Submission to the Australian Senate regarding the Landholders' Rights to Refuse (Gas and coal) Bill 2015

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This document contains my advice and opinions in response to the proposed *Landholders' Right to Refuse (Gas and Coal)* Bill 2015, before the Australian Senate. These opinions are my own, based on my experience as a hydrogeologist and geochemist.

The Bill contains two major components:

1. A new provision stipulating that landholders must be provided a written request before a corporation can enter their land for the purpose of coal or gas mining, and that landholders have a right to refuse entry for such purposes;
2. A new law that prohibits the practice of hydraulic fracturing in mining for gas in Australia.

I am an academic conducting teaching and research in the field of hydrogeology (ground water science). I have nearly 10 years of experience as a researcher, and more than four years as a lecturer running courses for 3rd and 4th year science and engineering students at RMIT. I also currently supervise three PhD projects that relate to issues of groundwater quality. I am currently being funded by the Victorian State Government to conduct research into the baseline groundwater chemistry in major Victorian aquifers that have been proposed as potential targets for unconventional gas activity. This research project involves assessing potential future water quality impacts of unconventional gas on groundwater and developing monitoring and protection strategies for these regions. In this sense, I feel qualified to provide opinions on this bill.

As my expertise is in hydrogeology, most of this submission relates to the second part of the bill, outlining my arguments for considering a ban on hydraulic fracturing in Australia. On balance, my opinion is that there are grounds for seriously considering enacting such as ban, because there are major potential risks to the environment and human health associated with hydraulic fracturing, and unconventional gas extraction more generally (regardless of whether it involves hydraulic fracturing or not).

First part of Bill (Landholders' right to refuse):

One point relating to the first part of the Bill (Landholders' Right to Refuse), Division 2 (Page 7 line 18-21) is the requirement that a corporation seeking to enter a property to conduct coal or gas exploration or mining needs to provide: '*e) an independent assessment of the current and future risks associated with the proposed gas or coal mining activity on, or affecting the land and any associated groundwater systems*'.

In my opinion, this is a welcome idea. Such assessments should also include surface water as well as groundwater systems as:

a) Surface water can frequently be put at risk during coal and gas mining, and
b) Surface water is typically in connection with groundwater and interacts with it extensively.

Some questions may arise as to level of detail required to be included such assessments. In my experience, assessments of this nature commissioned by mining companies often include lengthy ‘desktop’ studies of the hydrogeology of a region, but the scale may be inappropriate (too large or too small) and they typically do not include adequate resources and time to install new groundwater monitoring wells and other infrastructure, so that baseline conditions can be comprehensively documented. This is vital so that any modelling predictions about the impacts of mining can be conducted with a high level of confidence. Numerous examples of problems in predicting impacts due to inadequate monitoring data can be seen in cases referred to the Independent Expert Scientific Committee on Large Coal Mining and Coal Seam Gas.

This issue could potentially be addressed in the Bill, e.g., by stipulating some minimum requirements of the groundwater assessment, which include drilling an adequate number of groundwater monitoring wells and collecting data from these for a baseline period prior to any further activity being conducted.

Second part of the Bill: Proposal to ban hydraulic fracturing in Australia

The extraction of unconventional gas often requires hydraulic fracturing to release gas trapped in shale or coal seams, and it may also be associated with extraction of large volumes of water, particularly in the case of coal seam gas (e.g., Biggs et al, 2012). The practice of hydraulic fracturing (‘fracking’) is still highly controversial globally, with some nations (e.g. France) and sub-national jurisdictions (e.g. New York State, Tasmania) banning it for various periods of time due to environmental and health concerns.

Since 2010, a growing body of research has been carried out worldwide (particularly in the United States) to understand the impacts to the environment and human health associated with unconventional gas. Major risks from hydraulic fracturing to groundwater and surface water include:

a) Risk of increasing stray or ‘fugitive’ gas into shallow aquifers and/or the near surface atmosphere
b) Risk of increasing pathways and connections for fluids (including potential contaminants) to travel between different geological layers, potentially into important groundwater or surface water bodies.
c) Pollution risks associated with ‘flow-back’ or ‘produced’ water that is generated during hydraulic fracturing and/or gas well development (note that ‘produced’ waste water is generated from coal seam gas mining regardless of whether hydraulic fracturing is employed or not, and is a pollution risk in most unconventional gas developments)

