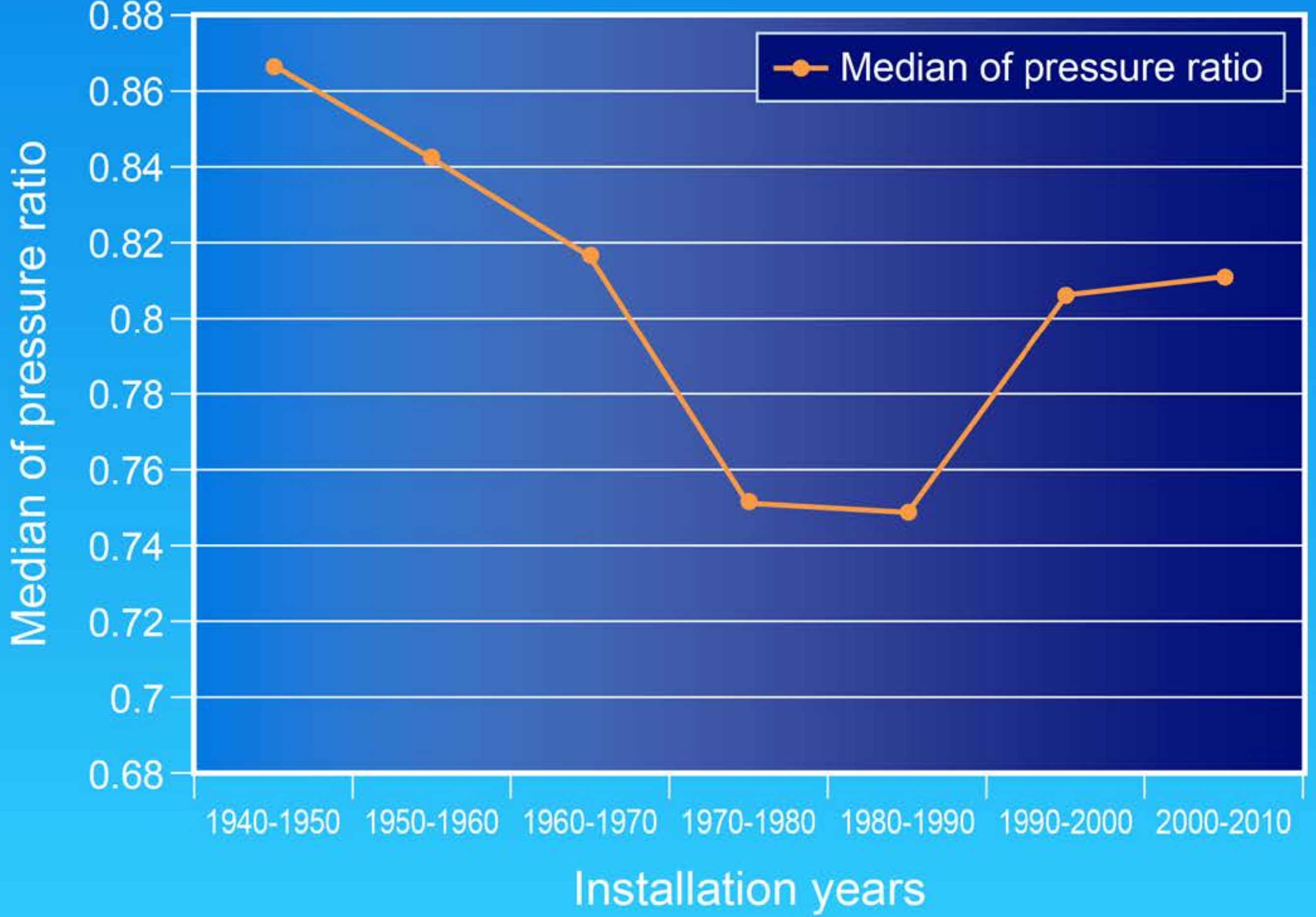


QAe1950

Failure Mechanism versus NG Pipeline Age



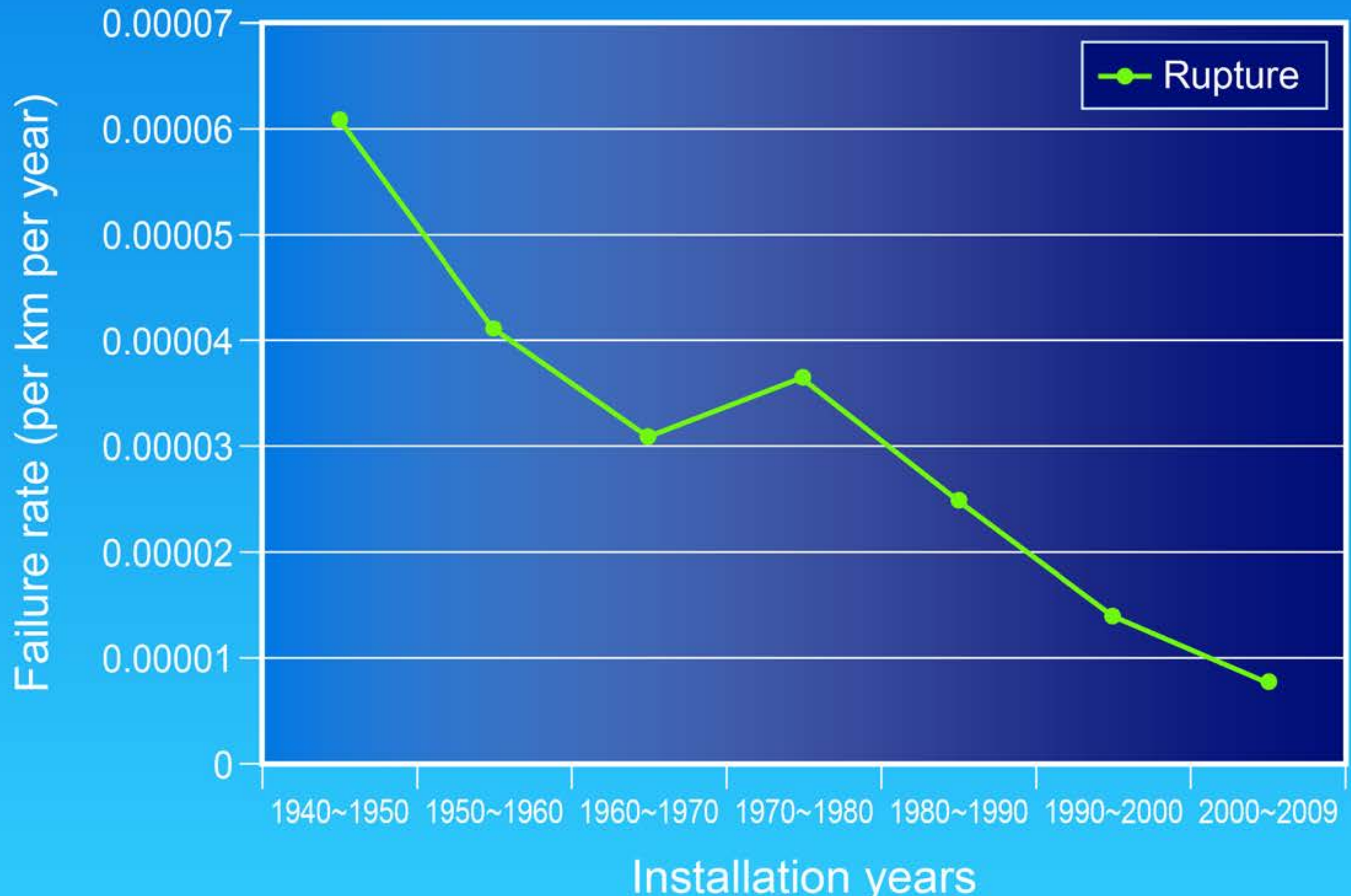
Failure Pressure to MAOP versus Pipeline Age



