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# THE REGULATOR'S PERSPECTIVE - BEST PRACTICE ACTIVITY APPROVAL PROCESSES FOR EGS PROJECTS (INCLUDING INDUCED SEISMICITY)

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## ABSTRACT

Benign and valuable outcomes are key objectives for geothermal industry activities. Trust in the capacity of both industry and regulators to deliver outcomes that satisfy stakeholder expectations are the foundation for investment and expeditious land access and activity approvals. These principles and practices are especially important for operations perceived to be new and with uncertain risks

Imperatives to deliver benign outcomes and expeditious land access motivate the behavior of the regulator for geothermal, upstream petroleum, high pressure pipeline and gas storage operations in the State of South Australia. The legislative framework in South Australia (*Petroleum and Geothermal Energy Act 2000*[1]) and the behavior of the regulator, Primary Industries and Resources – South Australia (PIRSA) are recognized by industry as "a relatively straightforward regulatory system, which could be considered a benchmark for other jurisdictions" (Productivity Commission, 2009).

The regulatory instruments that have delivered both trust and efficiency in South Australia are: non-prescriptive; allow for innovation while ensuring that operators demonstrate their ability to manage all possible risks to an acceptable level; and entail extensive stakeholder consultation to set standards which are aligned with community expectations.

Operations in South Australia include internationally significant Enhanced Geothermal Systems (EGS) developments. Recognizing EGS is (at least to the public) a new technology with uncertain risks, PIRSA has taken account of international developments (Majer, Baria and Stark, 2008) and commissioned research (Hunt and Morelli, 2006 and Morelli and Malavazos, 2008) to increase certainty in relation to risk management for EGS operations.
This paper describes the objective based, one-stop-shop approach taken in South Australia to deliver expeditious land access and activity approvals, while building trust in regulation and the geothermal industry's operations to deliver desired, benign, sustainable and successful outcomes. The basis for informed activity approvals for EGS operations is discussed in some detail.

[1] As amended and published by the South Australian Government (2009)

## EFFICIENT CO-REGULATION THROUGH STATEMENTS OF ENVIRONMENTAL OBJECTIVES (SEOs) AND ENVIRONMENTAL IMPACT REPORTS (EIRs)

The South Australian geothermal licenses shown in figure 1 are governed by the *Petroleum and Geothermal Energy Act 2000* (P&GE Act),

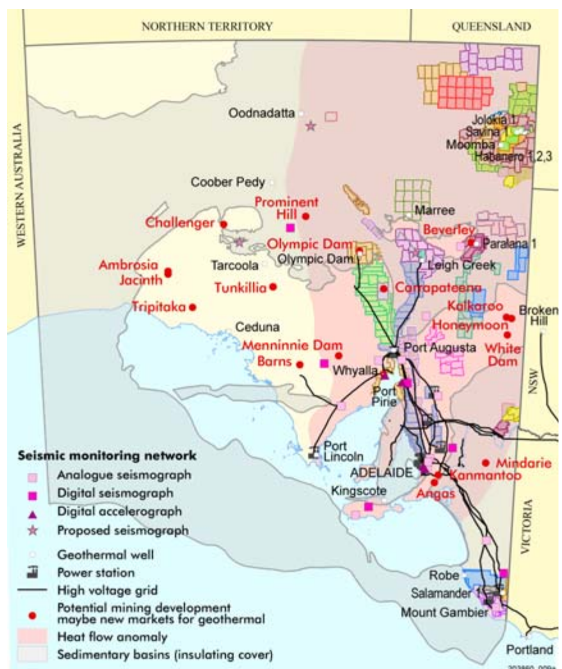

Figure 1.Geothermal licenses in South Australia and the South Australian Heat Flow Anomaly (adapted from Neumann, et al 2000)

In the context of the P&GE Act, the legal standards set for the protection of natural, social, heritage and economic environments are agreed through a robust, open and transparent research and consultation process that culminates in P&GE Act license operators owning and abiding by SEOs and associated EIRs (Laws, et al, 2002). EIRs detail potential impacts of proposed operations and specify strategies to mitigate risks to as low as reasonably practical (ALARP).

SEOs set standards for area and operation specific compliance with co-regulatory objectives for the sustainability of natural, social, heritage and economic environments. Hence, SEOs enable PIRSA to act as a first-line, one-stop-shop for co-regulation for the full-cycle of geothermal, upstream petroleum, high pressure pipelines and gas storage operations in the State of South Australia.