Each of these risks is reviewed further below, based on a survey of the recent research literature:

a) *Fugitive gases*

When a gas reservoir is disturbed by drilling, hydraulic fracturing, de-watering or a combination of these, there is a potential to cause gas to migrate from the reservoir to other parts of the sub-surface, such as aquifers above the gas deposit (which may be used for water supply), and/or the surface atmosphere. There is now clear evidence that fugitive methane has migrated from deep gas reserves into shallow water supply wells in parts of the Marcellus Shale in Pennsylvania and the Barnett Shale in Texas associated with shale gas development in these areas (Darrah et al., 2014; Osborn et al., 2011; Jackson et al., 2013a).

Osborn et al, (2011) was the first high-profile study to collect data suggesting that the extraction of unconventional (shale) gas in the United States had resulted in increased methane concentrations in wells tapping overlying water supply aquifers, due to releases of fugitive methane. The basis of their findings was an examination of dissolved methane concentrations, isotopes of methane ($\delta^{13}C_{CH4}$ & $\delta^{2}H_{CH4}$) and higher chain hydrocarbons (ethane and propane) in areas close to (<1km) and far from (>1km) major areas of hydraulic fracturing in equivalent geology (the Marcellus Shale). This study, and follow up work by Jackson et al (2013a) determined that water wells close to hydraulic fracturing activity contained significantly elevated methane (and ethane) concentrations compared to those outside areas of hydraulic fracturing activity, and that in these areas, the isotopes ($\delta^{13}C$) of CH_4 and C_2H_6, and the ratios of $CH_4/(C_2H_6 + C_3H_8)$ matched signatures of gas in the shale gas reservoirs as opposed to other potential gas sources (e.g., shallow, microbial gas).

This work was challenged (e.g., by Saba and Orzechowski, 2011; Schon, 2011; Davies, 2011) who argued that the gas industry deliberately targets areas that are naturally high in methane for gas extraction, and so the correlation observed in these studies does not prove *causation* due to hydraulic fracturing. Following this, Darrah et al, (2014) showed that in a subset of water wells sampled in the Marcellus Shale (Pennsylvania) and Barnett Shale (Texas), there was evidence of an increase in the methane levels over time in areas of hydraulic fracturing, over multiple sampling events. Darrah et al (2014) also conducted a detailed analysis of the gas compositions of groundwater samples in these areas, and were able to demonstrate distinctive compositions of noble gases (^{4}He, ^{20}Ne, ^{36}Ar) which were identified conclusively as fugitive gases in certain water well samples. This could only be explained by rapid migration of gases produced deep in the aquifers, as a result of shale gas development.

The mechanism by which gas migrates into shallower aquifers as a result of hydraulic fracturing has been explored in a number of studies (e.g. Jackson et al, 2013b; Vengosh et al, 2014) and include:

1. Leakage of stray gas originating in deep formations along poorly sealed gas production wells (see Figure 1 below, taken from Bair, 2010).

