CSIRO PUBLISHING

SUPPLEMENT | EXTENDED ABSTRACT
https://doi.org/10.1071/AJ22184

The APPEA Journal

Including sub-surface uncertainties in CCS hub investment decision making – a case history

Andrew Garnett[A], Iain Rodger[A] and Joe Lane[A,*]

For full list of author affiliations and declarations see end of paper

*Correspondence to:
Joe Lane
Centre for Natural Gas, The University of Queensland, Brisbane, Australia
Email: joe.lane@uq.edu.au

Accepted: 24 February 2023
Published: 11 May 2023

Cite this:
Garnett A *et al.* (2023)
The APPEA Journal
63(S1), S375–S378. doi:10.1071/AJ22184

ABSTRACT

Large-scale carbon capture and storage (CCS) hub investments require design choices regarding sizing (in Mt-CO_2/year) and project build-out phasing. Investments in capture and transport represent the majority of overall project capex, with the 'size' of that infrastructure ideally optimised to capture and deliver steady rates over the asset lifetime. However, there is a risk that the sub-surface injection (i.e. storage) rate cannot be sustained at the specified capture rate. The investment risk in sizing major capture and transport equipment therefore lies in the uncertainty surrounding future dynamic performance of the storage site(s). This paper builds on a previous investigation for the Surat Basin, examining the role that sub-surface uncertainties play in this hub- sizing risk. Articulating the value of investment in additional appraisal information, shows that the acquisition of critical, uncertainty-defining data can reduce final investment risk in capture and transport, helping to 'right size' the hub build. Screening-stage modelling of technical and economic uncertainty plays a crucial role, characterised with a target unit technical cost (UTC) that represents the life-cycle, constant real-terms, carbon price ($/t) required for storage that would result in a break-even economic development. The presence of pre-development uncertainties in long-term dynamic performance, and the need for appraisal to reduce that uncertainty, effectively increase the required break-even storage price. Alternatively, ignoring that uncertainty could lead to under-performance of the storage resource (inability to sequester at the capture design-rates) and significant over-investment in capture and transport infrastructure, increasing the overall cost of CO_2 sequestration.

Keywords: CCUS, decision, dynamic capacity, hub, injection, investment, probability, risk, storage, success, Surat, uncertainty, value of appraisal.

Introduction – prior study of the Surat Basin storage prospects

Given the uncertainties involved in predicting long-term injectivity and therefore storage site dynamic performance (Lane *et al.* 2021), quantifying the *probability of success* for a defined project size is crucial to understanding storage prospects in screening-stage studies. We define the technical probability of success (TPOS) as the probability that a target sustained rate of injection (Mtpa) can be sustained for 30 years. Economic probability of success (EPOS) is the probability that the 30-year sustained injection rate can be achieved within a given target (or hurdle) unit technical cost (UTC – \$/t-CO_2).

A previous study (Garnett *et al.* 2022) applied those metrics to early storage appraisal work that was undertaken during a CCS hub investigation for the Surat Basin in Queensland, Australia (Garnett *et al.* 2019). That analysis, summarised here in Figs 1, 2, showed how the collection of targeted information can substantially reduce the uncertainties in expected site performance, providing great benefit to storage investors and hub designers. The appraisal work (reflected in Fig. 2) ruled out many of the 'high decline' rates and very low well initial rates that had previously been assumed to be a possibility (Fig. 1). For projects <20 Mtpa, this changed the TPOS relatively little. For larger projects the appraisal reduced the TPOS, identifying there would be greater levels of well interference (in a better, more connected, higher permeability reservoir) and limitations in the maximum allowable well count (due to improved understanding of the reservoir extent). The effect

