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Drilling into the technology landscape of fracking

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Abstract

Fracking is one of the most controversial topics in energy production. Supporters of fracking claim it increases energy independence, and has lowered both gas prices and CO_2 production in the US. Opponents claim that it can threaten groundwater and cause earthquakes.

This paper will leave the controversy to others, and instead talk about patents in fracturing. The reason for this is that patents can be an excellent and accessible guide to the development and ownership of any technology.

Fracking is generally regarded as the combination of 'slickwater fracturing' and horizontal drilling. These two technologies were thought to have been first combined in 2002, and this combination is thought to have driven the current boom. Production of the resulting shale gas has increased greatly from about 2005 onwards. In Australia, Santos uses fracking in the Cooper Basin.

A search for fracking patents identified 2361 patent families. 300 new patent families are being filed every year, which is a much lower rate than some other energy technologies. However, merely counting the number of patent families does not tell us about the most important clusters of activity, and which companies dominate these clusters. For this reason Griffith Hack's associate Ambercite has developed Network Patent Analysis (NPA), which can help explore and further understand developments in this increasingly important technology.

NPA firstly identified similar patents to boost the total dataset to almost 100,000 patents, and then identified the leading 965 patents in this expanded dataset. These patents were unusually tightly clustered compared to some other areas of technology, with only three clusters being found. The subject matter of these dominant clusters were:

- 'Stabilization' (54% of estimated patent value, and referring to stabilization of the underground channels formed in fracking)
- 'Liquefaction of hydrocarbons' (35%)
- 'Viscosity control' (8%, referring to viscosity control of fracking fluids)

This small number of clusters, the dominance of these clusters by a small number of patent owners, and the relatively low number of patents suggest that fracking as a technology is still maturing. This is not surprising considering the current technology of fracking is just over 10 years old.

Keywords: *Fracking, hydraulic fracturing, patents, Network Patent Analysis*

Introduction

Fracking, or hydraulic fracturing, has had a major impact on gas production in the United States, and could have the same impact in Australia. Fracturing oil sands and other gas or oil bearing substrates dates back to 1865, when nitro-glycerine was first lowered into oil bearing sands to blast fractures and improve production[1].

Production grew steadily until about 2002, when a company by the name of Devon Energy combined 'slickwater hydraulic fracturing' (use of chemicals in fracturing, explained below) with the already established technology of horizontal drilling to create the modern version of fracking:

"That was the 'aha' moment. At that point, it was this worldwide breakthrough," [2]

Gas production has certainly increased since then. Production of shale gas from fracking has increased ten-fold from 0.45 trillion cubic feet [12.6 billion cubic metres] in 2005 up to 7.1 tcf [200 bcm] in 2012, and this is expected to double to around 16.7 tcf [470 bcm] in 2040.

Not surprisingly, this has to lead to a decline in natural gas prices in the US, down from a peak of US$13 per thousand cubic feet in July 2008 to a price of $5.60 in May 2014[3].

Australia is not nearly as developed in this area as the US, but we are progressing. Fracking has recently been deployed by Santos in the Cooper Basin, helping to boost gas production from this longstanding gas field.

Fracking, like coal seam gas, has generated worldwide controversy, and they can be confused with one another even though both extraction methods are based on different principles. Coal seam gas is extracted by pumping water into and from the coalbed so that both gas and produced water come to the surface. Fracking can be used to help increase the production of coal seam gas[4].

The complex political debate surrounding fracking and coal seam gas is best left to those who are better qualified to expand the arguments for and against both techniques. It is sufficient for the purpose of this paper to say that the incidence of fracking is increasing in some countries.

What is fracking?

Fracking has been well covered by others, so will only be briefly covered here. Figure 1 (page 3) is an excellent overview.

It is clear that fracking involves a combination of technologies:

- Deep drilling
- Horizontal drilling
- Injection of fluids under pressure to fracture the shale
- Viscosity control agents (sometimes known as 'slickwater additives')
- Proppants (particulates to help keep the induced fractures open)

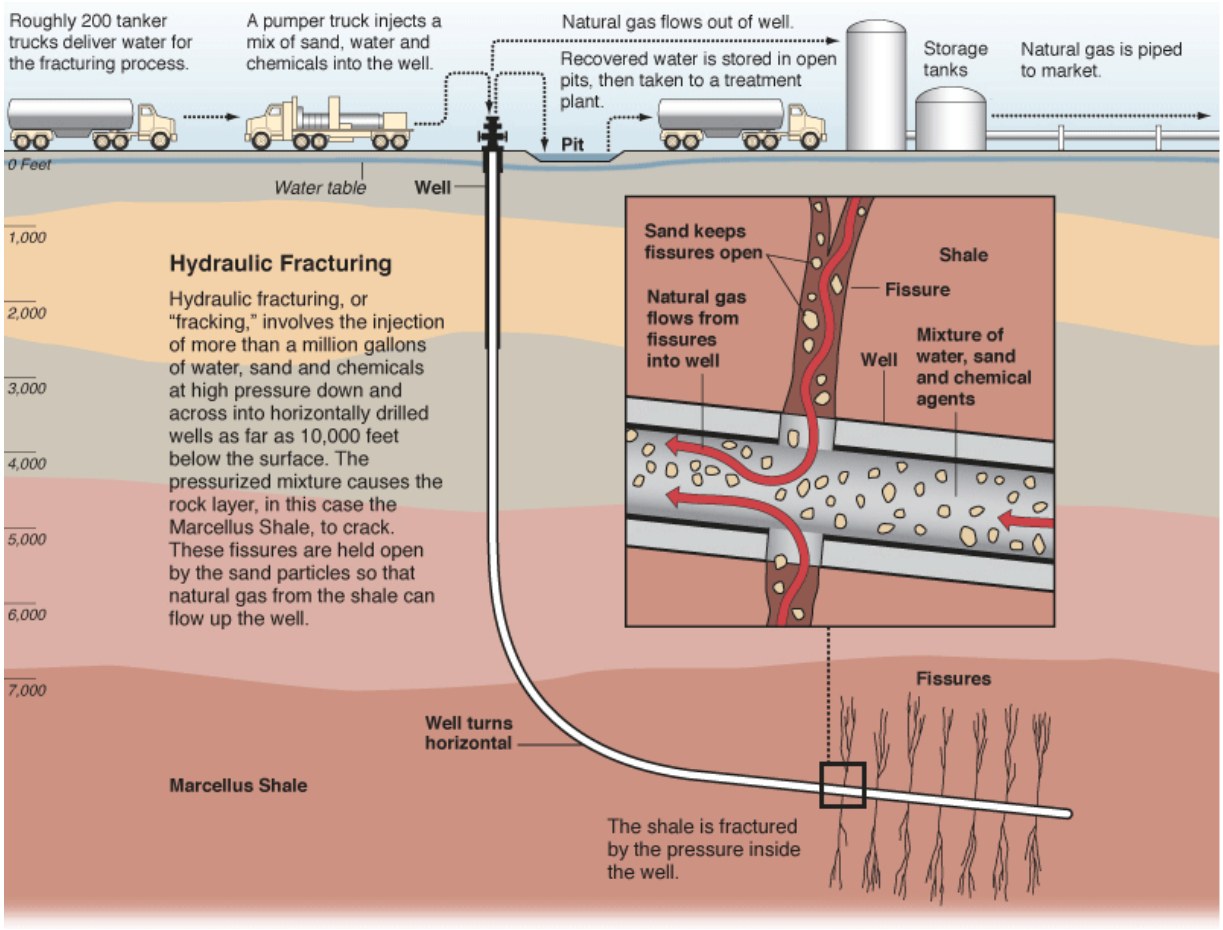


Figure 1. Schematic description of fracking (Grenberg 2012, used with permission).