2. Leakage of gas along legacy/abandoned water, oil or gas wells which create a connection between geological formations

3. Migration of gas from deep reservoirs along fractures and faults, which may be enhanced by hydraulic fracturing

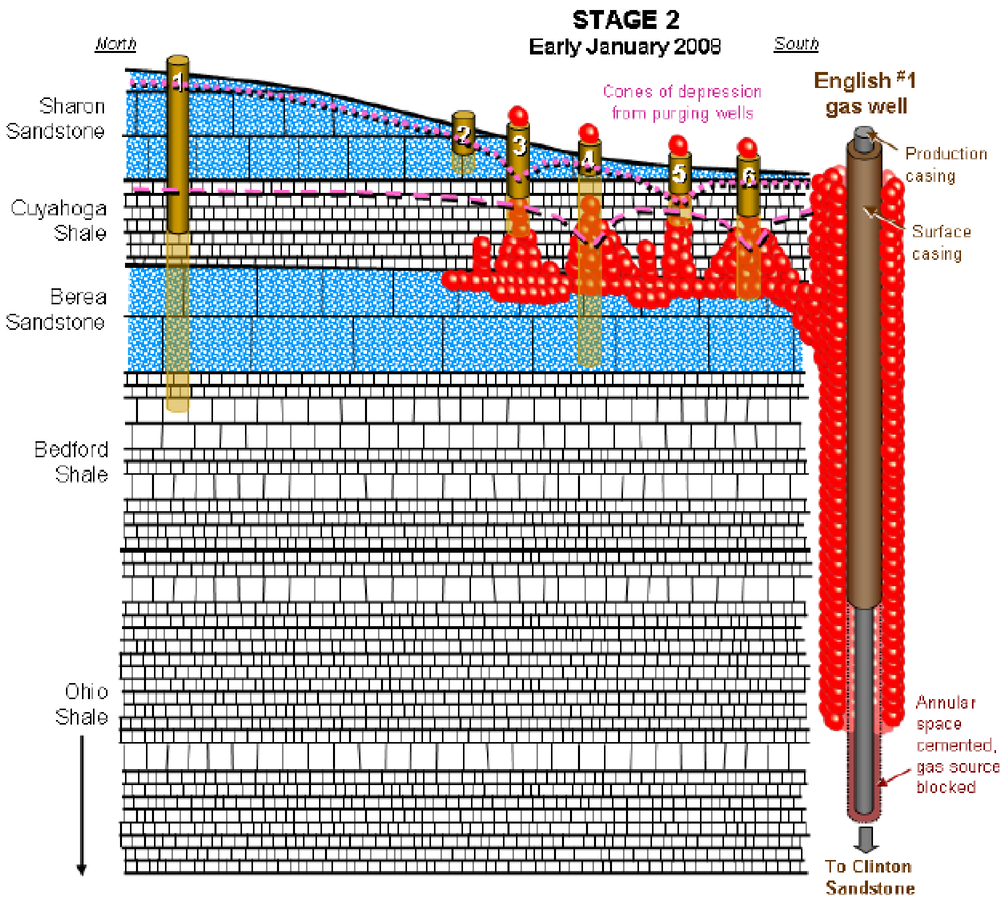

Figure 1: Schematic diagram showing the mechanism of gas contamination of shallow aquifers, based on case study in Ohio (Bair, 2010).

Of these mechanisms, the strongest evidence to date is for 1 & 2; the migration of gas from target formations along poorly sealed and/or abandoned boreholes reaching shallow water supply aquifers (Fig 1; Bair, 2010; Darrah et al, 2014; Vengosh et al, 2014; Jackson et al, 2013b). This underscores the importance of proper well construction, maintenance and full life-cycle care for both water and gas/oil bores. Proponents of the unconventional gas industry argue that with adequate controls and protocols on well construction and maintenance, problems of this nature can be avoided.

However, Jackson et al, (2013b) cited petroleum industry data which showed that in some areas of intensive oil and gas production (e.g. Alberta, Canada; Gulf of Mexico, U.S.), on the order of 5 to 20% of historically drilled wells show evidence of poor seals and therefore may act as pathways for gas migration. The risk of this pathway increases with both the number of wells drilled and with the time since drilling and development took place, as faults in the cementing or casing of wells are likely to get worse as time passes. Whether all wells (water, gas, oil, active, inactive, abandoned) can be effectively monitored and prevented from acting as pathways for methane contamination in a given area of mining is a question of critical importance to the future viability of the onshore gas industry worldwide. There are serious doubts about whether well-integrity can be ensured for long enough periods of time and in a large enough number of wells to prevent gas migration and contamination over the long-term.

Other issues associated with uncontrolled gas releases resulting from accidents during well construction have also been documented. A major incident involving uncontrolled methane release into shallow groundwater wells occurred due to a well ‘blow-out’ in Bainsbridge, Ohio (Bair et al 2010), affecting private water wells in the township. Such incidents underscore that even when good procedures are followed and maintained by most of the industry, accidents can and do happen, and these can have detrimental impacts on human and environmental health.

Fugitive methane to the surface atmosphere

In addition to the risks of contaminating water supply aquifers with gas, there is also a risk that emissions of methane to the atmosphere may increase as a result of hydraulic fracturing or gas development generally. Methane is a potent greenhouse gas, and any increases resulting from unconventional gas require careful monitoring. Howarth et al, (2011) was one of the first and most widely reported studies in the US to suggest that fugitive methane to the atmosphere was increased by shale gas development, and that rates of fugitive methane due to well, pipeline and other leaks were under-estimated by national inventories of greenhouse gases.

