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ELECTRICITY GENERATION USING A SUPERCRITICAL CO_2 GEOTHERMAL SIPHON

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ABSTRACT

This is a Report produced after a small Workshop organised by the Queensland Geothermal Energy Centre of Excellence in Brisbane on 25-26 August 2008. The first day of the Workshop concentrated on the feasibility of supercritical CO_2 geothermal siphon as a new way of exploiting hot rock geothermal resources to generate electricity. The second day of the Workshop discussed the future research strategies for the Queensland Geothermal Energy Centre and other national and overseas research groups in the broader geothermal energy context – the main research thrust in the near future for the Centre as well as the others who participated in the Workshop. This document offers a summary of the discussions during the first day. It is organised in six Sections, corresponding to the six Focus groups in the Workshop.

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As a background to the following sections, it should be noted that a supercritical CO_2 siphon (Brown, 2000; Pruess, 2006; Gurgenci et al, 2008) offers a series of potential advantages that may expedite commercial exploitation of some geothermal resources. There are however significant issues that need to be resolved. A list of such issues would include but not be limited to the geochemistry of supercritical CO_2; dealing with reservoir water; long-term effects in terms of reservoir connectivity; the source for CO_2 to activate the reservoir and long-term retention of CO_2; and design and optimization of turbines and air-cooled heat exchanger systems to work with the supercritical CO_2.

This document is a summary of the discussions as captured by the Workshop organisers during the Workshop and listed under six Focus Group headings. Although all care has been taken to ensure accuracy and adequacy, the following does not necessarily constitute a true representation of the views of the Workshop participants.

FOCUS GROUP A – GENERAL FEASIBILITY

Rapporteur: Jeff Tester

While this is definitely an exciting concept and has great potential, a careful approach is needed. The following issues have been identified by this focus group:

- What is the need for a demonstration now? Can we advance our knowledge without rushing to a field demonstration?
  - This idea is far-reaching and outside the boundaries of the Engineered Geothermal System (EGS). Therefore, it may take time to identify and resolve all relevant issues.
  - Present EGS thinking is focused on water and yet needs to be proven. No EGS system has worked for a convincing length of time. There is a danger that vigorous pursuit of the CO_2 concept could defocus water-based EGS efforts.
  - Some fundamental research may be needed before a field demonstration is possible.
  - It is important that the objectives and the procedures for a field demonstration are planned carefully? Failure is costly and haste and early failure may kill the topic unnecessarily.
- Each reservoir is different. If this idea is to make an impact, it should be part of a national assessment of possible sites. In other words, given diverse reservoir geology, can we make a national assessment of the supercritical CO_2 geothermal siphon?
- What are the benefits for Queensland on the international stage for pursuing this approach? The role for international collaboration also needs to be identified.
- Importance of key infrastructure
  - Access to CO_2 at an acceptable cost.
  - Proximity to the electricity grid.
  - Access to cooling water.

- The reservoir will be developed in stages. The conditions will be different in each stage and need to be analysed separately. This includes transition from the system start-up first to a mixture of CO_2+Water +hydrocarbon and then to a CO_2-filled reservoir. This is a key issue.
- There is need for additional fundamental research on key physical/system parameters:
    - Equation of state, e.g. the density as a function of temperature, pressure and the vapour fraction or □=f((T, p, x) for
        i. sCO_2+water
        ii. sCO_2+water+salt+hydrocarbons.
    - Accurate viscosity and thermal properties at the start-up and the steady-state conditions of the reservoir.
- The matter of decoupling the surface from the subsurface merits attention but it is obvious that they need to be coupled at some stage.
- Clarification is needed on who will own the long-term responsibility for the resultant reservoir, including the liability for future CO_2 leakage.
- Long-term rock/water/sCO_2 interactions must be modeled and their effects studied on
    - System performance
    - CO_2 containment.
- How will the work be coordinated and prioritized nationally and internationally?