**Trust Underpins Efficient Co-regulation**

Embedding relevant local, State and Federal objectives and standards into SEOs make a breach of co-regulatory standards a breach of the P&GE Act.

Stakeholders are engaged during the development of EIRs and draft SEOs and usually in a staged process that entails face-to-face meetings. The process for SEO consultation with stakeholders can take 3 months or more depending on the level of impact of the activity, and stakeholder consultation requirements. Given potential for relatively low environmental impacts and sufficient prior publicly developed and disclosed criteria, the Minister (who is an elected Parliamentarian) may agree public consultation may be restricted to a time after a relevant SEO is fully developed for consideration. Public consultation is undertaken for the development of other EIRs and draft SEOs.

Final SEOs, final EIRs and annual statements of licensees' performance against SEOs and the Minister's determinations of the level of environmental impact of proposals are freely available to the public on PIRSA's website.

This openness and transparency underpins trust in PIRSA's roles as first-line regulator for: the integrity of plant and equipment; the protection of: water; air; flora; fauna; landscape; heritage; native (aboriginal) title; and as an interlocutor for disputes between P&GE Act licensees and stakeholders in multiple land use. In addition to the first-line roles listed above, PIRSA also works closely with South Australia's, lead agency for the regulation of occupational health, safety and welfare (SafeWorkSA) matters.

Formal agreements and policies explicate mutual expectations and underpin both the efficiency and effectiveness of co-regulation. Hence, licensees have a one-stop-shop for regulation.

Australia's Productivity Commission (2009) review concludes that PIRSA "has a clear mandate, clear regulatory responsibilities, good processes to engage with other agencies, and checks and balances that apply in high risk situations" and "is widely seen as a model for other jurisdictions to emulate".

**Geothermal SEOs and EIRs**

The P&GE Act requires that any activity can only be conducted if it is covered by an approved SEO for the region and/or land system within which it will be carried out. Hence, geothermal operators must develop appropriate EIRs and SEOs or conclude a bridging assessment to make plain the practicality of adopting and then abiding by pre-existing SEOs for analogous operations in analogous areas. When adopting pre-existing SEOs, the bridging assessment must satisfy relevant co-regulators that location-specific risks are adequately covered in adopted SEOs. If location-specific risks are not already adequately covered, then a new relevant SEO is drafted by the operator for stakeholder consultation. In some instances, SEOs developed for petroleum license activities are adopted for analogous geothermal operations.

EIRs underpin the relevance and contents of SEOs. All licensed field activities must be covered by an SEO approved by relevant Minister(s).

When considering EIRs, PIRSA makes a determination whether proposed activities should be characterized as low-, medium or high-level environmental impact. For activities characterized as:

- Low-impact – PIRSA consults with relevant co-regulatory government agencies.
- Medium impact – PIRSA undertakes public consultation with support from the operator; and
- High impact – an Environmental Impact Statement process is instigated under South Australia's *Development Act 1993*.

In this way – final SEOs cover all material concerns raised by stakeholders.

Licensees are required to report annually and by exception on their performance against SEOs. Five-yearly reviews consider the efficacy of SEOs and, following the principle of transparency, these reports are available to the public from PIRSA's website. Table 1 provides examples of EIRs and SEOs that illuminate potential risks, strategies to mitigate risks to as low as reasonably practical and standards for outcomes for geophysical survey and well operations (including drilling) used to date for deep geothermal well operations.

Geodynamics demonstrated the existing Cooper Basin SEO for drilling and well operations was relevant, and adopted that SEO for its operations in the Habanero, Jolokia and Savina wells.

Petratherm also adopted the Cooper Basin SEO for its Paralana 2 drilling and well operations.

Panax Geothermal has adopted the Otway Basin (Jacaranda Ridge) SEO for its Salamander 1 drilling and well operations.