Bureau of Economic Geology

QAe1951

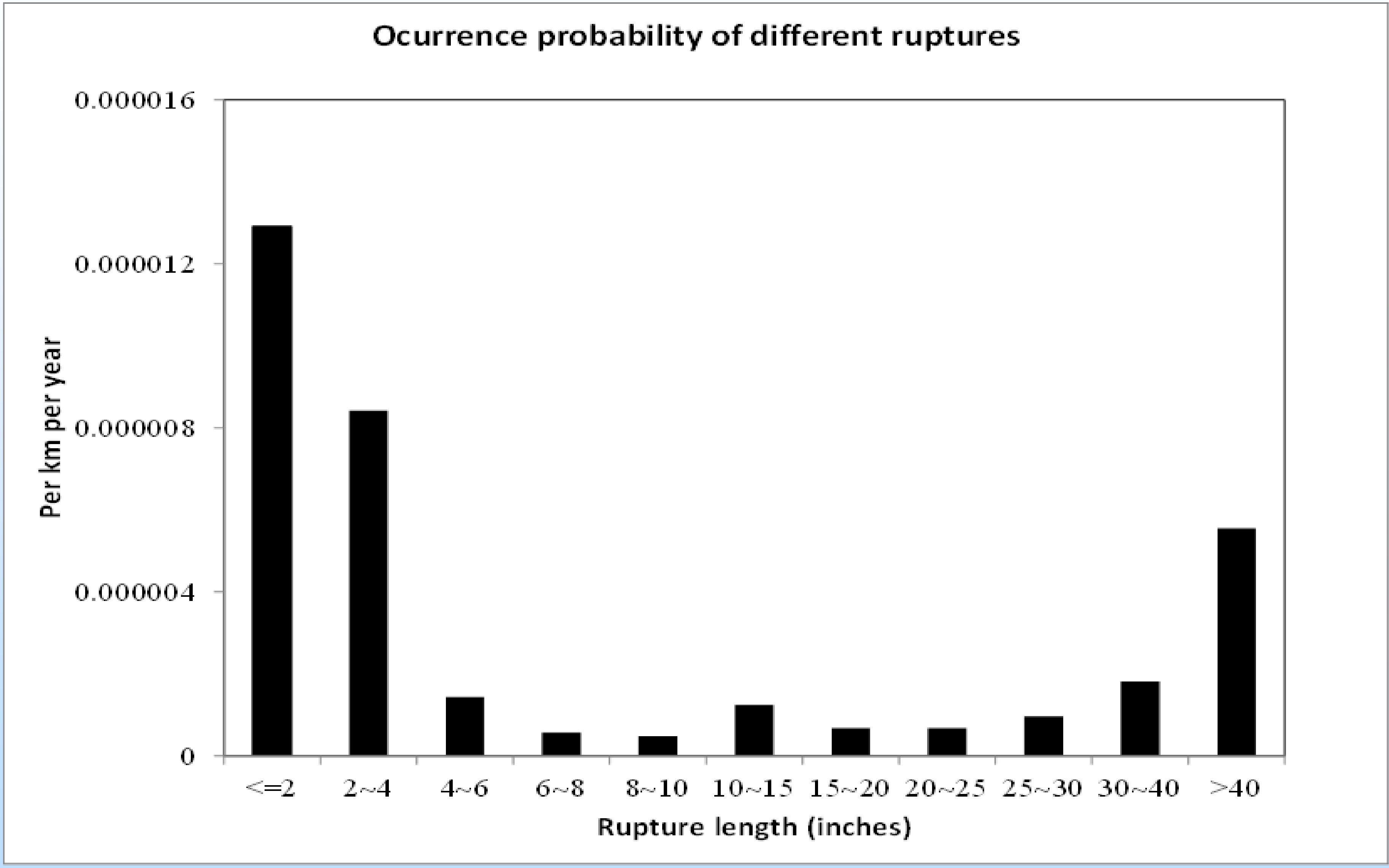
Rupture Rate Versus NG Pipeline Age



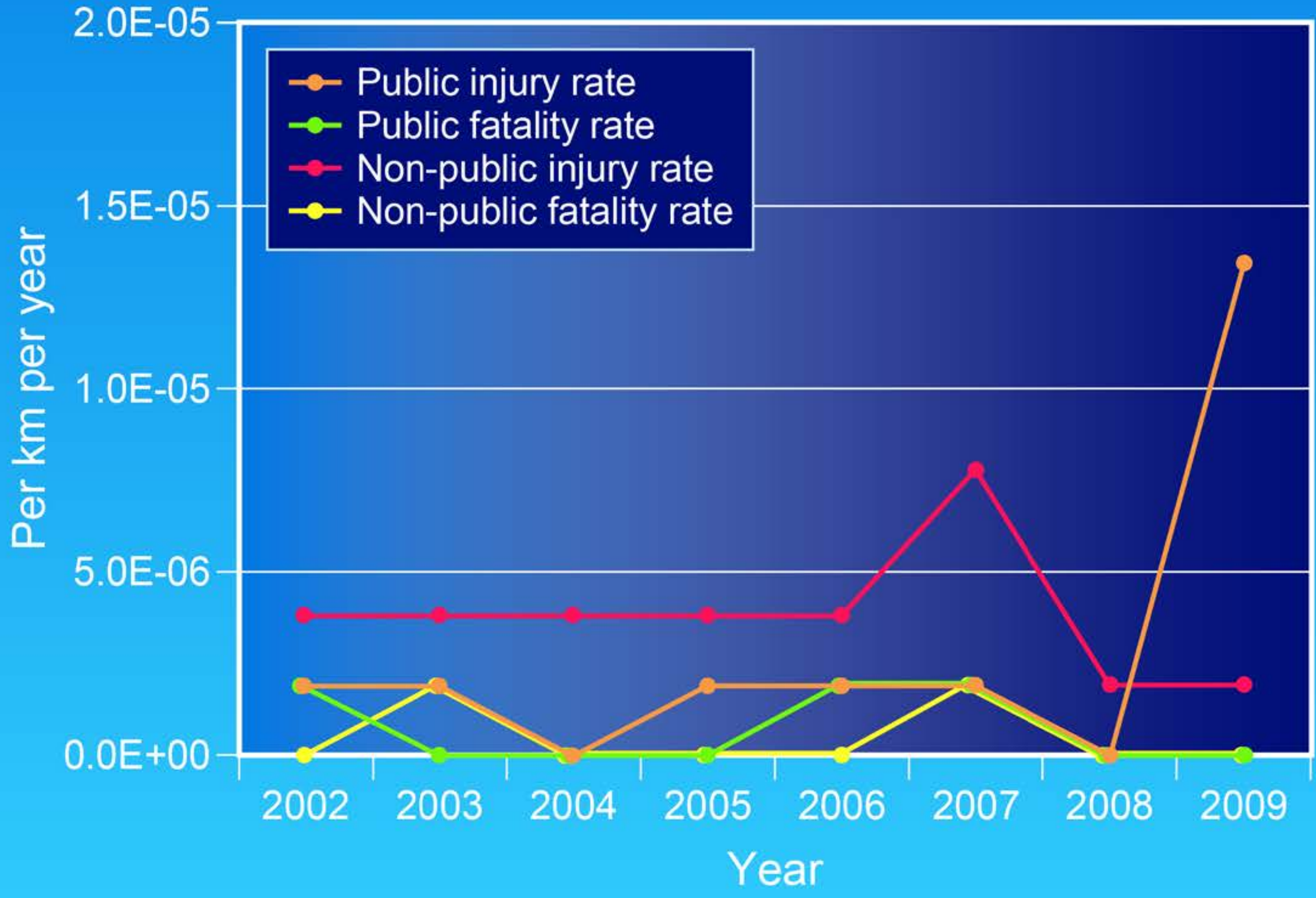
Bureau of Economic Geology

QAe1953

Most Ruptures are Small



Public versus Company Injury/Fatality Rates



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)

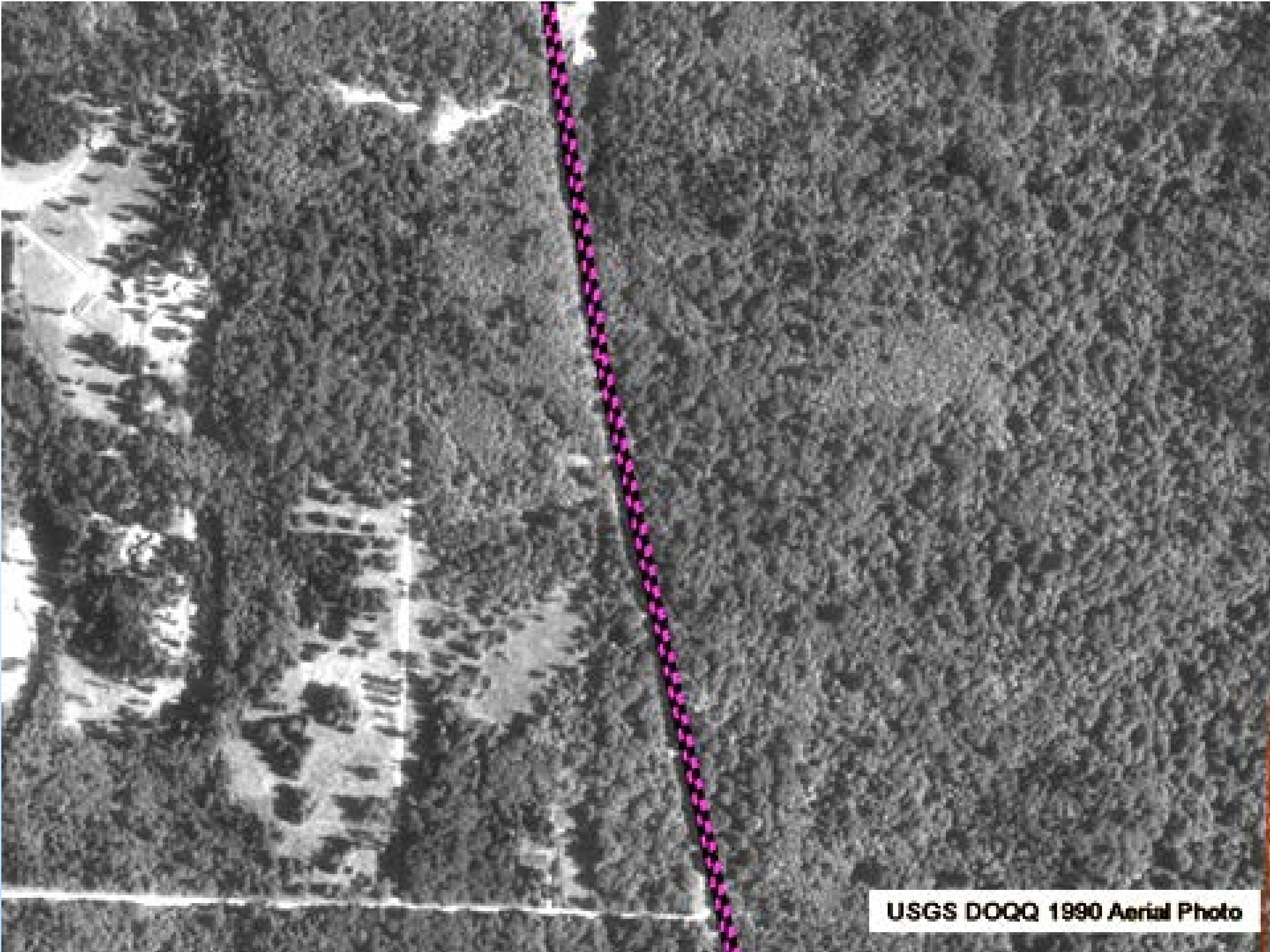
High Consequence Areas

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


USGS DOQQ 1990 Aerial Photo


NGA 2002 Aerial Photo

Public versus Non-Public Risks

Public fatality risk = 7.2×10^{-7}

Non-Public fatality risk = 4.8×10^{-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 CO_2 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

