Introduction to Hydraulic Fracture Stimulation

Worldwide History

Pumping fluids and proppants under pressure down a well was first trialled in Kansas in 1947. In this experiment, 3,800 litres of gelled petroleum and sand were injected into a gas producing limestone formation at a depth of 730 metres, followed by an injection of a gel breaker. While this experiment failed to produce a significant increase in gas production, it did mark the beginning of hydraulic fracture stimulation.

In 1949 Halliburton became the first company to extract natural gas in commercial quantities through hydraulic fracturing. The technology available at the time only enabled the stimulation of loose geological formations. Thereafter, the process was commercially successful in stimulating gas wells and began to grow rapidly from 1950.

Horizontal drilling allowed the wells to access more of the hydrocarbon bearing formation. The first horizontal well was drilled in the 1930's and became common by the late 1970's. In the mid-1970's, a partnership of private operators and United States government agencies fostered technologies that eventually became crucial to the production of natural gas from shale rock, including horizontal wells and multi-stage fracturing.

Modern day hydraulic fracturing did not begin until the 1990's, when George P. Mitchell (of Mitchell Energy and Development Corporation) combined horizontal drilling with hydraulic fracturing. This enabled the commercially viable production of gas from the Barnett Shale in North-Central Texas.

The Society of Petroleum Engineers estimates that 2.5 million hydraulic fractures have been undertaken worldwide, with over 1 million in the United States. Additionally, tens of thousands of horizontal wells have been completed over the past 60 years.

Recent technology trends in hydraulic fracturing have included the development of horizontal wells, multi-stage fracture programs, systems that recover, treat and re-use returned fracture fluids, the use of saline and brackish water in fracturing fluid and the use of lower toxicity chemicals. In the last decade, there has also been a focus on developing tools and materials to increase the effectiveness of hydraulic fracture stimulation treatments and exploring alternatives to, or strategies to minimise, the use of water and chemicals, driven by resource recovery and public concerns. To date, hydraulic fracture stimulation using water-based fluids has been the predominant method in Australia with limited experimental application of high pressure nitrogen and propellants (high energy gas fracturing).

History in Western Australia

In Western Australia, more than 600 wells have undergone hydraulic fracture stimulation in conventional reservoirs since 1958. The first hydraulic fracture stimulation in Western Australia was conducted in that year on the Goldwyer 1 well 100 km southeast of Broome. Fracture stimulation or re-fracturing has been conducted on 563 wells on Barrow Island since 1965. These activities involved small scale fracturing and were conducted at relatively low hydraulic fracturing pressures

(~1,300 per square inch (psi), or 8,963 Kilopascal (kPa)) for the purpose of improving oil recovery from the oil producing sands on Barrow Island. More recently 12 hydraulic fracture stimulations have occurred in Western Australia between 2004 and 2015, all conducted in vertical wells and using more contemporary hydraulic fracturing methods. Table 1 below is a complete list of stimulated wells in Western Australia.

Well Name	Well Completion Date	Onshore /Offshore	Basin	Approximate Location	Range of Stimulation Depth (metres)
Barrow Island (500+ wells)	1964 onwards	Onshore	Carnarvon	Barrow Island	Various
Arrowsmith 2	18/06/2011	Onshore	Perth	30 km north of Eneabba	2639 - 3293.3
Asgard 1	29/09/2012	Onshore	Canning	50km wsw of Fitzroy Crossing	2567.9-3403.4
Blina 3	04/10/1982	Onshore	Canning	100 km south east of Derby	1459.5 - 1478.5
Bootine 1	22/11/1981	Onshore	Perth	West of Gingin	3752.5 - 4085
Corybas 1	07/03/2005	Onshore	Perth	Dongara area	2514 - 2536
Dongara 03	18/09/1966	Onshore	Perth	Dongara area	1602 - 1696
Dongara 09	08/05/1969	Onshore	Perth	Dongara area	1685 - 1726
Dongara 15	04/11/1969	Onshore	Perth	Dongara area	1652 - 1717
Dongara 21	05/03/1980	Onshore	Perth	Dongara area	1589.5 -1601.2
Dongara 24	28/03/1981	Onshore	Perth	Dongara area	
East Lake Logue 1	28/01/1983	Onshore	Perth	Dongara area	2324 - 2335
Ejarno 1	25/06/1981	Onshore	Perth	Dongara area	2727 - 2734
Gingin 1	15/07/1965	Onshore	Perth	West of Gingin	3949 - 3956
Goldwyer 1	22/11/1958	Onshore	Canning	100 km south east of Broome	1161 - 1196
Great Sandy 1	13/11/1981	Onshore	Canning	150 km south east of Broome	1478 - 1494.7
Grevillea 1	21/09/1982	Onshore	Canning	100 km south west of Fitzroy Crossing	1635 - 1639
Hedonia 1	27/09/1984	Onshore	Canning	100 km south east of Broome	1512 - 1535
Indoon 1	14/12/1982	Onshore	Perth	Dongara area	2191 - 2208
Meda 1	21/11/1958	Onshore	Canning	100 km south east of Derby	1600 - 2041
Mondarra 2	18/02/1969	Onshore	Perth	Dongara area	2736 - 2740
Nita Downs 1	30/09/1983	Onshore	Canning	150 km south east of Broome	1510 - 1540
Pictor 2	05/12/1990	Onshore	Canning	100 km south of Derby	929 - 956
Setaria 1	31/05/1989	Onshore	Canning	200 km south of Fitzroy Crossing	436 - 447
Senecio 2	21/15/2005	Onshore	Perth	16 km east of Dongara	2785 - 2860.5
South Pepper 04	17/05/1984	Offshore	Carnarvon	30 km south of Barrow Island	1230 - 1236
Turtle 1	09/03/1984	Offshore	Bonaparte	150 km north east of Wyndham	1615 - 1624
Turtle 2	02/07/1989	Offshore	Bonaparte	150 km north east of Wyndham	2420 - 2446

