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Engineering and legal considerations for decommissioning of offshore oil and gas infrastructure in Australia

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Offshore oil and gas platforms, pipelines and other ancillary offshore infrastructure are aging in Australia and current regulatory frameworks favour complete removal at the end of life. However, evidence indicates that artificial reefs have formed around some of these structures and their removal could cause more harm than good. Furthermore, other perceived social, environmental and economic benefits of a total removal policy may not be warranted. The Australian regulator (NOPSEMA) is currently exploring the possibility of supporting an in situ decommissioning policy, in which alternatives to full removal such as leaving in situ, partial removal or nearby relocation may be adopted if demonstrated to be the preferable approach. This will necessarily involve changes to law and policy but such amendments must be evidence-based. The evidence needed will largely involve the disciplines of engineering and natural sciences, but also fields such as environmental management, economics, social sciences and law. If Australia were to progress an in situ decommissioning policy shift, research will be needed across all of these areas in the specific national context. This paper commences by outlining emergent engineering knowledge, showing the general conservatism of current methodologies available to assess the integrity of decommissioned offshore facilities. Thereafter, the particular legal environment in Australia is explored. This article contributes to the growing body of literature on in situ decommissioning but in setting a multi-disciplinary research agenda takes a more holistic approach.

Introduction

The first infrastructure for the offshore petroleum industry was constructed in the early 1920s. The disposal of these installations did not begin until the 1970s with more complex structures being decommissioned in the 1990s (Athanassopoulos et al., 1999). Today there are thousands of offshore oil and gas installations and platforms across the globe in addition to a range of subsea infrastructure, pipelines and wells. Much offshore infrastructure has been in service for several decades and is due or will soon be due to be decommissioned (Hamzah, 2003). For example, over 550 platforms and subsea production facilities are situated in the North Sea, a mere 7% of all North Sea installations have been decommissioned to date and much is forecast for the coming three decades (Royal Academy of Engineering, 2013), while South East Asia hosts close to 1700 offshore installations, nearly half of which are older than 20 years and are due to be retired (NUS, 2013).

In Australia, the first offshore petroleum infrastructure was constructed in the Bass Strait in the 1960s (DIIS, 2015) with construction accelerating in the 1980s with the development of the North West Shelf (Haggerty & Ripley 1988). Over the intervening period the sector has grown significantly and today Australia is one the world's major liquefied natural gas (LNG) suppliers. Taking into account the timeframes for exploration, project development and operations, much of the early infrastructure is now towards the end of its life. Assets may function beyond their initial design life through reassessment of the infrastructure condition (so-called 'life extension') if a field continues to produce economically. Additional infrastructure may be installed to optimise production methods that may cause existing infrastructure to be unused. In the context of this paper, “end of life” is taken as when economically viable production is no longer possible using the existing infrastructure or asset configuration, and a decision is made by the Operator to abandon the infrastructure. Decommissioning is always a consideration regardless of the age of the asset, because of its influence as a future liability. However, attention on decommissioning issues is becoming increasingly visible in Australia as end of life is imminent for a number of developments. Over the coming years decisions will increasingly need to be made about the decommissioning approach for more of that infrastructure.

The sections that follow demonstrate the engineering and legal concerns and possible responses. No doubt there is further research to be undertaken and evidence to be gathered but a key issue for the future is to ensure that the Australian law and policy framework deals adequately with decommissioning and in doing so provides certainty and the optimal outcome across owners, investors and operators as well as other stakeholders including the broader community.

The end of life options for offshore infrastructure include complete removal (the current position in Australia), in situ decommissioning (leaving the infrastructure in place either completely intact or with the topsides removed and legs toppled), removal and relocation offshore (for example as a dive site or fishery), as well as partial removal (removing some parts of the infrastructure while leaving others in situ)(Ekins et al, 2005). Offshore relocation and in situ decommissioning have received attention in recent years as science has emerged of the artificial reefs that form around infrastructure during their operations, leading to enhancement of the habitat and biota. Recent Australian observations of biota at oil and gas installations include Pradella et al. (2014), Mueller (2015) and Leckie et al. (2016) (Figures 1, 2).

Figure 1. Established marine ecosystems around offshore oil and gas infrastructure (Figures adapted from Leckie et al. 2015; Leckie et al. 2016)

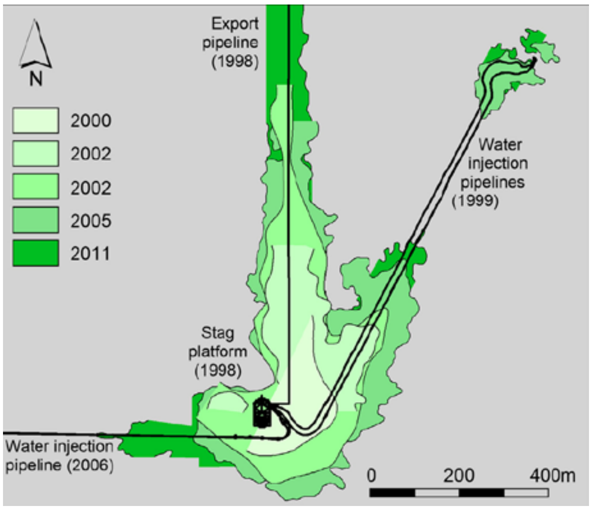


Figure 2. Growth of seabed pockmarks linked to fish activity around a pipeline system offshore Australia (Mueller 2015)

The potential role of oil and gas infrastructure as habitat for marine biota is a major driving force of the 'rigs-to-reefs' debate and policy changes that provide for partial removal (Claisse et al. (2014), Macreadie et al. (2011)). Current rigs-to-reefs options often involve relocating the rig to a new site, thus reducing environmental benefits in terms of preserving an established ecosystem. A further development of decommissioning policy would be a wholly in situ approach with the rig remaining at its original location on the basis of an improved environmental outcome, potentially with societal and economic benefits also resulting. The successful implementation of a ‘rigs-to-reefs’ program in the US has drawn interest in Australia.

International law and policy has a significant role to play in setting standards in ocean areas and has provided a framework for decommissioning that influences the approaches in many nations including Australia. Whilst this international framework is critical, it is also clear that different law and policy approaches have been taken in different countries and their analysis is also relevant (Techera and Chandler, 2015).

