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Economic Synergies from Tighter Agri-Business and Coal Seam Gas Integration

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Abstract

In addition to government royalties, Australia's coal seam gas (CSG) development has been beneficial in terms of facilitating regional economic development and growth, expansion of remote populations and facilities, increased employment opportunities and improved regional infrastructure, mainly in regional Queensland. There is substantial revenue potential for the Australian economy from the export of the resource to international energy markets. Many current CSG operations in Australia are located in prime agricultural-cattle grazing regions. Failure to identify potential coexistence opportunities between agribusiness promoting industries (API's) and the CSG industry could limit the agriculture value chain and consequently restrict Australia's food security and agricultural export potential. The economic benefits of the CSG industry combined with the importance of a sustained agricultural industry lay the foundation for investigating coexistence opportunities between these industries. Emphasis has been placed on potential synergies exhibited by the CSG industry (namely from CSG by-products) and the local agricultural industry which is typically dominated by API's.

Keywords: coal bed methane, coal seam gas, cattle value chain, agricultural value chain, energy-food nexus, gas & agricultural coexistence, agribusiness

1. Introduction

Growing concern of climate change has increased environmental awareness and driven a global initiative for nations to lower their carbon footprint by implementing strategies to reduce greenhouse gas emissions [1–3] as highlighted by the Paris Climate Change Conference and the resulting COP21 agreement. As Australia aims to contribute towards global energy policy measures of transitioning to a lower carbon economy, growing interest has emerged in the development of CSG and other unconventional sources of natural gas [4]. Australia has an

abundant supply of CSG resources estimated to be around 168,600 Petajoules (PJ) in 2012 [5], with potentially rich CSG areas, yet to be explored [6]. With growing demand for low-cost gas production, Queensland is playing a key role in Australia's CSG exports with the construction of three CSG to liquefied natural gas (LNG) facilities (each with two LNG trains), worth approximately ~ \$USD60 billion [7–9] of infrastructure investment.

Despite the direct economic potential of providing CSG-sourced energy to domestic and international markets and the relatively lower emissions of gas fired power over coal there has been some public concern associated with the expansion and development of Australia's CSG industry. These concerns are typically related to environmental issues (sustainable management of the typically large volumes of saline-rich CSG associated water (CSGAW) that is produced as a by-product of CSG extraction) and land-use conflicts amidst already existent agricultural operations [4]. Due to the total dissolved solids (TDS) content of the CSGAW, it requires desalination and amendment to some degree before use in most surface applications. Recognising various industries or entities that can beneficially use CSG by-products will help alleviate the concern associated with the large brackish-water flows [4]. It is crucial to have carefully planned water management policies to strategically manage the volumes of water generated from the CSG industry and thereby maintain a sustainable balance [10, 11]. Careful evaluation of the beneficial use of the CSG-associated by-products can promote co-existence of other complementary industries that could provide sources of additional revenue for the CSG industry [5, 6] and expanded or new agribusiness opportunities. Potential end uses of the CSGAW that have been studied in this article include, irrigation, watering of livestock, abattoir/meat processing industry, leather industry/tanneries, discharge to surface waters, aquifer recharge, artificial lake or constructed wetlands for recreation and ecosystem diversity, coal mine water, cooling tower water, saline inland aquaculture, water storage to combat rural fires, and growth medium for cultivating microalgae for the biofuel industry [12, 13].

Characteristically, the location of Australia's CSG industry is within regions of high resource (CSG) potential but minimal urbanised development. These areas are often dominated by intensive farming and agricultural-rich lands (livestock and irrigation properties). Therefore, it would be mutually beneficial to maximise coexistence opportunities between the CSG industry and agribusiness, by promoting complementary industries which already dominate the agriculture-based rural economies. The notion of coexistence in this article can be defined as the synchronistic functioning of the CSG industry with the local API typically in close proximity to CSG operations. API's have been defined as industries or local business that promote or assist in the sustainability or development of the native agriculture based supply chain. Due to the rural nature of many of the CSG developments and their proximity to agricultural lands, identifying regional synergies is beneficial in terms of facilitating economic development and growth that leverages the local workforce capabilities and expertise. Furthermore, it is critical to coordinate and network with the local landowners and agricultural community to facilitate the effective establishment and efficient integration of the CSG industry with existing agribusinesses. This chapter investigates the coexistence potential between the already present agricultural industry, CSG industry and API's, by exploring the possibility for the beneficial use of by-product CSGAW and services by a variety of industries. A coexistence model is presented, which may be applied for agribusiness in already existent CSG-rich regions or new CSG extraction and processing sites being planned in agriculture-based areas; all this, so the nexus between food and energy can still occur.

2. CSG background

2.1. Natural gas from unconventional reservoirs

The composition of the extracted gas from both conventional and unconventional reservoirs is mostly methane [4, 14]; however, the source rock strata and the extraction techniques dictate the classification of the natural gas [8, 15]. **Table 1** provides a summary of the main differences between natural gas sources. In the case of conventional gas, the natural gas migrates through buoyancy and natural pressure gradients within permeable strata (porous sandstone, siltstone or carbonate geological formations) to a point where it becomes trapped and therefore may not even require pumping to collect at the surface [15]. However, for unconventional natural gas (such as CSG), low permeability strata hold gas in place via capillarity or adsorption rather than buoyancy effects [14]. In Australia, the CSG industry is the most developed out of the remaining gas types sourced from unconventional reservoirs [5].

2.2. CSG extraction

Coal seam gas (CSG) is an unconventionally sourced natural gas which usually contains approximately 95 + % methane, and is found adsorbed within the underground coal seams [4, 5, 8]. Coal is a carbonaceous or carbon-based sedimentary rock that formed from terrestrial organic matter such as trees, which decayed and compressed over many millions of years [16, 17]. Due to ongoing high pressure and temperature-associated compaction processes from the deposition of overlaying strata, the coal was naturally buried to varying depths depending on the extent of forces experienced by the associated geology [8, 16, 18]. This coal formation process is known as coalification [4, 19]. Depending on the geological history, the coal is classified into different ranks which are defined as the extent or level of coal maturation [8, 20, 21]. Low coal ranks are typically located close to the surface and are relatively 'younger' compared to higher coal ranks which have been buried deeper over longer time periods [8, 22]. With coalification associated processes, there could be thermogenic methane produced as a result of chemical reactions within the decaying organic matter and once generated, it becomes adsorbed into the matrix of the coal [23, 24]. Additionally, biogenic methane can also be produced from microbial activity, typically at temperatures less than 70° Celsius and at shallow depths. Biogenic methane can also be adsorbed into the coal matrix [25, 26]. Apart from methane, additional gases such as nitrogen and carbon dioxide also have the potential to migrate through the coal strata and consequently get adsorbed into the coal matrix in varying amounts [8, 27]. Geological investigation techniques and organic geochemistry analysis can reveal the most likely source and process from which the gas originated [20, 23].