Well Name	Well Completion Date	Onshore /Offshore	Basin	Approximate Location	Range of Stimulation Depth (metres)
Valhalla North 1	22/02/2012	Onshore	Canning	90km wnw of Fitzroy Crossing	2827.9-3270.9
Walyering 2	25/12/1971	Onshore	Perth	Badgingarra Area	3702 - 3722
Warradong 1	14/04/1981	Onshore	Perth	Dongara area	3178 - 3188
Warro 1	20/09/1977	Onshore	Perth	70 km north east of Jurien Bay	3971 - 4093
Warro 2	05/04/1978	Onshore	Perth	70 km north east of Jurien Bay	3991 - 4073
Warro 3	20/03/2009	Onshore	Perth	70 km north east of Jurien Bay	3744 - 4254.1
Warro 4	11/05/2011	Onshore	Perth	60 km east of Jurien Bay	3878 - 4079
Warro 5 (ST)	05/09/2015	Onshore	Perth	55km north of Dandaragan	4331-4394
Warro 6	03/11/2015	Onshore	Perth	55km north of Dandaragan	4306-4459
Whicher Range 1	22/09/1968	Onshore	Perth	20 km south of Busselton	4050 - 4285
Whicher Range 2	27/07/1980	Onshore	Perth	20 km south of Busselton	3951 - 4026
Whicher Range 3	08/05/1982	Onshore	Perth	20 km south of Busselton	4020 - 4357
Whicher Range 4	03/11/1997	Onshore	Perth	20 km south of Busselton	4045 - 4380
Whicher Range 5	21/01/2004	Onshore	Perth	20 km south of Busselton	4001 - 4262
Woodada Deep 1	18/04/2010	Onshore	Perth	63 km south of Dongara	2283 - 2424.4
Woodada 02	03/08/1980	Onshore	Perth	20 km north east of Leeman	2309 - 2460
Woodada 03	11/01/1981	Onshore	Perth	58 km south of Dongara	2413-2478.5
Woodada 04	05/04/1981	Onshore	Perth	20 km north east of Leeman	2138 - 2271
Woodada 05	18/03/1982	Onshore	Perth	20 km north east of Leeman	4372 - 4378, 2402 - 2407
Woodada 06	08/05/1982	Onshore	Perth	20 km north east of Leeman	2140 - 2238
Woodada 08	18/09/1983	Onshore	Perth	20 km north east of Leeman	2146 - 2231
Woodada 16	01/10/1999	Onshore	Perth	20 km north east of Leeman	2248 - 2286
Yowalga 3	17/01/1981	Onshore	Officer	550 km east of Wiluna	2057 - 2062
Yulleroo 1	05/12/1967	Onshore	Canning	100 km east of Broome	3394 - 3407
Yulleroo 2	10/05/2008	Onshore	Canning	100 km east of Broome	2853 - 3119

Table 1. Stimulated petroleum wells in Western Australia. Source: Department of Mines, Industry Regulation and Safety, WA.

Hydraulic Fracture Stimulation

Hydraulic fracture stimulation involves pumping fluids and ‘proppants’ (solid material such as sand or ceramic beads) into a low-permeability rock under high pressure to create fine fractures. Typically, the fluid is about 90 per cent water with 9.5 per cent proppant, which is designed to keep the fractures open; the remaining 0.5 per cent is made up of chemical additives. Chemical additives are used to thicken and suspend the proppant in the fluid, stop microbial growth, prevent corrosion and make it easier for the fluid to move through the fractures.

