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Part 1

Setting the Stage
CHAPTER 1

Introduction: Importance of Cooperation in Development of Petroleum Resources

ANATOLI BOURMISTROV AND FRODE MELLEMVIK
Part 2

Politics and Economics
CHAPTER 2

The International Context for Barents Oil and Gas – Asia’s Double Impact

INDRA OVERLAND, NODARI SIMONIA, SERGEI VASILIEV AND ELANA WILSON ROWE

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Introduction

This chapter lays out the global and regional context for oil and gas developments in the Barents Sea. The international context – and how this context is interpreted and understood by decision-makers - will play a decisive role in determining how the Barents Sea evolves as a petroleum province. Whatever oil and gas is found in the Barents Sea will only be exploited if there is sufficient demand for it. With the technological challenges and high cost of extracting oil and gas under remote Arctic conditions, that is an important ‘if’. The Shtokman project has already been shelved for the time being, partly because American demand for LNG did not live up to expectations.

We suggest that influences from Asia may be decisive for the development of the Barents Sea. This may seem paradoxical, considering that this sea is about as far away as one can get by ship from the rapidly growing economies of East and South Asia. Consequently, a good deal of this chapter is devoted to introducing the reader to this line of reasoning, which can be summarized as follows: Barents Sea oil and gas development will be technically difficult and expensive compared to other potential competing sources of petroleum. Consequently, overall demand for oil and gas will need to be high in order for such developments to be profitable and the rapidly growing Asian economies are essential in this regard. Furthermore, a key potential actor in the Barents Sea is Russia. Russia is the world's largest country and faces choices between eastern and western orientation that no other countries face in the same way. This manifests itself in several ways. As a geographic giant, Russia has a range of undeveloped oil and gas reserves to choose between and some of them are simply closer to Asia than the Barents Sea. Politically, Russia is out of step with its European gas customers and may seek to export to countries that are more politically compatible.

In addition to our focus on Asia as a key factor in global developments of relevance to the Barents Sea, we look at both Norwegian and Russian perspectives on the Arctic region. Russia – with the longest Arctic coastline of all littoral states and the undisputed majority of Arctic oil and gas reserves – garners an added level of attention.

The chapter starts at the global level, with an overview of the oil and gas market projections of the International Energy Agency (IEA) for the coming years. Unconventional oil and gas and climate policy receive particular attention. It then moves to the regional level, where it looks at both the European gas market and Arctic politics. The concluding section summarizes how all of the factors covered are relevant for the scenarios on the development of the Barents Sea that conclude this volume.
The chapter has important interfaces with Chapter 5 on the bilateral relationship between Norway and Russia, where the impact of the Russian-Western conflict over Ukraine on Norwegian-Russian relations is discussed; and with Chapter 4 on Norwegian-Russian business to business cooperation. It could benefit from being read in conjunction with those chapters.

Global demand and supply projections: IEA and OED

As a starting point for understanding the evolving international context for the development of the Barents Sea, we take the IEA’s World Energy Outlook 2013 projections for the world in 2035. We also make some comparisons with OPEC’s projections and find that they point in the same direction, although there are some interesting differences. We then discuss unconventional hydrocarbons and attempt to give the reader an appreciation of how the uncertainties at play in this field can influence oil and gas developments in the Barents Sea.

According to the primary projection of the IEA, regardless of new policies and programs that will be put in place to encourage energy savings, global energy consumption will keep growing and will increase by around one-third in 2035 compared to 2011. This is based on the assumption that the world population will grow by 1.7 billion and the world economy nearly double by 2035 (IEA 2013: 33). This is in spite of a projected drop in the relative share of fossil fuels in the world’s energy mix will fall from 82% to 76% (IEA 2013: 57). The absolute consumption of natural gas will grow continuously, and gas demand is projected to rise by almost 50% by 2035. Although this is clearly a picture of continued growth, there is a geography to this increased demand – it is not evenly spread around the globe and international supply/demand patterns are likely to continue to change. The share of global energy demand in non-OECD countries in 2035 will be 64%, with fossil fuels continuing to meet most of the demand (IEA 2013: 481).

The emerging economies with their rapidly growing populations, industrial production, and increasing urbanization will account for more than 90% of net energy demand growth (IEA 2013: 55). China is projected to account for the largest share of the growth in global energy demand, followed by India, where demand will more than double, and finally by the Middle East. To be more specific, Middle Eastern countries will be the second-largest group of gas consumers by 2020 and third-largest group of oil consumers by 2030 (IEA 213: 55). And, China has already become the largest oil-importing country in 2013. Its share in world energy consumption is projected to amount to 33%, as Chinese energy demand rises by 60% between 2010 and 2035. By contrast, OECD energy demand in 2035 is expected to be only 3% higher than in 2010. Furthermore, unconventional domestic resources in some OECD countries will further change the import/export picture. The United States, for example, is projected to meet almost all of its energy needs from domestic resources by 2035. China will therefore play a decisive role in global energy markets over the projected period. This will require more energy to satisfy the growing demand.

<FIGURE 2.1. HERE>
Global oil demand

The IEA expects that the growth in global demand for oil will be slowed by energy efficiency measures and higher prices: the crude oil price is expected to rise to 125 USD per barrel in 2035. The overall, the share of oil in the primary energy mix is likely to drop from 32% in 2012 to 27% in 2035 (IEA 2013: 61). Nonetheless, absolute global oil demand will reach almost 100 mb/d in 2035, up from 87 mb/d in 2011 (IEA 2013: 55).

The reduction in US oil imports on the one hand, and the rising oil consumption in emerging economies on the other hand, will have consequences for trade flows along some key strategic maritime and pipeline transportation routes: Asia-Pacific markets are already exerting a powerful pull on oil, drawing it away from North Atlantic consumers. Over the projection period towards 2035, Middle Eastern supplies for Asia will be supplemented by growing volumes produced in Russia and Kazakhstan, and possibly Brazil and Canada.

Global natural gas demand

The IEA expects that new sources of gas, both conventional and unconventional, will bring greater diversity to global supply. In the LNG market, which is particularly relevant for Barents Sea prospects, the IEA believes that growing supplies of LNG will create new linkages between regional gas markets, gradually making the market for natural gas more global and levelling prices. But there will still be differences between the prices in different parts of the world, and above all there will remain a large difference in the transportation cost for LNG and piped gas. Thus gas extracted in the Barents Sea and gas extracted in the Russian Far East may not have the same value – especially if the former must be transported as LNG and the latter can be transported via pipeline.

Natural gas demand is projected to grow from 3.3 trillion cubic meters (tcm) in 2010 to over 5 tcm in 2035, an increase of almost 50% (IEA 2013: 99). The IEA expects its share in the energy mix to rise from 22% in 2010 to 24% in 2035 (IEA 2013: 100). The natural gas supply-demand balance will significantly depend on the extent to which the North American experience in producing shale gas, a development discussed in detail below, is replicated elsewhere. For countries currently reliant on important gas, there is certainly a temptation to develop indigenous resources, when possible. Consequently, the IEA projects that the global supply of shale gas will expand significantly, accounting for almost half the increase in global gas production (IEA 2013:108). Such a development would certainly put pressure on exporters of conventional natural gas and challenge the traditional oil-linkage pricing mechanism for gas (IEA 2013:108; 128-129).

Demand for natural gas is expected to exceed that for oil during the projection period, since natural gas is cleaner both in terms of greenhouse gas emissions and local air pollution and is therefore seen in many countries as a replacement for coal. Natural gas is also seen as an alternative to nuclear energy, which is being phased out (at least for the time being) in some countries following the 2011 Fukushima Daiichi nuclear power plant accident.

For purposes of comparison we turn now to OPEC’s World Oil Outlook 2013. This report suggests that over the period of 2010-2035 global energy demand will increase by 52%. Fossil fuels will account for 80% of the global total by 2035, and oil will retain the largest share. Oil demand will increase by 20 mb/d over the period 2012-2035, reaching 108.5 mb/d by 2035.
According to OPEC; natural gas use will rise fastest among fossil fuels, reflecting the growing importance of shale gas as a source of energy in the US and Canada.

OPEC represents the majority of the world’s major oil exporters, and thus its perspective may have a bias towards their perspective, i.e. expecting high oil demand. IEA represents most of the world’s major oil importers, and thus its perspective may have a bias towards their perspective, i.e. expecting low oil demand. When their predictions are largely in line with each other as in this case, it is an important signal about expectations for the future and this signal is observed by oil and gas companies taking decisions about whether and how to invest in the Barents Sea.

Unconventional hydrocarbons

Regardless of which set of projections policymakers and company executives rely upon, it is clear that they must operate in an environment of increased dynamism and uncertainty. Oil and gas companies need to accurately assess how the energy market situation unfolds and adapt rapidly to changes in forecasts and realities, the rapid-growth markets evolution being one of them. How oil and gas companies interpret current global developments will be decisive for whether they choose to invest in the Barents Sea or not. A key uncertainty that we explore in this section are the varied opinions on the medium and long-term significance of unconventional hydrocarbons in order to give the reader an appreciation of the challenges involved in projecting trends in energy markets.

Estimates of ultimately recoverable resources of oil continue to increase as technologies unlock new types of resources, such as light tight oil, that were not considered recoverable only a few years ago. Declining output from existing fields is a major driver of upstream investment in unconventional sources. The latest IEA estimates for remaining recoverable resources show 2,670 billion barrels of conventional oil (including natural gas liquids), 345 billion of light tight oil, 1,880 billion barrels of extra-heavy oil and bitumen, and 1,070 billion barrels of kerogen oil (WEO 2013: 421). The share of conventional crude oil in total oil production is expected to fall from 80% in 2012 to two-thirds in 2035 (WEO 2013: 457).

Unconventional sources of petroleum also change the geography of the market. For example, according to the IEA’s World Energy Outlook 2012, the United States is projected to become the largest global oil producer overtaking Saudi Arabia in the mid-2020s and a net oil exporter around 2030, all thanks to the advanced upstream technologies that allow large-scale production of light tight oil and shale gas. Brazil’s deepwater oil likewise makes the country a heavyweight in the global energy picture. While the US attracts quite a bit of newspaper inches on the topic of unconventional sources, if one is to use the term “revolution” about developments in the natural gas sector based on the criterion of fast growth, it is at least as applicable to Qatar as to the US. In 2002, this small country produced only 29 bcm and exported 19 bcm as LNG. By 2012, Qatar’s LNG exports amounted to 105 bcm (of which 67 bcm went to the Asia Pacific), bypassing Saudi Arabia, Indonesia and Nigeria and to become the world number one exporter. In addition, Qatar supplied another 19 bcm of gas to its Middle Eastern neighbours by pipeline. So, currently Qatar constitutes a more serious challenge to Russian and Norwegian future gas supply from the Barents Sea than shale gas. Similar developments may also happen elsewhere: Australian exports of LNG are expect to reach 88 million tons per year by 2017 with even more coming online by 2021 (Tsafos 2013:...
and major new finds off the coast of East Africa that will likely also be turned into LNG one day, the most important upstream factor in the global gas market may not be shale gas but rather new sources of LNG. For US shale gas to play a role beyond North America, it is in any case going to have to be turned into LNG, and any LNG made from unconventional gas is likely to be more expensive than LNG from large conventional gas fields.

The potential significance of unconventional resources also needs to be balanced against the possibility that they may not prove as revolutionary as first expected. For example, there was much ado about shale gas in Poland. ConocoPhillips and other forty companies arrived to prospect for it. They promised energy independence to the Polish government and said Polish gas would oust Russian gas from the EU market. In 2011, the US Department of Energy estimated that Poland could have 5.3 trillion cubic meters of shale gas which would be sufficient for 300 years of Polish consumption. However, Exxon Mobil withdrew from Poland in 2012, and in May 2013 another three companies withdrew from shale gas in Poland – Marathon Oil, Talisman Energy, and Polish state-run Lotos. ConocoPhillips is still thinking about whether to stay or go. In 2014 there was still no shale gas in the country’s commercial energy mix and it was not clear when, if ever, any major projects would be realized. One of the few things that might change that was the conflict in Ukraine, but Polish shale gas would still have to compete against LNG.

Around 2012 the attention shifted from unconventional gas to unconventional oil. Oil is more valuable than natural gas, and it is easier and cheaper to transport. If there is a shale oil revolution, it is more likely than shale gas to have consequences beyond the United States in places like the Barents Sea.

There are different views on the promise of shale oil. The IEA (2014) has predicted that it will spread beyond North America by 2020. Others, are more, or very, skeptical. Arthur Berman (cited in Stafford 2014) argues that many numbers and forecasts are exaggerated, and that oil companies do this because their conventional oil reserves are falling and they do not have anything else to point to than shale oil. He states “There have been some truly outrageous claims made by some executives about the Permian basin in recent months that I suspect have their general counsels looking for a defibrillator” (Berman cited in Stafford 2014). In another analysis, Spencer, Sartor and Mathieu argue that the changes in the US industrial sector attributed to shale gas and shale oil are in fact due to other causes and that the growth of unconventionals therefore will not go as far as some expect.

How shale oil and gas develop in the future depends on how the geology of new exploratory areas works out, what progress is made in equipment and engineering and has and to what extent governments of different countries facilitate such developments through legal and economic regimes. We are therefore not in a position to pass final judgment on the potential of shale oil and gas, but can only note that there are starkly opposing views on the phenomenon and scenarios for the future of the Barents Sea must therefore take into account both possibilities

**Post-Soviet oil and gas exports turning east**

Despite major uncertainties about the role of unconventionals in the global energy supply picture, the projections reviewed above are clear about global demand and place great weight on the growing Asian economies. Developments in Asia are decisive for the global petroleum sector, and thus for both Norway and Russia as major oil and gas exporters to international markets. But more than 75 percent of Russia’s own territory lies in Asia and in this respect
Russia is itself a major Asian power. As a consequence, the pull of Asia plays a role for Russia not only in terms of international markets, but also as a factor in its domestic priorities. In this section we take a closer look at some of the options and factors that shape how Russia approaches the growing export opportunities along its eastern borders – and the consequences this could have for the Barents Sea.

Traditionally the Russian oil export balance has been in favour of the West. The same applies to the other two major oil-exporting former Soviet republics, Kazakhstan and Azerbaijan. In 2012, out of total oil exports from former Soviet republics amounting to 424 million tons, Europe and North America received 313 million tons, while the Asia-Pacific countries took 93 million tons (BP 2013). Driven by the developments outlined in the previous section, this pattern has started to change and this section briefly export relations/plans with China, Japan and the Korean peninsula.

After the first part of the main East Siberia-Pacific Ocean (ESPO) pipeline and its China spur began to function, under a USD 25-billion Chinese credit line for Rosneft and Transneft, 15 million tons of oil are delivered through this pipeline to China annually (Finansovyye izvestiya 2009). The second part of ESPO was completed by the end of 2012, and the pipe’s capacity already reached 80 million tons per year. Simultaneously Rosneft became the main driver in Russia’s East Siberia-Far East petroleum sector, and concluded an agreement on an additional broad Chinese credit line with CNPC in October 2013 (USD 270 billion including prepaid nearly USD 70 billion). According to this agreement, Rosneft would deliver to China during next 25 years 365 million tons of oil (Vedomosti 2014).

After transfer to rail, oil from Skovorodino is delivered to the terminal at Kozmino Bay. This has had a considerable impact on Japan’s oil imports. In 2006, when Japan began purchasing oil from Sakhalin, the share of these shipments in its oil imports was just 0.7 per cent. A year later it increased fivefold, reaching 3.5 per cent. In 2010, with the start of ESPO shipments from Kozmino, Japanese imports of oil from Russia amounted to 14.5 million ton, or 6.4% of its total oil imports. Simultaneously, for the first time ever the Middle Eastern share fell below 80 per cent (Bustelo, 2008: page number if possible; BP 2011). Statistics on LNG produced by Sakhalin Energy, the operator of the Sakhalin-2 project, tell a similar story.

The Japanese–Russian energy trade is likely to increase in the coming years. In connection with the Fukushima accident and shutting down of other Japanese nuclear power reactors, the discussion of the old proposal to build an underwater gas pipeline to Hokkaido has been revived in Russia. In 2012, Vice President of Gazprom, Alexander Medvedev, and Democratic Party of Japan policy chief, Seiji Maehara, agreed in Tokyo to carry out a feasibility study for a gas pipeline linking Hokkaido and the Sakhalin Islands (Daily Yomuri 2012).

Along the same lines, the Trans-Korean Gas Pipeline is also worth mentioning as an illustration of Russia’s efforts to increase its energy exports to Asia. This pipeline is 1100 kilometers long and planned as an extension of the Sakhalin-1 – Khabarovsk – Vladivostok pipeline. This project is usually discussed as part of a package with the Trans-Korean Railroad (planned as an extension of the Trans-Siberian one). Since both the pipeline and the railroad are supposed to go from Russia to South Korea through North Korean territory, the importance of these schemes cannot be measured just by stable supplies of gas or transits of goods. Implementation of the Trans-Korean projects might contribute to a new atmosphere of
cooperation on the peninsula, and eventually contribute to reducing one of the major geopolitical impediments to economic integration in East Asia.

Both projects had been offered more than once to both the North and the South, and more than once both the North and the South expressed their approval (Gabuev 2011: page number if possible). South Korea demonstrated its seriousness towards the projects by building its own section of the railway that now ends near the border with the North, and in October 2011 Russian Railroads ran a trial train along the upgraded trans-border route between Khasan on the Russian side and Rajin on the North Korean side. In the end of June 2014 the new leadership of North Korea unexpectedly proposed in the spirit of “perezagruzka” to South leadership to resume negotiations (Strokan 2014: page number if possible). So far the negative attitude of the US has not permitted the Trans-Korean projects to go beyond the talking stage. The death of Kim Jong-il also contributed to disrupting plans. What will happen next is not known, but Russia’s stake in both these projects is high – especially now that Russian officials, businesspeople and academia are paying more attention to Asia than ever before.

**Consequences of Russia’s eastward turn for the Barents Sea**

However, Russia is not the only country paying attention to these growing Asian economies. Australia is also projected to greatly increase its supply of LNG to the region, and further down the line new large discoveries off the coast of East Africa may also come into play. Demand from China and other Asian countries may easily grow to absorb these new volumes, or they may fail to do so, depending on the policies of those countries. The price that Russia will get for its future LNG exports in Asia will therefore depend on the balance between the growth in LNG from other sources and the energy policies of the purchasing countries and what the outcome will be is impossible to predict. Should Asian LNG exports turn out less profitable than hoped for, and less profitable than Atlantic LNG exports, it could invigorate Russian interest in the Barents Sea. Should Asia turn out to be highly profitable, it would reduce Russian interest in the Barents Sea.

Thus developments in Asia will be important for what happens in the Barents Sea. The Asian countries are the main drivers of increased exports and have helped, and may or may not continue to help keep oil prices high. High prices can facilitate the implementation of costly Barents projects. At the same time, for Russia as a country with much territory and many resources right next door to these growing markets in Asia, the growth is a driver of shift away from the Barents Sea and towards fields and infrastructure in the eastern part of the country. Even with their low levels of debt, the Russians do not have unlimited amounts of capital to invest, and priorities have to be made.

But what then if there is a change in China’s economic fortune? China has experienced 30 years of steep economic growth, as well as dramatic demographic and social changes. Although it is beyond the scope of this article to assess the likelihood of a downturn in the Chinese economy, in a scenario building exercise such a possibility must be taken into account. Should it happen, the impact on the Barents Sea might again be dual: a lowering of world oil prices that makes it more difficult to carry through Barents projects, at the same time as it might increase Russian interest in the Barents Sea relative to East Siberia and the Russian Far East. These effects would depend on whether a Chinese crash were accompanied by a downturn in Western economies. If it were, Barents Sea petroleum activity would unlikely pick up, because the oil price would fall even lower and Western markets would not be so much more attractive than China.
Russia’s reorientation towards the East is mirrored in Statoil’s new deal with Rosneft. In May 2012, Rosneft and Statoil signed a comprehensive cooperation agreement that included exploration for oil and gas in the Sea of Okhotsk, off Russia’s Pacific coast. The same month, it was reported that Statoil would withdraw from its joint project with Gazprom and Total to develop the Shtokman gas and condensate field in the Russian part of the Barents Sea (Lorentzen 2012: page number if possible).

These moves surprised many. The Shtokman field had been the most talked about project in Statoil’s global portfolio and one that the company had worked hard to gain access to. The 2007 merger between Statoil and Hydro was the largest ever in Norwegian history, and one of the main reasons for it had been the desire to join forces in order to improve the chance of getting access to Shtokman (Buanes et al. 2006: page number if possible; DN 2006; Noreng 2008: page number if possible; Reiten cited in Steen 2007: page number if possible). Whereas the Shtokman field is located just over 200 kilometres from the Norwegian–Russian maritime boundary and thus near many other Statoil projects, the Sea of Okhotsk lies ten time zones east of Norway on the other side of the planet (Overland forthcoming 2015: page number if possible).

It could seem that Statoil was making a shift away from the previously so powerful Gazprom to the ascendant Rosneft, and at the same time a geographical shift from the Barents Sea to the Sea of Okhotsk. The former was probably true, the latter not. Although Statoil was clearly giving up on Shtokman for the time being, the deal with Rosneft included other components such as the shale oil near Samara and the North Komsomolskoe field in West Siberia, which is a complex gas and condensate field with a thin band of oil. It appears that for Statoil these were the real draws. The deal also included the Perseevskiy area in the northernmost part of the previously disputed area in the Barents Sea, but the companies would have to make a very big find indeed, and it would have to be oil rather than gas, to be able to develop anything in that area if Shtokman was not viable. Thus Perseevskiy may have been included more as a matter of principle (Statoil also likely wanted more southern parts of the formerly disputed area, which were given to ENI instead). Thus rather than reflecting Statoil’s priorities, the inclusion of Okhotsk in the new deal reflected the priorities of Rosneft and the Russian state.

While Statoil has been enticed by Rosneft into looking towards the Russian Far East, much of the company’s investment is other parts of the world, especially the United States and Brazil. Thus while Russia’s national oil company is increasingly looking east, Norway’s is increasingly looking west. Should these two trends continue and strengthen, the Barents Sea might fall between two chairs.

**Norwegian and Russian supplies to the European gas market**

In spite of Asia’s pull, both Norway and Russia have longstanding and to some extent interplaying commitments to the European gas market. However, the centrality of Russian gas in the EU is easily overplayed. In the decades following the signing of the historical “gas for pipes” agreements signed between the USSR and Germany in 1970, 1972 and 1974, in spite of an increase in the physical volumes of gas deliveries from the Soviet Union, the Soviet Union’s share in total volume of European gas imports more than halved. This happened due to diversification of import sources (from Norway and Algeria as well as other North African countries, plus Qatar, Trinidad and Tobago, among others.). Russian gas now represents about one third of EU imports, yet this corresponds to only 5-6% per cent of total EU energy consumption (Eurostat 2014a).
Norway, by contrast, exports smaller volumes but its share in the EU gas market has been increasing steadily. In 2002, Norway supplied the EU with 61 bcm gas per year, nearly half as much as Russia, which was then supplying over 128 bcm. But Norway, whose oil production is declining and gas production rising, gradually increased its gas exports to Europe and precisely during the worst years of the financial crisis, 2008-2011. Norwegian exports jumped to approximately 93 bcm and finally to 107 bcm in 2012 (Qatar also experienced an increase in exports to the EU). At the start of the financial crisis, Gazprom’s export to the EU also increased to 154 bcm in 2008. But Russian exports did not steadily increase as did Norwegian exports to the EU – by 2011 there was a decline to 141 bcm. That was partly driven by negativity towards Russia after the 2008 War in South Ossetia and the 2009 gas quarrel between Russia and Ukraine.

Irrespective of this competition between the two countries in the EU gas market, there is a lot of potential for Russia and Norway to cooperate not only in the Barents Sea, but also in a broader Arctic framework. As noted elsewhere in this chapter, scale economies can be gained through cooperation, enabling Barents-Sea projects that would otherwise be unprofitable. This is especially true when it comes to the highly expensive transport infrastructure for natural gas. For more on this, see the chapter on bilateral relations.

In the years after the financial crisis, EU gas demand stagnated and oscillated (Eurostat 2014b), but in the longer term it is set to rise, something which is of interest to both Norway and Russia. However, it remains to be seen whether Russian gas producers will benefit from this increasing demand. The Russian-Western relationship after the annexation of Crimea and war in East Ukraine is significantly worse and a greater effort to reduce dependency on Russian gas can be expected.

As a consequence of that crisis, the European gas sector will likely be reorganized to minimize its dependence on Russian gas. Efforts may be made to speed up the commencement of indigenous shale gas production as well as reorientation of gas imports, though so far European shale has been no success and LNG will remain more expensive than piped Russian gas. Though it is hard to forecast how and how fast the evolution of the European gas market will occur, it is obvious that the crisis in Ukraine will accelerate change.

**The Arctic context**

Having reviewed a bit of the global political landscape to gain a sense of the broader picture, we will now zero in on the politics of the Arctic region. Are there political or security aspects that could slow (or accelerate) the interest in Barents Sea oil and gas?

“Race for the Arctic” and the “New Cold War” are common newspaper headlines when it comes to coverage of Arctic affairs. In popular media, the Arctic is often portrayed as a zone of potential conflict – with unresolved boundary issues, rapidly changing sea ice cover and tempting natural resources forming a potentially explosive political cocktail (Wegge 2011: page number if possible; Wilson Rowe 2012: page number if possible; Young 2009: page number if possible). However, the region possesses a strong track record of post-Cold War peace and cooperation. Following the end of the Cold War, the governments and peoples of the Arctic increasingly engaged in a range of cooperative activities designed to address issues of shared concern and to raise the profile of the Arctic as a political and geographical region, such as the Arctic Council and the Barents Euro-Arctic Region (BEAR). The Arctic Council has high-level representatives from all of the eight Arctic states (Canada, Finland, Denmark/Greenland Iceland, Norway Russia, Sweden, and the US), indigenous peoples of the Arctic region participate as “permanent participants”, and a number of non-Arctic states and
NGOs have observer status. The BEAR is a regional initiative in the European North involving national and local government, civil society and indigenous peoples.

The subsequent proliferation of activities aimed at promoting stable and ongoing cooperation in the circumpolar North had to do with the Arctic being a relatively secure source of non-renewable resources (oil, gas and minerals), awareness of the heightened impact of global environmental problems (such as global warming and transboundary pollutants) on the Arctic environment, and the increased politicization of Arctic indigenous peoples (Keskitalo 2004; Kraska 2011; Stokke and Hønneland, 2007; Tennberg 2000; Young 1992; Young 2009).

Political leaders and civil servants representing Arctic states have, in recent years, become a coordinated chorus extolling the peacefulness of the region. As of 2012, the key policy documents of the five Arctic coastal states (Canada, Denmark/Greenland, Norway, Russia, USA) are striking in the extent to which they overlap in highlighting problems and opportunities of importance for the Arctic region (Wilson Rowe 2012). For example, all country statements pointed to climate change, increased human traffic and presence (e.g. shipping) and the promise of natural resources extracted in a fragile environment as drivers of political attention to the Arctic. All of the documents point to the peacefulness of the Arctic region and the cooperative nature with which potential conflicts of interests are resolved (Wilson Rowe, 2012). We argue that it is highly unlikely that the Arctic will become an arena for military confrontation. All Arctic littoral states have economic interests in the Arctic, and armed confrontation in the region would worsen the prospect for profit from the region.

All Arctic states also have a professed interest in sustainable and responsible stewardship of the Arctic environment in their key policy documents. There has been a binding agreement ‘On Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic’ signed that addresses accident preparedness and response (2013), as well as a set of ‘best practice’ guidelines for the petroleum development produced in 2007 (AMAP 2007). However, it is unlikely that they will adopt policies in circumpolar regional bodies, like the Arctic Council, that could eventually act as a brake on Arctic petroleum development. In fact, one of the main points of divergence in their Arctic policy documents is exactly about whether the Arctic Council should be a “decision making” or “decision shaping” body, with the majority landing on the today’s milder version of decision-making (Solli, Wilson Rowe, and Yennie Lindgren, 2013). While Arctic regional bodies will remain an important site for the formation and discussion of best practices, it is likely to be national environmental debates (and possibly more local domestic debates) that would be the most influential in shaping Barents Sea outcomes.

The framings of the political Arctic as a smoothly coordinated zone indicate that the Arctic coastal states see their own northern interests as best-served through today’s arrangements, which award primacy to existing international law and the littoral states themselves. Emphasizing the peacefulness and cooperative nature of the region is one way of casting the suggestions of outside actors for expanded participation or additional layers of governance (including environmental governance) as superfluous. It also makes it easier to draw attention to the economic possibilities of the region, rather than an emphasis on security concerns.
Conclusions

In this chapter, we have noted the particular importance of Asia for developments in the Barents Region, and that it may represent two contradictory effects. Firstly, most of the growth in global demand for oil and gas during coming decades will be found in the Asian countries (along with the countries of the Middle East, but they have their own supplies). How demand develops in Asia will therefore be decisive for whether prices are high enough to support oil and gas extraction under the harsh (and expensive) climatic conditions of the Barents Sea. Secondly, the growth of Asia is changing Russia’s internal priorities. Russia has many oil and gas fields from which to chose from, and vast areas that have not been explored properly. As Russian actors increasingly look to Asia, they are prioritizing the development of resources closer to Asian markets and this may lead to slower development and fewer opportunities for Norwegian–Russian cooperation in the Barents Sea. The question is which of these Asian effects will be strongest.