Patents in fracking

Patents on fracturing go back a long way, even before the advent of hydraulic fracturing. The inventor of explosive fracturing, Colonel Roberts, received US patent 47458 for the ***Improvement in Exploding Torpedoes in Artesian Wells*** in April 1865, and followed this with US59936 in November 1866 for ***Improvement in method of increasing capacity of oil-wells***. Both patents claimed aspects of the use of gunpowder in oil wells to increase oil production. Similarly, Stanolind filed a patent for hydraulic fracturing in 1949, which was later sold to Halliburton[5].

Society benefits from patent filings in two ways. Firstly, inventors and their backers or employers can feel more confident about commercialising new technologies. Secondly, published patents are freely available on a number of public access websites.

Data about patent publication is well organised and catalogued and, again, available from a number of different sources, some of them in the public domain. Hence, published patents can be used as a guide to the development and ownership of almost any technology. In this paper, we use patent data to illuminate the state of fracking (although of note, Devon Energy did not appear to have patented their 2002 breakthrough).

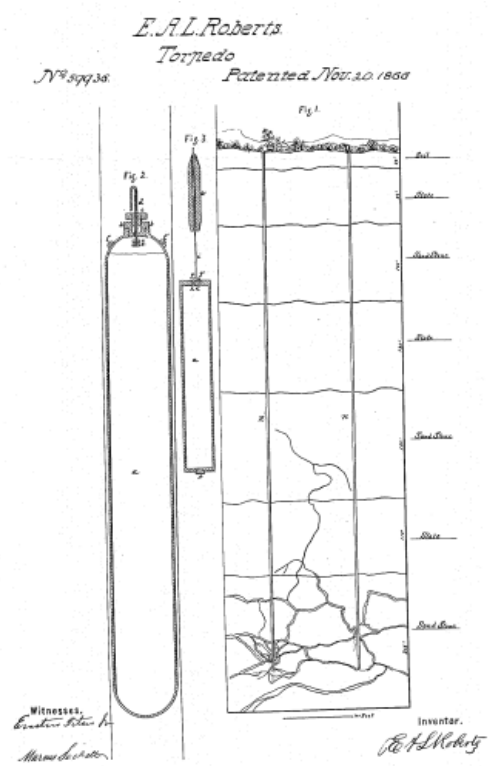


Figure 2. Drawing from patent US59936, filed in November 1966.

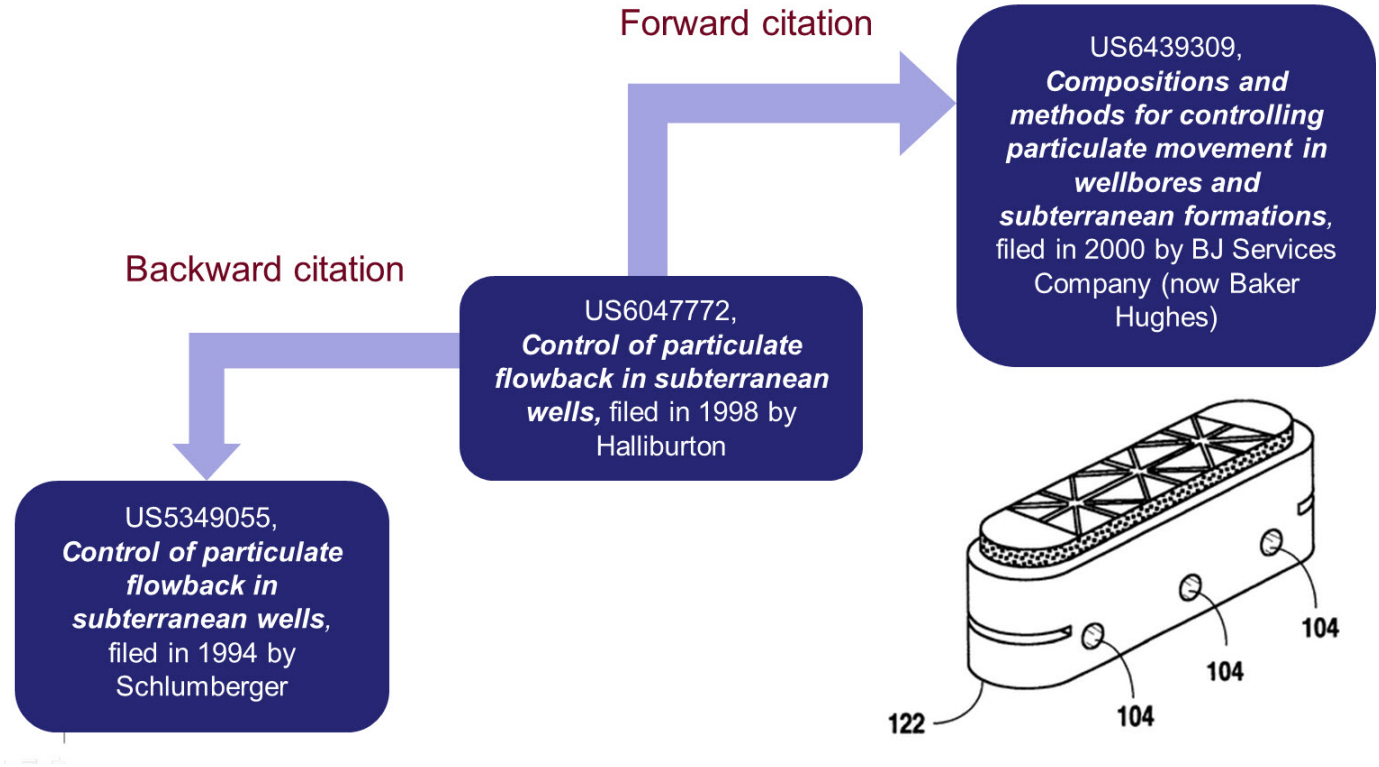
Network Patent Analysis

You may be surprised to learn that patents are not equal in terms of importance or value, and it can be hard to determine which patents deserve more attention. One means of making such an assessment is by analysing patent citations.