The sequence and composition of hydraulic fracturing treatments underground corresponds to the physical properties of the rock formation. The sequence described below from a Marcellus Shale in the United States is just one example. Each rock zone is different and requires a hydraulic fracturing design tailored to the particular conditions of the formation. As such, while the process remains essentially the same, the sequence may change depending upon unique local conditions. It is important to note that not all the additives are used in every hydraulically fractured well; the exact “blend” and proportions of additives will vary based on the site-specific depth, thickness and other characteristics of the target formation.

Stages of Hydraulic Fracture Stimulation

Acid Stage

This usually consists of water mixed with a dilute acid such as hydrochloric or muriatic acid. The acid clears any remaining cement debris in the wellbore from the well completion and provides an open conduit for other fracture fluids by dissolving carbonate minerals and pre-existing opening fractures near the wellbore.

Pad Stage

Thickened water without proppant material is injected into the well bore. The pad stage fills the wellbore with the thickened water solution (described below), fractures the formation and helps to facilitate the flow and placement of proppant material. In Western Australia fractures are typically around 3 to 6 millimetres wide, up to 400 metres long and usually less than 100 metres high.

Prop Sequence Stage

The prop sequence stage may consist of several sub stages of water combined with proppant material. Proppant consists of a fine mesh sand or ceramic material, intended to keep open, or “prop,” the fractures created and/or enhanced during the fracturing operation after the pressure is reduced. Proppant material may vary from a finer particle size to a coarser particle size throughout this sequence.

Flushing stage

A volume of water is injected, sufficient to flush the excess proppant from the wellbore. When the pumps are turned off, the proppant contained in the fluid remains in place, holding the fractures open and allowing the excess hydraulic fluids and then oil and gas to flow out of the shale and up the wellbore. The fluid can be recovered at proportions of 40 to 70 per cent and reused in further hydraulic fracture stimulation programs.

Oil and gas is produced from the shale in the immediate vicinity of the induced fractures. Initially the production rates are high, as the oil and gas that is made available by the hydraulic fracture stimulation flows to surface and is produced. This initial high production rate decreases as the amount of oil and gas left adjacent to the fractures diminishes. The effectiveness of hydraulic fracture stimulation is enhanced in combination with horizontal drilling because horizontal wells produce oil and gas from the length of horizontal rocks formations, whereas vertical wells only intersect a short portion of the formation (Figure 1). This reason is why drilling new wells is necessary and why horizontal drilling has been so successful in shale gas development overseas.

