The Curtin University Oil and Gas Innovation Centre Well Decommissioning Research Strategy 2018 - 2023

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Summary

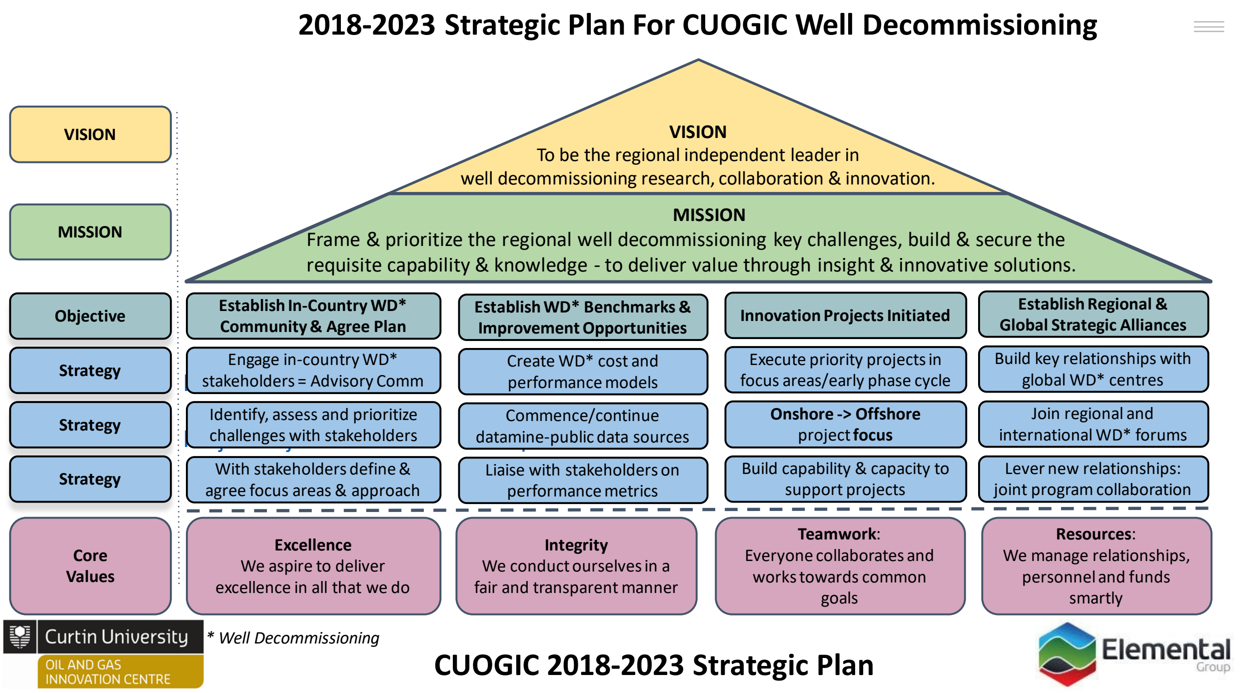
This report proposes a strategy for the Curtin University Oil and Gas Innovation Centre (CUOGIC) to be the regional independent leader in well decommissioning research, collaboration and innovation. The strategy has been developed based on a review and assessment of well decommissioning practice, standards and regulatory guidelines to determining both the current challenges and potential innovation opportunities.

In summary the key well decommissioning challenges in the Australian context are:

- Limited quantification and sharing of well decommissioning cost and risk data within the oil and gas industry; restricts the understanding of the key drivers, hinders the comparison with international best practice and prevents the establishment of a cost and risk metrics and forecasts - hence identification of improvement opportunities.
- Uncertainty of well and completion condition data, at end of field life, impacts well decommissioning program – what improvements can be made if the risk was better defined and quantified?
- Wells which were plugged, abandoned and handed back to the Government some time ago, using technology and practices of the day – what are their long term integrity risks and what uncertainties need to be resolved?
- How do the regional approaches to risk management differ, have they been objectively quantified and compared to determine what is "better" – establish best practice and assess what approaches are best for the Australian context.
- Last 3 year reduction in oil and gas prices (revenue), along with an increase in volatility, has placed numerous producing assets under financial stress. Neither the Operator nor the Government wish to accelerate cessation of production – need innovation from all areas of cost/risk/fiscal to maximise value of the existing asset
- How can innovation opportunities (i.e. new materials, P&A methods, risk assessment techniques, new standards) be efficiently and safely implemented?

In consideration of the above challenges a total of six major innovation focus areas, or "innovation channels", have been identified with a selection of topics within each. These channels include: 1) legal, commercial and cost, 2) knowledge and risk, 3) environment and subsurface, 4) well decommissioning design, performance and operations, 5) techniques and tooling and 6) materials. A range of technologies have also been identified which could be applied to each of the channels and at the various phases of a well decommissioning program. The details of these are captured in Section 4 along with a technology guide providing 23 items, their qualitative relative value and prioritisation over the next 5+ years (see Figure 5.3).

While this is an important first step and provides a basis to initiate research activity in support of CUOGIC's vision; key stakeholders have not been engaged, potential opportunities have not been fully assessed and ranked nor has the preferred execution methodology been defined and collaboration partners selected. This all needs to be addressed by an appropriate plan, to frame and prioritize the regional well decommissioning key challenges, build and secure the requisite capability and knowledge – to deliver value.



There are four primary objectives proposed in the 2018 to 2023 strategic plan. They are:

1. Establish in-country well decommissioning community & agree plan
2. Establish well decommission benchmarks and improvement opportunities
3. Initiate and deliver innovation projects
4. Establish regional and global strategic alliances

The success of this strategy hinges on the ability to achieve three outcomes:

- Build strategic alliances across several areas of the well decommissioning industry that align with the strategy.
- Resource CUOGIC with personnel, and establish the collaboration partnerships such as WAERA's research parties, that are capable of executing the strategy, and
- Executing and achieving the objectives set out in the strategy.

The key activities for the roll out and execution of CUOGIC's Well Decommissioning strategy over the next 12 months are expected to be as follows:

1. **Network engagement - establish a well decommissioning advisory committee**

Identify and engage "broad network" of organisations and people to solicit ideas, challenges, opportunities and preparedness to join a well decommissioning advisory committee. Most of the stakeholders that CUOGIC will interface with are external to the academic environment. To guide CUOGIC along the journey and assist achieving the outcomes an advisory committee of selected representatives from industry and regulators will be put in place. The advisory committee will assist in balancing academic and industry objectives with commercial realities. A terms of reference has been written for this advisory committee and the target is to have the advisory team in place by Q1 2019.

2. **Opportunity framing and programme planning**

Assess, rank and select opportunities following "broad network" engagement. Create draft "plan to a page" for priority projects (i.e. 2 off projects addressing strategic objectives 2 and 3) along with a 2 year research opportunity road map. Update the well decommissioning strategy if required.

3. **Industry based projects identified, defined, resourced & initiated**

Formal opportunity discussions with industry representatives from priority projects and develop formal proposals. Programme kick-off following technical and commercial clarifications.

Preface

In March 2017 Curtin University established the Curtin University Oil and Gas Innovation Centre (CUOGIC) for technology research. Its objectives are:

- Be the 'shop front' for the industry to do demand-driven research with Curtin and partners
- The Centre operates and works across faculties (Science and Engineering; Business and Law) and associated departmental disciplines
- The Centre brings multi-disciplinary research and development expertise to the oil and gas industry technology challenges. It is the LINK that creates and enhances collaboration.
- The Centre will be the engine to grow Curtin University's capability and expertise in key areas in collaboration with industry and external research partners

At the Curtin University Oil and Gas Innovation Centre, a priority is to play a pivotal role in the dynamic oil and gas well decommissioning space by assisting the fossil fuel industry in Australia and in the Asia Pacific regional to improve their well decommissioning cost and execution performance. The Centre is focussing on delivering world class abandonment and well decommissioning research, education, disseminating information and ideas across this spectrum of well types and geographic landscape and stakeholders. Our focus is to increase the level of collaboration between industry, regulators and universities to reduce costs by integration of best practice and leveraging collaborative results and sharing focused studies and research.

Within the oil and gas project decommissioning process, innovation has been recognised by National Energy Research Association (NERA, 2016) as being an important component. It is to be encouraged, integrated and implemented into the project management life cycle of well abandonment. NERA (2016) concluded that Australia has significant room for improvement to even reach median performance on a global basis let alone become world class at well abandonment.

In 2018 CUOGIC commissioned with financial support of WAERA the Elemental Group to review and assess well decommissioning practice, technology developments, standards and regulatory guidelines, identify the current challenges and opportunities and propose a strategy to deliver high value decommissioning research and innovation for the region.

We have the unique opportunity to distil and disseminate the major lessons in well decommissioning through our relationships with professional organisations and leading research houses in the EU as well as the USA. The creation of professional relationships and research opportunities with professional bodies, academia and well decommissioning operators within the Asia-Pacific and Australasian region is a priority. Many of these groups provide engineering and manpower support and advisory services to Middle Eastern and Australasian operations.

Purpose and structure of this report

The purpose of this report is to review and assess well decommissioning practice, standards and regulatory guidelines, determine the current challenges and opportunities and propose a strategy for the Curtin University Oil and Gas Innovation Centre to collaboratively deliver high value decommissioning research and innovation for the region.

The report has three parts. The first, provides an overview of industry well plug and abandonment challenges, practices and technologies, terminologies, standards, risks and costs. The second part focusses on technology and innovative solutions which are conceptually proposed. These are categorised into six well decommissioning focus areas, or “innovation channels”, along with a range of potential project topics. The third and final section of the report defines a 5 year strategic plan and technology guide, engaging with key industry and agency stakeholders, to deliver the value adding insights and innovative solutions for the next 5+ years.

1 The Well Decommissioning Challenge

Understanding and quantifying the magnitude of well decommissioning work scope on a global scale is challenging. Even if the number of wells to be decommissioned are understood, the scope variability, combined with end of field life uncertainty, can make cost forecasting difficult.

Production facility 'life extension' and well lifecycle management, along with varying legislation models and changes in asset ownership, contribute to 'end of field life' uncertainty. There are a number of publications available (e.g. Oil and Gas Authority (2018), Oil and Gas UK (2015-2017)) which not only provide cost forecasts for the total decommissioning liability by region, but also the relative contribution of wells to that overall liability. The basis and transparency of this cost data is however not easy to determine.

In the United Kingdom continental shelf (UKCS), it is forecast that, between 2017 and 2025, 349 fields will be decommissioned resulting in activity on 200 platforms resulting in approximately 2500 wells being plugged and abandoned (Oil And Gas Authority (2018)). The current value of this well decommissioning work, at 49% of the overall decommissioning budget, is 8.3B GBP (~14.8B AUD). The estimated by well average platform well plug and abandon cost is 3.8M GBP (6.8M AUD) and the estimated value of a subsea well plug and abandonment is 9.7M GBP (9.7M AUD). These estimated prices are 5% less than equivalent Class 4 or Class 5 estimates the previous year.

In the United States Gulf of Mexico, over 100 platforms are planned to be removed per year. It is estimated platform well plug and abandonment operations are in the order of 150K USD (210K AUD) and plug and abandonment of deep water (>400 ft water depth) subsea wells is in the order of 21M USD (29.4M AUD).

Over the next 50 years Australia is expected to have a well decommissioning liability of 20B to 25B USD of an estimated 50B USD total oilfield decommissioning liability (Wood Mackenzie, 2016). In simple terms, this is a massive CAPEX outlay by operating companies with no Return On Investment (ROI). More broadly, in Asia Pacific region, more than 380 fields are expected to cease production in the next decade. (Wood Mackenzie 2018). There are nearly 2,600 platforms and 35,000 wells with a well decommissioning proportional cost of 50B USD.

Australia is a diverse and comparatively small geo-market on the global well decommissioning map. The market covers the spectrum of high cost high rate subsea gas wells to low cost low rate onshore coal seam gas (CSG) wells. NERA (2016) benchmarked Australia below the median percentile in decommissioning competency within the international community. Recent well decommissioning projects demonstrate considerable improvement in our decommissioning competency however this may not be attributable across the board.

Australia is also a proportionally more expensive sector of the global decommissioning market. As stated by NERA (2016) Australia's high average cost (greater than the mean) per BOE for decommissioning is attributed to higher rates and complex offshore wells in platform and subsea conditions. These statistics contrast strongly with the lower cost and higher number of 6000+ coal seam gas wells (Queensland Department of Natural Resources and Mining, 2018) that are currently supplying LNG feedstock on the east coast of Australia and will require abandonment in the near future.

Relative to the UKCS and GOM decommissioning activity; Australia and Asia historically have experienced only minor levels of activity. However, the forecast volume of work to be undertaken, and the value of this work, over the next ten years is significant. This is primarily due to the traditional oil and gas fields nearing or exceeding their original 25 year design life and our more recent expansion and maturation of the CSG industry. This significant increase in well decommissioning demand warrants focused attention on a number of work fronts at CUOGIC.

Acknowledged leaders in the area of well abandonment are Norway and UK. These two countries are on the leading edge of well abandonment thinking, regulation and project execution. Much of the innovation and leadership development is driven by government acknowledging the magnitude of the challenge and exploring changes to fiscal policy and regulation. The foundation of many years of structured industry focus on oil and gas principles and process safety is evident in the application of principles and guidelines generated by United Kingdom Oil & Gas (UKOG) and Standards Norway who administer the NORSOK standards.

The NORSOK standards have been developed, and are implemented, by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations. In the pursuit of common frameworks between companies, the NORSOK standards, such as NORSOK D10, are intended to replace oil company specifications.

In Australia adoption of UKOG and NORSOK standards is evident and besides being accepted as good practice, may also be in response to the regulatory environment moving from a historically prescriptive style of legislative framework (thou shalt) to an ALARP (As Low As Reasonably Practicable) risk management environment that is premised on 'prove what you have done and how you manage risk'. Through our academic and professional connections, CUOGIC is well positioned to consolidate and strategically leverage existing relationships with these European Union and UK leaders.

There is also the acknowledgement of a maturing risk awareness and increased engagement by regulators, operators and contractors alike with European and American counterparts. This is supported by the raft of legislative updates at both a state and federal level in the last 3 years that address risk management, field decommissioning and specifically well decommissioning.

The Department of Industry, Innovation and Science (2018) has recently tabled a discussion paper reviewing the framework for decommissioning offshore petroleum infrastructure in Commonwealth waters. The purpose of the paper is to ensure the Commonwealth framework is fit for purpose for the anticipated increase in decommissioning activity. The review focusses primarily on environmental and well integrity outcomes and regulatory oversight. Within the discussion paper there is a focus on legal and financial responsibility along with post title compliance and enforcement. These topics are very much associated with well decommissioning programs and the obligations following title relinquishment.

The range of technical challenges, regulatory challenges and cost/risk challenges for oil and gas operations provides opportunities for CUOGIC to assist industry reduce costs across the major geologic basins of Australia. A benefit of industry collaboration is being able to contribute to conversations regarding public perception and the Social License to Operate (SLO).

2 The Basics

To appreciate the simplicity and contrasting complexity of well decommissioning, it is important to first understand the foundations and fundamentals of oil and gas field development and well construction. Grasping the foundation concepts of oil and gas field development contextualises the well life cycle processes and specifically end of well life decommissioning processes incorporating the engineering and execution practices.

The resulting body of knowledge can then be analysed to uncover the myriad of opportunities for education, performance and technological improvement.

2a **Oil and Gas Field Development**

A commercially successful oil and gas field development life cycle has the following development phases:

- Exploration
- Appraisal,
- Development and then
- Decommissioning

Exploration well drilling activities involve drilling oil and/or gas wells where the probability of intersecting a commercially viable hydrocarbon resource is low or the presence of hydrocarbons is not fully understood. Exploration wells have a typical probability of commercial success of less than 10%. If the well is deemed not to be commercial and no other use can be applied to the well, then the well is often permanently decommissioned or 'plugged and abandoned' while the drilling rig is 'on location'. In the situation when the well does intersect hydrocarbons and is deemed 'successful', or classed as a 'discovery', the surface location, reservoir intersection or the well design are sufficient to allow repurposing the exploration well into an appraisal or production well. In this case the well maybe temporarily secured or 'suspended' and left in this condition for some period of time until re-entered during appraisal or development activities or decommissioned.

Appraisal well activities involve drilling wells to determine the areal extent of the hydrocarbon discovery and to better understand reservoir properties and/or production behaviour. Oftentimes, appraisal wells are designed and located so that if they are successful, they can be repurposed at a later date into a 'production' well. In this case, the well maybe temporarily secured or 'suspended' at the end of appraisal drilling and left in this condition for some period of time until re-entered during development activities or decommissioned.

Development well activities involve drilling and completing wells to efficiently and effectively recover hydrocarbons. These wells often have optimal surface location, a wellhead, Xmas tree and appropriate casing scheme designed for production and completion activities and a trajectory that optimises hydrocarbon recovery in accordance with the geological model. Depending on the reservoir properties and the field development plan, the wells maybe designed for production, injection or disposal purposes (Figure 2.1).