The projections of the IEA and OPEC foresee steady growth in demand for oil and gas. On the one hand it is possible that unconventionals could oversupply the market, on the other hand climate change threatens to undermine demand. It is difficult to judge the likelihood of either of these developments, but, interestingly, many Russian experts remain skeptical of both. And in the short term it is the perceptions of Norwegian and Russian actors that are most important. Russian experts’ divergent opinions on the significance of these trends that are so widely accepted by Western actors may open up more possibilities for investments in the oil and gas sector in the Barents Sea than a more pro-climate and pro-unconventionals perspective would have done.

The discussion above clearly indicates that the future of Arctic hydrocarbons definitely cannot be analysed or projected just on the basis of simple arithmetic equations and calculations using demand-supply projections, no matter how accurate and reliable initial source data might be. Technological, geological, and, to an even greater extent, political factors create a whole array of uncertainties and easily make any assumption or projection obsolete and irrelevant.

Assumed developments

- The Arctic and especially the Barents Sea is unlikely to be the setting for a major geopolitical conflict and Arctic political bodies are unlikely to propose binding agreements that would restrict oil and gas development. For the development of the Barents Sea, the global context will therefore be more important than Arctic politics.
- Global energy demand is going to continue growing.
- Climate change mitigation is going to remain on the agenda. But as coal produces greater emissions that oil and gas, if there is an effective follow up agreement to the Kyoto Protocol it is most likely to affect coal, and it could even give natural gas a boost.
- Russia will continue to reorient its exports towards Asia.
- In the aftermath of the Ukraine crisis, the EU will attempt to reduce energy imports from Russia, and the collapse of the Ukrainian economy combined with efforts to increase energy efficiency will also reduce the market for Russian gas.

Uncertainties

- Will the oil price rise, stabilize or fall?
- Will the gas price rise, stabilize or fall?
• Will demand for oil and gas imports be concentrated in the Atlantic basin area or Asia? Currently import growth is concentrated in Asia, but if there is a slowdown in China’s growth, Asia’s importance may diminish at the same time as oil prices fall.

• Will the rapid development of unconventional oil and gas spread beyond the United States, and how expensive will unconventionals be. If they become cheap enough, they will be prioritized over Arctic resources.

• Will there be a global, binding and effective agreement to follow up the Kyoto Protocol, and what would its impact be on demand for oil and, especially, gas?

Possible outcomes for petroleum developments in the Barents Sea

• Barents gas may be in high demand, or not.
• The oil price may rise, fall or stay stable.
• Barents gas may or may not be attractive relative to other areas available to oil companies.

References


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Finansovyye Izvestiya (2009, September 24). Upstream, 3 September 2010, p. 30. (Full reference is required)


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Introduction

Introduction will be written after the meeting in Bodø in September following the common standard and the final chapter contents.

Hydrocarbon resources in Russia and the Barents Sea

Russian official data on country's oil reserves had being classified as a 'state secret' since the Soviet time and until the last year. In July 2013, Prime Minister Dmitry Medvedev, following the message of the President Vladimir Putin, signed the Governmental Resolution that excluded oil and petroleum gases from the state secret list (Government 2013). As these data became open, Minister of Nature Resources and Ecology of Russia Sergey Donskoy told that as of 1 of January 2013 Russian oil reserves of categories ABC1 amounted 17.8 billion tonnes and C2 – 10.9 billion tonnes, and reserves of natural gas were 48.8 trillion cubic metres (ABC1) and 19.6 trillion cubic metres (C2) (REF). Minister Donskoy also informed that existing Russian classification of oil and gas reserves and resources calculation (see Table 3.1.) was outdated and should be changed getting closer to the international PRMS (Petroleum Reserves and Resources Definitions) of Society of Petroleum Engineers (SPE) or a Norwegian system (Kezik 2013). Thus, according to BP estimations, Russian proved hydrocarbon reserves were 11.9 billion tonnes of oil and 32.9 trillion cubic metres of natural gas at end of 2012 (BP 2013).

Ministry of Nature Resources and Ecology of Russia (Minprirody) has developed and approved new classification for assessment of hydrocarbon reserves and resources (see Table 3.2.) that will come into force on 1 January 2016 (Ministry 2013a). A new classification takes into consideration not only geological characteristics of a deposit but also economic parameters for its development. Companies – licence owners should re-calculate hydrocarbon reserves and resources for their fields during 2014-2015 (Ministry 2013b).

Recoverable reserves of hydrocarbons on the Russian Continental shelf are assessed to be 10.8 billion tonnes in oil equivalent, and hydrocarbon recoverable resources are estimated to be 98.7 billion tonnes in oil equivalent (Ministry year). The prospective oil and gas territory in the Russian sea areas is estimated as 4 million square kilometres of the total area of the continental shelf of 6.2 million square kilometres (REF).
The Arctic shelf of Russia has a total area of 4.5 million square kilometres and about 75% of it has prospects for hydrocarbon resources (REF). The best researched area is the western sector of the Arctic shelf with large deposits of Prirazlomnoye and Dolginskoe of oil; and Shtokmanovskoye, Leningradskoye, Ledovoye, and Rusanovskoye of gas and condensate. According to the US Energy Department 2009 report, 43 of 61 significant Arctic oil and gas fields were located in Russia (REF).

Assessment of undiscovered oil and gas resources in the Arctic, published by US Geology Survey in 2009, indicated that the total mean undiscovered conventional oil and gas resources north of the Arctic Circle were estimated to be about 90 billion barrels (12 billion tonnes) of oil; 1669 trillion cubic feet (470 trillion cubic metres) of natural gas, and 44 billion barrels (4 billion tonnes) of natural gas liquids (REF). 84% of those resources occur offshore, where Barents and Kara seas are among most prospective ones (REF). The South Kara Sea areas contain almost 39% of Arctic undiscovered gas (REF).

In the Energy Strategy of Russia for the period to 2030, it is stated that the exploration rate of hydrocarbon resources for the Russian continental shelf in total is below 10%. The exploration rates of resources on the continental shelf in the Caspian Sea are 15.7% for gas and 15.9% for oil; in the Okhotsk Sea – 14.4% for gas and 17.9% for oil; and in the Barents Sea – 15.5% for gas (REF).

The Ministry of Nature Resources and Ecology together with the Ministry of Economic Development of Russia have elaborated the State programme for the Russian continental shelf exploration and development (REF). The programme is planned up to 2020 and focused on geological exploration of the continental shelf; technical and technological procurement; construction of coastal and offshore oil-and-gas production units and infrastructure; communication and hydro-meteorological support; environmental protection and nuclear safety; scientific-research, legal and personnel support.

According to the State Strategy for exploration and development of oil-and-gas potential of the continental shelf of the Russian Federation, in 2020, there should be located recoverable hydrocarbon resources on the Russian continental shelf on the levels of 23-26 billion tonnes of oil and 90-100 trillion cubic metres of natural gas; including the recoverable reserves on the level of 10-13 billion tonnes of oil and 10-20 trillion cubic metres of natural gas. The annual production offshore in 2020 may reach the levels of 95 million tonnes of oil and more than 150 billion cubic metres of natural gas (REF).

**Oil production prospects for the Russian Barents Sea and beyond**

The US Geological Survey assessed undiscovered conventional petroleum in the Barents Sea at the levels of 1.5 billion tonnes of oil, 11 trillion cubic metres of natural gas, and 270 million tonnes of natural gas liquids. Most of undiscovered hydrocarbon resources are estimated to be in the Russian sector of the Barents Sea.

The oil production in the Russian Barents Sea has begun with the start-up of Prirazlomnoye oil field in 2013. Prirazlomnoye is one of the largest oil fields found in the Russian western Arctic shelf. Discovered in 1989, the Prirazlomnoye field is located in the Pechora Sea, about 60 kilometres north of the main land cost, with the sea depth of 19 metres. Recoverable oil reserves (C₁-C₃) of the field are estimated at 77 million tonnes, the maximum yearly oil production is estimated to be about 6.5 million tonnes (REF).
The license for the development of Prirazlomnoye oil field belongs to the Gazpromneft Development Company (former Sevmorneftegaz, and Gazpromneft Shelf), subsidiary of Gazprom (REF).

Prirazlomnoye oil field was put in commercial production in December 2013, and the first oil of the new blend Arctic crude was shipped to the West European market in April 2014. Arctic crude oil from Prirazlomnoye can be shipped for export westwards via the Barents Sea and eastwards by the Northern Sea Route. The yearly production maximum can be reached by 2020 (REF).

The major part in the future offshore petroleum production in the Pechora Sea is linked to Dolginskoye oil field discovered in 1999 (REF). The license for oil exploration and production at this field was given to Gazprom in 2005. Dolginskoye field with recoverable oil reserves ($C_1C_2$) estimated at 235 million tonnes is located north of Prirazlomnoye. It is the largest among discovered oil fields in the Pechora Sea (REF).

Oil production is planned on three more licensed sites in the Pechora Sea – Medynsko-Varandeyskiy area, Kolokolmorskiy and Pomorskiy blocks. The licenses are owned by Arktikshelfneftegaz, and the oil fields can be put in operation after 2012. The estimated recoverable oil reserves of these three blocks may exceed 300 million tonnes (REF).

In 2008, Ministry of Economic Development of Russia elaborated the Concept of the State programme for exploration and development of the continental shelf of Russia (REF). According to the passive scenario of the Concept, the maximum yearly oil production on the shelf will be 30 million tonnes in the period from 2010 to 2030; and by the active scenario, oil production, with development of discovered and prospected oil fields on the shelf, already in 2020 may reach the level of 90 million tonnes per year.

Huge hydrocarbon resources discovered and prospected in the Barents, Pechora and Kara seas are a driving force for future industrial development of the Russian Western Arctic regions. One of the Russian Arctic shelf biggest hopes is the Shtokman gas and condensate field in the Barents Sea. A high priority is also given to Yamal Peninsula and its adjusted shelf areas in the Kara Sea. Russian gas monopolist Gazprom is the owner of Shtokman, which will be developed in cooperation with Total and Statoil, and most of Yamal projects. The biggest Russian oil company Rosneft will explore Kara Sea shelf in alliance with the USA's ExxonMobil, where they started exploration drilling in August 2014 (REF). The second largest Russian gas producer Novatek went for cooperation with French Total and Chinese CPC on developing Yamal LNG project (REF).

Shtokman

The Shtokman project has been prioritised by the authorities and companies, discussed on the political arena and highlighted in media for the last ten years. The project development has several sides and challenges – economical, technological, environmental and political. Discussion on a high level resulted in 2007 with signing agreements and establishment cooperation between Russian Gazprom, French Total, and Norwegian Statoil at the Phase 1 of the Shtokman field development. In 2008, the Shtokman Development Company was established with 51% shares of Gazprom, 25% of Total, and 24% of Statoil. In 2012, Statoil left the project and sold its shares to Gazprom.
Shtokman gas and condensate field was discovered in 1988 (REF). The field is located in the central part of the Russian sector of the Barents Sea shelf, at local sea depths of 320-340 metres about 600 kilometres northeast of the city of Murmansk.

The proven reserves \((C_1C_2)\) of the field make up 3.9 trillion cubic metres of gas and 56 million tonnes of gas condensate (REF).

Gazprom Neft Shelf, a 100% subsidiary of Gazprom, holds the license to search for, explore, and produce gas and condensate from the Shtokman field (REF). Shtokman Development AG, a joint venture of Gazprom and Total will be the owner of the phase 1 project infrastructure during 25 years, starting from the date the field is put on stream.

Annual gas production during the phase 1 of the project should be on the level of 23.7 billion cubic metres of natural gas that will be split for producing 7.5 million tons of LNG, and piping 11 billion cubic metres southwards (REF). According to the plans agreed in 2011, the supply via the pipeline was to start in 2016, and LNG supply in 2017 (REF). The pipeline from Shtokman field should go to Teriberka, a settlement about 100 kilometres east of Murmansk, and then to Volkhov in the Leningrad region to join Nord Stream Gas pipeline going through the Baltic Sea. The LNG plant can be also built in Teriberka. However, the Shtokman project startup has been postponed several times and final technical solutions with investment frameworks have not been agreed.

The Shtokman project will be developed in three phases – each for production of 23.7 billion cubic metres of natural gas per year. When the Shtokman project runs on a full scale, the yearly production at the field will be on the level over 70 billion cubic metres of natural gas and 0.6 million tons of gas condensate (REF). Gazprom decided that pipeline gas deliveries from the Shtokman field to the European market would take priority over LNG shipments. Shtokman was identified as the resource base for Russian gas export to Europe via the Nord Stream Gas pipeline.

New perspectives for joint oil and gas projects between Russia and Norway were opened with the maritime delimitation treaty that was signed in 2010 and ratified in 2011. The treaty establishes the boundary between two countries in the Barents Sea and the Arctic Ocean. Possible joint projects in the former “grey zone” have not replaced Shtokman, but affected its development plans.

**Hydrocarbon resources in the Norwegian Barents Sea**

While the major part of the Russian oil and gas production originates onshore, all Norwegian petroleum resources have been located offshore. The Norwegian continental shelf comprises a total of 2 million square kilometres in the North, Norwegian and Barents seas. Traditionally, the North Sea is the main petroleum area in Norway, where 60 fields were in production by the end of 2013, 16 fields were producing in the Norwegian Sea and one in the Barents Sea. Since 1971, oil and/or gas have been produced from a total of 91 fields (MPE and NPD 2014).

Large areas of the Norwegian continental shelf have not been opened yet for petroleum activities, including the major part of the Norwegian sector of the Barents Sea – the northern Barents (MPE and NPD 2014).

In the Norwegian petroleum resources classification system introduced in 2001, resources are divided into classes and project status categories, and comprise recoverable resources. The classes are: historical production (S), reserves (R), contingent resources (C) and undiscovered
resources (P). The project status categories are numbered from 0 to 9, and some also have attributes F for 'first' and A for 'additional' (see table 3.3.) (NPD 2011).

TABLE 3.3. HERE

The Norwegian Petroleum Directorate (NPD) estimates that the total discovered and undiscovered petroleum resources on the Norwegian continental shelf amount to about 14.2 billion cubic metres of oil equivalents. 44% of the total resources, 6.2 billion cubic metres of oil equivalent, have been produced. The total remaining recoverable resources amount to 8 billion cubic metres. Of this volume, 5.1 billion cubic metres are proven resources, while the estimate for undiscovered resources is 2.9 billion cubic metres (MPE and NPD 2014).

Exploration activities have been carried out in the Barents Sea for more than 30 years, but so far, only Snøhvit gas field operated by Statoil has been developed. Reserves of the field are estimated to 193 billion cubic metres of natural gas and 15 million tons of gas condensate (REF). Snøhvit came on stream in 2007 and will produce until 2035. Natural gas from the field is liquefied at Melkøya, the northernmost LNG-plant with the capacity of 5 million tonnes per year, and shipped for export. In 2013, first LNG from Melkøya was shipped for export eastwards through the Northern Sea Route along the Russian Arctic coast (REF).

The second to be developed in the Barents Sea is the Goliat oil and gas field that is operated by Eni 65% with Statoil 35% and located between Snøhvit field and Melkøya island. The field should be in production for 15-20 years, reaching a maximum of 5 million tonnes of oil and 1.3 billion cubic metres of gas per year (Bambulyak and Frantzen 2011: page number if possible).

In 2013, five new discoveries were made in the Barents Sea with total resources of 57 million cubic metres of oil equivalent. By the end of 2013, total hydrocarbon resources in the Barents Sea accounted for 1.8 million cubic metres of oil equivalent, out of which 72% or 1.3 million cubic metres were undiscovered, while the total estimate of undiscovered petroleum resources on the Norwegian continental shelf was 2.9 million cubic metres of oil equivalent (MPD and NPD 2014).

Legal framework (please, check the level of subheadings in the whole chapter)

 Licensing in Russia (here and in the following subheadings level is assumed to be 2- therefore italics)

According to amendments to the legislation in Russia enacted in 2008, the licenses on Russian continental shelf are granted for exploration and production of oil and gas on non-tender basis (President 2008). The license holders and users are chosen among the Russian companies with more than 50% shares controlled by the Russian Federation, and companies with at least 5 years’ experience of project development in the Russian continental shelf. Foreign companies may act as operators. Those changes in the legislation granted exclusive rights for oil and gas exploration and production on the Russian continental shelf to the largest Russian companies, state owned Gazprom and Rosneft. In 2012, the state owned company Zarubezhneft bought the Arktikmorneftegazrazvedka (AMNGR) Company that had over 5 years’ experience of petroleum exploration and production on the Russian continental shelf and, therefore, joined Gazprom and Rosneft in this exclusive list of possible license owners. The same year, Zarubezhneft applied to Rosnedra for getting exploration licenses on the continental shelf of the Barents and Kara seas (REF).
By the end of 2010, there were granted 45 licenses on the Russian continental shelf, among them, 12 to Gazprom Group, 16 to Rosneft, 6 to Lukoil, 5 for PSA in Sakhalin, and 14 to other petroleum companies (Bambulyak and Frantzen 2011).

At the end of 2013, Gazprom owned 36 licenses on the Russian continental shelf, and Rosneft had 46 including licenses on the Russian part of the former disputed area with Norway in the Barents Sea. The entire Russian part of the former "grey zone" was divided on three large blocks – Fedynsky in the south (38.1 thousand square kilometres), Central-Barents (15.8 thousand square kilometres) in the middle, and Perseevsky (23 thousand square kilometres) in the north. The licenses on these three blocks were granted to Rosneft in 2012, the same year the Company signed cooperation deals with Eni for the first two blocks and with Statoil for the northernmost one (REF).

The largest deal on the Russian continental shelf, so-called the Arctic Deal, Rosneft signed with ExxonMobil in 2011 (after the similar deal with the British Petroleum was banned). Now, the deal includes 10 license blocks in the Kara, Laptev and Chukchi seas with the total area over 760 thousand square kilometres (REF).

All above mentioned Rosneft's deals for the joint work on the Russian continental shelf have the same terms on shares – 66.7% is owned by Rosneft and 33.3% by cooperating partners (REF).

**Liberalisation or monopolisation**

In April 2012, four large Russian private oil companies – LUKOIL, Surgutneftegaz, Bashneft and TNK-BP addressed a letter to at that time Prime Minister Vladimir Putin where stated that limitations put on private petroleum companies to access the Russian continental shelf could be one of the key element to negatively affect implementation of the state programme for the shelf exploration. The same month, Rosneft invited those companies to join the state oil major in 12 licensed areas on the Russian shelf, including the ones in the Barents Sea, on the same terms that were offered to foreign companies (Staalesen 2012: page number if possible). In July 2012, Federal Antimonopoly Service of Russia published proposals for changing federal legislation that could allow any Russian company with relevant experience to work on the continental shelf. In August 2012, Minister of Nature Resources Sergey Donskoy presented the draft Programme for the Russian continental shelf exploration and development to 2030 and stated importance of giving access to exploration and production licences to private petroleum companies (Ernst & Young 2012). In September 2012, heads of Rosneft and Gazprom Igor Sechin and Alexey Miller sent a letter to President Vladimir Putin where expressed their concern over governmental plans to liberalise access to explore the continental shelf by private companies, and also asked to accelerate the process of giving their companies licences they applied for in 2010-2012. In January 2013, President of Rosneft Igor Sechin and Head of Gazprom Alexey Miller sent a letter to Prime Minister Dmitry Medvedev where again asked the Government to keep the monopoly of state owned companies over the continental shelf licences and not to allow private companies doing even seismic surveys (Arctic-Info 2013). As for now, the point on state companies' monopoly over the continental shelf projects retain unchanged.

In June 2014, Rosneft started geological exploration at five license blocks in the Barents and Pechora seas: West Prinovozemelsky and Perseyevsky in the Barents Sea, South Russky, South Prinovozemelsky and West Matveyevsky in the Pechora Sea. Drilling on those blocks in planned in 2016 and 2017 (Rosneft 2014).
Change in the Russian licensing regulations enacted in 2008 was one of the largest but not the first step made for centralisation of the Russian petroleum resource management system during the recent decade. Until 2004, there was applied so called a 'double key' rule (REF to the Law...), when the license for petroleum exploration and production onshore had to be given based on joint decisions of the federal and regional governments, i.e. signed by both Russian Minister of Nature Resources and the Governor of the region. This 'double key' rule was abolished with the Federal Law approved in August 2004 that gave an exclusive right to grant a license for petroleum exploration and production to federal authorities (REF to the Law).

Licensing in Norway

In Norway, the Petroleum Act provides the legal basis for the licensing system (REF). Exploration and production licenses are awarded through licensing rounds. Prior to that, the area must be opened for petroleum activities by the Parliament's (Storting) decision. The licensing round for a number of blocks is announced by the Government. Only companies that meet certain criteria can apply and be granted a license. As it is stated by the Norwegian Ministry of Petroleum and Energy, these criteria are relevant, objective, non-discriminatory and announced (REF). The Ministry grants a license to company or a group of companies based on applications received, and designates a responsible operator. The production license regulates rights and obligation of the companies and grants them exclusive rights for exploration and production of hydrocarbon resources within the licensed area. Oil and gas produced within the licence is owned by licensees equally to their shares in the joint venture.

Oil and gas activities on the Norwegian continental shelf started in the North Sea and then moved north to the Norwegian and Barents seas. The major part of the Barents Sea is regarded by the petroleum authorities as a frontier area (MPE and NPD 2014) with limited geological information, significant technological challenges and lack of infrastructure. In 2004 with the 18th license round, the principles of relinquishment in frontier areas were amended. In spring 2013, the 22nd licence round was completed and 24 licenses in the Barents and Norwegian seas were granted to 29 companies out of 37 participated. Two Russian companies have got shares in three licenses in the Barents Sea. Lukoil got 30% share in the joint venture with Centrica (50%) and North (20%) on the block 709, and 20% with Lundin (40%), Edison (20%) and North (20%) for the block 708 close the border with Russia. Rosneft has got 20% share in the license 713 operated by Statoil (40%) where Edison and North has 20% each (REF).

The 23rd licensing round with invitations to nominate areas on the shelf was started in August 2013. By the nomination deadline in January 2014, the Ministry of Petroleum and Energy had received proposals from 40 companies, including Lukoil's and Rosneft's Norwegian subsidiaries, for 160 blocks as candidates for the licensing round (NPD 2014).

Environmental regulations

Both in Norway and Russia, pollution without permission is not allowed (REF to PCA and 7-FZ). In both countries, each oil-and-gas project offshore should go through state environmental review procedure with necessarily environmental impact and risk assessments (REF). In Norway, the impact and EIA procedure is applied at all project implementation stages. In Russia since January 2007, EIA and state environmental review are applied at the project design stage only (Golubeva 2013: page number if possible). Public participation is guaranteed but realised differently in Norway and Russia (Moe 2010: page number if possible).
Environmental control of petroleum industry in Norway

Norway has an integrated national system for the environmental control and monitoring on the Norwegian continental shelf that is divided on 11 regions (REF). Environmental pollution and use of chemicals by the oil-and-gas industry offshore are regulated by the national laws: the Pollution Control Act, the Climate Quota Act, the Product Control Act, the Petroleum Activities Act, and other regulations and guidelines of the responsible national authorities.

Prior to opening an area of the Norwegian shelf for exploration for petroleum hydrocarbons, the government initiates an Environmental Impact Assessment (EIA) for the region in question (REF). Ministry of Petroleum and Energy is responsible for all necessary information to be collected and presented to the Parliament (REF). The Parliament then makes decision for opening that particular region for hydrocarbon exploration or not. In the Lofoten waters and the Barents Sea, Norway is introducing the ecosystem approach for an integrated management plan taking into account all kind of man’s impact to these marine areas (REF).

Petroleum industry in general is not permitted to discharge any environmental harmful substances to the sea on the Norwegian continental shelf (REF). In Lofoten waters and in the Barents Sea the 'zero discharges' rule is applied, i.e. the regulations do not allow any harmful substances discharges to the sea. The purpose of the environmental control and monitoring is to measure any possible impact of the discharges of chemicals, produced waters and cuttings, or other kind of disturbances due to the petroleum activities (REF). All compounds being discharged must have a certificate showing that the compound does not harm the environment at the given concentrations; the documentation is based upon standard environmental toxicology tests. The industry must have permits for all the compounds being used and discharged during their operations, and deliver detailed annual reports. The industry does not pay for these permitted discharges. However, financial compensation to Norwegian fishermen is regulated by the Petroleum Activities Act. In case of accidental pollution, industry should pay all necessarily costs for clean-up and recovery of the polluted area (polluter pays principle). Best available technology (BAT) and best available practice (BAP) principles must be used for improving the production circle and reduce the environmental impact of the activities (REF).

When a petroleum company has been awarded a license for exploration and production of hydrocarbons at a particular locality, the company must carry out environmental monitoring in the vicinity of the offshore installations (Framework Regulations; Pollution Control Act). The industry also has to provide on own initiative information on possible environmental impacts of their activities. The Norwegian Environment Agency is the responsible authority for deciding upon guidelines and overseeing the environmental monitoring on the Norwegian continental shelf (REF). The monitoring regions, principles and procedures for environmental control and monitoring are described in the national Guidelines (Iversen et al. 2011: page number if possible) elaborated on the basis on international ones under OSPAR convention (the Convention for the Protection of the Marine Environment of the North-East Atlantic). The petroleum industry organizes and pays for environmental monitoring, while the monitoring itself is carried out by independent accredited scientific consultants on contract base. The reports are delivered to the Environment Agency and made available for the public (REF).
Environmental monitoring of offshore petroleum activities in Norway is a key element of the state and industrial environmental control system, which is built as an ecosystem based and dynamic.

A baseline study following a predefined monitoring program in the vicinity of the offshore installations is carried out prior to the onset of production drilling, and later environmental monitoring (following the same methods as in the baseline study) are performed on regional base every third year (REF). The monitoring includes taking samples of the sea bed, analysing the sediment for given heavy metals and oil compounds, as well as analysing the biodiversity of the macro benthic community. Norwegian ISO based standards are used for carrying out the programme. The combined results from the sediment analyses and the state of the benthic communities are used for calculating the degree and size of the sea floor being impacted by the oil and gas activities. Data from the offshore environmental monitoring is also used in connection with Norwegian reporting to OSPAR.

Environmental monitoring offshore includes both monitoring of the sediments and monitoring of the water column (REF). Measurements of concentration levels of given compounds in selected organisms and in the water, are key elements for environmental monitoring in water column in the vicinity of petroleum facilities offshore.

**Environmental monitoring and control system in Russia**

The state environmental management and control system in Russia has been built with the polluter pays principle and introduction of environmental payments as financial compensation for industrial pollution (REF). The environmental payments are divided on payments for regular (permitted) industrial pollution (emission, discharge, and waste disposal); and payments (fines) for violation of environmental regulations (accidental acute pollution) (REF).

The system for environmental payments in Russia consists of methods for defining and calculating costs for environmental protection measures; economical assessment of environmental impacts; and calculation of losses due to violation of environmental regulations (REF). Environmental payments are calculated as a sum of economic losses through environmental damage assessment, and/or payment for covering certain environmental protection and restoration measures, like environmental payments for indisputable losses, as losses of fishery resources, occurred due to offshore petroleum activities are paid to the federal budget or special fund for fish restoration (fish breeding)

Russian environmental legislation, with the basic Federal Law On Environmental Protection, set principles for defining limits for industrial environmental pollution as an impact to be allowed through ecotoxicology based Maximum Permissible Concentrations (MPC) for each pollutant to be emitted or discharged. The state also establishes rules and guidelines for calculating environmental payments for pollution below and above permissible levels, as well as for violation of environmental regulations. Basic norms of payments (fees) for emission into atmospheric air, discharge into waters, and waste management (treatment and disposal) are set by the Russian Government (REF).

The state and industrial environmental management systems are built to control and monitor the industrial pollution for each regulated (with defined MPC) contaminant to be emitted, discharged or disposed.
State environmental supervision (from July 2011, the term 'state control' was replaced by 'state supervision' in environmental management (REF)) of the industrial activities in Russia is carried out by the Federal Service for Supervision of Natural Resources Use (Rosprirodnadzor), agency under the Ministry of Nature Resources and Ecology of the Russian Federation (REF). This agency controls implementation of the environmental regulations (permissions to pollute within certain limits) set for the industry and supervise industrial environmental control and monitoring system, including inspection of pollution reports and verification of industrial laboratories. Since 2010, Rosprirodnadzor is also responsible state authority for carrying out environmental review of petroleum projects on the Russian continental shelf (Kirillov 2013: page number if possible).

Industrial environmental control is obligatory for oil-and-gas activities and is part of the industrial environmental management system. The company operator is responsible for identification of sources of pollution (emission to air, discharge to water, waste disposal) for each regulated pollutant, measuring the pollution load (mass of emitted/discharged pollutant per year), and calculation of environmental payments – fees to be paid to the state (REF).

