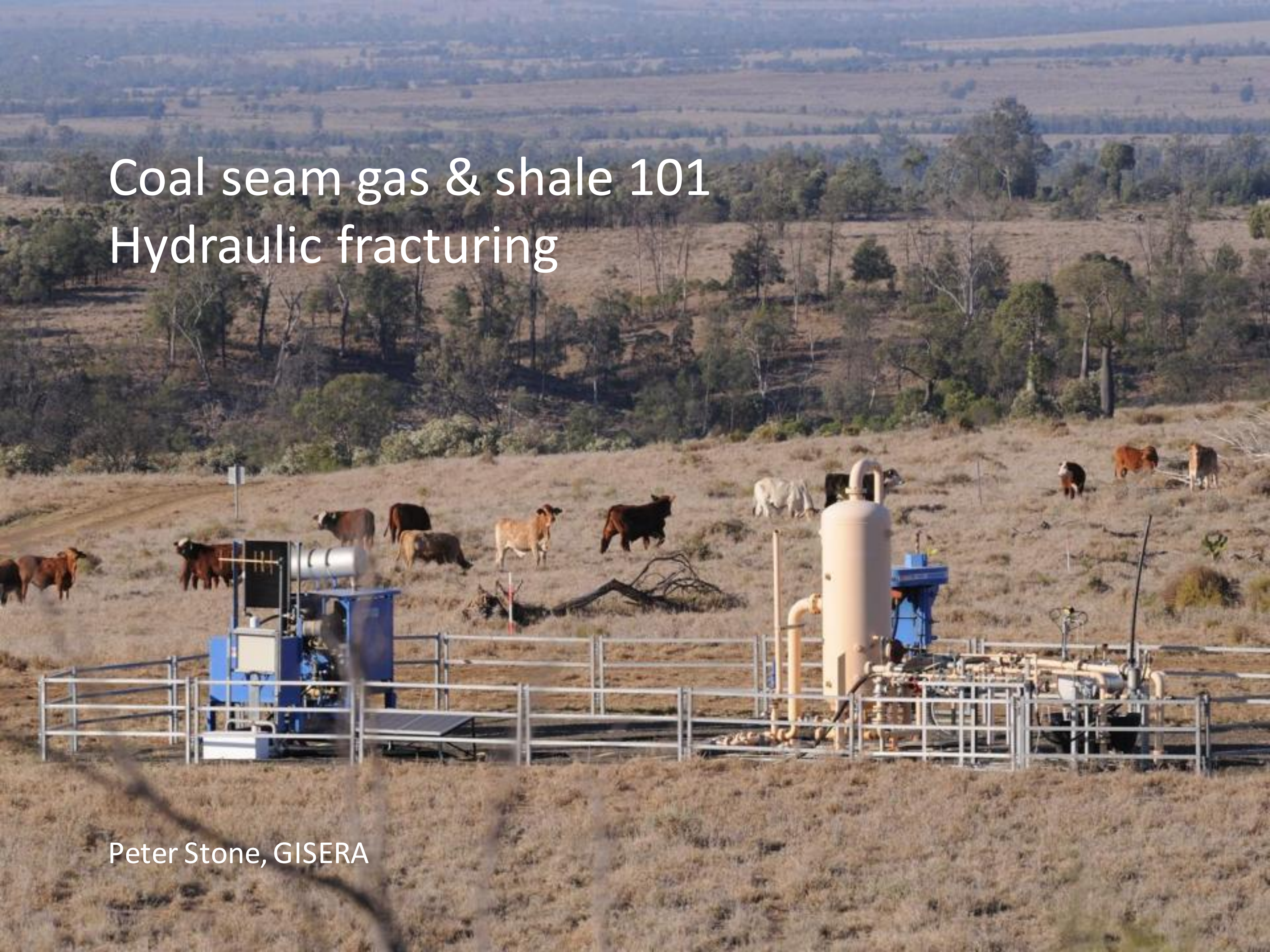
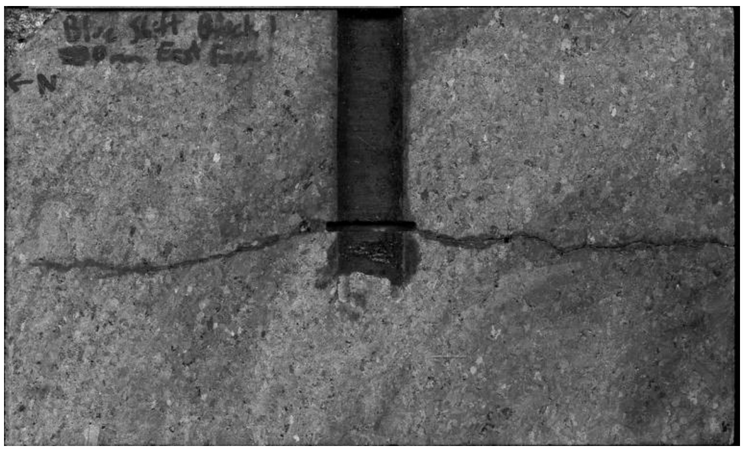


Coal seam gas & shale 101
Hydraulic fracturing

Peter Stone, GISERA

What is hydraulic fracturing?