**Table 1. Examples of Environmental Impact Reports and Statements of Environmental Objectives (SEOs)**

**Geophysical Surveys**

- State-wide EIR for non-seismic geophysical surveys
  www.pir.sa.gov.au/__data/assets/pdf_file/0003/50844/EIR_GeoOps_NonSeis.pdf
- State-wide SEO for non-seismic geophysical surveys
  www.pir.sa.gov.au/__data/assets/pdf_file/0004/50845/SEO_GeoOps_NonSeis.pdf
- Cooper Basin EIR for geophysical operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0011/27398/cooper_basin_geophysical_operations_eir.pdf
- Cooper Basin SEO for geophysical operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/27397/cooper_basin_geophysical_operations_seo.pdf

**Drilling and Well Operations**

- Cooper Basin EIR for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0004/27409/drilling_and_well_operations_eir_february_2003.pdf
- 5-Year Review of Operations, Addendum to Cooper Basin EIR for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0009/123030/Santos_-_Drilling__and__Well_Ops_EIR_Addendum_-_November_2009_Final.pdf
- Cooper Basin SEO for drilling and well operations
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/123031/Santos_-_Drilling_and_Well_Operations_SEO_-_November_2009_Final.pdf
- Habanero Well Operations EIR
  www.pir.sa.gov.au/__data/assets/pdf_file/0018/27441/habanero1_eir_sept2002.pdf
- Habanero EIR and SEO for circulation
  www.pir.sa.gov.au/__data/assets/pdf_file/0007/27439/habanero_circulation_eir_seo_oct2004.pdf
- Jacaranda Ridge 2 EIR
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/52588/Adelaide_Energy_PEL_255_Region_EIR.pdf
- Jacaranda Ridge 2 SEO
  www.pir.sa.gov.au/__data/assets/pdf_file/0010/52597/Final_Adelaide_Energy_PEL_255_SEO.pdf

### Activity Approvals

Local issues for particular field operations are addressed case-by-case during activity approval processes. In the activity approval process, PIRSA reviews: operator capabilities; fitness-for-purpose of plant and equipment; risk assessments concluded by licensees; and site specific environmental impacts. License operators who have demonstrated capabilities that consistently achieve regulatory compliance require low-level surveillance and only need to notify the regulator of activities, rather than seeking case-by-case activity approval.

### Advance Notice of Entry

License operators must provide 21 days notice in writing to users of the land that may be affected by specific regulated activities to relevant stakeholders, including PIRSA. Land users have 14 days to raise access-related concerns with the license operator and have the option of raising the concern directly with the regulator, and the final dispute resolution is a Warden's Court proceeding.

## INDUCED MICRO-SEISMICITY

The most advanced engineered geothermal system (EGS) projects in Australia are remote from population centers, so experience in Australia will be gained while potential risks of induced micro-seismicity are effectively managed. This experience will be of great value in showing the extent and magnitude of induced micro-seismicity, the reliability of pre-stimulation predictions, and providing a logical basis for predicting safe distances from fracture stimulation operations in built-up areas.

### Regulatory Research for EGS Operations

Many of the geothermal resources in South Australia are expected to be hydraulically fracture-stimulated to achieve optimum (high) rates of heat flow from well-bores. Fracture stimulation of reservoirs inevitably induces seismic events of some measurable magnitude. Proper planning and management of EGS operations can ensure that risks to people, buildings and infrastructure are reduced to as low as reasonably practical and acceptable levels.

To inform regulation, mitigate potential risks and address concerns raised by stakeholders, in 2005, PIRSA contracted University of Adelaide researchers to address a critical uncertainty shared by all geothermal licensees planning to demonstrate EGS in South Australia. That research (Hunt and Morelli, 2006[2]) assessed induced seismicity within the context of local geologic conditions in the Cooper Basin, and concluded:

- Granite basement in the Cooper Basin in South Australia is ideally suited to EGS activities in terms of its compressive stress regime (prone to sub-horizontal fracture propagation), low levels of natural background seismicity and the availability of extensive high quality reflection seismic to illuminate faults and fracture trends;
- Reactivation of faults in the vicinity of the Habanero site is unlikely. This is due to the nearby faults being beyond the reach of the induced seismicity associated with EGS activity.
- Induced seismic events at the Habanero well site in the Cooper Basin could reasonably be expected to fall below the background coefficient of ground acceleration (0.5 g)

[2] http://www.iea-gia.org/documents/InducedSeismicityReportSHuntDraftOctober2006Malvazos4Jan07.pdf

thereby not exceeding the government's current building design standards for peak ground acceleration.

These findings informed the regulator and stakeholders that the fracture stimulation of geothermal wells in the Cooper Basin could be safely managed so that micro-seismic events induced during the fracture stimulation:

- would not exceed design standards for ground movement;
- were unlikely to induce slip and consequent, larger seismic events on larger geological faults; and
- were unlikely to create hydraulic communication between the stimulated granite (basement) zones below 4,000 metres and the overlying sedimentary Cooper Basin above 3,700 metres.