Waste management is based on the hazard class assessment (REF). In Russia, waste is divided in 5 hazard classes (see Table 3.5. – include table?) (REF). Projects on waste management, recycling or disposal, go through EIA and state environmental review procedure.

State environmental monitoring of the Russian continental shelf, including the Russian part of the Barents Sea, is established according to the Federal Laws: On Environmental Protection, On Continental Shelf of the Russian Federation, On Exclusive Economic Zone of the Russian Federation (REF). The agency of the Ministry of Nature Resources and Ecology – the Federal Service on Hydrometeorology and Environmental Monitoring of Russia (Roshydromet), is the responsible authority for managing the Unified State Environmental Monitoring System (REF). The environmental monitoring system of Roshydromet is region (regional network of offices and monitoring points) and pollution based. Research institutes under the Ministry of Nature Resources and Ecology also run state projects for monitoring offshore environmental pollution on requests from the Ministry. The state monitoring of marine biological resources in Russia is responsibility of the Federal Agency of Fisheries and carried out by its subordinated research institutes (REF). For example, any new technology or equipment to be applied offshore that may impact marine biological resources should be reviewed by CUREN (the Central Department on Fishery Review and Norms on Protection and Restoration of Water Biological Resources and Acclimatisation) and environmental monitoring programme should be approved (REF).

Industrial environmental monitoring system in Russia is pollution source based (REF). Industry is obliged to establish and carry our environmental monitoring of environmental impact sources within the industrial environmental pollution control system. Industry monitors the sources of pollutants permitted for emission to atmospheric air, discharge to water, and waste disposal places with areas of impact. Environmental monitoring program (with list of pollutants to be monitored, terms, measurements or calculation methods) is developed for each pollution source (REF).

In 2013, the changes to the Federal regulations came in force that obliged all operators of offshore petroleum projects to elaborate oil spill contingency plans and present them for state environmental review, to implement oil spill response system according to the adopted plan, and to provide financial guarantee for paying all costs in case of an accidental oil pollution, including compensation for environmental damage (President 2012).
According to the Federal Law On the Continental Shelf of the Russian Federation, waste disposal and discharge of pollutants is not allowed on the Russian continental shelf (REF to the Law). That means that all drill cuttings, chemicals and produced water cannot be disposed on the sea floor or discharges to the sea waters within the continental shelf area and must be transported and treated onshore (see Table 3.6.- in accordance with the numeration it should be 3.5.).

**Norwegian-Russian environmental cooperation**

The Agreement between the Governments of the Kingdom of Norway and the Russian Federation on Environmental Matters was signed in 1992 as a renewal of the first bilateral governmental agreement signed between Norway and the Soviet Union in 1988. At the political level, the cooperation operates through the Norwegian-Russian Environmental Commission co-led by state environmental authorities, the Ministry of Climate and Environment from Norway and the Ministry of Nature Resources and Environment from Russia. Bilateral activities are carried out as projects within the joint Work Programme agreed every second year (Ministry of Climate and Environment 2010). The management of resources in the Barents Sea in a sustainable way based on scientific knowledge and ecosystem approach has been one of the main focuses in the bilateral environmental cooperation. The Environmental Commission initiated and supported a number of projects aimed at analyses, improvement and harmonization of environmental requirements and standards for oil-and-gas industry prior to their operations in the Barents Sea, e.g. Exchange of competence on EIA processes in Russian and Norway started in 1999 (Dahle et al. 2000: page number if possible; Golubeva and Svensen 2001: page number if possible; Lukin et al. 2012: page number if possible), Coordinated Environmental Monitoring Programme 2002-2011 (CEMP) (Savinov et al., 2011: page number if possible), Joint guidelines for post oil spill damage assessment 2006-2010 (Studenov et al. 2009; Dahle et al. 2011: page number if possible). In 2009, the Joint Norwegian-Russian environmental status report on the Barents Sea Ecosystem was presented (Stiansen et al. 2009: page number if possible) that addressed all aspects of the sea ecosystem and highlighted increases in petroleum and shipping activities as significant challenges (Ministry of Climate and Environment 2010).

In June 2006, the Norwegian Parliament ratified the integrated management plan for the Barents Sea and Lofoten that was up-dated in 2011 (Government of Norway 2011; von Quillfeldt 2012: page number if possible). One of the most important issues stated in the management plan is the establishment of special marine protection areas where oil exploration will not be permitted at all (Moe 2010: page number if possible). The Norwegian management plan for the Barents Sea has being presented and promoted on the Russian side within the Joint Environmental Commission meetings, and development of the common principles for resources and environmental management for the whole Barents Sea discussed (Moe 2010: page number if possible; von Quillfeldt 2012: page number if possible). In response, the State Oceanographic Institute under the Ministry of Nature Resources and Ecology of Russia elaborated the Methodology for Marine Spatial Planning and Comprehensive (Integrated) Nature Resources Management Plan in the Barents Sea taking into account International Experience and the Best Practices of Transborder Resources Use (Zemlyanot et al. 2013: page number if possible) that is under discussion now. The Methodology and the Plan were elaborated within the Russian Federal Task Programme 'World Ocean'. The Methodology and the Plan proposals are based on the Large Marine Ecosystem concept and eco-system approach in management.
Norwegian and Russian environmental authorities, research institutes and NGOs collaborate and implement joint projects to study and protect the Barents Sea ecosystem within other bilateral and international platforms also, including the Joint Norwegian-Russian Fisheries Commission that was established by the decision made in 1974 (JointFish 2011); the Arctic Council with its working groups (AMAP, PAME, ACAP, CAFF, EPPR, SDWG); EU-Russia cooperation programmes, such as Kolarctic; the Barents Euro-Arctic Region with environmental working groups and sub-groups operating at national and regional levels, NATO-Russia Science for Peace and Security (frozen at the moment), Norwegian Research Council and the Russian Foundation for Basic Research cooperation programmes, petroleum industry associations and projects, like INTSOK RU-NO Barents Project, Barents-2020 Harmonisation of HSE Protection Standards for the Barents Sea, Joint industry project of the International Association of Oil-and-Gas Producers (JIP OGP) on Arctic oil spill response technologies, and others.

Oil pollution prevention and response

Oil spill response in the Russian Barents Sea (here and in the following subheadings level is assumed to be 2- therefore italics)

In the Russian Federation, all issues related to emergency prevention, response and security, including oil-spill response (OSR), are under the purview of the Unified State System of Emergency Prevention and Response (henceforth: USSPR) (President, 1994; Government of Russia, 2003). OSR in Russia is a tiered system (IPIECA 2007; Semanov and Ivanchin 2004: page number if possible) where the first level responds to local and/or municipal spills, the second to regional ones, and the third to federal spills. It has been characterized as complex, multi-organizational structure and regulated by an extensive legislative framework (Rambøll Barents 2010: page number if possible; Ivanova 2011: page number if possible; Sydnes et al. 2013: page number if possible).

Russian legislation ranks emergencies caused by oil spills in terms of their potential severity, based on the volumes of oil spilled (Government of Russia 2000), with five categories of oil spills on land and three at sea (Ivanova 2011: page number if possible). Contingency plans are based on the maximum possible volumes of oil spilled and are enacted depending on the category of an oil spill. (Government of Russia 2000).

All activities related to OSR are carried out according to contingency plans established at the federal, regional and local/object levels (Government of Russia 2002; President 2012b). Initially OSR in Russia is the responsibility of the industrial operators, who are obliged to have and implement oil-spill contingency plans for their projects (Government of Russia 2002; President 2012b). If an oil spill at the offshore facility shifts from the local to the regional level of emergency, the regional plan comes into action. A similar procedure is applied if an oil spill extends up to the federal level. Contingency plans at regional (federation subject) and facility levels are developed by operators, and then confirmed by regional and responsible federal authorities in the region, and approved by the Ministry of Energy and Ministry of Emergencies (Government of Russia 2002). At the federal level oil-spill contingency plans at sea are elaborated by the Federal Budgetary Institution State Marine Coordination and Emergency Rescue Service of the Russian Federation (henceforth: Gosmorspasslužba). These are to be approved by federal authorities, including the Ministry of Transport, the Ministry of Emergencies and the Ministry of Nature Resources and Ecology.

Operators are to establish oil-spill response teams (Government of Russia 2002; President 2012b). As few operators have own response teams, the majority out-source these services to
private or state OSR providers. In addition, operators are to establish an environmental monitoring system, including an oil-spill detection system and ensure have a system for early warning and communications. Finally, operators are to have financial provisions to cover OSR costs including compensation and environmental damages (President 2012b).

The OSR system in the Barents sea is established by the Ministry of Transport of the Russian Federation and its subordinate authorities including the Federal Agency of Marine and River Transport (henceforth: Rosmorrečflot), the Federal State Unitary Enterprise ‘Rosmorport’, and Gosmorspasslužba (Ministry 2009; Government of Russia 2013b; Ministry 2013). These agencies operate at the federal level. Rosmorrečflot develops the OSR system at sea and conducts its general management, while the Gosmorspasslužba is in charge of the daily operational activities of the system (Ministry 2009). Gosmorspasslužba’s head-office is in Moscow, while nine branches operate in all sea basins in Russia (Gosmorspasslužba 2014). The Northern branch of Gosmorspasslužba with headquarters in Murmansk is responsible for OSR operations from the Norwegian–Russian border in the west to 125°E in the east, i.e. covering the whole Russian part of the Barents Sea (Smirnov 2013; Korenev and Vassiliev 2013; Bambulyak et al. 2014). It is the main provider of search and rescue and OSR services at sea in the Russian Arctic (Government of Russia 2013b; Ministry 2013). Rosmorrečflot and Gosmorspasslužba coordinate OSR activities in the Barents Sea through Marine Rescue Coordination Centres (henceforth: MRCC) and communicate with relevant authorities in case of incidents.

**Oil spill response in Norway**

The Pollution Control Act of 1981 (further PCA 1981) is the legal basis that establishes the general requirements for the OSR system and the basic principles, demands, and obligations to the organizations involved in activities that may cause acute pollution in Norway (PCA, 1981). The PCA 1981 establishes the ‘polluter pays’ principle in Norwegian OSR. Another cornerstone of the Norwegian policy against acute pollution is the use of preventive and risk-reducing measures (Coastal Administration 2010b).

The Norwegian OSR system is a tiered system based on private, municipality, and state systems. All levels of contingency act in accordance to their contingency plans that provide guidance for acting in emergency situation (PCA 1981, § 41). The private industry’s and municipalities contingency plans are based on requirements set by the Norwegian Environment Agency who also approves the plans (PCA 1981, § 41, 44). The Department of Emergency Response of the Coastal Administration is responsible for maintaining the national contingency, including all three levels. The Coastal Administration in cooperation with Climate and Pollution Agency and the Norwegian Directorate for Civil Protection, have developed a ‘unitary command system’ (ELS) for fire, rescue and acute pollution that is to be applied during operations (DSB 2011).

Oil spill response is primarily the responsibility of the polluter, who is in charge of emergency operations in the event of acute pollution resulting from its activity regardless of the size of an oil spill (PCA 1981, § 40). Petroleum operators are obliged to establish contingency plans OSR systems to ensure safe operations (PCA 1981, § 41). Contingency plans are to ensure that response organizations and procedures are established (PCA 1981, § 41). In Norway, all private offshore operators are members of the Norwegian Clean Seas Association (henceforth: NOFO) (Coastal Administration 2010b). The NOFO’s main task is to maintain the oil spill emergency preparedness on the Norwegian Continental Shelf and coordinate the activities of private companies (NOFO 2011b). NOFO is a part of the national OSR system and can mobilize significant resources in the event of acute pollution (NOFO 2011b; SINTEF 2010).
The NOFO’s OSR capacity is organized as ‘Clean Seas Association systems’ including equipment and personnel, located along the coastline in five different regions (NOFO 2011b).

Municipalities and inter-municipal response regions are primarily responsible for minor incidents of acute pollution within the municipality, but also to provide assistance if the polluter is unable to handle the incident on its own (PCA 1981, § 43). The municipal fire departments are responsible to provide OSR and have a set of equipment and trained personnel. Municipalities are also obliged to provide each other assistance both in case of oil spills from shipping and offshore installations (PCA 1981, § 47). Inter-municipality OSR coordination is organized through 32 inter-municipal regions established by the government and covering the entire country. These act when municipalities need assistance, and are also obliged to assist each other in cases of emergency. The Norwegian Environment Agency sets the requirements for the level of contingency both at the municipal level and that of inter-municipal regions.

State contingency is the core of the Norwegian OSR system. The Norwegian Coastal Administration, under the Ministry of Transport, is responsible for the enforcement of the Pollution Control Act in part of acute pollution. It is also the national administrative authority on maritime safety and the maintenance of national preparedness against acute pollution. The State contingency plan under its auspices includes national, international, and private agreements with actors to provide resources. State contingency is based on a regularly revised and updated environmental risk assessment (Det Norske Veritas 2010b; Norwegian Pollution Control Authority 2001) and is primarily focused on maritime traffic and responding to accidents along the coast (Det Norske Veritas 2010b). State OSR capacity, including technical resources and trained personnel, is organized in 16 depots along the coastline. The Coastal Administration is obliged to ensure additional protection in cases where private operators or municipalities are not capable. The agency communicates with municipalities affected by an oil spill according to the national contingency plan; it oversees operations conducted by private business and municipalities, and in the event of major incidents may take over the management of the operation (PCA 1981, § 46). During state-run operations both private operators, municipalities, and other public authorities are part of the response operation and are obliged to provide assistance (PCA 1981, § 47). The PCA, further, gives the Coastal Administration the right to mobilize and coordinate all national resources into one national OSR organization in the event of large oil spills irrespective of their origin (PCA 1981, § 46). This is ensured by a compensation scheme that guarantees that all costs derived from providing such assistance will be reimbursed (PCA 1981 § 2; 76). As such, the three levels of contingency are to operate as a single integrated response operation when required (PCA 1981). There are no formally established criteria for when the Coastal Administration may take control over OSR operations (PCA § 46).

Oil spill response cooperation in the Barents Sea

Norway and Russia has well organized cooperation to fight with accidental oil spills in the Barents Sea. This cooperation is built on the basis of the bilateral governmental agreement on maritime safety and environmental protection against oil pollution signed in 1994, with a Joint Norwegian-Russian Contingency Plan for the Combatment of Oil Pollution in the Barents Sea as its integral part. This agreement was based on the 1990 International Convention on Oil Pollution Preparedness, Response and Cooperation (OPRC Convention 1990) that encourages its parties to "co-operate and provide advisory services, technical support and equipment for the purpose of responding to an oil pollution incident" (Sydnes, A.K. and Sydnes, M. 2013: page number if possible). The agreement gives a platform to
responsible authorities from both countries to run practical joint activities, including joint exercises that are arranged annually, one year in Norway and another in Russia (Bambulyak and Frantzen 2011: page number if possible). State departments responsible for oil spill preparedness and response at sea lead the cooperation, the Norwegian Coastal Administration, which is now a department under the Ministry of Transport of Norway, from one side and the State Marine Coordination and Emergency Rescue Service of the Russian Federation (Gosmorspasslužba) under the Ministry of Transport of Russia from another. Other state departments, like units of the Norwegian Coast Guard, Russian Ministry of Emergencies and regional environmental authorities, as well as professional private companies and environmental NGOs take part in workshops and exercises. The cooperation is managed by the Joint Norwegian-Russian Steering Group, established in 2006 with a Memorandum on Maritime Safety, and the Planning and Policy Group.

The joint oil spill contingency plan establishes the four steps to be taken during the stages of an oil spill response operation: discovery and alarm; evaluation and plan invocation; containment, counter measures, clean-up and disposal; and documentation and cost recovery. So far, the joint contingency plan has not been implemented in a real case, as there has not been an oil spill to activate it, and joint exercises, called 'Exercise Barents', provided the only opportunity to assess the regime's effectiveness and reveal possible gaps in preparedness. These exercises are also important for professional training, experience exchange and capacity improvement. Since 2006, Exercise Barents can also be combined with Barents Rescue and Norwegian-Russian search-and-rescue exercises (Sydnes, A.K. and Sydnes, M. 2013: page number if possible). In addition to exercises and official meetings, the authorities arrange education and training courses and provide technical support to oil spill response units.

In addition to the bilateral cooperation, both Norway and Russia are active participants of the multilateral cooperation established under the Arctic Council. Its Emergency Prevention, Preparedness and Response (EPPR) Working Group facilitates the exchange of information and practical experience among the Arctic States on issues related to the prevention, preparedness, and response to all kinds of environmental emergencies in the Arctic, including oil spills (INTSOK 2014). Both Norway and Russia are parties to the Agreement on Cooperation on Marine Oil Pollution Preparedness and Response in the Arctic of 2013 (Arctic Council 2013). EPPR is tasked to maintain the Operational of the Agreement and to follow up evaluations from exercises (INTSOK 2014).

Both Norway and Russia the United Nations Convention of the Law of the Sea (UNCLOS), as well as adopted by the International Maritime Organization (IMO) the International Conventions to prevent and compensate environmental damage by oil pollution from seagoing vessels: on the Prevention of Pollution from Ships (MARPOL); on Civil Liability for Oil Pollution Damage (CLC); on the Establishment of an International Fund for Compensation for Oil Pollution Damage (FUND); and on Civil Liability for Bunker Oil Pollution Damage (BUNKER). (INTSOK 2014). IMO is currently developing an International Code of safety for ships operating in polar waters (Polar Code), which should cover the full range of design, construction, equipment, operational, training, search and rescue and environmental protection matters relevant to ships operating in Arctic and Antarctic waters (INTSOK 2014).

**Conclusions**

Conclusions will be finalised by the end of August when other co-authors (Lars-Henrik Larsen and Vlada Streletskaya) provide their contributions.
Key issues: harmonization in licensing procedures (anything left to liberalize?), EIA/ERA, RB and BAT, ‘zero discharge’ (produced water and drill cuttings), environmental monitoring, environmental damage assessment.

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CHAPTER 4

Norwegian-Russia petroleum B2B Cooperation in the Case of the Barents Sea

JUNE BORGE, ANATOLI BOURMISTROV AND ANDREY KRIVOROTOV

Introduction

Delimitation line dispute between Norway and Russia in the Barents Sea, being unresolved for many decades, was unexpectedly settled in 2010. What was unparalleled compared to other international precedents is that it was huge area that was delimited, and the resulting delimitation line has become the single longest borderline in today’s Europe. We will not discuss here why it is done and to what extent this agreement is important for Russia and Norway (see for relevant discussion e.g. Gorst (2013), Moe et. al. (2011); Krivorotov (2001)). Rather we will focus more on the analysis regarding cooperation opportunities this agreement opens up for bi-lateral industrial cooperation especially for companies located in the Northern parts of both countries. In analyzing the future of the Norwegian-Russian industrial cooperation based on opportunities the delimitation line agreement brings, the aim of the chapter is two-fold. First of all, it describes the current status of Norwegian-Russian B2B cooperation in the petroleum industry in the High North and provides analysis of driving forces and major factors currently influencing and limiting the scope of cooperative development in the petroleum industry on the Norwegian and Russian sides. This analysis implies both major petroleum companies as well as companies in the supply industry in both countries. Second, the chapter ends by providing input for scenarios for future development of the industrial cooperation based on opportunities which are opened up by the delimitation line treaty in the Barents Sea.

Cooperation between petroleum majors: reciprocity of interests

Cooperation in the offshore petroleum industry between Western and Russian petroleum companies is a plausible and beneficial strategy because of reciprocity of interests. On the one hand, major Russian petroleum companies do not possess experience and technologies to develop Russian Arctic offshore alone (The Economist, 2004). Being for decades focusing on development of onshore resources, offshore competence of Russian companies has therefore not advanced as far and quickly as some of Western companies. Thus, in the developing petroleum resources in the High North, it is indispensable for Russian petroleum companies to gain access to valuable experience and technologies possessed by Western companies in addition to the obvious needs in the petroleum industry of entering the partnerships with Western companies to reduce exploration risks and share development costs (Øverland et.al., 2013). There are also other rationales for Russian companies, like improving their public image or getting access to the partners’ assets worldwide in quest for internationalization.
On the other hand, Russia possesses tremendous amount of already discovered and undiscovered petroleum resources (Zolotukhin, 2011). Therefore, international petroleum companies (including Norwegian) are interested in gaining access to Russia and its petroleum projects to secure their own long-term activities (Øverland et. al., 2013).

Russian and Norwegian challenge scale, groundbreaking development of the Arctic shelf to compensate the falling production in their key provinces (North Sea for Norway and Western Siberia for Russia) that have entered the mature phase.

From the very outset, Norwegian companies have looked a very reasonable choice for Russian companies to forge partnerships with especially in the High North. Geographical proximity, historically constructive bilateral relations, the common interest in exploring and preserving the Barents Sea (which among other helped create efficient fishery management regimes in 1970s), and the big interest of Norwegian companies to gain access to Russian petroleum resources played their role. But the Norwegian advanced technologies were eventually of utmost importance. At least ever since the Norway-Russia government dialogue on energy and environment was launched in 1992, the offshore competence and experience of the Norwegian companies have been appreciated highly in Russia.

The Russian natural gas monopoly Gazprom, both directly and through its subsidiary Rosshelf, cooperated closely with the two Norwegian petroleum producers, Statoil and Norsk Hydro, through the ‘90s on exploration and development of several prospects and fields in Eastern Barents and Pechora Seas (including notably Shtokman). In 2004, a trilateral MoU was signed by Gazprom, Rosneft and Statoil aiming at cooperation on Shtokman, Snøhvit projects, and Russian access to Statoil’s regas facilities in North America. Later on, similar MoUs and cooperation agreements covering broader areas of the Arctic shelf were signed in 2005, 2009 and 2010.

Therefore, at no surprise both Statoil and Hydro were shortlisted by Gazprom in 2005 as potential partners to develop Phase 1 of the Shtokman gas and condensate field. However, key decision-makers in Russia may well be motivated by a longer array of reasons and criteria when choosing international partners. For instance, the involvement and importance of French Total as a consequence of long-term cooperation between Russia and France could have represented challenge for Norwegian actors in positioning themselves in relation to Shtokman (Jensen & Øverland, 2011).

**Shtokman Development AG: experiences and lessons**

Analysis of cooperation within Shtokman Development AG represents a particular interest. The special project vehicle (SPV) to develop Shtokman Phase 1, was set up in February 2008, originally owned by Gazprom (51%), the French Total (25%), and Statoil (24%). This JV became the first practical attempt of Russian-Norwegian upstream cooperation on developing a specific Barents Sea field. Besides all business merits, it also fit perfectly into the foreign policy approaches of both Norway and Russia of the time, who equally highlighted the High North as a top political priority.

The project was also groundbreaking in other respects. The field itself is in top 10 globally in terms of resources, and located much further north (73°30’N) than any of the producing fields

so far, in an area with seasonal heavy ice, threat of iceberg impact, polar lows, and several months without sunshine. Shtokman Phase 1 was also supposed to bring about the first-ever offshore gas production from the Russian Arctic seabed, the first Russian Arctic LNG plant (in Teriberka near Murmansk), and to become a trendsetter on the Russian shelf in respect of applying cutting-edge technologies, advanced project management techniques, highest ethical and HSE standards. Last but not the least, it was a testing ground for a new model to attract foreign investments at the times when private investors (either Russian or foreign) had been barred legally to enter the Russian Arctic shelf.

In 2008-2012, Shtokman Development AG delivered comprehensive onshore and offshore surveys, front-end engineering design (FEED) and technical design according to Russian standards, environmental impact analyses, numerous governmental clearances, etc. The SPV ran tenders for all principal equipment packages, mapping opportunities to maximize local content within research, manufacturing, and industry education. It also helped identify a whole set of gaps in the Russian legislation on continental shelf, many of which were bridged by a Russian federal law adopted in late 2013.

Thanks to the efforts of Shtokman Development AG and all the three shareholders, the understanding of both the challenges and opportunities of developing high-latitude Arctic shelf has grown dramatically. It was proved that a sustainable production of hydrocarbons from such a remote field in extreme Arctic conditions is technically doable. Meanwhile, the economics of this project, originally targeting the US market, suffered dramatically from the shale gas revolution, which affected several Arctic offshore projects worldwide. This was exacerbated by the global economic turmoil. In 2012, the shareholders stated that a final investment decision could not be made, and Statoil had to leave the project soon after. Despite that, both Russians and Norwegians gained valuable experience working together, and Statoil maintains a strong desire to cooperate, all the more that licensing both in the Russian part of the Barents Sea and other Russian seas gained a huge momentum since 2012.

Cooperation between Rosneft and Statoil

Rosneft has recently been active in developing several agreements with Statoil. On May 5th 2012 Rosneft and Statoil signed a cooperation agreement on joint offshore operations in the Barents Sea and Sea of Okhotsk\(^2\). The agreement covered joint exploration of fields in the Russian section of the Barents Sea and Sea of Okhotsk as well as Rosneft’s Participation in the O&G activities on the Norwegian Continental Shelf. The agreement had also laid foundation for a new global partnership between companies presenting possibility of acquisitions by Rosneft of interests in Statoil’s international projects. The agreement also included the intention to create spin-off effects for the regional supply industry by indicating intention to place orders for ice-class vessels and drilling platforms on the Russian shipyards.

A month later, on June 21st 2012, Rosneft and Statoil signed follow-up agreements on joint bidding for licenses in the Norwegian section of the Barents Sea and on joint technical evaluation of tight oil resources in Russia.\(^3\) On August 30th 2012 Shareholder and Operating Agreement was signed which lead to establishment of a Joint Venture for four offshore licenses in the Barents Sea and the Sea of Okhotsk. Rosneft received 66.67% of ownership


and Statoil 33.33%. Statoil was also supposed to fund 100% of costs in the exploration phase. Agreement has also stipulated exchange of technical personnel.

On November 23rd 2012 companies announced a joint “Declaration on Protection of the Environment and Biodiversity for Oil and Gas Exploration and Development on the Russian Arctic Continental Shelf” which was supposed to lead to the development of a Coordination Center with representation of the key Russian governmental agencies (e.g. Roskosmos) and ministries. This was a joint initiative which aimed to improve coordination for safe exploration of O&G resources on the Russian side.

As a matter of reciprocity in interest and closeness of cooperation, Russian companies Rosneft and Lukoil have entered operations on the Norwegian Continental Shelf. Those two companies were among the 29 companies which got licenses in 22nd bidding round (Gorst, 2013). Rosneft has a 20% stake in block 713 together with Statoil and Lukoil has a 20% stake in block 708 (among other together with Lundin (Sweden) and North Energy (Norway)) and a 30% stake in block 719 (among others together with Centrica Resources (UK) and North Energy). For both Russian companies, this partnership on the NCS may represent a valuable experience of joint offshore operations in the High North, especially for Lukoil which by the Russian legislation is not allowed to participate in the offshore field development in the Russian High North.

Reciprocity of interests in developing petroleum in the Arctic, but how and where in the Barents Sea?

Above mentioned analysis demonstrates that the cooperation between major petroleum companies in Norway and Russia has developed from and recognition of reciprocity of interests in benefits of joint development of the Russian and Norwegian parts of the Arctic Continental Shelf. In this sense, the 2010 Murmansk Treaty has created a new cooperation spot, namely joint development of trans-boundary hydrocarbon deposits in the Delimited Area (those that extend across the delimitation line). According to Article 5 and Annex II of the Treaty, a Unitisation Agreement shall be signed for each of these fields, so that it may only be developed by Russian and Norwegian legal entities together under a Joint Operating Agreement. This sets ground for the petroleum companies to cooperate in developing the resources in the High North based on reciprocal interests.

Article 5 makes it clear, however, that ‘If the existence of a hydrocarbon deposit on the continental shelf of one of the Parties is established and the other Party is of the opinion that the said deposit extends to its continental shelf, the latter Party may notify the former Party and shall submit the data on which it bases its opinion’. In this case the Parties shall start respective unitization discussions. In the course of these, ‘the Party initiating them shall support its opinion with evidence from geophysical data and/or geological data, including any existing drilling data and both Parties shall make their best efforts to ensure that all relevant information is made available for the purposes of these discussions’. This essentially means that in order to launch the unification process, both Parties shall follow a similar timetable in the geological exploration (seismic shooting and drilling) in the delimited area.

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5 http://www.statoil.com/en/NewsAndMedia/News/2012/Pages/23Nov_Arctic.aspx
6 According to the Russian legislation, only Russian state owned petroleum companies that have at least 5 years of experience of working on the Russian continental shelf can develop Russian offshore petroleum resources.
Despite that, the two nations show unequal dynamics in terms of leasing acreage and exploration. On the Norwegian side, seismic shooting started minutes after the Treaty came into force, early on July 8, 2011, while licensing has been allowed in the southern part only (Barents Sea South East licensing area), and the first blocks awarded only in 2013. Russia started seismic shooting a year later, in 2012, but even before that the whole delimited area had been split in three big blocs. Licenses for all the three were granted to Rosneft, which started seeking for foreign partners to explore these (in a similar way as it had engaged ExxonMobil into its blocks in Kara Sea).