The geological structure of coal is characterised as a coal matrix (containing micropores), which is surrounded by a network of water-filled cleats or fractures [20]. Over time as the CSG resource is formed, it is adsorbed within the coal matrix and is typically found adjacent to the water-filled cleat structure [18, 20]. If the pressure in this coal-cleat system is decreased by drilling wells and producing water from the cleats, then the methane gas loses its adsorptive affinity with the coal structure and consequently de-sorbs and migrates with the water through the coal structure and is collected at the surface through production wells, as a gas-water mixture [8, 28, 29]. The CSG resource is then piped to a processing facility where it

Attributes	Natural gas from conventional reservoirs	Natural gas from unconventional reservoirs		
		CSG	Shale gas	Tight gas
Hydrocarbon composition	<ul style="list-style-type: none"> Mainly methane (impurities ethane, propane, butane, condensate) May also be co-located with oil 	<ul style="list-style-type: none"> Mainly methane (usually 95 + % purity) 	<ul style="list-style-type: none"> Mainly methane but can have condensate 	<ul style="list-style-type: none"> Mainly methane
Typical host rock permeability (TP)	<ul style="list-style-type: none"> Underground reservoir in sandstone, siltstone, or carbonate rock <p>TP: ≥ 1 mD</p>	<ul style="list-style-type: none"> Coal seams the coal matrix <p>TP: 1–10 mD</p>	<ul style="list-style-type: none"> Shale rock (more impermeable than coal) <p>TP: 10^{-3}–10^{-9} mD</p>	<ul style="list-style-type: none"> Varied rock locations (gas migrates into low permeability limestone & sandstone or siltstone reservoirs) <p>TP: 10^{-3}–1 mD</p>
Typical depth	<ul style="list-style-type: none"> 1000–6000 m 	<ul style="list-style-type: none"> 200–1000 m 	<ul style="list-style-type: none"> 1000–2000 m 	<ul style="list-style-type: none"> >1000 m
Extraction	<ul style="list-style-type: none"> Vertical/directionally drilled wells Gas transport due to natural pressure and buoyancy 	<ul style="list-style-type: none"> Desorbed by depressurization of coal seam by water removal Vertical, horizontal or directionally drilled wells In Australia around 30–50% of wells will require stimulation in the form of hydraulic fracturing 	<ul style="list-style-type: none"> Shale is highly impermeable and requires hydraulic fracturing Horizontally drilled wells 	<ul style="list-style-type: none"> Vertical, horizontal or directionally drilled wells Large scale hydraulic fracturing required May need well acidizing to stimulate gas production from low permeability wells
Significant resource location	<ul style="list-style-type: none"> WA, SA, QLD & offshore (federal) 	<ul style="list-style-type: none"> QLD, NSW 	<ul style="list-style-type: none"> SA, NT, QLD & WA 	<ul style="list-style-type: none"> WA, SA, VIC
Significant production location	<ul style="list-style-type: none"> WA, SA & offshore (federal) 	<ul style="list-style-type: none"> QLD, NSW 	<ul style="list-style-type: none"> SA 	—

Table 1. Some key differences between natural gas sources (adapted from [8]).

undergoes dehydration and compression. The gas is then transported via pipeline network to power stations for electricity generation [30]. Since the completion of the offshore LNG facilities, Queensland has been exporting liquefied CSG to international gas markets [31].

2.3. CSG water production

Generated in large volumes during the CSG extraction process, the CSGAW is regarded as one of the major by-products of the CSG production process, the other being salt (which is dissolved in the associated water) [32]. **Figure 1** is a schematic representation of a generic CSG production curve for gas and CSGAW. Actual production curves are highly variable across a particular asset or between sedimentary basins. For example, the average CSG well in the Surat Basin in Queensland produces between 1 and 2 million standard cubic feet per day (MMscf/d) of gas but the best wells exceed 20 MMscf/d [9]. The historical ratio of water production to gas production across all of Queensland's CSG wells over time is plotted in **Figure 2** and ranges between about 60 and 120 ML/PJ. Initially, when the CSG production wells are depressurized, large volumes of CSGAW are produced [4, 5]. As time progress, these significant water volumes decline, with increasing CSG flows [8, 32, 33]. Typically, the flow of CSG then gradually falls towards the end of the life of the CSG production well, when it can be decommissioned [34].

2.3.1. Water quality

CSG water chemistry is influenced by the geochemistry of the originating coal seams from which the water was removed from, as well as extent of interactions with other subsurface groundwater flows [8, 34]. CSGAW has been typically characterised with high levels

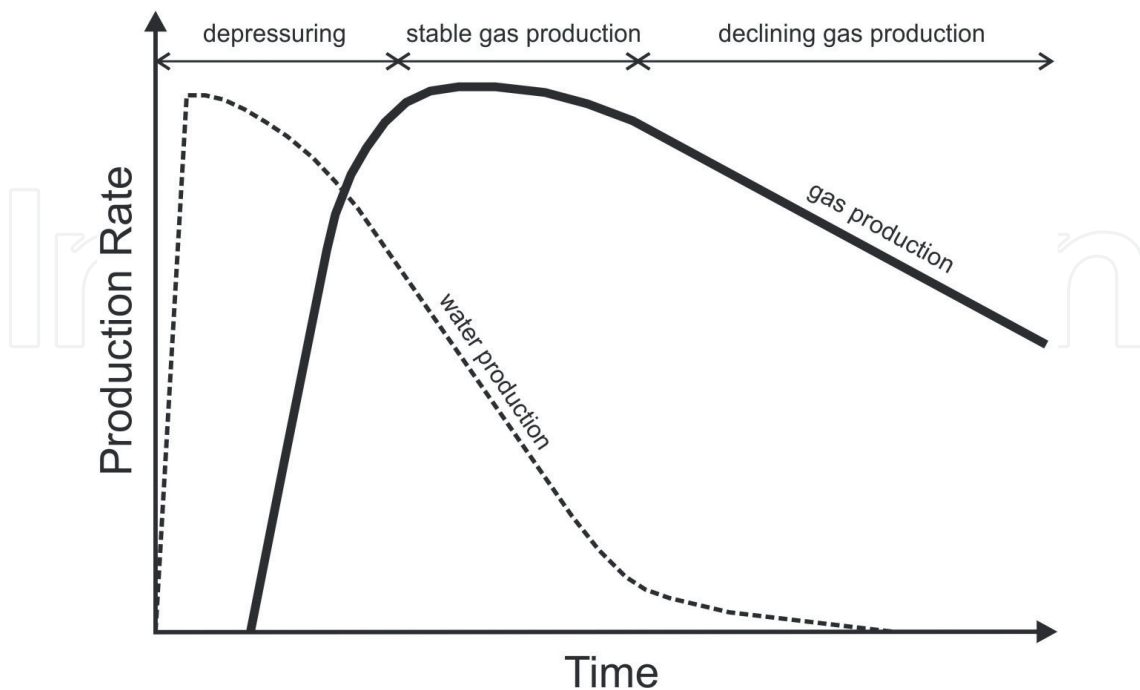


Figure 1. Typical CSG well production stages (modified from [14]).