- Hydraulic fracturing is the use of fluid pressure to create fissures in solid substrate
- The gas industry uses ‘fraccing’ to increase the rate and extent of recovery of gas
- Gas flows more rapidly & completely through the fracture than through coal or rock

Fraccing uses fluid pressure to create cracks for gas and water transport

How does ‘fraccing’ work?

- Industry animation of well completion
- Industry animation of fraccing

Why hydraulic fracture? Dollars!

- increase flow rate from
  - low permeability reservoirs
  - damaged wells
- connect natural fractures to a wellbore
- increase the reservoir volume in contact with a wellbore
- connect the full vertical extent of a reservoir with a horizontal well
- decrease pressure drops around a well to increase flow into the well

Fraccing can be strategically or tactically deployed

Fraccing differs in coal & shale

Character	Coal	Shale
Drilling direction	Mainly vertical	Mainly horizontal
Depth	400 - 1,000 m	2,000 - 4,000 m
Frac frequency	10-60%	100%
Frac extent (L X H)	200 - 300 x 5 - 30 m	500 - 1000 x 30 - 300 m
Frac fluid volume	ca 1 ML (0.1 - 10 ML)	ca 20 ML (5 - 40 ML)
Frac pressure	35 MPa or 5,000 psi	35 to 70 MPa or 5,000 to 10,000 psi

Greater depth, harder rock & lower gas content
require more invasive fraccing

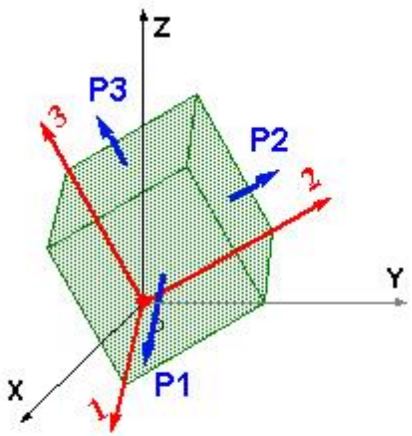
The scale of shale fraccing operations

A single (Marcellus) shale well:

- 1,000 to 1,500 m horizontal lateral
- $3.5 to $6.5 million
- 10 to 15 fractures per well
- 15 megalitres per well
  - 375 x 45 kL trucks
- 2,000 tonnes of proppant per well
  - 50 x 40 tonne trucks

Each fracced CSG well is about 10% that scale

The physics of fraccing



The magnitude & direction of principal stresses control:

- pressure required to create & propagate fracture
- shape and vertical extent of fracs
- direction of frac
- stresses seeking to crush and embed proppants

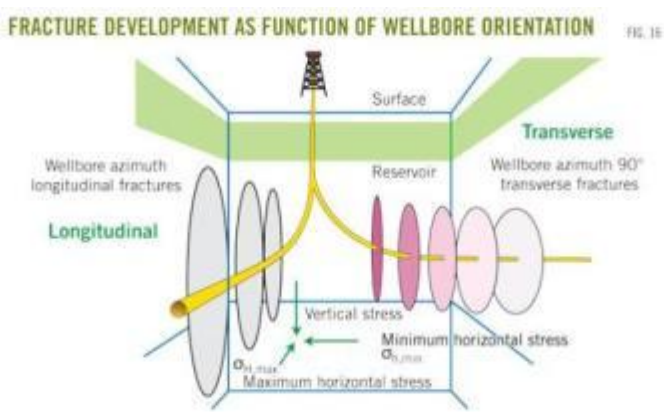
Rock properties are the most important variable in a frac job

Physics - pressure

- fraccing pressure must exceed the pressures of overload & fluid friction
- pressure requirements increase with:
  - depth
  - injection rate (extent of fraccing sought)
  - viscosity of fraccing fluid
- this explains why the pressure needs of shale >> CSG