During patent examination, the patent examiner and the patent applicant refer to earlier patents which contain similar inventions. These references (or 'citations', see below) are often available online, and so it is possible to build up vast networks of patents linked to each other via such patent citations. Patents with many overlapping citations tend to be in similar areas of technology. Individual patents having many citations, particularly when cited by later patents, tend to be more important.

Ambercite has developed Network Patent Analysis (NPA) to apply these principles to large groups of patents in given areas. NPA is described elsewhere[6] but, from the viewpoint of this paper, NPA does three things:

- Identifies the most connected patents, leading to a manageable number of patents (965 patents in this study).
- Organises these remaining patents into clusters of similar patents.
- Ranks the remaining patents in an overall sense, and also within each cluster.

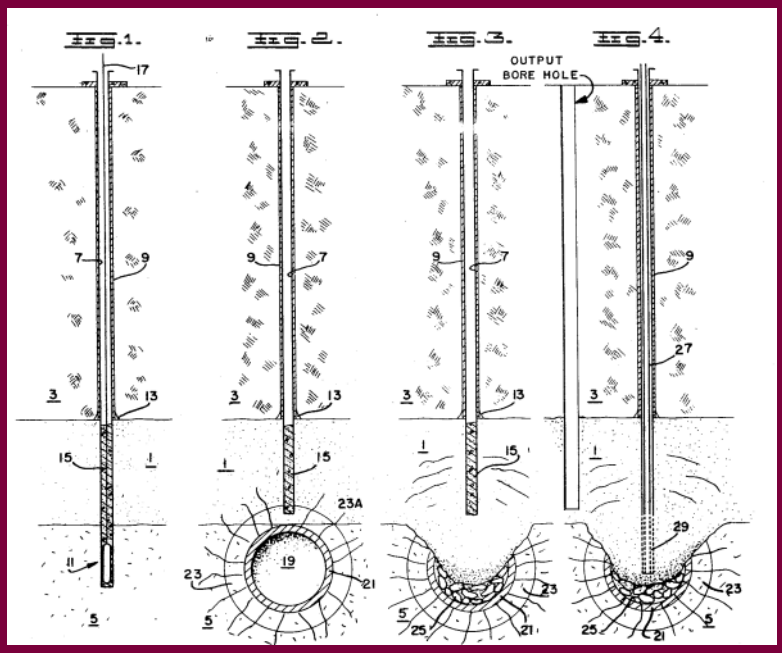


What are patent citations?

For a patent to be granted by a patent examiner, it needs to be novel (new) and inventive over all earlier inventions, which are otherwise referred to as 'prior art'. But how does a patent examiner find the prior art? This can come from two sources. The patent examiner will begin a diligent search in sophisticated databases for similar earlier patents and other publications (such as scientific papers) that disclose similar inventions.

In some cases the patent applicant will either voluntarily or be forced to declare any similar prior art they are aware of. This can lead to a large number of prior art documents, although in practice it is often only the most similar prior art documents are listed. A reference to an earlier patent or other document is known as a 'backward citation'. Similarly, a 'forward citation' is a later patent that cites the patent you are looking at as part of its examination process. The value of forward and backward citations is that they can help identify similar patents to a patent you are already interested in.

Fracturing using nuclear bombs!



The use of explosives to help with oil recovery goes back to 1865. No doubt a bigger bang lead to greater oil recovery in some cases. For this reason Richfield Oil Corporation in 1963 filed US3506069 for a ***Process for recovering petroleum utilizing a nuclear explosion***.

This patent even proposed the use of hydrogen bombs:

In some cases, depth permitting, a thermonuclear explosive device, i.e. hydrogen bomb, can be utilized if desired either in the vicinity of a limestone layer for reducing the limestone to calcium oxide or for fracturing the surrounding formations to make them more permeable for secondary recovery processes or for other purposes.

Believe it or not, this technology was trialled by the US Atomic Energy Commission who detonated an underground nuclear explosion in New Mexico and five more in Colorado between 1967 and 1973. These explosions were found to increase natural gas production, but this gas was flared off [7].

How we found fracking patents

There is a variety of approaches that could be used to find fracking patents. In this particular study, the following steps were applied, as shown in Figure 3

The Derwent patent database (from Thompson Innovation) was searched for patents that contained either of the terms:

> ALLD = Fracking or hydraulic* ADJ fracturing or (Fracturing NEAR3 subterranean)
>
> ALLD refers to 'all Derwent fields' (a range of fields including title and abstracts used to describe the subject matter of a patent), ADJ is short for adjacent, while NEAR3 means within three words.

This approach was broadly similar to the approach used by Cahoy, Gehman and Lei in their 2013 publication on fracking patents[8].

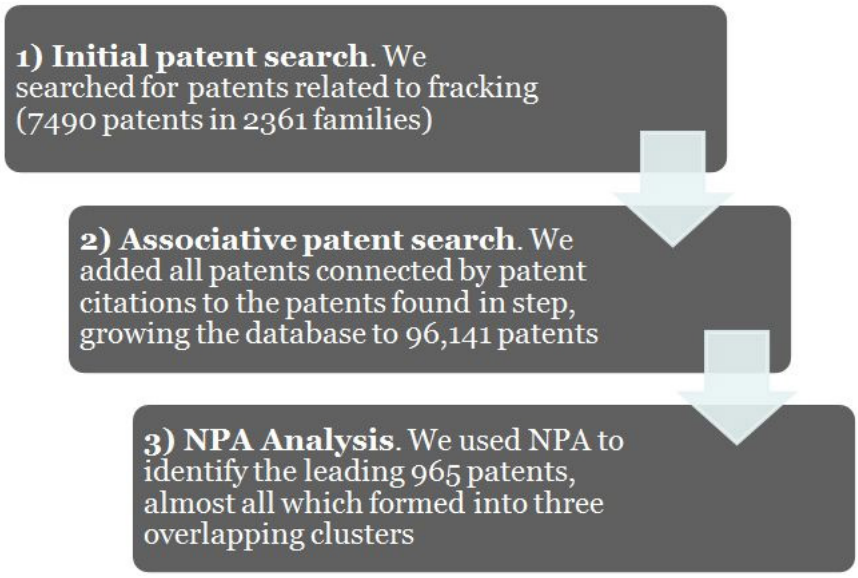


Figure 3. Overview of NPA process as applied to fracking.

Who were the leading applicants of fracking patents, and when did they file these patents?