This last finding is based on the prevailing, natural, highly compressive stress regime acting to constrain fracture propagation to sub-horizontal intervals. Indeed, fracture stimulation and injection programs in Geodynamics' Cooper Basin Habanero wells were both conducted safely and were successful in the enhancement and flow testing of EGS reservoirs.

## Risk Management for Induced Seismicity

Given the results in the Cooper Basin, and looking forward to many additional EGS projects in Australia (and South Australia, in particular), PIRSA commissioned the development of risk management protocols for induced seismicity associated with EGS reservoir development in 2007. The findings (Morelli and Malavazos 2008) are fully consistent with the findings of Majer, Baria and Stark (2008) and are summarized in Table 2.

## Running Ahead of the Frac Crew

An informed risk assessment for EGS operations starts with an analysis of:

- historical (monitored) earth movements magnitude and location; and
- geophysical survey data to relate earth movements to faults and fracture trends.

**Table 2** Information that can most help to inform activity approvals (or otherwise) for the fracture stimulation of geothermal reservoirs includes:

- Characterization of the local environment, infrastructure and population for vulnerability to ground movements and loss modeling (taking account of design standards)
- High-quality records of seismicity waveforms, magnitude and location;
- Thickness and shear velocity of soil and weathered cover over bedrock. Measuring shear velocities to 30 metres depth is a generalized suggestion;
- Reservoir data for characterization – including:
  - Orientation and magnitude of stress fields;
  - Location, extent of faults and fracture trends;
  - Mechanical, thermal and chemical rock properties, and
  - Hydrologic parameters (extent, pressure, chemistry and nature of confining aquitards)
- Conclude loss modeling (taking account of design standards and infrastructure that pre-dates design standards)

Non-exhaustive protocols for credible risk management for geothermal operations that may induce seismicity

- Apply national or international standards for risk management
- Proponent to demonstrate adequate assessment of potential consequence of induced seismicity for sites selected for hydraulic stimulation or large scale injection.
- Stakeholder engagement to start as soon as is practical
- If required, augment the existing seismic monitoring network to detect and gather seismic events of magnitudes (Richter scale) less than 3. It will be advantageous to deploy seismic monitoring stations to:
  - Continuous digital high sample frequency (≥ 100 htz) recording;
  - Attain adequate network to accurately locate seismic events and measure attenuation; and
  - Geophysical surveys to calibrate regolith response models at EGS locations.
- Maintain the seismic monitoring network for the life of the project.
- As practical, deploy at least one sub-surface seismic monitoring station (below regolith if possible) prior to hydraulic stimulation or large scale injection.
- Deploy down-hole and near surface monitoring stations to determine attenuation and regolith amplification.
- Sustain an evergreen watching brief so new information is assessed and considered for induced seismicity risk management.

The adequacy of seismic monitoring arrays has a bearing of the certainty of earth movement magnitudes, locations and sense of motion, and hence the usefulness of recorded (historical) base-line information. The seismic monitoring stations in South Australia are depicted in Figure 2. Additional seismic monitoring stations are located in adjacent jurisdictions. The locations of four additional stations in South Australia have been agreed between State and Federal Government agencies (as shown in Figure 2) and the equipment to be deployed will enhance detection resolution.

The detection limits of the existing seismograph network in and around South Australia is variable (as shown in Figure 2, based on Dent, 2009) but is generally adequate to detect magnitudes > 3.5 to 4 (Richter Scale) and is more resolute for settled areas. If required, existing networks can be augmented to provide higher resolution of the locations (at depth) of epicenters.

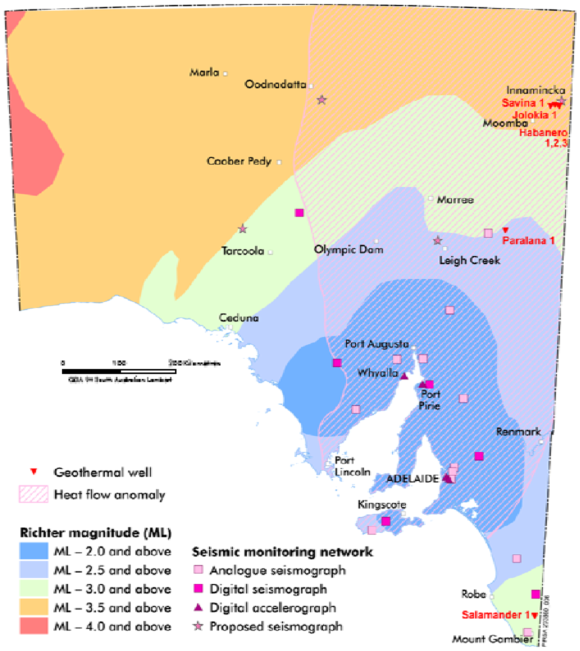


Figure 2. Locations and approximate detection capability of seismograph net work in South Australia (including use of seismographs in adjacent States and the Northern Territory. Adapted from Dent, 2009. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000).