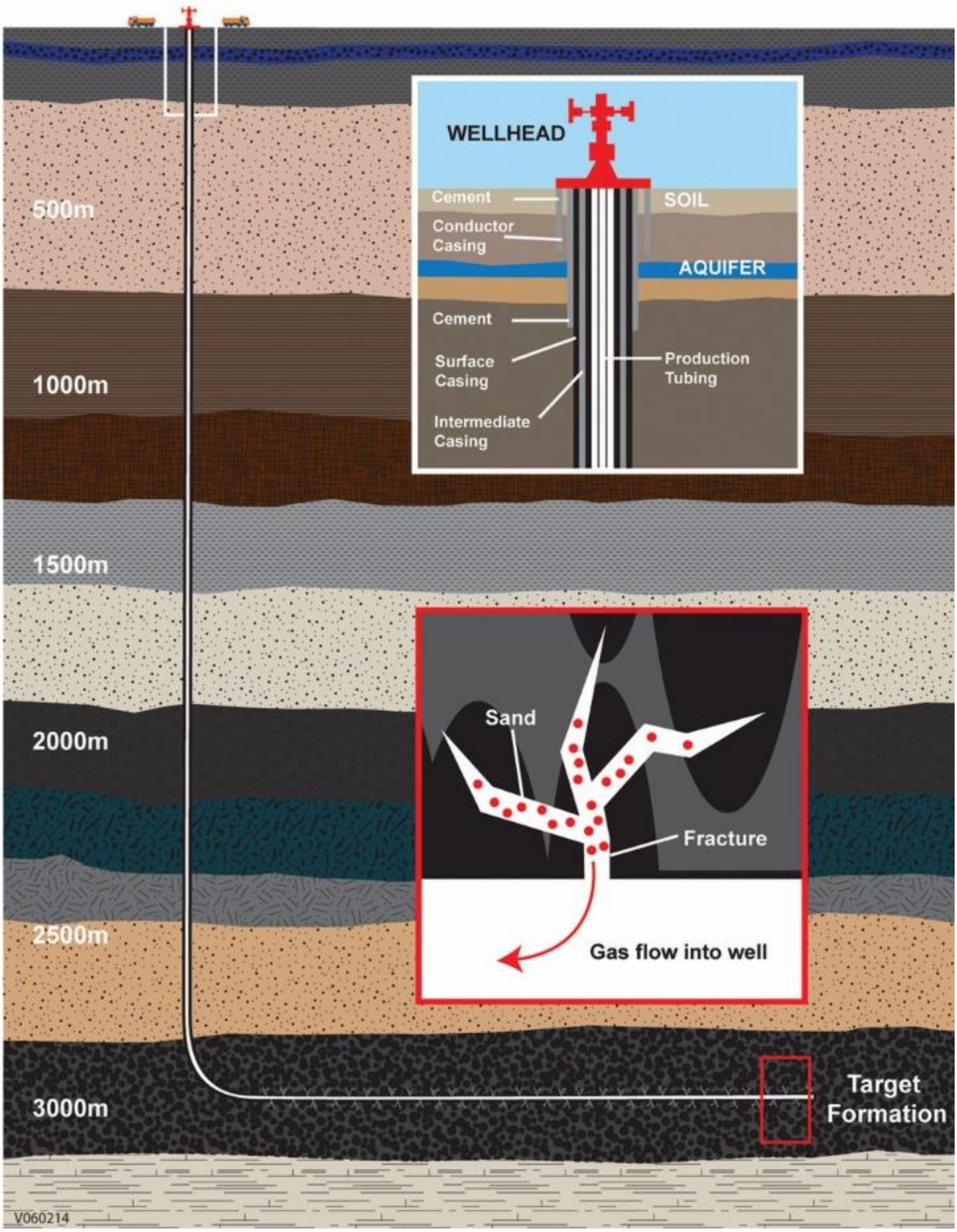

Figure 1. An example of hydraulic fracture stimulation based on Western Australian geology. Source: Department of Mines, Industry Regulation and Safety, WA.

Chemicals

The number, amounts and types of chemical additives used in hydraulic fracture stimulations are tailored to the conditions of the specific well, where each chemical component serves a specific purpose during the stages of a fracture stimulation. Typically, chemical additives in fracture fluids comprise around 0.5% of the fluid, where the remaining 9.5% and 90% is composed of proppant and water respectively.

The following table is a summary of the purposes of using chemicals in hydraulic fracture stimulation, how these chemicals work, examples of the types of chemicals used, and where they are used in common products to provide context.

Purpose	Action	Examples	Common Products*
Proppant	Physically holds open fractures to enable the flow of oil and gas.	Sand, ceramic beads.	Glass, ceramics, tiles pottery, sand.
Microbial control	Limits the growth of bacteria in fluids that may reduce flow rates and contribute to well corrosion	Glutaraldehyde, quaternary ammonium chlorides.	Medical and dental disinfectant, mould removal, throat lozenges, swimming pool algicide
Corrosion management	Removes or deactivates oxygen and other corrosive material in fluids which contribute to well corrosion.	Sodium sulphite, acetaldehyde.	Food preservatives, dyes, textiles, perfumes, plastics
Scale control	Limits the build-up of iron precipitates and mineral scale which can reduce the flow rate of fluids and contribute to well corrosion	Citric acid, thioglycolic acid, sodium erythorbate, sodium polycarboxylate.	Flavour enhancers, cleaning products, processed meats additives, soft drinks, hair treatments, leather processing
pH control, buffers, stabilisers, solvents	Adjusts the chemical and physical properties of the fluid to achieve optimal flow rates and pH ranges to prevent precipitation	Potassium carbonate, Sodium carbonate, sodium hydroxide, hydrochloric acid, ethylene glycol.	Soaps, glass, paper food additive, pool additives, car coolant.
Friction reducer	Reduces the friction forces of fluids being pumped into the well to increase flow rates	Polyacrylamide, sodium lignosulfates, glycerine.	Water absorbing toys, food preservatives, paper manufacture, leather treatments, hair products.
Clay stabiliser and inhibitor	Counters clay swelling in the well when drilling and in the rock being fractured to optimise drilling and flow rates.	Sodium chloride, isopropanol, potassium chloride, choline chloride, trimethyl ammonium chloride, silica gel	Table salt, hand sanitisers, hair products, pet supplements, dyes, poultry feed additives.
Gelling agents, binders and cross linkers	Increases the thickness of fluids, which allows proppants to be carried into rock fractures.	Guar gum, xanthan gum, MEA borate, sodium tetra borate, cellulose gum, polysaccharide.	Food thickening agent, cosmetics, toothpaste additive, hairspray, laundry detergents additives.
Breakers	Breaks down the gelling agents depositing the proppant into the rock fractures.	Sodium persulphate, hemicellulose enzyme, hypochlorite.	Hair colouring additives, food industry additives.
Surfactants	Reduces the 'stickiness' of fluids to improve flow rates.	Ethanol, lauryl sulphate, propan-2-ol.	Alcoholic beverages, detergent additives, cleaning agents.

