Summary Update: An Oil & Gas Assessment of Norway

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Introduction

The following is an update of the assessment of Norway's future production of *Regular Conventional oil and gas*, as given in *Campbell's Atlas of Oil and Gas Depletion* (Campbell, 2013). That reference contains additional graphs which have not been reproduced here.

Note that in addition to *Regular Conventional oil and gas*, Norway has resources of oil and gas in deepwater (>500 m water depth) and Polar regions (north of 66.56 °N). These resources are excluded from the definition of '*Regular Conventional*' oil, and are not included in the assessment given below. In addition, Norway produces natural gas liquids (NGLs) and has the potential to produce various other categories of *Non-Conventional* oil (such as 'light-tight' oil), and oil produced by gas- and coal-to-liquids processes, and biofuels. Production of these categories of liquid fuels is also is not included here.

Norway's production of *Non-Conventional* oil and gas has been modest having reached about 20% for oil and 15% for gas and are likely to remain at about these levels at least in the medium term. The assessment given below is thought to provide a reasonable prediction of Norway's *total* oil and gas production over this period. (Note that the *Atlas* models production of many of these other categories of oil and gas, but at a global level, rather than by-country.)

Geography

Norway forms the mountainous margin of Scandinavia. The coastline is cut by deep fjords, and flanked by a string of offshore islands, which shelter the inland waters. To the southeast, a deep inlet from the Skagarrak leads to Oslo, the capital. Norway also exercises jurisdiction of the Arctic islands of Svalbard (Spitzbergen) and Jan Mayen. The country measures some 1,700 km in length, reaching far into the Arctic Circle: from the southern tip of Norway to its North Cape is as far as it is to Rome. The country, with 5.1 million inhabitants, is sparsely populated.

Geology and Petroleum Systems

Norway's mainland is composed mainly of Palaeozoic rocks of the ancient Caledonian orogeny, but younger partly oil-bearing sediments form an extensive continental shelf covering the Norwegian and Barents Seas. The prime petroleum system comprises a Jurassic rift in the North Sea that formed as the Atlantic opened, when the continents began to move apart. It contains rich late Jurassic source-rocks, which have charged primarily underlying sandstone reservoirs with oil in rotated fault-blocks, as well as locally feeding overlying Cretaceous chalk and Tertiary reservoirs. The source-rocks become gas-prone along the eastern margin, and have also entered the gas-window where deeply buried to the west. Comparable systems are also present in the Haltenbanken area off mid-Norway and along the western margin of the Barents Sea. A secondary system within the same belt is provided by lean Middle Jurassic sources associated with coal.

Other systems have developed in the huge Barents Sea to the north, where they have generally suffered from substantial vertical movements of the crust under the weight of alternating ice-caps in the geological past. Jurassic, Triassic and even older source-rocks are locally present but have generally been depressed into the gas window over geological time. The vertical movements also damaged the cap-rocks sealing the reservoirs, leading to the escape and re-migration of oil and gas.

Exploration and Discovery

Oil exploration in Norway commenced in 1962, and grew at a comparatively modest pace under strict government control to reach an initial peak in 1997, in which year 37 exploration boreholes ('new-field wildcats') were

sunk. Exploration drilling then declined to less than ten boreholes a year in 2004 before surging in 2006 to an all-time peak of 45 in 2013, with exploration, targeted at progressively smaller prospects, being driven by higher oil prices.

One of the early finds was the giant Ekofisk Field, which came in as a surprise in 1969. In this area, Upper Jurassic source-rocks at peak generation underlie salt-induced structures, containing Chalk deposits, which just here contain adequate porosity to hold oil, thanks to having been deposited as slumps. The reservoirs are difficult to produce, due to low permeability, but various enhanced recovery techniques have lifted recovery to above 30%.

