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From the lab to the industrial park: lessons for the energy transition from past technology policy failures

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Production, distribution and use of natural gas in commercial and domestic settings is a well-established industry with an excellent public safety record in Australia despite the inherent risks. The industry faces a significant challenge in maintaining this in the escalating energy transition. Emerging technologies for hydrogen and other future fuels will move rapidly from bespoke, experimental, lab-based facilities to full-scale, manufactured, process plant with the necessary resources (both physical and human) stretched to the limit. A large effort in engineering research is targeting solutions to the myriad of technical issues that must be addressed, but too often we overlook the sociotechnical risks to public safety that must also be managed for the transition to be successful. This paper addresses such risks. Sociotechnical risks arise at all levels from government policy, through regulation, organizations, risks that arise from the capabilities, affordances, and constraints of the technology, risks that are epistemic in nature, and collective values, norms, and practices. We trace each of these sources of risk as they relate to the energy transition drawing on past cases of emergent technologies and failure cases for clues as to how such outcomes might be avoided.

Keywords: Emerging technologies, sociotechnical risk, hydrogen

1. Introduction

The transition to future fuels has already heralded a time of change for the gas sector and the pace of change is only going to accelerate. Processes and practices for managing gas safety are well understood and while there is a continuing commitment to public safety through this tradition, the industry is challenged with understanding how to manage sociotechnical risks through the energy transition. This paper presents a preliminary framework to support this.

The introduction of hydrogen and/or biogas and other future fuels into the existing gas system no doubt involves technical change, but it also involves other types of changes to the way work is done in organizations. This includes such issues as an increased pace of change generally, a change in skills required of technical staff, changes in experience and so competency that can be expected from suppliers and manufacturers, lack of past operating experience that would normally provide the basis for safety management and uncertainties and challenges to the regulatory environment. Changes will also occur in the base business of the gas companies as priorities change and revenue drivers shift. It is these changes to the social, rather than technical, aspects of the system that are the focus of this research paper.

2. Transition to Hydrogen

Australia produces gas domestically for use in homes and industry, and for export. A network of around 42,000 km of high pressure natural gas transmission pipelines, plus the associated low pressure distribution systems, transport gas from the remote locations where it is extracted and processed to populated areas where it is used. Natural gas currently provides 27 per cent of Australia's total energy needs including 19 per cent of energy for electricity generation and is used as a feedstock for petrochemicals manufacturing (AEP

2024). Due to its capital intensive nature, the industry for gas extraction and processing is undertaken by international oil majors. Onshore transportation and distribution are undertaken by a different group of companies with a stronger focus on energy markets and users. It is the ongoing operations of these gas pipeline companies (and the associated supply chain and regulators) that are the focus of this research.

Australia has committed to net zero carbon emissions by 2050 and as a result natural gas use is planned to move towards higher value and non-substitutable uses. There is currently significant debate about the best pathway towards decarbonization of household energy and the ongoing role of fuel gases. The gas sector has several trials for hydrogen injection into domestic networks underway and is planning to repurpose much of the existing gas network for hydrogen /natural gas blends and eventually pure hydrogen. Their business plans also include moving into hydrogen production, largely through use of electrolyzer technologies.

These plans are evolving rapidly but it is risks associated with such a major transition in the focus of gas pipeline businesses that are the subject of this research.

3. Method

3.1. *Framework for Sociotechnical Risk*

To study the impact on risk of the transition to hydrogen, we have chosen to use a sociotechnical framework which focuses on the interactions between the technology and the people who are involved in every aspect of selecting, governing, designing, constructing, operating and maintaining technological systems (Reason 1990). Together, the people and the technology comprise what can be called a sociotechnical system. Macrae's SOTEC framework for describing and categorizing sociotechnical sources of risk integrates structural, organizational, technological, epistemic, and cultural sources of risk. This is not to say that these sources of risk are independent – far from it. As Macrae notes 'each of these five domains of sociotechnical risk is deeply interrelated to and constitutive of the others, with the patterns of risk identified here amplifying, reinforcing, interacting and overlapping with one another' (2022, pg 2013). The framework was developed based on a review of autonomous vehicles (Macrae 2022) and has since been applied in the context of AI use in healthcare (Macrae 2024) and robotics (Winter et al. 2024). This work applies the same framework to the gas industry transition to hydrogen.