*These common products are listed to provide context, with no implication or presumption that they pose no risk to the environment or people when used in hydraulic fracture stimulation. They will be risk assessed as part of this inquiry.

Table 2. A summary of chemicals used in hydraulic fracture stimulation fluids, their purpose, actions and common uses. Source: Department of Mines, Industry Regulation and Safety, WA.

The Department of Mines, Industry Regulation and Safety regulations (DMIRS) require petroleum companies to publicly disclose all chemicals and additives introduced to a well, including those used for drilling, well construction and hydraulic fracture stimulation. Chemicals and additives introduced to a well or formation are publicly listed here. As an example, Table 3 details chemicals approved for the Asgard 1 and Valhalla North 1 wells operations, available on the DMIRS website.

Compound	**CAS Number**	**% Mass**
Water Supplied by Customer NO CAS	No CAS	92.538800%
Sodium Chloride	7647-14-5	0.189800%
Isopropanol	67-63-0	0.000300%
Water	7732-18-5	4.248600%
Sodium thiosulphate	7772-98-7	0.003600%
Choline Chloride	67-48-1	0.010500%
Glutaraldehyde	111-30-8	0.008400%
Ammonium Sulphate	7783-20-2	0.007400%
Polyacrylamide	25085-02-3	0.007400%
Sodium Polyacrylate	2594415	0.001200%
Sodium Bisulfite	7631-90-5	0.000200%
Alkyl Alcohol	56-81-5	0.003800%
2-Propenoic acid, homopolymer, ammonium salt	2594383	0.000200%
Ammonium Persulphate	7727-54-0	0.010200%
Potassium Persulfate	7727-21-1	0.000200%
2-Ethoxy-naphthalene	93-18-5	0.000200%
Potassium Hydroxide	1310-58-3	0.020400%
Potassium Carbonate	584-08-7	0.020400%
Ulexite	1319-33-1	0.014000%
L-Ascorbic acid, monosodium salt	134-03-2	0.001800%
Quartz	14808-60-7	2.454400%
Partially neutralized polycarboxylic acid polymer	68715-83-3	0.011600%
Distillates, Hydrotreated Light	64742-47-8	0.105200%
Guar Gum*	9000-30-0	1.089200%
Polyoxyethylene nonylphenol ether	9016-45-9	0.026300%
Quaternary ammonium compounds, bis(hydrogenated tallow alkyl)dimethyl, salts with bentonite	68953-58-2	0.026300%
1,6-Hexanediol	629-11-8	0.002600%
Hydrochloric Acid	7647-01-0	0.181500%
Formic Acid	64-18-6	0.001800%
Cinnamaldehyde	104-55-2	0.000300%
Tar Bases, Quinoline Derivatives, Benzyl Chloride-Quat	72480-70-7	0.000300%
Castor Oil	61791-12-6	0.000300%
Pine Oil	2228957	0.000300%
N-Benzyl-Alkylpyridinium Chloride	68909-18-2	0.000200%
2-Mercaptoethyl Alcohol	60-24-2	0.000200%
Polyoxyethylene-polyoxypropylene Block Copolymer	2594628	0.000200%
Diethylene Glycol	111-46-6	<0.00001%

Compound	CAS Number	% Mass
Sodium Erythorbate	6381-77-7	0.013000%
2- Fluorobenzoic Acid Sodium Salt	490-97-1	<0.00001%
3- Fluorobenzoic Acid Sodium Salt	499-57-0	<0.00001%
4- Fluorobenzoic Acid Sodium Salt	499-90-1	<0.00001%
2,4 Difluorobenzoic Acid, Sodium Salt	1765-08-8	<0.00001%
2,5 Difluorobenzoic Acid, Sodium Salt	522651-42-9	<0.00001%
2,6 Difluorobenzoic Acid, Sodium Salt	6185-28-0	<0.00001%
3,4 Difluorobenzoic Acid, Sodium Salt	522651-44-1	<0.00001%
2,4,5 Trifluorobenzoic Acid, Sodium Salt	522651-48-5	<0.00001%
2 - Trifluoromethylbenzoic Acid, Sodium Salt	2966-44-1	<0.00001%
3- Trifluoromethylbenzoic Acid, Sodium Salt	69226-41-1	<0.00001%
4- Trifluoromethylbenzoic Acid, Sodium Salt	25832-58-0	<0.00001%
2,3,4,5-Tetrafluorobenzoic Acid, Sodium Salt	67852-79-3	<0.00001%
Perfluorodimethylcyclobutane	2994-71-0	<0.00001%
Perfluoromethylcyclopentane	1805-22-7	<0.00001%
Perfluormethylcyclohexane	355-02-2	<0.00001%
Perfluoroethylcyclohexane	335-21-7	<0.00001%
i-Perfluoropropylcyclohexane	423-02-9	<0.00001%
Perfluorodecalin	306-94-5	<0.00001%
Titanium Oxide*	51745-87-0	0.100000%
Potassium Oxide	12136-45-7	<0.00001%
Iron Oxide*	1332-37-2	0.100000%
Dipropylene glycol methyl ether	34590-94-8	<0.00001%
Xanthanum Gum	1113866-2	<0.00001%
Silicon Dioxide	7631-86-9	<0.00001%
Aluminium Oxide*	1344-28-1	1.400000%
Iridium 192 Oxide	14694-69-0	<0.00001%
Calcium Oxide	1305-78-8	<0.00001%
Scadium46 Oxide	13967-63-0	<0.00001%
Antimony124 Oxide	14683-10-4	<0.00001%
Amorphous silica*	7631-86-9	0.400000%
TOTAL (including contingencies)		**103.000000%**