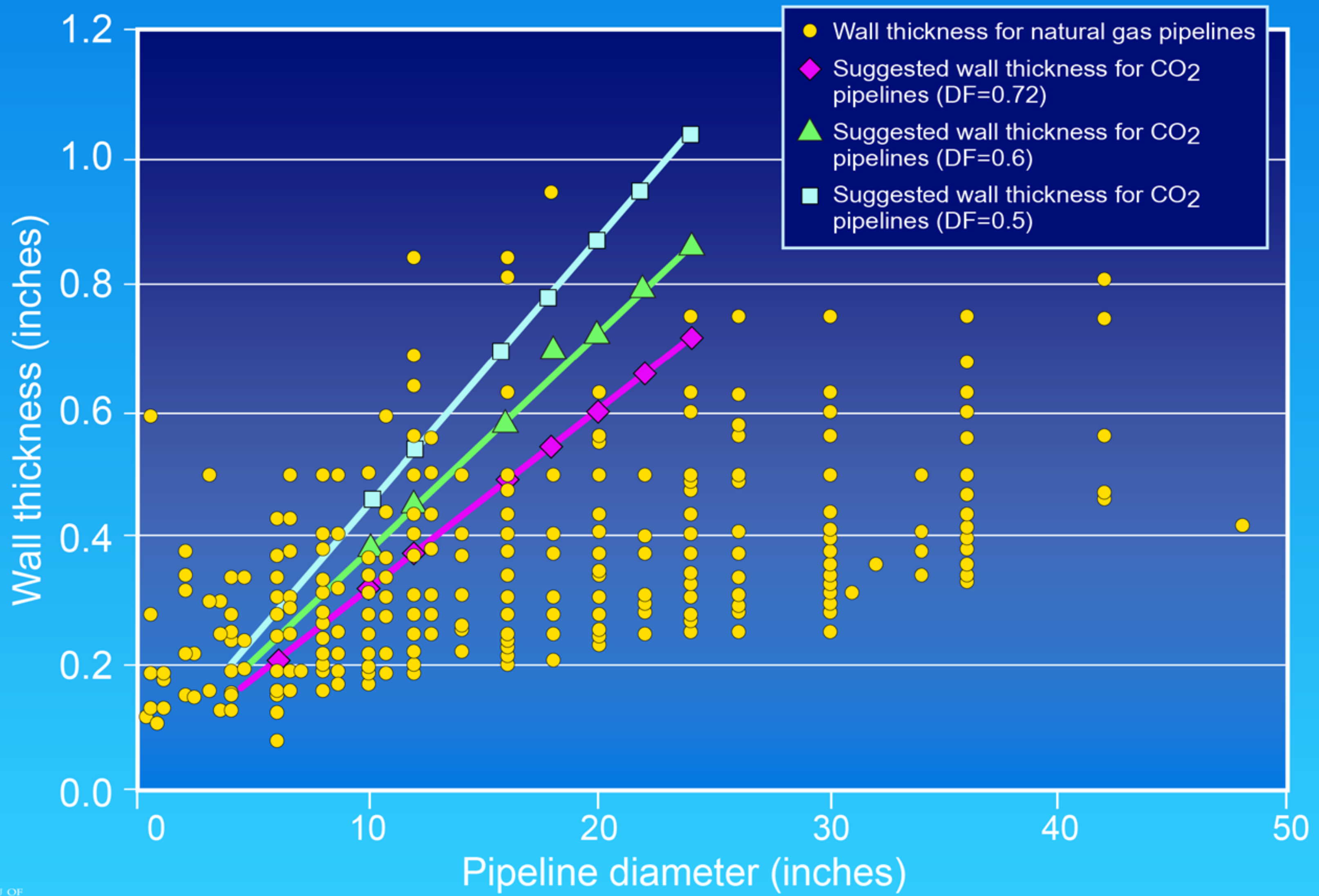
Design Factors for HCAs

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

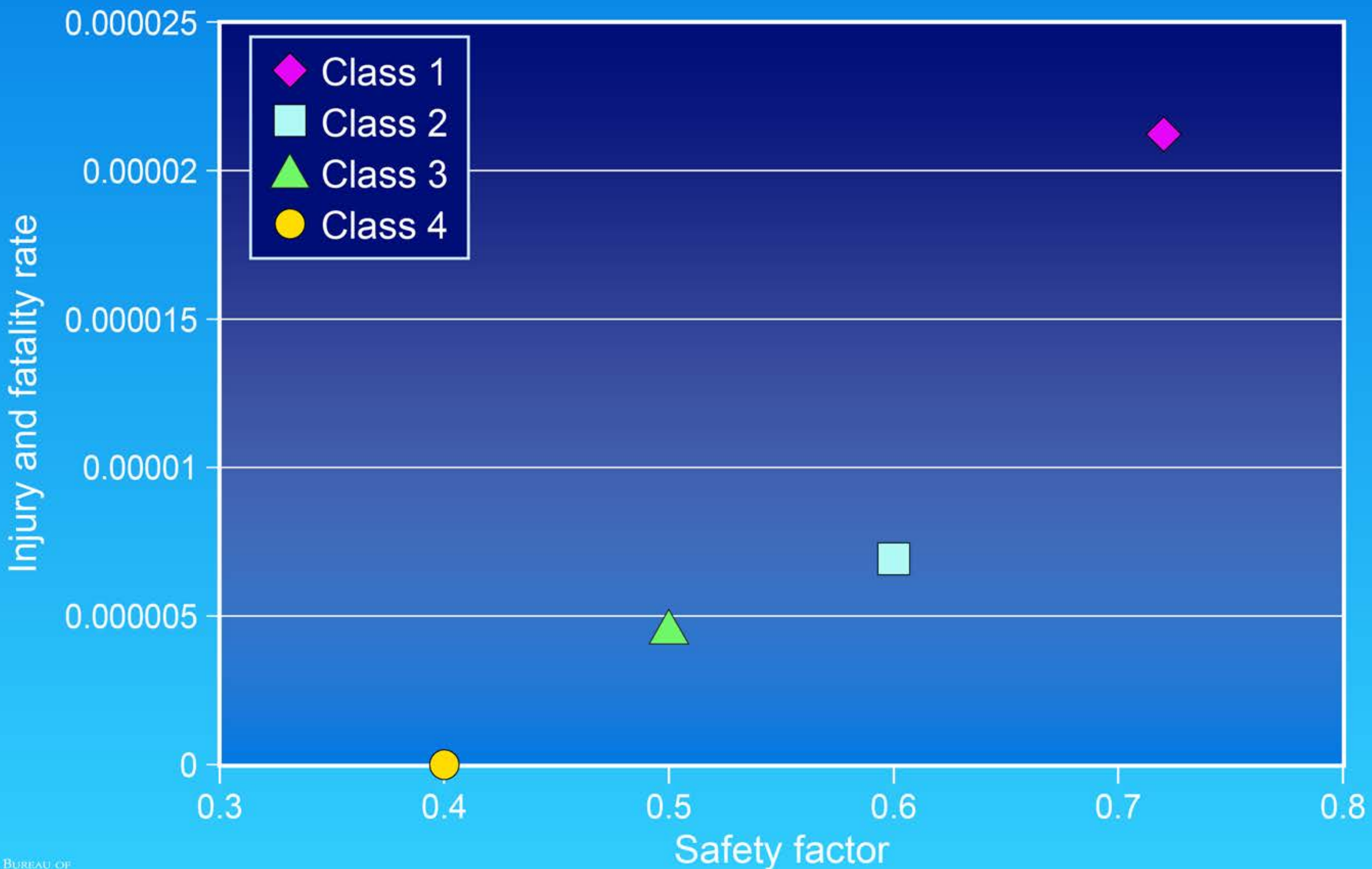
Pipeline Wall Thickness Versus Diameter



Bureau of Economic Geology

QAe1936

Safety Factor versus Injury Rate



QAe1955

Safety Factor Versus Fatality Rate

Bureau of Economic Geology

QAe1956

Safety Factor vs. Rupture (>10 in) Rate

Public Fatality Rate

Bureau of Economic Geology

QAe1940

Safety Factor vs. Rupture (>10 in) Rate

Bureau of Economic Geology

QAe1939

Public Fatality Rate

QAe1940

But do Design Factors Effectively Manage Risk of Fatalities?

Lets 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 INDIVUAL RISKS:

North Sea offshore oil and gas production

1 in 1000 or **1×10^{-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 **1×10^{-4}** per year

Flying: risk of **5×10^{-5}** per year.

Exposure to 10^{-3} Risks

Activity	Number of activities in one year that equals and IRPA of 10^{-3} per year
Hang-gliding	116 flights
Surgical anaesthesia	185 operations
Scuba diving	200 dives
Rock climbing	320 climbs

