

Answers to Questions on Notice regarding the proposed Middle Arm development in Darwin Harbour.

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First I'd like to summarise my responses to the three questions:

1. There are at least 5 new papers presenting new evidence on both chemical exposures and toxicology of harmful chemicals reaching the air and water sources during oil and gas operations that have the potential to cause the observed health harms associated with the industry. There are at least 3 new papers that provide new evidence of direct health impacts of these operations. All 8 papers were published in the last 10 months and add weight and strength to the evidence of harm.
2. I present reasons for significant public health concerns that emerge from the submissions and evidence presented by the Australian Marine Science Association that dredging and acid sulphate soils associated with the Middle Arm development may lead to mobilisation of heavy metals into marine ecosystems. I provide detail particularly regarding concern about the high toxic metal cadmium which is known to accumulate in fish and seafood organisms, and also in the liver and kidney of humans who consume foods with significant cadmium in them. Currently I am not aware of any data available regarding levels of cadmium in Darwin Harbour fish and seafood, nor in residents of the Darwin region. However, this should be investigated since any rise may cause detrimental health outcomes for consumers, especially those with other pre-existing health conditions, especially diabetes, heart disease and infectious diseases.
3. I present concerns regarding the response to questions on notice from the Middle Arm proponent, which suggests that the existing evidence on health impacts associated with oil and gas operations is not sound. Their response is based on comments on papers and reports from 2014, 2017 and 2019. I discuss the rising quality and quantity of research and urge the Senate Committee to not rely on old information, and instead look to the latest studies, such as those tabled by Senator Pocock, in the Haswell et al. (2023) report and research papers and other reviews in 2023 and 2024. I also caution that descriptions of research that continually attempt to dismiss or underplay quality findings without basis and demand more studies before acting is identified as unethical by the International Society for Environmental Epidemiology, as detailed in my previous Responses to Questions on Notice (Submission 8).

I follow now with Detailed Responses to the three questions.

Q1. Could you please provide an update on any new evidence that has been published since late 2023 on the impacts of fracking and oil and gas developments on human health?

Many peer-reviewed papers on the health risks of oil and gas developments have been published since late 2023. This is similar to the steep rise in peer-reviewed papers since the literature began emerging in 2012, and especially since 2019, as quality and scientific rigour of publications has also increased.

I will briefly describe some of the key studies and findings that have emerged in eight new publications – which essentially continue to add rigorous evidence to what has already been reported and synthesised ([Haswell, Hegedus and Shearman, Sept 2023](#) tabled by Senator Pocock). Some of this new evidence centres on mothers and children living near gas developments.

New papers on chemical exposures and toxicity

1. Doris, M., Daley, C., Zalzal, J. et al. (2024). Modelling spatial & temporal variability of air pollution in an area of unconventional natural gas operations. *Environmental Pollution* 348: 123773.

The authors describe their work as follows:

*“Despite the growing unconventional natural gas production industry in northeastern British Columbia, Canada, few studies have explored the air quality implications on human health in nearby communities. Researchers who have worked with **pregnant women in this area have found higher levels of volatile organic compounds (VOCs) in the indoor air of their homes associated with higher density and closer proximity to gas wells.** To inform ongoing exposure assessments, this study develops land use regression (LUR) models to predict ambient air pollution at the homes of pregnant women by using natural gas production activities as predictor variables. Using the existing monitoring network, the models were developed for three temporal scales for 12 air pollutants. The models predicting monthly, bi-annual, and annual mean concentrations explained 23%–94%, 54%–94%, and 73%–91% of the variability in air pollutant concentrations, respectively. These models can be used to investigate associations between prenatal exposure to air pollutants associated with natural gas production and adverse health outcomes in northeastern British Columbia”.*

This study provides strong evidence of the major contribution of oil and gas operations on the concentrations of 12 air pollutants in gas production areas in British Columbia, including carbon monoxide, oxides of nitrogen (NO, NO₂, NO_x) hydrogen sulphide, ozone, PM_{2.5} and PM₁₀. This information adds to the rigour of the EXPERIVA study which has already reported high exposures to some VOCs and heavy metals than the general Canadian population in an oil and gas operations area. Furthermore, the researchers found higher levels of VOCs in the indoor air and tap water of pregnant women associated with living closer to oil and gas operations.