The northernmost block of the delimited area, Perseevsky, became one of the principal pillars in a close cooperation between Rosneft and Statoil. However, it’s very remote location in the north of Barents Sea creates massive technological and logistical challenges. Drilling the first exploration well there is tentatively planned for 2015 and may cost hundreds of millions of dollars. If it was not possible to develop as big a gas field as Shtokman, then even further north it will certainly not be possible, so this is a bet on finding oil. Because of this, in the short-term, it seems that the Norwegian Continental Shelf and particular the Norwegian southwestern, ice-free part of Barents Sea can be a driving force for the development of resources in the High North and, therefore, a basis for industrial cooperation between Norway and Russia (INTSOK, 2013).

**Cooperation in the supply industry: a mosaic of challenges**

Oil and gas companies are depends on various suppliers that offers products and services necessary to exploring, developing, producing and processing petroleum resources.

*Growing (potential for) Norwegian-Russian supply industry cooperation*

The Norwegian supply industry has gained strong international position and through Norwegian Oil and Gas Partners (INTSOK) foundation gains access to and exported Norwegian petroleum technologies on the international markets on the global scale. The Russian market has not been exception and Norwegian supply companies have been active in seeking access there for many years. Despite the fact that the size of the offshore market for supply companies is smaller in Russia compared to Norway in absolute figures (see Table 4.1), Norwegian supply industry identifies Russia as a main marked (alongside with Australia, Brazil, China, UK, US) due to its growth potential, especially in the offshore segment.

*<TABLE 4.1. HERE>*

Norwegian companies have already supplied critical pieces of equipment and services to the key Russian offshore projects. For example, in 2006, when Gazprom needed to drill appraisal well No. 7 at the Shtokman filed in the Barents Sea, it involved Norsk Hydro (which later merged with Statoil), who did the job from the *Deepsea Delta* drilling rig owned by Odfjell Drilling. Kværner, the Norwegian leader in gravity based structures (GBS), has been responsible for Engineering, Procurement and Construction (EPC) of the GBS for the Berkut platform to be used in Sakhalin-1 project in the Russian Far East, where both ExxonMobil and Rosneft participate. The delivery of the GBS was completed in May 2012⁷, and Kværner

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⁷ [http://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/The-Sakhalin-1-GBS-completed/](http://www.kvaerner.com/Products/Concrete-structures-for-offshore-platforms/The-Sakhalin-1-GBS-completed/)
managed to locate 90% of the production in Russia, essentially constructing a new plant in the Far East. Kongsberg-based FMC Technologies has delivered complete subsea production facilities for Gazprom-operated Kirinskoye field offshore Sakhalin, involving several other Norwegian companies as subcontractors (e.g. Aker Solutions supplied the umbilicals). Kirinskoye became the first offshore field in Russia to be developed with a full subsea completion concept. It was put on stream in 2013, though Gazprom may revise the development scheme now, as major oil deposits were discovered in the field.

Quite a few Norwegian companies have supplied equipment packages to Prirazlomnaya, the platform which in March 2013 made the first Russian commercial delivery of Arctic offshore oil from the field in eastern Barents Sea. The list of suppliers includes Aker Pusnes and Hydramarine (offshore oil shipment system), Oslo branch of Siemens (all generators), Frank Mohn (fire extinguisher pumps), Øglænd systemer (cabling supports), Autronica (fire and gas alarm systems), Aker MH and Gann Mekaniske (drilling equipment). The leading Norwegian producers of offshore oilfield equipment, Aker Solutions and Kvaerner, ran the technical audit of the Sevmash shipyard in Severodvinsk (north of Archangelsk) where the platform was constructed. Global Maritime from Stavanger towed the platform from the shipyards in Severodvinsk to Murmansk and later on to the field in Fall 2011. The two multifunctional icebreaking supply vessels which support the platform, Yuri Topchev and Vladislav Strizhov, were designed by Moss Maritime, and their topsides were mounted in Havyard shipyards. Altogether, Norwegians were awarded contracts worth 25 per cent of the total value of supplies to Prirazlomnaya (Ramsdal, 2013).

Finally, in the end of July 2014, the Norwegian company Seadrill has signed a USD 4.25 bill agreement with Rosneft for leasing 6 offshore rigs throughout 2022 for its offshore operations. Rosneft has also committed to buy shares in North Atlantic Drilling (a subsidiary of Seadrill). The deal came right before US and EU imposed sanctions that aim to prevent export of equipment and technologies for deep-water and arctic production to Russian companies.

Examples above demonstrate that Norwegian supply industry has already entered and positioned itself on the Russian market. This gives a good departure point for increasing the Norwegian and Russian cooperation for deliveries to the Arctic Continental Shelf and involvement of the supply industry in Russia and in Norway in the large petroleum projects. Development of O&G fields in the Barents Sea is considered to be a great opportunity for both Norwegian and Russian companies. However, solutions developed by major petroleum companies, central and regional authorities will have consequences for business strategies of supply companies both in Norway and Russia, especially those which are located in the High North regions. One concern is that O&G projects in the High North will not create regional spin-offs because regimes will be created which will not favor local/regional suppliers. For instance, above-mentioned examples also demonstrate that well-established supply companies mostly do supply deliveries and operations in Russia and not many of those have HQs in the Northern Norway.

**Barriers for Norwegian-Russian O&G supply industry cooperation in the High North**

Important challenge here is that smaller and less internationally experienced suppliers located in the High North may not be able to quickly develop adequate capacities, technological competences, track record and financial strength which would match the requirements of contracts related to the petroleum projects in the High North. Those contracts are expected to
be larger in terms of volumes, scope and complexity, as well pose as exceptionally high requirements for performance standards, warranties, and quality assurance. In this sense, the concern is that contracts will fall into hands of more experienced international suppliers operating from already established international hubs outside the High North and in this way result in little engagement of and contracts for suppliers located in the High North (Nordområdeutvalget, 2013). The latest major Russian oilfield development, Vankor, located in a remote area of North Eastern Siberia, is a clear example. With 430,000 b/d of crude production in 2013, it stands for some 13.5% of the gross regional product, but less than 0.5% of employment. Neither the local workforce nor manufacturing enterprises were ready to work for the oil industry. As a result, each $100 worth of investment in upstream production in the region have only brought about $3.2 of investment in the local supply industry. In Norway, the development of Snøhvit offshore gas field in the Barents Sea (2002 – 2007) has been probably more successful in terms of local and regional effects (e.g. project reversed a negative population and employment trend, growth of residential construction and municipal taxation base, improved public infrastructure). However, deliveries from the local contractor industry still represented only 5% of the total volume of deliveries in the construction phase (Nilsen, 2012).

Petroleum companies can employ various mechanisms to influence engagement of supply industries in the petroleum projects and, in this sense, contribute to regional industrial development and international business cooperation. One such mechanism is a local content policy that may give preferences to particular kind of suppliers. For instance, Shtokman Development AG has developed a local content policy that prefers Russian (especially regional) suppliers under conditions that their experience, costs, delivery time are comparable to international supply companies. Such a policy may provide incentive to Norwegian supplier opportunity to enter the Russian marked through a close partnership with Russian companies (Bourmistrov and Mineev, 2011).

Another mechanism that petroleum companies can employ to develop industrial cooperation is through interaction with regional supplier associations/networks. There are interesting examples of how Norwegian Statoil has developed regional supplier associations in Norway (e.g. PetroArctic in the Norwegian High North in relation to development and operation of the Snøhvit gas field) and in Russia (Murmanshelf in Murmansk region and Sozvezdye in Arkhangelsk region). Those associations represent platforms that can function as areas of coordination between regional supply companies, national and international petroleum companies as well as local and regional authorities for O&G project development (Mineev, 2011).

Intensified cooperation between Norwegian and Russian companies of the supply industry located in the High North through already established platforms and arenas can be quite beneficial. One benefit can be a synergy effect to be gained between Russian and Norwegian companies. For instance, diversification of procurement risks and improved product and service quality can be achieved by the combination of technological competence and knowledge of local market conditions and specifics of regional and national legislation on both sides of the Norwegian-Russian border (Bourmistrov and Mineev, 2011). However, given the potential, practice shows that it is difficult for Norwegian companies in the supply industry to form committed and close partnerships with Russian companies and vise versa. Research demonstrates that “joint ventures” between Norwegian and Russian companies in the supply industry – in theory as a most favorable partnership form from perspectives of taking advantage and transfer of market knowledge to the respective partners and sharing of
investment and operational risks – is rarely used by Norwegian companies when operating in Russia (Borge, 2014).

For the Norwegian side, differences in company size, in management and business cultures as well as governmental regulation complicate cooperation (Skretting, 2011). Based on the study of Norwegian supply companies and their entrance and operation in Russia, Borge (2014) concludes that Norwegian companies tend to operate in the Russian marked through two major forms. They do it either through organizational form with no physical presence in the market and possession of market knowledge by trading through a local intermediary or a representative office, or through investing in the market with a with wholly owned ventures requiring physical presence and extensive knowledge about the market. Major constraints for Norwegian companies for doing business in Russia is to adapt and confirm to 1) the Russian business culture and 2) Russian red tape. Those trading in the Russian market act strategic avoidant towards these constrains as they avoid own confrontation and substitute lack of knowledge about these constraints by engaging an intermediary, and are thereby acting risk-averse. Those companies investing in the Russian market attempts to adapt to these constraints and are rather risk takers.

Thus, a “joint venture”, where risks and commitment to business are shared between partners, is not preferred partnership form in the supply industry. One reason can be that the Norwegian supply industry is still just in the phase of discovering Russian market that was so far rather limited for Norwegian offshore technologies. There is also very mixed experience of companies from other nations and industries which tried to set up joint ventures in Russia. Forming joint ventures may require even more time in order to build firsthand experience operating on the market, positive history of cooperation with local actors and learning through unlearning of well-institutionalized beliefs and myths about managing in Russian context (Svishchev, 2011).

There are several reasons for low international partnerships (and slow internationalization) of Russian companies. On the one hand, internationalization and international partnership can give Russian companies with unique products and service a rapid access to new markets and customers and in this way diversify the typical risks of doing business in Russia e.g. dependence on bureaucracy and few but big Russian petroleum majors (Marchenko, 2010). Such companies will be welcomed in not only Norway but also e.g. Brazil, China, India. When it comes to opportunities in Norway, the Norwegian Continental Shelf (NCS) has open also for Russian offshore companies to bid. However, this required a prequalification in a unified system “Achilles Joint Qualification System”8 (handling Norway and Denmark) that put rather strict requirements on companies to adopt and follow different international management standards. As of today, only six Russian companies are registered in the Achilles system; only two of those companies are located in the High North (see Table 4.2). For comparison, only eight Russian companies registered in the prequalification system for UK (FPAL), and only two companies are registered in both systems. As seen from Table 4.2, other European countries have much high level of presence in the “Achilles” system and therefore with potential for contracts on the NCS then Russian companies.

This may indicate that entering the NCS may represent a challenge for Russian companies to introduce international practices related to e.g. design principles, HSE standards, quality management standards, accounting standards to name a few. For instance, it may take considerable effort to learn new tendering procedures given the fact that tendering systems in Norway and Russia have quite different practices (Uzdenov, 2013). Thus, despite that

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adoption to international business practices can also give production efficiency gains to Russian companies, internationalization may also impose considerable organizational costs.

The former Soviet Union was generally self-sufficient in terms of oil&gas equipment and oilfield services, but the economic turmoil in the ’90s delivered a heavy blow on the industry. First, the domestic market collapsed. The newly established Russian oil and gas companies suffered permanently from a lack of cash and had to cut drastically on all expenses, including notably exploration, field development and partly even maintenance. Second, several Russian newly-born majors (like Tyumen Oil Company, YUKOS or Sibneft) singled out their oilfield service units into separate legal entities and sold them as non-core assets, exposing them to harsh competition. Third, the dramatic foreign trade liberalization allowed the global supply industry leaders like Schlumberger or Halliburton to make a strong entry into Russia (and even more so to other FSU countries).

| TABLE 4.2. HERE |

This trend was reinforced by the heavy influx of foreign investments, as international oil companies tended to rely heavily on their worldwide suppliers, being generally reluctant to place orders within the country. According to some estimates, foreign companies now hold about 65% of the Russian oilfield service market. Thus, the Russian supply industry has to tackle the same challenge nationwide as the North Norwegian industry faces in the regional level: to get a stronghold in the local market first. Over the past few years, the issue has enjoyed a high political priority with Russian authorities, who have set the goal to increase the domestic production of offshore equipment dramatically in order to meet the challenges of developing the Arctic seabed.

This being said, it is evident that the two nations could gain much benefit from combining their efforts in the High North, whereby certain goods and services for any Barents Sea projects (on either side of the delimitation line) could be delivered by Norwegian suppliers, and others by Russian ones. Norwegian companies can still enter the Russian side of the Barents Sea projects through partnership with or direct deliveries to the Russian companies. In turn, Russian supply companies don’t need a prequalification in the Achilles JQS to deliver to the projects on the NCS as long as they can deliver or make partnerships with Norwegian supply companies. As long as Norwegian and Russian companies can achieve some level of joint harmonization in routines and processes, this can be a feasible opportunity.

Moreover, this opportunity is there. Moving towards exploration of hydrocarbons in the Barents Sea requires a revision of all existing international standards for O&G industry because not many of those standards reflect or are developed for the special context of the Barents Sea. In 2005, Norway launched international Barents 2020 initiative, supported among others by Russian government agencies and O&G companies, to formulate recommendations for acceptable standards for the difficult area of the Barents Sea based on the analysis of the best available industry practices for offshore operations. The initiative has already made a considerable progress and even proposed amendments to those standards (Barents 2020, 2009). Such a pioneering work can lead to harmonization of practices and standards especially between Norwegian and Russian companies for safe exploration, production and transportation of oil and gas in the Barents Sea. Thus, adoption of those standards by Norwegian and Russian supply companies can provide important competitive advantage for closer industrial cooperation. Several projects are underway. One such project is RU-NO Barents project[^9] administered by INTSOK that focuses on the analysis of the arctic

[^9]: [http://www.intsok.com/Market-info/Markets/Russia/RU-NO-Project/About-RU-NO-Barents-Project](http://www.intsok.com/Market-info/Markets/Russia/RU-NO-Project/About-RU-NO-Barents-Project)
challenges, identification of best available industry capabilities and assess of the technology and solutions currently available and the technology and solutions needed for extracting oil and gas resources in the Barents, Pechora and Kara Seas. The project can result in a roadmap to innovations and further technological developments that can favor Norwegian and Russian industry cooperation and partnerships.

From this analysis, it is possible to conclude that forming committed partnerships and a more extensive cooperation between Norwegian and Russian local suppliers is possible but still a challenging task. Building a comprehensive cooperation strategy requires a clear understanding of what the competitive advantages of different companies are in a partnership (Skretting, 2011). Development of common understanding, standards and technological solutions needed for safe operations in the Barents Sea can provide an important foundation for such a competitive advantage to Norwegian-Russian industrial partnerships.

*Effects of Ukrainian crisis and introduction of Norwegian sanctions on Norwegian-Russian B2B cooperation*

On August 11th 2014, the Norwegian Government has announced that it joint EU’s and US sanctions against Russia. Particularly, it introduced restrictions on export of Oil&Gas technologies to Russian offshore petroleum sector projects. Export of technologies for oil exploration and production for deepwater, Arctic as well as shale oil project has become forbidden. Any other products or technologies for Russian petroleum industry should receive a prior permission by the Norwegian authorities. Prior approval is also required for any financing or service operations related to those products or technologies.

It is still unclear to what extent those sanctions will affect other areas of industrial cooperation such as gas technologies or engineering. There are also some uncertainty regarding interpretations of what the concepts of “Arctic” and “deepwater” technologies means. There are also some possible complications for Statoil because it is registered on the New York Stock Exchange and therefore can be forced to follow American rules and interpretations of sanctions.

Observers differ in views on the possible impact the sanctions. According to estimates by Bank of America Merrill Lynch, the Russian oil industry may lose up to $1,000bn of investments. With no access to advanced upstream technologies, the oil production will soon start decreasing by 1.5 per cent per annum due to the depletion of old fields, but this figure may well be minus 3 to 5 per cent, bringing about a loss of between $27bn and $65bn by 2020.

Standard & Poor’s on its part is of the opinion that most of the equipment which is hit by the sanctions, may well be produced domestically or imported from countries which have not joined the sanctions, notably from China. Oil pipes are a good example, as they are also in the list while Russia itself is a major net exporter of high quality pipes. As for the Arctic, deep sea and shale exploration & production, their contribution to the Russian upstream operations is so far marginal. The respective projects had either been already launched before the sanctions.
were imposed (like Rosneft-ExxonMobil drilling in the Kara Sea), or may be postponed – some of these like Shtokman had already been stopped well before the sanctions because of high production costs. However, S&P mean that a downgrading of the Russian sovereign ratings plus restricted access to the global capital markets may cause trouble.

Inside Russia, the discussion is heavily influenced by a broader policy context. Pro-western experts and media quote gloomy American forecasts and highlight the need for Russia to have free access to international markets and technologies. To the contrary, the government, patriotic-minded observers and national companies tend to believe that the sanctions may be overcome and represent a good reason to modernize the industry (in the same way as Russia’s own food sanctions against US, EU, Norway and Australia are supposed to give a boost to the domestic agriculture). However, all parties to the debate view sanctions as non-productive and harmful for both sides.

Summary

The aim of this chapter was to describe the status of Norwegian-Russian B2B cooperation in the petroleum industry in the High North including both major petroleum companies as well as companies in the supply industry in both countries. Below we summarize driving forces and major factors that promoted and limited the scope of cooperative development in the petroleum industry on the Norwegian and Russian sides.

Possible points to highlight in the summary:

- Cooperation between petroleum majors in Norway and Russia is based on reciprocity of interests: exchanging access to resources for access to offshore technologies
- Norwegian companies have goodwill and positive image in Russia which is reinforced by positive experience of cooperation
- Russian petroleum companies are moving into the NCS and there are already committed partnerships between Norwegian and Russian petroleum companies
- Norwegian supply industry has intentions to get even bigger part of expanding Russian O&G market (even though the Russian offshore equipment market appears to be smaller compared to Norwegian but it may bring about much higher margins). However, direct delivery is a generally preferred strategy for making business rather than development of committed partnerships/risk sharing with Russian companies
- Russian supply companies are not well positioned in the Norwegian O&G markets and face international competition on both markets
- Preferential treatment of Russian suppliers through procurement policies by petroleum companies’ side can improve internationalization of Russian companies, but it will any way require that Russian companies update their manufacturing systems towards international standards
- Joint Norwegian-Russian industrial projects aiming at reviewing and improving standards for O&G operations in the Barents Sea can provide unique opportunities for harmonization of Norwegian and Russian practices and give “first mover advantage”

Conclusions: input to scenarios

We end the chapter by providing input for scenarios for future development of the industrial cooperation based on opportunities that are opened up by the delimitation line treaty in the Barents Sea.
Assumptions (certainties)

- It is in the natural interest of both Russia and Norway, as the only two countries sharing the Barents Sea, to cooperate in meeting the common challenges of the area, e.g. exploration and development, environmental protection, resource management, promoting regional value creation and employment.
- This being said, the 2010 Murmansk Treaty realistically urges both countries to go ahead in exploring the delimited shelf area on their own, and cooperate only when the other party can prove that a field is transboundary.
- Arctic will remain high on the political agenda for all circumpolar countries and for China. China will in turn be an increasingly important partner for Russia and Norway, both in economic and political terms.
- Active oil&gas development offshore Barents Sea is a necessary, but not the only precondition for Russian-Norwegian petroleum-related industrial B2B cooperation onshore.
- US and EU introduced economic sanctions against Russia, Norway follows, albeit selectively.
- Western/Norwegian companies have secured a business portfolio in Russia (and Russian in Norway) before western sanctions have taken place and will probably continue to carry out their business commitments.
- Introduced sanctions will be followed strictly by both the Norwegian government and companies and this will limit a cooperation space.

Uncertainties

- How active and efficient will both Russian and Norwegian authorities be in promoting:
  - petroleum-related industrial investments in the coastal Barents Sea regions,
  - cross-border Russian-Norwegian B2B and people-to-people contacts (creating cooperative institutions, lifting administrative and cultural barriers, etc.)
  - institutionalization of results from cooperative initiatives to harmonize business practices and standards
- Will US, EU and Norwegian sanctions against Russia especially in terms of transfer of offshore and Arctic oil & gas technologies be lasting enough so that it will changes attitudes of Norwegian and Russian enterprises to do business with each other negatively? If the sanctions last, how fast will those widened to hit Russian companies’ operations outside Russia?
- Sanctions or no sanctions, will Russia allow for direct foreign investments in developing its Arctic offshore fields? If so, how actively will Norwegian companies pursue these opportunities?

Outcomes

- Will the main locus of cooperation switch from RCS towards NCS?
- Will Russian companies focus cooperation in the NCS because it can give access to technologies bypassing the export sanctions or focus more on the RCS in isolation and development of technologies and competence needed on their own?
References


CHAPTER 5

Norwegian-Russian Political Relations

INDRA ØVERLAND AND ANDREY KRIVOROTOV

(FORTCOMING)
Part 3

Technology and the Natural Environment
List of abbreviations used in the Part 3

1P, 2P, 3P, 1C, 2C, 3C Resource classification by the PRMS (Petroleum Resources Management System, SPE, Richardson, Texas, USA, 2007)

Aulacogen Intraplatform linear movable area in the form of a deep narrow trough bounded by faults; usually a combination of trough–graben and uplift–horst

Base of the reservoir Lower part adjacent to the underburden formations

Bitumen shows Minerals of organic origin with primary hydrocarbon base, occurring in solid, viscous and visco-plastic state. From a genetic point of view, they include oil, natural fuel gases, gas condensate, and natural oil derivatives (malthas, asphalts, asphaltites, kerites, humic-kerites, ozokerites, anthraxolites etc.) and their analogues (naphthoids)

BNKMT Barents-North Kara mega-trough

DOM Dispersed organic matter

Dry gas Gas characterized by predominance of methane in the composition, relatively low content of ethane and low (up to 1%) content of heavy hydrocarbons

EUR Expected Ultimate Recovery

FDA, FDZ Former Disputed Area / Zone

Heavy oils Oil with density higher than 0.860 g/cm³; usually 0.82-0.95 g/cm³ (below 0.83 the oil is called light, 0.831-0.860 – medium)

HJR Hjalmar Johansen Ridge

Ma Million years

NCS Norwegian Continental Shelf

ORF Oil Recovery Factor – a numeric expression of that portion of in-place quantities of petroleum estimated to be recoverable by specific processes or projects, most often represented as a percentage or a fraction

P90, P50, Pmean Proved, Probable and Mean resources. Measure of uncertainty, or maturity of resources. Described in details in PRMS publication (Petroleum Resources Management System, SPE, Richardson, Texas, USA, 2007)

PPR Possibly Petroleum Region

PR Petroleum Region
<table>
<thead>
<tr>
<th><strong>PRMS</strong></th>
<th>Petroleum Resource Management System, described by SPE/AAPG/WPC/SPEE (Petroleum Resources Management System, SPE, Richardson, Texas, USA, 2007)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rift trough</strong></td>
<td>The process of emergence and development in the earth crust of strip-like continents and oceans in plain zones of global-scale horizontal extension</td>
</tr>
<tr>
<td><strong>STOOIP</strong></td>
<td>Stock Tank Oil Originally In Place – the total in-place quantities of petroleum that are estimated to exist in naturally occurring reservoirs expressed at standard conditions</td>
</tr>
<tr>
<td><strong>Synclise</strong></td>
<td>Very gentle deflection of the earth crust within the platform, having irregular rounded or oval contours (up to several hundred, sometimes more than a thousand kilometers in diameter) and the depth usually up to 3-5 km (less often – deeper)</td>
</tr>
<tr>
<td><strong>TOE</strong></td>
<td>Tons of oil equivalent</td>
</tr>
<tr>
<td><strong>Top of the reservoir</strong></td>
<td>Upper part adjacent to the overburden formations</td>
</tr>
<tr>
<td><strong>UCube</strong></td>
<td>Upstream Cube, an Internet-based software, developed by Rystad Energy, a Norwegian company</td>
</tr>
</tbody>
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CHAPTER 6

Structure of the geological section and the main oil- and-gas content features

MARK L. VERBA, GENNADY I. IVANOV AND ANATOLY B. ZOLOTUKHIN

Geological zoning of oil and gas fields

Hydrocarbon potential of the Barents sedimentary basin, despite longstanding studies, hasn't been implicitly brought to light yet. In 1935 I.F. Pustovalov based on first discoveries in Polar Urals, Novaya Zemlya and Frantz Joseph Land for the first time mentioned possible hydrocarbon accumulations in the eastern part of the Barents Sea shelf (Pustovalov 1936: page number if possible).

I.S. Gramberg in 1966 used the regional geophysical data, that threw light on the Barents Sea, as a basis for the first quantitative evaluation of the Arctic shelves' hydrocarbon potential, of which the Barents shelf was highlighted as the most promising.

At the same time the prospecting until recently was limited by the southern border of the basin and only in patches covered its central part (Verba 1999: page number if possible). Since 1972 the activities have been carried out on a regular basis due to establishing in Murmansk City the first specialized geological and geophysical entity (K Mage, and later MAGE JSC), that started systematic geophysical surveying, oriented on searching areas suitable for subsequent oil & gas prospecting drilling. In five years more than two dozens of such areas have been found, but only after the discovery of the onshore oil deposit on the Kolguiev Island (first area outside the continental part of the Pechora Province) the drilling operations have been started. Above operations resulted in discovery of several gas and gas-condensate deposits in the South Barents Basin, including the discovery of huge Shtrukman Field. Above discoveries demonstrated that practically the entire Barents shelf area is promising in terms of its oil-and-gas content, although to different extents (Verba 1999: page number if possible).

The Barents Shelf geological structure key feature, which was steadily identified as a result of performed regional geophysical surveys, is the pervasive development of thick Jurassic-Cretaceous sedimentary cover, that superposes older undisturbed sedimentary sequences. This allows to consider such shelf as a typical coiledogenic structure and distinguish it as a unified shelf plate. Geological and geophysical data that had been acquired during recent decades by the researchers from different states and entities over the Barents Sea aquatic area and its framing were integrated into tectonic map 1:2500000, that illustrates the entire Barents-Kara Region (Khain 1978: page number if possible; Verba and Ivanov 2009: page number if possible) (Figure 6.1.).

Together with the part of island and mainland framing, including the Svalbard Antecline (except the Alpine dislocation zone on the island of Spitsbergen west coast), Grumant Anticline (FJL), Pechora Lowland and also the Karmakul Trough of the Novaya Zemlya, this
plate corresponds to large oil & gas province, which main structural and oil-and-gas content features comply with trends, that are unified for it. According to the majority of geologists’ viewpoint there are two groups of areas within the Barents Province. One area includes the Pechora sineclise, Svalbard and Central Barents anticlines, as well as Prinovozemelskaya and Kola-Kanin margin monoclines. The structure of the above areas includes practically the full set of Phanaerozoic sedimentary formations. The other group of areas includes the West Barents, South Barents, North Barents and East Barents rift depressions, composed of Late Paleozoic - Triassic complexes of terrigenous deposits (Figure 6.2.).

All nine areas (commensurable among themselves in terms of area), mentioned above, are subdivided into several regions. Moreover, one of such areas - the Ludlov Saddle, due to its specifics was suggested to distinguish as a separate region, not included into any adjoining area.

Present-day ideas on the potential oil-and-gas content of different regions and areas of the Barents Sea, and in general on geological zoning of the shelf are based on the results of numerous surveys. The majority of above researchers share the opinion that Barents shelf plate, as a coherent geological structure, along with adjoining onshore areas shall be considered as a unified oil & gas province (sometimes it is suggested to call it mega-province), which integral areas have common geological section features and commensurable specifics of distribution of HC deposits and/or their attributes.

**Promising regions located on the Barents-North Kara mega-trough framing**

All five petroleum regions, located on the Barents-North Kara mega-trough (BNKMT), to some extent are highlighted by the normal geological and geophysical profiles, which give rather good indication of the structure of sedimentary cover. Such geological and geophysical profiles, being comprehensive, comprise the national deep-profile and deep wells control network, and served as a base frame for correlation of intermediate seismic profiles, previously acquired on the Barents Sea aquatic area. Availability of numerous intermediate seismic profiles allowed interpreting volumetric data, acquired from the reference network of profiles.

We had to take into account that information, that has been published over the recent 1.5-2 decades, due to understandable reasons, has lost its specifics, which is necessary for comprehensive assessment of hydrocarbon potential of areas under the discussion and therefore we had to use previously acquired data, which is still valid.