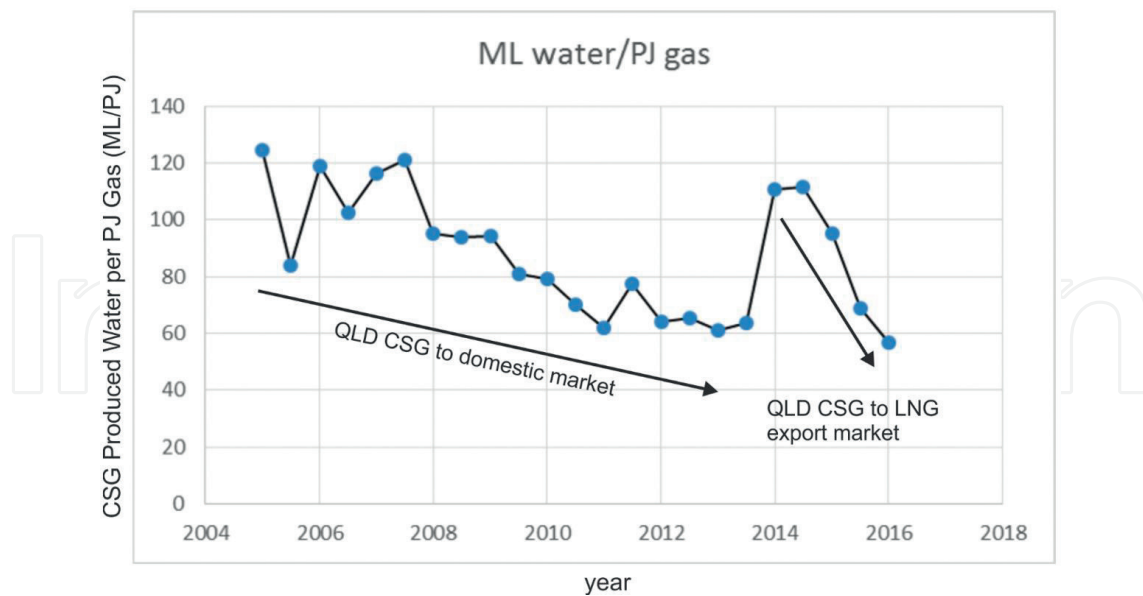


Figure 2. Queensland CSG production presented as Megalitre (ML) of produced water per Petajoule (PJ) of gas.

of dissolved solids & salts, oil based compounds (if thermogenic) and metals [3, 32, 35]. Chemicals used on the CSG operator’s sites during well construction, drilling, stimulation and maintenance activities [8] may also be present in the chemical profile of the CSGAW. The characteristic quality of CSGAW is outlined in **Table 2**. CSGAW extracted from the Surat Basin has been typically characterised as being alkaline in nature, with high levels of sodium, bicarbonate and chloride content [36]. Water is classified as ‘brackish water’ when the TDS

Water quality parameter	Unit	Range	Acceptable livestock watering limits
pH	—	8–9	None prescribed
Total dissolved solids (TDS)	mg/L	1200–7000	Table 6; Table 7
Sodium adsorption ratio (SAR)	—	107–116	None prescribed
Fluoride	mg/L	0.77–4.5	2–4
Sodium	mg/L	300–3461	None prescribed
Magnesium	mg/L	4–13	None prescribed
Silica	mg/L	19–51	None prescribed
Sulphate	mg/L	5–10	None prescribed
Chloride	mg/L	550–2092	None prescribed
Potassium	mg/L	20–78	None prescribed
Calcium	mg/L	2.3–24	None prescribed
Manganese	mg/L	0.07–0.10	None prescribed
Iron	mg/L	0.07–4.50	None prescribed
Bicarbonate (as CaCO ₃)	mg/L	580–2060	None prescribed

Table 2. Surat Basin CSGAW quality & acceptable livestock watering limits ([13, 36, 39]).

levels fall characteristically between 3000 and 15,000 milligrams per litre (mg/L); CSGAW is typically classified as ‘brackish water’ as it has total dissolved solids (TDS) ranging between 1200 and 7000 mg/L [6, 37]. Adequate water treatment and careful management practices are critical to prevent harmful effects on the environment and end user [38].

2.3.2. CSG water treatment methods and brine management options

The direct application of untreated CSGAWA is limited as its quality is often less than the required water quality of many end users [4, 40]. As previously mentioned, CSGAW contains levels of salt and other trace elements that may need to be removed before it is suitable for use. Therefore, most water treatment technologies rely on desalination methods such as reverse osmosis (RO) that then generate a highly concentrated saline effluent waste stream (brine) and a treated CSG water (permeate) stream [5, 6, 41, 42]. Many of the CSGAW treatment technologies are based on the idea of increasing the water recovery rate and consequently minimising the volume of brine [6, 38]. Furthermore, the viability of treatment processes is also largely determined by the cost factor associated with capital and operating expenditure [5].

For the RO plant to run efficiently there may be pre- and post- treatment required of the CSGAW. The major stages of CSGAW treatment include feed collection ponds (water collected to homogenise feedstock), ultra-filtration (removal of particulate matter), ion exchange (IX) (reduction of water hardness ions, Ca^{2+} and Mg^{2+}) and RO (desalination) units [6]. Chemical amendments and conditioning with dosing additives is further applied to ensure the treated CSGAW is suitable for the end user [5]. As an example, **Figure 3** represents the overall CSGAW treatment process that is employed at the Kenya Water Treatment Plant operated by QGC Pty. Ltd. and managed by SunWater [43].

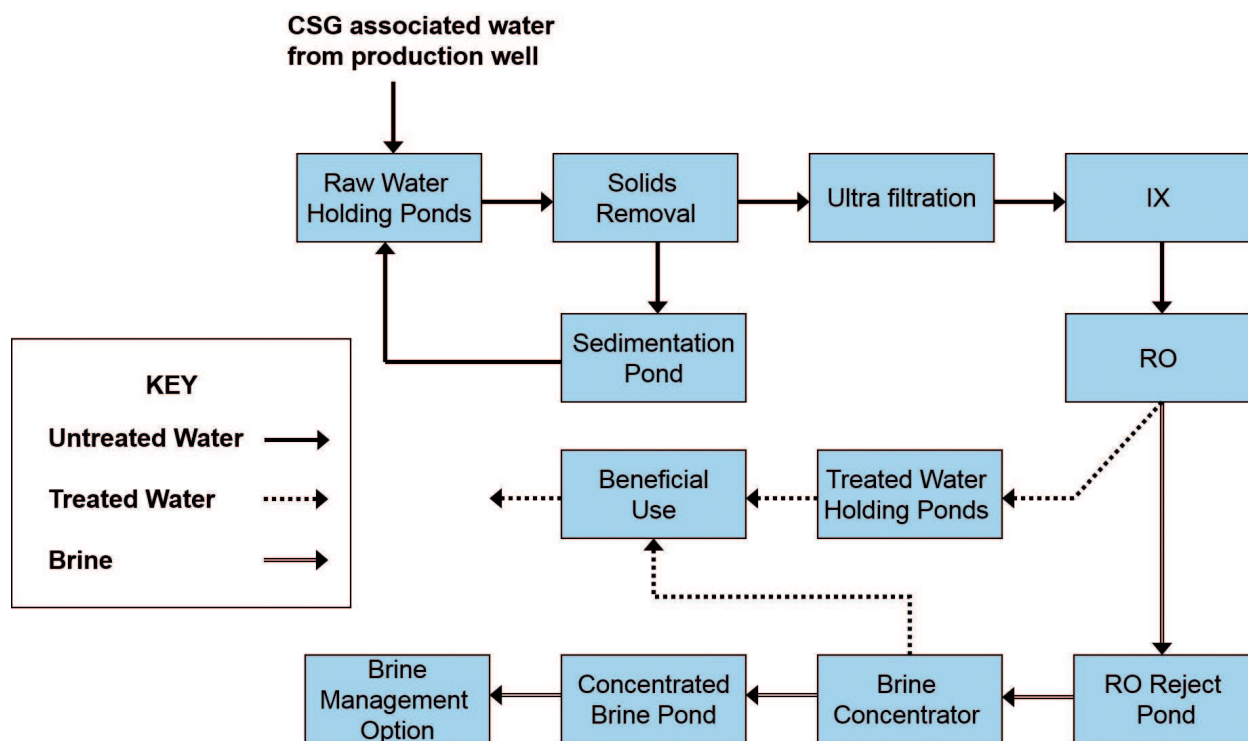


Figure 3. CSGAW processing scheme at Kenya Water Treatment Plant (modified from [39]).