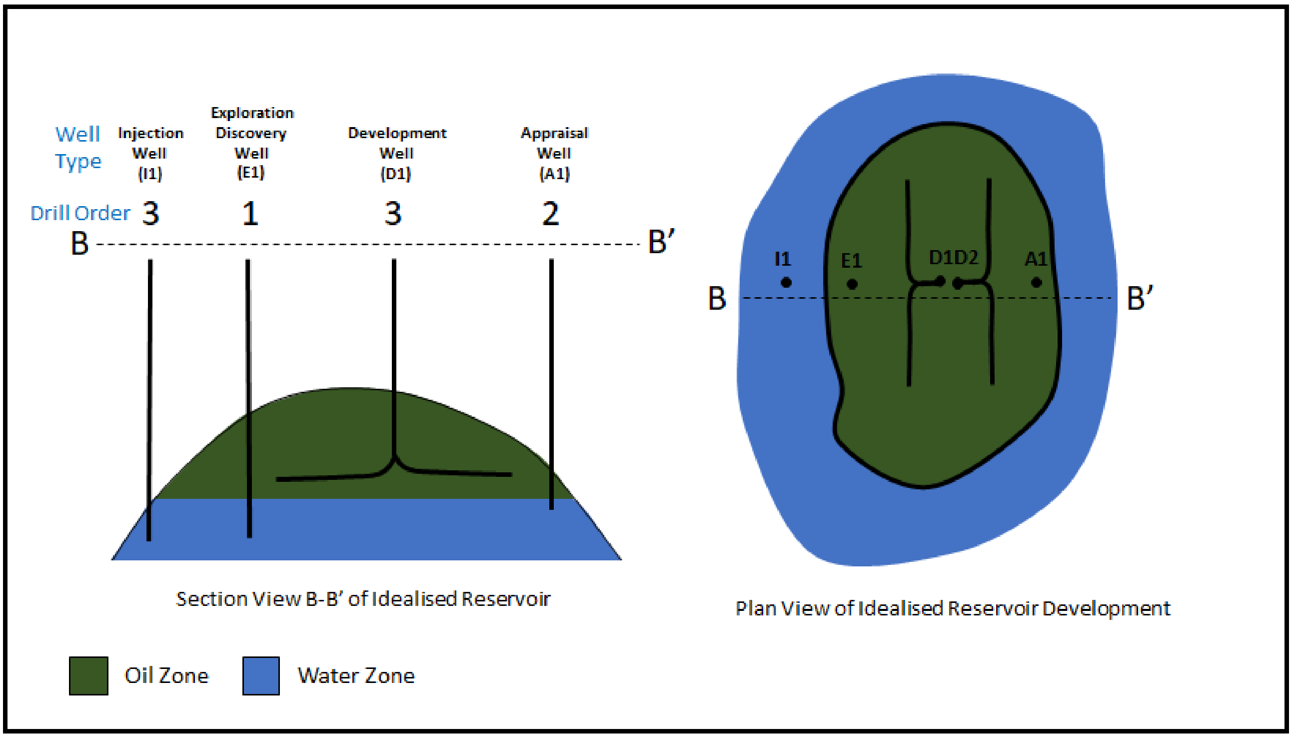


Figure 2.1. Execution sequence of each well major type for successful exploration, appraisal and development of an oil field. Section B-B' illustrates possible geometric and chronologic relationship between well types across the field.

A field development framework and cradle to grave field development life cycle, follows an idealised and 'gated' process flow that may consist of 5 or 6 phases depending on the organisation. The phases may not be sequential so the Project Management Body of Knowledge (PMBOK, 2013) refers to each of the 'phases' as a group. Decommissioning is the final phase or group in field development life cycle.

In project management, the phases are commonly referred to as:

- Initiating,
- Planning,
- Execution,
- Monitoring, and
- Controlling and Closing.

Operating companies may also refer to these phases or groups as Assess, Select, Design, Execute, Operate and Decommission or use equivalent terminology.

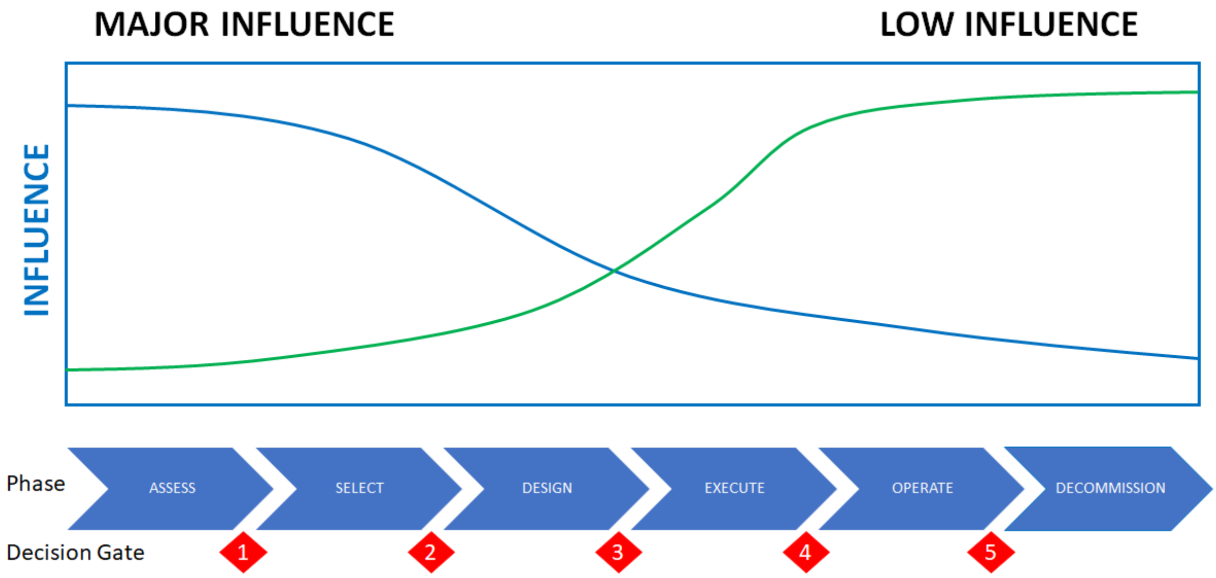


Figure 2.2 Conceptual project management flow in oilfield development showing the main elements and the concept of timing of design/technical/commercial influence and project expenditure.

These phases or groups are illustrated in Figure 2.3 and are defined as follows:

<u>Assess phase:</u> involves establishing whether a candidate project or opportunity has sufficient technical and commercial merit to move through the gate for further study.

<u>Select phase:</u> involves generating and reviewing potential field layouts, well design concepts and production profiles based on these concepts. These concepts are economically reviewed and a costed and technically and commercially robust design is selected and proposed as the field development concept.

Design phase: involves undertaking FEED (Front End Engineering and Design), sometimes referred to as Front End Loading (FEL) to provide the basis for a detailed cost estimate and Authorisation For Expenditure (AFE) and final economic review in preparation for Final Investment Decision (FID). The Field Development Plan and Environmental Plan may also be submitted to the appropriate authorities during this phase.

Execute phase: is the period after FID and the final detailed engineering and cost estimation is undertaken. Contracts for materials are let and activity programs are generated and approved by the relevant authorities. Facility construction and well construction occur and are prepared and documented for handover at the decision gate to Operations phase personnel.

Operate phase: involves receipt of the facilities, including wells, by the operating team. The facilities are started up and maintained during this phase.

Decommission phase: involves cessation of production and decommissioning of facilities, including wells. Stakeholders are engaged and documentation is prepared and submitted to the appropriate regulators and decommissioning activities are undertaken. This may or may not include well decommissioning, pipeline removal, facilities removal depending on the scope of the approved documentation.

	COMMON PROJECT PHASES OR GROUPS					
Common Oilfield Terminology	Assess	Select	Design	Execute	Operate	Decommission
Common Oilfield Development Duration	Exploration		Production (15 to 30 yrs)			
	Discover and Evaluate < --- 5 to 10 yrs --- >		Develop < --- 1 to 5 yrs --- >		Operate /Produce < --- 15 to 30 yrs --- >	Decommission 1 to 5 yrs
PMBOK Terminology	Initiate	Plan	Execute		Monitor and Control	Close

Figure 2.3 Conceptual project management flow in oilfield development showing the main elements and the relationship with traditional PMBOK project management terminology.

2b Well Life Cycle?

The cradle to grave life cycle of a well has a process management flow that often aligns with the field development framework. Decommissioning is the final phase in the well life cycle and represented by the specific activity referred to as well abandonment (See Table 2.1).

In some cases the well's purpose might be modified during its life cycle. For example, an exploration well might be suspended and not abandoned as it needs to be repurposed into a production well. This may lead to a very significant time hiatus between suspension of the exploration well in the execution phase and abandoning the well in the decommissioning phase. This time period or 'operational hiatus' may add additional risk to the well integrity as the probability and consequence of time sensitive hazards, such as corrosion or wellhead snagging, may increase with the duration of the hiatus or well inactivity period.

Table 2.1. Stages of field development and project phases undertaken during a well life cycle for wells constructed in each field development stage.

PURPOSE	ASSESS	SELECT	DESIGN	EXECUTE	OPERATE	DECOMMISSION
Exploration Wells	**Project Feasibility**	**Concept Select**	**Detailed Design**	**Construct**	-	**Abandon**
Appraisal Wells	**Project Feasibility**	**Concept Select**	**Detailed Design**	**Construct**	-	**Abandon**
Development Wells • Production • Injector • water, gas, steam **Disposal wells** • water, solids, CO2	**Project Feasibility**	**Concept Select**	**Detailed Design**	**Construct** **Complete**	**Commission** **Produce** **Workover** **Suspend**	**Abandon**

With the continued push to accelerate development of hydrocarbon discoveries, in simpler, cheaper and faster ways, the boundary between the phases is frequently blurred in a technical sense but remains quite clear from a financial point of view because of the use of "decision gates". In the case of producing wells its operational history is a lot more complicated than that of an appraisal or exploration well. This history is often reflected in the lower cost and time to decommission an appraisal or exploration well versus a long term producing development well.

2c Major Well Categories

Classification of wells into categories can become complicated, much like a taxonomy. However, for the purposes of well decommissioning three major groups will apply (Figure 2.4). The first group is onshore wells and including unconventional or shale gas wells. The second group is offshore wells and this covers subsea wells as well as platform wells, which often have similar characteristics as onshore wells no matter what the water depth. The third group is comprised of Coal Seam Gas (CSG) or Coal Bed Methane (CBM) wells. The common properties of these well groups are presented in Table 2.2.

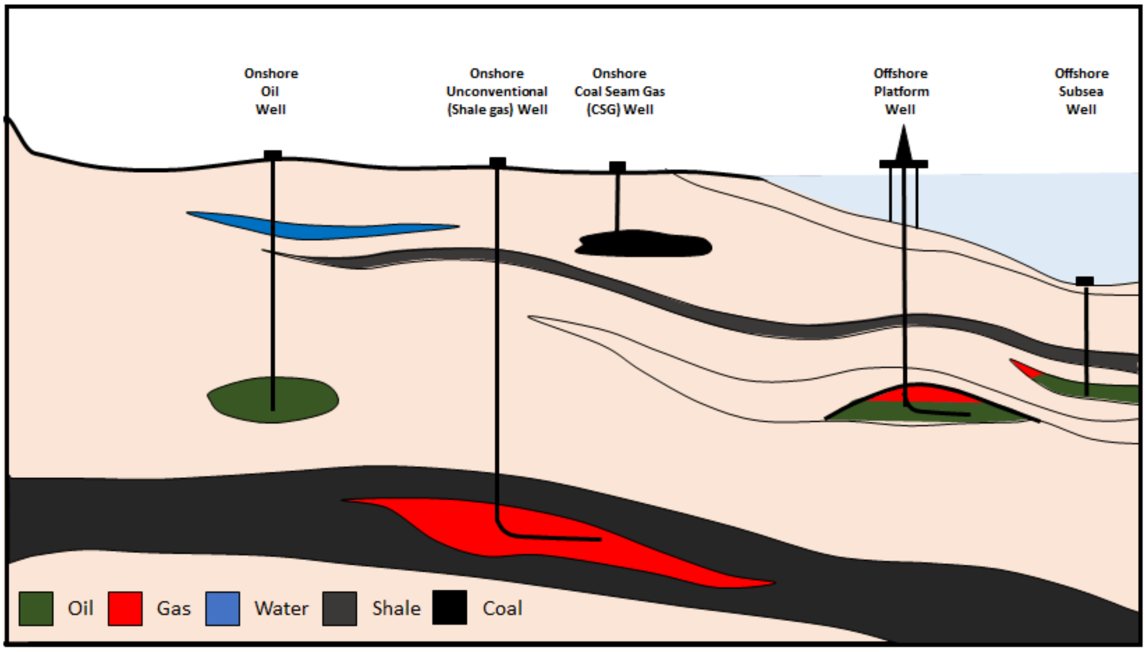


Figure 2.4 Illustration showing thematic and spatial relationships between different well types.

Table 2.2. Each well type can be loosely grouped on the basis of major well engineering and construction elements. This simplified approach amplifies the potential commonality of problems and their solutions across the well types independent of well location.

	ONSHORE			**OFFSHORE**	
	COAL SEAM GAS	**UNCONVENTIONAL**	**CONVENTIONAL**	**PLATFORM**	**SUBSEA**
Location	onshore coal field	onshore	onshore	offshore marine	offshore marine
Total Vertical Depth (TVD)	100's to 1000+m	1000m+	1000m+	1000m+	
Trajectory	Vertical, Deviated, Horizontal	Vertical, Deviated, Horizontal, ERD	Vertical, Deviated, Horizontal, ERD	Vertical, Deviated, Horizontal, ERD	Vertical, Deviated, Horizontal, ERD
Reservoir Pressure	Low	normal to overpressure	normal to overpressure	normal to overpressure	normal to overpressure
Reservoir Temperature	Low	normal to high	normal to high	normal to high	normal to high
Reservoir Productivity	Low	Low	normal to high	normal to high	normal to high
Wellhead Pressure	Low	Med	Med	Med	High
Xmas Tree Complexity	Low	Med	Med	Med	High
Site Access Risk	Low	Med	Med	High	V High

2d Well Decommissioning Cost Estimation

Estimating well decommissioning costs and communicating this information to stakeholders is a key requirement on all field decommissioning projects. Well decommissioning comprises 40 to 50% of field decommissioning costs (McKenzie, 2016) and there is continued focus on cost reduction and cost management throughout the project no matter what the phase of the project.

Table 2.3 defines the cost estimating basis typically applied to specific well decommissioning phases in accordance with recognised guidelines linking the reduction of cost uncertainty as a function of estimate maturity. Of particular importance are the following:

- Understanding the source of the numbers being provided.
- Understanding the risk profile that has been included and costed
- Understanding what has been exempted or omitted from the cost estimate, and
- Variance analysis from previous estimates

Table 2.3 Well decommissioning phase cost estimate basis using OGUK (2015), UKCS (2018) & AACE (2015). AACE apply 5 levels of estimate classification. 4 levels are applied here (see AFE Class).

	Assess	Select	Design	Execute
Well Decommissioning Classification	Grouped (lumped) into broad Categories	Split into granular Categories	Details Understood	Details Understood
Data / Well Reviews	10 to 25%	100%	100%	100%
Activity Duration Basis	Regional / International Benchmarks x Scaling Factors	Some optimisation of time estimate on a category basis x Scaling Factors	Detailed understanding of time estimates on a per well basis	Detailed time estimate on a per well basis
AFE Class	1	2	3	4
Accuracy	-30% to +50%	-15% to +30%	-5% to +15%	-5% to +5%
Cost Basis	Regional / International Benchmarks x Scaling Factors	Estimates x Scaling Factors	Contract Pricing	Contract Pricing
Mobilisation / demobilisation / Allowances	Company estimating procedures	Company estimating procedures and risk assessments	Contracts and quotations	Contracts
Activity Allowances	Company estimating procedures	Company estimating procedures and risk assessments	Engineering estimates	Engineering estimates
Contingency Basis	As per estimating procedures	As per estimating procedures and risk assessments	Modelled risk assessment results	Modelled risk assessment results

The majority of cost elements in well decommissioning are time based and generation of the estimate is commonly an integrated exercise between the cost estimating function and the well engineering function. To create a time-based well decommissioning cost model, there are four elements to understand:

- Time based duration,
- Time based cost base,
- Non-time based costs, and
- Risk and contingency expectations.

Each cost estimate break down (i.e. sometimes referred to building blocks or work breakdown structure – WBS) is often unique to the company, the cost estimating function and engineering functions that creates the estimate. Each estimate typically includes the generic elements in Table 2.5. Irrespective of the well decommissioning project the cost blocks, for each of the main well categories, are very similar. For example the main change from CSG wells through to high rate subsea gas wells is the value of each cost block.

By way of illustration, in Oil and Gas UK 2018 Cost Estimate report (Oil and Gas Authority 2018), the approximate P50 value for subsea well decommissioning (plug and abandon) costs is ~GBP 14M versus P10 of ~GBP M and P90 of ~GBP 45M. This contrasts significantly with platform plug and abandon costs of P10, P50 and P90 of ~GBP 0.5M, GBP 1.2M and GBP 4M respectively. This validates the concept of the potential differences in outcomes when budgeting for decommissioning the different well types. On a risk versus cost basis the three wells types of CSG, onshore and subsea wells could plot as illustrated in Table 2.4.

Table 2.4. Perceived risk / cost versus well complexity for different well types.

	RISK / COST SEVERITY			
	LOW	MODERATE	HIGH	HIGHER
WELL COMPLEXITY - HIGH		Platform Wells	Platform Wells	Subsea Wells
WELL COMPLEXITY - MEDIUM	Onshore Wells	Onshore Wells	Platform Wells	Subsea Wells
WELL COMPLEXITY - LOW	CSG Wells	Onshore Wells		

Table 2.5. Common cost elements of most common well decommissioning cost estimates.