<u>FOCUS GROUP B – FIELD DEMO</u>

<u>Rapporteur: Joe Reichman</u>

The following features need to be considered when selecting a site for field demonstration:

- Quality of the geothermal resource
    - Depth and temperature
    - The reservoir may be at lower temperatures and shallower depths but must always be in hot rocks (not in the sedimentary layers).
- Statutory
    - There must be appropriate geothermal permitting in place.
- Infrastructure
    - Proximity to the source of CO_2
    - Cost of CO_2
    - Cost of connecting to the electricity grid
    - Start-up power.
- Environmental impact
    - Retention of CO_2
    - Disposal of water in the reservoir.
- Reservoir water – Hot WET Rocks will be the norm. Therefore, one has to consider disposal of the reservoir water. Drying the reservoir may take several years. The reservoir would most likely contain brine, which cannot be released to the environment. Possibilities are reinjection to hot rocks in another site or desalination.
- At what point should one have a demonstration? One probably should be searching for a site in parallel with the fundamental research and start planning for a field demo as soon as a suit able site is identified. While this could be considered risky, the reward is substantial and timeliness is important.
    - Overall, the industry is pursuing more conventional geothermal prospects at the moment.
- At the first glance, two locations can be identified for consideration as possible CO_2 geothermal siphon field demonstration sites:
    - Moomba region – While in South Australia, ready access to CO_2 may make it a suitable field demonstration site. The gas fields in Moomba are releasing about 1m tonnes of CO_2 per year at the moment. This is reasonably pure CO_2. By injecting at 3.5 km depth, one can target power production 1 MWe or higher in a demonstration project.
    - Otherwise, most of the CO_2 in Queensland is produced by power plants along the coast. There are efforts in trying to identify hot temperatures in the Surat Basin. If they succeed, Surat Basin could provide a suitable location. Alternatively, one may target a demonstration at shallower depths and lower temperatures (2-3 km and @150 ^oC) but still in the basement rock.

<u>FOCUS GROUP C – INFRASTRUCTURE</u>

<u>Rapporteur: Simon Bartlett</u>

- Long-term sustainability
    - Geothermal power will be feasible in Australia only as a long-term large-scale operation. Otherwise, it would be difficult to make the requisite infrastructure investment in, for example, the electricity transmission lines. The proposed concept may not be feasible at such a large scale because of its dependence on fossil-fuel power plants for replenishment of CO_2.

This is a possible flaw in the proposed model.

  - Is it viable to expect the existing fossil-fuel plants to continue into the future?
  - Is this only a transitionary technology?
  - It must considered against alternative transitionary technologies:
    - Gas
    - Wind
    - Nuclear
    - Clean coal with geosequestration.
  - A more suitable fluid for the geothermal siphon may need to be explored.
- Electricity Transmission Infrastructure
  - Present geothermal resources are remote from the grid. There is a need for economies of scale to justify transmission line construction.
  - Transmission implications
    - Long distances, 500 – 1500 km
    - Multiple transmission lines are needed for security of supply (at least 2 to 3)
    - Transmission line capacity cannot start small and increase gradually.
  - Investment and Costs
    - ~$5 billion transmission
    - ~$750m pa costs
    - ~$50/MWh for transmission costs
      - To be compared against the current $30/MWh that covers generation *and* transmission.
  - Issues
    - Not justified economically
    - Who will pay?
    - Technical challenges of long transmission lines.
  - One needs to target closer geothermal sites
- CO_2 Supply
  - Coal-fired power plants provide the only option:
    - Central Queensland – 5000 MWe
    - Surat Basin – 1500 MWe
    - Hunter Valley – 8000 MWe
    - Latrobe Valley – 5000 MWe.
  - A possible model is where the coal-fired power plants capture and geo-sequester CO_2 in storage, from which the geothermal plant extracts the CO_2 and transports to the geothermal site.
    - The cost of carbon capture and geo-sequestration could be the responsibility of the coal-fired power generator
    - The geothermal plant operator would have to pay for the cost of transporting the CO_2 to the geothermal resource
    - Considerable CO_2 storage capacity is essential to buffer the geothermal plant against planned and unplanned interruptions in coal-fired power plant production schedules.
  - The infrastructure challenges in this model for CO_2 Supply are
    - Carbon capture by the coal-fired power plant owner
    - Geosequestration by the coal-fired power plant owner
    - CO_2 extraction by the geothermal operator.
- CO_2 Transport
  - Pipeline required for 1-2 GWe geothermal power
    - □1m x 1500km
    - With pumping stations along the way
  - Pipeline Cost
    - $1.5m/km → $2.5b for a 1500-km pipeline
    - $400m per annum
    - $30/MWh (=$400,000,000 divided by 1500MWe x 24 h/days x 365 days).
  - Technical Issues
    - Corrosiveness of CO_2
    - Power supplies to the pumping stations
    - Security of supply, e.g. will a single pipeline be enough?
- Geothermal Plant Infrastructure (see Figure 1)
  - Large area needed for each 50-MW module.
  - Matrix of power modules are needed as shown in the sketch.
  - Major distribution networks for CO2 and electricity are needed as the requisite infrastructure.
  - One needs to relocate the pipeline, the transmission lines and the plant every 15 years.
  - Maintenance of systems.

