International seminar on Risk Assessment and Management in Capture, Transport and Storage of CO2 (CTSC) activities: methods, experiences and perspectives

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Injection et stockage du CO2: risque objectif et risque acceptable

Actuarial risk assessment of expected fatalities attributable to carbon capture and storage in 2050

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CIRED

1. Risk assessment methods

Constructivist

- Psycho
- Socio
- Eco

Realist (get expected values)
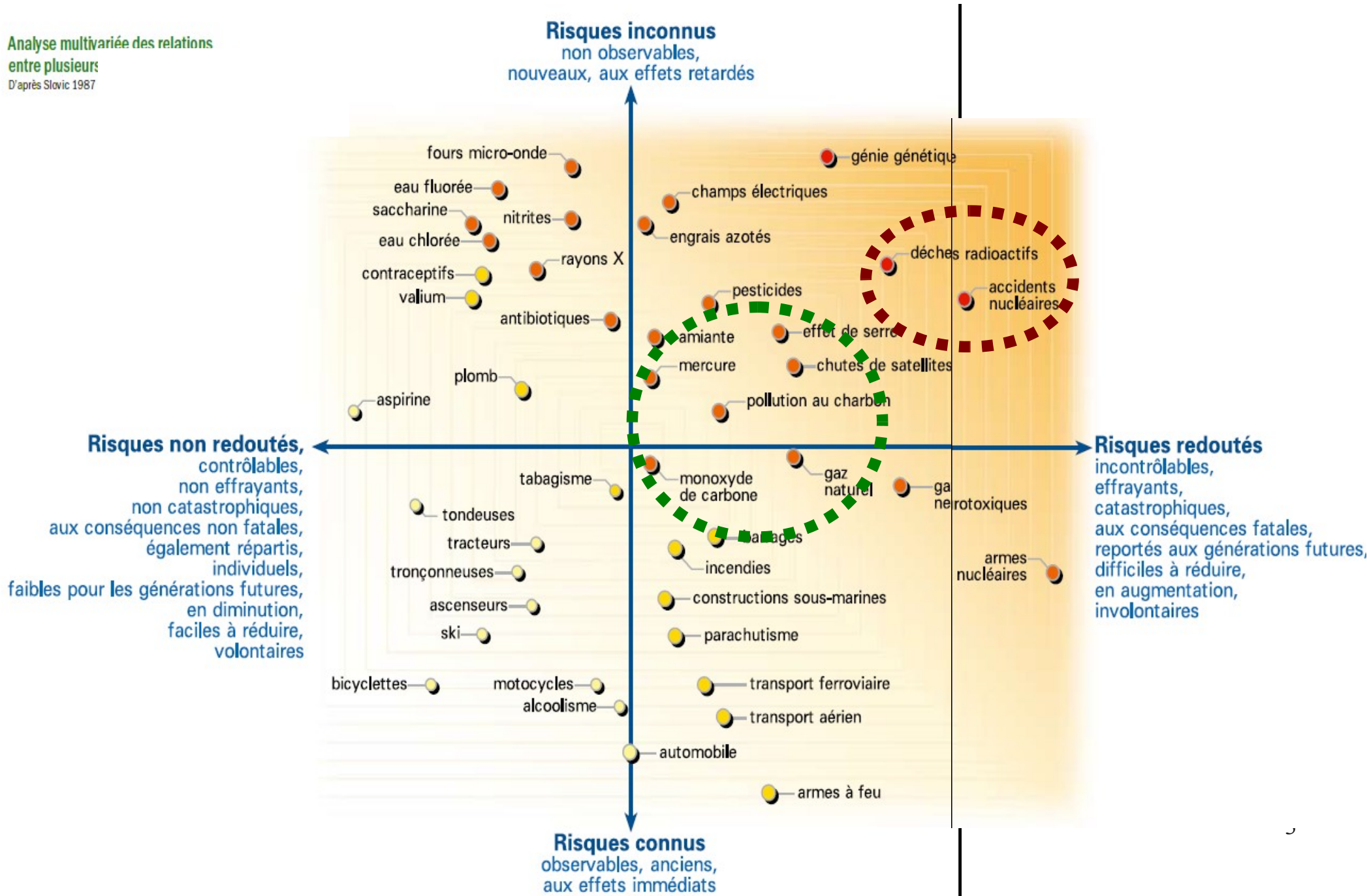
- Probabilistic Risk Analysis (failure trees)
- Toxico/Epidemio (experiments)
- **Actuarial** (extrapolates from empirical data on analogues)

For example, we look at accidents data for natural gas transmission and hazardous liquids pipelines, then :

Expected fatalities = Extrapolated rate x Activity level

CSC: Risque connu ? Risque volontaire ?