CATEGORY	SUB-CATEGORY	NOTES	CSG	ONSHORE	PLATFORM	SUBSEA
TIME-BASED COSTS			x - most likely included p - possibly included			
Supervision		Company supervision (maybe contracted out)	X	X	X	X
Drilling Rig Day Rate	Day Rate and extra time based costs	Rig, rig crew and additional crew	X	X	X	X
Third Party						
	Drilling/completions fluids and data logging services	Mud logging and drilling and completion fluids services.	P	X	X	X
	Cementing and Pumping Services	Pumping cement and pressure testing well barrier integrity	P	X	X	X
	Wireline Services	Electric line & slickline services for well barrier integrity verification and/or specialist tools	P	X	X	X
	Milling and fishing Services	Milling casing and recovering damaged tooling or wellbore equipment to surface	P	X	X	X
	Diving ROV	Subsea ROV equipment and specialist recovery equipment and personnel				X
	Directional Drilling, MWD and surveying	Specialist equipment and personnel dependent on well activity plan.	P	P	P	P
	Well testing / flowback services	Equipment & personnel to manage returned hydrocarbons	P	P	P	X
	Completions and Workover Services	Personnel & equipment to recover completion and equipment	P	X	X	X
	Solids Control and Waste Management	Manage and process waste returned to surface as necessary	X	X	X	X
	OEM services (XT, wellhead, completion equipment etc.)	Personnel and handling equipment to access wellbore and ensure integrity of OEM equipment such as Xmas tree, etc during well operations.	P	X	X	X
	Casing Running/Recovery Services	Personnel to recover tubing and casing and re-run as necessary (maybe rig service)	P	P	P	P
Freight and Transport	Road, marine, helicopter, air (RMHA)	Transport charges for road, marine and air transport activities.	P-R	P-RA	X (RMHA)	X (RMHA)
Supply Base / Support Warehousing	Marine, post charges, land	Charges for supply base and equipment consolidation and handling	X	X	X	X
NON-TIME BASED COSTS						
Mobilisation / Demobilisation		One off costs for mobilisation of specialist equipment, rig etc to/from location.	P	X	X	X
Site Survey		Site survey costs	P	P	P	P
Civil Works		Site preparation costs	P	P		
Regulatory Compliance		Regulator documentation and submission costs	X	X	X	X
Third Party						
	Wireline / Slickline	Run / Activity Charges	P	X	X	X
	Tubular Running Services	Run / Activity Charges	P	P	P	P
	Inspection	Inspections of equipment and services prior, during and post activities	X	X	X	X
	OEM equipment and specialist tooling	Specialist tooling and run charges for OEM equipment.	P	X	X	X
	Drilling / Completion Fluids		X	X	X	X
	Cement and additives (or equivalent services)	Well Barrier Components installed into well	X	X	X	X
	Fuel	Rig, vessel and third party generator/compressor fuel usage	X	X	X	X
ALLOWANCES						
Equipment Upgrade		Allowance for activity specific upgrades to equipment.	P	P	P	P
Activity Efficiency Uplift		Adjustment for extra risk of activities not going as planned.	P	P	P	P
Weather	Seasonal weather, cyclone impacting operations	Impact of weather on planned activities	P	P	P	X
Foreign Exchange		Projected FX variation over life of estimate and/or project.	P	P	P	P
SUBTOTAL						
CONTINGENCY		% Contingency in line with Estimate Class	X	X	X	X
TOTAL						

3 Insights

3a How Do You Decommission a Well, Issues and Opportunities?

The process and ultimate outcome of well abandonment is to safely and securely reconstruct the well barrier envelopes equivalent to the natural formation to reduce the potential for fluid and/or pressure migration from reservoir(s) to the environment. This process can be colloquially referred to as "restoring the cap rock" (UKOG, Well Decommissioning Guidelines, Issue 6, 2018) (Figures 3.1, 3.2 and 3.3). The risk of barrier failure with time is determined and reduced through design, risk assessment, technology selection, installation method and post job verification and possible long term monitoring on a case-by-case basis.

Well abandonment can be, and frequently is, a time consuming and expensive process. In the Assess, Select and Design phases there is a strong emphasis on understanding risk, reducing activity complexity, reducing planned activity time and increasing commercial efficiency through engineering/contracting and supply chain management.

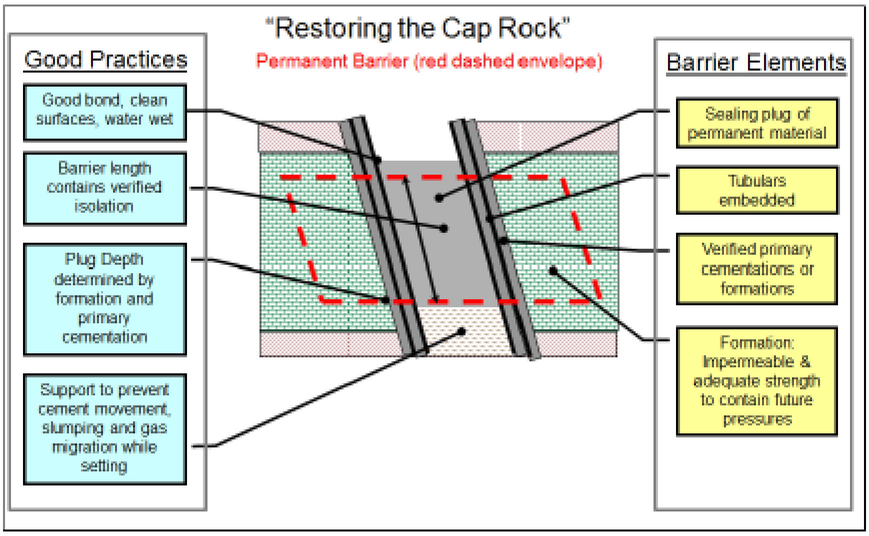


Figure 3.1. Ideal characteristics of a permanent well barrier element. Oil and Gas UK, Well Decommissioning guidelines, Issue 6, 2018.

No two wells are exactly the same and herein lies the challenge for the engineers, managers and regulators. This is true even in producing fields with hundreds or thousands of wells and multiple producing reservoirs. In these large fields, the well design may have common elements but the quality of the well barriers may not be uniform across the field and this leads to abandonment challenges and design solutions that are bespoke and specific to each well.

The largest reductions in execution time and therefore cost reduction from the original estimate are achieved in the Assess and Design (planning and early engineering phases) of an well decommissioning project. Commonly referred to as 'front end loading', this period in a project cycle is where good engineering and risk management practices and effective decision making are critical to generation and execution of a safe and effective well abandonment program.

During the early phases of the decommissioning project, Assess, Select and Engineering, there are often significant opportunities to achieve step changes and improve the abandonment process flow. Specifically, this is the period when review, research, application and risk assessment of new technology solutions takes place. Teams are asked to be creative and look for 'out of the box' solutions.

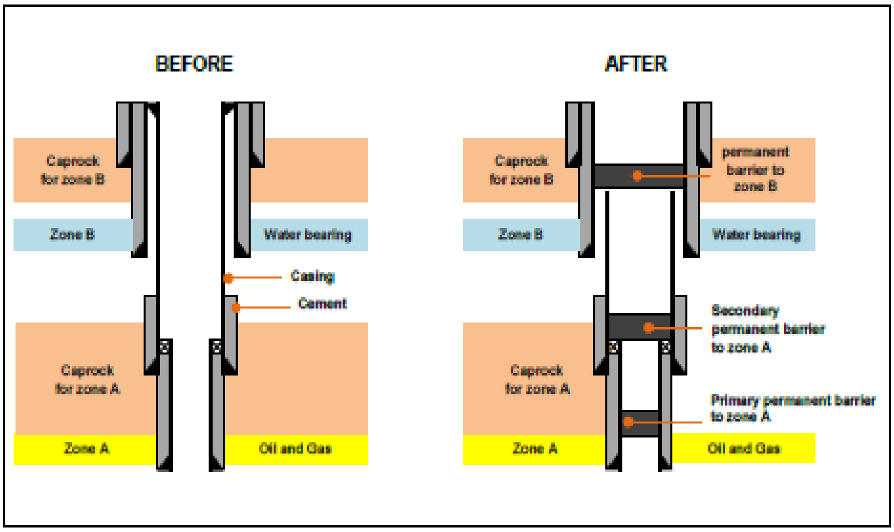


Figure 3.2. Simplified schematic showing the ideal characteristics of a simple well design and positioning of permanent well barrier elements before and after the well abandonment process. Oil and Gas UK, Well Decommissioning guidelines, Issue 6, 2018.

Across the spectrum of conventional, unconventional, coal seam gas onshore and offshore well abandonments that are common in Australia, the workflow and activity phasing are similar. The major differences in abandonment of these well types are:

- Magnitude, complexity and intricacy of the abandonment activities,
- Dimensions, weight and complexity of the equipment required to provide well specific solutions,
- Regulator framework that all well activities must comply with.
- Cost framework including site access, manpower, equipment rates and equipment mob/demob.

Many workflow events are common across all abandonment projects and well types including:

- Data review
- Abandonment program generation and risk assessment
- Activity permitting and regulator approvals (operator/contractor and regulator)
- External inspection of surface equipment
- External inspection of gauges, indicators of internal pressures and/or barrier integrity
- Access to the well location
- Access to the wellbore
- Removal of unwanted wellbore equipment and material
- Evaluation of current well barrier element status
- Creation of a wellbore environment suitable for installing a well barrier
- Installation of well barrier elements to re-create the well barriers
- Removal of surface expression of the well as necessary
- Management of generated waste recovered to surface

However, the uniqueness of the abandonment process is illustrated in Table 3.1 in an overview of aspects of the workflow that are typically addressed during the well decommissioning.

Table 3.1. Table illustrating some aspects of workflow and their variation with well type.

WORKFLOW ITEM	OFFSHORE MARINE	OFFSHORE PLATFORM	ONSHORE CONVENTIONAL	ONSHORE UNCONVENTIONAL	ONSHORE CSG
Data Review	Well reports Public archives Production reports Offset well data	Well reports Public archives Production reports Offset well data	Well reports Public archives Production reports Offset well data	Well reports Public archives Production reports Offset well data	Well reports Public archives Production reports Offset well data
2. Program generation and Risk Assessment	Environmental Assessment Abandonment Program HAZID	Environmental Assessment Abandonment Program HAZID	Environmental Assessment Abandonment Program HAZID	Environmental Assessment Abandonment Program HAZID	Environmental Assessment Abandonment Program HAZID
3. Activity Permitting	Offshore regulator /NOPSEMA	Offshore regulator /NOPSEMA	Onshore Regulator	Onshore Regulator	Onshore regulator
4. External Inspection	Marine Survey/ROV	Topsides / Visual	Cluster / Spatial Visual / aerial	Cluster / Spatial Visual / aerial	Spatial Visual / aerial
5. Barrier Integrity Check	Remote Instrumentation Marine Survey / ROV Visual / Interface XT	Remote Instrumentation Operator check	Instrumentation Operator check	Instrumentation Operator check	Instrumentation Operator check
6. Access to location	MODU / Jackup / LWIV / Support-IMR Vessel	Marine Jackup	Boat Road Air	Boat Road Air	Boat Road Air
7. Access to wellbore	Marine riser and subsea BOPs Surface BOPs and marine riser Coiled tubing Specialist equipment	Coiled Tubing Unit Self Erecting Platform rig Offset vessel Jackup rig Hydraulic / Workover rig Surface BOPs	Coiled Tubing Self Erecting/Truck mounted Platform RIg Land rig / Workover rig Doubles/triples/Super Singles	Coiled tubing Land Rig / Self erecting/Truck mounted/Workover rig Doubles/singles/Super Singles	Hybrid /Coiled Tubing Unit Self Erecting/Truck mounted rig Lightweight rig Workover rig
8. Well barrier Status Verification	Wireline logs; Cement bond logs, Wall thickness logs, internal calliper logs; behind pipe logs Positive and negative pressure tests Load bearing tests Well barrier placement job logs	Wireline logs; Cement bond logs, Wall thickness logs, internal calliper logs; behind pipe logs Positive and negative pressure tests Load bearing tests Well barrier placement job logs	Wireline logs; Cement bond logs, Wall thickness logs, internal calliper logs; behind pipe logs Positive and negative pressure tests Load bearing tests Well barrier placement job logs	Wireline logs; Cement bond logs, Wall thickness logs, internal calliper logs; behind pipe logs Positive and negative pressure tests Load bearing tests Well barrier placement job logs	Wireline logs; Cement bond logs, Wall thickness logs, internal calliper logs; behind pipe logs Positive and negative pressure tests Load bearing tests Well barrier placement job logs
9. Creation of well barrier installation environment(s)	Pressure control Change out wellbore fluids Drill out cement plugs Drill out / cut and/or pull packers Cut tubing / casing Mill casing / tubing Pull tubing / casing / completion Recover wellbore debris Manage waste at surface	Pressure control Change out wellbore fluids Drill out cement plugs Drill out / cut and/or pull packers Cut tubing / casing Mill casing / tubing Pull tubing / casing / completion Recover wellbore debris Manage waste at surface	Pressure control Change out wellbore fluids Drill out cement plugs Drill out / cut and/or pull packers Cut tubing / casing Mill casing / tubing Pull tubing / casing / completion Recover wellbore debris Manage waste at surface	Pressure control Change out wellbore fluids Drill out cement plugs Drill out / cut and/or pull packers Cut tubing / casing Mill casing / tubing Pull tubing / casing / completion Recover wellbore debris Manage waste at surface	Pressure control Change out wellbore fluids Drill out cement plugs Drill out packers Cut tubing / casing Mill casing / tubing Pull tubing / casing Recover wellbore debris Manage waste at surface ** design dependent
10. Installation of well barrier elements	Install mechanical well barrier element support plugs Install well barrier cement plugs	Install mechanical well barrier element support plugs Install well barrier cement plugs	Install mechanical well barrier element support plugs Install well barrier cement plugs	Install mechanical well barrier element support plugs Install well barrier cement plugs	Install mechanical well barrier element support plugs Install well barrier cement plugs

	Perforate wash and cement to place well barrier cement plugs across multiple casing / tubing strings Place alternative technology well barrier plugs	Perforate wash and cement to place well barrier cement plugs across multiple casing / tubing strings Place alternative technology well barrier plugs	Perforate wash and cement to place well barrier cement plugs across multiple casing / tubing strings Place alternative technology well barrier plugs	Perforate wash and cement to place well barrier cement plugs across multiple casing / tubing strings Place alternative technology well barrier plugs	Place alternative technology well barrier plugs
11. Removal of surface expression of well (as necessary)	Cut and remove wellhead and/XT Often cut and wet-stored on seabed for later recovery by less costly methods.	Cut and remove wellhead and/XT Materials may be stored on platform for efficient management during later decommissioning	Cut and remove wellhead and/XT Environmental Reinstatement	Cut and remove wellhead and flow head Environmental Reinstatement	Cut and remove flow head Environmental Reinstatement
12. Waste management (as necessary)	Management, transport and disposal of: Contaminated fluids Contaminated drilled cuttings / cement returns Swarf (metal milling debris) NORMS management Excess tubing / casing wellhead / XT	Management, transport and disposal of: Contaminated fluids Contaminated drilled cuttings / cement returns Swarf (metal milling debris) NORMS management Excess tubing / casing wellhead / XT	Management, transport and disposal of: Contaminated fluids Contaminated drilled cuttings / cement returns Swarf (metal milling debris) NORMS management Excess tubing / casing wellhead / XT	Management, transport and disposal of: Contaminated fluids Contaminated drilled cuttings / cement returns Swarf (metal milling debris) NORMS management Excess tubing / casing wellhead / XT	Management, transport and disposal of: Contaminated fluids Contaminated solids returns Excess well components

The wide range of variables that must be considered in decommissioning a well demonstrates that the efficiency of designing and risk assessing a well decommissioning program can be dependent on the quality and ease of access of the data available to the engineering team in the Assess and Select phases of a well decommissioning project.

Risk assessment is a structured and often straightforward process and often based on appropriate international or Australian standard. However, reality is that often parts of the process can be a very complicated and/or long winded. This is particularly evident when basic or interpreted data are ambiguous and forward plans rely on this data.

3b **What Materials Are Used To Contain Pressure and Fluids?**

In general terms, the aim in well decommissioning is to create a series of permanent barriers that have similar properties to the reservoir seal and sufficient dimensions and internal competency to be considered that the risk of degradation and migration of pressure along or up the wellbore and into the overlying formations or to the surface has been engineered and reduced to ALARP. Although this is not a definition this statement covers the practical intent of what is being attempted to achieve.

In well decommissioning around the world, the most common material installed as a permanent barrier is ‘cement’. More specifically, this is ‘portland cement’ to which a number of additives are included to assist the cement stay competent and be able to be put in place (pumped) and then setup with known properties over a period of time. The additives and the processes used to place the cement into the wellbore are designed and tested to ensure that pressures and fluids, typically hydrocarbons, below the cement plug do not migrate into the cement during the job and destabilise the cement formulation or contaminate the cement. This ensures that the resulting well barrier element(s) meet the design and integrity criteria.

Portland cement is selected as it is the easiest to procure and prepare in the field, it has similar properties to the rock that it is replacing and has been widely tested and accepted as having suitable properties for long term stability of its physical properties.

The range of cement-based solutions that are available for well decommissioning is very large in number however cement is not a one size fits all solution. Some of the problems considered include placement in intervals where there are tight tolerances and the laws of physics reduce confidence in cement plug integrity. Other situations such as insitu wellbore fluid incompatibility or borehole temperatures and reservoir pressures, wellbore angle (inclination) may increase the risk of installing a poor quality cement based barrier. The engineering challenges as well as the commercial drive to conduct well decommissioning operations more efficiently, in less time and with less people are some of the factors that incentivise the race for replacements to portland cement.

Replacement of cement based products with alternative materials is often considered by both engineers and stakeholders to be problematic. A major reason is that a permanent well barrier is considered to be ‘eternal’ and the long term integrity of replacement materials may not pass the risk assessment or a ‘social licence to operate’ litmus test(s).

In the quest for quicker, lower total cost and more versatile abandonment solutions, there is focus in academic and corporate research facilities to create effective alternatives to the commonly used materials and applied methods. There are many different standards and methods that can be applied when testing and validating new technology. This can be somewhat confusing and many companies rely on field testing to verify the long term suitability of the technology.