3.2. *Data Sources and Analysis*

This paper is based on desktop research which involved review of past accident cases, especially cases that involved an emergent technology, coupled with a review of the literature on risk in cases of emerging technologies and energy transitions. We reviewed a wide range of sources looking for perspectives on sociotechnical risks relevant to the energy transition and key management strategies. These sources address risk prospectively and retrospectively. As part of the process of establishing the nature of the challenges that the industry faces we have conducted this review of the literature in conversation with an industry steering group, who have had some input into our review especially in terms of relevant disaster cases, and have been able to comment on our findings in regular meetings. Our understanding of the transition context also comes from attending industry symposia including several online industry events in Australia and internationally. The primary data sources are detailed below.

3.2.1. *Accident Case Studies*

Based on our knowledge of past major accident cases and including some recommendations from the industry advisory group, we have chosen a set of accident cases to review including Chernobyl (Higginbotham 2019), Challenger (Higginbotham 2024), Titan (United States Coast Guard 2024), the Australian Home Insulation Scheme (Hanger 2014), and California energy policy (Blunt 2022) to appreciate how sociotechnical sources of risk play out.

3.2.2. *Academic and Grey Literature*

We have purposively reviewed academic literature drawn from various disciplines (risk, science and technology studies, organizational sociology, megaprojects and engineering studies) seeking out key publications, running keyword searches in leading journals, and chasing sources that others have referred to. We have also reviewed publicly available material on risks and lessons learned from the energy transition.

4. Findings

4.1. *Structural Sources of Risk*

Structural sources of risk arise from interdependencies and interactions between different parts of the technical and social structures. Structures act as sources of risk by amplifying or transmitting local sources of failure. Structural characteristics of the system allow failures in one area to rapidly degrade or impact on other parts of the system. In the hydrogen case, the social structures of the sociotechnical system are largely fixed by the existing gas industry. Structural risk arises when there is a mismatch between the existing structural arrangements and the requirements of the new sociotechnical endeavour of transitioning to a new source of energy.

4.1.1. *Safety Regulation in Conditions of High Uncertainty*

An effective regulatory regime in practice fosters the continuing coproduction of social order (in our case, no accidents) by integrating both science and the law (Demortain 2017). This is difficult enough when it comes to public safety where the events that regulation is designed to prevent are rare but catastrophic. For new technologies, uncertainty is increased even further due to the lack of a track record to draw on. The stakes are high, so it is important to consider how regulation addresses new technologies.

The options for regulation of new technology can be thought of as two-fold – stretching the pre-existing legal framework to cover the new application or creating a novel regime (Faulkner and Poort 2017). Hydrogen technologies likely to be adopted by the Australian gas industry are process facilities based on unit operations that have the same ethical and moral imperatives regarding workers and public safety as existing natural gas facilities (see Section 4.3). Based on Faulkner and Poort's arguments, there is no reason to adopt a different form of regulation in moving to this technology.

Other key factors are 1) the necessity for regulatory decisions to be based on the best evidence available and 2) the key role that regulators can play in sharing new knowledge across a sector (including across suppliers and other supply chain actors) as new technologies move into operations and an experience base develops. Australian regulators could play an important role in identifying and sharing performance trends (see also Section 4.2.1).

Uncertainty in the basis of regulatory decision making is a risk in the hydrogen transition, particularly when there is little operating experience available.

4.1.2. *Political agendas*

When it comes to the energy transition, regulation of industrial safety is only one aspect of the structures that link industry and government. It has long been the case that government has an interest in industry promotion due to the economic benefits that can bring but following major disasters in the twentieth century, government functions related to industry promotion and worker safety were structurally separated to ensure that regulation of worker safety was not compromised by other government policy objectives.

In an environment where decarbonization of the economy is a whole of government priority, the interaction between safety and other government policy objectives has the potential to impact safety outcomes. Vertesi and Boyd (2023) describe how political decisions linked to resources (both time and money) can put public sector organizations responsible for complex technologies (NASA and the US Census Bureau) into a 'resource bind' that impacts their ability to do their job. In practice, this can manifest as politically determined roll out dates, and the choice to pursue one technological solution over another. These kinds of issues played out in the California energy policy case, and the Chernobyl and Challenger disasters. Regulation of hydrogen safety could be predictably compromised by politically determined decarbonization targets, budgetary constraints, and even choices about where to invest.