*Ingredient in contingency product

Table 3. Chemicals approved for use for the fracture stimulation of the Asgard 1 and Valhalla North 1 wells. Source: Department of Mines, Industry Regulation and Safety.

All chemicals stored on an oil or gas site in Western Australia must comply with their corresponding Material Safety Data Sheets (MSDS) which identify management practices to ensure safe chemical storage, transport, use and disposal. These can be found here. The transport, storage and disposal of hazardous chemicals is regulated by several State government agencies. After fluid has been used down a well, the waste water returned to the surface can be re-used during further hydraulic fracture stimulations or stored in lined and bunded evaporation ponds or tanks. This is to prevent waste water from seeping into groundwater until it is removed by a licensed waste contractor and disposed of offsite at a licensed waste facility.

Water Use

In Western Australia, most of the water currently used for petroleum activities comes from underground aquifers. A water bore is constructed to extract groundwater for use in the drilling and hydraulic fracturing of petroleum wells. Prior to constructing bores or taking any water, proponents must apply to the Department of Water and Environment Regulation (DWER) for a licence under the *Rights in Water and Irrigation Act 1914*.

The quality of water for use in drilling and hydraulic fracturing does not need to be potable (i.e. fresh). Brackish or saline water can be used, as well as recycled water. Water may need to be pre-treated before use, depending on its constituents.

While some water is required to drill an oil or gas well, a larger amount of water is used during hydraulic fracture stimulation.

Hydraulic Fracture stimulation in the Perth Basin may require three stages of hydraulic fracturing per vertical well (of up to 3 km deep). This equates to using around 7,000 kL of water per vertical well: 2,000 kL for drilling and 5,000 kL for hydraulic fracturing. This is equivalent to almost 3 Olympic size swimming pools (a standard Olympic sized swimming pool contains 2,500 kL of water).

For horizontal wells (with a horizontal reach of one kilometre) using 10 fracture stages, around 18,500 kL would be required for hydraulic fracturing and 2,000 kL for drilling. This equates to about 8.5 Olympic size swimming pools. In the United States horizontal wells are typically drilled to lengths of around 1.5 km, and occasionally to lengths of around 3 km. To date, hydraulic fracturing has not yet been completed or proposed in a horizontal well in Western Australia.

The publication by the United States Energy Information Administration, Trends in US Oil and Natural Gas Upstream Cost (2016) states that 6 million gallons (about 23, 000 kL) of water is used per well with 25 fracture stages or 900 kL per fracture. This latest data suggests that with advances in technology the water required in Western Australia may be significantly less. It is also important to note that water requirements are site specific and vary depending on the physical properties of the rock formation, depth and thickness.

Drilling and well completions

Oil and gas producing wells are constructed with multiple barriers to isolate produced well fluids from subsurface rock formations and the external environment. Multiple barriers are an important element in modern well design to ensure well integrity, where individual barriers are designed to be independent and are constructed to international engineering standards (Figure 2). The number of independent barriers is proportional to the potential risk of a specific well. Barriers in well design comprise cemented steel casing, tubing, seals and valves. These components are specifically designed for the subsurface conditions of each well.

Well construction

The main above-ground barrier of a petroleum well is an assembly of valves and fittings that control the flow of oil or gas and is known as a ‘Christmas tree’ (Figure 2).

The Christmas tree sits on top of the wellhead and is the interface between the well and a production facility. It allows for surface monitoring and control of production of petroleum from a well.