The cost benefits of implementing new technologies can be very significant. There are many certification agencies that have become involved in introduction and risk assessments of new technology. Oil and Gas UK have been instrumental in taking a holistic approach to assist all stakeholders such as innovators, strategists, regulators and operators alike, understand the technical expectations of different stakeholders in designing and validating new and innovative methods and materials for well abandonment. In 2015, Oil & Gas UK issued Guidelines on qualification of material for the abandonment of wells to promote the investigation and qualification of alternatives to portland cement as a well barrier component.

Oil and Gas UK (2015) groups material types used in well barrier construction during well decommissioning into 10 categories and these are set out in Table 3.2.

Table 3.2 Example well barrier materials (OGUK, 2015, Guidelines on qualification of material for the abandonment of wells).

Type	Material	Examples
A	Cements / ceramics (setting)	Portland cement, pozzolanic cements, slag, phosphate cements, hardening ceramics, geopolymers
B	Grouts (non-setting)	Sand or clay mixtures, bentonite pellets, barite plugs, calcium carbonate and other inert particle mixtures.
C	Thermosetting polymers and composites	Resins, epoxy, polyester, vinylesters including fibre reinforcements
D	Thermoplastic polymers and composites	Polyethylene, polypropylene, polyamide, PTFE, PEEK, PPS, PVDF and polycarbonate including fibre reinforcements
E	Elastomeric polymers and composites	Natural rubber, neoprene, nitrile, EPDM, FKM, FFKM, silicone rubber, polyurethane, PUE and swelling rubbers, including fibre reinforcements
F	Formation	Claystone, shale, salt
G	Gels	Polymer gels, polysaccharides, starches, silicate-based gels, clay-based gels, diesel / clay mixtures
H	Glass	Hollow glass spheres (HGS) admixtures (non-foamed)
I	Metals	Steel, other alloys such as bismuth-based materials
J	Modified in-situ materials	Barrier materials formed from casing and/or formation through thermal or chemical modification

The requirements and field trial criteria and often the validation methods that should be applied are quite stringent. As can be seen from the diverse nature of well abandonment barrier installation and placement environments and the range of material types there is a lot of scope for applied research and bespoke solutions.

One wellbore component missing is the category of ‘mechanical’ devices. Mechanical devices are not considered as long term barrier elements at this time because many of their internal or working components cannot be demonstrated to exhibit stability over ‘geologic’ time. Items such as production packers or mechanical valve seals or gates may have the potential to degrade over time.

This is illustrated in Figure 3.3 that shows a stylised schematic of a production well that has been abandoned through tubing. In this case, a production packer has been left in place and used as a solid base for abandonment cement that has been placed between the tubing and the production casing. In addition, we can see that the bottom of the tubing has been closed off with a ‘plug’ so that the cement can be placed into the tubing and the bottom of the cement will not fall out into the bottom of the well. Over time the plug installed in the base of the tubing or the production packer may corrode or breakdown however the cement plugs in the tubing and production wellbore annulus and inside the tubing will be considered a permanent barrier to hydrocarbon or pressure migration.

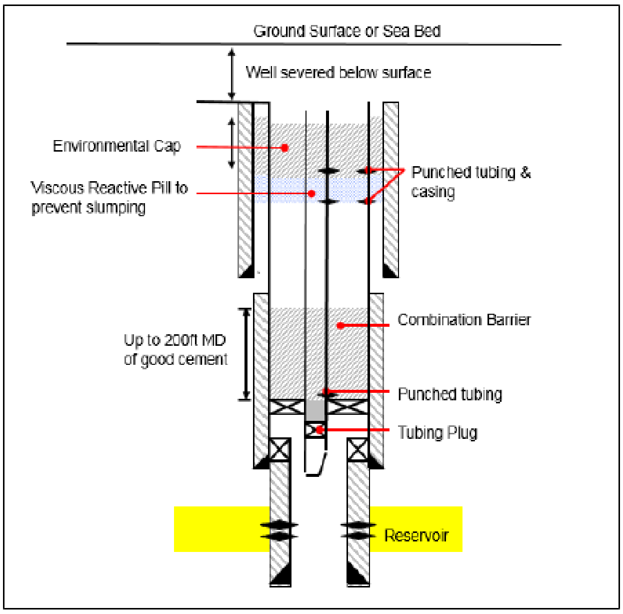


Figure 3.3. Illustration of a how a production well maybe abandoned by undertaking the well barrier placement activities through production tubing. The lower section of the tubing and production packer remain in place and perforating and well barrier placement activities using cement are undertaken through tubing. (Oil and Gas UK, Well Decommissioning guidelines, Issue 6, 2018).

The cement effectively isolates the casing and tubing walls from any migrating wellbore fluids and therefore reactions with migrating or replenishing fluids. As a result, chemical destruction of the steel may occur over time in isolated patches and not along the complete tubular length. It is therefore important to understand the competency and contiguous nature of the cement in the annulus.

In the Select and Design phases of a well decommissioning project, significant effort can be spent tracking down basic data on the cement jobs. Often times, cement job records are non-existent or publicly available records or data are sketchy at best. At other times there is no trace of evaluation logs or paper logs need to be digitised so that they can be re-interpreted with new algorithms.

It is envisaged that Portland cement will remain the 'go-to' component for many years to come. Alternative materials are becoming more readily available and there will be increasing application as their properties and application methods are streamlined and better researched and the risk-reward ratio better understood.

3c What Happens To Waste?

Every well decommissioning activity in Australia requires an approved Environmental Plan (EP) prior to starting activities. The environmental plan is often submitted well before the final operations plan, Well Operations Management Plan (WOMP) or drilling program is approved for the well decommissioning activity. The EP must integrate fully with the planned well decommissioning operations. Depending on the geographic area of activity there may be very specific limitations on allowable variations to the Environmental Plan. Engineers must be aware of best practice and waste management performance optimisation opportunities that arise from contractor solutions, commercial arrangements or technical advances closer to operations commencement.

Well decommissioning activities are often externally judged by the industry's ability to manage waste both during and after operations. Social License to Operate (SLO) is critical to success as a well decommissioning industry. Managing waste during this phase of the well life cycle is often complicated because we are often also addressing legacy issues. These problems can be old well construction problems as well as poor site layout, site loading bearing/rating limits, transport curfews handling equipment limits and fluid volume handling limitations. As well, particularly onshore, weather conditions such as tropical rain or cyclones can also create additional complications to handling waste with holding pits or ponds requiring attention and logistics management and emptying by disposal trucks.

Waste must be managed proactively throughout each activity of the well decommissioning phase. There are often five major waste streams that are managed via the Environment Plan and associated commitment documents during well operations:

- Fluids (Oil, water, synthetic based mud, completion brine, inhibitors)
- Solids (drilled cuttings, drilled and remnant cement)
- Metal cuttings (milled swarf)
- Radiation (NORM contaminated tubing and associated hardware)
- Steel (bulk recovered tubulars, wellhead, Xmas tree)

3d Risk Management

During the well decommissioning activity, the operations risk profile and well integrity risk profile increase because the activities and the number of known unknowns that must be managed increases. Risk management starts in the Assess and Select Phases. This is the starting point for managing the unknowns of pressure, temperature, geology and hydrocarbon properties. It is also at this time that well abandonment is first considered. How can the well be safely secured after exploring for hydrocarbons? In the case of a hydrocarbon discovery, the well and consequently the abandonment design of future wells are optimised as the engineering team focus changes to engineering design, approval, well construction, operation and production and appraisal of the hydrocarbon resource.

3e What are the Risks in Well Decommissioning

Historically, hydrocarbon exploration and production wells were comparatively quite simple in design. With continued evolution in engineering design, material properties, extraction technology and commercial drivers, hydrocarbons are now extracted from onshore and offshore oil and gas wells and from conventional and unconventional sources including shale and coal seam gas. As well, hydrocarbons are produced from reservoir formations ranging from sedimentary through to fractured volcanic rock with pressures ranging from ‘normal’ (sea or freshwater gradient) to considerably higher pressure. The complexity of design now includes materials and methods such as fibre optic and/or electro-hydraulic controls, exotic metallurgy, remote monitoring through satellite communications.

The top of mind response to a question on risk in the oil and gas industry, is often a catastrophic event. Most likely the response is dependent on recent media and news articles such as:

- Deepwater Horizon / Macondo event in the offshore Gulf Of Mexico (2010),
- Montara in northern offshore Australia (2009)
- The movie Gasland (2010) or the sequel Gasland II (2013) about onshore American oil exploration and production challenges.

The response to media coverage during these events demonstrates that public perception and social licence to operate is so important to the oil and gas industry. This same media also influences the stakeholders that the oil and gas industry interfaces with. Depending on your location, this can include:

- Federal Government agencies
- State Government agencies
- Local Government and agencies
- Landowners and landowner action groups

- Industry groups (APPEA, PESA)
- IMG's (Interest Motivated Groups)
- NGOs (non-government organisations)
- Land users such as fisheries and pastoral groups
- General public
- Commercial stakeholders in risk management such as:
    - Contractor organizations
    - Professional organisations
    - Insurance Companies
    - Supplier organisations
    - Licensing and compliance organisations

Technical stakeholders through organisations that generate 'definitive' standards documentation for the well abandonment and well construction activities such as:

- API (American Petroleum Institute),
- IADC (International Association of Drilling Contractors)
- UKOG (United Kingdom Oil and Gas),
- NORSOK,
- ISO (International Organisation of Standardisation).

Risk management and legislation applied to the oil and gas exploration and production business over the last 50 years has changed significantly from being prescriptive or rule based, to a performance-based regime that requires the title holder or permit operator to demonstrate that risk is proactively managed to ALARP.

It was the pivotal Piper Alpha incident in 1988 and the subsequent Public Inquiry set up in November 1988, 'The Cullen Inquiry', which initiated change across the globe in how the oil and gas extraction industry managed risk. This event marked the beginning of the transition from prescriptive risk management to performance-based style of management. A movement to ALARP where adopted control measures for any particular identified risk must be shown to collectively eliminate, or reduce that risk to a level that is ALARP. Arguments, must be reasoned and supported so that there are no other practical measures that could reasonably be taken to further reduce risk. The ALARP argument is underpinned by adoption of appropriate performance standards, sound engineering principles, specifications, good oilfield practice and implementation of a management system which supports and maintains them.

Today, the North Sea based regulators can be considered significantly influential in risk management both in a legislative and technical perspective. The leaders in well integrity and abandonment documentation are the Europeans; specifically, United Kingdom Oil and Gas (UKOG) and the Norwegian Petroleum Directorate (NORSOK). Publications by these two organisations in particular are pivotal and underpin documentation and methods that many other jurisdictions and industry operators apply to determine and manage risk during well operations and abandonment and decommissioning activities.

The commonly used terms of 'safety case', 'well barrier element', 'well barrier envelope' and 'well management plan', which are now common in the language of well activities and risk management, have direct origins from North Sea based regulators. The integrity and cohesiveness of the documentation they generate is a testament to the cohesiveness of the regulator, legislation, operator, contractor regimes in tackling common problems. In Australia we see the cohesiveness of regulator and operators improving with the recent, 2016 to 2018, updates to legislation and the commencement in 2018 of the Department of Industry, Innovation and Science Offshore Oil and Gas Decommissioning Framework - Initial Review.

3f **Risk Management and Well Integrity**

As a well moves through the phases of the well life cycle, technical understanding of the well environment is continually updated. In response to this increased volume of information, engineering and risk assessment and risk management techniques and processes are often adjusted. This concept can be illustrated in two examples: i) an exploration well drilled, evaluated and abandoned as part of an original drilling operation, and ii) a well that has been producing for 20 years.

In the first example an exploration well, that has just been drilled and evaluated and about to be abandoned, has a well understood technical risk profile because the design and well construction are recent and information on well barrier integrity is well known.

In the second example, by contrast, a well that has been producing for 20 years and has been worked over and re-completed several times has a less well understood risk profile. Produced fluids may have altered the structural integrity of the well barrier elements such as production casing by the mechanism of steel property changes caused by contaminants such as H_2S or reduction in wall thickness caused by sand production or corrosion by galvanic action of metals for example. This increased, and less certain, risk profile may require additional mitigation measures to manage risk, not only mechanical risk and well barrier integrity but also risk to personnel and the environment to ALARP.

In a drive to increase the understanding well integrity and therefore well abandonment integrity principles, one of the simplest and most effective methods of reviewing the integrity of a well at any time in the well life-cycle, is to consider individual components or 'elements' of a well and can they be combined to form a continuous well barrier envelope when combined with other adjacent elements (Figure 3.4).

The term 'well barrier element' is defined as a physical element which, in itself, does not prevent flow but, when combined with other well barrier elements forms a well barrier. A 'well barrier' is an envelope of one or more well barrier elements preventing fluids from flowing unintentionally from the formation into the wellbore, into another formation or to the external environment (NORSOK D-10, 2013).

The function of the 'primary well barrier envelope' is to prevent unintentional flow to the environment or other formations. The 'secondary well barrier envelope' functions to prevent unintentional flow if the primary barrier fails i.e. provide redundancy. Prudent well integrity management requires that a minimum of two well barrier envelopes be in place at any one time and that any deviation from this is risk assessed and documented. This requirement is to be in place before activities commence on the well, during activities and after activities are completed.

In an operating well, the well barrier envelope is comprised of a number of interlinking well barrier elements and, for a well component, such as a packer or tubing string, to be labelled or qualified as a well barrier element, the well component must be installed where it is intended and tested upon installation. Well barrier acceptance criteria are the technical and operational requirements and guidelines to be fulfilled in order to verify the well barrier element for its intended use (NORSOK, D-10, 2013).

The concepts of well barrier elements and primary and secondary well envelopes that apply during the commonly understood operations that may be undertaken during the well life-cycle are illustrated in Figure 3.4. The same principles of well barrier definition and well barrier envelope integrity interpretation apply to the more specialist activities that may occur during the well life-cycle. Depending on the well design and the challenges being managed, these activities may include electric wireline or slickline operations, coiled tubing (CT) operations, snubbing operations, underbalanced drilling (UBD), managed pressure drilling (MPD) and/or pumping operations.

The process of managing risk to ALARP can be assisted through the hazard identification process; often referred to as a 'HAZID'. Well barrier envelopes and well integrity are not the only risks to be managed during a well abandonment or decommissioning operations. At a high level there are many risk categories that must be considered and assessed for the proposed abandonment activity. Table 3.3 describes a spectrum of hazards that are addressed when attempting to comply with the regulator, operator and contractor safety management protocols and processes. This table also forms a basis from which improvement opportunities maybe identified.

Figures 3.5 and 3.6 illustrate some of the barrier failure modes that may need to be understood during a well risk assessment. These form only a subset of a risk matrix that may be generated as from a risk assessment applied to each phase of the well life cycle.

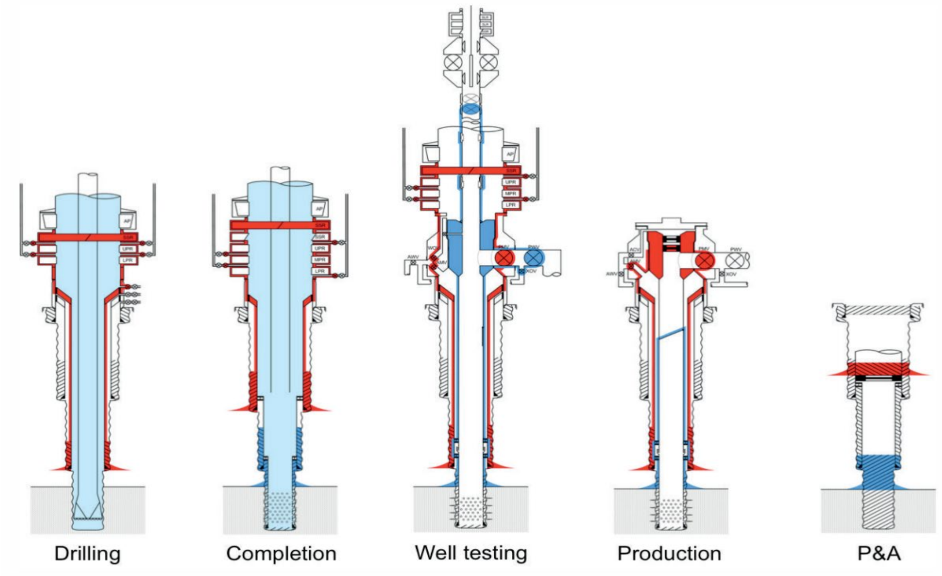


Figure 3.4 Examples of well barrier elements and envelopes that may be in place during the well life-cycle. The primary well barrier is illustrated in Blue and a secondary or backup well barrier is illustrated in red. This illustration is from Wellbarrier (2018) and demonstrates: (i) well barrier elements are many and varied throughout the well life cycle, and (ii) there are two well barrier envelopes in these examples.

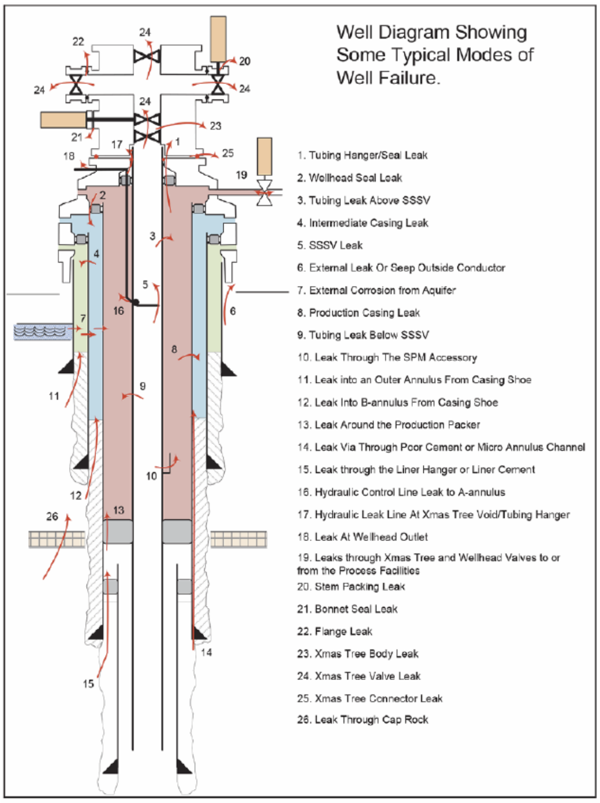


Figure 3.5: Well diagram illustrating some common modes of well barrier element failure (NOPSEMA, 2016).