High pressures are required to overcome large underground forces

Physics - orientation



- hydraulic fractures can't be "aimed"
- fractures propagate along pathways of least resistance
  - perpendicular to the minimum principle stress
  - vertical stress is often highest, so fracs often run vertically.
- coal seams are usually cleated (naturally fractured) which provides many pathways
  - about half the fractures in Australian seams are T-shaped and up to 75% are contained to the seam
  - the others grow in height to some extent and this is typically a feature of the basin and stress environment

Fractures follow the path of least resistance

Physics - speed

- speed of fracture propagation is tightly controlled
  - pressure, volume, viscosity, leakoff
- fracs may start at <10 m/min and slow to <1 m/min at the end of treatment
- speed increases with rock stiffness
  - stiff rocks (shale, sandstone, limestone) give narrow fractures
  - plastic rocks (coal) give wider fractures
  - more permeable rocks result in slower fracture growth

Fractures move slowly under fluid pressure control

Physics - extent

- Coal seam fracs are frequently short (10+ m)
  - undo damage to cleats caused by well insertion
- CSG fracs to enhance cleats are longer (200 – 300 m)
- Shale fracs are placed along a horizontal well, stimulating a volume of rock of 1000 m length and ≥ 150 m radius
- this explains widely differing frac fluid volumes of CSG & shale

Shale gas fraccing is more extensive than CSG fraccing

Physics - control

Fracc jobs are closely monitored & controlled using 3 methods

1. Direct far field
   - surface & downhole tiltmeters measure deformation caused by fractures
   - microseismic frac mapping measure noise
2. Direct near-wellbore
   - logging via video, temperature, production, tracer, etc
3. Indirect
   - models used to match injection pressure and rates used

Fraccing is closely predicted & real-time controlled;
sub-optimal fracc jobs cost money

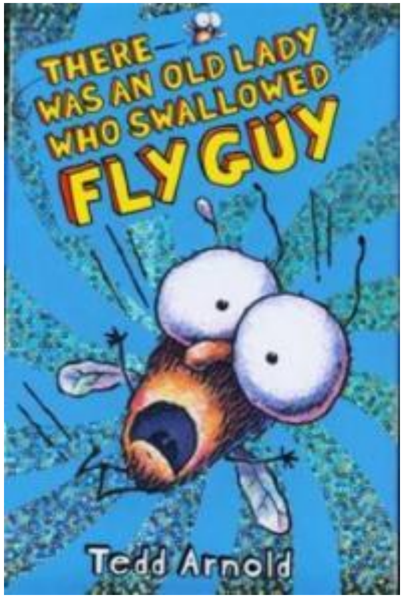
The chemistry of fraccing

The ideal fraccing fluid is:

- compatible with formation rock
- compatible with formation fluid
- promote fracture width via down-fracture pressure drop
- transports proppant
- returns to low viscosity for post-treatment cleanup
- cheap

It's hard to find one fluid that can do all this...

So a sequence of fluids is used...



A simplified sequence...

1. water to start fractures
2. biocides to control bacteria
3. gel to propagate fractures & distribute proppant
4. buffers to control pH of gel to maintain its consistency
5. breakers to dissolve gel
6. modifiers to neutralise biocide

A well-specific sequence

Fraccing chemicals allowed in Australia #1

Chemical	*Fraccing use*
1-Propanol	Complexor
2-Butoxyethanol	sed to reduce surface tension to aid in gas flow
Acetic Acid	pH buffer
Acrylic copolymer	Lubricant
Ammonium persulfate	Breaker used to reduce viscosity (turns a gel into water)
Boric Acid	Crosslinker to increase viscosity
Boric Oxide	Crosslinker to increase viscosity
Carbonic acid	Crosslinker to increase viscosity
Carboxy-Methyl Hydroxy-Propyl Guar	Gelling agent (thickens fluid to help suspend sand)
Crystalline silica (cristobalite)	Proppant (holds open fractures)
Crystalline silica (quartz)	Proppant (holds open fractures)
Citric Acid	Iron control or for cleaning well bores before fraccing
Diammonium Peroxidisulphate	Breaker used to reduce viscosity (turns a gel into water)
Disodium Octaborate Tetrahydrate	Gelling agent/Crosslinker to increase viscosity
Gas oils (petroleum), hydrotreated light vacuum	Guar liqufier
Fumaric acid	pH buffer
Gelatine	Corrosion inhibitor or gelling agent
Guar Gum	Gelling agent (thickens fluid to help suspend sand)
Hemicellulase Enzyme with/without Sodium Chloride	Breaker used to reduce viscosity (turns a gel into water)
Hydrochloric Acid	Cleaning of the wellbore prior to fraccing
Hydroxy-Ethyl Cellulose	Gelling agent (thickens fluid to help suspend sand)
Hydroxy-Propyl Guar	Gelling agent (thickens fluid to help suspend sand)
Magnesium silicate hydrate	Gelling agent