At the international level both the *United Nations Convention on the Law of the Sea* (UNCLOS) and the *London (Dumping) Convention* are relevant and Australia is a party to both. ‘Decommissioning’ is not specifically referred to, although reference is made to the need to deal with obsolete offshore platforms, and the term ‘abandonment’ is used (Hamzah, 2003). The earliest relevant international law is the 1958 Geneva Convention on the Continental Shelf (a predecessor to UNCLOS) which requires entire removal. This Convention remains in force and Australia has implemented this provision. The favouring of complete removal has also influenced the UK and EU policy (Techera and Chandler, 2015).

UNCLOS is now considered to be the dominant instrument in the area of oceans governance, and Article 60(3) provides that abandoned or disused infrastructure shall be removed taking into account ‘generally accepted international standards established… by the competent international organisation’. The Maritime Safety Committee of the International Maritime Organisation (IMO) has responded by developing soft law (non-binding) *Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf and in the Exclusive Economic Zone*

(IMO, 1989). Section 2.1 requires a case-by-case evaluation prior to any decision to allow offshore infrastructure to remain on the seabed. Criteria include the safety of navigation, rate of deterioration and risk of structural movement, environmental effects on the marine environment, costs, technical feasibility and risks of injury associated with removal. Finally, reference is made to 'determination of a new use or other reasonable justification' for in situ disposal. The reference to 'new use' is innovative and may include utilisation as an artificial reef. It is this approach that has been taken in some US states through its 'rigs-to-reefs' policy (US Bureau of Safety and Environmental Enforcement, undated). The Standards make provision for complete removal of structures in shallow water and weighing less than 4,000 tonnes, and allowing other concrete and steel structures to remain in place provided there is 55 m of clearance (IMO, 1989).

There are relatively few other relevant provisions in UNCLOS and the only other key international law is the *Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972* (London Convention) and *Protocol to the London Dumping Convention* 1996 (Protocol). These instruments focus on controlling pollution of the marine environment through regulating the dumping of waste. Under article III of the London Convention, dumping includes the deliberate disposal at sea of waste including 'platforms or other man-made structures' but not 'placement of matter for a purpose other than the mere disposal ... provided that such placement is not contrary to the aims of this Convention'. Again this would permit re-use of obsolete infrastructure as an artificial reef for example. The *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter* (Protocol to the London Convention) expanded the definition of dumping to include 'any storage of... platforms or other man-made structures at sea; and any abandonment or toppling at site of platforms or other man-made structures at sea, for the sole purpose of deliberate disposal' (Articles 4.1.3 and 4.1.4). Again an exception is given that dumping does not include placement for a purpose other than disposal, 'not contrary to the aims of this Protocol' (Article 4.2.2).

It is clear, therefore, that international legal frameworks have favoured complete removal but do not prohibit in situ decommissioning, or the spectrum of options in between including partial removal and relocation. This lack of certainty is unhelpful for countries seeking to implement law and policy and in circumstances where 'decommissioning may become one of the major issues facing the global offshore industry in the near future' (Parente et al., 2006). This brings sharply into focus the need to explore the various decommissioning options from perspectives of engineering, marine science – in relation to both conservation and fisheries – and to analyse laws and policies that can support and facilitate such activities.

Whilst the current regulatory framework has served Australia well during exploration and development phases, decommissioning is not appropriately addressed. In 2014 the Australian Government announced a review of Australia's offshore petroleum resource management framework by the Department of Industry Innovation and Science . The resulting Offshore Petroleum Resource Management Review (of which only the Interim Report of November 2015 has been released) examined the policy and regulatory framework which governs Australia's offshore oil and gas resources across all phases from exploration, project development and operations, through to decommissioning. The last of these was not, however, considered in detail and it is clear that much more work in this area must be done. In particular, in the Interim Report it was noted that '[t]here is a lack of clarity around policy and regulatory requirements for decommissioning offshore petroleum facilities in Commonwealth waters' (DIIS, 2015).

It is therefore timely to consider the myriad of decommissioning issues. In designing a decommissioning law and policy framework a complex balance must be made between economic, environmental, political and societal outcomes whilst addressing 'perspectives of risk and stakeholder expectations' (DIIS, 2015). However, it is clear that an appropriate regulatory framework cannot be developed in isolation of the science and engineering issues. This paper seeks to draw together these areas and advocates for greater inter-disciplinary engagement, as well as public engagement, as Australia seeks to advance its decommissioning agenda.

This article commences by exploring engineering issues, and emergent knowledge, involved in de-commissioning offshore infrastructure. Thereafter the Australian regulatory context is explored followed by suggestions to move the decommissioning dialogue forward. This article contributes to the growing body of literature on in situ decommissioning but in setting a multi-disciplinary research agenda takes a more holistic approach.

Engineering of decommissioning

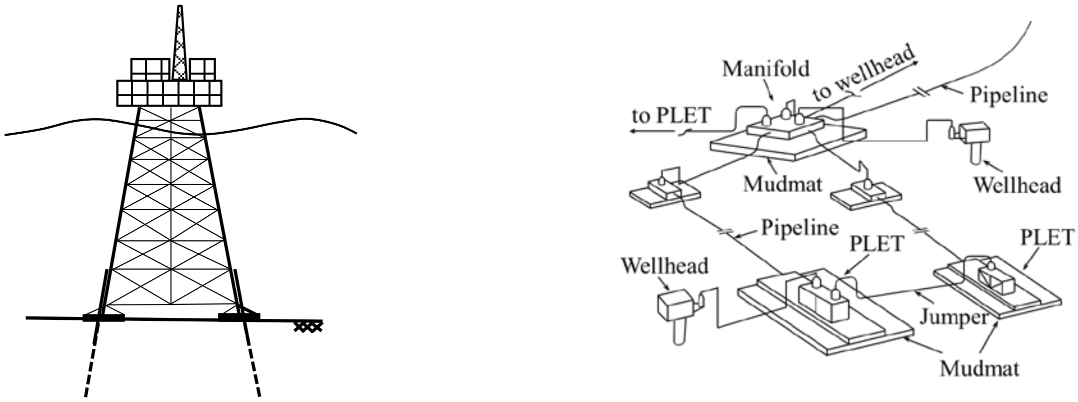
Offshore oil and gas infrastructure types

The offshore infrastructure that requires decommissioning when a field becomes unviable includes a range of facilities with varying scale, such as:

- *Platforms, composed of support structures and topsides.* The support structures are typically of steel latticework, or concrete pillars. The topsides are generally sandwich layers of steel decking supporting the production equipment and ancillary facilities such as accommodation.
- *Floating facilities*. Ship-shaped facilities are an alternative host for production equipment and facilities. These can be sailed away for ex situ decommissioning or re-use at the end of the field life. The associated mooring system of chains, wire rope and anchors also requires decommissioning, as well as the system of 'risers', or vertically-oriented pipelines linking the facility to the seabed.
- *Subsea equipment and supporting structures*. Subsea equipment includes wellheads, manifolds and termination structures for pipelines. An emerging trend is to place other parts of the production equipment on the seabed rather than on a platform or floating vessel, including gas compression facilities.
- *Pipelines.* Infield pipelines transmit hydrocarbons from a network of wells to a single production facility. Export pipelines send oil and gas to shore. Other small diameter pipelines deliver chemicals that are injected to ease flow in the main pipelines, and there are also cables for the provision of electrical and hydraulic power as well as communication via wire or fibre. Other short lengths of pipeline called spools or jumpers are used to connect subsea facilities.

- *Ancillary facilities*. Additional structures placed at the seabed include heavy concrete mattresses, rocks transported from land or other dense structures that are placed on pipelines to improve stability. Various types of structure are also placed on pipeline routes to create undulations that ease the relief of thermal expansion.
- *Wells*. Wells connect a well-head on the seabed to the hydrocarbon producing reservoir and comprise a bore lined with multiple strings of steel pipe, cemented in place. Wells are initially vertical, but at depth can deviate by any angle to horizontal and can extend for distances of several kilometres.

Two contrasting examples of field architecture are shown in Figure 3, which present different decommissioning prospects. Figure 3a is representative of a typical piled jacket, such as the Woodside North Rankin (NR) A and B platforms. These form two of the largest pieces of infrastructure that make up the North West Shelf Venture (NWSV), offshore Australia. The NRB platform has a topsides weight of 23,600 tonnes, supported by a steel jacket weighing a similar amount totalling 23,000 tonnes, standing in 125 m of water. In contrast, Figure 3b is indicative of a fully subsea development, such as the Gorgon project, which has no infrastructure above the water surface. One of the largest structures associated with Gorgon is the manifold structure located above the Jansz gas field, in 1350 metres of water. The manifold and the supporting steel mudmat each have a weight of around 1000 tonnes, occupying a footprint of ~ 40 × 30 m on the seabed. These units required special lifting equipment to be lowered to the seabed, during their installation in 2014.



(a) (b)

Figure 3. Contrasting offshore field architectures; (a) a steel jacket structure, such as at the North Rankin complex, part of the NWSV, (b) subsea architecture, such as at the Greater Gorgon Jansz field

Both the NWSV and Gorgon projects feed gas to onshore liquefied natural gas (LNG) plants. The gas is transmitted via pipelines with internal diameters of 0.6 – 1 m. These pipelines cross ~ 100 km of shallow water, typically 40 - 80 metres deep, where additional stabilisation measures are required to prevent damage during cyclones and under strong tides and internal waves. These stabilisation measures range from an additional layer of 50 - 200 mm of dense concrete applied to the outside of the pipeline, to intermittent anchoring via rock dump, concrete mattresses or piles that are driven or drilled into the seabed.

As outlined earlier in this paper, a common practice in the North Sea and in other regions is to remove all infrastructure upwards from a short distance below the seabed, with minor structures often also being recovered. For example, a recent decommissioning plan from a small North Sea project (Endeavour, 2013) reveals detailed arrangements to recover 250 segmented concrete mattresses, each weighing ~ 4 tonnes, for disposal in an onshore landfill site. For the more high profile case of the Brent Platforms, currently being decommissioned by Shell, a purpose-built vessel has been designed and built, at a cost of approximately US$2 billion. The *Pioneering Spirit* is 382 metres in length and features a unique twin hull design. This allows the vessel to straddle the topsides of an offshore platform and lift the deck free from the structure for removal to an onshore location. The total cost of decommissioning the Brent platforms is expected to be several billion UK pounds (Maritime Executive, 2015). These practices have been driven by legal developments including the *Convention for the Protection of the Marine Environment of the North-East Atlantic* (OSPAR) Annex III that requires States to prevent or eliminate pollution from abandoned offshore installations, and prohibits the dumping of such structures. The later OSPAR Decision 98/3 confirmed that this means the removal of the majority of all structures, with only the possibility of footings remaining. The only derogation from this rule is on a case by case basis and requires international approval (Techera and Chandler, 2015). These examples highlight both the significant engineering challenges associated with the removal of these facilities, as well as the breadth of activity that extends to even minor structures. In all cases, it is necessary to mobilise vessels and crew into a hazardous environment to perform these recoveries, and there are significant financial costs involved.

A conventional rigs-to-reefs approach involving relocation of a rig to another offshore site still requires removal and transport of the topsides and jacket structure, but removes the requirement of onshore disposal of the jacket. An in situ decommissioning approach would in addition alleviate the need for removal and transport of at least part of the jacket.

Beyond purely engineering considerations, approaches and responses may in part reflect different regulatory requirements in each jurisdiction. Permitting in situ decommissioning, or partial removal and relocation will not only affect existing infrastructure that is reaching the end of its life, but also decision-making regarding new projects. This lends weight to the argument that a clear law and policy framework will provide greater certainty for operators and investors.

There is little doubt that there are engineering challenges with decommissioning, whether infrastructure is removed completely, relocated or left in situ. The question can therefore be asked: from an engineering perspective is it possible, and indeed more rational, to leave offshore infrastructure in situ – or relocated elsewhere offshore – for decommissioning? The next section of this paper examines some of the engineering considerations of these approaches.

Engineering assessments: design criteria for the operating life vs. acceptance criteria for in situ decommissioning

If the costs and risk associated with engineered removal are to be eliminated, the alternative must be demonstrated to be safe from an engineering design perspective. The rationale for such an assessment is somewhat different for the post-decommissioned afterlife compared to the initial design life, when the field is producing hydrocarbons and there are many workers onboard. The key engineering design acceptance criteria for in situ decommissioning requires that the structure is sufficiently stable on the seabed that there will not be dispersal of the structure – in either large or small parts – that creates either unwanted environmental impact or a hazard to shipping. In other words, a minimum criteria that will ensure no adverse effect of the decommissioned structure on the surrounding environment and other ocean users. In contrast, during the initial design life for operation producing hydrocarbons and accommodating people, the design criteria are more stringent: tighter criteria govern the allowable movements or deformations of structures and pipelines. These criteria are set by the need for smooth operation of machinery and equipment, and prevention of damage to containment systems that would lead to hydrocarbon release, especially for manned facilities.