Analyse multivariée des relations entre plusieurs
D'après Slovic 1987

Risques inconnus
non observables,
nouveaux, aux effets retardés

fours micro-onde
eau fluorée
saccharine — nitrites
eau chlorée
contraceptifs
valium
antibiotiques
plomb
aspirine

génie génétique
champs électriques
engrais azotés
déches radioactifs
rayons X
accidents nucléaires
pesticides
amiante — effet de serre
mercure — chutes de satellites
pollution au charbon

Risques non redoutés,
contrôlables,
non effrayants,
non catastrophiques,
aux conséquences non fatales,
également répartis,
individuels,
faibles pour les générations futures,
en diminution,
faciles à réduire,
volontaires

Risques redoutés
incontrôlables,
effrayants,
catastrophiques,
aux conséquences fatales,
reportés aux générations futures,
difficiles à réduire,
en augmentation,
involontaires

tabagisme
tondeuses
tracteurs
tronçonneuses
ascenseurs
ski
bicyclettes — motocycles
alcoolisme

monoxyde de carbone
gaz naturel
gaz neurotoxiques
barrages
incendies
constructions sous-marines
parachutisme
transport ferroviaire
transport aérien
automobile
armes à feu

armes nucléaires

Risques connus
observables, anciens,
aux effets immédiats

Actuarial risk examples

- Your annual risk of dying is > 0.0001

- Tobacco kills 60.000 per year in France

- Road accidents killed 4.000 in France in 2009

How many for CCS in 2050 ?

Décès documentés / an, analogues naturels

Séismes	15000[a]	public
Volcanisme	490[b]	public
Vol. effusif	18[b]	public

Sources: (a) Base de données NOAA, moyenne sur [1700, 2008]

(b) Base de données NOAA / NESDIS, moyenne sur [1700, 2000]

Décès documentés / an, analogues artificiels

Industries de l'énergie: 1 827 décès/an

Source: Sovacool (2008), moyenne sur [1907-2007]

CO_2/Systèmes d'extinction :   4 travailleurs/an

Source: EPA, 1975-2000 average

CO_2/Agro-industrie :   3 travailleurs/an

Source : Louis et al. (1999)

Additional fatalities
expected in 2050, if CCS is used at a large scale
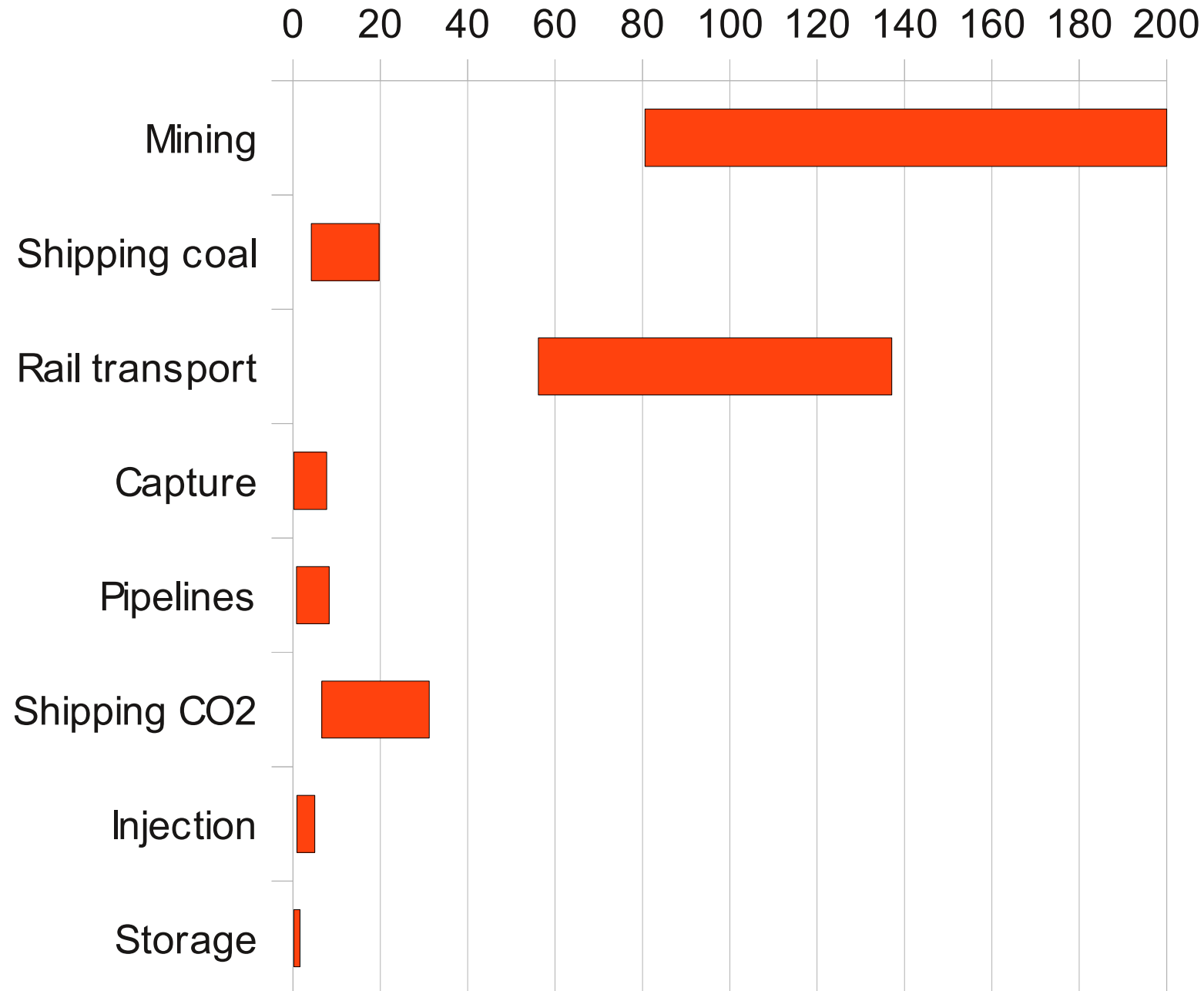
2. A big CCS scenario