Fraccing chemicals allowed in Australia #2

Methanol	Used to reduce surface tension to aid in gas flow
Mono ethanol amine	Gelling agent
Ethylene Glycol Monobutyl Ether	Mutual solvent
Muriatic Acid	Used for cleaning the well bore
Non-crystalline silica	Proppant (holds open fractures)
Poly (oxy-1,2-ethanediyl)	Proppant (holds open fractures)
Polydimethyldiallylammonium chloride	Clay control
Potassium Carbonate	pH buffer
Potassium Chloride	Clay inhinbitor
Quaternary Polyamines	Clay control
Sodium Acetate	pH buffer
Sodium Borate	pH buffer
Sodieum Bicarbonate	pH buffer
Sodium Carbonate (Soda Ash)	pH buffer
Sodium Chloride	Breaker used to reduce viscosity (turns a gel into water)
Sodium Hydroxide	pH buffer
Sodium Hypochlorite with/without Sodium Hydroxide	Antiseptic to elimate bacteria in water
Sodium Persulfate	Breaker used to reduce viscosity (turns a gel into water)
Terpenes/terpenoids/sweet orange oil	Used to reduce surface tension to aid in gas flow
Tetrakis (hydroxymethyl) Phosphonium Sulfate	Antiseptic to elimate bacteria in water
Tetramethyl ammonium chloride	Clay control
Zirconium complex	Crosslinker to increase viscosity

Toxicity of fraccing chemicals

- Human toxicity data not available for most fraccing chemicals
  - most are food industry chems
  - aquatic life toxicity data are often used instead
  - NICNAS completing toxicity assessment
- Aquatic toxicity values
  - highest (lowest LC50; 160 micrograms/L) for sodium hypochlorite (pool chlorine)
  - lowest (highest LC50; 24,000,000 micrograms/L for sodium thiosulphate (a dechlorinator).

Frac chemicals are not acutely toxic at the concentrations used

Toxicity of fraccing chemicals

- Most fraccing chemicals are required in high concentrations in order to be toxic
- Achieving a toxic concentration is difficult with CSG because:
  - the concentration in the frac fluid is initially low, and becomes lower when diluted by coal seam water (frac fluid represents about 0.07% of aquifer volume)
  - 60-80% of frac fluid is removed within 20 d of the frac
  - frac chemicals are actively (by addition of degraders) and passively degraded
- Recovery of fraccing fluid from shale gas fraccs is limited
  - 50-90% remains embedded in rock

Some chemicals hazardous if introduced to water supply; evidence suggests introduction is unlikely

The regulation of fraccing is state-based

Slight inter-state differences, but mainly:

- notify landholder & occupiers
- statement of chemicals used for each well
- assessment of implications of fraccing at each well
- completion reporting
- no use of BTEX or chemicals that are likely to produce BTEX

Operational challenges & risks

- life-cycle GHG emissions
- local air pollution
- water consumption
- water quality
- induced seismicity
- community impacts

Many possible risks but most are rarely or not realised

Lifecycle GHG emissions

- fraccing is more a facilitator than creator of GHG emissions
- much energy is expended in fraccing, but emissions are small compared with whole of lifecycle for shale or coal seam gas

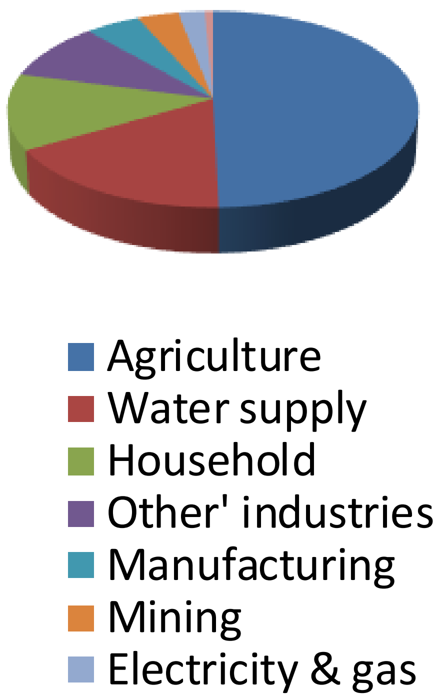
Fraccing's direct contribution to GHG minimal