2. Caron-Beaudoin, E., Akpo, H., Doyle-Waters, M.M. et al. (2024). The human health effects of unconventional oil and gas (UOG) chemical exposures: a scoping review of the toxicological literature. *Reviews of Environmental Health*, 2024. <https://doi.org/10.1515/reveh-2024-0076>

This study reviewed all studies published between 2000 and June 2023 which assessed the effects of UOG chemical exposures in models relevant to human health. Seventeen studies were identified which included analyses of oil and gas wastewater (produced and flowback wastewater), surface and groundwater near oil and gas production activities as well as mixtures of chemicals commonly used in oil and gas activities. The authors reported, “*All studies detected significant deleterious effects associated with exposure to UOG chemicals or samples, including endocrine disruption, carcinogenicity, behavioral changes and metabolic alterations*”.

The consistency between these findings regarding the toxicological potential of chemicals used in oil and gas production and evidence of their presence in both ground and surface water samples revealed in this review, with the repeatedly reported associations with negative health impacts suffered by people living near gas wells across the US and Canada, further supports a plausible causal relationship (that these chemicals actually cause the associated diseases).

3. Masoud, C.G., Modi, M., Bhattacharyya, N. (2023). High Chlorine Concentrations in an Unconventional Oil and Gas Development Region and Impacts on Atmospheric Chemistry. *Environmental Science & Technology* 57 (41), 15454-15464.

The authors reported, “*We measured several episodes of elevated Cl_2 [active chlorine] levels, reaching maximum hourly averages of 800 ppt, the **highest inland Cl_2 concentration reported to date**. Concentrations peak during the day, suggesting a strong local source (given the short photolysis lifetime of Cl_2) and/or a photoinitiated production mechanism. Well preproduction activity near the measurement site is a plausible source of these high Cl_2 levels via direct emission and photoactive chemistry*”.

The authors warned about the implications of these findings to human health. They stated, (emphasis added to aid the Senators to understand the importance of these findings):

“*The presence of elevated levels of chlorine (up to 800 ppt) in a VOC-rich environment in this oil and gas production region has serious implications for secondary pollutant production. ...**Some organochlorines are known to be toxic, and PM and ozone are criteria pollutants with known negative impacts on human health, highlighting the importance of understanding the impact of atmospheric chlorine levels on the formation of harmful secondary products***”.

4. Clark, C.J., Casey, J.A., Bell, M.L. et al. (2024). Accuracy of self-reported distance to nearest unconventional oil and gas well in Pennsylvania, Ohio, and West Virginia residents and implications for exposure assessment. *Journal of*

Exposure Science Environmental Epidemiology 34, 512–517 (2024).

<https://doi.org/10.1038/s41370-023-00637-8>

This paper explored the accuracy of self-reporting in relation to distance from oil and gas wells. They identified moderate agreement between self-report and actual distances. The authors explain that exposure-related surveys using self-reporting has been used to a limited degree in the oil and gas health literature. **Most of this use has been in relation to self-reported stress levels of residents, which can result from a range of factors, such as understanding of the peer reviewed literature, heavy truck movements away from the development, proximity to pipelines and ancillary infrastructure, and concern for one’s children who may be going to school near gas wells. Self-report is infrequently used in studies examining physical health consequences that use objective measures derived from clinical and hospital records, especially in the most recent research.**

5. Kashtan, Y., Nicholson, M, Finnegan, C. et al. (2024). Nitrogen dioxide exposure, health outcomes, and associated demographic disparities due to gas and propane combustion by U.S. stoves. *Science Advances* **10**, eadm8680. DOI:[10.1126/sciadv.adm8680](https://doi.org/10.1126/sciadv.adm8680)

This study adds significant weight to the growing evidence that the use of gas for cooking exposes household residences to unsafe levels of harmful pollutants. The authors explain,