As well as the differing design acceptance criteria that apply before and after decommissioning, it is likely that the design inputs will have altered, due to changes in the surrounding environment and the structural condition of the infrastructure over the previous tens of years of field operation. These changes can be both positive and negative. The changes in design criteria and inputs between the initial design of a facility and the in situ decommissioned state are discussed in more detail in the following sub-sections.

Engineering acceptance criteria for in situ decommissioned infrastructure

Conventional engineering design assessments in the oil and gas industry are predicated on a risk profile associated with the presence of hydrocarbons that have the potential to cause explosive damage and environmental harm, often in close proximity to temporary or permanently stationed personnel. Given the high potential consequences of an unwanted event, the design point is chosen to ensure an extremely low event probability, in order that the total risk is acceptable.

For oil and gas facilities that have undergone in situ decommissioning or have been decommissioned and relocated to another offshore site, the engineering integrity of the infrastructure post-decommissioning should be assessed using a different engineering assessment, because the associated risk profile is very different. There is no longer the presence of hydrocarbons – assuming well abandonment and facility purging has been performed correctly – and there are no personnel remaining on the platform (unless the post-decommissioning use involves transformation into, for example, a recreational facility).

The transformed risk profile means that engineering design assessments require recalibration, for example to revisit the ‘safety factors’ that contribute to the margin between the design loads and the available resistance. Also, the choice of input parameters requires revisiting. For example, a steel jacket structure offshore north west Australia may currently be designed to withstand a storm with a 10,000 year return period. This ensures a sufficiently low likelihood of structural damage in that event or other smaller events, given that personnel on-board would be immediately affected by any such failures, or an unacceptable oil spill may be triggered.

In contrast, the same facility when decommissioned offers no potential for hydrocarbon release and no human risk. Instead, engineering assessments must quantify the risk of the facility being unstable and moving en masse or via dispersal to present a hazard to the environment or to other ocean users, e.g. shipping or nearby active facilities. A consequence of instability may simply be a requirement, after the instability has been identified via monitoring, that engineered stabilisation measures be introduced. Therefore, a lower risk level may be tolerable post decommissioning and the engineering assessment may involve less onerous design events and reduced 'safety factors'. As well as instability of the overall facility, it is necessary to consider the potential for disintegration and dispersion of the parts, and the associated hazards and impacts. The potential disintegration and dispersal of subsea infrastructure as well as the main platform structures should be considered. As an example, if the facility corrodes such that erect structural elements disintegrate, they are likely to become more stable when dispersed locally at the seabed.

While the contrasting risk requirements during operation and after in situ decommissioning are somewhat obvious, current engineering practices are not easily translated between scenarios because of embedded assumptions and a lack of previous research focus on the very long term behaviour relevant to post-decommissioned integrity.

Permanent well abandonment (PWA), a critical part of decommissioning offshore oil and gas developments, is an established engineering process. While PWA involves engineering challenges in terms of the number and location of wells to be dealt with and the technology to efficiently and cost-effectively manage plugging and abandonment, PWA is required to the same integrity regardless of the post-decommissioned use or activity, i.e. whether a facility is removed completely, partially or left in situ. It is therefore not a consideration when reviewing alternative strategies for decommissioning.

The design inputs for the stability analysis of two types of decommissioned facility are now discussed. The transformation of certain design inputs over the operating life of the facility is highlighted, showing that these often have a net beneficial effect.

Engineering considerations for decommissioned platforms

Decommissioned platform structures can be left in place or partially removed (e.g. removing only the topsides, or the topsides and supporting structure down to a particular level, such as below the wave zone). The US 'rigs-to-reefs' program has predominantly taken the approach of removing topsides and then toppling or relocated the supporting jacket structure. Once the weight of the topsides is removed, the weight and wind loading transmitted to the supporting structure is significantly reduced, but wave loading on the jacket remains. The net effect is a reduction in load that is beneficial to the integrity of the jacket structure, and can be offset against any reduction in strength due to ongoing corrosion and other structural deterioration.

Removal of the topsides may, however, reduce the overall stability of the jacket structure. The vertical loading from the topsides weight may serve to stabilise the platform. This is because the weight counters any tension and uplift in the upwind legs if the jacket has piled foundations (which are common across the North West Shelf, Senders et al. 2013). If the structure has a flat base resting on the seabed (such as the Bayu-Undan steel jacket platforms in the Timor Sea, Neubecker & Erbrich 2004, or the Wandoo concrete platform, Humpherson 1998), the topsides weight contributes to enhance the sliding resistance. Without the topsides, the platform may therefore be less stable, even though the weight-induced load in the individual structural elements is reduced.

The stability and integrity of an existing platform, at the end of its initial design life, is already commonly assessed for life extensions, where the facility has a renewed purpose or the production is continuing as a result of tieback developments. Life extension requirements have therefore led to the development of methods for reassessing the stability and integrity of a jacket for a period from typically 30 years after installation onwards to up to 60 years beyond. The process of life extending an existing platform has been codified (Norsok 2015), and the techniques are relatively mature. A life extension assessment considers the current (e.g. 30 year old) condition of the facility (so-called condition-based design, e.g. Marshall & Copanoglu 2009, Solland et al. 2011, Paik & Melchers 2014), along with design criteria that are updated if required to reflect better information on the loading and the environment. The life extension analysis may also use new analysis methods that reflect changes to the state of practice since the platform was designed.

For a platform that is decommissioned in situ, the engineering approach can be the same as a life extension, but projecting further into the future, and recognising the changed consequences of failure without hydrocarbons and people present. This type of analysis, using established engineering methods including condition-based design, but projecting further into the future, can establish whether a jacket decommissioned in situ will satisfy requirements for stability and non-dispersion. Extrapolation of the engineering analysis to a longer future period will introduce uncertainties beyond conventional life extensions. For example, corrosion rates in the marine environment vary between regions and with water depth due to differences in temperature, water velocity, and biological effects (Melchers 2006). Effects of climate change on ocean temperature and nutrient levels may also influence corrosion (Chaves et al. 2016). A decommissioned structure may have minimal or zero planned maintenance, and protection and monitoring systems such as cathodic mitigation of corrosion may not be active. This need to project further into the future, under different conditions to the operating life, hampers projections of the deterioration in jacket strength.