« Avoiding 1 GtC of CO_2 emissions in 2050
by using CCS in baseload coal-fired power plants. »

Mine coal ⇨ Ship coal ⇨ Capture CO_2 → Pipe CO_2 / Ship CO_2 → Inject CO_2 ⇨ Store CO_2
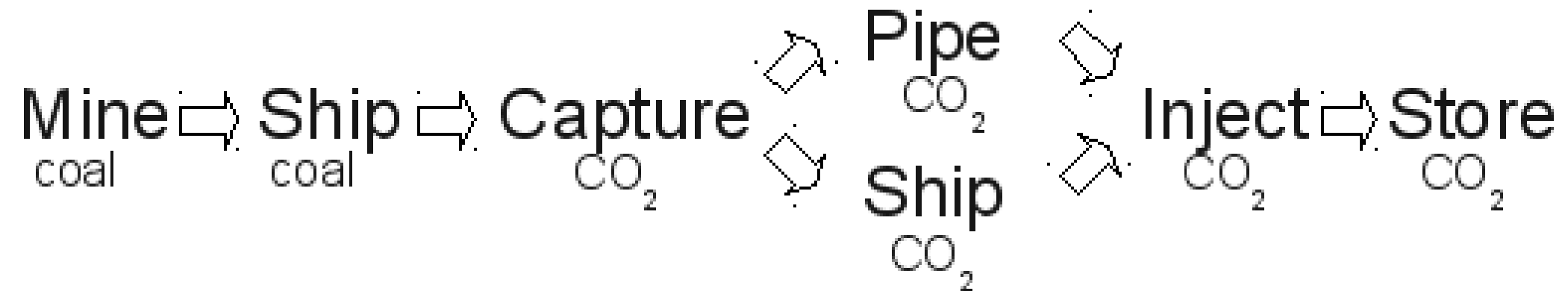
1 500 coal-fired power plants

- Burn 5.4 Gt of coal

- Capture and store 4.5 Gt of CO_2 (out of 5 Gt)

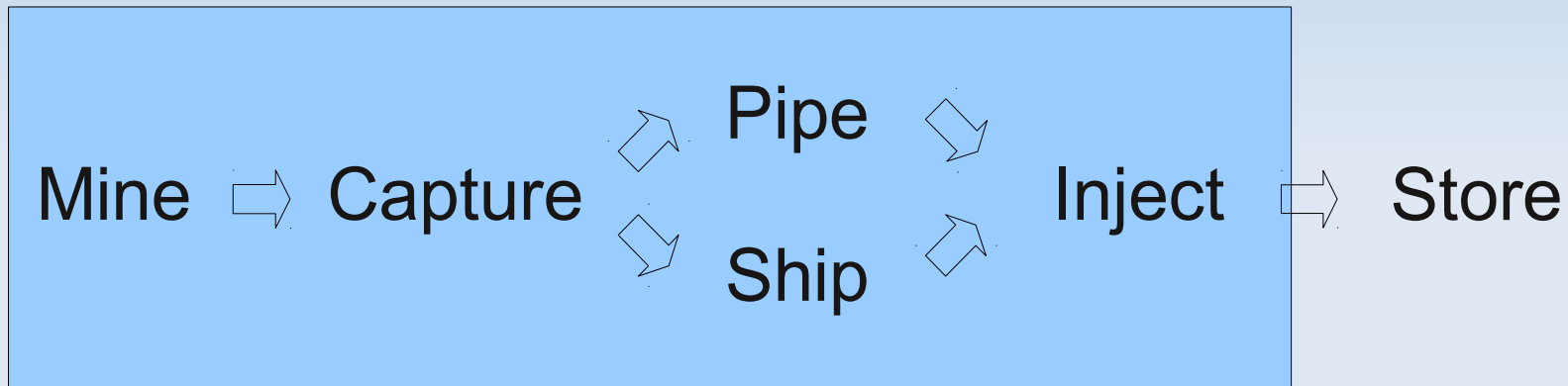- Each plant produces 3 Mt of CO_2 per year