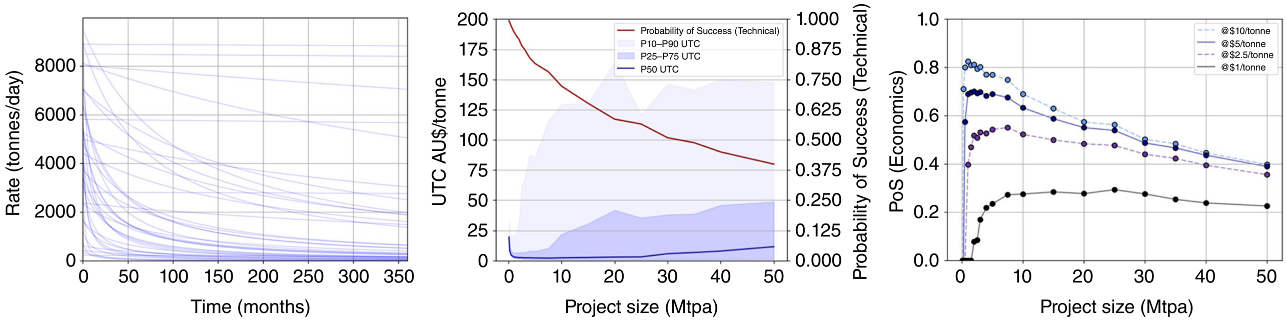

Fig. 1. Pre-appraisal uncertainty analysis for the Surat Basin: (*left*) example ranges of well initial and decline rates; (*centre*) resultant range of full project UTCs and Technical POS (red curve) by target project size; and (*right*) EPOS at specified UTCs for different sustainable injection rates.

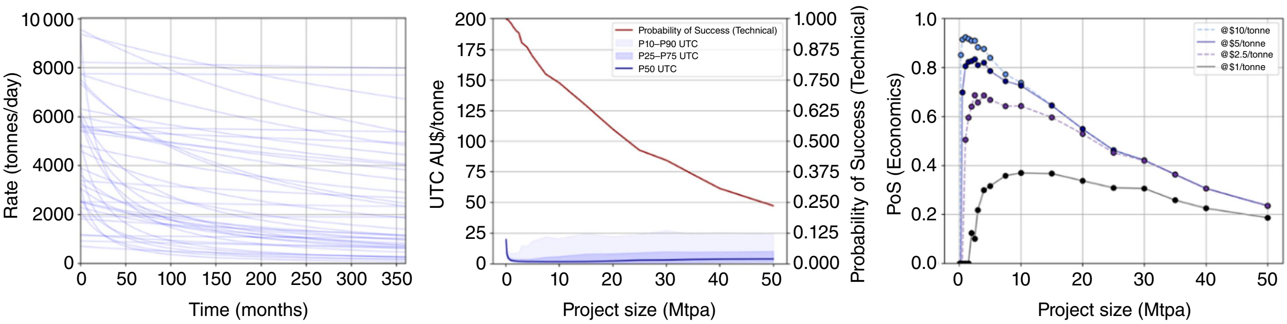

Fig. 2. Re-evaluated uncertainties after the early-stage appraisal that involved reservoir re-conceptualisation and re-interpretation of all dynamic data. (*left*) Re-evaluated spread of initial rate and decline; (*centre*) TPOS and UTC for different project sizes; and (*right*) EPOS at specified UTCs, for different project sizes.

on EPOS was somewhat different. The EPOS improved for smaller sized projects (e.g. for a target 5 Mtpa project, EPOS at UTC = $10/t was around 10% higher), whereas for larger projects (say 15 Mtpa) EPOS was unchanged. In other words, the new appraisal information was insufficient to change our understanding of economic risks for very-large-scale projects.

Addressing the residual geological uncertainties

At completion of that early-stage appraisal work, there remained two key *geological* uncertainties responsible for the suppressed TPOS and EPOS for larger projects – uncertainties which influenced the ranges of well initial rates; and uncertainties in long-term well decline (pressure transient) behaviour – see Garnett *et al.* (2022). Both were related intrinsically to the proximity and representativeness of existing well data around the storage site. Additional, site-specific well test data was needed to improve our understanding of possible well initial and decline behaviours, and reduce the range of associated values included in the economic modelling.

A new appraisal well drilled in 2021 showed permeabilities that were generally higher than had been expected, allowing the range of initial well injectivity estimates to be more tightly constrained in the model. That work did not, however, address the risk of longer-term pressure build-up (and injection decline). Contrasting with Fig. 2, the revised TPOS and EPOS estimates in Fig. 3 show how that additional information improves the understanding of storage risk for investors.

TPOS is generally higher (lower risk) for all project sizes by around 5–10% points. Similarly, EPOS is also improved for all project sizes. For example, for 5 Mtpa at $5/t the EPOS is now almost 90%, increased from 80% (similar magnitude of improvement for a 10 Mtpa project) For a very large project, say 20 Mtpa, the new information increases the EPOS at $10/t to just over 60% compared to around 55% pre-drill.