**Pechora Petroleum Region**

General idea regarding the structure of Pechora Petroleum Region sedimentary deposits and general trend of gradual downwarping eastward of Pechora plate folded basement, which sometimes is unreasonably called as sineclise, can be given to us by the fragment of reference profile 3-AR, acquired by the SEVMORGEKO Company (Figure 6.3.). Figure shows a full set of Phanaerozoic deposits, which thickness is gradually increasing from hundreds of meters to 8 km from West to East in the direction of Korotaiikhin Trough. Structures located to the West from Pechora-Kolvin aulacogen are identified as the Pechora basin, which is traced on the Barents Sea shelf as a Kola-Kanin monocline. Buried Bolshezemelski anticline (along the

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13 In regard to the geological zoning of the Barents Sea oil fields, in general, Russian and Norwegian researchers haven't built consensus yet: each country tries to highlight its own province, and to some extent it is reasonable, but in this case vast area of the Barents Sea, while being surveyed and HC resources, being developed, may become a conglomerate, consisting of a dozen of provinces.
sitional cover - Khoreiver Depression) and Varandei-Adzva structural zone, which includes Varandei and Medyn swells are located to the East from the aulacogen. Korotaikhin Trough, logated further to the East, in terms of its structure, is considered as a separate geological structure, although according to approved geological zoning of oil fields it should be attributed to the promising region under consideration (Belonin et al. 2004: page number if possible).

Oil and gas shows can be found within the Pechora Lowland practically along the entire cross-section of sedimentary cover – from Vendian through Cretaceous horizons, however the majority of valuable deposits are concentrated in much narrower interval of the cross-section - from mid-Devonian to Lower Permian, provided that even that part of the cross-section in terms of its producibility is nonuniform. During the Pechora Petroleum Region studying, which started in the last century, a lot of factual data was acquired and published in numerous works, where the present day vision of main trends, relating to vertical and lateral distribution of petroleum deposits, is totalized.

Hydrocarbon accumulations of different size are occurring practically within the entire sedimentary cover cross-section, but the oilers are mostly interested in mid-Devonian sandstones (sub-domannik complex) and Upper Carboniferous-Lower Permian carbonates (Borovinskikh 2003: page number if possible; Belonin et al. 2004 : page number if possible). The lower from above horizons accumulates nearly 75% of all commercial reserves of oil, while the upper from above horizons accumulates nearly 35% of explored reserves of gas and 20% of oil. More older deposits do not play significant role in total balance, and all in all their attribution to platform features is questionable.

Within lateral series the majority of reserves are clearly confined to the central zone of the plate, which coincides in the plan with line structure of Pechora-Kolvin aulacogen. Up to 62% of all HC resources of Pechora Petroleum Region are accumulated in that zone. From the South to the North the producing portion of the sequence is "rejuvenating" due to emerging pools in the Mesozoic deposits and decreased number of pools in the mid-Paleozoic, as well as due to decreased specific gravity of oils and replacement of oil pools with gas-oil and gas-condensate pools.

According to the estimates of V.N. Makarevich and his colleagues (Makarevich et al. 2000: page number if possible) nearly half of the initial total in-place resources of Timan-Pechora Petroleum Region (7.3 bln toe including 4.4 bln t. of oil) will be found on shelf. Highest estimates are given to areas adjoining the framing of aulacogens and to extensions of mobile swells, such as Kolvin, Sorokin and Medynski.

Vertically, as a rule, we can see the general trend, when heavy oils, downsection, are replaced with lighter ones and more saturated with gas, while the gases, on the contrary become heavier with depth and are enriched with heavy hydrocarbons (Anischenko et al. 1968: page number if possible; Dediev 1992: page number if possible). At depth less than 1.2 km one can find only heavy oils, below that depth down to 1.2 km moderate-heavy oils are dominating, at larger depths down to 4.0 km more frequently one can find light oil, and below 4 km nearly everywhere there are gas condensates, while light oils are occurring more rarely.

Extrapolation of trends related to oil-and-gas potential three-dimensional localization, which were identified at Pechora lands, were supported by discoveries of hydrocarbon deposits in some shelf areas, where the main structural elements of the Pechora Lowland can be directly
traced. Shelf extension of Pechora-Kolvin Swell is of special interest in terms of prospecting hydrocarbons (Makarevich et al. 2000: page number if possible). Up to 40% of explored reserves of oil and 74% of gas were discovered there.

Pomor and North Pomor brachy-anticlines are intersecting at the extension of Kolvin Swell. Above anticlines were the first local structures prepared for exploration drilling even in the early 70s. At Pomor anticline the gas pool was penetrated by drilling the Carboniferous deposits. Distinctive feature of that pool is the extremely high content of hydrogen sulfide (up to 8.5%), which obstructs the development of above pool.

Shelf extension of Shapkin -Uryakhinski Swell is traced not so clearly. It is linked up with Kolokolmor local high, and possibly Peschanozernoye high, where the first in the Barents Sea oil pool was discovered in Triassic deposits.

Peschanozernoye Oil Field is located on the northern coast of Kolguyev Island and is the first structure in the Barents Offshore Region, where the commercial oil inflow was obtained (Desyatkov 1993: page number if possible). Above structure comprises a dome-shaped fold of small size, which is well-shaped within Triassic deposits, although supposedly the structure is developing from Silurian deposits. The most full Paleozoic sequence was accessed at Pechanozerny area (down to Ordovician deposits, inclusively) with total thickness comprising 4.5 km. Studying of that sequence showed that forming of trap occurred inheritedly until the end of Triassic age.

Hydrocarbon inflows were obtained in rocks, varying from Triassic to Carboniferous, however only in the upper portion of the sequence they were of commercial value (Lower Triassic). Oil, gas and gas condensate were recovered in different proportions from that horizon. The oil has low sulfur content, low tar, with paraffins, and with high yield of light distillates. Density - 0.776 g/cm³. Oil recovered from the Upper Carboniferous deposits is heavier - 0.84 g/cm³. Condensate recovered from the Lower Triassic horizon has density, comprising 0.720 g/cm³ and 14% content of volatile (less than 100ºC) fractions. The gas is methane, nitrogen-methane. The pool can be attributed to flat sheet and roof deposit. Sandstone members with porosity up to 24-27% interbedded with siltstones and overlapped by the pelitic impermeable bed comprise the reservoir. The field is characterized by low elastic water drive, relatively low temperatures (36-41°C) and relatively low flowrates of wells (56 t/day on average.) under GOR comprising 130-500 cub. m-t.

Sorokin Swell is extending on the shelf area as a chain of local folds, integrated into Gulyaev Swell. North Gulyaev, Bolshegulyaev, East Gulyaev, and Prirazlomnaya local folds and a group of small domes within the Varandei Area are separated within the Gulyaev Swell. Oil & gas pools were penetrated by drilling within Upper Paleozoic deposits at three areas, mentioned above (Varandei-More, Prirazlomnnoye and North Gulyayevskaya).

Prirazlomnoye Oil Field in terms of its structure can be attributed to the northern extension of Sorokin Swell. The trap comprises the brachy-anticline fold, well-shaped along the entire studied sequence, from Silurian to Triassic deposits. Area of the structure comprises nearly 100 square kilometers, amplitude - 130 m, western leg is dislocated by the fault with amplitude up to 200 m. The oil pool is confined to porous Lower Carboniferous limestones, occurring at 2370-2487 m. The porosity of rocks is decreasing downward from 23% in the top of the reservoir to 5% in the base of the reservoir. The pool is massive, with bottom water at 2456 m. Oil is heavy (density - 0.92 g/cm³), resinous, with high sulfur content, and by its composition is similar to oils from other oil fields on Sorokin Swell.
The most eastern, among the prospecting structural zones of Pechora Lowland, is the Medyn Swell and it was traced at shelf as a strip comprising a set of local highs (Medyn More, Medyn 1 & 2 etc.). There are other structures on the shelf, like North Dolginskaya, Polyarnaya, Russkaya, Veltov, Sengei, Akvamarin and East Pechora, that do not have express links with II Order positive structures, mentioned above, and which haven't been explored through drilling (Figure 6.3).

*Kola-Kanin Petroleum Region*

Kola-Kanin Petroleum Region (PR) is the boundary region as a part of the Barents Province structure and can be traced as a long narrow strip along its entire southwest boundary from Pechora River to Finnmarken. In terms of structure it comprises a system of monoclines and asymmetric depressions, separating the Barents Shelf plate from the slopes of Baltic Anteclise and Timan Ridge. Kola-Kanin PR in the South includes Izhma-Pechora depression (stage) and Malozemelskaya Monocline are separated by the Seduyakhinski-Korgin mega-swell. Kola-Kanin PR also includes the Kola-Kanin Monocline, with Kola Swell in the North and linking with Finnmarken Monocline in the West (Figure 6.1., 6.2.).

This region among other PR of the Barents Province is characterized by better exploration status, using CDP seismic methods. Synthesis of above notions was performed, when plotting the tectonic map of the region (Verba and Ivanov 2009: page number if possible).

Kola-Kanin PR is mainly formed by the Paleozoic sedimentary complexes. In lower horizons the Tremadorian-Sedvelian and Ordovician-Nibelian series can be identified. Within the Kola shelf the Paleozoic deposits are underlying as undisturbed upper Riphean-Vendian deposits and they are partially overlapped by the Mesozoic sedimentary cover. Thickness of sedimentary cover rocks within the PR is rapidly increasing from hundreds of meters in the boundary zone to 6-8 km on the border with South Barents Depression. At the same time the Upper pre-Cambrian sedimentation mass, comprising here the basement of supracrystal complex, plays an important role in the sequence. Unlike the Kanin Peninsula sequences, where the entire rock mass of Neoproterozoic deposits is strongly disturbed, the deposits of that age occurring in the area, surrounding the Rybachi Island, are deformed much less and they are occurring subhorizontally.

Direct indicators of oil-and-gas potential within the area under consideration were identified in the Izhma-Pechora Depression, in the sequence, where the petroleum deposits were found within wide stratigraphic range – from Lower Devonian to Upper Permian and also at Finnmarken shelf. In other PR locations there are few indicators of oil-and-gas potential (Simonov et al. 2001: page number if possible). Mid-Paleozoic (Upper Devonian - Lower Carboniferous) deposits of Kontozer graben carry strongly metamorphosed bitumen of malt and adipocire type.

Upper Riphean deposits, rimming from the North pre-Cambrian metamorphosed deposits of Kola Peninsula carry some interbeds with extremely high content of organic matter and preserving the connate concentrations of HC.

Composition of gas extracted from above rocks indicates the presence of methane and heavy hydrocarbons in proportion 3.2:1 (Table 6.2.). Hydrocarbon gases, as a rule, are accumulated in porous (porosity up to 4%) sandstones, which testifies the migration origin of above HC. Oil & gas pool in Triassic deposits.
Prospects of discovering HC deposits relate both to old mid-Upper Paleozoic depositional complex and (to lesser extent) to Triassic complex. In addition we can consider that along with gas pool we have the same possibility to discover the oil pool. Some hopes are related to possible discovering of reef structures in Upper Devonian - Lower Permian carbonate rocks. The presence of such structures can be revealed based on seismostratigraphic analysis. (Ivanova 1997: page number if possible). K.Cosley and D.Tumei consider the presence of paleoappliniscin bioherms as quite realistic. If we assume (as it was mentioned previously), that barrier reefs are positioned in parallel to continental shelf margin and rim the edge of deep-water rift-related basin, then one strip of reef structures can be traced along the northern border of the region under consideration and which is broken in locations, where the terrigenous material is intensively withdrawn from the paleoland, while the second strip can be anticipated on the opposite side of the rift-related trough within the limits of of the Central Barents High.

Apart from that, within the limits of the region under consideration some anticline structures were revealed within the Upper Permian - Triassic terrigenous deposits, therefore petroleum pools of roof type can be found there. Above structures are located in two areas – on Kola Swell to the North from Murmansk City and on Korgin hemi-swell of Kanin Peninsula. Varyazh, Kurchatov and Rybachin dome-shape folds with area comprising 25-40 km² were delineated within the Kola Swell, while within the Korgin hemi-swell some smaller structures were delineated and which located as a chain along the hemi-swell sides. Gas chemical anomalies were identified, and they indicate the present-day migration of the methane, sometime enriched with heavy hydrocarbons. Despite the limited size of such structures, they are of some interest for prospecting and mainly perspective in terms of oil deposits, which can be discovered in carbonate Paleozoic complex at rather shallow depth.

Grumant Petroleum Region (PR)

Grumant PR, which in terms of tectonics corresponds to Svalbard plate, is quite nonuniform: In the West it adjoins the Cenozoic collision belt of West Spitsbergen, while the entire eastern framing is represented by the Barents-North Kara structures. Grumant PR covers the area of Spitsbergen and Franz Joseph Land archipelagos, the Persei underwater high and adjoining shelf shallow waters, extending to the South as far as Medvezhi Island and Nadezhda Island.

All stratigraphic Neogenic taxons, starting from Upper Riphean to Neogene with total thickness, comprising 7-8 km are available in the plate sedimentary cover sequence. The sequence of sedimentation mass is separated by the series of nonconformities, and the presence of such nonconformities testifies the repeated activation of tectonic environment (Haine 1978: page number if possible; Harland 1998: page number if possible; Verba 1998: page number if possible). Estimation of oil generation potential of that region is nonunique.

Stage of exploration of that region is quite nonuniform. Several wells were drilled within its limits and in many wells the shows of different hydrocarbons were encountered (Table 6.3.).

Devonian terrigenous complex will be the first sedimentary complex, if we look upsection, and its generation potential is considered as regionally tangible.

Oil shows related to that complex cover large area of archipelago. They were described at Torell Land in 1971 by L.G.Mukashev, and at Andrée Land by Yu.I.Mokin in 1972. (Krasil’ščikov 1996: page number if possible; Russian geological studies on Spitsbergen 1998: page number if possible), and the most complete observations were performed at Dickson Land. Upper Devonian deposits, accessed here in several wells, drilled in Pyramid mine camp surroundings, are characterized by increased impregnation. So, for example, in the core samples, taken from wells #.66, 68, 72, 74, 76 the sandstones saturated with oil were described. Above sandstone builds up the 5-12 m thick beds. Total thickness of the section saturated with hydrocarbons comprises nearly 120 m. Organic matter from enriched Devonian rocks, most likely, was the source of migrated fluids.

Impregnation of *Carboniferous* deposits was studied in detail in the Bille Fiord area, where the numerous HC shows have been encountered. Above shows were encountered in wells, where jet coring bit was used. Such wells were drilled on both sides of fiord, in the Mimer River Valley (to the West from the fiord) and also on the bank of Petunja River (to the East from fiord). The most valuable data was acquired from wells, drilled in the area of Ebba River.

Reservoir properties of Carboniferous reservoirs based on laboratory measurements of porosity and permeability were positive, regardless the pessimistic forecasts. We could identify four main types of porous-fractured reservoirs (Verba 2013: page number if possible).

Oil & gas generation potential of Carboniferous deposits is largely determined by the presence in the lower part of thick (up to 300 m) rocks enriched with organic matter and, if there are coal beds with reliable thickness. Organic matter catagenesis stage is increasing from West to East, from gas stage in the area of Triungen Town up to bituminous stage in the Pyramid Mine and coke stage in Gypsdalen. Wet gas in the carbonic rocks of Pyramid Mine and Petunia Bay corresponds to higher high-temperature stage of oil & gas generation stage.

*Triassic* deposits at Spitsbergen comprise the regional oil-and-gas bearing rock mass. Above deposits drive the majority of gas and bitumen shows.

Bitumen rock clay, solid bitumen and maltha were encountered in the Olenekian and Anisian Stage deposits at Festningsodden. In Sassen Fjord and Adventdalen similar shows were encountered in Olenekian, Anisian, Ladinian and Norian rock clay. Numerous oil and bitumen shows within entire Triassic geological section were encountered in Wiche-Bucht, Cape Murray, Ed. Wilhelm and Barents islands. Same shows were encountered in the Lower Triassic at Medvezhi Island, and in the Upper Triassic at Nadezhda Island. Impregnation of Carnian rocks was identified in the Grumant Well.

Gas shows in Triassic deposits were encountered while drilling wells named as Grenfiord, Ischegda, Tromsebreen and Grumant. Methane gas influx with flowrate 30-50 *thou.m*³/day were obtained in Wassdalen II Well and Haketangen Well. Gas influx in Tromsebreen Well is of interest since it was obtained at rather shallow depth, about 1000 m (Pentilla and Church, 1984: page number if possible).

Therefore there are two interesting aspects in the Triassic sedimentary complex: Complex is interesting both as a rock mass, which carries good reservoirs and, thus accumulating secondary fluids, and as an oil source rock.
Impregnation of Jurassic deposits is fully related to the rocks in the upper part. Homogenous clay rock mass of age from Oxford to Volgian universally carries an increased concentration of organic matter and bitumoid (0.6-5.8% and 0.2-0.6% accordingly). Composition of bitumen is indicative for syngenic bodies.

Lower Cretaceous deposits are characterized by the limited impregnation and increased gas saturation. On the bank of Gren Fjord, where the development of Aptian-Albian deposits can be observed, as well as in Erdman tundra and Adventdalen, the natural seepage of gas was encountered (Krasil’ščikov 1996: page number if possible; Russian geological studies on Spitsbergen 1998: page number if possible). In Norwegian well in Sassen Fjord, where jet coring bit was used, the gassing from Aptian-Albian deposits was observed during several years. The gas was methane, sometimes with heavy HC (up to 3.0%).

Paleogene sedimentary rock mass carries the oil pool, and was discovered in 1988 at the Lailen Area.

Oil indication in the Paleogene sandstones were revealed at Barentsburg Coal Mine in subsurface mine roadways, at Lailen, Grumant and Coalsbay sections in the coal exploration holes. Gas shows apart from areas, mentioned above, were also identified at Sars Cape, in deep well (Table 6.6.) on the northern bank of Van Mijen Fjord, as gas seepage at Serkap Land. At Geer Cape near Barentsburg the solid, wicked lenticular kerite was encountered in Paleogene rocks.

Oil & gas shows have been observed in 15% of coal exploration wells, where jet coring bit was used. Total number of such wells exceeded three hundred. Flares at wellheads sometimes burnt for several days. The most impressive oil show was observed at Well.561 at Lailen Area in September 1988. The pool was penetrated at 238 m from spud-in, 56 m upsection from the bottom of Barentsburg strata, and confined to porous sandstone interbed. The bottom of permafrost rocks could be the structural seal for the pool according to indirect data and geothermal observations in the well. Formation pressure hasn't been measured, but it provided a well-spring of oil, and the estimated flowrate comprised 6-8 tons/day, short-term gas burst were also encountered.

Crude oil comprised brown (with greenish cast) liquid, which rapidly solidified in case of temperature drop. In terms of its composition it was attributed to light oils, naphtheno-paraffin base crude, low tar, and low paraffin (Table 6.3.). Similar by their composition crudes are seeping from Barentsburg strata in mine driveway of Barentsburg Mine. Their flowrate comprises 30 l/day.

Composition of Paleogenic crude oil and its IR spectrum are nearly equal to crudes from Lower Triassic deposits at Kolguyev Island. Based on the results of liquid chromatography Paleogenic crudes are equal to crudes from mid-Triassic clay rocks from the Edge Island. Since the permafrost plays an important role in localising the oil pool at Lailen Area, then the migration process started in Neogene period continued nearly to Holocene.

Summarizing the statements from above, we should highlight that deposits, capable of generating HC, were identified within the wide stratigraphic range - from Upper Riphean to Paleogene, while the most prospecting rock masses are confined to Upper Devonian - Lower Carboniferous, Lower Permian, Lower-mid Triassic and Upper Jurassic - Lower Cretaceous deposits (Verba 2007: page number if possible).
If we spread above statements to adjoining, not explored in terms of petroleum geology aquatic areas of Spitsbergen shelf, then we can conclude, that the most promising in terms of oil generation are westernmost, perioceanic zone of PR and some central zones, like Olgin Trough, where the post-Cretaceous downwarping was the same strong (based on morphological data) than in previous periods.

Special position in that part of Svalbard "platform" is occupied by its utmost northern strip, which adjoins with deepwater Nansen Basin. Series of dome-shape structures was identified here at sub-oceanic depths (up to 2000-3000 m) in one of rift-related troughs of the Arctic Ocean (Brusilov Trough), applying different geophysical methods, (Verba V.V. et al. 2004: page number if possible). Above structures based on petrophysical data, acquired at FJL, as well as geothermal data (Verba V.V. et al. 2009: page number if possible) were interpreted as diapir folds(or cryptodiapir), formed by halogenic units. Presence of structures with saline domes in that part of the region allows to reconsider the perspectives of oil & gas potential of entire Eurasia Continental Margin (Verba V.V. and Verba M. 2007: page number if possible).

**Prinovozemelskaya Possibly Petroleum Region**

Prinovozemelskaya Possibly Petroleum Region (PPR) covers the strip of the shelf, adjacent to Novaya Zemlya Archipelago from the West, and which includes Admiralteiskoye High, Sedov Trough, Mezhdushar Monocline and Korotaikhin Trough (Figure 6.2.). The length of above PPR comprises nearly 1200 km, and the width - less than 150 km. The region under consideration can be clearly divided into two parts: South part (Korotaikhin) extends in NW direction and adjoins Pai-Khoi-South Novozemelsky section of the strip of Early Cimmerian folds; second -northern part (Sedov) of PPR extends along another section of Novozemelskaya strip of folds, which extend to NE and characterized with moderate infolded deformations. The interface between the above parts of PPR is located opposite to Karmakul Trough, which is formed by the Permian deposits, deformed even less than in the northern part of Novaya Zemlya.

Paleozoic rocks of Novaya Zemlya Archipelago were studied in terms of petroleum geology even in 30s of last century. N.A.Orlov, B.A.Alferov, N.N.Mutafi, I.F.Pustovalov have compiled first descriptions of bituminous rocks in different locations of Novaya Zemlya. More recent observations were performed by A.A.Petrenko, A.K.Krylova, E.M.Krasikov, R.A.Shekoldin, A.Z.burski, A.V.Ditmar, V.F.Nepomiluyev. Summarizing of above studies was done by B.A.Klubov (Klubov 1983: page number if possible). Within the limits of above PPR any oil or gas accumulations haven't been identified. However, acquired data testifies rather high probability of their discovery in Admiralteiski Swell. On oil & gas potential maps that region corresponds to aquatic area with density of predicted resources up to 30-50 thousand t/km$^2$ in the zones that are the most favorable for oil and gas accumulation.

The main potentially productive rock masses within the shelf geological section under consideration - are the Ludlov, Devonian and Lower Carboniferous carbonate rocks.

Therefore identified mineral tars mainly are secondary, moreover the migration, most likely, occurred at least in two stages. One stage, at a first approximation, can be compared with Triassic tectonomagmatic cycle, while the latter stage can be compared with Alpine activation. Laterally a link of less metamorphosed bitumens to zones with relatively low orogenesis can be noticed. Therefore we hope to discover oil bearing beds in Permian sandstones within the shelf area between the Admiralteistvo Peninsula and Mezhdysyar Island and in older rocks – Ordovician-Silurian carbonates, occurring between Schmidt Peninsula and Zhelaniya Cape. In terms of stratigraphy the megascopical bitumen shows occur more
frequently in Upper Silurian and Lower Carboniferous strata, and more seldom they occur in Devonian and Permian deposits and haven't been encountered completely in underlying, older units.

High degree of metamorphism of organic matter (semianthracitous stage, apocatagenesis), most likely, stipulated by intensive tectonic stresses, that earlier accompanied the Mesozoic orogenesis. In other regions of the Barents-Kara Area the degree of organic matter maturation is much less.

Therefore orogenesis at Prinovozemelsky Shelf exhibited much less, and organic matter, even in old mid-Paleozoic rocks, still keep its oil & gas generation properties.

Above statements may be used for approximate estimate of possible oil & gas discoveries within the Prinovozemelskaya Zone of boundary structures, located on shelf in the vicinity of the Novaya Zemlya shore. Within local structures, such as Pankratiev, Blednaya and Inostrantseva, identified in the North of Prinovozemelski Shelf, most likely, the most perspective rock masses will be mid-Paleozoic deposits. Possibility to discover petroleum deposits at such highs as Litke High, East Krestovski, Sulmenev, Martyushen, Gusinozemelski, West-Novozemelski and Mezhdusharski, located in the Sedov Trough and on the Mezhdushar monocline, is estimated as more limited. Moreover, most likely, the carbonate reservoirs within the Carboniferous deposits are the most promising. Overlying terrigenous Permian deposits seems to be less promising.

On local highs, such as Krestov, Admiralteiskoye and Pakhtusov, most likely the mid- and Upper Paleozoic carbonate complex will be the most promising.

So the significant number of bitumen shows, spread over the entire Novaya Zemlya coast for 1000 km, as well as doubled (at least) appearance of migration activity and availability of local structural traps on shelf - all of it testifies the high probability of available sedimentary masses, that are producible in terms of oil generation, and can be suitable for accumulation of hydrocarbon fluids within the section, from Silurian to Permian deposits (inclusively).

**Promising Regions of the Barents-North Kara Mega-Trough**

*Central Barents Possibly Petroleum Region*

The region under consideration in terms of its geological section attitude and abyssal structure and, probably, based on main features of oil-and-gas potential (not identified yet) is close to peripheral regions of the Barents Sea Petroleum Basin, which was considered above (Paleozoic terrigenous -carbonate rock masses play the key role in their structure). However, spatially the region under consideration is fully inside the Barents-North Kara Mega-Trough (BNKMT) and therefore formally should be considered as a part of that sub-province.

Similarity of geological sections and abyssal structure of the Central Barents Terrain and two platform blocks on both sides of BNKMT is confirmed by the results of physical field acquisitions and previously compiled paleo geological images (Verba et al. 1998: page number if possible). Grounds for such imaging (were presented earlier) are based on the assumption, that there is a large oceanic geological structure in the West Arctic Region, and within the limits of that structure during the second half of Paleozoic period the continental crust stress and forming of rift-related mega-trough (BNKMT) with suboceanic type of Earth crust took place (Verba 1977: page number if possible; Verba 1987: page number if possible, Gramberg 1997: page number if possible).
Dip-corrected mapping, performed on the base of this concept, demonstrates that based on the magnetic field behavior the Central Barents Anticline (CBA) is not different from regions comprising the eastern framing of BNKMT. Based on the results of paleomagnetic studies the position of CBA was restored within the system of adjoining structures of the Barents Sea Region and at the moment preceding the forming of BNKMT (Verba and Sharov 1997; page number if possible; Verba et al. 1998: page number if possible; Verba and Sakouлина 1999: page number if possible). The importance of above works is that (in particular) they could substantiate infeasibility to trace through the central part of the Barents Sea buried caledonite legs using the model, as it was suggested prior to commencement of shelf geophysical study and repeated nowadays by D. Gee (The Neoproterozoic Timanide Orogen of Eastern Baltica 2004: page number if possible).

Due to known reasons, above area of the Barents Shelf is still a frontier one. An exception from that is the regional reference seismic line 1-AR, which followed along the border of «grey zone», and not crossing it, highlighted the structure of the eastern part of the above area. On the presented portion of that seismic line one can see that along the cross-section, together with Mesozoic rocks typical for the Barents-North Kara Mega-Trough, there are also Paleozoic rocks, which, as earlier mentioned, are common to Timan-Pechora and Spitsbergen regions of the Barents Sea Petroleum Province.

In terms of structure above area pertains to Central Barents Block (terrain), and its structure is stipulated by the Demidov aulacogen, which is analogue to Pechora Kolvin aulacogen (Denisov rift-related trough) on Timan Pechora Trough and Andree Dickson aulacogen on Spitsbergen (Verba 1996: page number if possible). Thickness of sedimentary rock masses, functioning as a rift-related trough, comprises nearly 3.5 km that is quite comparable with data on Pechora Kolvin aulacogen, given above. According to velocity parameters and seismic facies pattern, having the shape of clinoforms with progradation of sedimentary prism in NE direction, we can suppose, that the rock mass under consideration is mainly represented by the terrigenous rocks accumulated in subaqueous environment of deltaic type. The width of the profile, as it is visible, may be a little bit overestimated, and considering the correction for nonorthogonality of cross-section it may comprise 140 km. This is a little bit less than at Pechora plate, and probably this testifies the trend of narrowing graben in the NE direction (Verba et al. 1990: page number if possible). Nearly in the middle of the trough one can see the axial horst with relative elevation amplitude about 1 - 1.5 km.