Transportation scenario

- Coal
  - 15% ships, 4 500 Nm
  - 85% railroads, 500 km

- CO_2
  - 90% pipelined, 100 km per site
  - 10% shipped, 5 000 Nm

Storage scenario

- 500 sites, 90% onshore

- 8.8 Mt yr^{-1} injected per site (8 wells * 1.1 Mt yr^{-1})

- 25 to 100 km² footprint each
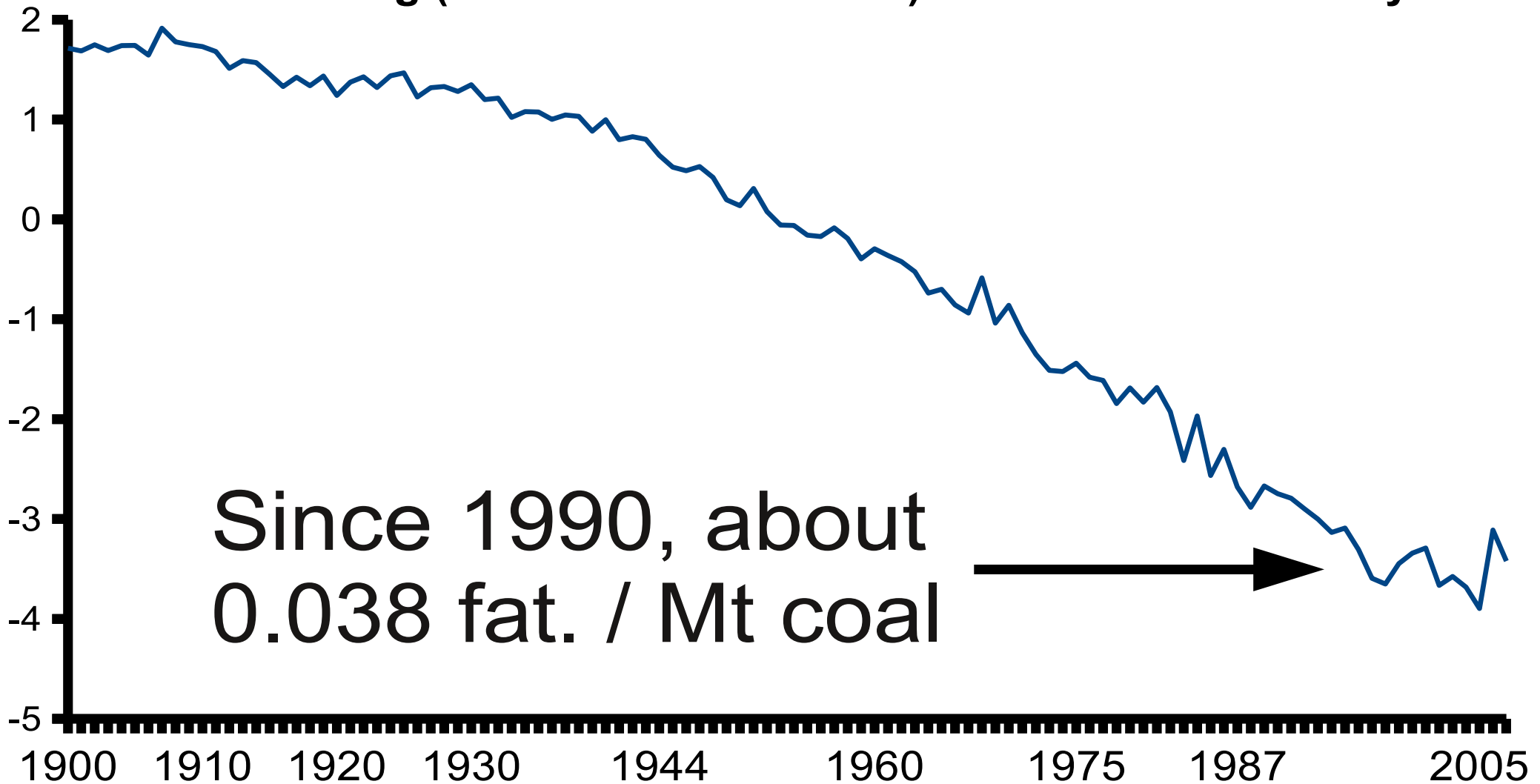
3. Mostly industrial risks