*“Gas and propane stoves increase long-term NO₂ exposure 4.0 parts per billion volume on average across the United States, 75% of the World Health Organization’s exposure guideline. **This increased exposure likely causes ~50,000 cases of current pediatric asthma from long-term NO₂ exposure alone.** Short-term NO₂ exposure from typical gas stove use frequently exceeds both World Health Organization and U.S. Environmental Protection Agency benchmarks. People living in residences <800 ft² in size incur four times more long-term NO₂ exposure than people in residences >3000 ft² in size; American Indian/Alaska Native and Black and Hispanic/Latino households incur 60 and 20% more NO₂ exposure, respectively, than the national average”.*

Direct Health Impact Studies

6. Willis, M., Campbell, E., Selbe, S. et al. (2024). Residential proximity to oil and gas development and mental health in a North American preconception cohort study: 2013-2023. *American Journal of Public Health*, 114(9), 923-934.

“Among 5725 participants across 37 states and provinces, residence at 2 km versus 20 to 50 km of active OGD was associated with moderate to high perceived stress (PSS ≥ 20 vs < 20: PR51.08; 95% CI50.98, 1.18), moderate to severe depressive symptoms (MDI ≥ 20 vs < 20: PR51.27; 95% CI51.11, 1.45), and psychotropic medication use (PR51.11; 95% CI50.97, 1.28)”.

To summarise, this study provides rigorous evidence that pregnant women across the United States and Canada who live near oil and gas developments are carrying a heavier mental health distress burden, a higher prevalence of moderate to severe depression and taking more medication to relieve these symptoms than those whose lives are not impacted by oil and gas.

Mental health prior to conception and during and after pregnancy has been linked to poor outcomes for both the expectant mother and the child. This study supports existing evidence that oil and gas developments may have transgenerational impacts on the mental health and wellbeing of future generations.

7. Aker, A.M., Friesen, M., Ronald, L.A. (2024). The human health effects of unconventional oil and gas development (UOGD): A scoping review of epidemiologic studies. *Canadian Journal of Public Health Canadian Journal of Public Health* 115:446–467 <https://doi.org/10.17269/s41997-024-00860-2>

These authors reviewed and synthesised the findings from 52 studies, many of which are cited in Haswell, Hegedus and Shearman, (2023). Their conclusions are also similar to that of the Haswell et al. (2023) report which was provided in the Senate Committee proceedings in Darwin. Like the Haswell report, this published study concluded:

“There is a growing body of research, across multiple jurisdictions, reporting adverse effects of unconventional oil and gas development exposure on human health, with an accumulating weight of evidence particularly in relation to birth outcomes and asthma. There is some evidence of disproportionately greater impacts in racialized populations with relatively little research focused on the differential exposure levels and effect modification by systemically disadvantaged populations”.

8. Hill, E (2024). The impact of oil and gas extraction on infant health. *American Journal of Health Economics*, 10 (1), pp. 68-96.

This seminal paper published in a peer-reviewed economics journal, examines the link between infant health and living near oil and gas wells. The author summarised the findings which add to many other studies reviewed in Aker et al. (2024) above and Haswell et al. (2023):

*“The benefits and costs of resource extraction are currently being hotly debated in the case of unconventional natural gas development (commonly known as “fracking”). Colorado provides a unique research environment to study the health impacts of conventional and unconventional forms of oil and gas development (OGD) given its long history of conventional OGD and recent expansion of unconventional OGD. I utilize detailed vital statistics and the mother’s residential address to define proximity to drilling activity. Using a difference-in-differences model that compares mothers residing within 1 km to mothers residing 1–5 km of a well (before and during/after drilling), **I find that proximity to wells before birth increases adverse birth outcomes and pregnancy-related complications. I find impacts on the extensive and intensive margins and across well types”.***

In summary, Senators should be aware that, as stated in multiple submissions and hearing presentations, there has been an extremely rapid increase in understanding and strengthening the evidence about harms to health and the environment associated with oil and gas developments. **These eight important papers published in just the last ten months clearly demonstrate that as more research is done, the evidence of harm accumulates, it does not diminish, concerns.**

Q2. Could you please provide an analysis or summary of any available evidence that may suggest there could be risks to human health from contamination from gas developments on food systems, including fisheries?