Petroleum wells are drilled in sections with each consecutive section deepening the well and having a smaller diameter than the previous section. The largest diameter section is drilled first; the smallest diameter section is the production hole, drilled last. When a particular section is drilled to its appropriate depth, steel casing made up of steel pipes joined together (casing string) is placed into the hole and cemented to the rock in order to isolate the rock formation from the wellbore. The next section drilled uses a smaller diameter drill bit in order to fit through the casing that has been cemented in the previous section.

Pressure testing is performed to ensure the cement and casing can withstand the pressures involved in subsequent down-hole activities (such as producing petroleum or conducting hydraulic fracture stimulation). Lastly, the production casing and cement layer are perforated to allow access from the gas-bearing rock formation into the wellbore. These perforations are generally less than a few centimetres in diameter.

The perforations enable gas to flow from the target rock formation into the wellbore and up the well to the surface, safely isolating the producing zone from groundwater aquifers. In the hydraulic fracture stimulation process, the wellbore is used to contain and transport injected hydraulic fracture stimulation fluids to the petroleum-bearing rock formation. It also contains and transports flowback fluids and produced water and gas to the surface.

A number of international studies have been completed examining well failure and well failure rates. “Well barrier failure” and “well failure” with a breach to the surrounding environment are not the same, because a properly constructed and designed oil and gas well will have multiple independent barriers providing well integrity. A well may have an internal barrier failure without resulting in hydrocarbons escaping to the environment. Continuous monitoring of well activity will indicate failure of a well barrier so that action can be taken immediately to correct the problem.

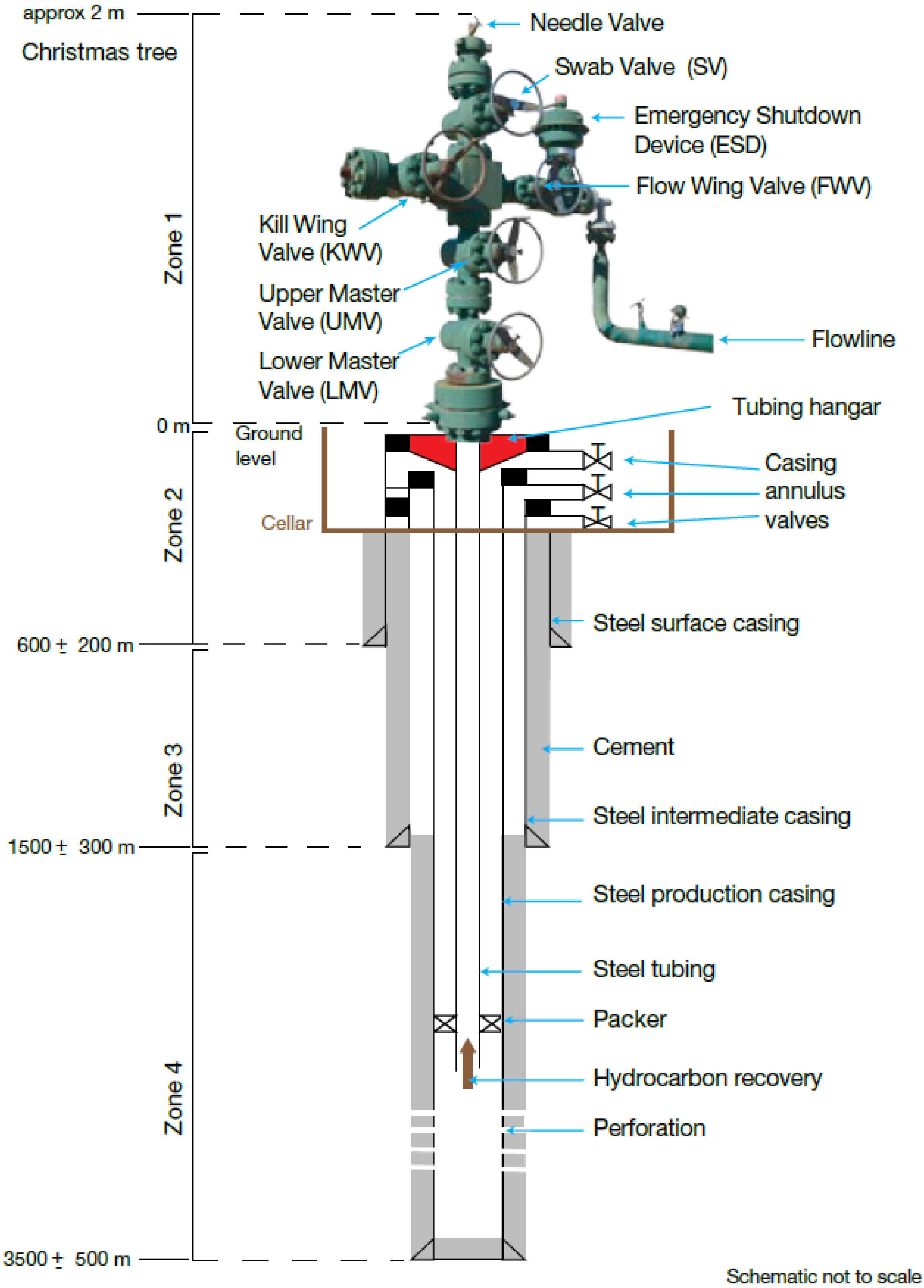

Figure 2. Petroleum well construction showing barriers below ground and valves above ground. Source: Department of Mines, Industry Regulation and Safety, WA