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 = 4.0×10^{-6}

Class 2 = 1.0×10^{-6}

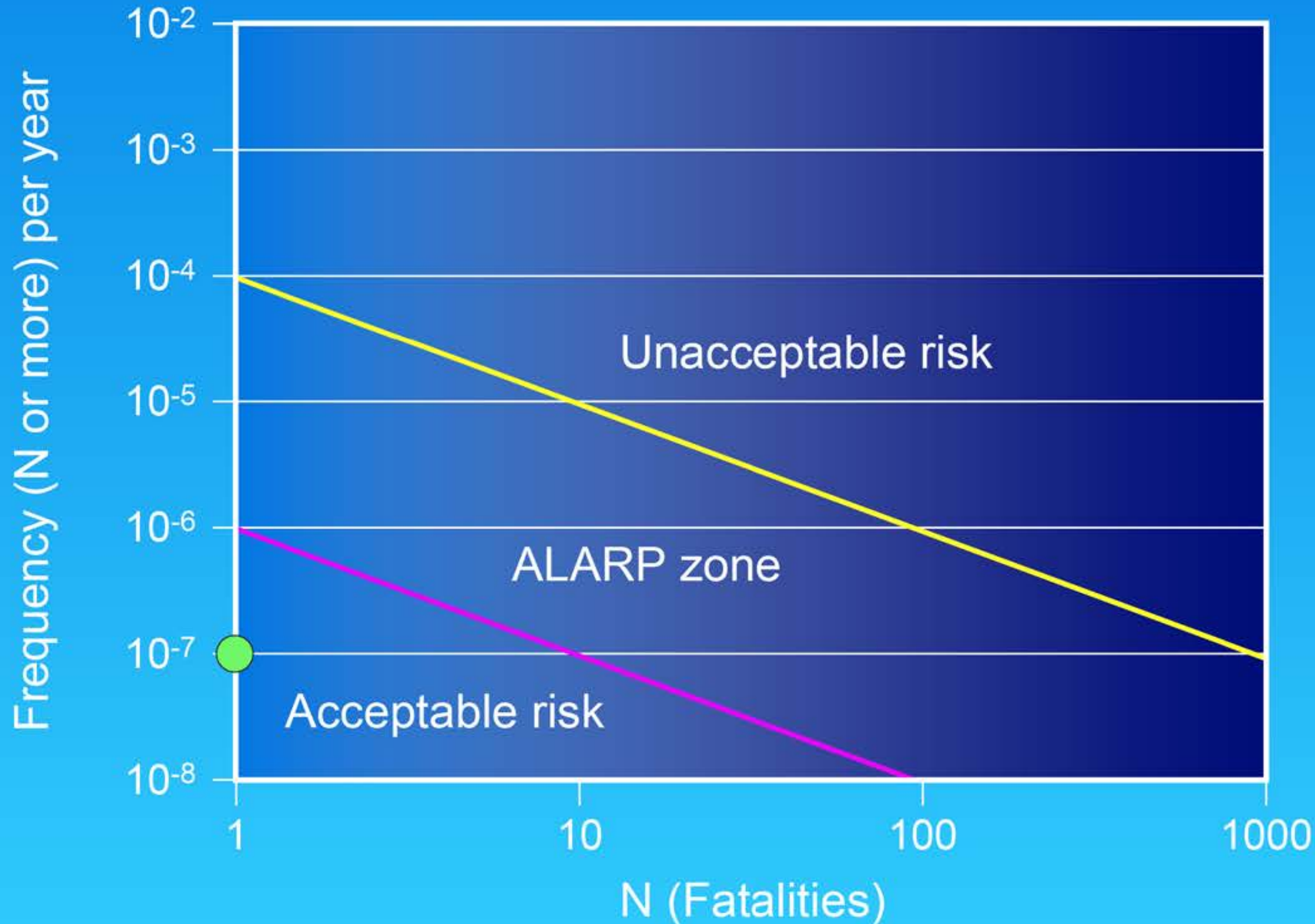
Class 3&4 = zero

Public Fatalities

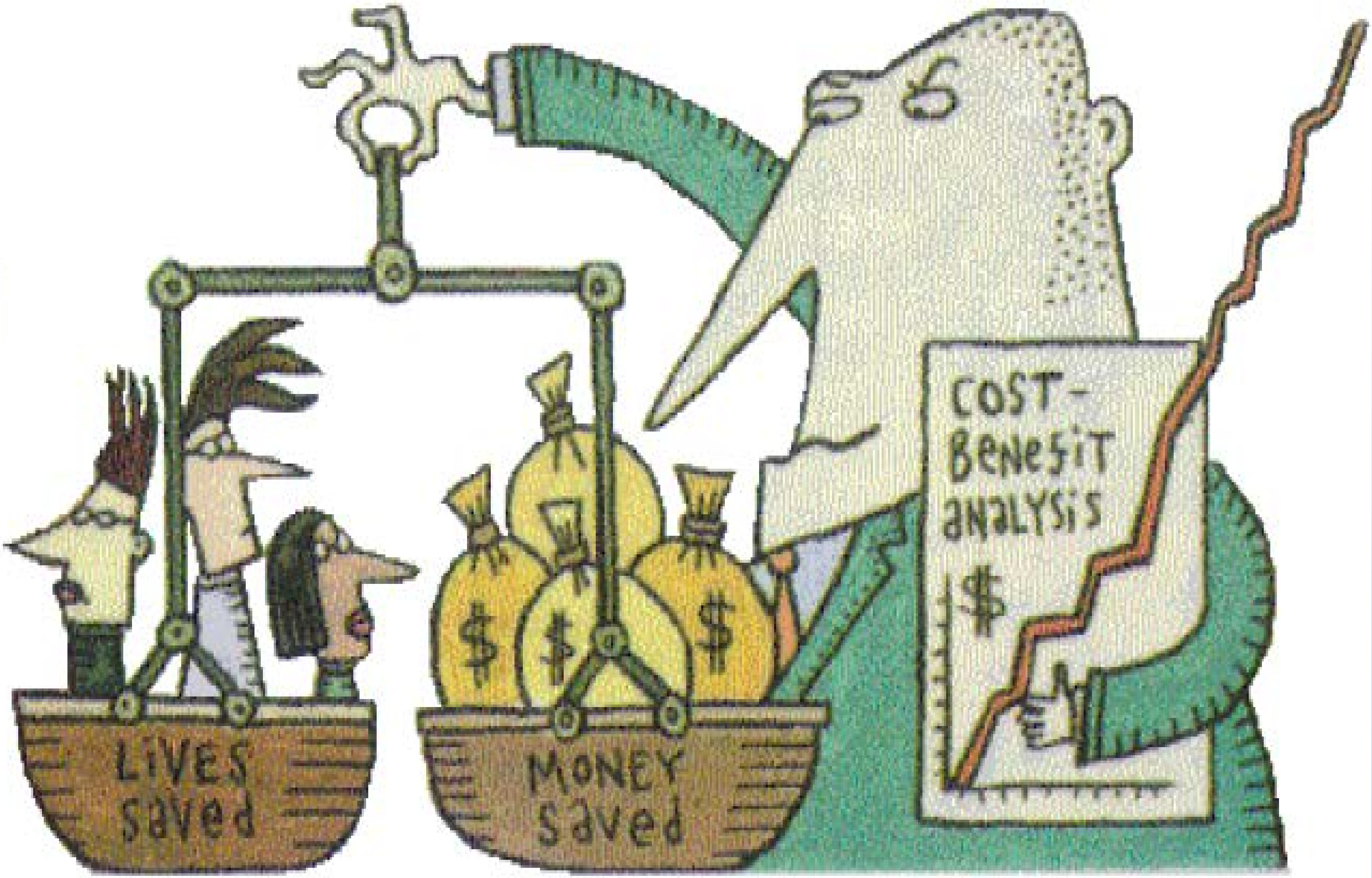
Class 1 = 1.0×10^{-6}

Class 2,3,&4= zero