The foundations of the jacket may be simpler to deal with. In contrast to this general reduction in jacket integrity, the geotechnical capacity of foundation piles, provided by the surrounding sediment, appears not to deteriorate with time, but generally rises, typically by a factor of 2 or more for some seabed conditions (Lim & Lehane 2014, Yang et al 2016).

Engineering considerations for decommissioned pipelines

Pipelines are often laid directly on the seabed in an unburied state, except where intensive fishing or shipping activity requires burial for protection. To ensure the pipeline is stable through the operating life, it is often necessary to add concrete weight coating or intermittent anchors, rock dump or mattresses that hold the pipe in place during storms. There has been a general recognition for many years that such an approach may be conservative (Palmer, 1996), because the pipe may ‘self-bury’ or lower into the seabed due to sediment transport processes.

This behaviour has only recently been quantified via laboratory testing (Draper et al., 2014; Cheng et al., 2014), backed up by systematic field observations from pipelines offshore of Australia (Leckie et al., 2015). This body of research has been distilled into design guidance that allows the progressive burial of the pipeline during the operating life to be 'banked' in design. This generally leads to a reduction in the stabilisation works required, because the stability of the pipeline progressively rises from the as-laid condition. Techniques are now available to predict whether the metocean environment and local sediment properties are conducive to self-burial, and if so, the rate at which self-burial will evolve, and whether this will be uniform along the pipe length or intermittent (Draper et al., 2014).

This research has application to post-decommissioned pipelines, because the techniques can be extrapolated to the very long term condition of pipelines left on the seabed. In this way, the balancing influences of (i) changing self-burial, (ii) reducing structural strength (due to corrosion) and (iii) potential changes in metocean environment – for example from climate change – can be connected into a systematic assessment of the long-term stability. This is a more rational engineering basis than the conventional design approach which assumes that as-laid burial conditions apply throughout the time period considered.

To date, when assessing the integrity of pipelines for the purposes of in situ decommissioning, direct observations of self-burial have been relied on in assessments of integrity. For example, the Challis field subsea flowlines, located in the Timor Sea, were observed to have become uniformly self-buried with only the upper 10 - 25% visible at the seabed (PTTEP Australasia, undated; Wright, 2015**)**. In this case these flexible flowlines – made from nylon and stainless steel – are expected to have a high longevity in the absence of the pressure and temperature cycles associated with operation.

However, the decay of plastic pipeline coatings, and other plastic elements within structures such as the plastic ropes in concrete mattresses, may eventually lead to a small volume of material release into the oceans. Ocean plastic accumulations are already found globally, and an additional $8M tonnes are estimated to be entering the oceans each year (WEF 2016), with Australian waters having a globally typical density of ocean plastics (Reisser et al. 2013). Set against these numbers, the relative impact contribution is important to recognise. Offsetting strategies may be a more appropriate use of resources, offering a greater net impact on the total volume of plastics present in the ocean compared to imposing a requirement to recover small volumes of plastics that are currently contained within large structural elements and may not be released freely into the ocean for a long period. Meanwhile, in relation to the steel component of pipelines, long term observations of corrosion show that the rates of material decay are highly region-specific (Rosen et al., 2015), as noted earlier for jacket structures.

Engineering considerations for decommissioned subsea facilities

Subsea facilities include a range of infrastructure that support subsea pipelines from the well to an offshore facility or to shore. They include pipeline end manifolds, pipeline end termination structures, in line structures, valve protection structures and pipeline buckle initiators. Many of these structures are supported on mat foundations, often with short vertical skirts that penetrate the seabed.

Engineering design for the operational life of subsea foundations is governed by capacity and serviceability (displacement) criteria. These ensure the foundation is sufficiently large to distribute the structure weight across the seabed and resist operational and environmental loads without unacceptable displacements that may prevent the structure from operating as intended or overstress connections, potentially leading to loss of containment. Development of fields with increasingly high temperatures and pressures in deepwater regions with very soft seabeds (for example, with the strength of toothpaste), leads to heavy subsea structures and increasingly large (and therefore heavy) foundations to support them. An extreme example is the Jansz manifold at ~ 1000 tonnes, while more typically subsea structures and foundations weigh ~1-200 tonnes, but still often require specialist vessels to install them.

Removal resistance of subsea infrastructure can exceed the installed weight due to (i) partial burial of the foundation and (ii) the strength of the seabed that leads to suction developed between the seabed and the underside of the foundations during lifting. The seabed supporting a subsea structure becomes stronger during the operating life simply due to the presence of the structure; the particles of the seabed rearrange in response to the additional weight, and the seabed becomes denser and therefore stronger as a result. A further reduction in seabed density and therefore enhancement in seabed strength can occur in response to operational activities, such as the shearing mechanism in the seabed invoked by thermal expansion and contraction of pipelines attached to a subsea structure.

Recent research has demonstrated gains in capacity of mat foundations due to changes in seabed strength due to simply self-weight loading (Gourvenec et al., 2015; Feng and Gourvenec, 2015) and due to operational processes (Cocjin et al., 2014; Cocjin et al., 2015; Feng and Gourvenec, 2016). Other research has demonstrated the development of suction under skirted mats when lifted, such that a mass of soil is brought up with the foundation rather than simply lifting the foundation off the seabed (Gourvenec et al., 2009; Mana et al., 2013; Li et al., 2015). The additional uplift resistance can be 5 – 10 times the product of the foundation area and the seabed strength, depending on the seabed conditions.

In the context of decommissioning, the increased seabed strength over the field life can have a significant impact on the required lift capacity for removal of subsea infrastructure. A significantly stronger lifting capacity may be required compared to installation. However, for in situ decommissioning, the research findings show that the geotechnical stability of subsea infrastructure may significantly increase over the field life, reducing the risk of dispersal of the infrastructure. This gain in foundation capacity, potentially coupled with a reduction in the loading on the infrastructure from partial removal, will tend to reduce the likelihood of the infrastructure being destabilised after decommissioning, relative to during the operating life.