4.1.3. *Project Delivery*

The energy transition by its very nature will involve significant capital works (Merrow 2024). The way in which capital works are executed has a significant impact on safety in operations as the accident record demonstrates. The Grenfell Tower disaster in London in 2017 (GTI 2019) from the built environment sector shows just how bad the outcomes can be when procurement goes wrong. In this case, cladding that failed to pass fire rating tests was knowingly supplied to a project that retrofitted it onto a high rise residential tower. As a direct result, an electrical appliance fire in one apartment rapidly spread to the entire building and 72 residents were killed.

Recent research related to risk governance in procurement (Hayes et al. 2023) speaks to risk sources in the area of project delivery, many of which are structural in nature. Bi-directional interconnectivity is important in supply chain and procurement systems, particularly within complex engineered projects that impact public safety such as we will see in the energy transition. Drawing on Roe and Schulman's interconnectivity framework (2023), the research showed that procurement failures often stem from viewing interconnectivity as a series of uni-directional transactions aimed at shifting risk, rather than fostering collaborative relationships. Facilitating reciprocity and collaboration among system actors promotes transparency and knowledge sharing, reduces costs, and minimizes delays, ultimately leading to better and safer project outcomes. Establishing trust-based relationships, utilizing suppliers' expertise, and adopting collaborative project delivery arrangements, such as early contractor involvement, can enhance project performance and safety in the hazardous sector. These factors only become more prominent in the hydrogen environment where epistemic risk is significant.

Effective mitigation strategies will be found in establishing the best structures for project execution. This research suggests that forms of relational contracting such as Early Contractor Involvement (ECI) may be most effective.

4.2. *Organizational Sources of Risk*

Organizational sources of risk arise from the social processes, organizing activities, and human and contextual factors that underpin new technologies (for instance, as detailed in Reason's (1997) Swiss cheese model.

4.2.1. *The Gift of Failure*

For new technologies in particular each fault and problem as technology is rolled out is a 'gift of failure" (Carroll and Fahlbruch 2011). Success and failure can be two sides of the same coin (Hayes and Maslen 2023) and so any failure has the potential to provide useful insights into the state of the entire system and so should be valued.

Learning from small failures has been taken up enthusiastically by many sectors and has led to the proliferation of database applications for recording and classifying incident reports. These knowledge embedding artifacts serve as 'boundary-spanning objects' that transfer, translate, transform, and distribute knowledge (Hecker 2012). They provide a mechanism for disparate pieces of knowledge to be connected or for specific pieces of knowledge to be shared. Each of these mechanisms is important in the context of collective knowledge for preventing rare events.

In the excitement of the new, early success can be taken as a sign that all is well. In the worst case, those involved lose the ability to imagine worst case scenarios and so the potential for disaster (Pidgeon and O'Leary 2000). We see this at play in the cases of Chernobyl, Challenger and Titan where earlier signs of trouble in similar facilities or on earlier missions were dismissed as irrelevant and/or the overall success of a small number of earlier missions was seen as a sure sign that risk was sufficiently controlled.

Organizational systems for collecting and analyzing data on failures are thus critically important in a safe hydrogen transition as are mechanisms for sharing between organizations.

4.2.2. *Forgoing Testing in the Rush to Production*

Losing the ability to imagine that the system might fail can have a direct impact on engineering work. This is never more important than in major capital projects linked to new technology such as hydrogen. During the fabrication and construction of new facilities, a key process for finding and correcting faults is effective inspection and testing (Hayes et al. 2023).

In the procurement context, inspection and testing is a key risk control in making latent problems manifest at the earliest possible stage. The effectiveness of inspection and testing regimes both depends on and also serves to build important trust relationships through the supply chain. Although in a project environment, such processes can be seen as causing needless delays. Accident cases also warn against cutting corners on inspection and testing, in particular Chernobyl and Titan.

Table 1. Current and future gas sector orientations towards hydrogen technology.