Mine ⇨ Capture ⇨ Pipe ⇨ Inject ⇨ Store

Ship

Mining 2.1 Gt of coal

- Less than what is mined today

- Risk levels are unequal
  - Dozens of fatalities per year in the US
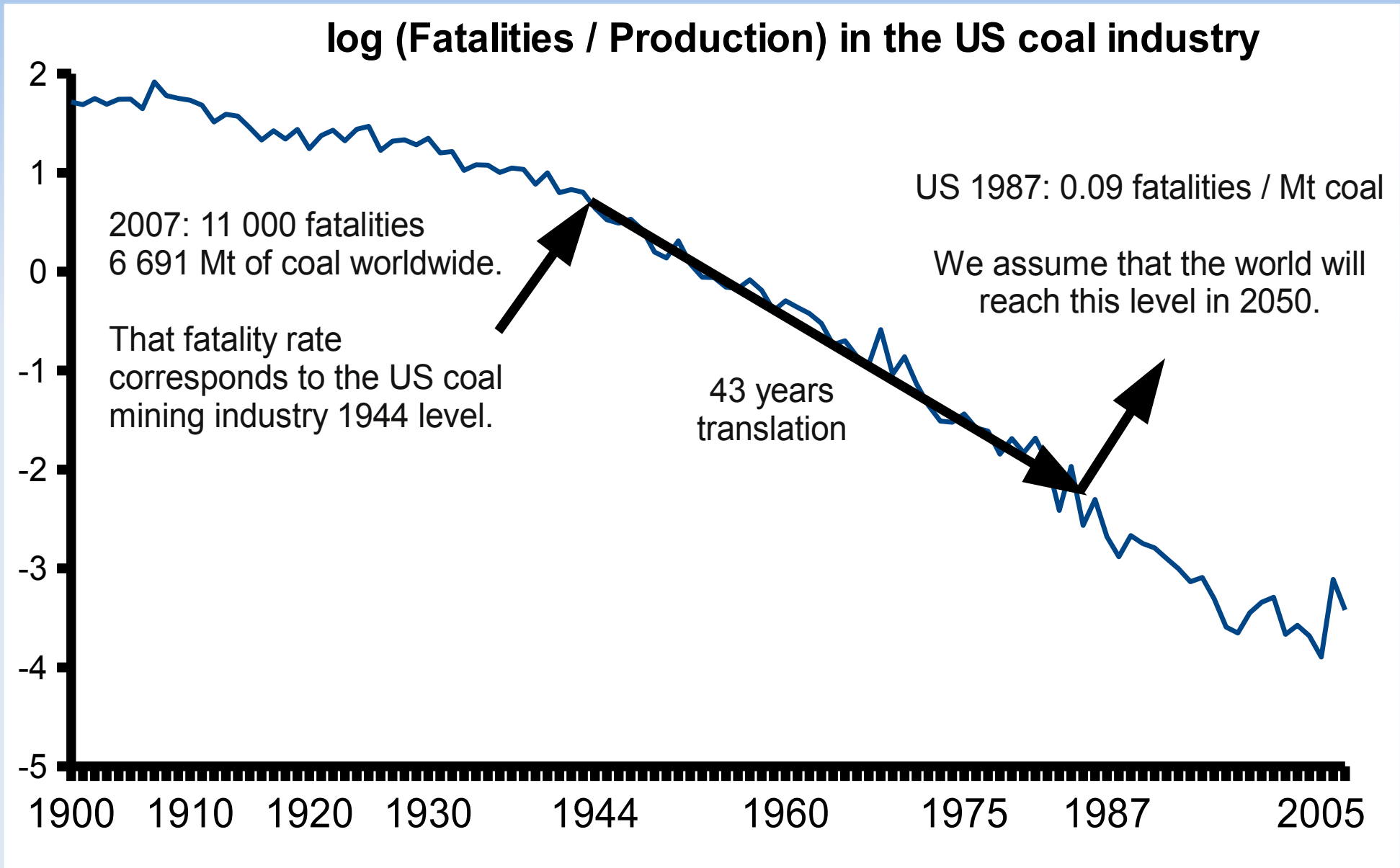 - Hundreds in China, for a production only 2.5x higher

US coal industry record

log (Fatalities / Production) in the US coal industry

Since 1990, about
0.038 fat. / Mt coal

0.038 * 2100 Mt = 81 expected fatalities

A less optimistic outlook

log (Fatalities / Production) in the US coal industry

2007: 11 000 fatalities
6 691 Mt of coal worldwide.