The saline waste effluent stream produced by the RO processing unit is typically further concentrated through the mechanical and thermal brine concentration units [6]. The brine concentration system is an integration of dehydration technology which includes, heat exchangers, falling film evaporation vessels, gas powered compressors, gas fired auxiliary heat chambers and de-aerators [44].

2.3.2.1. *Brine management options*

Brine is regarded as the concentrated saline effluent that is generated as the waste output stream from RO water treatment or brine concentrators [5]. Managing brine in an efficient and environmentally acceptable manner is of utmost importance to the CSG industry. One possible brine management option is to inject the brine generated from CSGAW treatment into a 'geologically isolated' containment that is at an adequate distance from any ground-water source. An alternative option is to evaporate the saline effluent (brine) to a more concentrated smaller volume or to further evaporate the brine to generate a dry solidified salt, which can then be transported to a waste disposal facility (operated by CSG company or off-site).

Therefore, an underlying aspect of brine management is brine volume reduction, to ease downstream processing of the large volumes of brine that will be generated over the life of CSG development. Growing interest is arising in minimising brine volumes by concentrating the saline effluent generated from RO water treatment, to ultimately produce commodity crystallised salts of potential commercial value. 'Recoverable Salts' include sodium bicarbonate, sodium carbonate and sodium chloride [4].

3. CSG services and potential agribusiness promoting industries

CSG developments primarily in Queensland's Surat and Bowen basins have introduced enhanced regional infrastructure to the remote landscape [45]. The presence of the CSG industry within a regional setting has introduced many new businesses that were not previously existent in the area. This has allowed for increased business activity and economic growth of the regional centres near the CSG industry [46]. Some of these enhanced community services facilitated by CSG developments are summarised in **Figure 4**.

Aside from community services, the establishment of the CSG industry in Australia has introduced an array of CSG field supporting infrastructure including underground gas and water gathering networks, gas processing facilities, water treatment plants, transportation networks & telecommunication systems to the CSG producing regional centres of Australia [4], many of which are on agricultural-rich lands [33]. The agriculture industry is by far the most established industry across a large part of Australia's regional area where many of the CSG developments are also located. Such an area is the agriculture-rich heartland of the Surat Basin in southern Queensland which is dominated by irrigation and cattle grazing lands [33]. An example of a regional setting that has experienced resource expansion such as this, is the Western Downs region in Queensland, due to its location within the CSG producing Surat Basin.

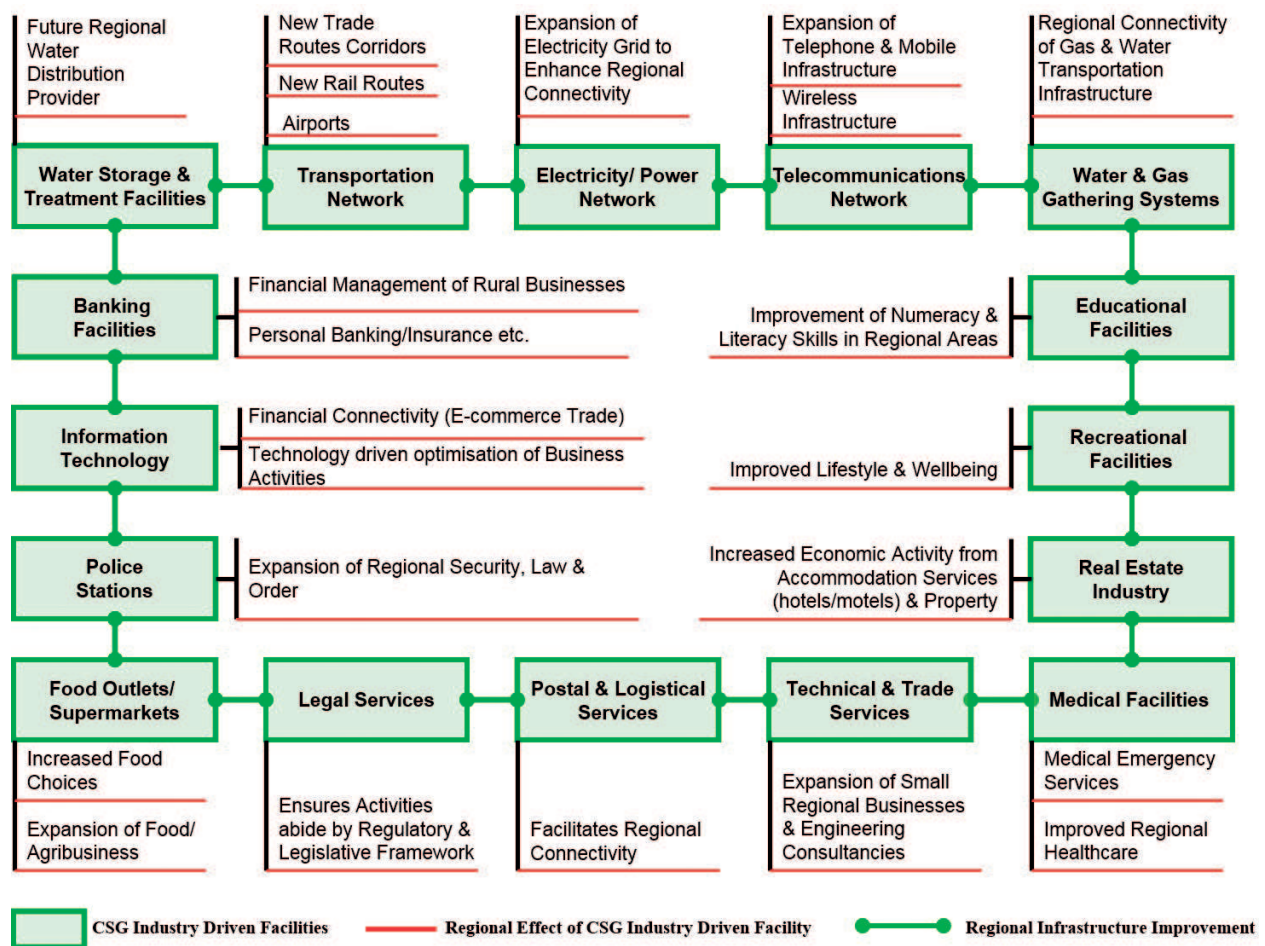


Figure 4. Effect of CSG industry driven facilities on regional infrastructure.