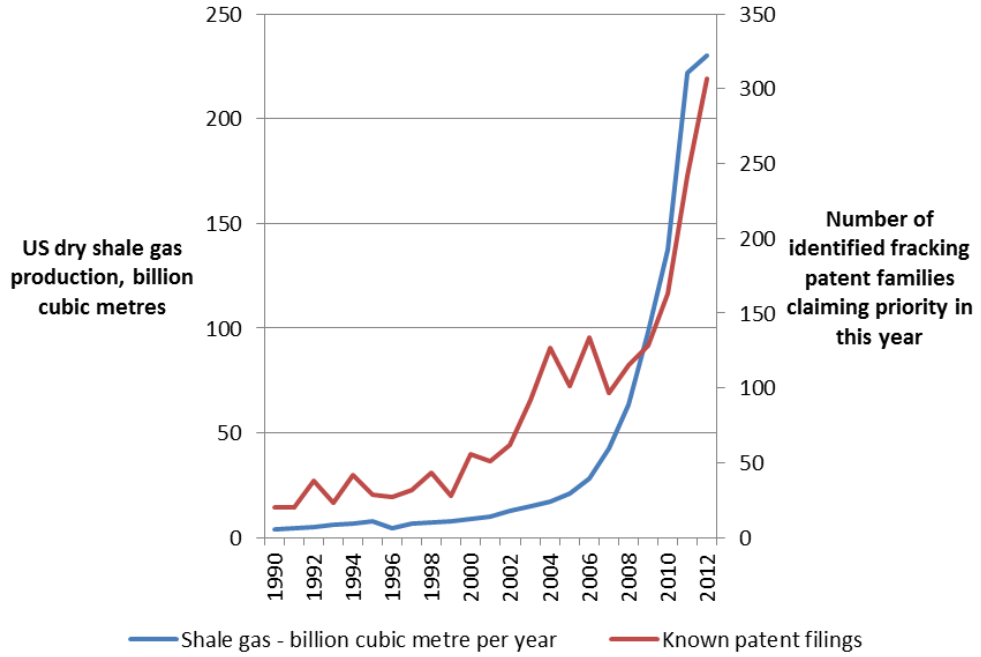


Figure 4. Priority year distribution for 2361 patents families found in patent search. For comparison, we have also provided data for US dry shale gas production (Adapted from data available at US Energy Information Administration website, 2012).

Patent filings grew steadily to about the year 2000, after which they increased rapidly to over 300 patent families filed per year in 2012 (Figure 4, above).

Nonetheless, 300 patents filed per year is not a high filing rate compared to the patent filing rate in many other areas of technology. For example, around 600 patent applications related to wind turbines are filed per year, while there are over 1000 solar photovoltaic patent applications filed every year[9].

Figure 4 shows how the growth in patent filings matched the growth in the production of shale oil, which is similar to what has been seen in other energy technologies[10].

The oil service companies Halliburton, Schlumberger and Baker Hughes were ahead of oil companies such as Exxon Mobil and Chevron (Figure 5, below). There were also a few chemical companies, reflecting the importance of specialised chemicals in fracking.

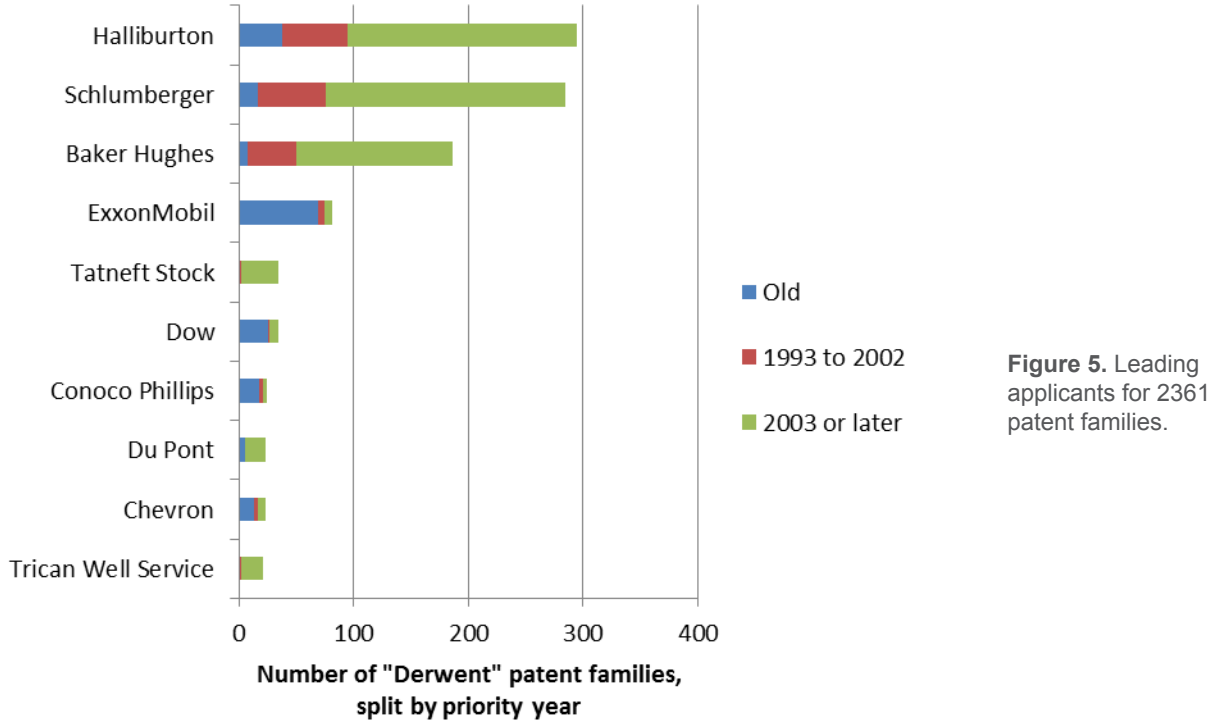


Figure 5. Leading applicants for 2361 patent families.

What were the leading areas of technology?