The location and magnitude of historical, recorded earth movements in South Australia are depicted in Figure 3. This map does not express the uncertainty of epicenter locations, but this uncertainty is a factor considered when assessing potential risks posed by EGS operations.

The most advanced EGS projects in Australia are those of Geodynamics (Habanero, Jolokia and Savina wells – see figure 1) and Petratherm (Paralana 2 – see figure 1). Only Habanero wells have been fracture stimulated by year-end 2009.

High resolution seismic monitoring arrays have been installed at Habanero and Paralana to better measure both background seismicity and seismicity induced during stimulation, production and circulation operations. The array positioned at Habanero can detect and locate events as low as -2.5 (Richter scale) at a depth of 5 km, with a 3D locational accuracy of about 30metres.

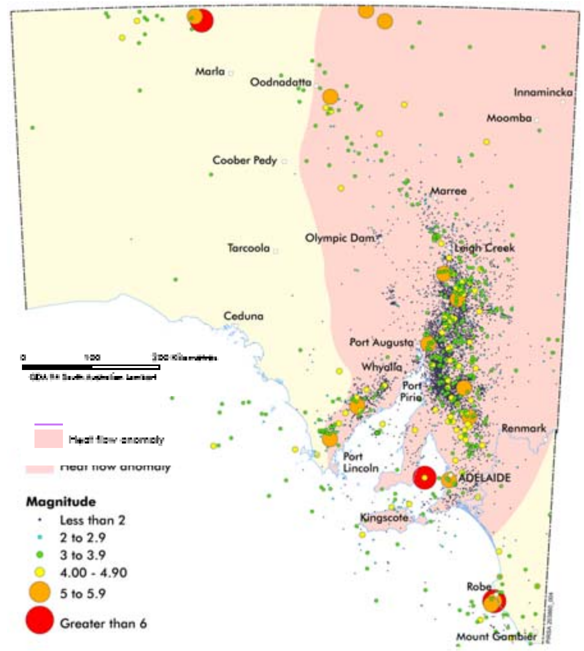


Figure 3 Location and magnitude of historical earth movement epicenters in South Australia. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000).

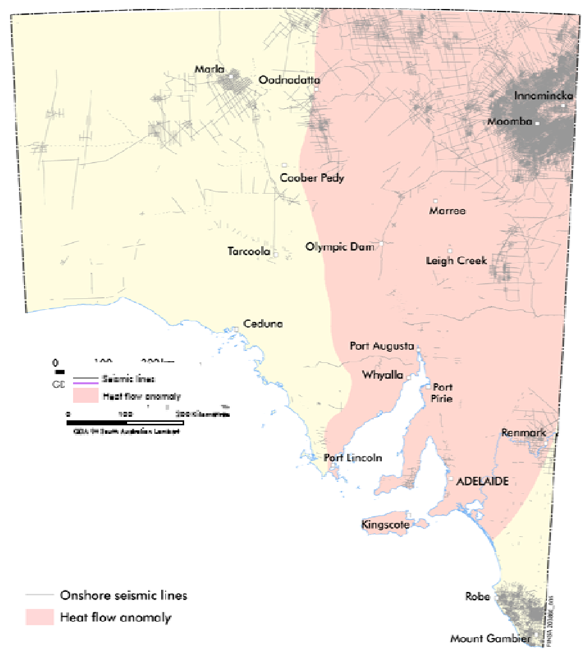


Figure 4. Reflection seismic lines (2D and 3D surveys) onshore South Australia. The South Australian Heat Flow Anomaly is also shown (adapted from Neumann, et al 2000

Hot Sedimentary Aquifer projects that do not require fracture stimulation and entail well operations largely analogous to petroleum well operations do not necessarily need to deploy seismic monitoring arrays.

Reflection seismic is useful to optimize drilling locations for EGS targets. Figure 4 depicts vast areas in the South Australian Heat Flow Anomaly that are remote from population centers, and covered with at least some modern reflection seismic information.