Engineering aspects: summary

This review of the engineering aspects of decommissioning has highlighted challenges associated with removal of oil and gas facilities, due to their scale. Engineering protocols exist for extending the operation of a facility beyond the original design life, and we have emphasised that these life extension principles represent a skeleton basis for the engineering of in situ decommissioning, which avoids some of the challenges of removal. Models for the long term condition of oil and gas structures, in the face of corrosion and material degradation, can be devised based on life extension approaches, if the future extrapolation has a sound basis. A recurrent theme of emergent research is that the stability of subsea infrastructure is often enhanced, over time, due to changes in the strength and bathymetry of the seabed caused by consolidation and sediment transport. This discovery, when matured into reliable and accepted forecasting models, provides support for in situ decommissioning as opposed to removal. This engineering outcome complements the recognition that these facilities can represent an important habitat for marine biota, which is better left in place than removed.

Meanwhile, the same emergent engineering concepts apply to the intermediate decommissioning option of relocating infrastructure offshore as an artificial reef, potentially with augmentation to maximise its performance as a fishery. Offshore artificial reefs are engineered structures subject to the same environment as oil and gas platforms, and comprised of similar elements and materials (e.g. Scott et al. 2015). Upscaling of this artificial reefing, whether or not connected with oil and gas decommissioning, will also benefit from engineering refinements.

Legal aspects of decommissioning

The regulatory challenges

The above analysis demonstrates the extent of recent research and developing engineering knowledge. Such information is critical if a science-based policy approach is to be taken. There is little doubt that there are further issues at the intersection of engineering, law and policy which will need to be explored further before any law and policy shift is made. At this point it is important to reflect upon the role of law and policy. Public policy provides a context and agenda which is actioned through regulation. Law itself can therefore be both regulatory and facilitative. Clearly there are standards to be set that must be adhered to with repercussions for failure to meet those standards. But law can also be utilised as a lever to facilitate the achievement of a policy outcome. If a change in policy is adopted, and in situ decommissioning becomes preferred, then the law can be drafted in ways aimed at facilitating this goal. The National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA) and the petroleum industry in Australia, is currently facing these very issues. Before considering recommendations for the future, the current Australian regulatory landscape must be explored.

The Australian Context

Australia is a federal jurisdiction which presents some special issues in the regulation of decommissioning, even offshore. The scheme of the Commonwealth Constitution is to allocate specific powers to the Commonwealth and residual powers to the states. The Commonwealth does not have a specific power to legislate for minerals and petroleum resources. Jurisdiction over onshore mineral and petroleum resources does not fall within the ambit of the enumerated powers in s51 of the Commonwealth Constitution. Having said that, certain of the Commonwealth's powers (such as under s51(xx) (Corporations), or s51(i) (Trade and Commerce) and s. 51(xxix) External Affairs) are sufficiently broad to allow control over major aspects of petroleum operations. The 1958

Geneva Convention and the external affairs power formed the constitutional basis for the Commonwealth to enact legislation regulating petroleum operations on the Australian continental shelf. The discovery of petroleum in the Bass Strait off the south-east of Australia in the 1960's prompted the passing of legislation to regulate those activities in the form of the Petroleum (Submerged Lands) Act 1967 (Cth), which was followed by the states and Northern Territory for their legislation, the intention being that there would be a common mining code regulating the continental shelf. A few years later the Commonwealth asserted its sovereignty over Australia's continental shelf as against the states and territories of Australia through the Seas and Submerged Lands Act 1973 (Cth). This was challenged by the state of New South Wales but was upheld by the High Court of Australia in *New South Wales v Commonwealth* (1975).

At that time the Commonwealth had virtually no competence in petroleum regulation while some of the states, such as Western Australia, did have and had been issuing permits offshore. So rights over the offshore area were segregated, under the Offshore Constitutional Settlement, an arrangement much of which persists to this day, with the states and Northern Territory playing an important role in the day to day regulation of petroleum operations (OPRR, undated). As a result state or territory offshore petroleum legislation applies for their coastal waters (the inner three nautical miles), and state or territory onshore legislation applies for internal waters, and any onshore operations. The Commonwealth legislation (and not the state or territory legislation) applies over the rest of the continental shelf. This area ("Commonwealth Waters") extends from three nautical miles offshore to the edge of the continental shelf, including the Exclusive Economic Zone (EEZ) (12-200 nautical miles).

What this means is that a gas pipeline connecting an offshore field in Commonwealth Waters to an onshore terminal would require three separate licences, one for each area. Decommissioning that pipeline would involve consideration of Commonwealth and state or territory petroleum legislation as well as other relevant Commonwealth and state and territory legislation relating to matters like the environment, safety and other specific areas (such as sea dumping).

The main focus of the rest of this section will be the decommissioning rules applying in Commonwealth Waters. There are several reasons for this. The first is that Commonwealth Waters include Australia's most important offshore sedimentary basins; the Carnarvon and Browse basins off Western Australia and the Gippsland basin off the coast of Victoria. The second, which is explained below, is that Commonwealth competence and influence over offshore petroleum regulation has been growing steadily since the 1960's and that of the states and the Northern Territory has declined. Finally, notwithstanding the enactment by the Commonwealth of an updated version of the mining code contained in the 1967 legislation, it still contains principles which are followed by the other states and Northern Territory in their offshore petroleum legislation. The principle statute which now regulates exploration and production of petroleum in Commonwealth Waters, including the development of fields and their decommissioning, is the *Offshore Petroleum and Greenhouse Gas Storage Act 2006* (Cth) (OPGGSA). The OPGGSA provides in s 572(3) that: "A titleholder must remove from the title area all structures that are, and all equipment and other property that is, neither used nor to be used in connection with the operations:(a) in which the titleholder is or will be engaged; and (b) that are authorised by the permit, lease, licence or authority." This provision is similar to the analogous provision contained in the statute replaced by the OPGGSA, s98 Petroleum (Submerged Lands) Act 1967 (Cth). The main difference is that s98 puts the removal obligation on the operator, while the OPGGSA puts it on the titleholder. As is discussed below, the OPGGSA does admit the possibility of in situ decommissioning, but exceptions to the removal principle and the associated policy are not well-developed.

The other principal Commonwealth Acts that need to be considered for Commonwealth Waters are the Environmental Protection and Biodiversity Conservation Act (EPBCA) and the Environment Protection (Sea Dumping) Act 1981 (SDA). The EPBCA provides that a person must not take an action having, or likely to have, a significant impact on the environment in Commonwealth Waters without the approval of the Environment Minister. The SDA, which implements the 1996 Protocol to the London Convention, requires a permit from the Minister for the Environment to dump waste, including platforms and man-made structures, in Commonwealth Waters.