Quality	Existing orientation	Future orientation re future fuels
Similarity/difference	Remotely operated flammable gas pipelines. Some companies are also experienced with process plant/unit operations including compression equipment and similar.	The broad nature of the facilities is unchanged although different unit operations will be introduced. Hydrogen is similar to natural gas. Differences are in scale but not nature.
Maturity	Mature technologies with incremental innovation.	Immature technologies still in the development phase.
Availability	Well established supply chains, experienced vendors and contractors with a large pool of resources to draw on.	Competing in a tight global market with a limited pool of highly stretched suppliers.
Location	Pipelines are a highly distributed system, but operationally largely passive with mainly remote operations.	Distributed hydrogen facilities could mean a substantial dispersed asset base of a type which requires more frequent on site presence.
Familiarity	Very familiar. Decades of operating experience to draw on.	Very unfamiliar. Only pilot scale facilities in existence. Many industry players have no specific experience of operating or maintaining these facilities.

4.3. *Technical Sources of Risk*

Technological sources of risk arise from the capabilities, affordances, and constraints inscribed into and produced by new material technologies. Table 1 shows some broad qualities of hydrogen technology compared to existing gas technology. While these may pose technical risks which must be addressed, in this context the sociotechnical implications are considered in developing the other four sources of sociotechnical risk.

4.4. *Epistemic Sources of Risk*

Epistemic sources of risk arise from the ways that knowledge and ignorance are constructed in relation to, and within, the new technology. Given the significance of knowledge to disaster prevention, we need to attend to questions of expertise, knowledge sharing, and the potential for perverse treatment of knowledge especially in the case of emerging technologies.

4.4.1 *Lack of Expertise*

Safe operations are critically reliant on the professionalism of personnel, but organizations often fail to recognize this or properly support its development. In the transition, one of the primary challenges that the industry faces relates to limited expertise in designing and operating systems with hydrogen. Such limits manifest in two ways – existing staff who may be expert in natural gas engineering but have little experience with hydrogen and new people brought into the sector to meet resourcing needs.

When we think about expertise it is important to keep in mind different forms of knowledge and how they interrelate. Engineering knowledge often calls up conceptual knowledge. While this is a critical foundation to engineering practice, we also know that field experience is vital to making sound decisions giving engineers a sense of what the technology that they are designing looks, feels, and sounds like in practice, and so what this means for construction and operation, and the management of risk (Ferguson 1994; Maslen and Hayes 2022). Within the sector there are some engineers that worked with hydrogen in the 1960s but for the most part the industry is facing a lack of hands-on expertise with hydrogen.

4.4.2 *Overconfidence in the face of uncertainty*

The technical failures that occur at the sharp end of major disasters are almost always the result of failure to recognize and apply known technical knowledge to a particular situation. The Titan submersible case offers a powerful reminder about how epistemic risks can manifest. Especially in the context of non-technical pressures whether economic or political, people working with emerging technologies people may be overly confident about their expertise in an area that they actually don't have depth of experience in. Those who act under this mindset may believe they are pushing boundaries or innovating, but they ultimately fall victim to their own cognitive blind spots.

4.5. *Cultural Sources of Risk*

Hydrogen technologies will be introduced to an established industry with well-defined cultural norms that will be challenged in several ways.

4.5.1 *The Need For Speed*

The first source of cultural risk that is particularly relevant to the hydrogen transition is attitudes towards time. The pace of change is very rapid and increasing which creates conditions that may cause problems in project execution and also makes it more difficult for public safety-related decisions to be made with the long term in mind.

The nature of capital project work always emphasizes the short-term goal of on time, on budget completion, but the energy transition is aiming to proceed at an even more accelerated pace than usual. Placing such a premium on meeting deadlines means that, in project organizations, speed is celebrated as 'a synonym of good' (Czarniawska 2013, pg 11) despite the problems that taking shortcuts can cause. Working at excessive speed poses a risk of 'false economy' where problems are identified late and are expensive to fix or even that facilities are put into production before all sensible safety checks are completed.

4.5.2. *Lying at Work*

Pressure on workers to achieve performance goals irrespective of the resources available to them creates conditions for a second source of cultural risk within organizations. A recent case relates to lying at PG&E related to their one call system performance (Hayes, Maslen, and Schulman 2024). Digging deeply into that case, we found that lying can grow up when people are given an impossible task threatened with severe consequences if the required performance is not met. People create what they conceptualize as 'short cuts' by reporting that work is done when it really has not been, even though an external view might be that they are telling outright lies with potentially serious longer-term consequences. Once such behaviors become established, it is very hard for anyone to change what is going on without external involvement – an external audit, a whistle blower - that bursts the bubble of belief that has been created that this is OK and relates the behavior back to the potential long-term impact.