Table 3.3. High Level view of a hazards and possible mitigations to illustrate possible identified risks and opportunities for risk management.

PROJECT PHASE	CATEGORY	RISK	DESCRIPTION	CAUSE	MITIGATION
EXECUTION	Personnel	Dropped objects	Recovered tubing breaks apart during handling	Tubing does not have sufficient integrity H_2S embrittlement Material corrosion Material erosion	Evaluation of tubing condition prior to retrieval Handling procedures Data review by chemist and metallurgist
EXECUTION	Personnel	Slips, trips and falls	Material such as milled swarf, recovered fluids and waste products at surface overflow in-situ waste receptacles	Handling techniques not optimal to recovered materials Recovered volumes and rates exceed handling capacity of surface equipment	Environmental Plan Handling Procedures Company procedures
EXECUTION	Environment	Spills and discharge	Recovered fluids and materials discharge into the environment	Surface pressures or recovered volumes not suitable for surface equipment	Environmental Management plan Handling procedures Safety Case Pre-job inspections
EXECUTION	Personnel	H_2S exposure	Release of H_2S gas at surface	Recovered fluids contain H_2S that is not planned for	Environmental Management Plan Procedures Vessel Safety Case
ASSESS OR SELECT	Environment	Not able to find location wellhead and/or Xmas tree	Wellheads and/or Xmas trees are covered in growth, migrating sand dunes or other substrate growth	It may have been 20+ years since wells were constructed. Substrate (marine or terrestrial) may have moved, regrown, covered over surface equipment and finding and/or entering location is difficult or considered impossible. Surface expression of the locations maybe not possible to find because of changes in geo-matic techniques and data management protocols	Environmental Management Plan Basic Data review Fact-finding trip / assessment survey
ASSESS OR SELECT	Asset	Damage or Loss of Containment	Access to wellhead or Xmas tree evaluated as high risk because of location in producing field.	It may have been 20+ years since wells were constructed. Available access platforms such as MODU, LWIV, truck mounted rig is considered high risk	Environmental Management Plan Basic Data review Fact-finding trip / assessment survey Operating procedures Management of Change
EXECUTION	Environment	Spills and discharge	Unplanned discharge to the environment from leaking wellhead or Xmas tree seals or seal faces or damaged hardware	Leak paths maybe opened on re-entering wellbore Insitu equipment / sealing faces may fail during integrity test(s) Equipment may not seal properly Management of pressures encountered	Environmental Management Plan Basic Data review Fact-finding trip / assessment survey Contingency plans Backup equipment
EXECUTION	Equipment	Loss of structural strength of conductor	Wellhead and/or conductors do not meet modern structural integrity requirements / standards	Corrosion of surface materials weakens materials below currently acceptable tolerances for connection to contemporary re-entry technologies Available technology weights and dimensions exceed original well equipment and design specifications.	Abandonment Program HAZID Specialist tooling Specialist material studies Pre-entry survey
EXECUTION	Pressure	Well control event	Unplanned positive pressures encountered	Pressure migration past original well barrier elements Pressure migration in fractures in sealing unit	Abandonment program HAZID Contractor equipment and procedures
EXECUTION	Wellbore conditions	Conditions different from planned	Real time data or conditions is/are significantly different from information in program	Basic data not correct Changes in wellbore conditions with time Reservoir data different from documented	Management of Change Process
EXECUTION	Well Integrity	Well barrier element(s) fail integrity test(s)	Well barrier elements fail integrity acceptance tests during well entry Well barrier elements fail integrity acceptance after installation	Barriers have degraded over time Agreed integrity protocols exceed barrier element competency Placement of well barrier element not correct Failure of well barrier element (mechanical, chemical etc.)	WOMP and/or drilling Program Contingency plans Management of Change Process

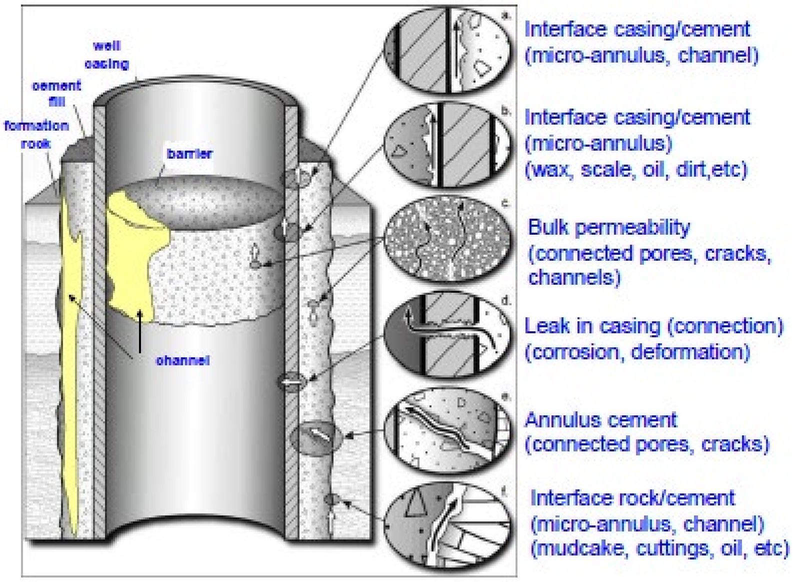


Figure 3.6. Barrier failure modes that may need to be risk assessed during a well abandonment. (Oil and Gas UK Guidelines on Qualification of Materials for the Abandonment of Wells, 2015)

3g Well Design and Abandonment Engineering Challenges

Hydrocarbon development projects continuously evolve and more basic and interpreted information becomes available as the development matures. In a successful oil and gas project, the evolution from exploration prospect to Final Investment Decision (FID) and production operations development, whether it be conventional oil and gas or unconventional shale gas or coal seam gas development, often involves the following activity sequence and constructing, operating, maintaining and decommissioning the following:

- Exploration wells:
  - Drilled to discover the hydrocarbon resource.
- Appraisal wells:
  - Drilled to understand reservoir characteristics and acquire additional data for certification of reserve volumes, development concept, upstream and downstream construction, marketing and project sanction.
- Development wells:
  - Designed, drilled and completed wells for production and reservoir pressure maintenance or disposal of processed fluids, gas and/or solids.
    - Production well (vertical, directional or horizontal, possibly extended reach profile)
    - Injection well for reservoir pressure support or assist hydrocarbons migration towards a common reservoir drainage point. Includes gas, water and steam injection wells.

  - Disposal well for pressure support or maintaining volumetric balance. Includes produced gas, CO2 or produced fluid wells.
- Workover activity:
  - Change out or isolate components out to enable more effective reservoir management.
- Suspension activity:
  - Shut in or isolate a well with the provision to bring the well back on production at a later date or delay the abandonment process. On occasion, the well may remain suspended because well access has been determined to be a high-risk activity. In some cases, exploration wells are suspended because their well design and surface location is considered suitable for the well to repurposed and completed for use as a production or injection well.
- Abandonment activity:
  - Installation of well barriers to reinstate 'natural' formation type barriers to inhibit reservoir flow.

Contemporary risk management techniques are applied throughout the well lifecycle by stakeholders in compliance with company risk management protocols as well as compliance with legislative expectations. Current state and federal legislation and international best practice is creating a risk management environment that promotes proactive risk management and well decommissioning or abandonment of non-producing or suspended well assets during field life to reduce risk to ALARP rather than continue to maintain the liability and inspection costs for the duration of the remaining field and/or well life.

The process of well design is conceptually similar throughout the project flow outlined above. Several factors combine to make each well, and therefore the well abandonment requirements unique. Specifically, the factors of:

- Geography. Where the well is located. Is it onshore or offshore, on a platform, part of a multi-well development, the topographic elevation and the terrain or substrate?
- Subsurface pressure profile. Normal, depleted, high pressure/high temperature, overpressure, shallow water
- Expected reservoir characteristics, 'normal', gas drive, solution drive, water drive, depletion drive,
- Expected production characteristics
- Directional profile
- Completion method. Cased and perforated, slotted liner, screens, gravel pack, expandable sand screens.
- Production and workover history.

All of these factors must be considered during the design, execution and operation phases of the project. As a well construction project moves through the well life-cycle, the number of 'unknowns' that must be addressed in the design process often, but not always, reduces until early production. The number of 'unknowns' then increases as well component age increases and the production well is worked over and/or recompleted, suspended and then ultimately decommissioned.

Well abandonment engineering design and activities follow a common sequence and methodology of:

- Data review
- Problem risk and operations assessment
- Program design
- Permits and approvals
- Mobilise equipment and personnel
- Arrive on location
- Establish pressure containment and enter well
- Evaluate well and barrier conditions
- Conduct any remedial operations
- Conduct barrier installation or reinstatement operations (Verify well barrier integrity)
- Remove Xmas tree and/or surface wellhead as per approved program
- Submit appropriate documentation.

Challenges that are commonly encountered in the design and execute phases of a well decommissioning project include:

- Access to wellhead or Xmas Tree is restricted. Infrastructure or geography may restrict access for intervention or workover.
- Structural integrity of wellhead and/or Xmas tree is less than originally specified or current regulations or equipment loads exceed original design and/or nominal design load ratings.
    - A real problem is that reduction in numbers of early generation MODU means that wells that were designed, drilled and/or completed and/or worked over with these 'smaller' sized rigs and equivalent marine risers and BOPs must now be accessed from larger MODUs using larger BOPs and heavier risers. This can create higher lateral loads on the Xmas tree / wellhead and/or conductor systems.
    - Well platforms may have been upgraded or re-rated with age and substructures and framework may not be able to distribute the loading requirements of contemporary rigs or application of modern HSE principles excludes setups and equipment loads that were previously acceptable.
    - Special tooling maybe required or specific or custom-made risk management techniques to access the wellbore. In marine environments this may mean that weather conditions and operating windows need to be risk assessed to reduce lateral riser loads or additional engineering and ancillary equipment may be required.

    - Opportunities also arise from these situations and alternative abandonment platforms such as subsea intervention vessels or subsea inspection, maintenance and repair (IMR) vessels are being adapted to partially fill this gap in the commercial and technical marketplace. Alternatively, lightweight fast response self-erecting hydraulic rigs have also been created to address these types of challenges. This is a simple but very effective illustration of how lateral thinking can provide opportunity in this vast world of well abandonment and decommissioning.
- Access into the wellbore to the depth of interest may be restricted because of conditions such as tubular or component failure, undocumented debris in the wellbore, chemical precipitates, tubular collapse, solids falling out from suspension in drilling or completion fluids to name a few.
- Well barrier integrity is not found to be congruent with the basic data or interpreted data available from the well files. Degraded well barriers are commonly interpreted from integrity evaluation logs taken upon entry of the well or re-interpretation of existing datasets. For example:
    - Cement bond logs or casing pressure data or cement bond logs show original estimated top of cement in the wellbore annulus to not be as originally assumed from the primary cementing job logs or cement job reports.
    - Tops of cement plugs or well annulus cement jobs are not as prognosed and additional cement plugs or top-up jobs are required to create well barrier elements with sufficient integrity to meet minimum barrier requirement as specified in current standards documentation.
- Unexpected high or lower pressure at surface than planned. May be caused by:
    - Pressure migration in the annulus or across formations.
    - Migration of fluids between zones with poor annular isolation such as in multi-zone developments with tight directional tolerances and challenging cementing programmes.
- Unexpected gas and/or fluids at surface.
    - H2S maybe encountered on circulation of well contents to surface. This may have been caused for example by production operations not correctly inhibiting injected seawater for reservoir pressure maintenance or degradation of wellbore fluids.
    - Unexpected toxic chemicals that are no longer used in contemporary drilling operations.
    - Degraded fluids that have broken down to primary or intermediate constituents with time and exposure to wellbore thermal cycling.

Opportunities arise in the project management process to reduce the variables being managed and the 'number of unique solutions' to a minimum. Each field often has a number of common elements that reduce the complexity of the process. For example, Xmas tree designs are typically from the same manufacturer with different variations for the well purpose. Many of the operational challenges that are encountered during well abandonment, such as Xmas tree valves not functioning correctly, or loading distribution limits on platforms, or wireline plugs stuck in completion strings have been uncovered during the well or field production history.

Table 3.4. Examples of hazards / challenges in different well categories illustrating the non-unique nature of problems and potential solutions.

CATEGORY	COAL SEAM GAS	UNCONVENTIONAL	ONSHORE	PLATFORM	SUBSEA
Data	Poor or non-existent records	Poor or non-existent records	Poor or non-existent records	Poor or non-existent records	Poor or non-existent records
Design	Existing well barriers do not meet current standards	Existing well barriers do not meet current standards	Existing well barriers do not meet current standards	Existing well barriers do not meet current standards	Existing well barriers do not meet current standards
Location	Poor or non-existent records	Poor or non-existent records	Poor or non-existent records		Poor or non-existent records
Wellhead Access	Covered by debris		Covered by debris. Difficult access with regrowth	Tight access because of platform reconfiguration. Reduced static loading limits impacts casing recovery methods	Corrosion challenges. Modern equipment too large and significant modification or different solutions required.
Xmas Tree	Covered by debris		Degradation or damage	Modern equipment too large and significant modification or different solutions required.	Modern equipment too large and significant modification or different solutions required.

3h Onshore and Unconventional Well Challenges

In Australia, the number of onshore wells is significantly greater than the number of offshore wells. This is reflected in the maturity of operations in areas such as the Cooper and Eromanga Basins and coal seam gas fields of Queensland. Good project management and cost control practices drive certain activity efficiencies in this environment.

The main advantage is that access is typically more straightforward and for the most part, transport to the oil field or well location is often times very practical and comparatively cost effective. Logistics is often via road, sealed or unsealed, and this may be combined with air support. When we compare the infrastructure costs of land and even helicopter operations in mountainous regions versus marine operations, it is easy to conclude that comparable technical well operations in marine operations often cost multiples of land operations.

Most notably location and pad management processes or layouts are often easier to set up in a cost-effective manner. At times it can be problematic to access the site with roads requiring permitting and sometimes many kilometres of road works when activities commence. These same conduits can also be flooded out during the wet season in the area or in neighbouring areas. This brings with it challenges that may need to be managed during the decommissioning activities.

In Australia, one of the major challenges in land operations is relative isolation from suppliers and supply chain logistics. It is not uncommon to mobilise equipment from one side of the country to the other for specific well decommissioning activities. This was a major point raised by NERA (2016) and is one element of the decommissioning budget that must be proactively managed from the initial contract and procurement plan through to well decommissioning execution and ultimately demobilisation.

Table 3.5 Conceptual overview: challenges/benefits of land based well decommissioning phase activities.

PHASE	CHALLENGES	BENEFITS
Assess	Managing Social Licence to Operate can be problematic and well decommissioning can take a higher profile than commercially desirable	Relatively easy access to site for Xmas tree valve and wellbore status updates
Select	Managing stakeholders and regulators for access to remote or isolated or 'rezoned' regions	Projects can often be conceptually designed and costed as discrete blocks of activity rather than continuous start-to-finish operations.
Design	Isolation of fresh water bearing zones is a higher priority because of potential proximity to waterways and human consumption catchment areas Chemical or galvanic corrosion from migrating artesian or saline water flows can be more problematic than planned for in original well designs.	Integration of batch concepts in multi-well pad layouts leads itself to innovative contracting of engineering and contract execution strategies. Innovation concepts are more cost effective and often lower risk to trial onshore rather than offshore.
Execute	Weather effects on logistics and infrastructure may impact operations for extended periods of time Access to wellsite is comparatively easier so maintenance of 'social licence to operate' can require more work	Piecewise execution of pad preparation, operations, wellhead removal and remediation is a possibility and is often more cost efficient Access to wellbore can be achieved at relatively low cost and ahead of time. Stable operating platform and load distribution handling

Each well is often considered to be unique when it comes to the decommissioning activity sequence and activity approvals from the appropriate regulators. In line with this thinking, operators and contractors often work intelligently to amalgamate operations and equipment efficiencies wherever possible to reduce the bespoke nature of well decommissioning activities and optimise drilling or workover rig technical specifications.

In land locations remediation operations may commence or be ongoing for one or more years after decommissioning operations cease. This is a long process and the visual and social impact of well and field decommissioning activities may be noticeable for considerable periods of time after field operations have ceased. For this reason, site access, the effects of weather and waste management are often focus areas in land operations.

Three critical areas of well design in land-based wells that are often different are:

- Land based wells are frequently slimmer in design with reduced casing diameters or number of casing strings than marine based wells,
- Xmas tree dimensions and control valves are significantly smaller and often lower pressure rating than their marine counterparts, and
- If the well is classed as unconventional, the reservoirs may be extensively artificially fractured which may make zonal isolation during decommissioning more challenging.

The conductor and wellhead do not have to manage the significant lateral loading that is present in marine environment with surface rig movement and sideloading of marine risers from water current movement. Most often the cellar and conductor have been installed prior to arrival of the rig.

Surface Xmas tree and operating hardware is often lower in pressure rating, smaller in physical dimensions, lighter in mass and easier to install, operate and maintain than their offshore platform and subsea counterparts. Coal seam gas well surface hardware installations are even lighter still.