Since 2005 significant reforms have taken place in the regulation of petroleum activities in Commonwealth Waters and, apart from sea dumping which remains with Department of the Environment, day to day administration is now in the hands of two Commonwealth bodies, NOPSEMA and the National Offshore Petroleum Titles Administrator (NOPTA). NOPSEMA was given statutory responsibilities which include occupational health and safety, structural integrity of facilities, wells or well-related equipment and environmental management under the *Offshore Petroleum and Greenhouse Gas Storage Amendment (National Regulator) Act 2011* (Cth). NOPTA is responsible for resource management, titles administration and advice to the Joint Authorities; a Joint Authority exists for the offshore area proximate to each state and the Northern Territory, constituted by the resources minister for the relevant state or the Northern Territory and the Commonwealth minister. The Joint Authority concept goes back to the 1967 common mining code and is the main remaining state and territory involvement in decision-making. As part of the reforms of the regulation of offshore petroleum the applicable regulations were consolidated and revised, a task completed in April 2011 resulting in the *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009* (Cth), *Offshore Petroleum and Greenhouse Gas Storage (Safety) Regulations 2009* (Cth), and *Offshore Petroleum and Greenhouse Gas Storage (Resource Management and Administration) Regulations 2011* (Cth)).

Under the OPGGSA and its regulations decommissioning activities must be conducted under an accepted field development plan, well operations management plan, offshore project proposal, environmental plan and safety case, and accordingly variations to cover the decommissioning activity will have to be approved before it commences. NOPTA reviews field development plans which require approval by the relevant Joint Authority. NOPSEMA approves the other plans and the safety case. The starting point for the NOPSEMA approvals is an offshore project proposal which must be submitted under the Environment Regulations prior to commencing an offshore project and which covers any activity undertaken for the purposes of the recovery of petroleum. The offshore project proposal is a life-of-project approval which describes each activity that is part of the project, the facilities used and how those facilities will be dealt with at the end of the project. An environment plan cannot be submitted until NOPSEMA has accepted an offshore project proposal that includes that activity. As a result of other streamlining reforms in 2013 approval of actions subject to control under the EPBCA, is generally no longer required. This is because environmental approval by NOPSEMA of most petroleum activities in Commonwealth Waters is taken to satisfy EPBCA requirements.

The possibility of an alternative to the removal obligation in OPGGSA s.572(3) lies in the fact that it is subject to any other provision of the OPGGSA, the regulations and a direction given under certain sections (see s.572(7)). Indications of other approaches are to be found in several places. OPGGSA s.270, which deals with the surrender of titles, provides that the Joint Authority may only consent to a surrender of a title if the titleholder has to the satisfaction of NOPSEMA removed all property brought into the area to be surrendered by any person concerned in the operations authorised or "made arrangements that are satisfactory to NOPSEMA in relation to that property". OPGGSA, s.586, which gives NOPSEMA power to issue directions to titleholders to remove property from a title area, also allows NOPSEMA to direct the titleholder to make other arrangements satisfactory to NOPSEMA in relation to property. Presumably these arrangements could fall short of complete removal. If the titleholder was able to make arrangements satisfactory to NOPSEMA for non-removal in connection with surrender of the title, then this would squarely raise the question of whether the removal obligation had been overridden. As a practical matter, if the surrender was consented to by the Joint Authority in those circumstances, it is inconceivable that action would be taken to enforce removal under s.572(3). The question then becomes one of whether it is possible to make those arrangements.

There is currently no clear policy guidance on whether in situ decommissioning would be accepted and in what circumstances. As a practical matter the fact that the removal obligation is subject to the qualifications mentioned in the previous paragraph means that the regulator's views can have a large influence on the way decommissioning is carried out, and the titleholder and regulator are forced to negotiate about which decommissioning option is suitable (Barrymore and Butler, 2015). A discussion paper produced in 2008 highlighted several things. First, that there are a number of ways in which a structure may be decommissioned and that the most appropriate option will likely vary between installations (DRET, 2008). One of the options discussed was the creation of artificial reefs (DRET, 2008). The point is made that the case for an artificial reef may need careful, evidence- based assessment and analysis which critically considers a range of matters including the values and motivations, the likelihood of artificial reefs addressing those values, evidence of other impacts and potential impacts on fisheries. Second, that discussion paper suggested that 'any decommissioning proposal needs to have an acceptable environmental impact, acceptable safety considerations, not expose other users of the sea to risks, and, within these constraints, minimise cost for industry and any residual liabilities for the community'. This can be regarded as supportive of in situ decommissioning (DRET, 2008). Third, the existing regulatory model involves a range of authorities and decision makers and there may be opportunities for streamlining.

What would be an acceptable environmental impact for a plan involving in situ decommissioning is likely to be a critical matter. The Environment Regulations incorporate an outcomes-based approach through the requirement of an environment plan governing decommissioning. The outcomes sought include reducing environmental impacts and risks of an activity to as low as reasonably practicable. The *Environment Regulations, 2009* require that the plan must demonstrate that the environmental impacts and risks of the activity will be of an acceptable level. Minimizing environmental impact may necessitate in situ decommissioning in some circumstances, if complete removal would pose a greater environmental risk or cost. Such a scenario is likely where significant coral reefs have developed on infrastructure, or where ecologically-significant species are resident. For example, the detection of an endangered deep-water coral species on structures in the North Sea during the 1990s raised ethical and legal issues regarding the protection of such species during the decommissioning process (Bell and Smith, 1999).

Setting the agenda

Australia has become a global leader 'adopting new technologies and developing innovative approaches to oil and gas exploration' (DIIS, 2015). It is clear that the same level of leadership is now needed to provide clarity and certainty on decommissioning. The Interim Report indicates some appetite for this with identified actions including development of a clear policy framework for the decommissioning of offshore petroleum fields and associated infrastructure and that the 'Department of Industry, Innovation and Science will work with NOPSEMA, government agencies, industry and other stakeholders to develop a decommissioning policy framework' (DIIS, 2015).