Characteristic feature of aulakogen is the presence of large anticline highs on its western and eastern flanks in Mesozoic deposits. One high is called Fedynski Dome, and the other – Fersman Dome. Uniformity of common tectonic position of Denisov, Demidov and Andree Dickson aulacogens was mentioned in several works (Pavlenkin 1985: page number if possible; Verba et al. 1992: page number if possible; Seismic-geological model of the lithosphere in the Northern Europe: the Barents region 1998: page number if possible) and thus enabling to say about their probably similar oil-and-gas potentials. Moreover, the presence of large anticline structures, carrying large commercial reserves of hydrocarbons on the flanks of Denisov aulacogen, and clear indicators of oil-and-gas potential on the eastern flank of Andree Dickson aulacogen, allows to forecast similar (by size) HC accumulations on the flanks of Demidov aulacogen. In consideration of the foregoing above region of the Barents Sea Petroleum Basin can be reviewed as possibly petroleum region, and its productivity, by analogy with Timan Pechora Province, may be related to Paleozoic deposits. If we compare it with adjoining depressions then we can suppose at least the same prospectiveness of Mesozoic sedimentary complex.
South Barents Petroleum Region

Shelf of the southern part of the Barents Sea at present is an area where the most intensive petroleum exploration activities are held. By now more than three dozens of local structures and four gas fields (gravitating toward the depression flanks) have been discovered in the South Barents Petroleum Region. Even the first well, named Sevmorgeo-1 (drilled in 1983), became the high-performance. It was on the high and later was called Murmanskaya Well. An influx of dry methane (flow rate about 1 mln m$^3$/day) was obtained from Upper Triassic red color sandstones. Such event can be considered as birth of the largest gas producing region on the Russian shelf. Later the gas pools were discovered at North Kildin and Ludlov areas and huge gas deposits were discovered at Shtokman area.

Oil & gas generation potential of South Barents PR sedimentary sequence can be characterized only based on well logs of wells, that were drilled here and penetrated the Mesozoic bodies. Underlying deposits, which may play the most important role in terms of HC accumulations in Mesozoic strata, haven't been explored by drilling within the limits of depression yet and, therefore, the extrapolation of data from depression framing cannot be fulfilled quite correct.

Data on offshore wells were at different times published by Yu.F. Fedorovski, A.V. Borisov, E.A. Margulis, A.I. Danyushevskaya, B.I. Petrova, E.G. Bro, Z.Z. Ronkina, Z.S. Gordon, V.M. Komarnitski, V.K. Gorokhov, V.S. Vinnikovski et al. (REF according to guidelines) Results of the studies demonstrate that within the studied section we can see regular increasing of organic matter concentration upsection, from basis points in the Lower Triassic up to one and a half percent (and more) in the Mid- and Upper Jurassic and Lower Cretaceous. More detailed analysis of organic matter vertical distribution has revealed that vertical distribution was well correlated not only with age, but (much better) with the rate of sedimentation.

Murmansk Field comprises a flat-lying dome-shape fold with area nearly 150 sq. km and the horizontal offset amplitude in the top of Triassic deposits comprises about 110 m. Gas pools were discovered in all Triassic series and confined to beds of deltaic sandstones and siltstones, which are strongly varying in the strike. Gas pools are sheet type, roof type and massive. Different formation productivity: Flowrates from the Upper Triassic comprise nearly 100 thousand m$^3$/day. (Well #.22 - 144 thousand m$^3$/day.), from the mid-Triassic - the flowrate is nearly the same (Well#.24…130 thou.m$^3$/day.), and from the Lower Triassic - much more (Well#. 24 - up to 740 thousand m$^3$/day). Gas is dry.

While drilling Kurentsov Area and penetrated the mid-Triassic deposits the increased gas indications were encountered, however the beds, highlighted by logging were not tested.

At North Kildin structure an influx of methane gas was obtained from Lower Triassic in Well#80. Its flowrate comprised 369 thousand m$^3$/d.

Shtokman Gas Condensate Field is the largest on the Barents Shelf. It was discovered in 1988. The field comprises large dome-shape fold within the Jurassic-Cretaceous deposits (Fedorovski et al., 1990), with area comprising nearly 800 km$^2$ and with amplitude of nearly 200 m. Based on the results of well testing three pay zones were identified within the Jurassic – J0, J and J2. Above pay zones represented by poorly cemented, fine and medium grained
sandstones with kaolinite cement, and had high porosity and permeability. Top seal are shale members that are providing hydrodynamic isolation of deposits. Pools are sheet type and massive. Gas flow rates reached 0.5 thousand m$^3$/day. Gas contains condensate, which is considered as primary. Density – in the range of 0.837…0.875. Presence of normal and isoprenoid alkanes in hydrocarbons of gas condensate strata $J_o$ indicates ther partial relatedness with dispersed organic matter of Jurassic shales. According to V.M. Komarnitski the main sources of hydrocarbons are Lower Triassic or underlying deposits.

Similar gas and gas condensate accumulations can be found in Jurassic deposits in downwarped BNKMT areas.

Sedimentary rock mass occurring at 1200-1300 m, and even below, currently are actualizing their generation potential, and they were placed in such environment as a result of last sag, i.e. during Pliocene (5 Ma).

Epigenetic hydrocarbons, which accumulations are usually confined to such depths as 2-2.5 km, and owe their origin to organic matter from deep occurring rocks, Triassic period or older. Migration of above hydrocarbons is also rather young (20-25 Ma). Based on encountered geochemical anomalies in local structure vicinity, we can conclude that partial redistribution of HC within the sequence is still going on.

Lateral trend of changing the oil-and-gas potential of the sequence is clearly visible in Table 6.4., which is compiled, based on data from two neighbouring regions - West Barents and Pechora. The table shows, that, revealed regular "rejuvenating" of pay zone in the Pechora PR goes further in the NW direction up to Shtokman field. At the same time oil in the sum of hydrocarbons is gradually replaced by the gas and gas condensate. Such relationship allows to suppose possible widespread development of petroleum accumulations within the Jurassic and Lower Cretaceous sections in the North of the Barents Sea.

TABLE 6.4. HERE

North Barents Petroleum Region

Distinguished as a separate region, the North Barents PR has a lot of common features with the South Barents PR, and totals the central, most downwarped part of BNKMT. The interface between these two regions goes across the Ludlov Saddle.

Within the North Barents Depression cross-section (total thickness estimated as 14-16 km), the dominant role is played by the rocks of Permian and Triassic period, that build up thick (6-7 km) avandeltaic rock masses with clear clinoform structure and which are overlapped by the less thick Jurassic-Cretaceous cover. The cover is represented by normal shelf horizontally stratified facies.

There is a wildcat well at Lunin Area, which was suspended with bottomhole at 1405 m in the Upper Jurassic bituminous clay. Small gas pools in Aptian sandstones at depth, not exceeding 1000 m, were identified in that well. This testifies that apart from Jurassic deposits some perspectives may be related to Lower Cretaceous sand strata.

Drilling at Ludlov Area yielded more weighty results. In 1990 the large gas condensate deposit was discovered in the mid- Callovian and Kimmerian-Oxford sandstones. The thickness of sandstones reached 85 m (pay zone is $J_o$ analogue of Shtokman field). As a result of testing the gas influx was obtained with flowrate comprising nearly 500 thousand m$^3$/d. Gas is methane, low nitrogen, with no sulfur. Gas indications were also identified in the
The Cretaceous part of the sequence, and in the Neokomian, but the sand-siltstone interbeds, carrying non-commercial gas pools here, are thin enough (not more than 10-15 m) (Borisov et al., 1995).

The well has penetrated one of abovementioned «bright» seismic horizons, which was compared with fluids from underwater discharges (Ivanov et al. 2013: page number if possible, Seismic-geological model of the lithosphere in the Northern Europe: the Barents region 1998: page number if possible) and above comparison showed, that rock body, intersected by the well, was built up by the Irish touchstone with amygdaloidal structure, and this smoothly corresponded to moderate deepwater environment, where the underwater discharge of Irish touchstone took place (Alekhin 1988: page number if possible). Age of the Irish touchstone on the basis of K-Ar dating method comprises 131 and 159 Ma (Komarnitski et al. 1993: page number if possible).

Two wells were drilled within 1990-92 at Ledovaya Area at southern and northern domes. Hydrocarbon accumulations were penetrated in the mid-Jurassic (beds Jо, J1 – gas, J2 – gas condensate). As a result of J1 testing an influx of gas was obtained with flow rate, exceeding 400 m³/day.

North Barents PR northeastern blocks of northern margin are in some way similar to Izhma Pechora structures of Timan Pechora Area, which allows to improve seriously the predictive assessment of this poorly studied northern margin of the Barents Sea.

East Barents Petroleum Region

It is the most long-distance from the mainland area of the Barents Sea Petroleum Basin, and located to the East from Vilchevskaya Saddle, and remains the poorly explored part of the aquatic area. Apart from regional gravimetric data, acquired even in 70s and 80s of the last century, the PR was explored in the southern part, using CDP seismic reflection method and therefore appropriate seismic lines were acquired. One of such lines – 4-AR is attributed to reference lines (Ivanov et al. 2009: page number if possible; Ivanov et al. 2010: page number if possible) as shown on Figure 6.7. Available data allows to state that structural and compositional complexes of sedimentary cover, identified within the North Barents PR, are extending in the eastern direction. If there are no deep wells, and key sections on the land of the island we can suppose that the sedimentary cover structure of this aquatic area will be stipulated by the mesozoic terrigenous deposits, and their thickness based on CDP reflection method data may comprise 6-9 km. Comparison of available seismic sections with cross-section of three Mesozoic depressions, reviewed above, which together with East Barents PR constitute the single structure of rift-related Barents-North Kara Trough, favors such supposition.

Geochemical studies have been carried out and focused on the seafloor sediments of St. Ann Trench (Ivanov et al. 1999a: page number if possible). Studies revealed some indications of gaseous HC (Ivanov et al. 1999b: page number if possible; Ivanov et al. 2011: page number if possible), Geochemical data complete with geothermal data from M.D.Khutorski regarding Orel Trench (Khutorski 2007: page number if possible) shows the activity of present-day migration of HC gases and is the indirect indicator of available HC accumulations in the subsoil. Besides that, being a part of single geological structure means that in principle all parts of downwarping areas of BNKMT have similar oil-and-gas potential features. Based on this assumption we can anticipate commercial HC deposits within the Jurassic and Upper Triassic strata of the sequence.
Concluding remarks

General trends of oil & gas potential

Information regarding the oil & gas potential indications in different areas of the Barents Province allow (regardless of their incompleteness) to make some conclusions on spatial-temporal trends of oil & gas generation process in the region under consideration. Availability of such trends that were previously studied by geologists with different degree of detail enables to compare them with main oil-and-gas potential features of the Barents Province and, based on that comparison, make an estimate of HC accumulations discovery perspectives in not explored yet areas of the region.

Spatial pattern of distribution of oil & gas potential attributes

Lateral distribution of HC deposits, just as in other petroleum basins, is subject to quite clear tectonic control, which exhibits in the regular change of average reserves density, balance of oil and gas, oil composition and number of pools within the section.

As it was previously mentioned, above trend is clear through the example of Pechora Kolvin aulacogen, along which the chain of petroleum fields is located. Above field accumulates in total more than two thirds of ultimate reserves of Pechora PR. Not so clearly (probably due to worse exploration degree) one can trace the linear structural "organized nature" of local highs, which accumulate hydrocarbon deposits in the West Barents PR. In both cases we can see clear gravitation of fields with gas and gas condensate pools to axial zone of sedimentary basin, while the oil pool appear at some distance from above zone, and as a rule are located bilaterally, on both sides of symmetry fabric axis. Within the Grumant PR due to structural heterogeneity of that region bilateral symmetry of oil and bitumen shows' locations is exhibited much worse, however even in that case one can see their confinement to the flanks of West Spitsbergen Trough. Oil pools were not identified in the South Barents Gas Region, while the gas and gas condensate pools are gravitating to the peripheral zones.

Second important finding, resulted from analysis of deposits' lateral distribution lies in narrowed stratigraphic range of oil-and-gas potential within the axial zones of sedimentary basins and, at the same time, the pay deposits are "rejuvenating". This trend was analyzed above through the example of Pechora, West Barents and Grumant PRs.

Within the limits of the Barents Petroleum Province the stratigraphic range of rocks, containing oil-and-gas content indications is widely varying - from Vendian to Paleogene period. Along with that the depositional complexes, where oil and gas pools are occurring more frequently can be allocated. Within the Pechora PR above complexes include Upper Devonian and mid-Upper Carboniferous complexes, which accumulate nearly 90% of all HC resources of PR (see Figure 6.2.). Similar distribution of oil-, gas-, and bitumen- shows one can see within the sedimentary section of Grumant PR, with distinction that the Triassic complex is added to regional oil-and gas bearing complexes for Grumant PR. While approaching to the Barents-North Kara Mega-Trough the role of Triassic complex is increasing, while in the axial zone of the mega-trough the Triassic-Jurassic and even Lower Cretaceous become pay, as a rule. Thus along with selective confinement of oil-and gas potential to particular stratigraphic levels, we can observe regular "rejuvenating" of pay deposits in the direction of axial zone of BNKMT. Moreover, reduction of the age interval occurs synchronously, within the boundaries of which oil & gas deposits can be found more frequently.
Clarification of pools distribution by depth is quite complicated due to different representation of available data and due to nonuniform exploration degree of different regions and areas. At the same time at a first approximation it becomes clear that there is a trend of downward shift of oil & gas pools maximum development zone within rift-related depression compared with adjacent stable blocks. That trend can be noticed both in the distribution of gas pools and, to lesser extent, in those of oil pools. In all reviewed cases oil pools could be found within the wider range of depths than gas pools. Through the example of Pechora Plate A.Ya.Krems noted that for the Upper Pechora River the clear vertical zoning of oil & gas show is indicative: Higher than 1300 m - heavy oils (very often with dry gas), 1300-3200 m - light oils and gas condensate, and below 3200 m - gas condensates, very seldom with heavy residual oil. Within the West Barents Region the majority of identified pools, both gas and oil, regardless of enclosing deposits, are located within the narrow range of depths from 2500 m to 2900 m (see also Table 6.5).

This data testifies tough thermobaric environment for hydrocarbon accumulations in rift-related downwarps, and, on the contrary, relatively soft limitations in terms of thermal regime and pressure in the peripheral regions of the province. Since that peculiarity of HC accumulations distribution is well correlated with geothermal field parameters (Tsibulya and Levashkevich 1992: page number if possible), then one can conclude, that in general case the magnitude of registered heat transfer is directly linked to the depth of main oil and gas accumulation zone, while the current geothermal gradient is inversely linked to the average - (for the region) height of oil-and-gas column.

When we compare the influence of analyzed factors, one can notice, that their impact is opposite in sign: In direction to rift-related structure depocenter and, at the same time, the hydrocarbon accumulations occurring depth is increasing, while the age of enclosing deposits is decreasing.

Therefore for regions, where available data allows to exercise particular judgment, one can observe common regular gravitation of oil pools to regional structure periphery, while the gas pools, and specially the gas condensate pools are gravitating to its near-axial zones. When comparing with tectonic elements, then such trend looks like confinement of gas condensate pools to zones of clear exposed rifting, while the oil pools are confined to post-reef downwarps and depressions. That trend exhibits both on a scale of 1 Order structures (sineclises, downwarps), and on a scale of entire province.

TABLE 6.5. HERE

Stages of petroleum generation

Identification of temporal trends within the oil-and-gas generation processes is the most complicated task, since the direct indications of migration age are small in number, while the indirect indications are not always convincing. However, the data, given above, regarding separate regions of the province enable to conclude, that priority in forming the most convincing indications of oil-and-gas potential of its sedimentary rock masses belongs to the youngest migration stage, which in the area of consideration doesn't coincide in time with Alpine epoch of tectogenesis.

We want also to add, that according to messages from Norwegian geologists, the Cenozoic uplift processes exerted the key influence on forming the oil and gas fields in the western part of the Barents Sea. Uplift means elevation of the territory, which in our case took place in two stages. Analysis of radioactive element decay track in apatite grains enabled to date the first
phase as 40-60 Ma, while the second phase was dated as 5-15 Ma, moreover to the North from the explored areas, in the direction of Spitsbergen, above phases merged into one.

Indirect indication of young age of migration can be found in materials of geothermal studies. As it was mentioned before, one can observe satisfactory coincidence of present-day thermal anomalies with zones of oil and gas accumulation, which can be explained by availability of cause and effect relationship of such events.

Finishing the review of general trends of spatial-temporal distribution of direct oil-and-gas potential indicators, we can conclude that even the availability of such trends can strongly testify identity of all its structures to one integral oil-and-gas bearing province. Above said relates to vertical distribution of the main oil and gas-bearing rock mass, controlled by the sedimentation factor. It also relates to lateral zoning of oil and gas accumulation, which is determined by the by the tectonic factor, and also the above said relates to naftidogenesis staging, linked to common for entire region shows of geodynamic processes.

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Fedyn High / Hjalmar Johansen Ridge (HJR) – a new geological prospect within the Former Disputed Area (FDA)

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The previous disputed area has the size of the Norwegian North Sea with large identifiable structures not too far from several large gas fields, like Snøhvit and Shtokmanovskoe. As we would expect, this creates curiosity and speculation about possible Hydrocarbon (HC) recourses there (Ræstad 2005: page number if possible). From the Russian side the major part of geological and geophysical data in the disputed area were collected into the early 1990s. On the Norwegian side the Norwegian Petroleum Directorate (NPD) started seismic data collection the next day after the negotiations were concluded.

We can so far refer to assessments of the resources in the Norwegian part of the Barents Sea published by NPD, but these are excluding the former disputed area. However, if we consider the proven plays in that Norwegian part of the Barents Sea, we can clearly see that most of the plays are cut straight along the border of the disputed area (see Figure 8.1. in Chapter 8). And it is probably would be right even to assume that these Norwegian prospective areas continue into the disputed area. 8 of the 23 plays in the Norwegian part of the Barents Sea are confirmed, meaning producible oil or gas has been found there (Pöyryn 2009: page number if possible). The NPD estimates that there are 5.7 billion boe of yet-to-find resources in the Norwegian part of the Barents Sea; not including the disputed area, (www.npd.no). So, the next question then is; how much HC we can expect to find in the previous disputed area?

According to Russian database, estimates of the previous disputed area resources are included in resource assessments of the Russian Barents Sea. Several structures have been identified by the Russian side, among which the Fedyn High or Fedyn Arch is the most notable, see Figure 7.1.

According to last estimates the disputed area holds 6.8 billion tons of oil equivalents, corresponding to almost 50 billion boe. This is almost 7 times larger than resource estimate made by NPD (5.7 billion boe) for the Norwegian part of the Barents Sea (Pöyryn 2009: page number if possible). On the other hand, the Russians have reasons to be more optimistic. The Shtokmanovskoe gas and condensate field discovery alone is three times the NPD estimate for the whole Norwegian part of the Barents Sea. However, we shouldn’t forget that the previous disputed area has no reserves which can be termed “proven”, since exploration drilling has not yet taken place in this region.

Currently, there are a lot of discussions regarding the reliability of the Russian estimates. They are also difficult to compare with the NPD estimates since the two are of such different magnitudes. However, the Severo-Kildinskoye is a proven gas discovery right next to the border of the Grey Zone Area. This implies someone could have a pretty good idea of the
geology towards west. Regular seismic surveys in the border areas were conducted by the Soviet Union starting in 1978. Four wells have been drilled in the vicinity of the disputed area on the Fersmanovskaya and Severo-Kildinskaya structures. Russia resumed seismic activities in 1999.

The main structural elements in the Former Disputed Area are from south to north: the Finnmark Platform, the Tiddly Bank Basin, the Hjalmar Johansen (Fedyn High), the Nordkapp Basin, the Bjarmeland Platform, the Central Bank High and the Hopen/Persey High. To the east lie the hydrocarbon prolific South and North Barents basins, while to the west the Hammerfest Basin has finally proven its commerciality. However, it is ambiguous to put forward that huge Russian gas discoveries in the Jurassic to the east can be duplicated in the previous disputed area based on its propinquity. The reason is the presence of a marked transition from the Jurassic aged gas fields in the Barents basins up on to the platforms where the Jurassic aged sediment cover is thin and lying at a shallow depth. Paleozoic and Mesozoic aged rocks subcrop below the Quaternary in the disputed area with no Tertiary aged sediments present. In the Nordkapp and Tiddly Bank basins, Triassic sands trapped against salt pillows are the main prospects. Triassic fluvial sands trapped against salt have been found to be gas bearing in the Pandora discovery in the southern Nordkapp basin. By this we can claim next 3 main period formations which are most likely have HC presence prospects, there are: Triassic, Paleozoic, and Pre-Jurassic source rocks.

Triassic aged clastics are the most obvious Mesozoic target for hydrocarbon exploration on the platforms. Triassic fluvial sands have been found to be gas-bearing in the Severo-Kildinskaya field close to the former Gray Zone. The sands are reported to have reasonable porosity and relatively low permeability, but net to gross ratio and thus connectivity is a key parameter. The key well drilled by Statoil in 2005 on the Finnmark Platform close to the previous disputed area, targeting a huge stratigraphic trap, was abandoned as a dry well probably because of lack of a good migration pathway and/or poor seal (Ræstad 2005: page number if possible).

In the Paleozoic, the most attractive prospects are shallow water platform carbonates of Permian and Carboniferous age. Four wells have tested carbonate prospects on the Finnmark Platform east of the Nordkapp Basin. With one minor non-commercial oil and gas discovery, two wells with oil shows and one dry well, some of the play models are confirmed, but to date success has been limited. Reservoir development is primarily related to dissolution during subaerial exposure, or re-deposition of bioherm build-ups. The Permo-Carboniferous build-ups constitute prolific reservoirs in the Pechora Basin far to the east, and together with the Triassic clastics represent the main potential reservoir horizons in the previous disputed area. The Russians have pointed out numerous seismic anomalies that could be related to both Triassic sands and Permo-Carboniferous bioherm build-ups.

With regards to Pre-Jurassic source, with respect to source rock, the prolific Jurassic Hekkingen Formation has barely reached maturity in the South Barents Basin to the east. However, shales in the Upper Permian Tempelfjorden Group are in the oil window along the platform margin and on the Hjalmar Johansen/Fedinsky High and are gas-prone in the deeper northern parts of the Gray Zone. The recently discovered deeper oil bearing formations in the Goliat oil field to the west are important evidence for the presence of a pre-Jurassic source rock of probable Middle Triassic age (Ræstad 2005: page number if possible).

The Barents Shelf, however, has a challenge that is the Cenozoic deep erosion that has breached earlier oil reservoirs either by fault induced leakages or by gas expansions due to uplift. Erosion has been in the order of 1000-2000 metres in the previous disputed area, and is
a negative factor in the prospectively evaluation. From a structural point of view, the Hjalmar Johansen High/Fedyn High is huge basement induced uplift some 130 km in diameter. The Russians have indicated and named five potential prospects in the vicinity of the high. The deepest targets in the Paleozoic are within acceptable depths for reservoir preservation. This high and the eastern end of the Nordkapp Basin are potentially the two most attractive areas for future exploration. Mapping over these structures has been based on a fairly dense seismic grid. Since surveys have been started in the nearby areas of the previous disputed area and data collected indicate that factors necessary for hydrocarbon generation, migration and preservation are present. Structures forming large potential traps have already been identified. However, more extensive and better quality seismic data are required in order to properly evaluate the reservoir potential. Drilling must be carried out to assess the quality of the source and reservoir rocks, thereby confirming the commerciality of a discovery. The next subsection gives a short overview on the Former Disputed Area evenly spread over the Norwegian and Russian parts of the Barents Sea representing large hydrocarbon resource potential for both countries.

The disputed area in the Barents Sea: more than 4 decades of negotiations

Norway and Russia extended their exploration activities to the potential hydrocarbon-bearing reservoirs in the region in the late 1970s, but in the 1980s they agreed not to carry out any kind of survey works in the previously disputed area. The “1957 Agreement” was established by Norway and the Soviet Union. In that document both countries agreed on their first maritime boundary in the Arctic. This boundary runs from the northern end point of the land boundary in a north-eastern direction through the Varangerfjord and terminates on the Varangerfjord’s closing line, thereby not extending into the Barents Sea. But in 1963 and 1968 (Agreement Between the United Kingdom and Norway, 1965 each State claimed exclusive rights to the continental shelf so that Norway and Russia entered into informal talks about their maritime boundary in the Barents Sea in 1970. They agreed to conduct negotiations on the basis of Article 6 of the multilateral Convention on the Continental Shelf (1958) named “1958 Convention”. In 1977, the negotiations became further complicated by the establishment of a 200 nm Norwegian Exclusive Economic Zone (EEZ) and a 200 nm Soviet Fishery Zone. The geographical scopes of these zones were not completely identical with the Norway’s and Russia’s continental shelf claims in the Barents Sea. The so-called “Loop Hole” in the middle of the Barents Sea covered an area of some 62,400 km² of seas that was completely surrounded by the countries’ 200 nm zones. The 1978 “Grey Zone Agreement” applied to a total area of 67,500 km² in the Barents Sea, of which 23,000 km² was in undisputed Norwegian waters and 3,000 km² was in undisputed Russian waters. The following almost 2 decades were spent to negotiate the “Law of the Sea Convention”, which was ratified by Norway and Russia in 1996 and 1997, respectively, thereby modifying the rules applicable to the delimitation of the continental shelf and the EEZ (Agreement between the Russian Federation and the Kingdom of Norway 2007: page number if possible). After decade of silence, in 2010 finally the “2010 Agreement” defines the maritime delimitation line by 8 points and splits the disputed area nearly in half, see Figure 7.1.
The agreement accounts for the longer Russian coastline, but other factors Russia called on earlier do not seem to have influenced the boundary line. The 2010 Agreement will not affect the application of agreements on fisheries cooperation between the States Parties. However, once it enters into force, the 2010 Agreement would terminate the Grey Zone Agreement of 1978 as well as the 1980s moratorium on the exploration and exploitation of hydrocarbon resources. Additionally, there are provisions for coordinated exploitation of trans-boundary hydrocarbon resources.

The 2010 Agreement also defines the maritime boundary of the outer continental shelf in the Arctic Ocean.

Norway is particularly interested in the development of hydrocarbon deposits in the area because since 2001, oil production on the Norwegian shelf has declined, with much production coming from discoveries made during the 1970s and 1980s and with very few large recent discoveries (literally only one large field, the Johan Sverdrup field) on the Norwegian Continental Shelf (NCS).

But for Norway as well as for Russia the activities may still not increase fast due to the indication of a climate change. For example the melting of thin first year sea ice might allow thicker multi-year pack ice to drift into the exploration areas, or melting permafrost might destabilize roads and pipelines onshore, etc.

However, the Former Disputed Zone has large exploration potential, which necessitates collaboration between Norway and Russia in many areas, like monitoring climate and metocean conditions, environmental studies, fishery and, not the least, oil and gas exploration and production. It is quite natural to forecast that development of most of the hydrocarbon resources in the new province will be based on a so-called Unitisation Approach.

<FIGURE 7.2. HERE>

References

Agreement between the Russian Federation and the Kingdom of Norway on the Maritime Delimitation in the Varanger Fjord Area (2007), signed in Moscow on 11 July 2007, U.N.T.S. Reg. No. 45114; and 67 U.N. Law of the Sea Bulletin 42, art. 2. (ensure that the reference is in accordance with the guidelines)

Agreement between the United Kingdom and Norway Relating to the Delimitation of the Continental Shelf Between the Two Countries (1965), signed at London on 10 March 1965, in force 10 March 1965, 551 U.N.T.S. 213, art. 4. (ensure that the reference is in accordance with the guidelines)


Econ Pöyryn (2009) “What if an Agreement was reached with Russia over the Area of Overlapping Claims?”, Norwegian Continental Shelf Quarterly, NCSQ, No 4, 2009, pp. (ensure that the reference is in accordance with the guidelines)


CHAPTER 8

Barents Sea hydrocarbon resources base and production potential

ANATOLY B. ZOLOTUKHIN, FIRST NAME SUNGUROV AND VLADA STRELETSKAYA

Introduction

The Arctic continental shelf is believed to be the area with the highest unexplored potential for oil and gas as well as for unconventional hydrocarbon resources such as gas hydrates. The region has potential as a future energy supply base.

The Russian part is recognized to be the largest among oil and gas resources owned by Arctic nations. However, scarce information and available geological data create uncertainty regarding a future role of the Russian Arctic as main base of energy supply in the second part of the XXI century. A further uncertainty is the pace at which production from northern areas including the Arctic, will be brought onstream – either because of national policy, infrastructure development or investment by the state and the oil companies. These areas embrace those where development has already been started (Offshore Sakhalin, Pechora Sea, Yamal peninsula) and those awaiting future involvement, like Barents and Pechora Seas, Kara Sea, East Siberia, near Yamal shelf, and Far East (Zolotukhin 2014: page number if possible).

Challenges associated with the Arctic oil and gas resources development (severe climate, presence of ice, high cost, undeveloped infrastructure, low exploration status, often lack of technology and appropriate equipment, shortage of qualified personnel, environmental issues, logistics, etc.) together with geopolitical issues present real and potential threats to the development of development of the oil and gas fields located in the Arctic.

However, future tremendous opportunities to extract, transport and consume vast arctic petroleum resources are driving forces to stipulate development of domestic and international petroleum industries and their active collaboration.

Active involvement of the Russian Arctic resources in the global energy supply process needs a clear understanding of the market potential for Russian gas and oil (required volumes, time frame, transportations routes) and requires close attention of the government to the most important issues that should be in place.

The future role of the Arctic region should be further understood and its resources should be further explored and assessed. There is no doubt that in the second part of XXI century production of HC in the Arctic petroleum mega basin will be as important in energy supply as Persian Gulf and West Siberia basins today.