The value of further appraisal

Significant uncertainties remain for large-scale industrial hub developments, relating to the prospect of pressure build-up and long-term injection rate decline. These uncertainties could be addressed by collecting additional data, for example, through extended well tests that could cost several million dollars. A key question is whether this additional investment in data would be worthwhile. A decision on whether to invest in such new information (appraisal)

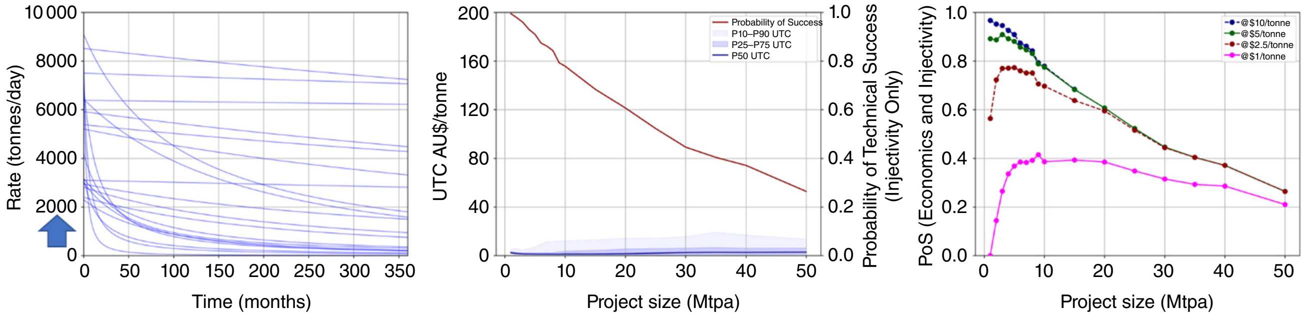

Fig. 3. (*left*) Re-evaluated uncertainties in initial rate after the new 2021 appraisal well; (*centre*) TPOS and UTC for different project sizes; (*right*) EPOS at specified UTCs for different project sizes.

depends therefore on (i) the tolerance of the investor to risk (i.e. of over- or under-investing in capture and transport, or being exposed to effective carbon prices lower than those required for break-even); and (ii) the expected gain or 'value of information' (i.e. the potential impact of new information on the TPOS and EPOS at project sizes relevant to the capture and transport size design choices).

Conceptualising the value of appraisal information

Evaluating the *value of information* (VOI) or *value of appraisal* (VOA) usually requires an assessment of storage development NPV (net present value) *and* an *a-priori* assessment of the likely (conditional) change in probability of success (ΔPOS) that would arise from a specific appraisal program. Rather than using NPV, we can instead set decision 'hurdle rates' based on a *tolerable* storage development UTC. While the whole-of-hub, break-even price would be much larger than the storage development UTC, the latter is useful for assessing the value of appraisal information gathering.

Defining unit appraisal cost (UAC) as Appraisal Costs/PV (injection), and a discounted, real-terms unit price earned, RTUPE, as PV(revenue)/PV(injection): the appraisal investment can be justified if:

$$\{\mathrm{RTUPE} - \mathrm{UTC}\} \times \Delta\mathrm{POS} > \mathrm{UAC} \tag{1}$$

So, investment is justified if the (likely) change in POS after appraisal would be:

$$\Delta\mathrm{POS} > \frac{\mathrm{UAC}}{\{\mathrm{RTUPE} - \mathrm{UTC}\}} \tag{2}$$

Or, appraisal is justified if proponents are confident that carbon price earned is higher than the storage-only break-even, UTC:

$$\mathrm{RTUPE} > \frac{\mathrm{UAC}}{\Delta\mathrm{POS}} + \mathrm{UTC} \tag{3}$$

The need to put appraisal investment 'at risk' has the impact of increasing the required future 'carbon price' to achieve *risked*, break-even conditions. Estimating changes in TPOS and/or commerciality considerations (i.e. likely carbon prices earned in terms of an appraisal margin above UTC) can inform discussions on prospective appraisal spend. From a detailed VOI-VOA analysis, four decision outcomes are possible:

(1) to appraise and increase POS, especially for larger projects;
(2) to develop the full hub;
(3) to 'walk away'; or
(4) to develop increasing sizes in a phased way.