Mehreen & Underschultz [39], have investigated and analysed several industries that could potentially use the CSG by-products using screening matrices. Those industries with a link or contribution to the agricultural value chain, are natural candidates for implementation in the present agriculturally-rich CSG development areas. The screening matrix criteria are presented in **Table 3**. A comprehensive literature review was conducted by Mehreen & Underschultz [39] to assist the screening matrix analysis, whereby each criterion was rated (1 = low, 2 = medium, 3 = high). The scores were then totalled for each industry. Upon careful consideration and assessment of the applicability of each industry as a beneficial user of the CSG by-products, the screening matrix analysis revealed that industries that were closely associated with or contributing to the agricultural value chain (typically API's) scored highly. These API's with high coexistence potential with the CSG industry are: meat processing, irrigation, tanneries and livestock watering. An excerpt of the literature review with specific reference to these high-scoring API'S is summarised in **Table 4**. The agricultural landscape surrounding CSG developments is typically dominated by cattle grazing properties which are notably sustained by the API's that have scored highly in the screening matrix results. Therefore, the authors have placed a greater emphasis on analysing the cattle industry-based agricultural value chain for promoting coexistence opportunities with the CSG industry.

Screening matrix criteria	Description	Question guide
Environmental sustainability	Environmental impact from establishment of prescribed industry was considered as a vital criterion to assess its viability.	<ul style="list-style-type: none"> Is this option environmentally sustainable?/Does this option utilise a waste product of the CSG industry?
Location/Proximity (importance of location)	The distance between the source of the CSG industry derived service and the end user for beneficial use was regarded as critical due to increased costs that may be associated with transportation.	<ul style="list-style-type: none"> Can the end user be in close proximity to the source location of the CSG industry derived service?
Reliability	There must be a consistent uptake of the CSG industry derived service by the proposed option for beneficial use for there to be an ongoing and 'reliable' coexistence of all industries. A point to consider is that there should be an adequate production of the service to meet high level demands from the end user, or alternatively, there must be a sufficient demand from the end user industry for a reliable uptake of the CSG industry derived service.	<ul style="list-style-type: none"> Will the end user regularly use the CSG industry derived service?
Technical feasibility	The potential co-existent industry should possess a high level of technological maturity for a high score in this criterion. Alternatively, industries with underlying technologies which are considered to be under research and development (R&D) phase were scored as having low technical feasibility.	<ul style="list-style-type: none"> Is the underlying technology mature and well known for the functioning/establishment of the industry?
Community benefit	For a high score in this criterion, potential industries must directly inject benefit to the regional community near the CSG development. This benefit can be sourced from increased employment opportunities, increased social awareness of local businesses, and any facilitation of the regional community's wellbeing. Those industries that are regarded as having a justifiable negative impact from a social context have been considered as poor contributors to the advancement of the regional community.	<ul style="list-style-type: none"> Will the community benefit from this industry?

Screening matrix criteria	Description	Question guide
Social acceptance	For there to be co-existence of other industries alongside the CSG industry in the nearby regional area, there must be acceptance of receiving the CSG industry derived service from the regional community. Those options that are traditionally regarded as propagating community benefit from a social standpoint have been scored highly.	<ul style="list-style-type: none"> Will there be social acceptance for this industry? Are there any social repercussions associated with this industry?
Supporting workforce	Industries which require a workforce with skills that are already present in the CSG development area were considered as a great advantage, as it would promote the local employment sector without the need for upgrading skills or further training; consequently, these industries were scored highly.	<ul style="list-style-type: none"> Is there a supportive workforce already present in the regional area of interest for colocation/coexistence of this industry?

Table 3. Screening matrix criteria ([39]).

3.1. Crop cultivation–irrigation

As Queensland's CSG operations are distributed across the agricultural landscape, the use of CSGAW for irrigation purposes, especially in its large production volumes is a practical option [48, 55]. A successful implementation of the CSGAW irrigation scheme is in the Australia Pacific LNG Project which is enabling the use of treated CSGAW for drip irrigation projects involving a 300 hectares (ha) Pongamia plantation (bio-fuel crop) [80].

Some extent of treatment or amendment of CSGAW is required prior to irrigation use [48]. Defective plant growth patterns have been exhibited by crops that have been experimentally irrigated with certain untreated CSGAW [4, 13]. The direct application of CSGAW for irrigation purposes is therefore impractical, in most cases as it quite often of a poorer quality than the present water source distributed for irrigation. The successful implementation of this water management option is highly dictated by the CSGAW quality parameters such as salinity and sodicity. As a basic minimum requirement, CSGAW must be treated for the removal of salt prior to use for irrigation purposes [48]. Irrigating low salt tolerant crops with raw CSGAW which is saline will cause crusting of soil structure, decreased water retention ability, and increased soil erosion from runoff, in turn defecting healthy crop growth [13]. Soil chemistry (salt levels, pH), climatic conditions, crop salt tolerance ranges, topography of land are also critical parameters that dictate the extent of water treatment required prior to irrigation use of CSGAW [4, 48]. **Table 5** outlines the salt tolerance ranges for potential crop groups.

Beneficial use option/Industry	Key criterion	References
Irrigation	Environmental sustainability	[4, 13, 47–50]
	Location/Proximity (importance of location)	[4, 13]
	Reliability	[4, 13, 51]
	Technical feasibility	[13, 48, 52]
	Community benefit	[4, 51, 52]
	Social acceptance	[4, 51, 52]
	Supporting workforce	[53]
Livestock watering	Environmental sustainability	[4, 6, 54, 55]
	Location/Proximity (importance of location)	[13, 56]
	Reliability	[6, 13, 57, 58]
	Technical feasibility	[13, 59]
	Community benefit	[13, 59]
	Social acceptance	[6, 13]
Abattoir/Meat processing industry	Environmental sustainability	[60, 61]
	Location/Proximity (importance of location)	[13, 62–65]
	Reliability	[60, 61, 63]
	Technical feasibility	[60, 61, 66, 67]
	Community benefit	[66]
	Social acceptance	[67, 68]
	Supporting workforce	[53, 69]
Tannery/Leather	Environmental sustainability	[70–75]
	Location/Proximity (importance of location)	[13, 76, 77]
	Reliability	[4, 73, 77–79]
	Technical feasibility	[73, 76–79]
	Community benefit	[73, 76–79]
	Social acceptance	[76–78]
	Supporting workforce	[53]

Table 4. Summary of literature for the beneficial use of CSGAW by high-scoring API’s (modified from [39]).

While CSGAW that has been treated in accordance with the regulatory standards [13, 81] may be argued as being safe to use for irrigation purposes, there has been some research that suggests that from a long-term perspective, there may be cumulative concentration of salts over time, which can pose a threat to soil structure. The impact of CSGAW irrigation and its associated environmental sustainability should be considered on a case-by-case basis as each site differs in its soil and crop profile [48]. The average water usage per property and subsequently

TDS (mg/L)	Water salinity rank	Crop suitability	Potential crop
<390	Very low	High sensitivity	Flowers/fruits
390–780	Low	Reasonable sensitivity	
780–1740	Medium	Reasonable tolerance	Clover
1741–3120	High	Tolerant crops	Corn, Lucerne, sorghum, soy bean
3121–4860	Very high	Highly tolerant crops	Cotton, cereals (wheat), barley
>4861	Extreme	Usually too saline	—

Table 5. Crop suitability based on irrigation water salinity ([13, 39]).

irrigation extraction volume allocations should be implemented [4]. Providing CSG-sourced water for irrigation purposes would help in drought-proofing the land and improving land productivity (increased opportunity to harvest crop and livestock grazing yield), thereby boosting the economic potential for agribusiness and directly opening up potential investment opportunities such as food-based tourism [52].