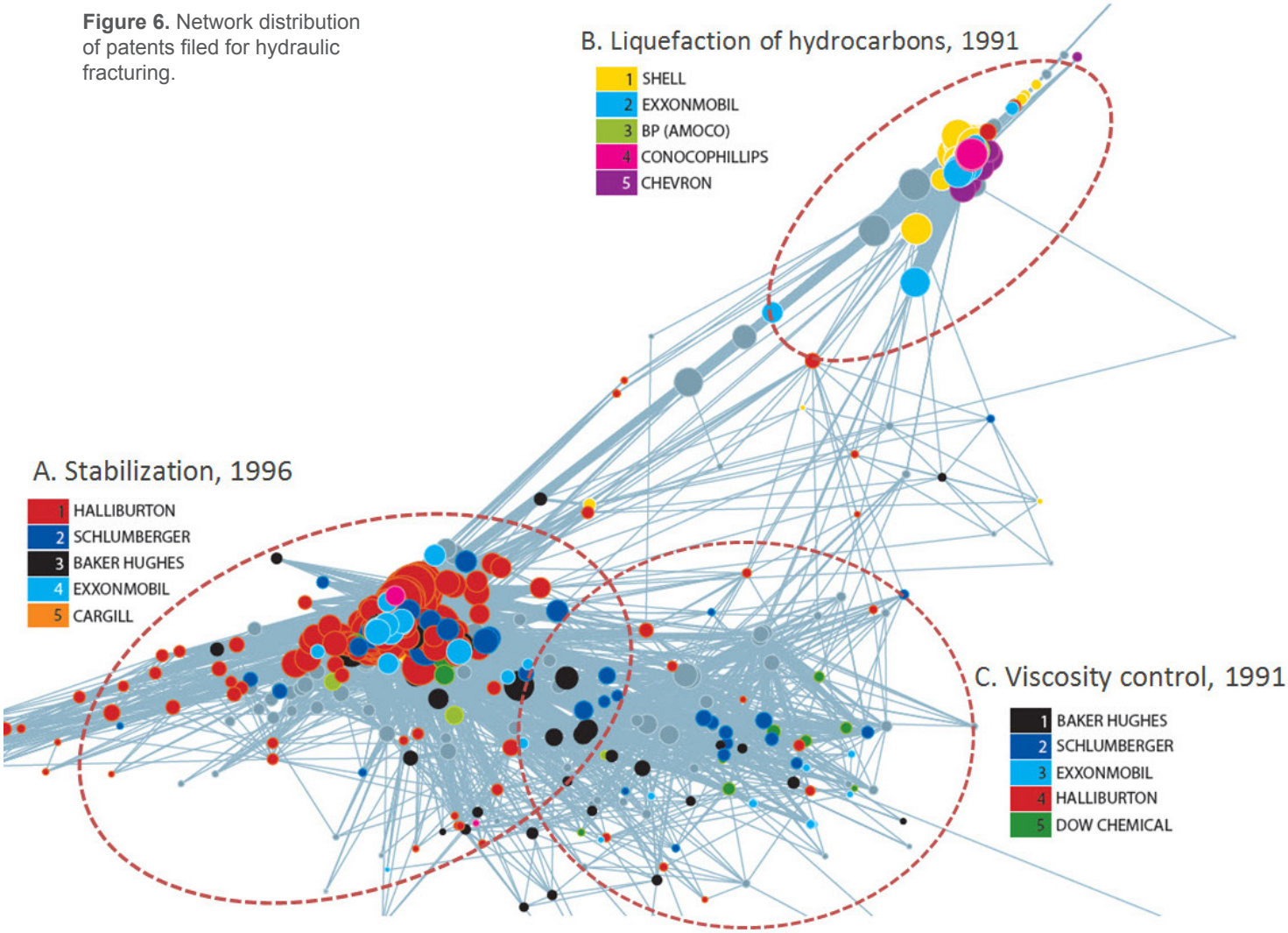


Figure 6. Network distribution of patents filed for hydraulic fracturing.

The value of NPA is that it can be used to highlight the leading areas of patent filing activity.

Figure 6 shows a NPA map for the leading 965 patents found in the full NPA process. Note that the two main clusters were both large and heavily interlocked. This is an unusually low number of clusters – other NPA studies we have run have produced 20 to 30 clusters. This means that fracking includes many closely related technologies.

Details of the 3 clusters, along with the 31 patents that did not fall into any one of the clusters, are listed in Table 1 (page 8). This includes a calculation of the proportion of 'cluster value' for leading applicants – i.e. individual patents are weighted based on NPA metrics, and these weightings are agglomerated to show the relative dominance of individual patent owners.

Cluster, and suggested title	A – Stabilization	B – Liquefaction of hydrocarbons	C – Viscosity control	Z – Broker patents (not clustered)	All patents
Proportion of calculated patent value for leading 965 patents	54%	35%	8%	2%	100%
Average priority year	1995	1996	1992	1997	1995
# of patents	529	322	83	31	965
Average citation year gap	11.9 years	10.8 years	5.6 years	-	-
Leading patent owners (proportion of cluster value)	Halliburton (51%, 272 patents)	Shell (54%, 181 patents)	Baker Hughes (17%, 14 patents)	Halliburton (24%, 8 patents)	Halliburton (29%, 291 patents)
2nd leading owner	Schlumberger (7%, 35 patents)	ExxonMobil (5%, 15 patents)	Schlumberger (16%, 12 patents)	Schlumberger (12%, 4 patent)	Shell (20%, 191 patents)
3rd leading owner	Baker Hughes (6%, 26 patents)	BP [Amoco] (4%, 13 patents)	ExxonMobil (11%, 10 patents)	Shell (10%, 3 patents)	Schlumberger (6%, 51 patents)
Top ranked patent	US6169058 *...fracturing composition comprising a... dispersion of... swellable particles...* (1997 Baker Hughes)	US5366012 *Method of completing an uncased section of a borehole* (1993, Shell)	US5551516 *Viscoelastic surfactant based aqueous fluid systems...* (1995 Schlumberger)	US4305463 *Oil recovery method and apparatus* (1979, Oil Trieval Corp)	US6169058 (#1 in cluster A)
2nd ranked patent	US5979557 *Methods for limiting the inflow of formation water…* (1997, Schlumberger)	US4390067, *Method of treating reservoirs...* (1981, ExxonMobil)	US8273693, *Polymeric gel system and methods…* (2007, Clearwater)	US5377756 *Method for producing low permeability reservoirs using a single well* (1993, ExxonMobil)	US5979557 (#2 in cluster A)
3rd ranked patent	US7934557 *Methods of completing wells...* (2007, Halliburton)	US5217076, *Method and apparatus for improved recovery of oil...* (1991, John Masek)	US5964295, *Methods and compositions for testing subterranean formations* (1996, Schlumberger)	US4399866, *Method for controlling the flow of subterranean water…* (1981, Atlantic Richfield)	US5551516 (#1 in cluster C)

Table 1. Details of clusters found.

In summary, Figure 4 and Table 1 tell us that:

- More than half of the patents are found in the main cluster, A 'Stabilization', which relates to technologies used to stabilise the fractured formations after fracturing. This dominance by a single cluster is comparatively rare in NPA studies.
- The other two clusters are 'Liquefaction of hydrocarbons' (35% of patent value) and 'Viscosity control of fracking fluids' (8% of patent value).
- Halliburton is the leading applicant of the Stabilization patent cluster (51% of the estimated patent value in this cluster), while Shell is the leading applicant of the Liquefaction patent cluster (54%). This dominance of individual clusters by large companies is not unusual.Some companies simply build up a critical mass of expertise in technologies in a given area. We can also speculate that a strong concentration of patents in one particular technology may be commercially strategic, deterring others from venturing into that area of the patent landscape, although this may change as the as the technology landscape of fracking continues to mature and diversify.
- Overall, Halliburton also has the most patents. Halliburton may not have invented fracking, but they were the first to license this technology soon after it was invented. Halliburton has continued to dominate fracking ever since, to the extent that when clean water regulations in the US were amended to exempt fracking activities this exception became known as the 'Halliburton Loophole' (although the public support of these amendments by former Halliburton CEO and then Vice-President Dick Cheney may also have contributed to this).
- With the exception of Shell's heavy dominance of the liquefaction cluster, the big oil companies are relatively (and perhaps surprisingly) quiet in this area.