The peak of discovery came in 1979, when prime Jurassic prospects yielded a number of giant fields in the North Sea, including Statfjord and Oseberg, as well as the massive Troll gasfield to the northeast. Haltenbanken off mid-Norway came in during the early 1980's delivering a number of fields in a similar setting, including Heidrun, with about 1 Gb of oil, found in 1985. One late major gas discovery was Ormen Lange with 14 Tcf of gas, which was found off mid-Norway in 1997 in water depths of almost 1,000m. Another late surprise find, known as the Johan Sverdrup Field, was made in 2010. It lies on the flanks of the long-known Utsira High, a major structural uplift, and relies on very subtle stratigraphic traps on the flanks, which were missed during earlier phases of exploration.

Production and Consumption

Oil production in Norway commenced in 1971 and grew steadily to peak at 3.2 Mb/d in 2001 before declining to 1.6 Mb/d in 2014, being now set to fall at the current depletion rate of about 4% a year, apart from a brief surge from the Johan Sverdrup field. This is a relatively high depletion rate and reflects the efficiency of offshore operations in Norway. The country with its small population consumes only 88 Mb/a, leaving over 90% for export.

Gas production commenced in 1971, and grew to a plateau, set by pipeline capacity of around 1 Tcf/a, which lasted until 1991. It then increased again towards a new plateau in the 4 - 5 Tcf/a range, a year, made possible by the construction of a new export pipeline, so that this level of production may last until around 2027. Consumption is minimal at 170 Gcf/a, meaning that most is available for export, including that from the deepwater and Polar areas.

Charts in the Atlas

Not included here, but shown in the *Atlas* are the following charts:

- Annual oil discovery and production vs. date, where discovery is given by oil industry backdated proved-plus-probable ('2P') data, i.e., the most-likely data.
- The same discovery data, but plotted against discovery effort (here, new-field wildcats) to give a 'creaming curve', from which Norway's probable ultimately recoverable resource ('URR') of *Regular Conventional* oil of oil can be estimated.
- A 'Hubbert linearisation' plot that uses production data to also estimate the country's URR.
- A chart using the URR estimate arrived at, and which plots both '2P' discovery and production on a cumulative basis. Such a chart allows the evolution over time of a country's yet-to-find, discovery, reserves and production to be easily visualised.

The data used in these charts are mainly from the Norwegian Petroleum Directorate, which publishes comprehensive oil and gas data for the country, but augmented with other public-domain and oil industry data.

Forecast of *Regular Conventional* Oil and Gas Production

With these data established, and with the corresponding data for *Conventional gas*, it is possible to forecast future production of these classes of Norway's hydrocarbons, using the methodology set out in Campbell (2015). The following forecast is based on end-2014 data, and is an updated version of that in the *Atlas,* which was based on data to end-2010.

Note that the forecast here is thought to give a valid general picture of the situation, but naturally all forecasts are subject to surprise developments, some positive but others negative. The anomalous low oil price of the recent past may render some of the older oil and gas fields uneconomic, prompting their early abandonment. But on the other hand a recovery in oil price could have the opposite impact, increasing the volumes of oil and gas recovered. This is not an exact science.

The table below presents the main data and results of the 2014 model.

NORWAY									Version date: 2014	
Production to 2100						**Peak Dates**			**Area**	
Amount			**Rate**				**Oil**	**Gas**	'000 km2	
	Gb	Tcf	Date	Mb/a	Gcf/a	Discovery	1979	1979	Onshore	Offshore
Past	25.8	66	2000	1176	1758	Production	2001	2018	324	2300
Future	12.2	104	2005	985	3004	Exploration	2013		**Population**	
Known	11.0	99	2010	682	3786	**Consumption**	Mb/a	Gcf/a	1900	2.25
Yet-to-Find	1.2	5	2020	460	4500	2014	88	170	2014	5.1
Discovered	36.8	165	2030	281	2797		b/a	kcf/a	Growth	2.1
TOTAL	38	170	**Trade**	472	4290	Per capita	17	42	Density	16

Table: Data and results for Norway's production of *Regular conventional* oil and gas

Notes:

Regular Conventional oil refers to light and medium gravity oil (>17.5o API) that is produced from conventional oil fields, and excludes oil produced from water depths greater than 500 m, or from Polar regions. (Note that this definition excludes oil from natural gas liquids (NGLs); that from tight rocks where production must be by hydraulic fracturing ('light-tight' oil); from tar sands; very heavy oil deposits where the oil must be heated or otherwise treated before production; and oil produced by retorting kerogen.)