This section gives an overview on hydrocarbon resources allocated in the Russian and Norwegian part of the Barents Sea and shows existing opportunities for a joint development of one of the richest petroleum mega basin in the world.
Petroleum resources of The Great Barents Sea

There is a common view that shelves of the Barents, Kara and Pechora seas are considered as the most prospective areas for offshore oil and gas field development. With nearly 31 billion tons of oil equivalent (BTOE) of oil and gas resources (ca. 223 billion barrels of oil equivalent (Bboe)), the Barents and Pechora seas represent one of the most attractive areas of the petroleum resources development.

So far two gas-condensate fields – Shtokmanskoye and Ledovoye, and three gas fields – Ludlovskoye, Murmanskoye and North-Kildinskoye have been discovered in the Barents Sea. Potentially interesting structures have been detected in the Fersman-Demidov shoulder, Shatsky and Vernadsky swells, and also in the area of Medvezhy and Admiralteisky swells (Zolotukhin and Gavrilov 2011: page number if possible).

<FIGURE 8.1. HERE>

The former “Grey zone”, which was disputed between Norway and Russia, has a high potential in the area of Fedynsky Swell and East-Barents foredeep where quite a number of structures are very prospective for both gas and oil.

Up to the present time oil has not been discovered in Russian Arctic seas except the Pechora Sea, therefore these locations, including Admiralteisky swell, are of particular interest.

It has earlier been anticipated that development of the Barents Sea will start from the Shtokman field, which later would be accompanied by the satellite fields of Ledovoye, Ludlovskoye and Terskoye and later by the fields of the Fersman and Demidov swells. This concept would have been enable utilisation of available infrastructure so as to reduce investment costs.

The 2010 Norwegian-Russian agreement on delimitation of the Barents Sea has opened a new round of cooperation between two countries on the development of Arctic resources. The new agreement opens new opportunities for active cooperation in developing this strategically important region. Possible large accumulations of petroleum resources in the delineated zone are located closer to the shoreline than the Shtokman field, and this may facilitate a new concept of the whole Barents region development, as it is further discussed in Chapter 9 (old 7).

The shelf of the Pechora Sea is the only one among all the Russian Arctic shelves where the oil has been discovered. The main fields of this region are the Prirazlomnoye, Dolginskoye, Medyn-more, Varandey-more and Kolokomorskoye oil fields, the Severo-Gulyaevskoye oil-gas-condensate field and the Pomorskoye gas-condensate field. Besides these fields there are several large and prospective structures located in the south eastern part of Pechora Sea:

Yuzhno-Russkaya, Pakhanchevskaya, Sakhaninskaya and Papaninskaya. According to the estimates, total resources of the Medyn-Varandey and Kolokomorsky structures amount to 410 million tons of oil with a recoverable volume of 80 million tons. It is planned that the Prirazlomnoye field will start the oil production in the Pechora Sea followed by development of other fields.

It should be briefly noted here that development of the Barents Sea may be more cost-effective if its resource base is united with resources of the Kara Sea and the Novaya Zemlya
archipelago is used as a cluster base for development of the whole region. In this case the “unitization principle” can be implemented that might improve economics of field development due to less overall investments in common infrastructure (Efimov, et al. 2014: page number if possible).

**Hydrocarbon resources of the Barents Sea**

This section is devoted to a new outlook on the Barents Sea petroleum resources generated with the assistance of the modern internet-based methodology, namely, UCube designed by Rystad Energy, a private Norwegian company.

Figure 8.2. gives an outlook on oil and gas resources of the Barents Sea, which for convenience is split in Norwegian and Russian parts.

<FIGURE 8.2. HERE>

<FIGURE 8.3. HERE>

Figure 8.3. indicates that both Russian and Norwegian parts of the Barents Sea are at nearly the same development stage. As follows from the left-hand side plot of Figure 8.3., larger resource base of the Russian part is mostly gas prone (ca. 80% of resources is gas), while the gas / liquid ratio in the Norwegian part is close to 60/40. The right-hand side of Figure 8.3. shows that the Former Disputed Area has a high contribution to the resources base of both Norwegian and Russian parts of the Barents Sea, which indicates large potential for international collaboration in this area.

<TABLE 8.1. HERE>

As follows from the Table 8.1., overall EUR potential of the largest 10 fields and potential structures located in the Russian part of the Barents Sea exceeds by nearly 3.5 times that of Norwegian part. Undiscovered potential in the Norwegian area accounts for almost 83% of EUR, while the Russian yet-to-find resources, due to Shtokman discovery, are slightly below 55% of EUR.

It should be noted here that contribution of the Pechora Sea to the hydrocarbon resources of the 10 largest fields and structures of the Barents Sea is very moderate. From all discovered fields and identified prospective structures, with the total number of them close to 30 (see Figure 8.2.) only Prirazlomnoye field with its EUR of nearly 70 million TOE (in the Russian estimates – ca. 72 million TOE) is included in the table.

<FIGURE 8.4. HERE>

This is explained by a concept used in UCube software: only assets believed to be commercially viable are included in EUR resources. Thus, an estimate made by using UCube software may (and certainly will) disagree with the Russian evaluation of resources of the Pechora Sea that is primarily based on the concept of Initial Geologic Resources (STOOIP) multiplied by the average ORF (Oil Recovery Factor), available at this stage of estimates and typical for the region of study.

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14 All the estimates referred to in this section and the following parts of the chapter are based on the use of the UCube software developed by Rystad Energy, an Internet-based company specializing in hydrocarbon resource evaluation and production forecasts. A short description of specifics of the UCube evaluations is given at the end of this section.
There are no debates regarding analysis of strong and weak points of both approaches. Important is that they are based on different concepts and thus, rather compliment than contradict one another.

Our rough assessment, based on STOOP and ORF evaluation concept, indicates that Pechora Sea alone has in-place volumes amounting to ca. 20 billion boe (2.7 BTOE)\textsuperscript{15}. This quantity is enough to secure produced volumes in the forecasted period (2014 – 2040) close to 3360 million boe (758 million TOE). In order to maintain this production, approximately 500 production and injection wells should be drilled in the region in this period, starting from 5-8 wells drilled annually during 2014 – 2018 and then gradually increasing the number to 25 by 2030 and remaining at this level in the following decade 2030 – 2040. The total number of rigs that should be engaged in the drilling campaign continuously over few decades in the Pechora Sea represents a real challenge to the development program. Another challenge is a lack of infrastructure that should be developed in the region over this time (2014 – 2040).

Prospectivity assessment of petroleum resources associated with producing and discovered fields in the Norwegian part of the Barents Sea is illustrated by Table 8.2.

\textbf{<TABLE 8.2. HERE>}

As follows from the Table, Snohvit, the largest discovered and the only producing field in the Norwegian sector of the Barents Sea accounts to nearly 58% of all the discovered resources (EUR) in the area.

UCube enables to forecast future production and answer a very important question: for how long and how much hydrocarbon resources can be (cost-effectively) produced in both sectors of the Great Barents Region (Figures 8.5-7.).

\textbf{<FIGURE 8.5. HERE>}

As follows from Figure 8.5, Norwegian sector of the Barents Sea has higher chances to be developed faster with higher annual production than its Russian counterpart. By 2040 the overall annual production from the Norwegian sector can reach 550 million boe with the average gas / liquid ratio nearly 50/50 value. Started with Prirazlomnoye field in 2014 production from the Russian part of the Barents Sea is expected to reach 400 million boe by 2040, to which gas contributes with nearly 72%.

The shape of the forecasted production indicates a steep production growth in the period from 2030 to 2040 which will, most likely, remain valid for few decades beyond 2040. Obviously, production potential of the Great Barents Region is so high that it can supply the world with oil and gas at the annual rate that can be reached by 2040 (950 million boe or 130 million TOE) for more than 100 years.

In conclusion, we would like to note again that future tremendous opportunities to extract, transport and consume vast arctic petroleum resources of the Great Barents region are driving forces to stipulate development of domestic and international petroleum industries and their active collaboration.

\textbf{<FIGURE 8.6. HERE>}

\textsuperscript{15} This quantity is somewhat moderate as compared with 4.9 BTOE given in (Beloin and Prischepa, 2006).
Specifics of the UCube evaluation of resources and recoverable volumes

The Resources in UCube do not correspond directly with company reported 1P (Proven/Proved Reserves) or 2P (Proven + Probable Resources) numbers. To reduce confusion the term Resources, not Reserves is used in UCube. The Resources in UCube correspond to the Expected Ultimate Recovery (EUR) of the fields. The EUR number is based on reported 1P and 2P numbers, as well as empirical studies and case-by-case judgment. Whereas real fields may have both 1P, 2P, and 3P (Proven + Probable + Possible) reserves, 1C, 2C, and 3C contingent reserves, as well as low, best and high estimate prospective resources, each UCube asset is assigned only the EUR, which is assumed to include all the above contributions. Similarly, UCube assets have only one lifecycle, whereas real fields may have resources of different maturity.

Petroleum resources are best classified by the Petroleum Resources Management System (PRMS), as described by SPE/AAPG/WPC/SPEE and illustrated by Figure 8.8 (Guidelines for Application of the Petroleum Resources Management System, 2011, Petroleum Resources Management System, 2007).

The Resources variable in UCube is identical to the sum of future production, thus Resources and Production variables are internally consistent (with the exception that Other liquids are not included in Resources). For one asset the Resources value for a year is identical to the remaining reserves at January 1st that year, i.e. the sum of Production for this and the following years (see Figure 8.9.).

Resource Classification Proxy

The Resources variable can be split by the Resource Classification Proxy. This split is modeled, and the purpose is to simulate the process of maturing the resources at asset level. This is shown for one asset in the Figure 8.10 below. Before the license is awarded the resources are "Prospective unawarded".

Through seismic interpretation, exploration, appraisal, and field development the resources are gradually matured to P50 and P90 resources, and the remaining resources shrink as resources are produced. Note that since P50 includes P90, and Pmean includes P50, the system displays the additive "P50 (increment)" and "Pmean (increment)". Thus P50=P90+P50 (increment). The Resource Classification Proxy can be used to analyze how companies mature their portfolios, and to estimate 1P and 2P values at portfolio level.

Based on Resources, Resource Classification proxy (horizontal dimension in the SPE classification chart) and Lifecycle Category (vertical dimension) this approach enables to work out 1P and 2P estimates at portfolio (company, region, country, ...) level.

The correspondence between these definitions and the PRMS definition is indicated below.

References
Belonin M.D., Prischepa O.M. (2006) “Oil and gas resources of the North-West region of Russia and prospects for their development”, Moscow, … (ensure that the reference is in accordance with the guidelines)


Guidelines for Application of the Petroleum Resources Management System, SPE Oil & Gas Reserves Committee, SPE, Richardson, Texas, USA, 2011. (ensure that the reference is in accordance with the guidelines)

Petroleum Resources Management System, SPE, Richardson, Texas, USA, 2007. (ensure that the reference is in accordance with the guidelines)

Zolotukhin, A., Gavrilov, V. (2011) “Russian Arctic Petroleum Resources”, Oil & Gas Science and Technology – Rev. IFP Energies nouvelles, DOI: 10.2516/ogst/2011141, pp.-. (ensure that the reference is in accordance with the guidelines)

CHAPTER 9

Development of Hydrocarbon Fields in the Newly Delineated Border Area of Norway and Russia with Emphasis on Subsea Development Schemes

MARIA BULAKH, OVE T. GUDMESTAD AND ANATOLY B. ZOLOTUKHIN

Abstract

The U.S.G.S (United States Geological Survey) have estimated that the mean undiscovered, conventional; technically recoverable petroleum resources in the Barents Sea Continental Shelf include up to 11 billion barrels of crude oil, 10.7 trillion cubic meter of natural gas, and 2 billion barrels of condensate (Klett and Gautier 2009: page number if possible).

The recent agreement (signed in 2010) between Russia and Norway regarding the border line in the Barents Sea offers extraordinary opportunities for Norwegian-Russian cooperation in hydrocarbon development in this Arctic Sea. The newly delineated area, the previously disputed zone (also popularly termed the “Grey Zone”) is about 175 thousand km$^2$. The potential reserves of the former disputed territory are about 360 million tons of oil and nearly 6 trillion cubic meters of natural gas. According to earlier geological surveys (Econ Pöyron 2009: page number if possible), the largest deposit (hydrocarbon prospect) is the Fedyn High (Arch)/ the Hjalmar Johansen Ridge (HJR). Its resources (when we transfer the gas to oil equivalents) are estimated to be around 10-12 billion b.o.e. (barrels of oil equivalent) or might be even higher up to 18.7 billion b.o.e. (Barents Observer 2013: page number if possible)

In this chapter we will observe the physical environmental conditions in the HJR/ Fedyn High Area and their main challenges, to suggest possible scenarios of oil and gas fields’ development and arrangements.

Introduction

The Barents Sea is the most western among the arctic seas off the coasts of Western Russia and Northern Norway. The Barents Sea is located between the northern European coasts and the islands of Vaigach, Novaya Zemlya, Franz Josef Land, Spitsbergen, and Medvezhy Island. The Sea communicates with the warmer Norwegian Sea, the cold Arctic Basin and also with the Kara and White Seas.

The area of the Barents Sea is 1.4 million square kilometers with an average water depth of 230m. The water volume is estimated to 322 000km$^3$. Typically 3/4 of its surface is covered by ice during the winter and it never freezes completely due to the influx of warm Atlantic waters, preventing the cooling of the surface layer to the freezing point.

The bottom is not uniform, having crossed seamounts, valleys and gutters. The hydrological conditions of the sea are affected by the river flow in its south - eastern part. In general, however, the flow is relatively small (annually 163 km$^3$) and therefore has little effect on the salinity and chemical composition of the Barents Sea water, which is close to the characteristics of ocean water (Dodrovolskii and Zalogin 1982: page number if possible).
The Barents Sea water masses represent a combination of influence of energy exchange with the atmosphere and water circulation. Inrush of water from other basins and underwater uneven terrain create a very complex system of surface and deep currents, in which the numerous branches of the Norwegian current and cold water coming out of the Arctic Basin and the Kara Sea play the leading role. Periodic tidal currents are superimposed on a system of permanent currents; periodic tidal currents in the surface layer may reach 150 cm/s and this rate exceeds the rate of constant currents (Gyromereorology and gyrochemestri 1990: page number if possible).

Major deposits discovered so far in the Barents Sea outside the formerly disputed area include The Norwegian Snøhvit gas field and Goliat oil field, the Johan Castberg Field (formerly termed the Skrugard field) and the Russian Shtokman gas field.

**Physical environmental conditions in the area of HJR/ Fedyn High area**

*Climate*

The climatic conditions of the Barents Sea in the HJR/ Fedyn High area are determined by its proximity to the warm Norwegian Sea and to the cold Arctic Basins areas. Through the Barents Sea the greater part of the warm North Atlantic cyclones take their course, coming to the east and northeast of the Arctic region. Often this transfer of warm air masses is suspended by powerful polar anticyclones, accompanied by the penetration of cold Arctic air masses far to the south (Gyromereorology and gyrochemestri 1990: page number if possible). This is one of the most troubled aspects of working in the region and might cause a number of challenges while conducting surveys or exploration activities. That is why, before starting drilling and production works, we should collect a database about the physical conditions in the region and present forecasts for the long term, establishing exceedance probabilities of waves, winds, polar low effects, etc. for operational and design conditions (Gudmestad 2013: page number if possible).

As mentioned above, compared to all other Arctic seas, the climate of the Barents Sea is characterized by relatively high air temperatures, mild winters and high rainfall. The average temperatures in the coldest months in the eastern part are along the coast equal to: -10°C to -15°C and further north up to -20°C to -22°C. In July the average temperature in HJR/ Fedyn High Sea’s area ranges from +1°C to +7°C. Under the influence of incoming masses of warm water and air from the Atlantic Ocean and the cold air from the Arctic Basin, the climate in the Barents Sea, especially in the eastern part, is very heterogeneous.

Some areas are subject to physical conditions that differ significantly from those found in the Norwegian Sea. The most significant criterion is the presence of sea ice, for which borders can be illustrated as proposed by DNV in the Barents 2020 project, Figure 9.1:

<FIGURE 9.1. HERE>

The Sub-arctic area ii: Barents Sea offshore (the coast of Norway and Murmansk) is generally ice free. The previous Gray Zone is located in this region and considered to be a dominantly ice free area, with local first year ice sheets in the winter time and with occasional icebergs (Abramov 1996: page number if possible).

*Hydrological regime*
The hydrological regime of the “Grey Zone” area of the Barents Sea has a great diversity and develops as a result of the circulation of waters with different origins and different properties:
- Warm water coming from the North Atlantic Ocean,
- Warm and fresh waters with low density from the rivers,
- Relatively cold local waters,
- Cold polar waters.

Water temperature

In the Barents Sea the water temperature, has a much greater influence than in other Arctic seas on all processes associated with the density structure of the water (convection, the formation of layers, etc.). In addition, in the Barents Sea and in the “Grey Zone” area particularly, the water temperature is a key indicator of the distribution of warm Atlantic waters, which determine the ice conditions.

Sea level and tidal waves

Wind-surge level fluctuations reaching the coastal sea areas are at a level of 1-2 m (in the southeastern part of the sea, even 3-4 meters). The tidal wave moves eastward into the Barents Sea in the HJR/ Fedyn High destination and the value of the major tidal component (M2) in Vadsø in the eastern part of Finnmark, is 1.09 m (BarentsWatch, UNEP/GRID-Arendal). It is known that the combined storm surge and the tide can cause considerable flooding as was the case in the Varandey area on July 24th 2010 when the oil treatment and storage terminal located kilometers inland were flooded and the air runway close to the coast was damaged.

Currents

The “Grey Zone” has a complex system of surface and deep currents due to its location, the most common feature of which is the movement of water in counterclockwise direction, see Figure 9.2. Formed by large-scale processes in the North Atlantic ocean-atmosphere system, it is responsive to the variability of the synoptic conditions directly above the Barents Seas. Also the spread of the tidal wave from the Atlantic and the Arctic Basin and the variability of the density structure of sea waters influence the current pattern. One of the main features of the Barents Sea dynamics in the previous disputed area is the tidal currents. Caused by tidal level fluctuations the current has the same frequency, but the direction change of tidal currents is not the same in different regions. The speed of tidal currents is usually higher than the rate of the constant tide, especially in the surface layer; the mean velocity in this current is 0.10-0.12 ms⁻¹, (NERSC (Figure 9.2.), Gyromereorology and gydrochemestri 1990: page number if possible)

Waves

Most storms and hurricanes in the Barents Sea are dominated by south-westerly weather, which is the sector with the longest wave generating fetches. It is seen from NORSOK Standard N-003 that the significant wave height $H_{w0}$ and related maximum peak period $T_p$ with an annual probability of exceedance of $10^{-2}$ for sea-states of 3 hours duration in the Western Barents Sea are comparable with the other areas on the Norwegian Continental shelf, however, peak wave periods are longer than in the North Sea and comparable to those in the
Norwegian Sea. Iso-curves for wave heights are indicated with solid lines while wave period lines are dotted see Figure 9.3. for reference.

<FIGURE 9.3. HERE>

While the design conditions are well established, the main challenges for the construction work in the Barents Sea are the lack of predictability of the weather during the (early) and late construction season, mainly due to unpredictability of the polar low pressures. This might lead to long periods with “waiting on weather” (Gudmestad and Karunakaran 2012: page number if possible).

It is also important to mention the ice edge’s influence on the wave climate, especially in the northern and eastern areas. At a given location the fetch length will increase in summer from sectors subject to winter icing. Therefore the resultant wave heights of waves from this direction will be greater in summer than during the winter. In the marginal ice zone itself the presence of ice will dampen out and reflect energy arriving from the off-ice sector such that the wave height will decrease somewhat away from the ice edge.

Winds and polar low pressures

The wind in the middle and eastern areas (which include the “Grey Zone”) is dominated by cyclones that form in the North Atlantic and move into the Barents Sea. The effect of the land sea breezes diminishes approximately 20-50 km from land (Norwegian Meteorological Office: Polar Lows in the Arctic. http://www.met.no). According to the climate specifics of this area, in summer period the pressure gradients are weaker and the wind direction is more equally distributed between the main wind axes, along southwest-northeast, in the Barents Sea. And one more challenge we might meet in this area is that low pressures which occur over northern Scandinavia during the summer lead to more frequent occurrence of northeasterly to easterly winds.

Huge attention must be paid to the phenomena of Polar Low Pressures, which is the most specific phenomenon of this area and which occurs from early fall to late spring. A polar low is a small, but fairly intense atmospheric low pressure system found in maritime regions, well north of the polar front. The typical diameter is 100–500 km and the average life span is 18 hours. The polar low gives strong and rapidly changing winds and dense showers of snow or hail, and is generally more unpredictable than the larger and more common synoptic lows (Norwegian Meteorological Office). For 15-18 hours duration the average maximum wind speed is 46 knots, which is a severe gale. 35-50% of the lows have storm force winds of 50 knots or more, and the strongest recorded since 2000 had a wind speed of 70knots. The polar low is mostly found in the Norwegian and Barents Seas (see Figure 9.4.), with the majority being between 65°N and 74°N. The season is from October to the end of May, with the most polar lows occurring in the months of December to March. Typically 10 to 20 fully developed polar lows are seen in the Norwegian and Barents Seas during the season.

<FIGURE 9.4. HERE>

Formation

A polar low forms when unstable air in the lower atmosphere interacts with cold air above. A typical precursor to its development is cold Arctic air at low levels moving southwards over the Gulf Stream outside the Norwegian coast. Stability then decreases due to the heat from the
sea and large convective shower clouds form. These have a strong vertical motion of air and an influx of air occurs under the base of the cloud. In areas of strong convection, the shower clouds organize in lines (troughs) with surface winds of 30–40 knots associated with the influx. When the convection interacts with cold Arctic air at heights of 5–8 km, the influx at the surface grows strong enough for a vortex to form and a polar low is born.

Due to their violent and sudden nature, the polar lows have been the cause of many losses at sea. In the past, polar lows were extremely challenging to forecast. Their small size meant that they easily were hiding between observation points in the Arctic, and they did not have a sufficiently high visibility in the weather prediction models. Also, the physical processes were not well enough described in the models. This led to poor model performance and often false or absent indications in the numerical prognoses, as well as a general lack of confidence among forecasters. Subsequently, the lows were often omitted in forecasts to the public. In recent years, the availability of satellite data (images of cloud structures) and wind data from the sea surface has greatly improved. Satellite data are now assimilated in the numerical models and, together with a finer resolution; this has led to a higher quality of short range forecasts. Forecasts of potential polar lows are now routinely included in text forecasts of gale warnings, as well as in forecasts for aviation or maritime users. Still, however, there are large uncertainties in these weather forecasts (Wilcken 2012: page number if possible).

Ice conditions

The Barents Sea is linked to the Arctic seas, but it is never covered with ice completely. This occurs due to the influx of Atlantic waters, which does not allow water to cool to freezing temperatures. Because the ice exchange in the Barents Sea is negligible and its amount is just about 3% of the ice in late winter, the ice of local origin is mainly dominating. In some years only there is multi-year ice in the north-western and north-eastern parts of the sea where the most area is covered. The largest ice cover is usually observed in mid-April, the lowest - in late August and early September. The remaining part of the Barents Sea is usually ice free south of 75°N.

The south-eastern and middle parts of the sea are cleared from ice in May usually, but sometimes it stays there until August. The thickness of ice cover in winter reaches 70-75 cm (Gyromereorology and gydrochemestri 1990: page number if possible). The central areas of the sea are cleared from ice in June and July. By this time it reaches the thickness of 1 m. The minimum number of ice in the north part of the sea is observed in August. The ice cover in the open sea has a high degree of continuity throughout all winter (Gyromereorology and gydrochemestri 1990: page number if possible)

Icebergs

Icebergs, as shown at Figure 9.5., drifting in the Barents Sea originate from the glaciers at Svalbard and Franz Josef Land. They are usually rather smooth, less than 100m thick and with a horizontal extension of maximum 300-400m (DNV 2008: page number if possible if possible). A number of giant icebergs have, however, been observed. In 1881 one iceberg was observed close to the Norwegian coast as far south as 70°N, and in 1929 twenty icebergs were observed off the east coast of Finnmark (Dodrovol'skii and Zalogin 1982: page number if possible). Apart from these reports no icebergs have been observed south of 72.5°N and west of 32°E. This former disputed area is liable to iceberg appearances first of all because the climate conditions and such effects as Polar lows pressures. The probability of finding icebergs within an area of 100 x 100 km is shown in Figure 9.6. The construction contractors will, however, by all means try to keep away from floating ice features and there will be
warnings in case ice floats into the construction area, (Gudmestad and Karunakaran 2012: page number if possible).

<FIGURE 9.5. HERE>
<FIGURE 9.6. HERE>

Spray icing

Another challenge for Fedyn High region is the **sea spray icing**. Wind speed and air temperature are the most important parameters affecting sea spray icing intensity. The wind speed has an obvious effect on the generation of sea spray. In addition it influences the cooling rate of the airborne droplets. The intensity of icing will steadily increase with decreasing air temperature from about -2°C and down to the lowest temperature to be anticipated during offshore operations. The influence of sea surface temperature on the icing intensity is less than for wind speed and air temperature. It is of importance in the initial stage of icing, i.e. at moderate wind speeds and air temperature down to -5°C, but has a marginal influence at high icing intensities. This factor should be considered very carefully while any kind of topsides works is on-going on site.

**Development schemes, main challenges for Fedyn High/ HJR**

The main purpose of this chapter is to determine the possible development schemes for prospects on the Fedyn High in the Barents Sea. The Field Development is the process/activities necessary to design and construct and install all facilities needed to enable bringing the petroleum from the source rock to the refinery or land terminal. The design criteria for the field development concept choice are given by:

- Oceanographic and Meteorological
- Reservoir and fluid properties
- Well completion data
- Process and operation data
- Host facilities data
- Transport to market
- Safety and hazard requirements

Operating by these factors we can present a table of possible schemes regarding to Fedyn High physical environmental and will give a recommendation about the most promising development solution, Table 9.1., provided that the well stream product is mainly dry gas.

<TABLE 9.1. HERE>

By preparing this concept screening table, we can see the advantages of Subsea System with production pipeline to shore with multiphase flow, which will require relatively dry gas (Minikeeva and Gudmestad 2013: page number if possible). With the development of subsea processing technologies, the subsea to shore solution will be even more attractive as water can be taken out from the well stream using offshore processing equipment located at the sea floor. Worldwide experience of sub-Arctic offshore oil and gas fields’ development gives us thus a recommended development scheme for the Fedyn High region.

In the North Sea, the oil companies previously often built large production platforms standing on the sea floor, equipped with process facilities separating gas/oil and water. The gas is sent to market via pipeline, while the oil shipped directly or sent to shore in
another pipeline. Today, the operators often choose subsea developments where the untreated well stream is sent directly from a subsea template to an existing platform or to shore in one multiphase pipeline. In cases where a subsea development with multiphase transport is feasible, billions may be saved by dispensing with costly platforms.

The remoteness of many huge oil and gas deposits, combined with the harsh environmental and ice conditions means that Subsea to Shore development can offer significant benefits over any kind of platform. In some cases, tie back to shore might even be a strict necessity for the technical and economic feasibility of the field development. For instance, this scheme was successfully applied and is currently on stream in the High North offshore (Norway and UK) at the Snøhvit field in the Barents Sea (146 km offshore), the Ormen Lange in the Norwegian Sea (120 km offshore), and the Laggan Tormore project in UK part of the North Sea (143 km offshore, closer to the North Atlantic).

In case of the Fedyn High the most challengeable task is how to provide sustainable multiphase flow management over ultra-long distance (about 320 km offshore) and deliver electrical power to subsea from shore. We will try to identify the major long subsea tie-back issues, clarify which are the limiting factors and the related technology barriers appropriate to this region. The main purpose of this discussion is to see if the step-out distances would be technically feasible based on the existing technologies.

We will state that the most probable development solution for the Fedyn High/HJR prospect (in case of a gas find) will be based on an all-subsea production system, controlled remotely from shore through electro-hydraulic umbilicals, with multiphase flow pipeline to an LNG plant onshore. Alternatively pipeline transport to the market will be discussed.

For Fedyn High/HJR an all-subsea development scheme with a long step-out distance, a subsea high voltage power distribution system may be required in order to provide sufficient power. Hence, support subsea gas compression units will most likely be considered for this area. For time being, the required power levels and transmission distance exceed the current capabilities of the industry in this regard.

The subsea wells are proposed to be tie back to a cluster manifold. Each manifold and XMT template should include a “fishing-friendly” integrated protection structure that deflects trawl boards, so that fishing activities can take place across the seabed where the subsea facilities are located, if deemed necessary. The subsea trees should have remotely operated valves that are used to control the well stream. To provide a large bore diameter will help to avoid significant pressure drop and accommodate large gas volumes. As required subsea trees will be equipped with a variety of instrumentation for monitoring operational performance, for instance, high resolution pressure and temperature transmitters and wet gas flow meters, etc. All these necessitate high data transmission rates. The Central Distribution Unit (CDU) is one of the main pieces of equipment in a full subsea complex.