The final option could be taken in circumstances where appraisal tests need to be so large, or would take so long, that phased development is the optimal risk reduction approach. In this case, information from early (lower rate, but higher pre-appraisal POS) phases would be used to inform POS for larger-scale development.

While the *a-priori* estimates of ΔPOS and appraisal costs are relatively easy to explore, the main sensitivity to appraisal investment is the developer's view of future carbon prices and their risk-tolerance, as indicated by their judgement of the likely appraisal margin (RTUPE − UTC) that can be earned.

It is important to note that VOI and VOA are understated in this method as they do not evaluate the benefit of reducing risk of over-spend in the capture and transport elements of the project (i.e. where the designed steady capture and transport rate exceeds the sustainable storage/injection rate).

References

Garnett AJ, Underschultz J, Ashworth P (2019) Scoping study for material carbon abatement via carbon capture and storage. Project Report. The University of Queensland Surat Deep Aquifer Appraisal Project. (The University of Queensland) Available at https://espace.library.uq.edu.au/view/UQ:734606

Garnett AJ, Rodger I, Lane JL, Hurter S (2022) Basis of design for CCS Hubs - the importance of uncertainties in dynamic storage capacity. In 'Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16)', Lyon, France, 23–27 October 2022. Available at http://dx.doi.org/10.2139/ssrn.4286100

Lane J, Greig C, Garnett A (2021) Uncertain storage prospects create a conundrum for carbon capture and storage ambitions. *Nature Climate Change* **11**(11), 925–936. doi:10.1038/s41558-021-01175-7

Data availability. The synthetic data used in this study will be shared upon reasonable request to the corresponding author.

Conflicts of interest. The authors confirm that there are no conflicts of interest.

Declaration of funding. No funding from external organisations was received for this research.

Acknowledgements. This study built on results from The University of Queensland Surat Deep Aquifer Appraisal Project, a 3-year, AUD 5.5 million project funded by the Australian Government through the Carbon Capture and Storage Research and Development and Demonstration (CCS RD&D) program, by Coal21/LETA, and The University of Queensland. Software for that project was provided by CMG Ltd, Geoteric, IHS Markit, Rock Flow Dynamics and Schlumberger. The following organisations provided additional dynamic data, technical advice and support, Santos, QGC/Shell, APLNG/Origin, Bridgeport, Armour Energy and CTSCo. Vektor Dewanto assisted with the graphs in this paper.

Author affiliation
[A]Centre for Natural Gas, The University of Queensland, Brisbane, Australia.

The authors

Professor Andrew Garnett is Director of the UQ Centre for Natural Gas, leading a large multidisciplinary research program spanning social and environmental impact, cost and supply optimisation, with a particular focus on the Queensland industry. He has more than 30 years' international experience within multinational companies across conventional and unconventional hydrocarbon projects. Prior to joining UQ, he led the ZeroGen carbon capture and storage (CCS) project. As Director of the UQ CCS Program, he led a 3-year study identifying strategies to make material emissions cuts in Queensland as well as to enable low carbon baseload power, deliver significant benefits for regional employment and stimulate the hydrogen economy. Prof Garnett makes regular contributions to the policy and planning processes for the global transition to a low emissions economy; including as a reviewer for the International Energy Agency's '*World Energy Outlook (Natural Gas)*' and '*Energy Technology Perspectives*' products.

Iain Rodger is a Petroleum Engineer currently working for the Centre for Natural Gas at UQ. His work is focused on reservoir simulation; in particular, his research is related to unconventionals and Carbon Capture and Storage projects. Iain graduated from the University of Edinburgh with a BSc (Honours) in Chemistry with Environmental Chemistry, before completing an MSc in Petroleum Engineering at UQ.

Joe Lane has been working in the research sector for 16 years, focusing on major change in Australia's water, food and energy systems. He has contributed to the startup of major initiatives on energy transition challenges (global, India, Australia), now with the UQ Centre for Natural Gas. Joe's earlier career as a Process Engineer was followed by research and policy implementation roles in the Queensland water resources sector. Over the last 5 years, he has worked with experts in CO_2 geo-sequestration, to explore the broader challenges posed by the uncertainties involved in the storage development process. He leads the Centre's investigations into energy transition implications for the electricity sector, and for the role of carbon offsets.