Regular Conventional gas excludes gas produced by hydraulic fracturing of tight rocks, as well as non-conventional gas sources such as coalbed methane etc.

Gb: Billion barrels.

Tcf: Trillion cubic feet.

PAST: Cumulative quantity produced to end-2014.

FUTURE: Model prediction of cumulative quantity that will be produced over the period 2015 to 2100. This is composed of:

Known: That quantity already discovered but not yet produced (i.e., ~'2P' reserves); plus

Yet-to-Find: The quantity that will be discovered in the period 2015 to 2100.

DISCOVERED: That quantity already discovered; equals: PAST plus Known.

TOTAL: The total amount of ***Regular Conventional*** oil and gas that the model assumes will be produced in Norway to 2100. This equals: PAST plus Known plus Yet-to find, and is an approximation for the country's URR values for these classes of hydrocarbons.

Rate: Annual production at year indicated; data to 2010 are actuals; 2020 and 2030: forecast.

Trade: Quantity exported in 2014, calculated as production less national consumption.

Peak Dates: Year of maximum volume of: discovery; production; exploration (as measured by exploration boreholes drilled).

Area: Norway's territorial area: Onshore: land area; Offshore: area of Norway's oil and gas rights.

Population: Millions, in 1900 and 2014.

Density: Land area population density in persons/sq. km.

The output of the model is plotted in Figure 1.

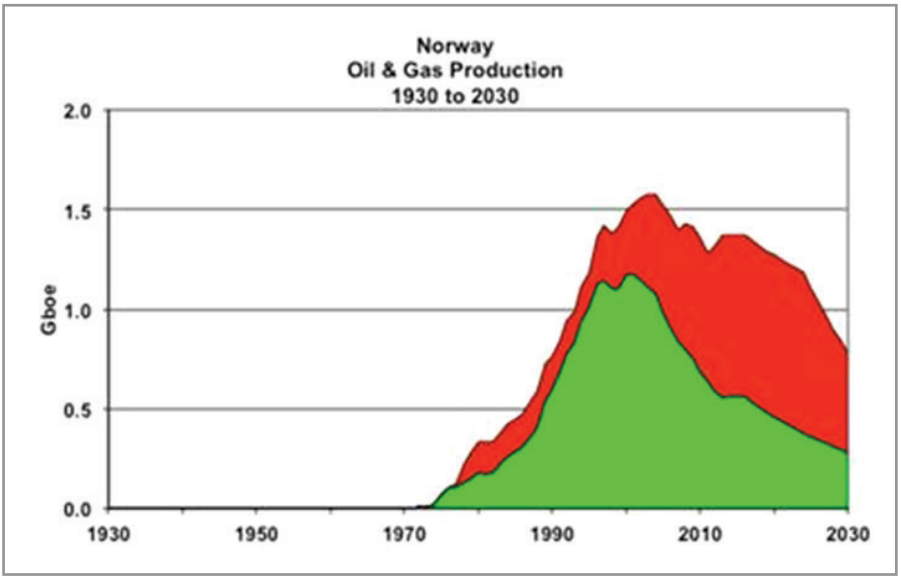

Figure 1: Norway: Production of ***Regular Conventional*** oil and gas: : 1930 – 2014; Forecast: 2015 – 2030; (Gboe/yr.)

Notes:

Green: Production of ***Regular Conventional*** oil.

Red: Production of ***Regular Conventional*** gas. (Gas production converted to Gboe by dividing Tcf by 6.)