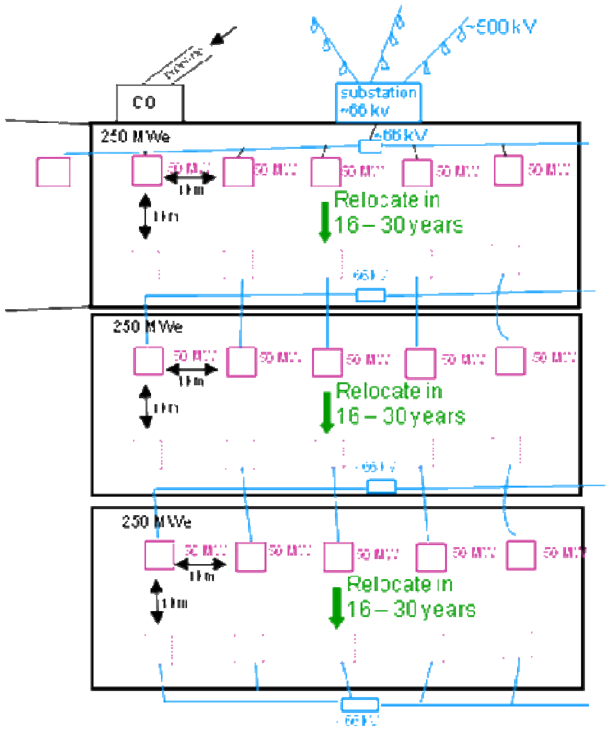

Figure 1: Geothermal plant infrastructure

- Infrastructure Investment in Current Regulatory Framework
  - Existing regulatory framework is market-based to encourage lowest-cost solutions
    - 20% MRET or Mandatory Renewable Energy Target (transitionary?)
    - CO_2 certificates.
  - Yet Geothermal Energy (including the cost electricity transmission, and the cost of CO_2 in the geothermal siphon concept) is very expensive.
  - Will the private enterprise invest given the uncertainties of sovereign risks?
  - In providing emission-free baseload power, its competitors are clean coal and nuclear. Will the geothermal power (including all add-ons) be cheaper than these two?
  - A policy change on nuclear power would change things dramatically.

The following points were raised by the floor following the *Focus Group C* presentation.

- Renewable alternatives, e.g. solar thermal power are more expensive than geothermal.
- Directional drilling will make the size of the site quite small. All the holes for a 50-MWe can be drilled from the same pad.
- While the investment is large in total, it would be made over a long period and in stages.
- For a field demonstration of the geothermal concept, a CO_2 pipeline needs not be built if the demo site is close to CO_2 supply.
- Political imperatives are driving away from demo to immediate commercialization of IGCC. Similar mechanisms may militate here against a field demonstration forcing us directly towards a commercial trial.
- Distance is the problem in this picture. To save on the pipeline and transmission costs, Longreach might be a suitable demo site (large producer of CO_2).
- Longreach power stations are 2/3rd into their economic life and this can be a threat for the long-term supply of CO_2.
- New Queensland power stations are all gas-fired (1500 MWe) using coal seam methane with reduced CO_2 emissions.
- These are very high costs but they are not very high compared to the costs of CCS. The carbon capture and sequestration costs are presently very high. In fact, the high cost of CCS may be a serious threat to the long-term viability of the CO_2 geothermal siphon power plant. Will CCS be viable in the long run to keep providing CO_2 to the geothermal siphon power plants?
- Coal-fired power stations are looking expensive in comparison to Integrated Gasification Combined Cycles – which produce little CO_2. The geothermal siphon plants may lose their supply of CO_2 in Queensland with a shift to IGCC and coal seam methane.
- The perceived advantages for CO_2 as a working fluid for exploiting low-grade heat need to be separated from sequestration issues.
- A possible option for CO_2 reuse is converting it to CO at high temperatures and then converting CO to hydrocarbons by using the Fisher-Tropsch process. (If CO_2 is heated to 2400°C, it splits into carbon monoxide and oxygen. The Fischer-Tropsch process can then be used to convert the CO into hydrocarbons.)