3.2. Livestock watering

Land areas that are dominated by grazing activities and animal farming require feedlots facilities for providing fodder and water to animals, prior to slaughter. Such feedlot facilities require an adequate supply of water for animal consumption (livestock watering). Using CSGAW for the feedlots industry assists in providing water supply to drought affected areas which can allow the functioning of the livestock industry which will directly benefit the meat processing agriculture value chain to have a supply of livestock for slaughter. The tolerance range of livestock to the consumption of untreated CSGAW varies (Tables 6 and 7). Typically,

Livestock	Total dissolved solids (mg/L)		
	No adverse effects on animals expected	Animals may have initial reluctance to drink or there may be some scouring, but stock should adapt without loss of production	Loss of production and a decline in animal condition and health would be expected. Stock may tolerate these levels for short periods if introduced gradually
Beef cattle	0–4000	4000–5000	5000–10,000
Dairy cattle	0–2400	2400–4000	4000–7000
Sheep	0–4000	4000–10,000	10,000–13,000*
Horses	0–4000	4000–6000	6000–7000
Pigs	0–4000	4000–6000	6000–8000
Poultry	0–2000	2000–3000	3000–4000

*Sheep on lush green feed may tolerate up to 13,000 mg/L TDS without loss of condition or production.

Table 6. Livestock tolerance range for drinking water ([4, 39, 81]).

TDS (mg/L)	Results
<1000	<ul style="list-style-type: none">• Highly tolerable for all livestock
1000–2999	<ul style="list-style-type: none">• High satisfactory tolerance for all livestock with some cases of diarrhoea reported for livestock consuming the water source for the first time.
3000–4999	<ul style="list-style-type: none">• Satisfactory for livestock with some diarrhoea reported for livestock consuming the water source for the first time.
5000–6999	<ul style="list-style-type: none">• Reasonably safe however should be avoided for pregnant and lactating animals
7000–10,000	<ul style="list-style-type: none">• High risk to young offspring however older livestock may still consume the water supply
>10,000	<ul style="list-style-type: none">• Unsuitable for all livestock

Table 7. Effect of TDS levels on livestock ([12, 39]).

the quality of CSGAW is regarded as being within the acceptable limits for livestock watering purposes [4]. There have been some cases where excess fluoride levels in the water (non-CSG sourced) supplied for livestock consumption have caused poor dental health (e.g. fluorosis) in the affected animals [13]. If raw/ untreated CSGAW is deemed unsuitable for direct livestock consumption, then low level CSGAW treatment must be implemented to eliminate the water from high TDS and fluoride levels, prior to livestock consumption [13].

3.3. Meat processing

There is a growing demand for high-quality meat produce both in the domestic Australian and international markets. This is representative of the economic revenue associated with meat production, where ~ \$USD 1.2 billion was generated from the sale of Australian meat products [82]. The Department of Agriculture, Fisheries & Forestry (DAFF) has reported that there is a lack of adequate meat slaughtering and processing sites in Queensland, Australia [83]. New slaughter and meat processing facilities must be constructed to meet the demand from international markets for Australia’s high-quality meats. Constructing abattoir and meat processing facilities in grazing corridors would reduce the transportation costs associated with transferring livestock from grazing fields to slaughter houses and inject economic revenue to the agricultural value chain. Furthermore, this colocation would also reduce transportation costs associated with transferring treated CSGAW for use at the abattoir site. Approximately 44% of Australia’s total cattle numbers are present in Queensland [84]. Abattoir facilities are heavy users of water particularly during slaughtering and downstream meat processing stages [61, 63]. An environmental concern by many already existent abattoirs is the typically high nutrient load of the effluent water, which cannot be directly used as fertiliser. In such cases, amended CSGAW can be mixed with the effluent stream as a diluting agent, making it viable as a nutrient rich fluid to be applied on crops. The economic potential of the meat processing industry from both a local and international standpoint is vital to the growth of Australia’s agribusiness sector.

3.4. Tannery: Leather processing industry

The waste brine generated from CSGAW treatment can be beneficially used in leather manufacturing processes. Saline rich feed water (e.g. brine) is required for curing the hides,

particularly for antibacterial purposes, as well as for degreasing processes [85]. The tannery facility may be constructed at a proximal distance from the CSGAW distribution and abattoir sites, to optimise costs associated with the transportation of water and hides. The leather processing industry is a viable user of water, however flows (treated CSGAW and brine) will be directly related to the number of carcasses processed at the abattoir, which will in turn have consequences for the number of hides produced for leather manufacturing.

Providing CSGAW and CSG industry-sourced brine to the leather processing industry has massive potential to inject new economic opportunities for the local economy and creates avenues for international export if produced on a large scale. Purposefully co-locating tannery facilities with CSGAW distribution sites, has the added advantage of processing recycled tannery effluent waste through the same water treatment site. This suggested industry would promote the agricultural value chain and provide a potential coexistence opportunity for both the CSG industry and an API.

4. Agribusiness promoting industries: Coexistence potential with coal seam gas

As the 'native' industry in CSG operating areas is the agricultural industry and associated agribusinesses, it is important to facilitate the growth and progress of those industries. The concept of a supply chain is services from one entity flow to another entity, through a medium that allows the flow of services to take place. In this way, services of one industry can pass their benefit to another industry, thereby contributing to a supply chain type model. Similarly, services provided by the CSG industry (such as by-product CSGAW) to local agribusinesses, can help to facilitate the agricultural value chain by enhancing food productivity, injecting investment opportunities, promoting agri-based tourism and trade prospects. Mehreen & Unterschultz [39] propose an agri-based industrial coexistence model which promotes local synergies between the CSG industry and local agribusinesses. The model given in **Figure 5** schematically represents the potential synergies between entities involved in the cattle value chain and the CSG industry, specifically focussing on CSGAW (and brine in the case of leather processing). This co-location of agri-based industries around the CSG developments allows the growth of the agriculture value chain, increased employment opportunities, regional infrastructure growth, and enhanced utility infrastructure [33, 46, 86].

The CSG water treatment and distribution facility can deliver CSGAW that has been amended (to the respective regulatory standards) for irrigation to nearby agricultural farms. Feedlot operations are provided with fodder or other feed crop that has been harvested by the agricultural farms in the area. These agricultural farms may even provide livestock (e.g. cattle) grazing lands. Untreated or amended CSGAW (treated in accordance with respective regulatory guidelines) (**Tables 6 and 7**) can be provided to feedlot operations for livestock consumption. The feedlots near abattoir / meat processing facility in the area, can provide livestock for slaughter. Treated CSGAW provided to the abattoir, can be utilised during sterilisation, evisceration, slaughtering and other meat processing stages. An anaerobic digester (AD) can treat the feedlot and abattoir effluent streams (high organic load dominated by biologically hazardous material) to produce biogas (methane) and highly concentrated nutrient load (potential