As the table and Figure 1 show: Norway's production of *Regular Conventional* oil peaked in 2001, and the model forecasts that the production of *Regular Conventional* gas will peak in 2018. Taking both these classes of hydrocarbon together, their combined peak was 2004. This date agrees with the oil-plus-gas peak shown in the 2015 edition of the BP *Statistical Review of World Energy*, but where the latter data include production of 'all-oil' and 'all-gas'. As mentioned earlier, while Norway has the potential to produce a range of non-conventional oils and gases, and also of 'other liquids' such as biofuel, it is unlikely that production of these will do much in the near or medium term to offset the declines in the production of *Regular Conventional* oil and gas shown here.

To conclude this section of Norway's likely future production of oil and gas, included here is a recent chart by the Norwegian Rune Likvern showing Norway's past production by field, and possible future production, including the likely impact of the Johan Sverdrup field; Figure 2.

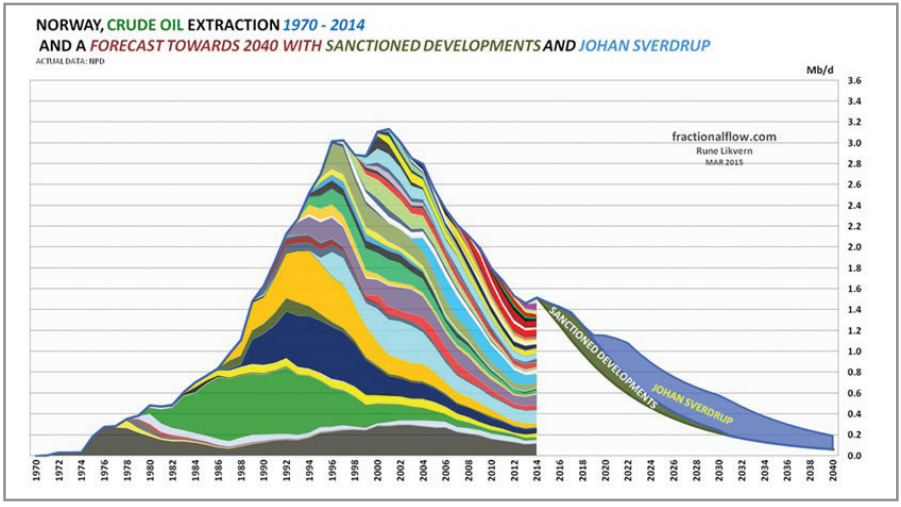

Figure 2: Norway: Production, 1970 - 2014, and forecast to 2040.
Source: Rune Likvern, (fractionalflow.com), http://fractionalflow.com/category/norwegian-crude-oil-production/, March 2015. (Thanks to M. Mushalik's website, http://crudeoilpeak.info, for drawing attention to this chart.)

On Figure 2, Likvern notes:

> "*The chart shows the historical extraction (production) of crude oil (by discovery/field) for the Norwegian Continental Shelf (NCS) with data from the Norwegian Petroleum Directorate (NPD) for the years 1970 – 2014. The chart also includes a forecast for crude oil extraction from discoveries/fields towards 2040, based on reviews on individual fields, NPD's estimates of remaining recoverable reserves, the development/forecast for the R/P ratio etc., as of end 2014.*
>
> *Further, the chart shows a forecast for total crude oil extraction from sanctioned discoveries/fields (green area) … and the expected contribution from Johan Sverdrup (blue area) (at end 2014*

> *estimated at 2.22 Gb) … which is now scheduled to start flowing in late 2019. … "Sanctioned Developments" … represents the total contributions from 8 sanctioned developments of discoveries now scheduled to start to flow between 2015 and 2017.*
>
> *My forecast for 2015 is 1.47 Mb/d with crude oil from the NCS.* [This] *includes all sanctioned developments and not discoveries … and contingent resources in the fields. The forecast is subject to revisions as the reserve base becomes revised (as discoveries pass the commercial hurdles), which likely will fatten the tail post 2020 of the forecast. …* [The forecast] *assumes some reserve growth, but does not include the effects from fields/discoveries being plugged and abandoned as these reach the end of their economic life.*"

As Figure 2 shows, the general mechanism driving the resource-limited peak of conventional oil production in a region is clear: decline of the large early fields not being compensated after peak by the production from the numerous later but smaller fields.