As clearly described in submissions provided to the inquiry, both written and oral presentations in the Hearings, the Australian Marine Sciences Association has extreme concerns regarding the absence of data and understanding of the existing impacts of the Inpex LNG development, which are likely to be compounded by the addition of a further major development at Middle Arm. Alarming information was provided by Associate Professor Karen Edyvane on Day 2 of the Canberra Hearings regarding the paucity of understanding and the lack of resources available to properly conduct the comprehensive research needed to remedy this situation. AMSA's Middle Arm Sustainable Development Precinct–Strategic Environmental Assessment & EIS submitted to the Executive Director of the NTEPA provides a litany of deficits and inadequacies in monitoring and assessment of impacts on Darwin Harbour.

AMSA states in their submission,

“AMSA remains concerned at the major potential marine environmental impacts associated with the proposed MASDP – including impacts on marine megafauna (including dolphins, turtles, dugongs and sharks); fisheries (commercial and recreational); the cumulative impacts of dredging; acid sulfate soils; and the impacts of heavy metals on the food chain, food safety, public health, Indigenous harvest and Traditional Owners. In addition, the potential major climate change risks and impacts on the MASDP (particularly sea-level rise, flooding) and emissions profile of the MASDP, particularly its gas-related activities.

In relation to the specific proposed MASDP referral, AMSA reaffirms its national position statement on climate change and its strong support for urgent, immediate and drastic climate action. We note and endorse the recent International Energy Agency's global call (18 May 2021) for no new fossil fuel supply projects.

*... as an unproven and expensive technology, AMSA strongly recommends against the establishment or public investment in any **carbon capture and storage infrastructure.***

*...Similarly, AMSA has serious concerns relating to the development of any industries in the MASDP involving **petrochemicals processing** (e.g. plastics production), due to their reliance and ongoing demand for oil/gas (as the primary feedstock) – **and also, the ongoing and recognized threats to public health and also the major threats posed by current (and increasing) production of plastics to the world’s oceans”**.*

I concur with Associate Professor Edyvane that there is no way we can understand the impact of the Middle Arm development without understanding the impacts that the existing gas developments by Inpex and Santos have already had on the Darwin Harbour ecosystem and health. **I extend these concerns to human health via the food chain.**

I first urge all Senators to review again the detailed evidence provided by experts at AMSA and recognise that we have far from sufficient understanding or ability to predict the physical, biological and chemical environmental impacts of the proposed Middle Arm development.





Secondly I wish to add to these concerns from a public health perspective. It is well established that **dredging and acid sulphate soils** entering the marine environment can **uncover and make heavy metals like cadmium, lead and arsenic ‘bioavailable’** – which means these metals can enter the tissues of marine plants and animals rather than being inert and harmless. With this entry, these metals then accumulate, increasing in concentration through the food chain with the potential of harming humans who consume them.

Heavy metals like lead, cadmium and arsenic not only accumulate in the environment, they also accumulate within the human body, hence the more of these metals in one’s dietary intake, the greater the concentration and risk of disease.

My own research on the heavy metal cadmium was conducted in the early 2000’s when we found evidence that higher levels of urinary cadmium were associated with higher consumption of turtle (and possibly dugong) liver and kidney and wild clam consumption among Torres Strait Islander women. Furthermore, we found that higher urinary cadmium levels were associated with increased frequency of markers of renal damage among women with diabetes, compared with those having lower cadmium levels (Haswell-Elkins et al., 2007a,b, 2008; cited in Satarug et al., 2023).

Many studies have found that dietary exposure, age, nutritional status (especially of iron levels), tobacco smoking and physiological needs such as during pregnancy are key factors determining the amount of cadmium within a person’s body. Consumption of various seafoods including oysters, and organ meat from dugong, turtle and cattle are known to be important cadmium sources, especially where soil and plants are contaminated by industry or natural sources.

Research on cadmium has grown substantially since that time and recent research has linked levels of cadmium to a very wide range of health impacts. A diagram taken from Nucera et al. (2024) summarised the ways in which cadmium (Cd), mercury (Hg), arsenic (As) and lead (Pb) impact on the cardiovascular system.