Subsequently, a number of studies looked to quantify fugitive methane to the atmosphere in areas inside and outside unconventional gas fields. Two approaches to data collection have been applied, namely ‘top-down’ methods, utilizing satellite based remote sensing (e.g. Kort et al, 2014) and ‘bottom up’ methods, identify points of emission at their source on the ground (e.g. Leifer et al, 2013; Maher et al, 2014; Day et al, 2014).

In terms of ‘top-down’ estimates, Kort et al, (2014) identified a region of very high methane emission in at the borders of Arizona, New Mexico, Utah and Colorado, with significantly higher methane emissions than previously reported. This was consistent with ground-based ‘bottom up’ estimates and was attributed to intensive gas, oil and coal extraction and processing. In terms of ‘bottom up’ estimates, Leifer et al (2013) conducted trans-continental scale measurements of methane in the United States from a mobile vehicle. They compiled an array of near-surface methane concentrations in areas of known oil and gas activity in Texas and California and showed that these areas were characterized by significantly higher levels of emissions than other regions, above the typical atmospheric background range of ~1.8 to 2.0 parts per million.

In Australia, Maher et al (2014) used a similar method to monitor near-surface methane concentrations in northern New South Wales and southeast Queensland, comparing areas within coal seam gas development (e.g. the Tara gas field) with areas outside gas fields. They demonstrated that average and peak near surface methane concentrations were elevated in coal seam gas fields (up to 6.5 parts per million, and consistently above 2ppm) relative to areas of no coal seam gas development and similar geology. Possible explanations are either increases due to leaks around gas well production and collection infrastructure; increased soil gas emissions, or de-gassing from produced water stored in above ground ponds containing dissolved methane.

Follow up work by Day et al., (2014), examined gas leaks in some of Queensland’s coal seam gas fields, using similar technology. This work targeted gas production wells and pipelines, looking to identify any potential sources of leakage from this infrastructure to the atmosphere. They found that the majority of operating CSG wells showed little or no evidence of any methane leakage, and that in general gas contents were at background atmospheric levels. However, one well was identified with increased levels, associated with a valve on the production well which periodically vented methane.

Radon and other hazardous gas emissions

A recent study conducted in the United States by Casey et al, (2015) examined large numbers (nearly 1 million) of measurements of radon gas (Rn^{222}) from the basements of houses situated above the Marcellus Shale, where hydraulic fracturing has been extensively practiced over the last decade. The authors found that from their very large sample of measurements, there was a statistically significant increase in the levels of radon in basements above areas of hydraulic fracturing compared to areas without shale gas development. The data were adjusted for a range of potentially complicating factors, including geology, building characteristics and weather conditions.

Radon is a naturally produced radio-nuclide sourced from the decay of radium in rocks and minerals; however it is a hazardous gas and potential cause of lung cancer. Radon tends to be elevated in water and soil gas that has been in recent contact with deep geological formations containing the naturally occurring uranium series elements (including coal and shale). Increased levels of radon into basements as observed in this study indicates an increased overall flux of soil gas from underlying geology to the surface in areas of hydraulic fracturing. This indicates that hydraulic fracturing has an impact on the transport of gases from underground to the surface.

These findings are consistent with work carried out in Australia by Tait et al, (2013) who also showed that areas of intensive coal seam gas development (e.g. Tara gas field, Surat Basin) in Australia were characterized by higher fluxes of radon, as well as CO_2 from soil gas. This was proposed to be an indicator of an increased flux of sub-surface gases in these areas.

b) *Risk of increasing pathways and connections for fluids (including potential contaminants) to travel between different geological layers*

While there is still little evidence to date of hydraulic fracturing leading to regional scale mixing of saline and fresh groundwater bodies from different depths or major contaminant migration along fracture/fault zones, the capacity to detect and document these impacts is still limited. This is because of the long times-lag that exists in many groundwater systems, which mean that an impact in one place may not be seen at another location for a significant period of time (decades or longer in some cases, e.g., Currell et al, 2015). Unconventional gas is often extracted in very deep sedimentary basins, where naturally the groundwater flow paths and travel times are very large (thousands of years). Therefore, in many cases it is too early to say whether effects such as regional depressurisation of coal seams may be leading to large scale cross-flow of contaminated fluids to areas where negative impacts may be felt – such as shallow water supply aquifers or springs, wetlands and river systems connected to the groundwater.

c) *Pollution risks associated with ‘flow-back’ or ‘produced’ water*

During unconventional gas development, large volumes of waste water are produced. This comes from one or both of the following sources:

- Water injected into the well at high pressure during hydraulic fracturing which then returns back to the surface (‘Flow back water’)
- Water extracted from the coal or other geological formations in order to reduce pressure and release gas from the deposit to the surface in wells (‘produced water’).