In summary, Norway is a country where for *Regular Conventional* oil and gas it is almost certain that only modest scope remains for new discoveries in comparison to past volumes, where the original recoverable stock of these classes of oil are significantly depleted, and hence where the country's *resource-limited* production peak of these hydrocarbons in total is now past.

Norway's Oil Age in Historical Perspective

Finally, in light of the above information, we are in a position to attempt to set Norway's 'Oil Age' into a wider historical perspective, as follows:

Norway was already occupied some 14,000 years ago by hunters emanating from Europe. Later came more settled communities who fished the lakes and fjords, sustaining themselves with difficult agriculture in a cold climate. They were isolated communities under petty kings and warlords. The Viking era, with an advanced culture, followed during the first millennium, when warriors in longboats headed south to colonise and trade, as well as to rape and pillage. The Norwegian Vikings went westwards to Iceland, Greenland, the Shetlands and Ireland, where they established settlements. Some may even have landed in North America.

King Harald 1st succeeded in unifying the Kingdom in the 9th Century, but dissent amongst his successors led to fragmentation, with the country

falling at different times under the control of the Danish and Swedish kings until 1297, when the three countries were unified, with Norway becoming a province of Denmark. The Black Death pandemic decimated the population during the 14th Century, thanks to a particularly active rat, called *ratus norvegicus,* which was later well-known to seamen and infested the New World.

Denmark, which had been an ally of France in the Napoleonic wars, was forced on defeat to cede Norway to the Swedish king in 1814. This was opposed by the Norwegian people, who wished for independence. Various conflicts and disputes with Sweden occupied the 19th Century as a growing wave of nationalism built momentum. It was in part stimulated by a cultural flowering, as exemplified by the author, Ibsen, and the rediscovery of the ancient Norwegian language and folklore. Finally in 1905, an independent kingdom was declared with the crown being offered to Prince Carl of Denmark, who became Haakon VII. The First World War soon followed but the Scandinavian countries, including Norway, managed to maintain their neutrality.

The inter-war years saw the gradual development of fisheries, canning and shipping. Norway's great hydroelectric potential was tapped, being used particularly to refine aluminium and produce synthetic agricultural nutrients in a development of great significance for Europe. Even so, life was hard, leading to much emigration to the New World, as well as a growing spirit of egalitarian co-operation at home.

Norway was victim of an unprovoked German invasion on 9th April 1940. It was forced to surrender after a short struggle, but not before the curator of a museum on the mouth of the Oslo fjord had managed to cause the sinking of a battleship by firing an ancient canon. The King escaped to England to establish a government in exile, while a puppet Nazi regime under Vidkum Quisling was established in Oslo. An active Resistance movement throughout the country contributed to the eventual liberation on May 8th 1945, but was unable to prevent the retreating German troops from destroying several towns in the north under their *scorched earth* policy.

Post-war reconstruction was built on the already well-entrenched co-operative spirit, with virtually all aspects of national life being placed under strong government control. The shipping industry was rebuilt, partly with generous tax treatment, giving rise to various shipping dynasties. They conquered world markets with capitalistic drive on

the high seas, but changed their coats in home waters to become unostentatious and responsible patrons of their communities. Socialist governments, built more on co-operation than envy, dominated the post-war epoch.

If anyone in Norway thought about oil at this time, they pictured the sands of Arabia, little imagining that the stormy waters of the North Sea might one day give them a key oil position. Few noticed the first hint coming from the discovery of the giant Groningen gasfield in the Netherlands. It in turn attracted attention to the adjoining waters of the southern North Sea, which was soon to be rewarded with a string of gas fields extending into British waters.

Not long afterwards the European office of Phillips Petroleum of Bartlesville, Oklahoma, turned its eyes north to wonder what the northern North Sea might offer, opening talks for exploration with Norway. At that time, jurisdiction extended only three miles from the shore, so the countries bordering the North Sea had to decide how to divide it. At first, ever-fair Norway opposed the notion of a median-line on the grounds that it would give a disproportionate share of the mineral resources to the coastal States at the expense of the inland countries. Britain, by contrast, pressed for a median-line solution, eventually winning the support of Norway. In fact, Norway is bounded by a deep trench, which would have deprived it of the prospective tracts if water-depth alone had been taken into account. By this thin thread hung the train of events that would eventually deliver untold wealth to Norway, making it one of the world's largest exporters of oil and gas.