In the land environment, surface wellhead equipment is often sized around 13-⅝” or smaller versus offshore operations equipment where it is often sized on 18-¾” wellheads. One critical design and efficiency impact this has is that the size and load rating of lifting and handling gear is often much less than marine based equipment.

Waste management and wellsite remediation can also be challenge that needs a well thought out solution particularly as we become more sustainable in our thinking and company operating principles. How much waste can be recycled or repurposed at site or even disposed of at site and at what cost and time penalties versus being trucked off site and sent to alternate waste treatment facilities. This is an ongoing challenge where the nett environmental benefit (NEB) or environmental cost reward balance needs to be fully understood.

3i CSG Well Decommissioning

In Queensland, coal seam gas producing wells outnumber conventional oil and gas wells in a ratio of approximately 10 to 1 according to Queensland Government, Petroleum and Gas Production Statistics (Dec 2017). At this time, 6093 CSG wells were contributing to hydrocarbon production across the Surat and Bowen basins versus 623 conventional oil and gas production wells.

Coal seam gas wells are designed to intersect coal measures and drain methane from underlying coal measures. Production surface pressure and produced volumes (mscfd) are relatively low and production intervals are selected principally on the basis of permeability and commonly the wells reach a total depth of between 500 and 1000 m TVD. Many wells are vertical however, depending on geological setup of the basin and the stress regime, as well as economic considerations, the wells maybe drilled directionally, such as in the Bowen BASIN, and often from a pad layout. The directional profile is often optimised for fault intersection and reservoir permeability and drainage conditions.

Coal seam gas production involves managing large volumes of produced water. Many wells fill naturally with water which is then pumped from the wellbore. This process reduces the hydrostatic overbalance where hydrostatic pressure of the water in the wellbore exceeds the pore pressure of gas in the coal seam. The reduction in hydrostatic pressure allows the gas to migrate from the coal pores through natural or artificial coal seam fractures and into the wellbore. In some regions the coal formations are fractured or “fracced” to increase the effective drainage or surface area of the wellbore by many orders of magnitude. This increases the potential for larger volumes of gas to enter the wellbore and create a well with a proportionally higher rate of gas production.

These wells are designed for significantly lower pressure and lower production rates than conventional oil and gas wells or unconventional shale gas wells. Well design follows the same design principles as conventional oil and gas wells. The main differences are:

- Water production as the coal seams are dewatered over the production life.
- Lower wellhead pressures than conventional oil and gas wells.
- Production profiles that have a long tail.
- Adaption of the well design for mining after decommissioning as appropriate such as incorporating fibreglass casing over intervals that may be mined.
- Production efficiencies maybe designed into the wells as a 'base case'.

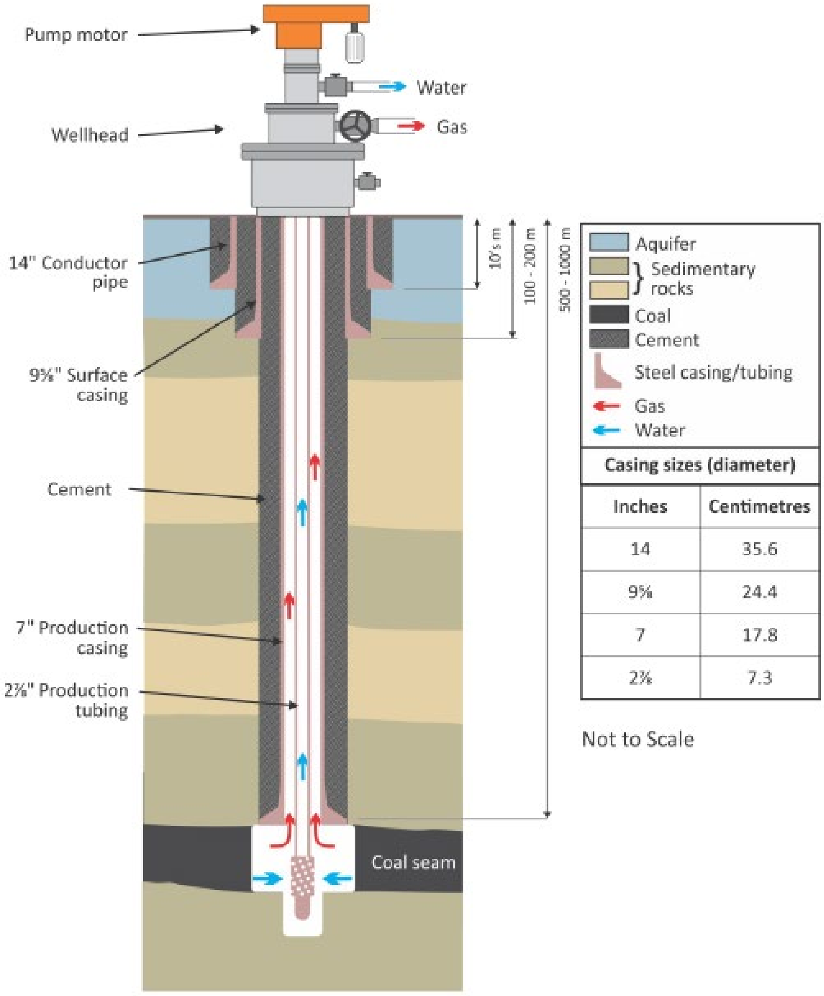


Figure 3.7. Generic illustration of a vertical producing coal seam gas well. (CSIRO, GESIRA S.9; 2018)

CSG wells have a strong economic drive to be drilled and completed efficiently and very cost effectively. The same philosophy goes for decommissioning these wells. Efficiency is increased when production is aggregated and wells are drilled from a common drill pad. This reduces both well construction costs and tie-in costs as well as decommissioning costs because of the ability to conduct operations with a production or 'batch' style approach. As well as conducting operations more effectively, surface facility management is more efficient.

Decommissioning of wells needs to be thought of during the design phase of these wells. In cases where the coal seam may be accessed at a later date, there is a requirement to design wells so that mining machinery will be able to mine the coal safely. In this situation, wells are designed to include fibreglass inserts so that mining equipment will not be damaged as it would be with traditional steel casing.

Decommissioning also needs to be thought through with respect to material and method selection. Some of the regulator documentation issued on CSG well decommissioning is prescriptive. This makes sense because the regulators are looking for consistency of work standards in a regulatory environment where the frequency of physical inspection maybe low and the contractors may be under time pressure to perform acceptable quality works because of the nature of their contract structure.

The CSG industry has received a lot of focus from government agencies and in particular the decommissioning aspect of the well life cycle. CSIRO have been very active and in early 2018 published the Final Report of GISERA Project S.9: Decommissioning coal seam gas wells. This document summarised the results of public and industry workshops into CSG well decommissioning in the past, present and future.

3j Is decommissioning offshore wells more difficult?

Well decommissioning challenges are magnified as operating conditions progress from the shoreline and marine splash zone and into transition zone and the marine and deeper marine environments. The change in the surrounding medium from air to fresh or brackish and then saline water combined with increasing depth of operations and increases in pressure and temperature and reduction in substrate competency brings with it ever increasing technical complexity and challenges to conducting safe well decommissioning activities.

As water depth increases subsea well complexity increases from simple onshore wellheads that have been physically enclosed below the water level to protect them from the marine environment to purpose built subsea Xmas trees that are several stories high with control systems ranging from simple hydraulic to complex electrical and fibre-optic controls, custom metallurgy, anode stacks and extra redundancy and remote operation access.

We also see a similar change in platform design from simple multi-well arrangements, that look and feel much like an onshore development has been transferred offshore, to monopods or similar structures where real estate and loading limitations are restricted and the well conductor plays an integral structural role in transferring structural loading from the platform to the seabed. Control systems for production management and well integrity monitoring range from manually operated and manually read pressure gauges through to control systems that are remotely monitored and operated. In remotely managed operations, the control panels maybe on an adjacent platform or onshore.

In Australia, marine oil and gas field developments include wells constructed on monopods, complicated platform arrangements and/or subsea and produced through subsea flowline architecture. Access to many subsea development wells for decommissioning activities is often not straightforward.

The range of operations platforms for wellbore decommissioning activities range from float over or tender assist drilling (TAD) rigs, self-erecting rigs, coiled tubing units (CTU) and hydraulic workover units (HWU) rigged up on platforms to moored or dynamically positioned Modular Offshore Drilling Units (MODU) to drill ships. This most recent period of relative quiet in the industry has seen repurposing of infield maintenance and repair (IMR) vessels and lightweight intervention vessels (LWIV) into platforms suitable for all of the well decommissioning process or specific operations. The majority of these operations platforms have application in Australia.

Most well access platforms such as MODU and jackup drilling rigs are mobilised into Australia from overseas, often Asia or the Gulf of Mexico. The initial campaign costs and daily operating rates are extremely high, in comparison with onshore cost structures. This promotes innovation and application of a robust and extensive design engineering and risk management processes. These processes are not simply about managing costs but also reduce potential for budget overruns through contingency planning and astute contingency and operational and financial management.

It is not quite this straightforward but onshore wells are the closest analogues to platform wells which typically have surface mounted trees and relatively easy access for inspection. The challenge often is that access to the wellbore for decommissioning operations may be integrated with production operations and require structural modifications to the platform or other custom access modifications. As well, supply chain access is via marine vessels or helicopters and infrastructure such as self-erecting derricks or CTU for well decommissioning operations may need to be mobilised and erected prior to commencement of wellbore access operations. Manpower also require accommodation which may no longer be practical or original accommodation modules have been repurposed.

These challenges often require an integrated approach to risk management and operations planning by the well decommissioning, well operations and/or well maintenance teams. These planning events can occur years prior to well decommissioning commencing. Often the design concepts and detailed engineering are outsourced using an Engineer-Procure-Construct (EPC) or Engineer-Procure-Construct-Install (EPCI) style of contracts.

Subsea, well integrity challenges abound as illustrated in Figure 3.5 which showed the potential leak paths in Xmas Trees. Often times these challenges must be addressed so that the potential for problems during well decommissioning operations are managed to ALARP. Some of the failures illustrated are from mechanical seal failure and others from metallurgical corrosion or other incompatibilities. Many of these challenges are addressed with the original equipment manufacturer where still available.

Removal of subsea Xmas trees and wellheads can be problematic. It is common practice to cut the conductor casing and associated casing strings just below the seabed and then recover the casing stubs, wellhead and/or Xmas tree to surface as one package. The Xmas tree may either be refurbished depending on the age and condition or prepared for the recycling process. Recycling well components can be a complicated process and can be quite costly from an environmental perspective so life cycle management of existing subsea equipment is addressed in the Environmental Plan. One review that is undertaken is the Nett Environmental Benefit Analysis (NEBA). This reviews the environmental cost of removing the Xmas tree and wellhead system and recycling it using commonly available techniques versus leaving the equipment in situ after being properly isolated.

4 A Renewed Focus on Well Decommissioning

Over about 18 months from June 2014 and January 2016, oil as a commodity lost approximately 70% of its commercial value as price dropped from USD 111/bbl (June 2014) to USD 35 (January 2016). Well decommissioning equipment, service and manpower rates are now significantly lower and operations efficiency is much higher. The relative cost of well decommissioning has significantly reduced and the potential for budget overruns from these inefficiencies has reduced.

Pressure on profit margins increased in response to; (i) the oil price reduction, and (ii) relatively high operating expenses from the times of higher oil prices. Companies, contractors and regulators were all driven to improve the economics of now marginal or negative cash flow fields now with relatively high operating costs. Astute management balanced economic returns with the opportunity to decommission wells at the lowest cost for a long time.

During periods of lower oil prices, contractor, operator and regulator business models were challenged to repurpose existing technology or research into the alternative revenue streams. Well decommissioning is one area in the well life cycle that has been given a lot of focus.

Governments also experienced a reduction in oil-price based revenue as excise or taxation income was reduced as the commodity price dropped. Regulators also used this opportunity to be more insistent that operating companies take action and address the legacy issues of well decommissioning now that contracting prices were at an all-time low. Across the globe there has been a significant effort by legislators and regulators alike to reduce the legal, commercial and environmental risk profile for their stakeholders. This has seen widespread proliferation of legislation and regulatory updates and focus in the area of well decommissioning. A result of this approach has been an uplift in the awareness of well decommissioning and increased focus on innovation.

Many governments around the world have created funding and incentive avenues to assist commercial and academic research and development. Some governments such as UK, USA and Norway have promoted early adoption of new technology and actively promote new technology development and application because, amongst other reasons, it directly lowers the operator and therefore the government’s cost liability.

Currently, the areas of government funded innovation, research and development in well decommissioning are quite broad reaching. Many of the larger oilfield service providers and operating companies are conducting internal research directly or funding external research activities through relationships with specialist contracts and/or research facilities. Well decommissioning has an expansive range of stakeholders and innovation in well decommissioning is very diverse.

4a Innovation Channels in Well Decommissioning

Based on the review and analysis above, the following technology areas and pathways are proposed.

Innovation in well decommissioning can be grouped into six major channels with a number of innovation components in each channel. The integrated nature of these relationships is illustrated in Table 4.1 and 4.2.

Table 4.1 Innovation channels and innovation components illustrating the diversity in stakeholder engagement.

	INNOVATION CHANNEL	INNOVATION COMPONENTS
1	**Legal, Commercial and Cost (LCR)**	Legislation overhaul, regulation and standards updates, international and industry legal best practice, regulation focus groups, certification bodies and agencies standards Commercial contract modeling, multi-party liability management, cost recovery optimisation, taxation management Cost control and cost management
2	**Knowledge and Risk (KnR)**	Archival and data management, data mining, best practice understanding and dissemination Risk management (legal, commercial, design and operations), risk determination, risk review processes
3	**Environment and Subsurface (ENV)**	NEBA (Nett Environmental Benefit Analysis) Material life-cycle management Subsurface studies
4	**Well Decommissioning Design, Performance and Operations (DPO)**	Performance benchmarking, Optimisation of processes, Restructuring of traditional working methods Migration of operations to non-traditional operating platforms Project planning systems, methodology and software Engineering and activity design improvements and optimisation
5	**Techniques and Tooling (TnT)**	Migration of traditional operations to non-traditional operating platforms Design and construction of operation / specialist tooling Innovation of new technology to address holistic problems
6	**Materials (MAT)**	Creation of new material solutions Iterative innovation of material or process solutions Methods and processes for validation of new materials and processes

Innovation is either a breakthrough ‘eureka’ moment, or an iteration or ‘continuous improvement’. Iterative innovation is most common and common examples of iterative innovation include: (i) a software upgrade, (ii) application of creativity in legislation, regulatory or commercial frameworks, (iii) modification of an existing design for an increased operating parameter range such as higher wellbore temperature, or (iv) re-purposing or integrating existing technologies.

It can be generalised that there are three categories of stakeholders involved in each innovation channel namely:

- Governments and their respective regulators and constituent stakeholders,
- Operating, contracting and specialist support and service companies, and

- Engineers, specialists and personnel responsible for design and execution of approved well decommissioning works.

Table 4.2 Illustration of range of technologies that could be applied to well decommissioning phase activities.

PHASE	INNOVATION CHANNEL	TECHNOLOGY CONCEPTS	EXAMPLES
Assess	**2 KnR** **4 DPO**	Big data and cloud-based data mining technology Design modification concepts eg specialist platform rigs and platform loading limitations, quick access onshore rigs or workover equipment, quick release equipment	Use cloud-based technology to data mine disparate data sources 20 to 30 years old to examine records of well construction activities Application of modern material and design criteria to interface older or degraded equipment
Select	**4 DPO 6 MAT** **2 KnR 4 DPO 5 TnT** **4 DPO** **3 ENV** **2 KnR 5 TnT** **6 MAT**	Specialist engineering, chemistry and materials studies. Early identification of new technology applications. Use of contractors to design solutions to access difficult physical locations NEBA (Nett Environmental Benefit Analysis) of leaving wellheads or production equipment in situ Application of specialist algorithms to interpret vintage data sets Design and implementation of experiments to validate material degradation and/or revised material specifications	Specialist metallurgical studies to determine load profiles of metals in potentially corroded environments Scoping studies to determine how to create self-erecting workover platforms load old platforms where traditional access has been removed by earlier modifications Wellhead or Xmas tree substrates are frequently habitats for marine or bird life. Environmental analysis may conclude that the environmental cost of removal and disposal exceeds the benefit of leaving the equipment in place. This is more and more common in marine environments.
Design	**1 LCC** **5 TnT 6 MAT** **4 DPO 5 TnT**	Tender creative activity solutions based on achieving a specific result rather than a prescriptive work method Research and design of solution specific equipment and/or materials Specialist equipment to facilitate entry into degraded wellheads	Contractor led solutions or design competitions. Research, design and validation of a plugging material. For example, a resin or cement for application in a oil or water wet environment in a specific temperature or pressure regime and well geometry such as between two tubing strings.
Execute	**4 DPO 5 TnT** **4 DPO 5 TnT**	Use of specialist electric line or slickline tooling Application of 'new' technologies to reinstate well barriers using non-traditional techniques or materials	Non-traditional wireline tooling to sever tubulars with non-explosive methods or chemical free Use of exothermic reactions or liquid metals to recreate well barrier or reservoir sealing formation

Each category of stakeholder has implicit in its core values to conduct safe operations and reduce liability and risk.

<u>Channel 1 - Legal, Commercial and Cost</u>

Every well decommissioning activity relies on having a robust and well understood legal, commercial and cost framework. Often risk is included in this channel however, because of the practical and significant influence on hazard identification and technical risk management by engineers and company and regulator driven processes, risk is integrated with knowledge management in Channel 2 Knowledge and Risk.

Innovation in the Legal, Commercial and Cost channel is widespread and far reaching. This is demonstrated by the quantity and frequency of legislation updates and stakeholder engagement workshops on legislation and regulation that impact well decommissioning.