Metal	Disease
Cd 	<ul style="list-style-type: none"> • Atherosclerosis • Ischemic heart disease (IHD) • Coronary heart disease (CAD) • Dilated cardiomyopathy (DCM) • Heart failure (HF) • Hypertension • Stroke
Hg 	<ul style="list-style-type: none"> • Atherosclerosis • Ischemic heart disease (IHD) • Myocardial infarction • Endothelial dysfunction • Thrombosis • Hypertension • Stroke
As 	<ul style="list-style-type: none"> • Atherosclerosis • Coronary heart disease (CAD) • Peripheral arterial disease (PAD) • Myocardial infarction • Endothelial dysfunction • Thrombosis • Hypertension • Stroke
Pb 	<ul style="list-style-type: none"> • Atherosclerosis • Coronary heart disease (CAD) • Peripheral arterial disease (PAD) • Endothelial dysfunction • Heart failure (HF) • Hypertension • Stroke

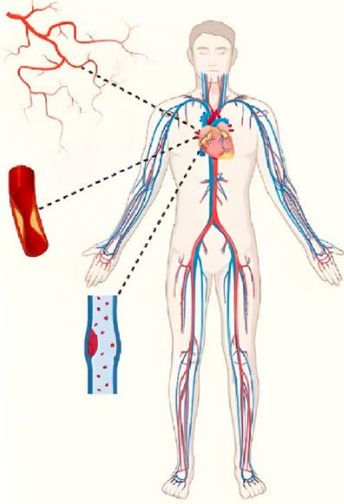


FIGURE 1
Main cardiovascular diseases of non-essential heavy metals.

(from Nucera et al., 2024, Non-essential heavy metal effects in cardiovascular diseases: an overview of systematic reviews. *Frontiers of Cardiovascular Medicine* 11:1332339. doi: 10.3389/fcvm.2024.1332339)

This study examined seven reviews which described the results of 153 studies on the impacts of cadmium on these multiple types of cardiovascular disease. They concluded that exposure to heavy metals clearly plays an important role in the development of cardiovascular disease. Although other factors are also important, it is essential to note that those underlying factors, such as obesity, diabetes and inadequate diet, are highly prevalent in populations likely to be exposed in Palmerston and Darwin – making them even more susceptible to compounding risks to additional cadmium in their diet.

Zeng et al. (2020) found that prenatal (cadmium levels in mother’s urine) and postnatal (children’s cadmium blood levels) exposure to cadmium among pre-school children to be linked to reduced immune responses. This suggests that early cadmium exposure **may increase the risk of infectious diseases among children which already pose serious health risks to children in the Northern Territory.**

Finally, a seminal paper in the *Archives of Toxicology* by Satarug et al (2023) from the Kidney Disease Research Collaborative at the Translational Research Institute and Department of Nephrology, Princess Alexandra Hospital, provided evidence that cadmium levels are associated with:

lower birth weight (10 studies),
pre-term birth (10 studies),

cognitive development (9 studies),
signs of kidney damage (28 studies),
urinary stones (6 studies),
cardiovascular disease (32 studies),
stroke (38 studies),
bone disease [osteoporosis and osteopenia] (17 studies),
fractures (8 studies),
prediabetes and diabetes (42 studies),
blood pressure and hypertension (38 studies).

As well as the following cancers:

Lung cancer (14 studies)
Breast cancer (40 studies)
Kidney cancer (9 studies)
Pancreatic cancer (6 studies)
Prostate cancer (14 studies).

In summary, I conclude from this and other research on cadmium and other heavy metals that can be mobilised by dredging and acid sulphate soils, that heavy metals pose a substantial additional potential health risk associated with the proposed Middle Arm development. My view is in tandem with that of AMSA regarding marine ecosystems upon which the viability of marine fisheries, traditional food security for Aboriginal people and recreational businesses depend.

Q3. At a public hearing in Canberra, Tamboran undertook to provide on-notice a critique of several high-grade peer-reviewed articles looking at the impacts of gas developments on human health. Tamboran has now provided those critiques, which can be found on the APH website (in document 32 on this [webpage](#)). As an expert in this area of research, could you please provide a critique of each of Tamboran's critiques to those papers?