What can we learn from the leading patents in the largest clusters?

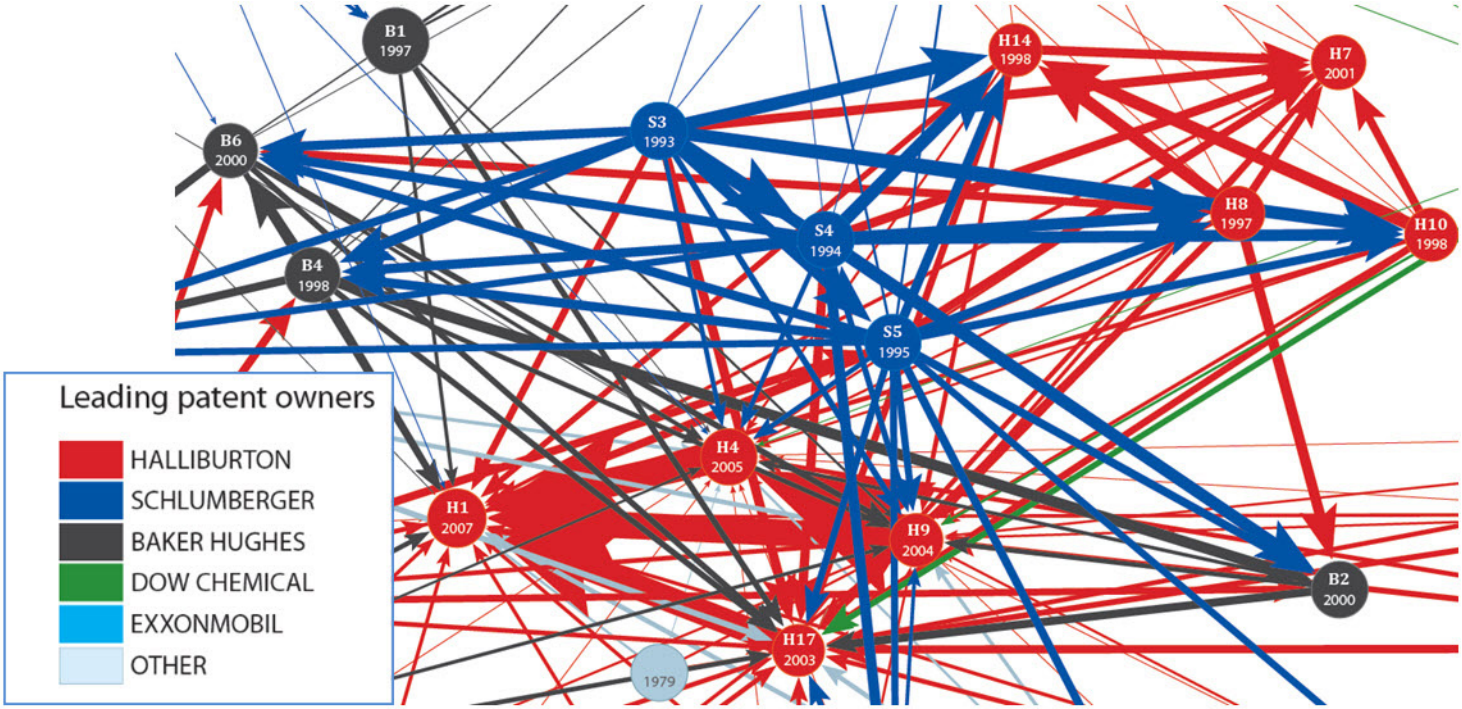


Figure 7. Detailed network of top 42 patents filed for fracking.

Cluster A – "Stabilization"

Figure 6 (page 7) is a high level view of the leading 965 patents. However, it can also help to deep dive into the landscape in much the same way as increasing the zoom within Google Maps increases the available detail. In this case, we end up with a map showing the top 42 patents, as shown in Figure 7 (above). All of these patents are found in cluster A 'Stabilization'.

Note that each patent has a symbol and filing year, where the symbol refers to the applicant and the relative ranking of the patent. Hence S1 refers to the top ranked Schlumberger patent, which is US5979557 ***Methods for limiting the inflow of formation water.*** This patent was filed in 1996, and refers to the selective blocking of the water bearing zone, but not the hydrocarbon zone, by using a viscoelastic surfactant capable of forming worm-like micelles in an aqueous environment.

This map also shows the directions of the citation connections between the patents. The arrow in every case points to the later patent (i.e. the patent that cites the earlier patent).

Pointing the arrow this way highlights the 'flow of ideas' through the patent network – and also potential patent infringement risks. Few people appreciate that when a patent owner has incorporated a patented invention inside a new commercial product or process, there is a risk that they may be infringing one or more of the backward citations for that patent.

It should be strongly emphasised at this point that patent infringement can only be determined by qualified patent attorneys or patent lawyers who have fully reviewed the patent claims and the alleged infringing product. Nonetheless, NPA can provide indicators about where such infringements may be found.

At this scale, some of the finer details of the network becomes clear: To a large extent, the Schlumberger (blue) and Halliburton (red) networks are networks within themselves. The majority of the Schlumberger (blue lines) reference/cite other Schlumberger patents. Similarly, the red Halliburton network is also mostly referenced to itself.

Forward citation patent symbol	Owner of forward citation	Patent number and filing date	Patent title	Broad invention
H14	Halliburton	US6047772, 2009	*Control of particulate flowback in subterranean wells*	Use of tackifying compound to reduce flowback, including in conjunction with fibres
H8	Halliburton	US5833000, 2007	*Control of particulate flowback in subterranean wells*	Use of tackifying compound to reduce flowback, including in conjunction with fibres
H10	Halliburton	US5853048, 1998	*Control of fine particulate flowback in subterranean wells*	Use of tackifying compound to reduce flowback, including in conjunction with fibres
B2	Baker Hughes	US6508305, 2000	*Compositions and methods for cementing using elastic particles*	Use of elastic material to help manage shrinkage (eg in wellbores), which can include processed wood, i.e. fibres
B4	Baker Hughes	US6059034, 1998	*Formation treatment method using deformable particles*	Use of deformable material to help reduce flowback (but not with fibres)
B6	Halliburton	US6330916, 2000	*Formation treatment method using deformable particles*	Use of deformable material to help reduce flowback (but not with fibres)

Table 2. Leading forward citation patents from patent S3 (US5330005).

However there are some crossovers, such as patent S3, US5330005 for ***Control of particulate flowback in subterranean wells***, which was filed by Schlumberger in 1993. This patent claims the use of fibrous material to help reduce flowback during fracking. The S3 patent has thick (suggesting strong relationships) forward citation arrows to a number of non-Schlumberger patents, including the patents listed in Table 3 (page 12).