It is not difficult to see that organizational conditions in the hydrogen transition requiring people to completing huge amounts of work in conditions of uncertainty with very tight deadlines means the environment is ripe for this kind of behavior to occur. Recent reports about faked research results regarding tests on hydrogen refueling equipment at a South Korean research institute called Korea Institute of Industrial Technology (Kitech) seem to be just such a case (HIL 2024).

It is to be expected that problems will arise in development and implementation of hydrogen technology. For early faults and failures to be available for organizational learning, incentives to cover up problems must be minimized. The PG&E study emphasized that preventing systematic deception requires fundamental changes to organizational systems and culture. Managers must be prepared for bad news to emerge if they want change to happen. In addition, the research highlighted that the design of reward systems must ensure that desired behaviors are actively encouraged rather than just providing an incentive to hide undesired behaviors and or outcomes (Hayes, Maslen, and Schulman 2024).

4.5.3 The People Left Behind

The creation of new business areas within the gas companies will necessarily be done in parallel with running the gas facilities that have been in place for many years. There is potential for risk associated with these assets to increase as organizational focus moves elsewhere. This can be seen very clearly in the California Energy Policy case and in some recent CSB/NTSB investigations. These cases turn significantly on senior management attention and funding priorities moving to new business areas and away from maintaining base assets.

Another related issue is the potential change in attitude of people at a more working level within these parts of the organization. People working on stranded assets can feel left out and anxious as they face a professional existential threat of their job disappearing and their expertise being no longer valued. The study by Song et al. (2024) of the impact on metro train drivers of moves to AI and driverless trains is a direct illustration of the negative impact that workplace anxiety can have on job performance.

People at all levels of an organization are influenced by organizational priorities and despite a business focus on hydrogen, natural gas assets must be run in a safe way for some time to come.

6. Discussion

Based on a review of relevant literature, and consideration of the context, the transition of the gas pipeline sector to hydrogen poses a series of sociotechnical risks. These include:

- Uncertainty in the basis for regulatory decision making.
- Multiple political goals potentially impacting the regulatory focus on safety.
- Lack of trust relationships with new suppliers and contractors as the basis for successful project execution.
- A need to maximize learning across the sector from inevitable faults and failures as the technology becomes operational.
- Temptation to forgo effective inspection and testing in the rush to production.
- Lack of expertise in existing and new people.
- Overconfidence in the face of uncertainty.
- The need for speed leading to poor decision making.
- Time pressure and uncertainty leading to lying at work.
- Lack of focus on safety from people left behind.

Industry organizations challenged with risk management of emerging technologies lean towards considering the challenges in technical terms. Indeed, in the many symposia that we attended in the course of this work the discussions principally focused on matters of hydrogen storage, integrity management considerations in light of the new material, and so on.

The SOTEC framework (Macrae 2022) brings into focus the multiple and interrelated sources of risks in the case of emergent technologies. The framework is not technologically blind, focused only on the actions and inactions of people. It requires that we engage with the specific nature and challenges of the technology as we consider structural aspects including regulation and political factors, organization, culture, and the treatment of knowledge.

This phase of the work has focused on laying the foundation for an extended field-based analysis of the energy transition. The above list is thus a preliminary set of considerations that we will be investigating empirically. In particular, future work needs to lean into the technological details of the hydrogen transition to appreciate how these specificities give rise to specific structural, organizational, cultural, and epistemic challenges.

7. Conclusion

This brief review of the sociotechnical sources of safety risk introduced into the pipeline sector as a result of the introduction of hydrogen has highlighted nine risks that need attention during the transition. Macrae's SOTEC framework (2022) has provided a useful method of analysis and risks exist across structural, organizational, technical, epistemic and cultural domains.

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References

AEP. (2024). Uses of Natural Gas. *Australian Energy Producers website*. https://energyproducers.au/fact_sheets/uses_of_natural_gas/.

Blunt, K. (2022). *California Burning: The fall of Pacific Gas and Electric and what it means for America's power grid*. Portfolio/Penguin.

Carroll, J., and B. Fahlbruch. (2011). ''The gift of failure: New approaches to analyzing and learning from events and near-misses." Honoring the contributions of Bernhard Wilpert." *Safety* Science 49, 1-4.

Czarniawska, B. (2013). Is speed good? *Scandinavian Journal of Management 29,* 7-12.

Demortain, D. (2017). Expertise, Regulatory Science and the Evaluation of Technology and Risk: Introduction to the Special Issue. *Minerva 55 (2),* 139-159.