FOCUS GROUP D – RESERVOIR

Rapporteur: Victor Rudolph

- All real systems all have water. A dry reservoir is not a realistic expectation.
  - Reservoir stimulation and plant operation procedures must be designed with ability to handle water in the reservoir.
  - The reservoir water may provide an advantage rather than a hindrance. This possibility needs to be investigated.
  - It is not clear how long it would take to dry off a reservoir but it could be quite long.
  - Reservoir water loss is a variable, for example, no water losses are expected at the Geodynamics site since the reservoir is capped and sealed. If uncapped, the water would flow for hundreds of years at the Geodynamics reservoir.
- It is typical that underground reservoirs are poorly characterized.
    - Outcomes in the field can be controlled only poorly or are not controllable at all.
    - Many things are location dependent and experience in one site is not directly applicable to a new site.
- Fracturing/flow properties of reservoir are of key importance.
  - Enhancing and controlling these fractures (their size and directionality) is the essence of reservoir stimulation.
  - The EGS reservoirs are stimulated using water. The geothermal siphon would have the option of using CO_2 but it is not clear which one is better. CO_2 fracturing is commonly done in oil industry but its usage in the present context needs to be investigated.
  - Reservoir stresses and stress directionality are important parameters concerning reservoir stimulation and utilization.
  - Temperatures and drawdown rates depend on fracture patterns and fracture patterns are influenced by the stress conditions.
  - The effect of thermal shrinkage of the reservoir rock on permeability would also be important over the plant life.
- Underground chemistry
  - Rock/pore water/fracture flow interactions
    -
    - Possibly different mechanisms apply near injection (dissolution) and production (precipitation) wells.
  - Figuring out these interactions for a specific site is difficult. Some ideas have been raised in the Focus Group but there are no easy solutions.
    - Typically, the only samples available are chips obtained while drilling and the task is characterization of the reservoir with reasonable accuracy from chips obtained while drilling only a few wells
    - What is required is a quantitative characterization as well as qualitative.
    - Historical analogs may be useful.
  - Unknown variability of the reservoirs
    - Representative samples?
    - Depth profile?
    - Complexity.
- Well arrangement & pressure/flow balance
  - The aim is power generation – not CO_2 sequestration. The reservoir must be planned to optimize the quantity and the cost of energy extraction over the target plant life.
  - Modelling is important to determine optimum well spacing, flow rate predictions, etc.
- Long-term CO_2 fate?
  - In general, an EGS reservoir looks like a robust storage space because it is deep and it is sealed (otherwise, it would not have the hot temperatures that make it a suitable geothermal resource).
  - Seismic events could generate a potential for loss to surface.
    - Seismic triggers experienced in past geothermal tests occurred only during the reservoir stimulation phase. The possibility of other seismic triggers for leakage to surface needs to be investigated.
    - The earthquake propensity and the likely effects of earthquakes need to be investigated for a given site.
- Different material choices may have to be made for constructing CO_2 geothermal siphon reservoirs.
  - This also includes the service equipment.

- There is a need for fundamental studies on properties of mixtures of a vapour and a supercritical fluid.

The following points were raised by the floor following the presentation by the *Focus Group D*.

- The 10% loss figure included in the Workshop papers may not be sustainable.
- This is not a sequestration project since no one would want to sequester CO_2 5 km deep and 1500 km away when it can be sunk 0.5 km down and only 100 km away from the source.
- Even if sequestration is not the aim, there will still be a need for millions of tonnes of CO_2 required to fill the reservoir and to start the heat extraction. Some of this will be sequestered. The CO_2 will be left there and this is a future liability.
- CO_2 is quite compressible and a lot more can be stored at 5 km depth and it would also be further away from the surface at those depths minimizing the chance of leakage
- There are two reasons to use CO_2 in a geothermal siphon:
    - It may be available in large quantities
    - Its thermodynamic properties are favourable
- When CO_2 is injected into hydrothermal reservoirs, it is known what happens. The experience would be useful to a geothermal siphon project. The hydrothermal experience suggests that there would be some sequestration of CO_2 as minerals, although this might be reversed when the reservoir dried off.