The above analysis demonstrates that different types of offshore infrastructure (for example, platforms versus pipelines) will require different engineering solutions, and therefore legal responses. This diversity may require more sophisticated law and policy responses extending beyond simple weight and water depth differentials provided for in the current international legal framework. The issues are made more complex because of the differing ages of the infrastructure; some was constructed at a time when removal was a clear requirement and yet it has been said that 'most offshore structures were not designed to be removed' (Parente et al., 1994). Further work is needed to map out the characteristics of the infrastructure and engineering issues pertaining to each.

Similarly, in relation to legal issues, NOPSEMA has acknowledged that a 'necessary first step … will be to examine decommissioning frameworks in comparable regimes around the world, to identify what has and has not been successful and the reasons why (DIIS, 2015).' The oil and gas industry may be global but there are a wide range of different legislative frameworks across the world, creating a complex regulatory landscape (Techera and Chandler, 2015). NOPSEMA has recognised that it is unlikely, given the differing ocean environments, that there will be a one-size-fits-all approach that would apply in all countries (DIIS, 2015). Nonetheless, science-based policy may lead to a suite of best practice options. A comparative analysis, from a variety of disciplines, is thus warranted.

The Interim Report also notes areas of concern in different disciplinary fields. In order to influence government and progress the policy shift necessary, these disciplines will need to work together to provide coherent and comprehensive evidence-based recommendations. The emergence in recent years of multi-disciplinary research centres and teams provides a valuable opportunity to do so. Such concerns are not limited to engineering and law. NOPSEMA has noted that

> 'as is the case with many complex public policy decisions, the most challenging aspects relate to uncertainty and values differences, particularly where these combine and make it

> difficult to identify options acceptable to all stakeholders. Similarly, differing perceptions of risk – especially where these occur over different timeframes – make it challenging to quantitatively compare and choose among decommissioning options based upon, for example, predicted environmental impact' (DIIS, 2015).

To overcome this challenge, and achieve a holistic approach to decommissioning, it is necessary to evaluate information on different considerations (law, engineering, environment, social, safety) against the criteria of multiple stakeholders. Emergent research and evidence cannot be applied without such a framework that facilitates quantitative and defensible decommissioning decisions that optimise decommissioning outcomes across competing stakeholder groups. Fowler et al. (2014) describe one such framework, based on participatory multi-criteria decision analysis (MCDA). A recent example of this new decommissioning approach is Shell UK's stakeholder consultation for the decommissioning of infrastructure in the Brent field, which involved direct stakeholder input into a multi-criteria decision analysis (Shell 2013).

One critical input to such a holistic approach will be determining the value for stakeholders of various potential re-uses of decommissioned infrastructure. These may include 'artificial reefs, marine research facilities, renewable energy technologies, aquaculture, and tourism' (DIIS, 2015). Of these options, the artificial reef option would conventionally require removal and relocation of platforms but would provide the best environmental outcomes if structures are not removed, given the extensive development of reef organisms that may have already occurred at installation sites. The other options would utilise infrastructure in situ for further development.. It is critical that the 'decommissioning decision-making framework must have flexibility to adapt to changes in science, technology, stakeholder perceptions and other circumstances' (DIIS, 2015). These decisions are important because if complete removal is favoured it has a more finite end point, whereas re-use will require ongoing 'complex legal and regulatory processes that require decisions around ownership transfers and liability' which must be provided for in any new regulatory framework (DIIS, 2015).

The Interim Report clearly envisages interaction with stakeholders including owner and operators themselves as well as engineering experts. Engagement is also needed with other disciplines including natural and physical sciences, as well as social sciences including sociologists, economists and those engaged in corporate governance. If anything can be learnt from the UK experience involving Brent Spar, it is that community engagement and support is critical.

The Interim Report does not deal with decommissioning in any detail and makes few recommendations beyond suggesting that it 'should be on a case-by-case basis' and that [s]afety and navigation will be of paramount concern, and the Australian Maritime Safety Authority should be involved in the planning process' (DIIS, 2015). It is therefore critical that further research is undertaken, in partnership with all stakeholders, alongside consultation envisaged by NOPSEMA, to inform science-based policy-making.

A further contribution to the Australian decommissioning debate is the recent report by the Australia's Federal Government Growth Centre, National Energy Resources Australia (NERA), on the Australian oil and gas industry competitiveness (NERA 2016). NERA highlighted Australia's requirement to build capability in the Abandonment phase of projects, describing Abandonment as "*a looming threat, or an opportunity*". NERA highlights Australia's US$21B future liability associated with decommissioning – which is shared between operators and taxpayers – and states that "*The opportunity and rationale is clear for Australia to invest and build the relevant capability before the wave of decommissioning activities commences. By finding solutions to reduce risk, time and cost of decommissioning, Australia could maximise value in this phase of the Oil and Gas value chain.*"

This call to arms urgently invites intensified cross-disciplinary activity, across research, policy and public awareness, in partnership with all stakeholders in Australia, to seek and facilitate novel approaches to oil and gas decommissioning.

Conclusion

Whilst all stakeholders will want to ensure decommissioning is achieved in the best way possible, a vital first step is determining precisely what it is that needs to be done. There is little doubt that pressures on the ocean environment will only increase. Growing populations will increase demand on fisheries and likely lead to the development of large offshore aquaculture projects. Similarly, the demand for energy may see broad implementation of wave energy and other renewables. Meanwhile, much of Australia's oil and gas infrastructure is located among popular commercial and recreational fisheries, and there is evidence that this infrastructure contributes to the abundance of marine life. This diversity of ocean uses militates against a purely targeted approach focusing on decommissioning in and of itself. A holistic approach, focusing on cross-industry and multi-disciplinary outcomes will be needed. Because Australia developed a strong offshore petroleum industry later than other jurisdictions, it is only now facing large scale decommissioning challenges; or viewed differently, opportunities.

Governing bodies and industry should carefully study the experiences of other nations in an attempt to adopt best practice and avoid previous pitfalls; and make a substantial investment in coordinated research across the numerous fields relevant to decommissioning. This review has highlighted the evidence that Australia's oil and gas infrastructure hosts diverse biota, and has shown that current engineering life extension approaches, coupled with emergent research, offer new potential to reliably evaluate the stability and integrity of infrastructure that is decommissioned in situ, or which is relocated and repurposed offshore. Development of this evidence base to support in situ or offshore-relocated decommissioning of obsolete platforms based on a rigs-to-reefs concept, along with in situ decommissioning of subsea infrastructure, could serve all stakeholders and the environment well. Australia is thus in a unique position to show leadership in adopting innovative approaches, but this must rest on a strong evidence base.

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