Deviated wells and multiple well pads

Historically, petroleum wells were drilled vertically, extending straight down into the targeted rock formation. Technological advances later allowed the drilling of horizontal wells at depth to access conventional reservoirs. Horizontal wells are commonly used in conventional offshore petroleum fields, where the wells are drilled from a platform in different directions. A horizontally drilled well can reach more than five kilometres from the platform in the US. This technology is now used in drilling for shale and tight gas, but to date is extremely rare in onshore wells in Western Australia.

To drill horizontally, a well is initially drilled straight down (vertically) to a point above the target rock formation and then slowly turned to drill in a shallow arc until the wellbore extends horizontally. The well continues horizontally until it reaches the desired length in the targeted reservoir formation. A horizontal wellbore contacts a greater surface area of the reservoir, allowing more petroleum to be produced.

Several horizontal wells can be drilled in multiple directions from a single well pad. Typically, five wells are accommodated on a single pad, although some pads have supported up to eight. This configuration results in a smaller surface land footprint, as fewer well pads and access roads are needed to produce the same amount of gas as many single well pads (Figure 3).

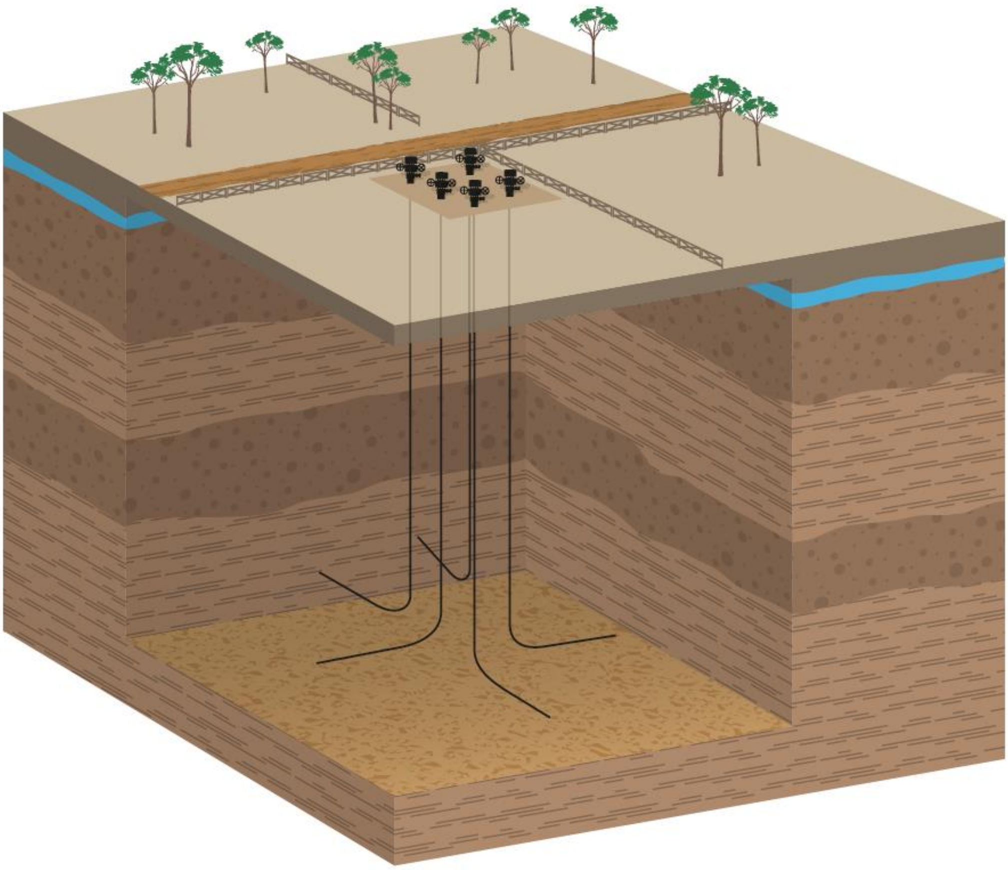

Figure 3. An illustration of multiple horizontal well completions from a single well pad. Source: Department of Mines, Industry Regulation and Safety, WA