That fatality rate
corresponds to the US coal
mining industry 1944 level.

43 years
translation

US 1987: 0.09 fatalities / Mt coal

We assume that the world will
reach this level in 2050.

0.094 * 2100 = 196 expected fatalities

CO2 capture risks

- Intoxication, drowning

- Frost, moving machinery

- Boiling Liquid Explosive Vapor Explosion (BLEVE)

Accident record

- Industry uses 100-115 Mt CO_2 each year

- 2 accidents over 1926 – 2007

- 12 fatalities

- 0.0017 fat. per Mt per year

- Extrapolates to 7.5 expected fatalities in 2050

Workers's safety records

- 3 to 14 fatalities / 100 000 workers / year in the *Electricity, gas and water supply* sector.

- Assume 7 500 to 15 000 exposed workers for the 1 500 sites

- 0.2 to 2.1 expected fatality in 2050

Pipelines safety in the USA

	Natural gas transmission (1986-2009)	Hazardous liquids (1986-2009)	CO_2 (1990-2009)
Serious incidents	2 318	4 088	20
Fatalities	65	54	0
Avg. network length (1000km)	522	255	6.2
Fatalities / 10^6 km / yr	5.2	8.8	0
95% confidence interval	4.0 - 6.6	6.6 - 11.5	0 - 24.3

No more than 24 fatalities per Mkm on CO_2 pipelines.

CO2 pipeline risk in 2050

- Accounting for less favorable

  - Population density

  - Technology

  - Social context

- We use 5 to 50 fat./Mkm/yr

- Scenario: 0.15 Mkm

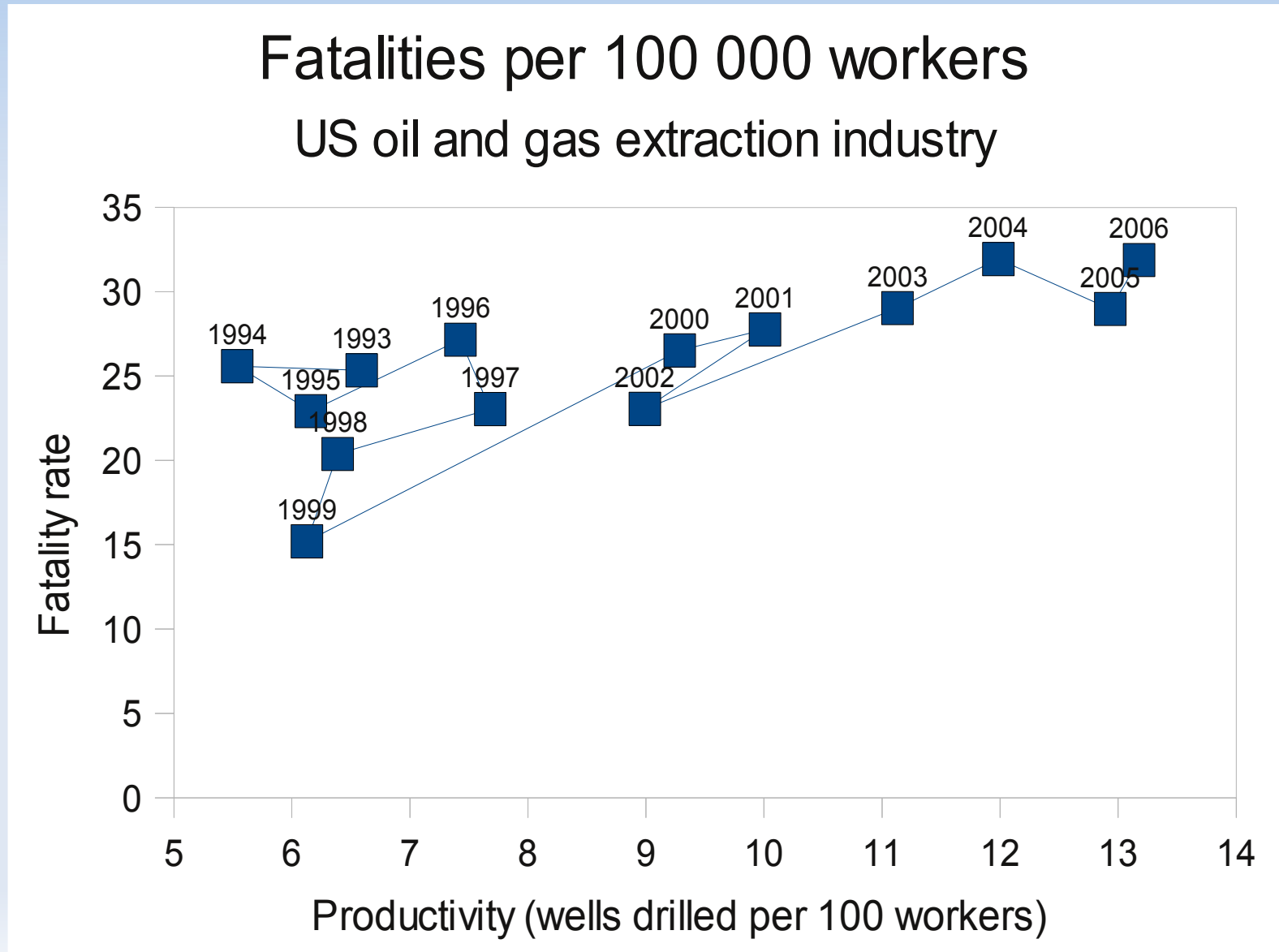- Result : 0.75 to 7.5 expected fatality in 2050