Local air quality

- CSG is ca 97% methane, 1-3% CO_2 and N_2
- shale gas is more variable, but is typically
  - +90% methane
  - +5% ethane
  - +2% propane
  - 1% CO_2 and N_2
- volatile organics and other hazardous chemicals found near well heads are consistent with use of diesel engines
- dust from traffic is most likely source of significant local air pollution

No established links to health impacts

Water consumption



- CSG 'produces' rather than 'consumes' water
  - 95 GL pa likely for Surat basin
  - ca 60% of agricultural water use
- CSG water production will depressurise aquifers and will affect ca 3% of existing water bores
- shale gas production will use significant volumes of water in largely arid environments
- questions about engagement of resources sector in water planning

Fraccing potentially regionally but not nationally significant

Water quality #1

- dialogue & literature dominated by what *could* happen
- a variety of potential pathways for contamination of water
  - inter-aquifer connection
  - methane leakage
  - out of zone fraccing chemicals
  - fraccing chemical spills
- despite >1 million shale wells these risks are virtually unknown

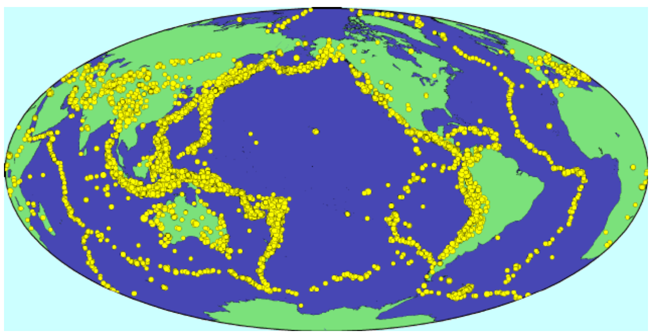
Lots of smoke but fire rarely evident

Water quality #2

- inter-aquifer connection virtually unreported, rarely confirmed
- no measured links between methane in aquifers & drilling, despite 3% well leakage rate
  - methane already in water; non-toxic, low solubility
- 50-90% of shale fraccing chemical not recovered
  - not out of zone, but adsorbed by shale rock
- ca 60% of CSG fraccing chemical recovered within 20 d

Surface spills during transport are greatest fraccing contamination risk

Induced seismicity



- shale gas fraccing has been related to seismicity once
- disposal of waste water rather than fraccing per se responsible
- induced seismicity possible if large quantities of water injected into existing faults for a long time
- CSG fraccing cannot induce seismicity
  - volumes & pressures too low, substrate too soft

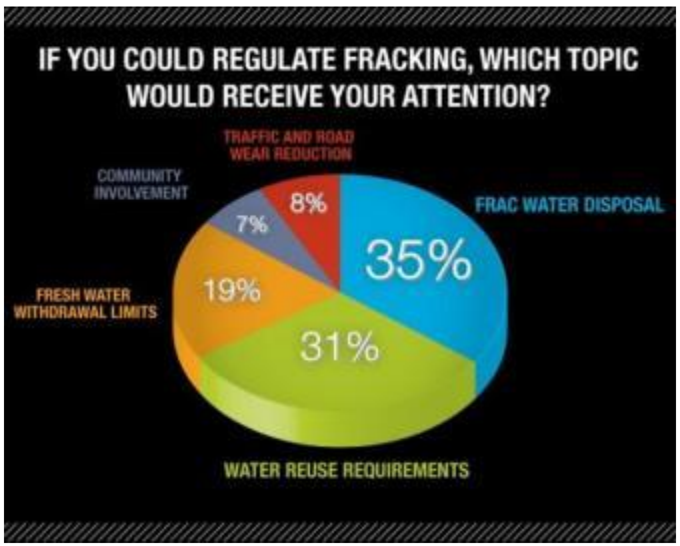
Fraccing-induced seismicity very unlikely

Community impacts

- distinguish impacts of fraccing from those of broader gas industry
- gas industry impacts material & well characterised
- material fraccing impacts very rarely established
- socio-psychological impacts conform with standard human responses to fear, loss of control, etc

Community impacts of fraccing are more a social than a biophysical phenomenon

Conclusion



- fraccing often & erroneously a synonym for gas industry impact
- gas industries have many impacts; most are unrelated to fraccing
- available science suggests a variety of potential fraccing hazards
- available science suggests a very low frequency and consequence of risk realisation

Fraccing is a common industrial tool

Thank you

Peter Stone

Phone: +61 7 3833 5659
Mobile: + 61 419 285 192
Email: gisera@gisera.org.au