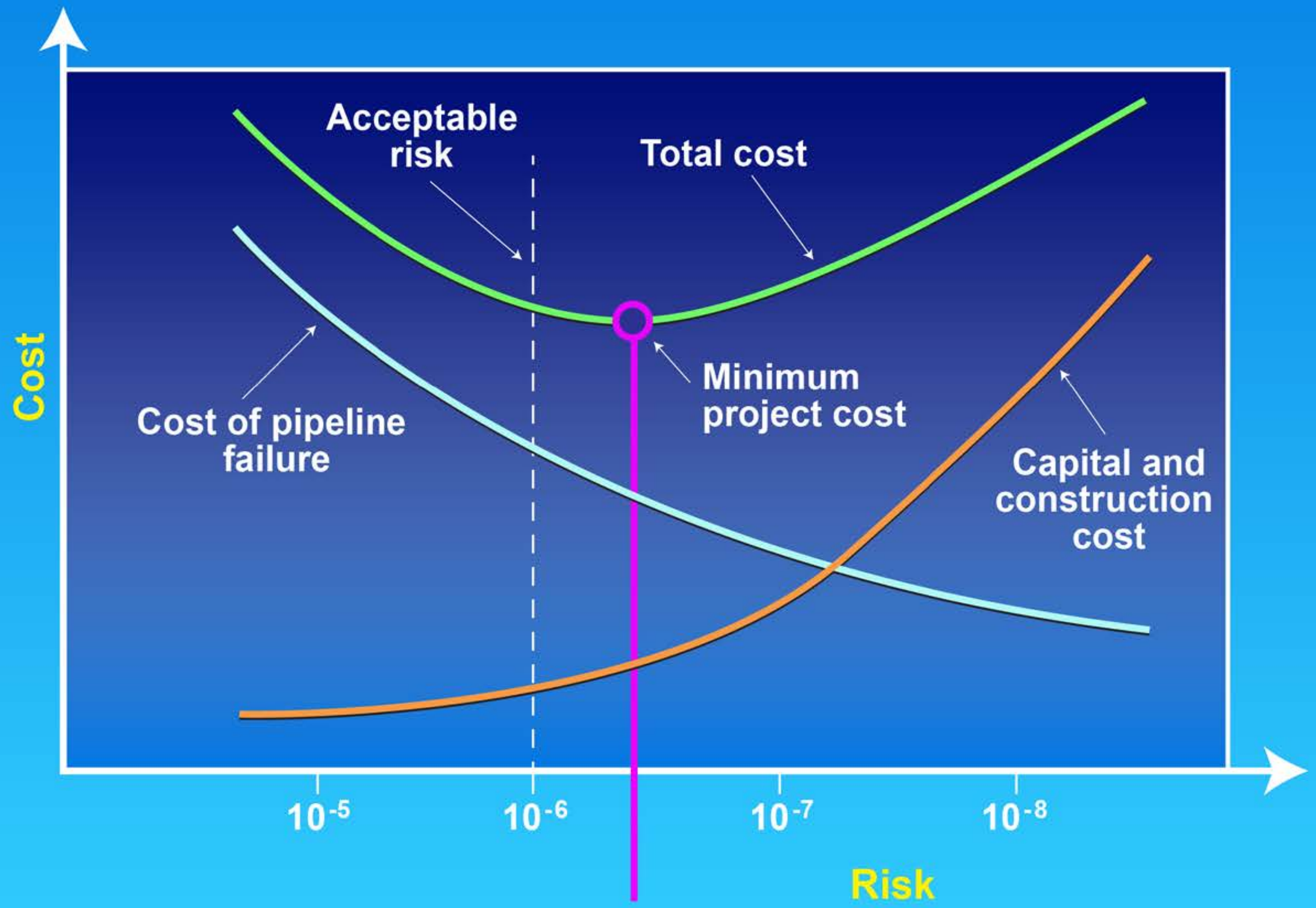
UK HSE Acceptable Risk



Cost Benefit Analysis


LIVES saved
MONEY saved
COST-BENEFIT analysis
$

Cost of Lowering Risk



Bureau of Economic Geology

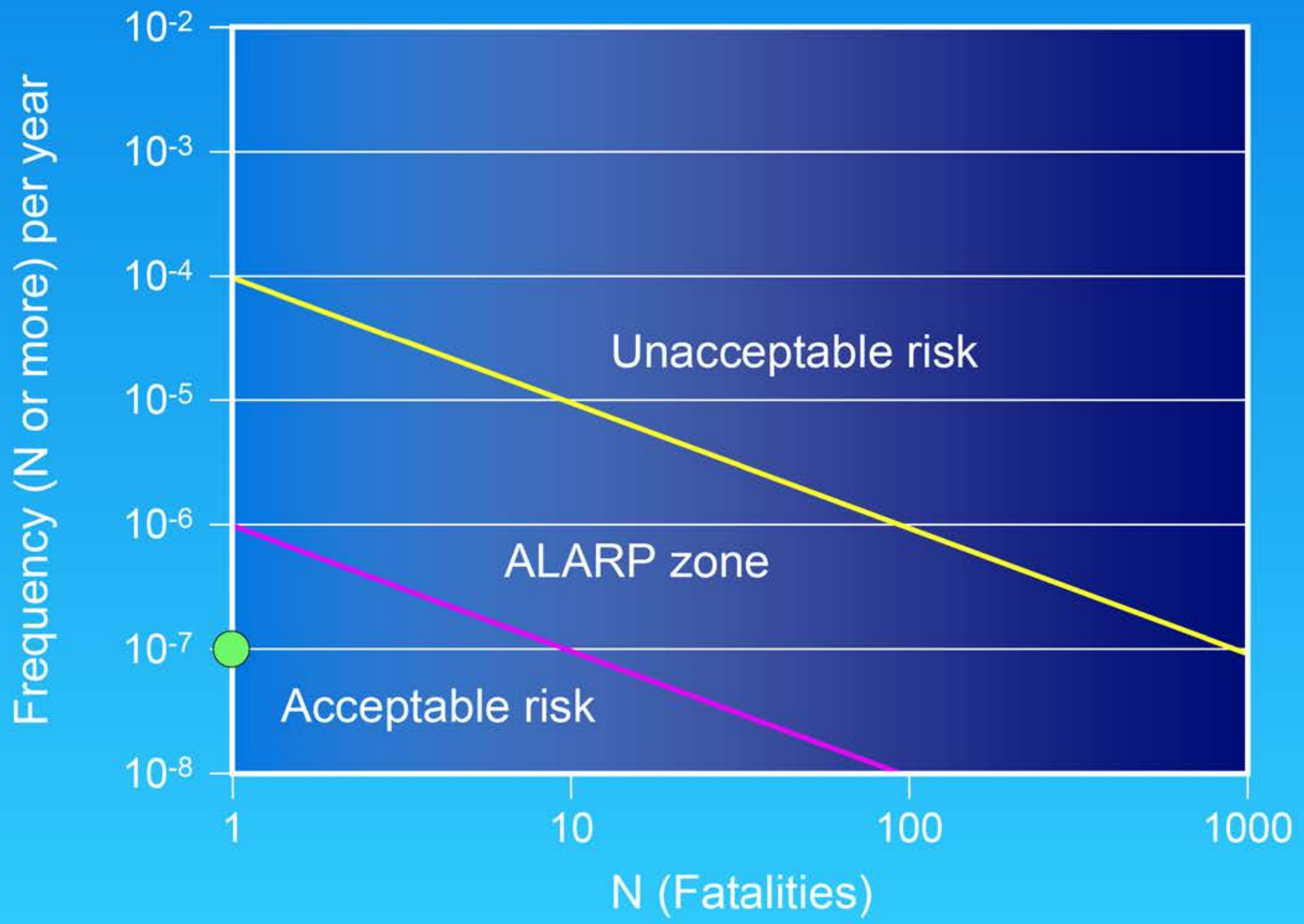
QAe1932

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 that set as acceptable in Europe…..

- Acceptable Level of Risk Revealed?

UK HSE Acceptable Risk



BUREAU OF ECONOMIC GEOLOGY

QAe1957

CONCLUSIONS: CO_2 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 CO_2 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?