I find that submission 32 provides no critique of high-grade peer-reviewed articles, there is no analysis of methods or findings which is required in a critique. Instead in Table item 4 there is a listing of various shortcomings that occur in early research in any field. There is no matching of criticisms with actual aspects of the papers presented by Senator Pocock, as these studies are of the highest possible quality and do not contain those limitations. Every field of research on highly complex operations like oil and gas is that early papers, such as the 2014 paper by McKenzie mentioned in Table item 5 of Tamboran's response, are needed to build the foundation for more sophisticated papers that emerge later. That has certainly occurred in the relevant literature on the health risks associated with shale gas.

It is remarkable that one 2014 paper is included in document 32 of Responses to Questions on notice in a research field that has grown rapidly. The 2014 paper is the only one of many much newer papers that did not find that proximity to oil and gas wells is associated with lower birth weights.

Incidentally, the 2024 paper by Professor Elaine Hill (number 8 above) **explained this anomaly** in the 2014 McKenzie paper (higher birth weights closer to drilling). Hill found that in Colorado which has had oil and gas activity since 1904, unlike Pennsylvania which only began in 2008, nearness to drilling activity is linked to higher socioeconomic status, which is linked then to heavier babies. This explains why McKenzie et al. (2014) found higher birth weights than expected, a confounder which the earlier studies did not control for but certainly all subsequent papers have done.

Unfortunately what we see in the information provided in QON document 32 is the problematic ethics of attempts at downgrading descriptions of evidence on matters which pose barriers to the application of the precautionary principle on significant human health concerns. In my QON Submission 8, I state:

“This is inconsistent with the Ethics Guidelines recently published by the International Society for Environment Epidemiology (Hetzl et al., 2024) which state that the epidemiologist should present the nature and extent of available evidence in a clear and objective manner, and in such a way as to avoid interfering with or obstructing a precautionary approach. In their “Toolkit for detecting misused epidemiological methods”, Soskolne et al. (2021) identify “Demanding an usually high degree of certainty for the public health problems to be addressed; claims that more data are needed for proof of elevated risks” are frequent ways that epidemiological methods are misused to obstruct a precautionary approach and cause confusion in communities”.

Document 32 also referred to a review by Bamber et al. (2019) which concluded that, “Studies of populations living near ONG operations provide limited evidence (modest scientific findings that support the outcome, but with significant limitations) of harmful health effects including asthma exacerbations and various self-reported symptoms. Study quality has improved over time and the highest rated studies within this assessment have primarily focused on birth outcomes. Additional high-quality studies are needed to confirm or dispute these correlations”.

I can say that indeed, **both study quantity and quality has continued to improve** over time. In the interim years since 2019 when there were approximately 1,902 published studies on the direct and indirect health impacts of oil and gas developments, today there are at least 2,303 such peer reviewed publications. Eight studies indicating negative health associations in the last ten months are described above. I urge the Senators to consult the papers by Caron-Beaudoin et al (number 2 above) and Aker et al. (paper 7), both reviews conducted in 2024 not 2019.

Document 32 also mentioned the Pepper review was conducted in 2017, when only 1,377 papers were available (one thousand less than today) and is significantly out of date.

Furthermore, the judgement of the Pepper Inquiry was theoretical, it was not grounded in, especially today’s, evidence and experience about what actually happens in oil and gas developments. Indeed, as noted in the Hansard, there have already been multiple

incidents and violations occurring in the exploration phase of gas developments, as well as a report of 11,000 tons of VOCs being emitted by the existing LNG facility in Darwin, 22 times the expected level of emissions in their Environmental Impact Statement. To say what might happen versus what actually will happen is an important distinction.

Furthermore, I have presented serious new concerns about the potential heavy metal mobilisation into marine foods consumed by the people of Darwin, from the dredging and acid sulphate soils associated with Middle Arm development. These concerns add a new potentially significant health dimension, adding to our serious air pollution concerns, related to the development of LNG export facilities in Darwin Harbour.

References cited in my Responses are available on request.