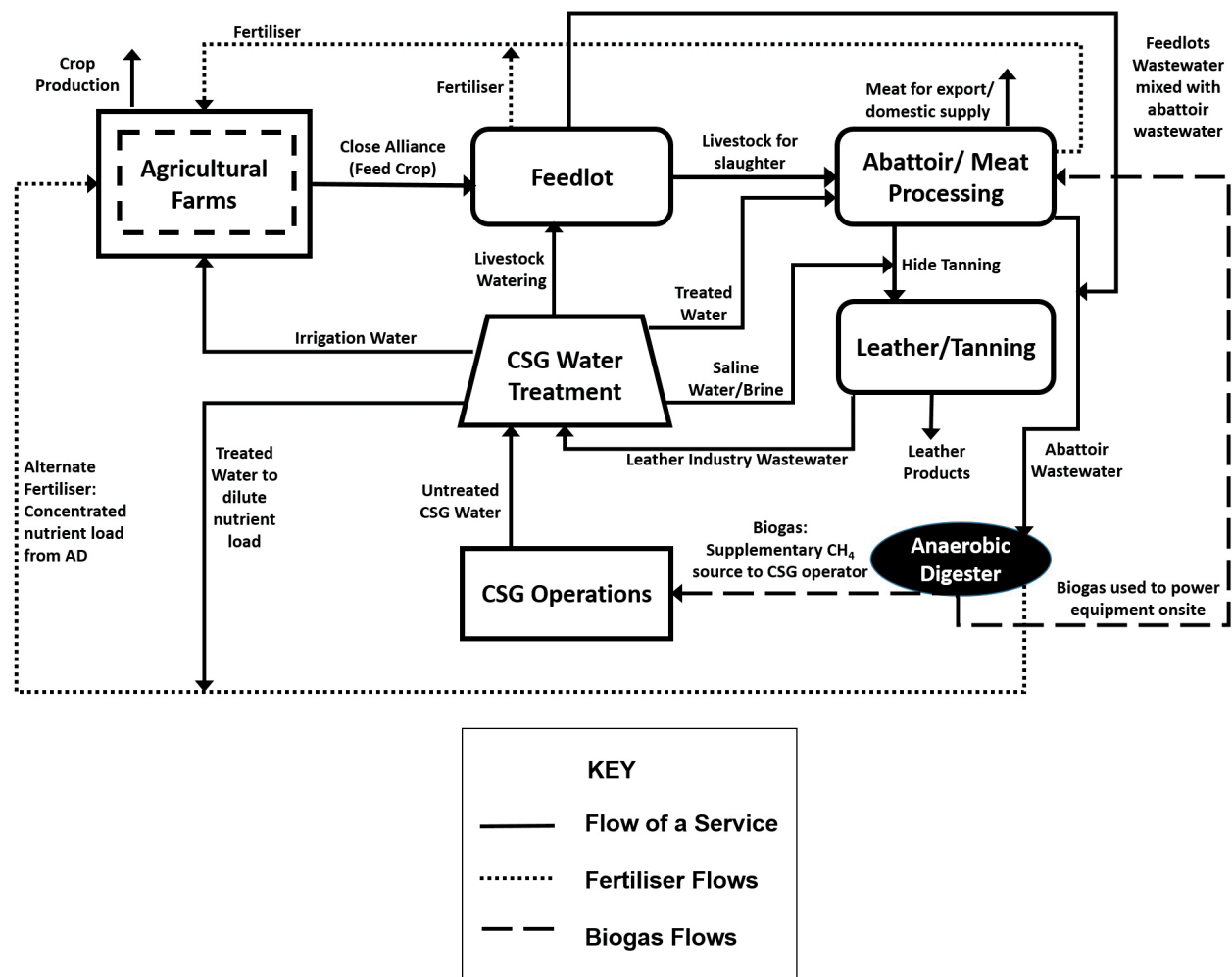


Figure 5. Suggested agri-based industrial coexistence model based on cattle value chain CH₄ = methane (modified from [39]).

fertiliser). Prior to using the fertiliser on agricultural crops, this nutrient load from the AD must be diluted with treated CSGAW from the CSG water treatment facility. This fertiliser can be commercialised as a selling product or can be provided to agricultural farms and grazing areas to grow crops. The biogas produced from AD can be processed for abattoir's energy use (equipment) or provided to the CSG operator as a supplementary methane source. The CSG Water treatment facility can provide the saline-rich CSGAW for leather processing in the tannery facility and also provide local water treatment capacity for otherwise unusable wastewater from meat processing and tannery operations. Note that other local services (telecommunication and transportation infrastructure, and services in regional towns) that have developed as a result of CSG development will have longer term sustainability if they are also servicing an expanding co-located agribusiness chain.

The water requirements from each API in **Figure 5** were calculated and compared with the modelled volumes of treated CSGAW for distribution from the CSG water treatment sites. This is summarised in **Figure 6**. Some assumptions that were taken into consideration when calculating water consumption rates are as follows:

- The water required for irrigation (4300 kL/day) is calculated for 40 ha of agricultural land [87]
- The average cattle numbers processed at the abattoir are at a rate of 1400 cattle per day [88]
- The water consumption for processing one cattle hide in tannery operations is 702 litres (L) [70]
- Water consumption per cattle head at feedlot operations has been taken as 130 L/ cattle head [88, 89]
- Typical water treatment installed capacity of 20,000 kL/day which is taken as being available from the CSG water treatment facility [90]

Upon calculation of the water consumption in the entities involved within the agri-based co-existence model, it was noted that the demand (8406 kL/day) is much lower than the average water supply capacity. As the local labour workforce has an agri-based skillset, there would not be a skill shortage for the API's involved in this model. In fact this would help retain the local agri-based workforce with more job options. The main concern associated with the sustainability of this coexistence model may be the extent of water supply in the future as the CSGAW production volumes eventually fall. One option would be to use present piping and well injection infrastructure built for recharging aquifers, to collect and re-harvest the CSGAW for a sustainable supply of water into the future, when the CSGAW production has reached its end of life period.

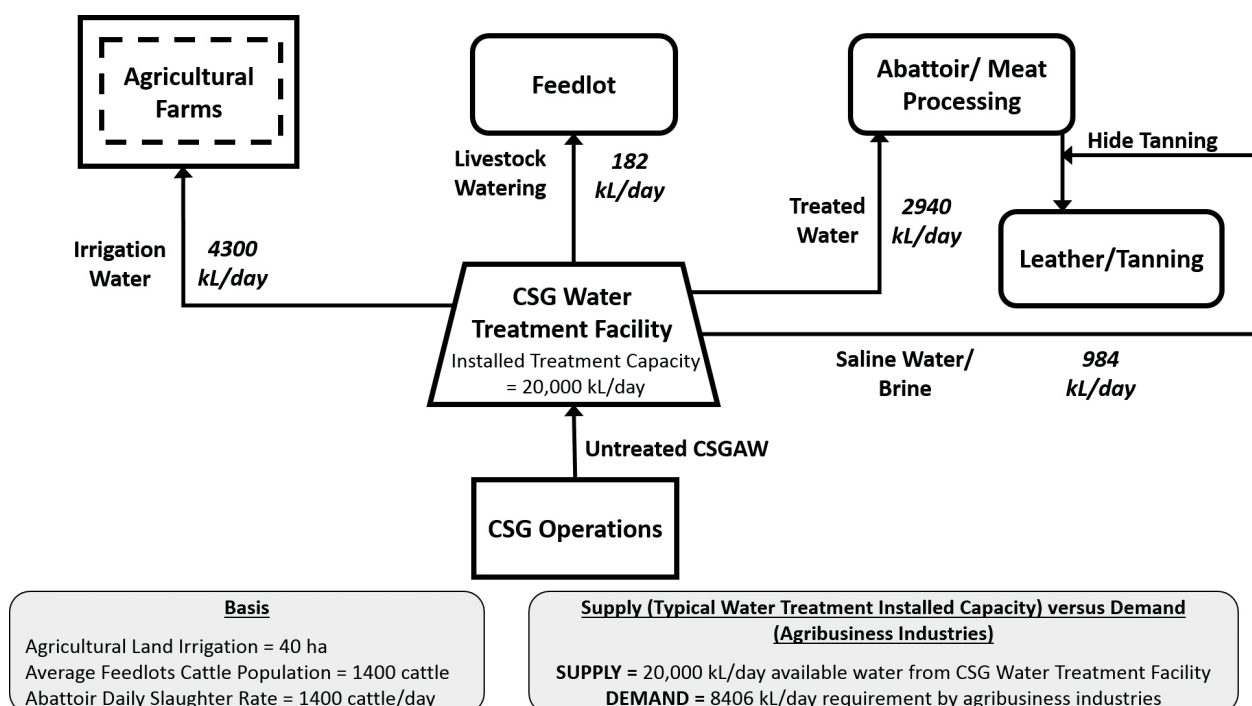


Figure 6. Typical water consumption by agri-business industries in comparison to coal seam gas water supply. kL = kiloliters (modified from [39]).