The first concessions (licences) were awarded in 1968 covering the southern part of the shelf, and led to the surprise discovery of the giant Ekofisk Field, owing its presence to the remarkable combination of geological circumstances, described above. Norway became an oil nation.

The next milestone came when Shell discovered the Brent Field in 1971 in the British sector of the northern North Sea, as improved seismic technology led to the identification of Jurassic troughs beneath the younger sediments. The field lay on a structural trend extending into Norwegian waters, where a huge structure was soon identified, yielding the Statfjord oilfield in 1973, which remains to this day the largest in the North Sea, with over 3.5 Gb of oil. Indeed, this author became involved in the official discussions over how to settle respective ownership between Norway and the UK of the reserves of this field, with every 1% change

in estimated oil-in-place volume translating to an approximate change of $1 billion in the field's evaluation. Needless to say, these were delicate, closely-watched negotiations.

With these oil discoveries, Norway reeled at the prospect of unimaginable wealth, and soon began to re-examine its oil policy, rightly fearing that oil might undermine its carefully balanced economy and society. To that point, the concessions had been granted on the basis of a normal royalty and corporation tax, but now the country moved to toughen its terms while respecting, in its ever-honest fashion, the rights already granted.

Britain had already created a State Oil Company under its then socialist government, which set an easy precedent for Norway to follow. Den Norske Stats Oljeselskap (or Statoil) was established under what at first sight seemed a highly advantageous arrangement, whereby it would hold a mandatory 50% in all concessions, with its exploration costs being met by the foreign companies. It even retained the right to increase its share to as much as 85% in the event of success. A special oil tax was also introduced. The world price of oil was soaring at the time in response to the 1970s oil price shocks, and the industry accepted these seemingly outrageous terms, not wishing to be left out of what was rightly perceived to be one of the world's last great conventional oil provinces. The Norwegians earned the sobriquet of being *blue-eyed Arabs*. But all was not what it seemed, for the companies' ever-ingenious tax lawyers soon found that they could take the cost of carrying Statoil as a charge against their taxable income. So, at the end of the day, it was the long-suffering Norwegian taxpayer who met the cost of the creation of the State Company, which started to burn up national wealth at a prodigious rate. It now employs more than 11,000 well-paid people.

In addition to Statoil were two other strong national companies, Norsk Hydro and Saga, which later merged and have now been absorbed into Statoil.

The Norwegian Petroleum Directorate was established by the Government to manage the oil business, deciding which companies would work together as groups, which prospects would be drilled and how many commitment wells were to be imposed, effectively treating the foreign companies as if they were contractors. But the companies did not object as, as mentioned above, the cost of all of this was taken as a charge against taxable income under terms that meant that they were

effectively spending *'20 cent dollars'*, enjoying a colossal unseen subsidy.

At first, the Government moved with admirable caution so as to accommodate the new industry into the economy. New licensing was delayed until 1979, when a number of prime prospects were awarded, yielding a string of giant discoveries to the north and east of Statfjord. But with the passage of time, the early caution was abandoned as the country succumbed to the political pressures of new Norwegian rig owners and contractors, who sought rapid expansion, and the people at large began to develop an unquenchable thirst for wealth; a departure from the attitude of their somewhat Spartan, God-fearing antecedents.