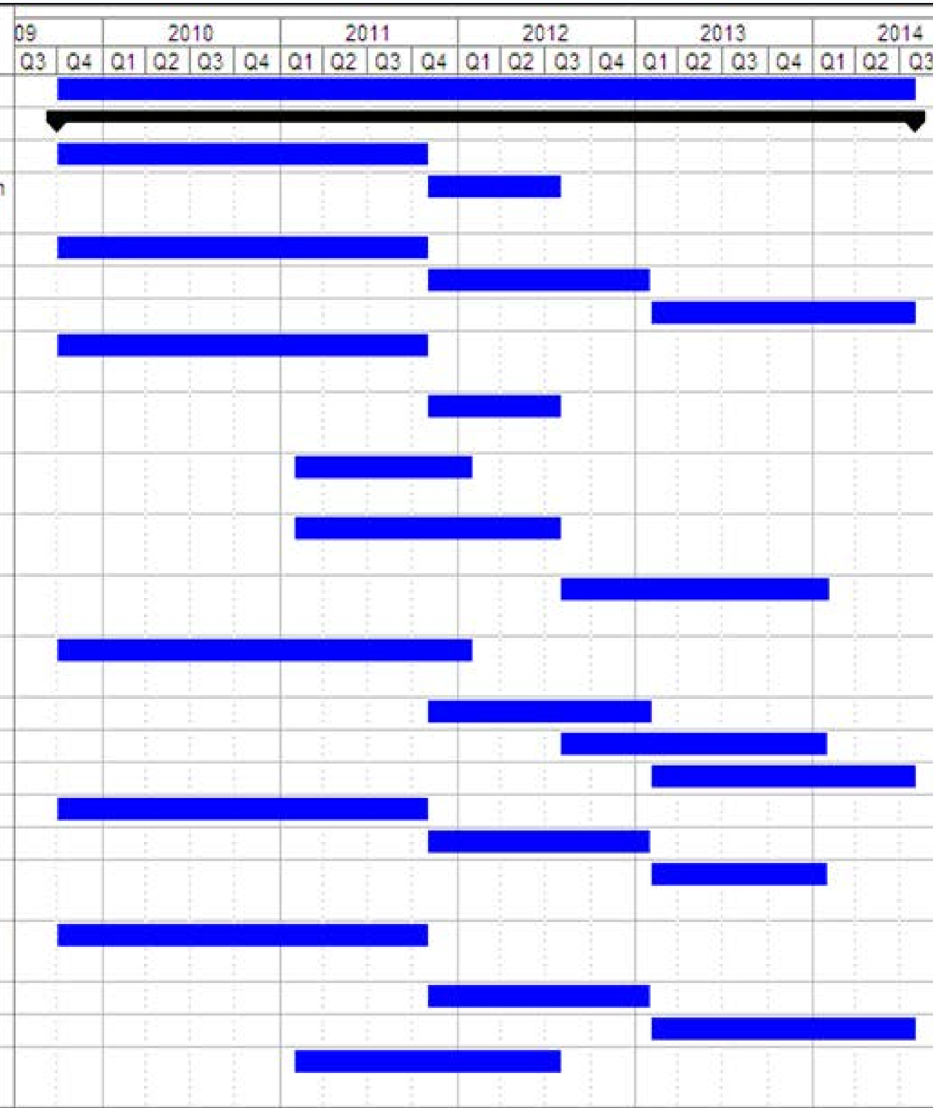
Appendix

Organization Chart

Project Director Ian Duncan Phone: 512-471-5117 Cell: 512-923-8016 ian.duncan@beg.utexas.edu		
Task 1 Management	**Task 2** Development and application of Conceptual Framework for Risk Assessments for CO_2 Sequestration Projects in Deep Brine Reservoirs	**Task 3** Development of protocols for risk assessment for geologic sequestration in brines
Task Leader: Ian Duncan	**Task Leader:** Eric Bickel 512 232 8316 ebickel@mail.utexas.edu	**Task Leader:** Ian Duncan

Gantt Chart

ID	Task Name
1	1 Project Management, Planning, and Reporting
2	**2 Development and Application of Conceptual Framework for Risk Assessments**
3	2.1 Compilation and critical review of existing site-specific risk assessments
4	2.2 Compilation of information on operational risks from CO2-EOR industry and identification of linkages between programmatic and technical risks
5	2.3 Development of prototype risk analysis methodologies
6	2.4 Implementation and testing of proposed risk analysis methodologies
7	2.5 Refinement of risk analysis methodologies
8	2.6 Analysis of programmatic and operational risks for CO2 sequestration projects based on data from CO2-EOR projects
9	2.7 Projection of risks for CO2 sequestration projects (based on data from commercial natural gas storage)
10	2.8 Identification of realistic, fact based, scenarios for leakage from geologic reservoir containment
11	2.9 Evaluation of the risk of leakage from geologic reservoir's containment based on an innovative new analysis using Bayesian inference based on flow simulations
12	2.10 Modeling of the risk of leakage from geologic reservoirs based on multiple flow simulations
13	2.11 Identification of risk associated with injection pressures and development of approaches to model flow under the influence of a pressure front
14	2.12 Modeling risks associated with pressure driven brine flows
15	2.13 Modeling risks associated with seal leakage
16	2.14 Estimating risk associated with seal leakage through fault, and fracture zones
17	2.15 Identification of risk associated with injection pressure inducing earthquakes
18	2.16 Development of site-specific risk protocols for pressure induced earthquakes
19	2.17 Modeling and analysis of risks associated with injection pressure induced earthquakes.
20	2.18 Evaluate risk related to CO2 dissolution into brine and entering regional flow systems
21	2.19 Modeling the changes in leakage risk related to CO2 dissolution into brine
22	2.20 Modeling the leakage risk related to CO2 dissolution in regional flow systems
23	2.21 Compilation of Data Relevant to Evaluating Consequences of Possible Leakage from Deep Brine Reservoirs



Bibliography

Duncan, I. (2013). Suicide by Catalytic Converter and Deaths at Lake Nyos; Is Carbon Monoxide the Toxic Agent? Implications for Leakage Risks from CO2 Pipelines. *Energy Procedia*, *37*, 7696-7701.

Duncan, I. (2013). The Bubble/Slug Flow Model for Methane Leakage from natural Gas Wells as an Analogue for Shallow CO2 Migration. *Energy Procedia*, *37*, 4692-4697.

Adelman, D. E., **and Duncan, I. J.,** 2012, The limits of liability in promoting safe geologic sequestration of CO2: Duke Environmental Law & Policy Forum, v. 22, no. 1, p. 1–66.

Nicot, J. -P., and **Duncan, I. J.**, 2012, Common attributes of hydraulically fractured oil and gas production and CO2 geological sequestration: Greenhouse Gases Science and Technology, v. 2, p. 352–368.

Ambrose, W. A., Breton, C., Hovorka, S. D., **Duncan, I. J.**, Gülen, G., Holtz, M. H., and Nuñez-López, V., 2011, Geologic and infrastructure factors for delineating areas for clean coal: examples in Texas, USA: Environmental Earth Science, v. 63, p. 513–532.

Bibliography

.

Duncan, I. J., Anderson, S., and Nicot, J. -P., 2009, Pore space ownership issues for CO_2 sequestration in the U.S., in Energy Procedia (v. 1, no.1), Proceedings of 9th International Conference on Greenhouse Gas Control Technologies GHGT9, November 16–20, Washington D.C., p. 4427–4431.

Duncan, I. J., Nicot, J. -P., and Choi, J. -W., 2009, Risk assessment for future CO_2 sequestration projects based on CO_2 enhanced oil recovery in the U.S., in Energy Procedia (v. 1, no.1), Proceedings of 9th International Conference on Greenhouse Gas Control Technologies GHGT9, November 16–20, Washington D.C., p. 2037–2042.