From an economic and community perspective, there is great value in promoting coexistence of agri-based industries alongside the CSG industry. However, the progress of amalgamating agricultural industries with the CSG industry has been slow [9]. There is cumulative effect of coexisting CSG developments in close proximity to agricultural developments that are complicated by community attitudes, local industries, environmental assets, and regulations [91, 92].

In regional CSG development, there is often concern for the preservation of environmental assets, particularly land and water as they provide economic value, ecological diversity, recreational value, and aesthetic value. As CSG developments are often located on prime agricultural land, land use conflict and stakeholder trust is a concern for gas operators [93]. A lack of trust in the CSG operator is quite often the most significant social issue which underpins many of the other concerns affecting the progress of promoting coexistence between agri-based industries and CSG industry [91]. Land access agreements and their associated 'confidentiality clauses' can contribute to the distrust with CSG operators and regulatory bodies. Some government or CSG operator funded financial incentive is provided to landowners to promote greater cooperation [92]. Farmers with increased distrust in the CSG companies can have negative opinion of other farmers that have accepted monetary incentive. This can be viewed as having betrayed the 'rural fabric' that unites farmers and can create a local divide within the farming community. These social issues must also be addressed in order to better promote the coexistence value of the agribusinesses alongside the CSG industry. Strategic governance by federal and state governments to ensure trust with the local landowners must take effect to bridge the gap between agri-based industries and the CSG industry.

Analysing the effect of the CSG industry from a social perspective is quite often not as 'tangible' as analysing economic growth or environmental impact [92]. Perhaps this is attributed to the ability to better quantify economic and environmental impacts rather than social indicators which tend to be more of a qualitative nature. Therefore, conceptualising the potential impact on the social fabric underpinning the regional communities in the heart of CSG development regions can be difficult and may pose a barrier to better understand the effect of the CSG industry on the community from a social perspective. This further complicates analysis of the coexistence potential between the CSG industry and agri-based industries. It is therefore important to consider the cumulative impact of CSG development rather than the isolated impact.

When there are industries that are sharing infrastructure, there is an increased risk to the normal business case. For industries to coexist and gain mutual benefit, requires mutual trust. When the business risk is too high to share infrastructure between industries, it makes coexistence difficult. In this case, one company owns the infrastructure (e.g. CSG industry owned water treatment facilities) and another entity such as a new meat processing plant could benefit from utilising that business service. If access to water treatment is a critical component of the business case for the meat processing plant, but not in its control, this could pose an unacceptable risk to the establishment of the meat processing plant. For example agricultural wastes are characterised as having a high organic load, particularly in animal-based agri-based industries [61, 63]. Combining waste streams from such industries, and processing the produced wastewater through the CSG water treatment facility may increase the risk to the business model, and may pose as an unnecessary complication for the CSG operator. There must be corporative legislations that will be designed to remove the business risk; the support of the federal

and state government is mandatory. Adequate planning must be implemented to remove such risks. The colocation reduces transportation costs dramatically due to the centralised location of the water treatment facility in relation to all the agri-based industries involved.

If agri-based industries are dependent on water, such a setup proposed in the agribusiness coexistence model in this paper, would mean that those industries will be heavily reliant on the CSG industry for providing water for their beneficial use. Due to the long period entailing the business case, it may be difficult to attract investment. This is perhaps another reason that has hindered the amalgamation of the CSG industry colocation with the agricultural industry sooner than later. Therefore, it will be important to find innovative business models that can alleviate these business risks and allow investment in a co-existence model where different industries can share infrastructure.

5. Conclusion

Upon investigation, it was found that the agricultural industry can benefit from the by-products and services of the CSG industry, mainly because of its shared location with many CSG developments and for the fact that the current workforce in these rural areas are related to the skillset required by new API's; therefore, no significant skills upgrade would be needed. This study has analysed the potential of CSGAW supply for the suggested API's: irrigation (crop harvesting), livestock watering, meat processing and leather manufacturing. It is regarded that some form of water treatment is required prior to beneficial use by the API's. Utilising CSG by-product synergies (particularly CSGAW) with API's helps maintain the sustenance of local agri-based industries and strengthens the agricultural value chain in the agriculturally dominated rural landscape which is native to many areas surrounding CSG developments in Queensland. The agri-based industrial coexistence model presented, allows for the API's to utilise the CSG industry's by-products for beneficial use and positively contribute to the sustainability and expansion of the agricultural value chain. It provides the potential as a 'drought buffer' for landowners, helps to maintain the local skills set and provides long-term jobs. Providing CSGAW for irrigating crops (for both human and livestock consumption) can be regarded as an initiator for expanding the meat processing and leather manufacturing industries; thereby enhancing land productivity and further strengthening the agricultural value chain. Furthermore, the colocation of API's in close proximity to the CSG water treatment facility would also ensure maximal use of a centralised utility & telecommunications infrastructure network. Re-harvesting CSGAW using the present infrastructure built for managed aquifer recharge, has been suggested as an option to ensure the reutilization of CSG-derived water for the API's, following the period of post-CSG production. Increased employment and export trade opportunities, sustainable crop harvesting, facilitating the operation of the local agricultural-based value chain, and generation of other industries (agri-tourism, biofuel generation, local meat and leather processing) are prospective opportunities associated with the agri-based coexistence model. The agri-based coexistence model integrates the agricultural value chain. In effect, it localises all the involved agri-sourced industries, thereby increasing connectivity of supply chain processing over short distances, greatly reducing transportation costs that would

otherwise be associated with transferring 'raw' products to additional locations for further downstream processing. Conventionally, the agricultural industry and the production of agri-based products are sourced from rural regions and regional towns, which are connected by highways. This creates a dispersed value chain. By implementing a more localised network of entities involved in the agricultural value chain (through the agribusiness coexistence model), the demand cycle for agri-based products can be better controlled due to the centralised nature of the system. On a local scale, the agribusiness coexistence model allows local consumers to purchase fresh 'home-grown' produce (better availability due to irrigation water supply), which further supports local farmers to maintain the 'locally-grown' initiative. Such policy adoption associated with the agribusiness coexistence model can also have a global impact, with the export of high-quality meats, and other agri-based food products to international consumers, injecting investment for Australia's economic prospects and further strengthening the agricultural value chain. The suggested agri-based coexistence model has shown the potential of concurrently developing CSG operations with agriculture-based industries, whereby the energy-food nexus can be maintained. Moreover, careful coordination and continuous engagement with the local industry is required for successful 'API-CSG' coexistence to occur.

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