In short, the bulk of Norway's oil had already been found by the early 1980's, and what followed has been little more than a mopping-up operation to find and produce ever-smaller accumulations, apart from a surprise Johan Sverdrup find in 2011. This unwelcome reality is however countered by optimists who continue to believe in exploration, drawing attention to the vast size of the Norwegian shelf, and expect that technological progress will extract more oil from known fields. Some improvement in recovery has indeed been achieved in the difficult chalk reservoirs, for which there was plenty of scope as very low recovery factors of below 20% were at first assumed. For a brief moment, it seemed that Statfjord could recover as much as 70%, setting a precedent for other similar fields. But it was later realised that its complex east flank also held large amounts of oil-in-place which was in fact replenishing the reservoirs, returning the recovery factor to about 45%. Some of the more recent small fields have given disappointing results, as companies were forced to make optimistic assessments to justify development at all. The licensing terms have been progressively ameliorated to match the dwindling oil prospects, and to keep the exploration business alive.

The golden days of Norwegian oil are accordingly coming to an end, but gas production is growing, calling again for clear thinking Government policy.

Some hopes have been expressed for new discovery in the deepwater Atlantic Margin that flanks Norway and the British Isles. The probability, however, is that the critical Upper Jurassic source-rocks are, at best, only locally present, and, even where present, too deeply buried to yield oil, save in some freak occurrences where re-migration from earlier accumulations has occurred. The province may, however, have considerable gas potential, although it will be very costly.

Norway's control of European gas supply carries geopolitical risks as it is never easy to be a rich man in a crowd of beggars, and Europe may put pressure on Norway to deplete its gas rapidly in order to counter the stranglehold of Russian supply.

With hindsight and a realisation of inevitable depletion, it might have been a better policy for Norway to have used its State Company to develop its oil and gas much more slowly, having said goodbye to the foreign companies after thanking them for their pioneering contribution. Although the country has invested almost a trillion dollars in an oil fund to try to save something for the future, oil and gas in the ground might have proved to be a much better asset. Statoil, evidently perceiving the limitations of the homeland, was allowed to move overseas on the well-known principle that *distant fields are greener*. It has been an expensive experiment with little to show for the investment.

Norway has suffered greatly from the recent collapse in oil price, following Saudi Arabia's decision to ignore its OPEC obligations to cut production to support price. Unemployment has soared with Stavanger, the oil capital, being badly affected. Several of the smaller oil companies that were formed in the boom days face serious financial difficulties.

In general, Norway's politics have moved to the right in recent years, eclipsing the long record of Socialist Government. Its electoral system however tends to give rise to coalition governments in which small parties may find themselves with a disproportionate power.

Norway was invited to join the European Union in 1994, but wisely declined after a referendum. The farmers and fishermen feared for the subsidies, and the country's oil wealth has enabled it to stand aside. Nevertheless, it voluntarily complies with much European legislation, not wanting to find itself too isolated. It has been an enthusiastic member of NATO, having had a common frontier with the former Soviet Union, and it has contributed greatly to various UN peace-keeping missions. The wealth of the country and its fair thinking people allowed a relatively massive scale of immigration. But there was a reaction in 2011 when an eccentric activist set off a bomb in Oslo and killed a large number of young members of the Labour Party attending a festival on a nearby island.

On the basis of the above, we can draw the following conclusions:

Norway's production of *Regular Conventional* oil peaked in 2001, and its production of *Conventional* gas is expected to peak around 2018. Taking both hydrocarbons together, their combined peak was in 2004. While the country has the *potential* to produce a range of non-conventional oils and gases, and also of 'other liquids' such as biofuel, it is unlikely that production of these can do much, certainly in the near or medium term, to offset the declines in the production of *Regular Conventional* oil and gas.

As Figure 2 demonstrates for oil, the mechanism that drives the production peak in a region is simply that decline of production from the large early fields is not compensated, after peak, by the production from the fairly numerous later but smaller fields.

In summary, for Norway, like many other countries, for *Regular Conventional* oil and gas only modest scope remains for new discoveries, her original recoverable stock of these classes of oil and gas are now well depleted, and hence her *resource-limited* production peak of these classes of oil and gas in total is now past.

However, Norway has a small population and, though past peak, still has large reserves of oil and gas remaining. As a result she is well placed to face the *Second Half* of the Age of Oil. In particular, the country has a tradition of closely-knit communities who can be expected to pull together to face the changing circumstances that lie ahead.

References

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