In this particular case, there appears to be direct overlap between subject matter of the S3 patent and the first four patents listed, but not the last two Baker Hughes patents.

Of note, the Baker Hughes patent that does feature fibres (B2) is located separately in the patent network to the other B4 and B6 patents.

However it should be noted that these top 42 patents are only a small fraction of the total number of forward citations from the S3 patent.

To illuminate all of these citations we can use a search tool such as AmberScope, which has been developed by Ambercite. By doing so, we can see all of the 229 forward citations from this patent (Figure 8, below).

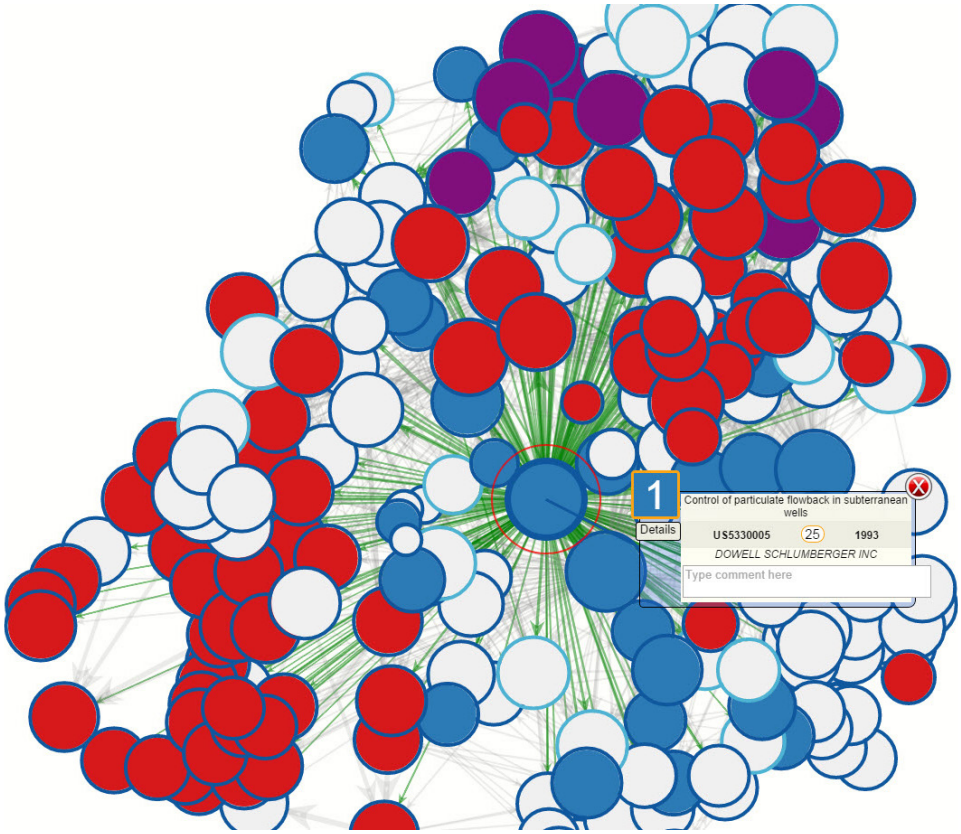


Figure 8. Full forward citation network from S3 patent (US5330005). As in Figure 5 and 6, Baker Hughes patents are coloured purple, Halliburton patents are red and Schlumberger patents are blue.

While helping to illuminate this patent network, the network is probably still too dense to fully understand. AmberScope employs a similarity filter to hide all but the most similar patents to any patent of interest.

By applying this filter, we can see in Figure 9 that the most similar non-Schlumberger patent is US6077772, ***Control of particulate flowback in subterranean wells***, filed by Halliburton in 1998, and claiming, in part, the use of coated fibres to reduce flowback. While helping to illuminate this patent network, the network is probably still too dense to fully understand.

Cluster B "Liquefaction of hydrocarbons"

The highest ranking patent in this cluster is US5366012 ***Method of completing an uncased section of a borehole***, which was filed by Shell in 1993. However, this patent is not representative of the rest of the cluster.

A more representative patent would be the second ranked patent US4390067, ***Method of treating reservoirs containing very viscous crude oil or bitumen*** (1981, ExxonMobil), which refers to 'drilling a horizontal well within the oil-bearing stratum, and heating the oil in the vicinity of the horizontal well to produce a hot liquid corridor.

Similarly, the second ranked patent owned by cluster leader Shell is #8 US4886118 ***Pyrolysis; enhanced oil recovery***, which was filed in 1988 and refers to heating shale oil to hotter than 600° C in order to improve recovery.

The forward citation network for US4886118 is shown in Figure 10 (right).

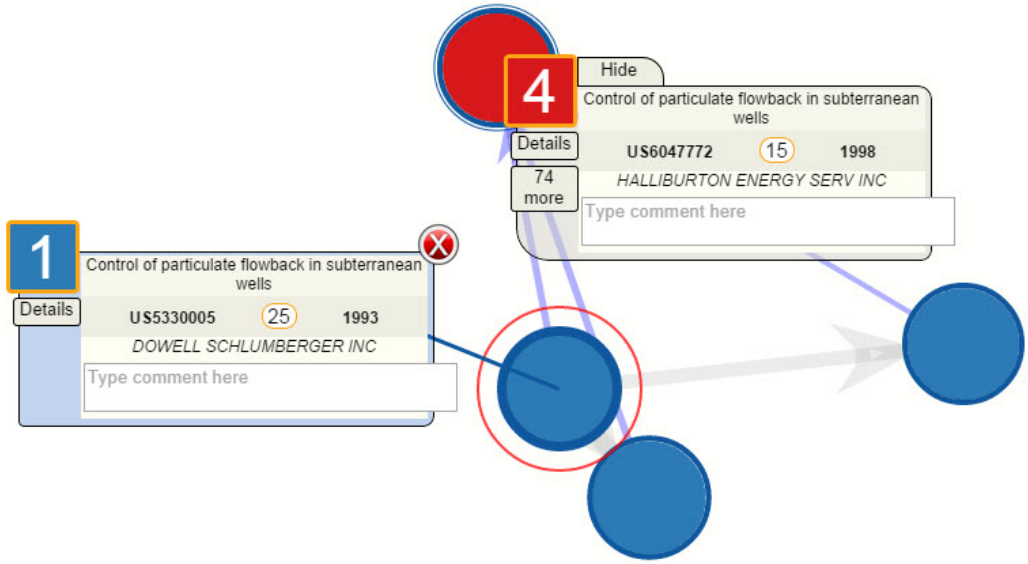


Figure 9. Most similar patents to S3 patent (US5330005). Blue patents are Schlumberger and red patents are Halliburton.