Faulkner, A, and L. Poort. (2017). Stretching and Challenging the Boundaries of Law: Varieties of Knowledge in Biotechnologies Regulation. *Minerva 55*, 209-228.

Ferguson, E. (1994). *Engineering and the Mind's Eye*. The MIT Press.

FFCRC. (2023). *Risk Governance Framework for Procurement in Future Fuels.* Future Fuels CRC.

GTI. (2019). *Report of the Public Inquiry into the fire at Grenfell Tower on 14 June 2017.* Grenfell Tower Inquiry (London).

Hanger, I. (2014). *Report of the Royal Commission into the Home Insulation Program.* Royal Commission into the Home Insulation Program, Attorney-General's Department, Commonwealth of Australia.

Hayes, J., and S. Maslen. (2023). Preventing Major Disasters: Success and Failure as Two Sides of the Same Coin. In A. Mica, M. Pawlak, A. Horolets and P. Kubicki (Eds) *Routledge International Handbook of Failure*.

Hayes, J., S. Maslen, and P. Schulman. (2024). A case of collective lying: How deceit becomes entrenched in organizational safety behavior. *Safety Science* 176 (106554).

Hayes, J., Pham, Y., Zhang, R., and Naderpajouh, N. 2023. *Risk Governance Framework for Procurement in Future Fuels.* Australia: Future Fuels Co-operative Research Centre.

Hecker, A. (2012). Knowledge Beyond the Individual? Making Sense of a Notion of Collective Knowledge in Organization Theory. *Organization Studies 33,* 423-445.

Higginbotham, A. (2019). *Midnight in Chernobyl: The Untold Story of the World's Greatest Nuclear Disaster*. Corgi Books.

Higginbotham, A. (2024). *Challenger: A True Story of Heroism and Disaster on the Edge of Space*. Penguin Viking

HIL. (2024). The Importance of Safety Auditing as the Hydrogen Economy Grows. Hydrogen Industry Leaders. Accessed 13 Nov 2024. https://hydrogenindustryleaders.com/the-importance-of-safety-auditing-as-the-hydrogen-economy-grows/.

Macrae, C. (2022). Learning from the Failure of Autonomous and Intelligent Systems: Accidents, Safety, and Sociotechnical Sources of Risk. *Risk Analysis 42 (9),* 1999-2025.

Macrae, C. (2024). Managing risk and resilience in autonomous and intelligent systems: Exploring safety in the development, deployment, and use of artificial intelligence in healthcare. *Risk Analysis*. https://doi.org/10.1111/risa.14273.

Maslen, S., and J. Hayes. (2022). "It's the Seeing and Feeling": How Embodied and Conceptual Knowledges Relate in Pipeline Engineering Work. *Qualitative Sociology 45 (4),* 593-616.

Merrow, E. (2024). *Industrial Megaprojects: Concepts, Strategies and Practices for Success*. John Wiley & Sons Inc.

Pidgeon, N., and M. O'Leary. (2000). Man-made disasters: why technology and organizations (sometimes) fail. Safety Science 34, 15-30.

Reason, J. (1990). *Human Error*. Cambridge University Press.

Reason, J. (1997). *Managing the Risks of Organizational Accidents*. Ashgate.

Roe, E., and P. Schulman. (2023). An interconnectivity framework for analyzing and demarcating real-time operations across critical infrastructures and over time. *Safety Science* 168. (106308).

Song, K., M. Guo, L. Ye, Y. Liu, and S. Liu. (2024). Driverless metros are coming, but what about the drivers? A study on AI-related anxiety and safety performance. *Safety Science 175:* 106487. https://doi.org/https://doi.org/10.1016/j.ssci.2024.106487.

United States Coast Guard. (2024). Titan Submersible Marine Board of Investigation.

Vertesi, J., and D. Boyd. (2023). The Resource Bind: System Failure and Legitimacy Threats in Sociotechnical Organizations. *Sociologica 17 (3),* 25-49.

Winter, P., J. Downer, J. Wilson, D. B. Abeywickrama, S. Lee, S. Hauert, and S. Windsor. (2024). Applying the "SOTEC" framework of sociotechnical risk analysis to the development of an autonomous robot swarm for a public cloakroom. *Risk Analysis*. https://doi.org/10.1111/risa.17632