Shipping casualties in 2050

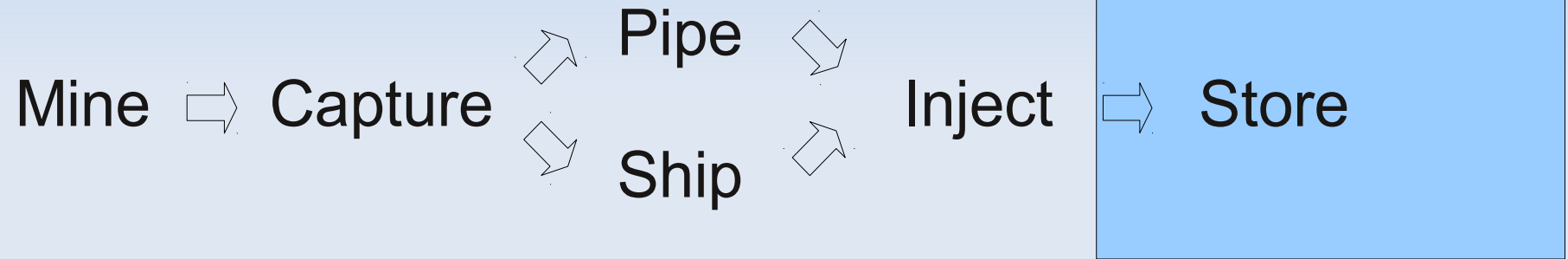|	Risk † now	Risk † extrapolated	CO2 ships Exp. fat.	Coal ships Exp. fat.
Tankers	11.7	2.9	6.6	10
All goods	28.6	10.9	24.6	40

† Expected fatalities per billion ton * nautical mile of shipping.

Injection at 500 sites

5 000 to 15 000 workers * 20 to 30 10^{-5} = 1 to 4.5 expected fatalities

Fatalities per 100 000 workers
US oil and gas extraction industry

4. Storage risks

Mine ⇨ Capture ⟋ Pipe ⟍
⟍ Ship ⟋ ⇨ Inject ⇨ Store

Storage, engineering estimates

Hazard event	Saripalli's Frequency estimates	Saripalli's Consequences index	Expected fatalities per event	Expected fatalities per 100 000 storage year
1. Well-head failure				
1A. Major wellhead failure	0.00002	1	1	2
1B. Moderate, sustained leak	0.0001	0.5	0.1	1
1C. Minor leaks of joints	0.001	0.1	0.01	1
2. Cap rock failure				
2A. Fractured cap rock	0.01	0.3	0.05	50
2B. High permeability zones	0.01	0.1	0.01	10
2C. Seismic induced failure	0.0001	0.8	0.5	5
TOTAL				**69**

Storage, negligible individual risk

- Minimum Endogenous Mortality criteria
  - How much is a negligible increase in your risk of dying next year?
  - 1 micromort (10^{-6})

- Application to storage : 0.2 to 0.9 expected fatalities
  - 25-100 km² impact area per site
  - 20 targets (people) / km²
  - 450 sites

Storage, tolerable risk

- In France, an industrial gas release risk with
  - Probability 10^{-3}
  - Consequence 1% lethal concentration
  - For less than 10 exposed persons
  ⇒ May be compatible with its environment

- That is, 10^{-4} fat. yr^{-1} is tolerable
- 450 sites, 0.045 expected fatalities

Storage, actuarial analogues

- For SEVESO plants : 10^{-2} fatality per year

- For ICPE : 10^{-4} fatality per year

- Storage seems regulated between these two classes of installations : 10^{-3}

- 450 sites, 0.45 expected fatalities

(tolerable risk << historical risk)

Is the storage risk negligible?

- People can inflate a risk 1000 times, if it is artificial, imposed and unfamiliar.

- We need to observe the storage system during 3000 site*years to accept with 95% confidence that safety is at 10^{-3} fatality per year. This means no fatality before 2030.