FOCUS GROUP E – POWER CONVERSION

Rapporteur: Trevor Gleeson

- Handling of the CO_2 does not offer new challenges. The oil/gas industry offers the requisite experience.
- Corrosion could be a problem.
    - Water from the reservoir will be picked up by the CO_2 at least until the reservoir is dried off. Possible options are
        - A binary plant during the drying period
        - Direct expansion of the CO_2 after the reservoir is dried off
    - Other minerals will possibly be present in the CO_2 stream. This probably would be site specific. The main issues are:
        - Can these minerals be separated before running the fluid through the surface plant
        - Otherwise, the geochemistry of the site will affect the materials used in the surface plant.
- Expander/Turbine
    - The current range of gas and steam turbines may not be directly applicable
    - New approaches/designs will be needed
    - The pressures are similar to steam turbines but supercritical CO_2 is denser. Therefore, it is conceivable that CO_2 turbines will be smaller
        - CO_2 is 2.7 times more dense – 190 vs 70 kg/m^3 @20 MPa.
    - The impact of turbine size on cost is not clear.
    - This is an engineering design problem and there are no fundamental difficulties.
    - Supercritical CO_2 is being proposed for refrigeration cycles and there can be lessons learned from those efforts.
- Cooling CO_2
    - If air-cooling is the only option, this would require very large heat exchangers
        - The presence of water in the CO_2 stream may lead to corrosion. Another complication would be the condensation of water creating a two-phase flow.
    - The pressure is very high (>8 MPa) to maintain supercritical conditions and this would require thick walls for the finned tubes adding to the cost.

The following points were raised by the floor following the presentation by the *Focus Group E*.

- The corrosiveness is a transition issue. Supercritical CO_2 is not corrosive when there is no water. Although it should be acknowledged that dry-off time could be very long for some reservoirs.
- There may be options to generate power during the transition from a wet reservoir to a dry reservoir, e.g. CO_2 as a geothermal fluid used to heat the fluid a binary plant.
- Options should be considered to be able to reuse the equipment at the next site.

FOCUS GROUP F – ENVIRONMENT

Rapporteur: Dennis Van Puyvelde

- Two new research programs are needed to address issues not covered under the present program headings:
    - Social and economic integration
    - Geology.

- New Program – Social and Economic Integration
  - Public perception is very important
  - One needs to identify
    - Key issues
    - Key stakeholders
    - Media strategies, including the terminology.
- New Program – Geology
  - The issues to be addressed under this new program heading were not discussed in detail in the Focus Group but it is clear that there will be a range of issues that will need a rigorous scientific approach.
- Environmental Issues associated with the CO_2 Geothermal Siphon concept are identified as follows:
  - Water use – in the context that water is scarce
  - Physical size of the plant and the impact on alternative land use and visual pollution
  - The environmental impact of the underground infrastructure is unclear and needs to be explored
  - Seismic events, e.g. the Basel experience
  - Production of CO_2
  - Production of water and dissolved materials and their disposal
  - CO_2 transport to the plant site and transmission of electricity
    - Costs
    - Resources for easements for lines and piles
    - Land clearing
  - As already mentioned before, it is important to that no CO_2 is emitted during production nor after the reservoir exploitation is complete
    - One needs to investigate whether the thermal insulation that must be present in a geothermal reservoir offers sufficient sealing.
  - Other natural resources may be co-located with the geothermal resource.
    - Will there be conflicts of interest?
    - Ownership of depleted oil and gas reservoirs?
- Supply of CO_2
  - The geothermal siphon will obtain its CO_2 from burning of fossil fuels. Will this cloud the clean energy credentials of other renewable energy (other forms of geothermal energy in particular)?
  - One needs to ensure that the pursuit of the geothermal siphon concept will not damage the efforts in other industries, e.g. CCS (Carbon Capture and Storage).
  - What purity is required in the CO_2 supply?
    - It costs more to increase the purity.
- Leakage of CO_2
  - The aim must be zero leakage.
- Life Cycle Analysis of carbon (and possibly other elements in the reservoir) needs to be carried out.

The following points were raised by the floor following the presentation by the *Focus Group F*.

- Perceptions must be managed:
  - CO_2 + moisture is an acidic mixture but this only applies during reservoir drying
  - Seismic risks are only present during reservoir stimulation not during operations
- If the association with the CO_2 is managed and explained properly, it can be turned into an advantage.
- If the plant is to claim carbon credits to defray the costs of securing its CO_2 supply, there will be a requirement to prove that the CO_2 is retained permanently.
- There might be opportunities to work with the CO_2 sequestration research community
  - They would have the experience and the tools to monitor possible CO_2 leakages in a field test.
- There may be options to generate power during the transition from a wet reservoir to a dry reservoir, e.g. CO_2 as a geothermal fluid used to heat the fluid a binary plant.
- Options should be considered for reusing the equipment at the next site

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