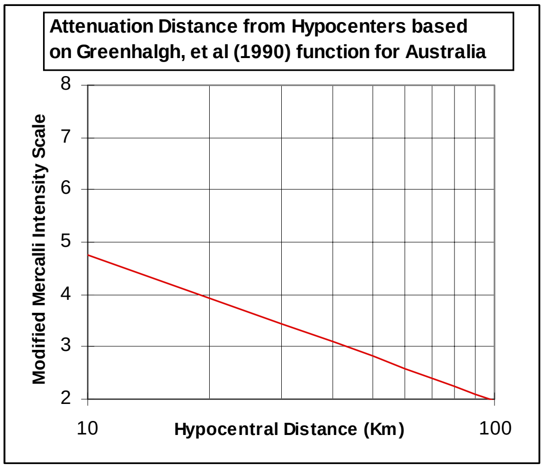


**Figure 5.** Estimated attenuation of earth movement intensity of a Richter scale 3.7 magnitude seismic event with distance from an event hypocenter in northeast South Australia.

### Tools of Trade in Assessing Attenuation Distance

The largest recorded magnitude seismic event associated with EGS operations at Habanero in the Cooper Basin determined to be of magnitude 3.7 on the Richter scale e.g. an event felt but one that would rarely cause damage.

Figure 5 is an output from a spreadsheet tool developed by PIRSA (Love, 2009) that uses estimates of earth movement (seismic wave) velocities to forecast modified Mercalli scale[34] intensity attenuation with distance from hypocentres. This spreadsheet tool estimates intensity attenuation based on five functions published in: Bierbaum, et al, 1994; Gaull, et al 1990; Greenhalgh, et al, 1990; and Greenhalgh, et al 1994. The Greenhalgh, et al (1994) function for Australia is considered the most appropriate of these five correlations to characterise seismicity induced during EGS operations at Habanero in the Cooper Basin in South Australia. More detailed analyses are expected to be concluded by EGS operators to optimise fracture stimulation programs, assess potential hazards, and underpin consultation with stakeholders. Based on this correlation (figure 5), the maximum (3.7 on the Richter scale) recorded event at Habanero is characterised as having attenuated to a modified Mercalli scale intensity of 4.8 at 10 km distance from the hypocenter and diminished to a slight intensity at a distance 20 km from the hypocenter e.g. <4 on the modified Mercalli scale, similar to vibration from the passing of a truck.

### Better Baseline Data

A unique opportunity arises for cooperation to efficiently meet multiple objectives for public safety, and exploration for EGS, unconventional gas reservoir sweet-spots and geosequestration.

This would entail cooperation of: government agencies responsible for assessing geo-hazards associated with earth movements; proponents of developing fractured reservoirs for the production of heat energy (e.g. EGS); proponents of developing coal bed methane, shale gas and tight gas reservoirs; and proponents of subsurface greenhouse gas storage

In particular – it will be advantageous for companies exploring for reservoir sweet-spots related to tensile rock fabrics and seismically quiescent storage reservoirs to coordinate plans in the context of:

- publically managed seismic monitoring networks, so those networks are augmented with multiple objectives in mind; and
- privately installed monitoring stations become public assets, post-decommissioning of industry's projects.

Cooperation will advance both knowledge of induced seismicity risks and reservoir development opportunities.

## CONCLUSIONS

1. Co-regulatory efficiency and effectiveness for geothermal operations can be delivered with an objective-based and transparent one-stop-shop approach as applied in South Australia.
2. PIRSA's research into potential risks posed by EGS operations has informed regulatory approvals for fracture stimulation operations in geothermal wells in areas that are remote from population centers.
3. The magnitude and extent of micro-movement induced by fracture stimulation and injection at Habanero in the Cooper Basin were largely as predicted e.g. EGS reservoirs were created and circulated without adverse impacts.
4. Experience in remote locations will provide benchmarks for the regulation of EGS projects nearer to populated locations.
5. Australia is becoming a globally important laboratory for EGS operations.

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[3] For a summary of alternative time-domain ground vibration units (acceleration,, velocity, displacement and corresponding peak values), refer to Hunt and Morelli (2006) and references therein

[4] The USGS describes the modified Mercalli scale at www.earthquake.usgs.gov/learn/topics/mercalli.php

6. Given enough experience – risk management strategies for fracture stimulating and injecting into geothermal reservoirs are expected to evolve and EGS operations are expected to become predictably profitable and reliably safe. The outcome will be wide-spread community and investor trust in EGS development.

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