This water is a waste product which requires careful management, as it is usually highly contaminated. It poses a risk to surface water and shallow groundwater systems located near to where the water is produced and stored. This is in my opinion the biggest and most pressing risk associated with unconventional gas production at present in Australia. There is a growing body of evidence that significant impacts to the environment are associated with flowback and/or produced water, both in Australia and internationally (e.g. see Currell, 2014; Khan and Kordek, 2014; Hannam, 2015; Warner et al 2013).

Volumes of wastewater produced from gas development are typically larger for coal seam gas wells than other unconventional gas types (shale gas, tight gas). For example Queensland Government statistics indicate that the total volume of produced water from CSG wells in the Bowen and Surat Basins in the 12 months from June 2013 to June 2014 was 26.74 Giga-litres ($2.7*10^7$ m^3/year), equivalent to more than 10,000 Olympic-sized swimming pools.

This compares to lower amounts of water produced from shale gas (e.g. Warner et al, 2013). CSG development in Queensland is expected to increase significantly over the next 10 years, and peak water production volumes have been estimated at 480GL per year (Biggs et al, 2012), which is equivalent to nearly 1 Sydney Harbour of water. This is an extremely large amount of water, and given the typical poor quality of the water, it is potentially a huge pollution source.

Unconventional gas waste water usually contains high levels of hazardous contaminants which are either associated with:

a) natural elements found within coal seams or shale beds

b) fluids used during hydraulic fracturing and brought back to surface as ‘flowback’

Contaminants typical of produced water from coal seam gas include high levels of heavy metals, radio-nuclides (radium, barium, uranium and thorium); high levels of salinity (e.g., total dissolved ion contents of ~5g/L and in some cases up to 30g/L); high levels of ammonia and fluoride (up to 10 mg/L), organic carbon, sulphides and sulphate reducing bacteria (APLNG, 2012; Biggs et al, 2012; Kahn and Kordek, 2014).

Contaminants typical in ‘flowback’ water produced by hydraulic fracturing include salts, acids (hydrochloric and acetic acid) organic chemicals (biocides, gelling agents, surfactants and corrosion inhibitors), caustic soda and other additives used to control the density and viscosity of the fluid (e.g. Halliburton, 2015). Shale formations usually also contain saline formation water, which in some cases contains high levels of radionuclides such as radium and strontium (Warner et al, 2013), and this mixes with fluids used in hydraulic fracturing before returning to the surface as flow-back.

In Queensland and New South Wales there are some policy arrangements and infrastructure which have been developed in recent years in an attempt to manage the large volumes of produced water from CSG (e.g. Biggs, 2012), however there still exists a large gap between the ideal scenario –involving the safe storage and treatment of all production water to a high quality before selling water to nearby water users – and the reality of how this water is actually managed in practice, which often involves:

-Extended periods of storage in dams, which can be subject to leaks, spills and overflows, that can contaminate groundwater (e.g. Khan and Kordek, 2014);

and/or

-Disposal into waterways or sewers, which occurs in contradiction to the wishes of environmental regulators such as EPAs (Hannam, 2015).