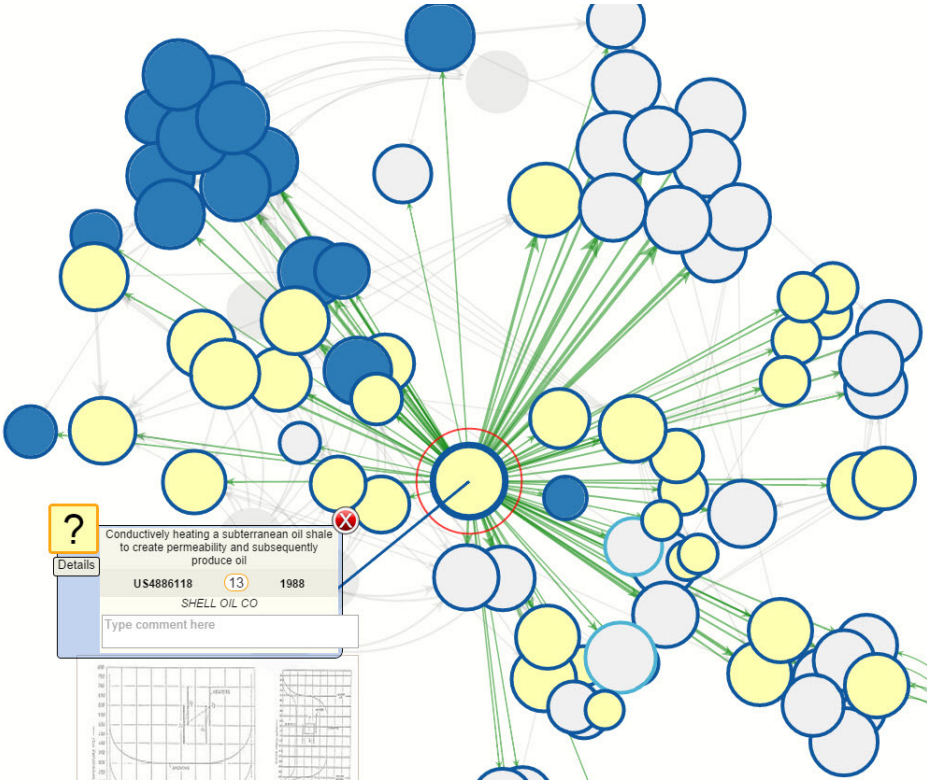


Figure 10. Forward citation network for Shell patent US488618. In this image, Shell patents are coloured yellow and ExxonMobil patents are coloured blue.

How do these results compare with other NPA studies for different technologies?

Figure 6 and Table 1 show a low number of clusters and a very high concentration of ownership. These can be contrasted with NPA studies we have done for different technologies, discussed in Table 3 (below).

The landscape for fracking patents is dominated by a small number of major technologies and major companies. The most similar NPA study where we have seen a similar relationship was the hybrid car study published in 2010 (based on a 2009 analysis). At that time Toyota dominated both sales and patent filings for hybrid cars, and this is broadly analogous to Halliburton's dominance of both fracking patents and strong position in fracking.

There is another analogy to hybrid cars worth considering – hybrid cars in 2009 were still regarded as relatively new compared to conventional cars, with the first volume hybrid cars released in the previous decade. Toyota dominated early sales of hybrid cars, but these are increasingly available from other manufacturers.

Similarly, it is only in the last decade that we have seen a dramatic increase in both fracking production and patent filing, despite the long history of fracking. Judging from what we have seen in other technology areas, we might expect to see dispersion of technology ownership as the industry matures.

Analysis	Number of patents in short list	Number of main clusters found	Relative ownership of leading applicant	Proportion ownership of 2nd ranked applicant
Drugs for Alzheimer's [11]	2153	24	5.5%	3.9%
Biofuels [12]	2458	20	2.3%	2.0%
Smartphones [13]	7093	16	9.0%	9.0%
Hybrid cars [6]	1000	1	15%	14%
Fracking (this study)	965	3	29%	20%

Table 3. Comparison of patent landscape with other published patent landscapes.

Implications for the oil and gas industry

The fracking patent landscape is highly interconnected and dominated by just a few major companies in the industry, such as Halliburton, Schlumberger, and Baker Hughes. Overall filing rates for patents are low, but have recently greatly increased.

Overall this would suggest an industry yet to fully mature, which may be due to the industry only comparatively recently moving to high production volumes. It is possible that as the industry matures, a greater spread of companies will develop many more new technologies to further grow and diversify the technology deployed in this industry. On the other hand, such a tight concentration of ownership may make it harder for new entrants to enter the industry.

However one of the most useful features of patents is that they all expire after 20 years. Sometimes they are even abandoned prior to their expiry date. The analysis of the leading patents in this paper has shown that many of the key patents we found are 20 years or older.

While a new entrant to this industry would have to consider the full range of patents filed and not just the patents discussed in this paper, this suggests that some of the initial key inventions may be available for use.

Something else to consider is that it is the oil and gas service companies dominate patent filings, not the oil and gas production companies. For this reason it may be easier for new production companies to commence fracking operations by working with the established service companies who presumably have managed all of the intellectual property risks.

Similarly, there may be fewer issues in having to deal with non-practicing patent owners than, for example, might be faced by companies in the smartphone industry.

Please note, this is not legal advice and we strongly suggest you seek appropriate legal advice before investing in this area.

What else can we do with NPA analysis?

In this particular study we have focused on the use of an NPA analysis to provide a unique overview of an otherwise very complicated area of patent filings, and to show how the technology is progressing in this area. Besides providing these types of high level insights, NPA results can have other applications, which include:

- NPA can provide **new insights on litigation**, including predicting and showing litigation risks, as well as illuminating possible outcomes. NPA can also help uncover prior art that may be missed by other patent analysis techniques.
- **Reducing research and development costs and risks** by comprehensively reviewing what has been done before, as expressed by the patent landscape.
- **Valuing patents** by providing a relative indication of the importance of individual patents.
- **Benchmarking patent portfolios**, either your own portfolio or portfolios belonging to competitors or potential acquisition targets.
- **Finding under-valued patent 'gems'** which could be defined as patents that rank higher in NPA analyses, or have higher than expected connectability with other patents in the cluster.
- Using NPA, we can also **show technology progression**, **identifying licensing opportunities**, and **market patent portfolios**.

About NPA and Ambercite

Network Patent Analysis (NPA) applies the wealth of information in patent citation data to group and rank patents, and provides a numerical analysis of patent litigation. NPA is being developed by patent analysts Ambercite, in conjunction with Griffith Hack.

Ambercite is the developer of a series of tools and services designed to make patent searching and mapping easier and more effective, including the AmberScope patent searching web app, Automated Patent Searching and portfolio analysis, and Network Patent Analysis.

Need to know more?

Please visit www.griffithhack.com/networkpatentanalysis or www.ambercite.com to learn more about NPA in general. If you are interested in a more detailed discussion of this paper, please contact:

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Full results are available upon request.

Acknowledgement

The significant input of Ewan Driver to the data analysis is greatly appreciated.

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