Commercial innovation is often not well understood however we are seeing on a global scale more creativity in commercial models in decommissioning space. A lot of this is around risk, performance and profit-sharing models.

Of particular interest to most stakeholders is the question of long-term liability. After a well is decommissioned the liability for these activities and the resultant well integrity is at some point transferred to the regulator. Without being too pedantic, the liability is then by default transferred to the citizens of the resident country for generations to come. It is therefore critical that liability be understood in light of the 'Social License to Operate'.

This is a very significant issue that will ultimately drive costs if not managed adequately. If industry is unable to sufficiently demonstrate integrity post relinquishment then regulators may have to intervene. As public awareness of decommissioning increases there will be wide spread pressure to ensure integrity for a very long time post relinquishment (i.e. "forever"). This is particularly important when considering legislation and liability management around implementation of 'new' solutions may create problems for generations to come.

Cost management and optimisation is a major driver for innovation in well decommissioning. It is therefore important to understand the benchmark costs of the past in order to understand where improvements can be made and also to highlight areas of interest where additional effort or attention can reduce costs and improve the benchmark in the future.

Costs manifest themselves in almost every decision made, or not made, in the well decommissioning project. There are many obvious and not so obvious areas of the traditional well decommissioning budget. Table 4.3 highlights some of the cost innovation areas of interest that involve one or more innovation channels. This demonstrates the value of integrated teams and solution orientation in well decommissioning projects.

Table 4.3 Examples of how the impact of integration of decision making can result in a positive cost outcome.

COST CATEGORY	COMMENTS
EQUIPMENT	Pre-job design and job planning requirements Mobilisation and demobilisation Usage (depth, time or operations based charging)
PERSONNEL	Pre-job design and job planning requirements Mobilisation and demobilisation Number and duration required per task or operation Specialisation of personnel
TIME BASED ACTIVITIES	Is this equipment run on the critical path? Or can other activities be run in parallel. Is this equipment operated in several runs with interpretation required between runs.
MATERIAL BASED ACTIVITIES	Does the equipment require material support
INTERFACE	Rig services required to support the equipment Rig footprint and rig services and rig zoning requirements Other third party services required to provide assistance / support
BACKUP CHARGES	Does the equipment or service require 100% redundancy or can the equipment be backed up by type?

There is increased attention on innovative solutions in cost and project services focus areas of contingency fund management, Foreign Exchange modelling and cost and performance norms/benchmarking through the project cycle. This is increasingly evident as the oil price lifts off recent lows and the commodity price cycle continues and the cost base rises and productivity and efficiency falls.

Channel 2 - Knowledge and Risk

Application of the three elements of correct knowledge, best practices and risk management is core to delivery of cost reductions as well as managing risk to ALARP across each project phase.

Of particular importance is ensuring the 'data library' of available information is mapped out and understood so that data and reports are managed appropriately and missing data records are recognised as not being available. That is so that the 'known unknowns', can be risk assessed and the impacts on the project risk profile are properly understood.

Data mining of archived data and well records and production data is one growth area in well decommissioning that is playing an increasingly larger role in the Select, Assess and Design phases of well decommissioning projects. There can be significant benefits to having a robust data analysis system and data mining process in place versus the time, cost and risk profile of undertaking operations with a more unknown unknowns. The importance of data mining and establishing a robust knowledge base is shown in recent acquisitions within the oil services industry.

Historic record management and data archival is often forefront of the well decommissioning engineering team's mind. This is particularly common in increasingly digital companies where paper manuals are often discarded. The reality is, that in many cases, original drawings of Original Equipment Manufacturer (OEM) equipment are 20 to 30 years old and definitely obsolete. A similar problem is present in the digital arena where formats of drawings are no longer support or resolution of the original scan is too poor to be usable.

Practices in each of the well decommissioning channels are continually improved upon. To stay competitive, it is important that regulators, operators and stakeholders are informed of the current state of play in the best practices of their specialty. This is an area of specialty that CUOGIC strongly believe that by managing relationships with our business and educational partners we can assist in within the Australian and international well decommissioning community.

Risk management is paramount to a successful well decommissioning project. Significant effort is applied to generation of opportunities to innovate in risk management. It is often the case that multidisciplinary risk review teams extract significant risk reductions in a project because of an integrated approach. This is not only in response to a different line of questioning but often application of a different risk quantification model to the activity or risk that has been identified. There have been many innovations in risk management in terms of application of risk theory, software development and integration of risk management processes into business systems. This is a focus area for CUOGIC.

Channel 3 - Environment - NEBA and Waste management:

Environmental management is often documented in the Environment Plan well before the well decommissioning engineers and integrated team have worked out the appropriate risk profile for the activities that they must undertake. As such, there is significant opportunity for scientists and well decommissioning engineers to work together and also with regulators for a much more sustainable outcome.

An initial approach to assess the range of potential decommissioning options was to undertake a Nett Environmental Benefit Analysis (NEBA), to leave surface equipment such as Xmas trees or wellheads in situ in the appropriate conditions. This method is now being replaced by comparative assessment; such as that defined by Oil and Gas UK (2015).

Management and custodianship of waste includes managing contaminated returned fluids and liquid/solid separation, radioactive waste management. These processes, techniques and management of sustainable outcomes can be a significant safety, financial and risk burden to third party contractors, drilling rig or vessel contracting companies, and operating companies alike. This is a continued area of challenge across the spectrum of stakeholders.

Four focus areas of waste management improvement include:

- Milling operations which includes the challenge of safely and effectively cutting and milling the casing and handling of metal cuttings or shavings (swarf) at surface. There is considerable effort underway to:
  - Minimise the volume of metal waste handled at surface, and
  - Handle produced waste swarf at surface in a manner that is safer than previous and with a reduced deck footprint. As can be imagined, traditional swarf waste is often returned to the surface looking like the turnings from a lathe in a machine shop. Research is underway to optimise the milling process to reduce swarf dimensions and improve swarf lifting and downhole recovery efficiency.
  - Many of the surface waste handling solutions applied in Australia, and particularly offshore, are delivered as packages which are manufactured overseas and imported from regions of the world that have a higher utilisation of this type of specialist equipment.
- Drilled solids and liquid separation and disposal is an increasingly challenging issue for well decommissioning operations. Often liquid phases are contaminated and are filtered to separate oil-water-solid phases at surface. Australian discharge regulations (offshore or onshore) may not be able to be met, or discharge is not approved in the environment plan. This may require that contaminated fluids and/or wellbore returns are transported by boat and/or truck to appropriate and/or licensed treatment facilities. This often results in

considerable additional cost and often requires that the chain of custody be established and monitored in the supply chain.

- Recovered casing and tubing and well hardware such as wellheads and Xmas trees also require a waste management plan as part of the environment plan. Depending on condition of the recovered material, distance from efficient transport and identification of a market, many of these recovered materials have no commercial value. The majority will be recovered to surface in a condition that is not fit for commercial reuse and will be sold as scrap and managed through scrap vendors into the recycling market.
- Radioactive waste is managed in Australia under both state and federal laws. Management of radioactive waste and particularly naturally occurring radioactive material (NORM) is state specific and can be problematic. On many occasions, production tubing with NORM scale and internal build up could be repurposed as cement stingers in the cement plug placement operation and encapsulated in cement, mechanically disconnected and left in the cement plug. On occasion, when NORM contaminated tubulars are recovered to surface, the NORM is managed as per the Environment plan and appropriate legislation. NORM contamination is also a known challenge on production facilities where the same produced fluids precipitate NORM inside flowlines.

There are many innovation opportunities in waste management in the technical as well as the legislative and regulatory arenas.

Channel 4 - Well Decommissioning Design, Performance and Operations

Efficient and effective well decommissioning outcomes hinge on undertaking a successful and well thought out Select and Design phase. The Select and Design phase, often referred to as Front End Loading, are where integration of the highest number of professional disciplines often occurs. The Select and Design phase engineers and specialists make the single largest impact on cost reduction, risk management and operation performance. A lot of effort is expended to applied innovation throughout the business process in these two phases.

A large part of data mining and the design phase is building an understanding of performance expectations for the proposed well decommissioning operations. Although a large part of this process, is forward looking it is built on historic performance. Building performance benchmarking is important to creating a meaningful story of what could be achieved in the future. Although much of this process is undertaken manually, there is increased focus on integration of disparate datasets in the pursuit of meaningful benchmarks. Technology changes and operations sequence change as tools, technology and regulations are continually upgraded. For example, in recent years the dynamics of the drilling rig market has changed significantly. This has created benchmarking, operations performance and well decommissioning design challenges because currently available BOP and marine riser equipment may have higher weight and loading specifications than design criteria for the wells being decommissioned. This impacts not only performance benchmarking but also decommissioning operations sequences, specialist tooling requirements, lateral solutions to risk management for example.

Operations optimisation is another area where tremendous creativity is being applied to reduce risk as well as cost exposure. This can be as simple as asking the question as to whether the planned or proposed operation can be taken off the critical path and undertaken concurrent with another wellbore operation or in a less costly manner or by alternate means? When questions are framed this way there is often a significant shift in thinking and fit-for-purpose solutions are generated as a result.

An example is the operation of removing a wellhead from a well in a marine environment. In a traditional single well operation, the wellhead maybe cut and recovered to the drilling rig in real time. An alternative scenario, that is becoming more common, is for the wellhead to be cut 2 - 5 m below the seabed by the rig and placed on the seabed and wet-stored until such time as a vessel, with a lower spread cost, is in the area and recovers the wet-stored wellhead.

A more complex question that has resulted in innovative solutions is as to whether operations can be undertaken on a non-traditional operations platform such as a light weight intervention vessel or infield maintenance and repair vessel. Onshore questions such as can this operation be segmented and undertaken in a piecewise manner to take advantage of local market conditions or developments in alternative solutions.

These styles of questioning and enquiry can be applied across all well types and operating conditions. The results of this style of enquiry are illustrated in the Oil & Gas Authority 2017 Decommissioning Cost report. This channel of well decommissioning design, performance and operations is an area of interest that CUOGIC propose to develop in the near to mid-term.

Channel 5 - Techniques and Tooling:

This channel of Techniques and Tooling is a focus area of innovation worldwide. One of the primary drivers is the cost-value equation that is extolled by both operating companies and the service industry. One sees expense and is looking for tools, techniques and services to reduce the cost and the other sees opportunity to leverage knowledge and systems to provide value and be compensated accordingly.

Specialist Tooling: The age of in-situ well equipment combined with a sometimes-tenuous history of well operating parameters and production fluid conditions means that the requirement for specialist contingent equipment is often identified early in the Select and Design phases risk assessment process. This tooling is frequently designed and manufactured as a contingency in case remedial actions must be taken or as a means to address uncertainties driving cost. Some of the specialist tooling needs can be summarised by the following:

- Evaluating annular cement quality through-tubing, enabling barrier placement/remediation to be effectively pre-planned
- Surface isolation materials and tooling to effectively isolate shallow gas migration - BiSN is an emerging technology but is expensive - Sandaban or equivalent is not yet proven across all applications as well as Resins
- The ability to remote monitor the completion integrity via subsea WHD technology
- Through tubing/completion rock-to-rock P&A barriers e.g. dealing with non-centralised pipe, control lines etc. without having to pull the completion
- Improved logging methods and technology (through tubing) to locate influx sources / leaks – to mitigate cost/time spent on problem identification and location

Many wells are also at the end of the field life and the original equipment manufacturer (OEM) documentation may be 20+ years old. The original engineering drawings, specification sheets and technical manuals were often printed and bound and now stored in archives or a basement filing cabinet. In today's ever ruthless digital age large quantities of documents are scanned and then shredded. Finding usable drawings and manuals for aging technical components can be challenging or nigh on impossible.

These challenges create opportunity for innovative solutions. Some solutions will be bespoke but many opportunities exist whereby creative thinking over a one or two-year period, including a manufacturing and field test cycle, could solve field wide and even perhaps industry wide problems. Challenges can be present with specific Xmas tree design(s), or wellhead stackup(s). Perhaps environmental conditions are such that traditional access or wellhead removal techniques are no longer appropriate.

<u>Tubing and Casing Removal Technology:</u> The use of rotary, chemical or plasma based radial cutting technology is common place when tubing or casing needs to be cut at a particular depth. Milling is the action of rotating a tungsten carbide cutter against or onto the wall of a casing or tubing joint. The milling action works much like a tool against a piece of steel in a lathe and generates metal shavings known as 'swarf' that are circulated up the wellbore and recovered at surface. This a well understood conventional process for removing intervals of cemented or free tubing or casing to expose the wellbore and facilitate setting a cement plug across the exposed reservoir formation.

Specialist 'old school' technologies such as cutters and motors for milling casing have undergone and continue to iteratively undergo upgrades in materials and design technologies and performance envelopes. Such tooling is now setting records for milling casing that were unheard of previously.

With the advent of plasma cutting technology to replace conventional milling there is potential for step changes in this area of well decommissioning operations. Plasma technology is now being used to remove lengths of casing or tubing in a single pass. This technology has been proven commercially and is well described by Kocis in 2017.

Integrated cementing and/or grouting technology: Commercialisation of perforate-wash-cement (PWC) technology is an example of iterative or continuous improvement innovation. Integration of three technologies into one assembly to run into the wellbore has facilitated a step change in well barrier installation using conventional cement.

Perforate-wash-cement (PWC) technology facilitates:

- perforation of a casing or tubing string over several meters or more, then
- an aggressive high-pressure wash to remove any movable, broken or loose cement from behind the casing or between casing strings, and
- conduct an efficient cement squeeze job across the perforated interval.

This integrated assembly and sequence of actions removes the requirement to:

- remove a section to expose the wellbore by a conventional milling operation,
- clean loose cement without an additional run for a jetting assembly, and
- set a cement plug across the exposed formations to establish a well barrier without running a specific cement stinger.

In the past few years the uptake of PWC technology has increased across the industry as the technology has become more reliable and accepted/proven. The question of the competency and integrity of the cement job and therefore the well barrier integrity has been verified by several top tier operators. Continued evolution and innovation of PWC technology, and the ever-driving requirement for operations simplification, increased personnel safety and reduced operating cost has seen the next evolution and adaptation of this technology to replace traditional explosive based perforating with mechanical perforating. This iteration has the benefits of a reduction in personnel safety risk, reduced loadout and handling costs, reduced procurement, reduced man power and contract overhead. Mechanical PWC technology may not be applicable 100% of the time however it does show the evolutionary steps that well abandonment technology is taking.

In a similar line of application, the operation of cementing multiple casing annuli concept has been optimised to be run from lightweight intervention vessels. This particular innovation eliminates rig operations and the costs associated with them and achieves this by applying technology in a different way and combined with removing the traditional operating platform of a traditional MODU or jack up and replacing it with a floating support or light weight intervention type vessel.

As can be seen with these recent innovations the benefits of innovation in one channel are often seen elsewhere in the project outcomes. Many of these applications require strong working relationships with the client over several years. This channel of techniques and tooling is diverse and CUOGIC believe that applications in onshore operations in the near to mid-term and offshore operations in the mid-term to long term is achievable.

Channel 6 - Materials:

Well decommissioning design, operations and risk review processes often highlight many well integrity challenges that were not present during the well construction activities. These challenges can include access to the interval of interest, tight annular tolerances, unknown fluid types, parted tubing, lack of well barrier integrity to name a few. Often placement of traditional well barrier elements such as portland cement based products may not be considered as the most appropriate technology to apply.

Replacement of traditional Portland cement products with lower cost, more problem or application specific solutions has been worked on for many years. Replacement of cement with resins, liquid metal replacement or exothermic reactions to liquefy the surrounding rock is a common innovation idea that has many proponents. Many of the solutions that are being trialled, such as resin or bismuth and/or associated metal alloys to replace cement or using thermite to recreate a physical formation barrier, are technologically not 'new'. Rather, the specific application and current commercial conditions are such that these technologies are being revisited and worked up using more recent tooling and design thinking. Recently, test applications of large BiSn plugs are have been undertaken and being reviewed (OGJ, 2018).

Successful acceptance requires collaboration with regulators and insurers to accept widespread replacement of conventional cement based abandonment materials.

In 2015, Oil & Gas UK issued Guidelines On Qualification of Materials for the Abandonment of Wells Issue 2. This provides a structure for researchers and innovators to apply during their design and market validation processes and illustrates that there are an abundance of research and education opportunities available in this market segment.

In Queensland, significant research has been undertaken on application of pre-moulded bentonite plugs for use in abandoning coal seam gas wells. This is an example of some out of the box thinking that can be applied in the decommissioning space.

Almost all applied material research in well decommissioning is being undertaken outside Australia. Creation of application specific and unique well barrier material solutions is a longer-term innovation opportunity.

4b Application of Innovation Channels

The diversity of stakeholders and the range of innovation opportunities to review and possibly apply in a well decommissioning project can be overwhelming. Depending on the stage of the project, application of some of the innovation themes may not be possible at that stage or may require a project recycle which may not align with project drivers. At CUOGIC we believe that there are certain areas of innovation in well decommissioning that we are best suited and positioned to pursue with our funding and resource model.

5 Strategic Plan of Collaboration, Innovation and Education

The vision is to be the regional independent leader in well decommissioning research, collaboration and innovation. Curtin University Oil and Gas Innovation Centre will positively contribute to the increasingly dynamic Australian, Asian and international well decommissioning community. In support of this vision, the mission of CUOGIC is to frame and prioritize the regional well decommissioning key challenges, build and secure the requisite capability and knowledge – to deliver value through insight and innovative solutions.

This strategic plan covers the period from 2018 to 2023 and incorporates two phases of development, integration and sharing of knowledge, skills and capability. Phase 1 nominally covers the first three years from 2018 to 2020 and Phase 2 covers the next three years from 2021 to 2023. The overall strategic plan is illustrated in Figures 5.1 and integrates with a simplified technical work guide that is based on the innovation channels and illustrated in Figure 5.2.