The recent controversy over AGL's Gloucester coal seam gas project is illustrative on the issue of how problematic the treatment and disposal of flow-back water produced during hydraulic fracturing can be:

- Contaminants were found in the flow back water produced from AGL's four pilot wells that were hydraulically fractured at Waukivory, with levels of some contaminants (BTEX, Monoethanolamine, THPS) found, exceeding ANZECC guideline values (AGL, 2015).
- The company spent many months trying to find a water utility willing to accept this wastewater under a trade waste agreement, and were refused repeatedly by Hunter Water and Mid Coast Water, due to concerns that the poor quality and high volume of water would create excessive pressure on treatment plant capacity (Hannam, 2015).
- Eventually, water was disposed of through the sewer system at Newcastle, following treatment. This type of disposal option is considered to be of low desirability by the EPA, and it is not sustainable for large volumes of water that can be expected to be produced at a major gas field.
- According to the recent Sydney Morning Herald report (Hannam, 2015), AGL still have significant volumes of contaminated flowback water in storage, with no plan for safe disposal. The fact that AGL were able to produce these significant volumes under their exploration permits, but did not have a fully developed plan in place to safely store, treat and dispose of it, indicates a flaw in the current regulatory regime for unconventional gas mining.
- In my opinion AGL should have determined exactly how the water was going to be stored, treated, and/or re-used, and obtained agreement from all parties involved before they were allowed to conduct any hydraulic fracturing at the site.

Groundwater contamination from Santos' Bibblewindi ponds at their Narribri CSG field is also an instructive example of the risks of coal seam gas produced water (e.g. Currell, 2014). In this case, high levels of uranium and salinity were recorded in a monitoring well near a wastewater dam used to store CSG produced water, and an EPA NSW investigation found that the water came from a leaking dam used to store this water. This is one of multiple incidents of this type in the Narribri gas project; in a previous incident, produced water was directly released into Bohena Creek, causing significant environmental damage (Cubby, 2011).

What is particularly concerning in this case is the location of the Narribri Gas field within the Great Artesian Basin groundwater system. The Pilliga Forest, where gas development and groundwater contamination has taken place, is one of the few pristine areas of high recharge to the Great Artesian Basin (Ransley and Smerdon, 2012; SoilFutures Consulting, 2014). It therefore provides source water (equivalent to the ‘headwaters’ of a river catchment) which continuously replenishes this major aquifer system. It is my view that areas of recharge to important systems like the GAB should be listed as ‘strategic groundwater protection areas’, in which activities such as CSG that could jeopardise the quality or amount of groundwater recharge entering the aquifer, are prohibited. This is the same principle as ‘Wellhead protection zones’ which apply in parts of North America, which restrict land use in areas known to recharge important water supply aquifers.

Even in cases where water treatment facilities exist to improve the quality of produced water, discharge to the environment of treated water can still introduce contaminants and have detrimental environmental impacts (e.g. Warner et al, 2013). Some research which I have supervised at RMIT (Duncan et al, 2014) found that it is extremely difficult to find an appropriate beneficial use and/or disposal method that match the volumes and timing of water produced from CSG operations, and the needs or capacity of the receiving environment to take such water. Treatment plants may not always be equipped to deal with high levels of certain contaminants and some, such as boron, are resistant to treatment by reverse osmosis for example. Reverse osmosis plants themselves also produce waste (brine) which also requires safe storage and disposal, so treatment is not a simple ‘silver bullet’ solution to the problem.

S. Kahn and Kordek published a report in 2013-14 for the New South Wales Chief Scientist and Engineer on CSG produced water and environmental problems associated with it, documenting the occurrence of numerous incidents of uncontrolled release of coal seam gas wastewater into the environment in Australia, and there is similar research emerging elsewhere worldwide (Warner et al, 2013). Given that CSG production water is far from reaching peak volumes in Australia and that amounts are likely to significantly increase (by at least an order of magnitude) over the next decade, I have serious concerns about the management of this water given the already high number of pollution incidents.

On a regional catchment scale, the quantities of salt being produced by CSG wells (for example in the Queensland Murray Darling Basin) are very substantial – of the same magnitude as salts produced from conventional irrigation and natural salt sources in these catchments (Biggs et al, 2012). This effectively means catchment salt input/export ratios are being doubled in the space of years due to salts dissolved in CSG wastewater. In my opinion these regional impacts are also not being given adequate thought when assessing individual unconventional gas mining projects.

Additional points:

A general point relating to both aspects of the Bill:

- The Bill mentions coal seam gas, shale gas and tight gas, but makes no mention of shale oil. This may also be a significant resource in Australia (although I do not have data on estimated prospective volumes). Shale oil extraction also generally requires hydraulic fracturing and so may be associated with similar risks to those described above. Unless there is a deliberate reason for omission, these resources might be considered for inclusion under the Bill.

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