Additional fatalities
expected in 2050, if CCS is used at a large scale
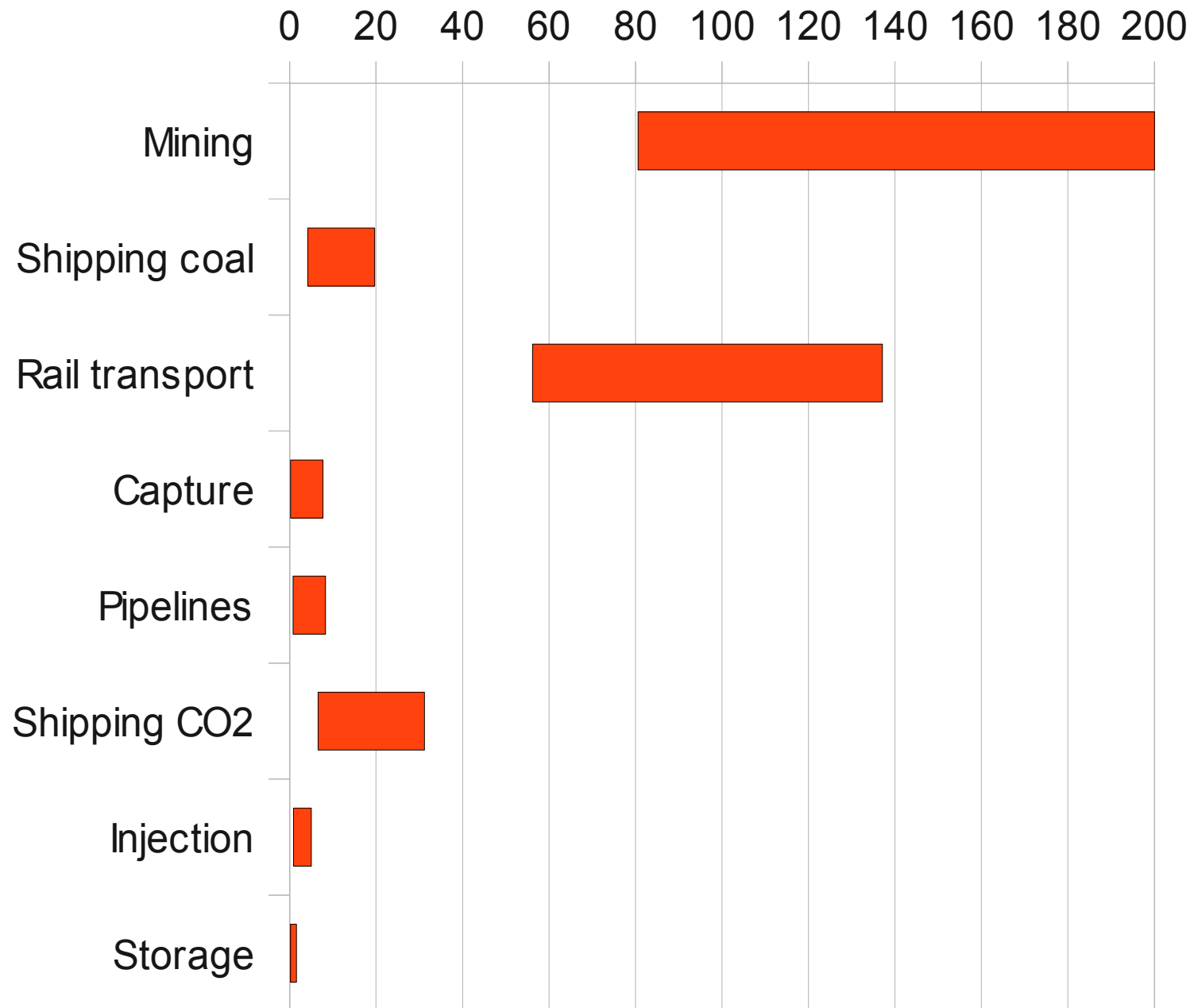
5. An economist's conclusion

- If mitigating climate change saves 10 000s of lives per year, then the scenario saves 1 000s. CCS passes this cost-benefit test.

- Fossil energy technologies have a lower record of big catastrophic accidents than
  nuclear
  large hydro

Thanks !

Tableau 1. Nombre de décès par décennie

Hydro
171.000

Chernobyl
>4000

Legend:
- □ Nucléaire
- □ Pétrole
- ■ Gaz
- ■ Charbon

Y-axis: 0, 1000, 2000, 3000, 4000, 5000, 6000

X-axis categories: 1907-1917, 1918-1927, 1928-1937, 1938-1947, 1948-1957, 1958-1967, 1968-1977, 1978-1987, 1988-1997, 1998-2007