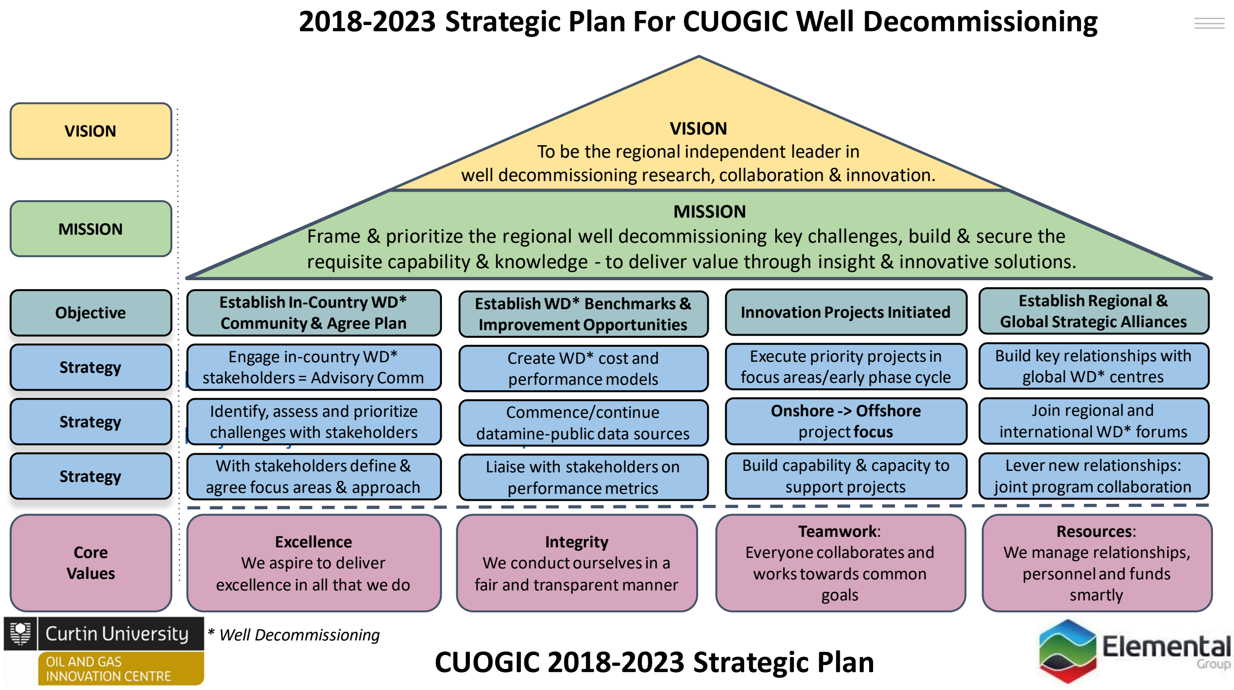


Figure 5.1. Strategic plan for Well Decommissioning 2018-2023

There are four primary objectives in the 2018 to 2023 strategic plan. They are:

- Establish in-country well decommissioning community & agree plan
- Establish well decommission benchmarks and improvement opportunities
- Initiate and deliver innovation projects
- Establish regional and global strategic alliances

The vision, mission and objectives are underpinned by four core values which are:

- Excellence, Integrity, Teamwork and Resources.

The success of this strategy hinges on the ability to achieve three outcomes:

- Build strategic alliances across several areas of the well decommissioning industry that align with the strategy.
- Resource CUOGIC with personnel, and establish the collaboration partnerships such as WAERA, that are capable of executing the strategy, and
- Executing and achieving the objectives set out in the strategy.

Most of the stakeholders that CUOGIC interface with are external to the academic environment. To guide CUOGIC along the journey and assist achieving the outcomes an advisory committee of selected representatives from industry and regulators will be put in place. The advisory committee will assist in balancing academic and industry objectives with commercial realities. The target is to have this advisory team in place by Q1 2019.

5a **Phase 1 2018 to 2020**

Phase 1 strategy focuses on establishing a foundation in the following areas:

Building a depth of well decommissioning engineering excellence to support the longer term vision.

- Intelligently packaging and disseminating best and top quartile practices to the well decommissioning community.
- Building working relationships with stakeholders through collaboration on projects that have between 2 and 5 years before execution.
- Establishing a risk management speciality in areas of well decommissioning that are difficult to quantify using current methods.
- Working with land based operators on cost effective application of best practice data management and risk management principles during the Assess, Select and Design phases.
- Establish an Australia wide well decommissioning model to create cost and technical benchmarks.

These areas of focus are enveloped in the details of the four pillar objectives and their underlying strategies. A key outcome of this phase is to have an engaged and active advisory committee and to secure one or more multi-year agreements to provide base research and innovation opportunities.

Phase 1: Objective 1: Establish In-Country Well Decommissioning Community & Plan.

This objective is underpinned by three strategies:

- Establish a multi-party advisory committee as previously discussed.
- Identify, assess and prioritize challenges with stakeholders
- With stakeholders define and agree well decommissioning focus areas and approach for CUOGIC.

The success of CUOGIC is dependent on the strength of the relationships it builds with stakeholders in the well decommissioning community at a government, regulator, operator, contractor levels to name a few. CUOGIC has, and will continue to build, strong relations with many international organisations involved in well decommissioning.

CUOGIC will first focus on Australian well decommissioning stakeholders; immediately engaging with them to share CUOGIC's vision and strategy to garner interest and feedback. From this broad engagement an advisory committee will be formed to support and confirm the focus areas, challenges and forward plan.

Phase 1: Objective 2: Establish Well Decommissioning Benchmarks & Improvement Opportunities.

This objective is underpinned by three strategies:

- Create well decommissioning cost, risk and performance models
- Commence review of public data sources
- Liaise with stakeholders on performance metrics

Outside of the technical aspects of well decommissioning, a large portion of discussion is focused on cost and cost management. In the UK for example, there is a government initiative to reduce decommissioning costs by approximately 35%. This objective is focused on generating a cost, risk and performance model(s) using publicly available data. There is potential to include legal and commercial input into this objective. There is a strategy element to understand stakeholder performance metrics to assist in creation of a long benchmark performance models and to identify improvement opportunities.

Phase 1: Objective 3: Initiate Innovation Projects.

This objective is underpinned by three strategies:

- Align with well decommissioning projects early in the project cycle
- Focus on onshore projects
- Build Engineering capacity to support projects

In an academic research environment, research projects take time to define and execute and their outcomes, by nature, may not be as expected. Therefore, it is beneficial to both CUOGIC and clients if CUOGIC builds the foundation of its work by assisting in well decommissioning projects with several years before execution. These projects would most likely be in the Select, Assess or early design phases and in the onshore environment. This environment is only a suggestion and dependent on the skill base of the engineering and specialist CUOGIC team members. It is important to build human resource capability early in phase 1.

Phase 1: Objective 4: Establish Regional & Global Strategic Alliances.

This objective is underpinned by three strategies:

- Build key relationships with regional and global well decommissioning centres
- Join regional well decommissioning forums
- Establish a presence at local and regional events

Initial indications are that CUOGIC will find it difficult to remain sustainable if CUOGIC focuses solely on Australia. It has strong relationships with Curtin University educational campuses in Singapore, Sarawak and Dubai as well as relationships with several European and American academic and research entities. CUOGIC has already commenced building additional relationships within the global decommissioning community. Establishing an international presence would also be assisted by joining regional and international well decommissioning forums.

5b **Phase 2 2021 to 2023**

Phase 2 strategy focuses on establishing a foundation for CUOGIC in the following areas:

- Work with supporting companies on offshore technology projects as well as third party testing and validation of well barrier elements. As opportunities present themselves with applied research candidates and PhD students, CUOGIC has an interest in generation of application specific well barrier elements and/or associated tooling. The human interface between theoretical and applied engineering is critical to technical and commercial success.
- Work with international and significant regional partners to establish pre-eminence of CUOGIC in regional decommissioning forums.
- Collaborate and integrate with operating and contracting companies alike to assist with technology transfer and equipment design challenges to transfer real-world problem solving well decommissioning skills to our students.
- Establish a Master's level education in well decommissioning through our regional connections.

These areas of focus are enveloped in the details of the four pillar objectives and their underlying strategies.

Phase 2: Objective 1: Continue In-Country Well Decommissioning Community Engagement.

This objective is underpinned by three strategies:

- Maintain advisory committee engagement: challenge and update program to demonstrate value
- Broaden engagement with WD community: identify new key stakeholders
- Consider development and roll out of higher education courses

Continued engagement of the well decommissioning community is important to success in this phase. Higher education is an avenue for engagement through Curtin University's overseas education campuses. CUOGIC will now have a foundation upon which to build and demonstrate to stakeholder groups.

Phase 2: Objective 2: Well Decommissioning Benchmark & Improvement Monitoring.

This objective is underpinned by three strategies:

- Maintain well decommissioning cost, risk and performance models
- Continue review of public data sources & liaise with stakeholders on performance metrics
- Determine impact of opportunity improvements

This objective is focused on maintaining a cost, risk and performance models using publicly available and industry supplied data. There is opportunity to include legal and commercial input into this objective. There is a long term goal to understand and update stakeholder performance metrics following opportunity implementation to monitor and assess impact.

Information and best practices in well decommissioning are updated continually and stakeholder engagement through information aggregation and dissemination is one effective strategy to build value for stakeholders.

Phase 2: Objective 3: Initiate Offshore Innovation Projects.

This objective is underpinned by three strategies:

- Continue to align with projects in early phases of the project cycle.
- Expand project capability to include offshore well decommissioning.
- Build engineering base to support offshore projects.

In this phase, it is important to build a capability base for offshore support. In the technology guide, the high value projects involve offshore activities such as rigless intervention and systems integration. With the inclusion of offshore projects, it is important to align with stakeholders that have projects with Execute phase that is several years out.

Phase 2: Objective 4: Maintain Regional & Global Strategic Engagement & Alliances.

This objective is underpinned by three strategies:

- Maintain relationships with regional and global well decommissioning centres
- Contribute to local, regional and international well decommissioning forums
- Lever new relationships to develop and deliver collaborative programs

Maintenance of relationships with global well decommissioning centres is important to build on work undertaken in Phase 1. Contribution to the global well decommissioning community must be increased in this phase. CUOGIC is to publish papers, contribute to and present at international forums. In addition, it is important to build and maintain a local presence and contribute to local events.

5c Technology Guide

The technology guide is based on building an innovation activity sequence to deliver a spectrum of innovation solutions that address higher value questions as: (i) capability of the innovation centre increases, and (ii) capability of strategic partnerships are better understood.

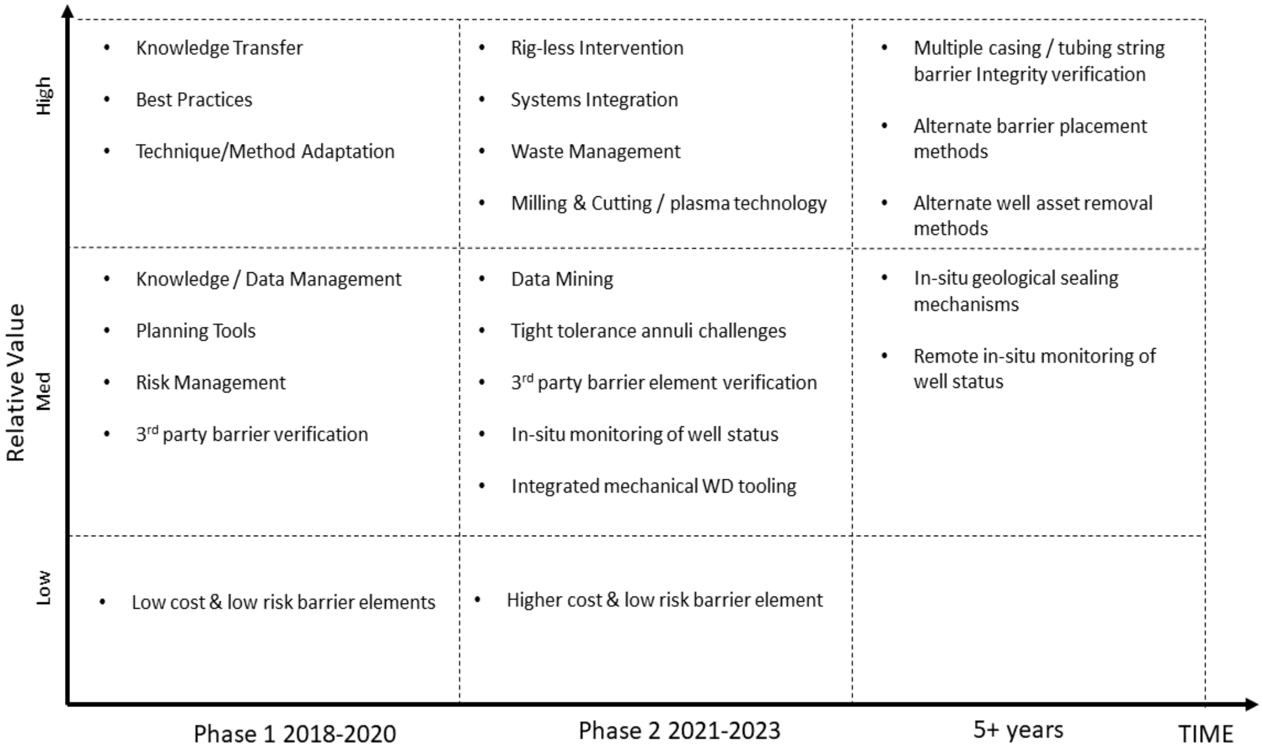


Figure 5.3 A simplified technology guide for innovation and expenditure of effort for the next 5+ years.

In Phase 1 the focus is on building relationships with stakeholders and delivering innovation focused on collaboration and integration of world best practice. The focus is on building competency on onshore operations, although offshore operations will also be considered if the opportunity arises. The highest relative value technology activities to undertake is collaboration with industry and centre of excellence and disseminate best practice awareness and knowledge transfer to the Australian well decommissioning community. Information is widely dispersed and CUOGIC aims to be influential as a well decommissioning best practice repository.

Relative medium value innovation focuses on knowledge and risk management. CUOGIC proposes to build its capability to assist operators and regulators with risk models and risk management optimisation. In addition, CUOGIC has access to material testing and certification facilities and will support third party validation of well barrier elements and tooling.

Relatively low value technology projects include design and testing of low cost well barrier elements. This is a precursor to Phase 2 where the technological program is more sophisticated.

In Phase 2 of the CUOGIC technology guide, innovation projects become more specific. This increased complexity reflects the capability building of Phase 1 and building a foundation to undertake projects in the offshore environment. The high value projects are more collaborative with themes such as rigless intervention, systems integration, waste management and tooling and specialist technology development.

The relative medium value projects include more sophisticated data mining, work on tight annulii challenges for well barrier installation and/or removal, third party barrier element verification and applied multi-party work on wellbore monitoring and specialist mechanical tooling. The relative low value projects build on the work from Phase 1 and include more complexity.

In the longer term, 5+ years, projects involve increased sophistication, collaboration and possibly downhole testing and validation. Emphasis is on integrating with and applying global research in well decommissioning practices and applied theory. Projects include very high value aspirations of multiple casing string barrier integrity verification, alternate barrier placement methods and alternate well asset removal methodologies. Projects with medium relative value include field specific analysis of in-situ borehole sealing methods and remote monitoring of in-situ well status.

One important aspect of this technology guide is the necessity to find and select partners that are prepared to align or support aspects of this work into the future. Some of the work will involve testing in real world applications and often this must be planned several years in advance.

6 Conclusion

Curtin University Oil and Gas Innovation Centre is focused on well decommissioning in Australia and South East Asia. With the assistance of oil and gas stakeholders in this region CUOGIC is in a position to make a difference to well decommissioning risk management, operating effectiveness and cost of operations. This involves open and effective collaboration and integration with all stakeholders on many levels.

CUOGIC has engagement with world class research institutions and commercial organisations. Curtin University has an expansive educational coverage of Australia and more regionally South East Asia. We are well positioned to be a considered voice and communicator on global decommissioning trends and strategies and best practice developments in Australia and throughout Asia.

We can be a repository for best in class well decommissioning practices in Australia and can assist companies and government agencies to improve the understanding of top quartile and best risk and operating practices. In doing so we believe that CUOGIC can help make a difference in the medium to long term.

The proposed phased strategy (2018-2020) is based initially on building a depth of well decommissioning engineering excellence to support the longer term vision including:

- Intelligently packaging and disseminating best and top quartile practices to the well decommissioning community.
- Building working relationships with stakeholders through collaboration on projects that have between 2 and 5 years before execution.
- Establishing a risk management speciality in areas of well decommissioning that are difficult to quantify using current methods.
- Working with land based operators on cost effective application of best practice data management and risk management principles during the Assess, Select and Design phases.
- Establish an Australia wide well decommissioning model to create cost and technical benchmarks.

The second phase of the strategy (2020-2023+) focuses on establishing a foundation for CUOGIC in the following areas:

- Working with supporting companies on offshore technology projects as well as third party testing and validation of well barrier elements.
- Expanding relationships with international and significant regional partners to establish pre-eminence in regional decommissioning forums.

- Collaboration and integration with operating and contracting companies alike to assist with technology transfer and equipment design challenges to transfer real-world problem solving well decommissioning skills to our students.
- Establish a Master’s level education in well decommissioning through our regional connections.

There will always be opportunities present themselves to be innovative or apply research results to real world problems. By aligning with the phased strategy approach and the technology guide, CUOGIC believe there is opportunity to assist many companies make a difference to the cost and technical outcomes of their well decommissioning projects.

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