The CDU is carrying hydraulic control fluid, high voltage electric power supply and a fibre optic modem for conversation between electrical and optical signals and a high speed communication system. High voltage supply is necessary in order to limit the electrical transmission losses over the long umbilical. All at all the CDU is distributed incoming electrical power, the control signals, anti-freeze chemicals and hydraulic out to the templates/manifolds and XMT trees by means of infield umbilicals. There is a number of other outstanding engineering solution to provide sustainable development of such a complex fields: the large bore subsea connection systems to diverless connections of the export and
infield pipelines, subsea pig launcher system for intelligent pigging of the pipeline and a new subsea transformer system for high voltage (typical 3000 volts).

The development of this Cold Climate region requires exclusion of almost all risks with regards to offshore operations, exploration and production as well as transportation. For example, if the primary fibre optic communication system through the main umbilical could fail, a secondary back-up communication system based on superimposing control signals on the high voltage power cables in the umbilical should be considered. A thorough risk analysis needs to be done in the early concept selection stages.

By giving this brief overview of the existing challenges we can conclude that the following areas would need to be examined:

- Multiphase flow regime (Flow Assurance)
- Electric Power Supply
- Hydraulic system
- Communication system and Electrical Signals
- Umbilical System

Even if this scheme of development in the North Sea is quite well known, in case of “Grey Zone” we met number of challenges - how to manage multiphase flow over ultra-long distance (about 320 km) offshore; how to deliver electrical power to subsea processing system from shore; and how a subsea processing system might influence on the main production and economical parameters in comparison with a multiphase flow solution.

We will try to clarify the limiting factors and the related technology barriers relating to this region. Moreover, the main purpose of this discussion is to present a case to conduct comparative analysis for two proposed scenarios for development of the Fedyn High/HJR, for a sketch see Figure 9.7.: 

- **Subsea Production System** (SPS) with subsea processing (separation, compressing/boosting) depends on fuel composition;
- SPS with multiphase flow to shore

To start this case study research, first we should assume the reservoir properties and fuel composition. As there is no detailed information regarding the possible prospects, we are not able to conclude on one particular scenario. So, we suggest several geological models with different reservoir characteristics.

There are three main reservoir characteristics that matter to production: the character of the reservoir rock, the composition and purity of the hydrocarbons, and the strength and nature of the drive mechanism which all influence the flow rate and ultimately the productivity of a reservoir. According to the proposed development schemes and fluid type, which is going to be discussed below, we will check how these reservoir parameters change over the field-life.

<FIGURE 9.7. HERE>

Regarding reservoir type geological data are discussed in previous chapters, by that we can conclude some fact about oil and gas prospects in the Barents Sea. If we will take a look on Figure 9.8. below, it might be seen that Barents region is represented by Oil Provinces in the High Northern and Southern part of the sea, meanwhile the Central and Eastern areas are promising for Gas and Condensate prospects. For instance, the giant oil resources in Pechora
Basin belong to southern part of the Barents Sea, and there is a unique gas and condensate field in the east of Barents – Shtokmanovskoe. A reserve of gas is is located in the south-west of Barents – the Snøhvit, Albatross and Askeladden reservoirs. The north western area is represented by the newly discovered Johan Castberg (Skrugard) oil field. So far the former “Grey Zone” is assumed to be a gas-dominated region, even if oil has also been encountered.

One geological model with particular reservoir characteristics could have four different types of fluid composition,

- **wet gas**,  
- **natural gas with condensate**,  
- **natural gas with some amount of oil or volatile oil**,  
- **oil field with some amount of dissolved natural gas or black oil**

Wet gas/Gas condensate to Volatile Oil is the most likely scenario for development solutions. These four hypothetic fluid composition models will also contain various amounts of water in the mixture, so by that we can conclude regarding the possibility of multiphase flow regime in all cases. Based on scenarios for the distributions of geological formations in the Barents Basin, and the experience of developing similar reservoirs, we can claim that the most likely HC prospects could be found in Triassic-Jurassic which consists primarily of shallow marine sandstones. Reservoir characteristics could be presented by:

- Porosity and permeability might be distributed such that porosity ($\phi$) values vary between 10% and 25% with a wide range of permeability values from 0.1 mD to 1000 mD;  
- Water saturation is considered in our geological model

Depending on the reservoir fluid composition the design of the SPS with subsea processing modules will vary. Subsea processing can take several forms, comprising a wide range of subsea separation and boosting scenarios. Table 9.2. shows a classification of subsea processing systems which might be used as well as being a basic reference to most common subsea processing scenarios. Strategic technologies that are believed to be essential for the successful implementation of subsea processing include multiphase pumping, compact separation and multiphase metering, which are all in varying stages of maturity.

Multiphase pumping usually represents the only commercial form of subsea processing. Multiphase pumping can be classified as a “Type 1” subsea processing system. It directly handles the multiphase mixture with a minimum of equipment. A multiphase pump is essentially a hybrid of a pump and a compressor. The gases are compressed toward the discharge end. This leads to a significant reduction in the gas volume fraction, the GVF and the volumetric rate, as well as an increase in the mixture density.

Subsea processing demonstrates a number of advantages:

- Accelerating production  
- Extending subsea tie back distance  
- Reducing well-intervention costs  
- Reducing subsea-development costs  
- Permitting oil and gas developments in harsh environments
Pumping multiphase production streams, however, still faces many challenges yet to be overcome, for instance:

- **Changes in flow condition during the life of the asset.** Over time actual production may deviate from the initial expectations, so the multiphase pump should be designed to have a wide range of operating parameters to cope with changing flow conditions.

- **Gas Volume Fraction (GVF) variation.** In extreme cases, this can be 100% liquid followed by 100% gas (i.e., GVF from 0 to 100%), which will cause sharp fluctuations in the pumped-mixture density. As a result, the pump load, and, thus, the torque of the shaft, may undergo abrupt variations that could result in serious mechanical problems in the pump. Multiphase pumps can also be used in conjunction with the other types of subsea processing schemes. For example, the **Type 2** subsea processing system makes use of partial separation of the produced fluids. In this case a multiphase pump will still represent the best option for pumping a liquid stream that will have some amount of associated gas. A multiphase pump or wet-gas compressor will also represent the best choice for the gas stream. If the gas stream is not left to flow under its own pressure, a multiphase pump or wet-gas compressor can boost pressure of the gas stream even when it contains several percent of liquid by volume.

A number of separation options are being considered for **Type 3 and Type 4** subsea systems. Subsea processing will avoid lifting large volumes of water to the surface for processing and disposal. This can reduce lifting costs and allow economies in topside water processing and handling capacities and could extend the economic life of deep water projects and reduce development risks. But a safety systems consideration for subsea processing is an area where not so much work has been done recently. While the remote subsea location reduces the risks to personnel, environmental risks still remain.

Subsea processing technologies are becoming preferable options to improve technical and economic performance, improving the reserves recovery and operation strategy, and even reducing the associated development CAPEX. Even though the benefits of subsea processing on the bottom are difficult to underestimate, there are still challenges that remain in the key pieces of the “SPS to shore” development concept.

The required power supply to subsea compressors typically would be in the range of 6 to 12 MW per compressor. It is hard to say for sure if subsea compressors will be needed for Fedyn High/HJR because of no exact information about the reservoir conditions (pressure, temperature) and the component mixture of the HC. If the technology will be required for Fedyn High/HJR the system most likely will work on the Åsgard field compressor station principle: flows through the existing pipelines into the manifold station, which distributes it into compressor trains located at the subsea compression station. In each compressor train, the multiphase stream is first cooled down in a specially designed heat exchanger and then it enters the scrubber where the gas and liquid (condensate and water mainly) are separated. The gas stream out of the scrubber is then routed to a 12MW centrifugal compressors and the liquid stream to a a 700-800 kW centrifugal pump. At the compressor discharge, a recycle line with a fast acting valve takes the gas back to upstream of the inlet cooler in case the operating conditions get close into the compressor surge curve. Yet at the compressor high pressure side, a discharge cooler lowers the gas temperature to below the limit dictated by the existing pipelines before it is cominigled with the liquid from the pump. At last, the multiphase stream flows back to the manifold station and further to shore.
As for Flow Management, Electrical Power issues are not less important and require outstanding solutions for long step-out subsea fields using subsea processing. Alternating current (AC) power at standard 50 Hz grid frequency (higher supply voltage) works sustainably, but it is very sensitive to the long distance, the power transmission losses will inherently limit offshore location to about 250 km. The limiting factors relate to capacity loading current, voltage variation and inductive losses. One of the solutions proposed is to use a lower supply AC frequency; with this approach even ultra-long step-outs are achievable (for example Stokmanovskoe field - 600 km offshore).

Hence, if we consider subsea compressors for Fedyn High subsea system, due to sufficient pressure drops on the well head and all over the pipeline, the power supply will be in the megawatts range like for a wet gas compressor (12 MW). It means that the longer step-out distance, the more benefits will be gained from the subsea compressor, but at the same time it requires a more difficult power supply at a sufficient level.

With increasing distance it is evident that the respond time will also be increased, i.e. the time elapsed between pressing the button in the onshore control module and when the subsea piece of equipment will actually respond on that command/signal. Solution is found for hydraulic system issues as well. It is proposed to use subsea accumulators on the wells, assisted by the accumulation effect provided by the umbilical itself. For communication and data transmission requirements for step-out field we should take an example of transmitting massive signals rates over transatlantic distance by using fibre optic technology. This technology has shown itself like a reliable and sustainable solution so an ultra-long distance for the communication systems should not be a problem.

Currently, umbilical systems used for subsea fields are rather complicated, both in terms of cost and technical complexity. For example, the main umbilical for Snøhvit is 144,267 m. long and weighs about 2,000 tonnes; in May 2012 Oceaneering received an order from Petrobras, for the supply of approximately 200 kilometers, or 125 miles, of thermoplastic production control umbilical for field development projects offshore Brazil in the Santos Basin. So, ultra-long distances can be accommodated by manufacturing the umbilical in several sections, which then are spliced together into one continuous length during installation. Such splices would offer a natural opportunity to insert optical isolating amplifiers or repeaters into the umbilical, thereby improving signal fidelity.

Flow assurance

Much attention is to be paid to design and operation of multiphase transportation systems (flow assurance). Multiphase transportation implies many new challenges:

- Under unfavourable conditions, oil and water may flow in large batches (slug flow) which can disturb the receiving facilities
- Oil and water may form emulsions which give high pressure losses and reduced production
- Wax and hydrates (an ice-like substance) may precipitate and block the pipe
- Unfavourable water chemistry may lead to fatal corrosion attacks piercing the pipe

Before commissioning a field, it is important to be able to predict possible problems and to predict flow patterns and pressure losses as accurately as possible so that pipelines and process plants may be designed optimally (Minikeeva and Gudmestad 2013: page number if possible).
Transport to market: LNG and/or Pipeline

LNG

Exploration and production of natural gas in the sub-arctic region create a challenge for shipping gas in such extreme conditions. In this paper, we mainly explore available alternative transportation options via LNG or Pipelines and do not investigate the natural gas market at all.

Energy demands are increasing steadily throughout the world, and concern for the environment and the greenhouse effects of fossil fuel, is growing. This development has contributed to the growing attractiveness of more environmentally friendly alternatives to oil and coal.

Natural gas is projected to be a growing fuel source through 2030 because it is clean-burning, reliable and abundant. Additionally, advances in technology have made it economical to ship natural gas all over the world, making it a truly a global resource.

To deliver the fuel to the costumes as well as to the local market, choice of transportation route and method is required. For Barents Sea area there are two ways: LNG and Pipeline transport. A discussion on the most suitable way of transporting will be given below.

By transforming gas from its natural state into liquefied natural gas (LNG), it can be delivered via tankers from distant production areas to markets that need it. Given its flexibility, environmental benefits and large resource base, LNG is a natural choice to help meet the world’s growing energy needs. Figure 9.3. briefly shows the LNG value chain.

It is easy to overlook the fact that LNG is not a new energy source. LNG technology and infrastructure provide a means of monetizing otherwise stranded gas reserves and bringing them to market. For the LNG industry, a growing long-term gas demand drives major investment in global LNG facilities. Furthermore, there is the prospect of further demand for natural gas as the world considers the future of nuclear energy.

Pipeline transport

Transportation to the markets is not a challenge for conventional LNG tankers. In figure 9.10. the main transportation export routs are shown. European market might be seeing like the main region to import LNG from the Barents Sea area. With LNG terminals onshore Norway or Russia, LNG transportation could be the most promising scheme for Barents region. International markets will be located in Asia and USA—where there is still a discussing on shale gas rates; and in this case LNG Must be delivered by vessels.

Regarding the natural gas consumption in Europe, we can also consider pipeline transport along the Norwegian cost or by pipeline net through the Russia Federation, for instance, using the “Nord Stream” pipeline to European market, see Figure 9.10.

Development schemes for oil fields

With reference to Table 9.5?, it must be noted that wet gas developments, gas-condensate developments and oil developments require use of offshore processing schemes. Thus there
will be a need for placing surface facilities with process equipment at the field offshore. Associated with this, the need to ensure safety during the entire lifetime of the production raises important questions, such as:

- Will there be a need for disconnection of the production facilities should ice drift or icebergs be threatening (Gudmestad et al. 2011: page number if possible)?
- Winterization will be necessary for all equipment (DNV 2013: page number if possible), personnel and evacuation means (Jacobsen and Gudmestad 2012: page number if possible).
- Oil spill pollution equipment must be developed to function in cold climate, possibly in icy waters. This remains a large challenge and should be discussed separately before a decision to develop a field is taken.

Conclusions

From above information and discussions we present the following conclusions:

- The Barents Sea area has very large potential for oil and gas developments as there are very interesting prospects that could contain large volumes of oil and gas
- The physical conditions of the area are very challenging and one will benefit from learning how to work in the Barents Sea by starting production in the ice-free part of the area
- Subsea development schemes provide the most promising methods for successful gas field developments
- The technology is still not sufficiently advanced for oil production without the use of surface vessels to provide the necessary processing
- Market situation for gas is challenging, however both pipelines to the European marked and LNG production represent well-established methods for safe delivery to the customers.

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CHAPTER 10

Petroleum Production Facilities in Arctic Operational Environments

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Introduction

As the petroleum industry is becoming more active in the Arctic regions and are planning the exploration and exploitation of oil and gas fields, it is important to take into account the special conditions that exist in the Arctic and how they are going to affect the design, the operations (including maintenance and support activities), as well as costs. Even though the oil and gas (O&G) industry has been active in Canada, Alaska (USA), Russia, and other regions with Arctic like conditions (e.g. the northern part of the Caspian Sea and Sea of Othotsk) for a long time, not much has been published on how the special conditions in the remote arctic locations affect an industrial production facility design, construction and installation, and not the least the operation, maintenance, support and end of life phases.

The design of facilities to be used in the Arctic region needs to be based on sound design criteria to avoid environmental disasters and high costs, and to improve the performance efficiency (Gudmestad et al. 2007; page number if possible, Gudmestad et al. 1999: page number if possible). The industry, society and other stakeholders will benefit from improving production facilities in the design phase and by making them more environmentally friendly, more safe, reliable and easy to maintain as well as more effective, efficient, productive, profitable and competitive.

The Arctic is said to have a harsh and cold environment, most of it has a remote location and a sensitive environment. However, one should be aware of that there is a large variation in the degree of coldness of the climate, harshness of the weather and the remoteness of the location. The south-western part of the Barents Sea, north of Norway, has for example a relatively mild sub-arctic climate due to the warm waters of the Gulf Stream which is an Atlantic Ocean current originating from the warm Mexican Gulf. The possibility of icebergs and drifting ice in this region is small. This region also is relatively close to the northern cities of Tromsø, Norway and Murmansk, Russia. However, an industrial production facility in this region will still experience low temperatures, large temperature variations and long periods of darkness during the winter. Other Arctic areas relevant for O&G production (such as the West coast of Greenland, North coasts of Alaska, Canada and Siberia, etc.) do have a much colder climate, more severe weather, and even longer distance from populated areas with good infrastructure, larger population and competitive markets for products, supplies, services and qualified personnel.

The unpredictable weather and harsh arctic climate found in most of the Arctic include cold temperature, wind, arctic hurricanes (polar lows), icing, snowdrift, etc., which will affect exposed equipment and personnel. The performance of the operating and maintenance personnel and work processes in general also will be influenced by the cold climate.
conditions, in particular by low temperatures and icing. The cold climate conditions will influence the functional performance of the equipment/machines/systems as well as the reliability. The remote geographic location, sparse population and poorly developed infrastructure will also cause increased demands on operational and maintenance logistics and industrial support services. To reduce risks, the functional capabilities need to be suited to the production strategies as well as manning and logistics needs to assure health, safety, environmental requirements as well as and costs and other requirements.

To be economical viable any industrial production facility need to have an acceptable performance. We may summarize that a production facility performance is dependent on that the technology (technical systems, equipment, machinery, processes, etc.), the organization (organization, facilities, support tools, external support, infrastructure, etc.) and the humans involved in all phases of the life cycle all have to produce acceptable performance. For example, an O&G production facility should be running when needed at a predefined acceptable operational state. For and O&G production facility, this is 24 hours a day, 7 days of the week, all year around, and this may be more difficult to achieve in an arctic climate with harsh weather condition at a remote location.

The adaption of a production facility design to the cold climate conditions and harsh weather may result in a more complex design through integration of hardware, software, sensors, controls, information technology, etc. However, this may also result in the systems having more complex failure modes, which are more difficult to diagnose and repair, and becoming more complex to operate and maintain. Reliability, maintainability, and supportability will be affected, and may result in reduced availability performance, increased costs, and, thus, reduced profitability over time.

Most maintenance activities should, in general, be proactive and planned. However, due to the harsh and unfamiliar environment, an increased number of unplanned failures (often occurring suddenly) may be expected and resulting in unplanned and expensive corrective maintenance and unplanned downtime with no production - especially in the beginning of the life cycle. Even if the production facility is designed to meet the climatic and weather challenges, its operation and maintenance strategies need to be developed to suit the localization and environmental conditions as well.

It is not difficult to imagine how a cold arctic climate and daily weather might affect a production facility as most have experienced cold temperatures and bad weather and felt how it affect our physical and mental state and our activities. However, in order to discuss the consequences of the particularities of an arctic operational environment, we will first take a look on the general goals of production facility operations. Thereafter we will discuss how the arctic climate and locations affects these goals and finally what can be done to overcome the operational challenges in an arctic environment and location present.

This chapter mainly focuses on the offshore oil and gas production in the south-western Barents Sea, north of Norway, where the current oil and gas activities are focused (Gudmestad 2013; page number if possible). Furthermore, we limit ourselves to discussing how the climate and weather influence an industrial production facility design, operation, maintenance and support. However, most of the discussion is general and relevant for other industrial operations as well.
Operational goals

To develop O&G fields in remote Arctic areas, the production facility needs to be designed such that the operations and maintenance activity performance ensure fulfillment of health, safety, environmental, and quality (HSEQ) requirements. Due to environmental concerns, a strict policy of zero release of waste and chemicals to the sea has been decided upon and will also be enforced. The Goliat field is located relatively close to shore and close to sensitive fishing grounds. Potential spills or leakage to the sea, therefore, will need to be dealt with at the design stage to reduce and/or mitigate risks. The design and operational concepts have to include measures to protect water, vegetation and wildlife. Furthermore, the climate will be more extreme than in the Norwegian Sea and the North Sea further south. The normal weather conditions may not be worse than experienced further south in Norway, but one will expect increased frequency of storms with increased severity, and thereby increased risks.

Modern industrial offshore production facilities are advanced, complex and integrated systems that are designed to safely, economically and continuously facilitate the transportation and processing of the oil, gas and water from the reservoir and transformation to energy used by the society.

The mechanical, hydraulic, pneumatic, electrical, etc., systems consists of dynamic machinery (with moving parts, e.g. motors, pumps, turbines, compressors) and static equipment (no moving parts, e.g. tanks, separators, pipes, pipelines, etc.) in combination with automation and control system consisting of sensors, switches, cables, controllers, electronics, electric circuitry, and software, placed on top of an offshore structure (e.g. a platform, ship).

The most important operational goals for such advanced, complex and integrated production facilities are normally specified with respect to the:

- Health and safety of the plant personnel and the surrounding society
- Pollution of the environment in which the facility is operated
- Plant availability over time
- Plant operational quality (effectiveness, efficiency, productivity, etc.)
- Quality of the plant output
- Life cycle costs and profits

Health

Health goals relates to the long-term effects from the technical plant, the operational, maintenance, etc. activities and the surrounding environment (e.g. local climate, and daily weather variations) on the plant personnel´s physical and psychological health. Furthermore, the plant and the plant operations should not affect the society and people living nearby. For example, pollution, noise, traffic, etc., should not make people living near the plant sick. Furthermore, the psychological health may be affected by location effects such as darkness, long distance to home, work related stress, etc., and may affect the quality and speed of work.

Safety

Safety relates to accidents and incidents that have an immediate affect negative effect on the plant personnel and people in the surrounding society (e.g. smoking is a health issue as it has no immediate negative effect on the smoker, whilst a falling hammer may have an immediate effect if it hits a person). We will discuss further the safety of the plant.
Environment

Environmental consequences can be both pollution to the surrounding environment (air, water, earth, etc.) or as wasteful energy usage. Animal, fish, birds, insects, etc., should not be affected by pollution from the plant, and by the plant activities. If energy inefficient machinery is used, pollution is created in producing the extra energy. For example, a machine often degrades and wears over time due to usage. This may result in increased energy consumption to produce the same output as when it was new. In this case, preventive maintenance of the machinery to bring it back to the original condition may cost a bit, but may also remove the pollution related to producing the extra energy, and also reduce the energy consumption and thereby the costs.

Plant availability over time

Plant output is dependent on that the plant is built to accommodate the production volumes anticipated and that it is available to be run when needed. This production capability and capacity also need to be consistent reliable over time to be competitive. The customers are interested and paying for safe, secure and timely delivery of the output (the product) with the right quality from the production facility. To ensure timely delivery one may build in buffers in the production system in case of an unplanned shutdown that will delay the delivery to the customer.

For example, for a typical offshore oil and gas production facility the goal is that the plant should be running continuously without interruption at all. However, things not always go as planned and sometime systems degrade/fail and cause oil and gas production interruptions. To minimize such interruptions some production facilities have, for example, built in storage tanks that can be used to store oil in case the oil tanker hired in to transport the oil to the customer is delayed. Similarly a tanker may load its cargo from the tank in case the production facility is having problems.

Another example of a buffer system that may increase the availability for shorter periods is the pipelines built to transport gas to the customers. As the pipelines have a large diameter and the gas is under large pressure, they contain a large volume of gas. If the production facility is facing problems and stop delivering gas into the pipeline, the customers still may still get uninterrupted gas delivery from the gas already enclosed in the pipeline (as a diver using gas from a high pressure air tank with a definite volume) until the pressure becomes too low. This solution buys some time and the customers do not see and experience the effect of a production problem. However, most often this is a solution that may be costly and which only will buy some time.

The assurance of the production availability is dependent on the reliability, maintainability and supportability of the plant machinery, equipment, components, etc.

Reliability

The main goal of reliability is to avoid that failures cause stoppages of the system function or reduced system function performance. To achieve high reliability the components should be manufactured to tolerate the internal and external loads and the wear and tear over time. The achievement of reliability is also dependent that the assembly, integration with other components, machinery and structure is done correctly and that installation, commissioning and testing processes are done correctly, as well as that operations are within specifications and intentions (i.e. the machine should be used for the purpose it is designed for without
overloading it). Furthermore, high reliability does not mean that machine is maintenance free - often high reliability is achieved due to excellent preventive maintenance done before the degradation is allowed to develop until the occurrence of a failure event where the performance is less than specified or completely absent and, in the worst case, causing a hazard for people and for the plant itself. Reliability is a design parameter - after the design phase the reliability can only reduce. Reliability improvement after the design phase requires a redesign of the technical function solution, an upgradation in the material selected, or a change in how the function solution is implemented in manufacturing, assembly, testing and integration with surrounding systems.

Maintainability

The maintainability is deciding how easy and fast one is able to perform preventive maintenance (before a failure event) and to perform restoration and repairs after a failure event. The maintainability parameters includes enough space to conduct maintenance activities, not too heavy components (built in lifting arrangement if the components are too heavy), usage of standard tools in maintenance activities, modular design that enable easy and fast exchange of deteriorated or failed modules, etc. The main maintainability goal is to reduce the downtime and to enable fast, safe, effective and efficient preventive and corrective maintenance activities.

Supportability

All systems need support services that are delivered by internal and external providers during the various life cycle phases. The support during maintenance activities may for example seriously affect the quality of the maintenance and the time the maintenance takes. If a spare part or a specialist needed for a maintenance activity is delayed, the consequences are extended downtime with no production and income to cover the costs that are running even though the production is not. Example of supports services needed during operations include spare parts and field engineers from an original equipment manufacturer (OEM), planning, scheduling and execution of maintenance activities, training of operators and maintainers, operational performance analysis, engineering during plant modifications, etc. The output of a supportability analysis decides how effective and efficient support services can be delivered to the system when it is needed. This requires that there is in place an organization with ability and means to plan, organize, administrate and to deliver the support when needed. This also requires an infrastructure that has capacity and capability required and that is also reliable.

One also should realize that reliability, maintainability and supportability are design parameters that should be thought about as early as possible in the design process to enable effective and efficient systems.

*Plant operational quality (effectiveness, efficiency, productivity, output quality, etc.)*

The operational quality is dependent on that the plant technology is designed such that technical processes are able to meet the production goals (quantity, volume, quality) effectively, efficiently and continuously when called upon. This requires that there should not be any bottlenecks in the technical process and that the technical systems functions as intended within specifications and without failure. The plant output should be of such quality that the customers are satisfied and are willing to pay full price. However, the operational quality is also dependent on being operated by qualified and skilled personnel and that there is
an effective and efficient organization in place to organize and administrate, plan and schedule, etc., the plant’s activities according to needs.

Maintenance needs

The maintenance needs are decided by the 1) unreliability of components due to insufficient or wrong quality of materials or manufacturing and assembly processes; 2) human errors due to insufficient training or poor operational and maintenance procedures; 3) statutory requirements which may vary depending on physical location, country, etc.; 4) accidents; etc. Maintenance is a compensating work process carried out to prevent system failure (preventive maintenance) or to restore the system function after a failure occurs (corrective maintenance).

Even simple systems are almost impossible to design so they are maintenance-free due to costs and technological considerations. Most advanced and complex systems are not 100% reliable and experience occasional failures followed by corrective maintenance. Systems that are 100% reliable are often due to the preventive maintenance designed to keep the systems running. Furthermore, even though components, equipment, system and machines have become much more reliable than before, the use of advanced, complex, and integrated systems has resulted in that failures may be difficult to diagnose, repair and/or restore and may as well increase the downtime and thereby reduce the production output and increase the downtime costs.

Life cycle costs

For a production facility to be profitable it needs to be able to produce the output at sufficient and agreed upon quality, and to deliver it at the right time and at the right costs to the customer satisfaction over time. The income from the output should support operational inputs (e.g. raw materials, organization, personnel, external support, etc.) needed to produce the output, the pay of the bank loans needed to build the plant, the insurance, etc. To be competitive the costs should be as low as possible and the quality as good as defined in the agreement with the customers.

Next we will discuss what is special about the arctic climate, weather and location and how are the plant goals affected.

The Arctic operational environment, key aspects of importance for production and maintenance

When considering industrial activities in Arctic locations one obviously need to consider the local climate and weather. Climate and weather both refers to who the atmosphere is behaving and its effect upon human life and activities (NASA 2005). Climate describes the average long-term weather over time and space, whilst weather refers to short-term (minutes to months) changes in the atmosphere. An easy to remember phrase expressed by Robert Heinlein in a science fiction novel in 1973 says that “climate is what you expect, weather is what you get”. Even though the climate data shows the average long term weather behavior, one need to use the extreme weather data for worst case scenario predictions for production facilities design dimensioning, as well as for the planning of any operational and logistic activities.

Weather may be described in terms of temperature, humidity, precipitation, cloudiness, brightness, visibility, wind, and atmospheric pressure (high/low) (NASA 2005). In addition one have to consider the winter darkness that increases in duration the more north one is from the polar circle.
The foremost and most important parameter is the temperature - it strongly affects the materials used and the human capability and capacity for cognitive and physical abilities. However, the other parameters should not be dismissed - often it is the combination of several factors that creates the most severe weather effects.

The humidity and precipitation in combination with wind may cause atmospheric icing that may cause accumulation of ice on facility structures. The cloudiness may cause stoppages in the helicopter activities important for logistics of people and materials. The long periods of darkness during winter may cause human depression, the period of brightness during the summer may cause sleep problems. It is well known that humans do more errors if depressed or tired. Visibility is reduced by when it is snowing, raining, foggy, or darkness. Strong wind in combination with precipitation in the form of snow or rain may reduce all kinds of operational activities as well as causing stoppage and delays in logistical operations.

As mentioned briefly in the introduction, the Arctic is a large area with huge variation in the climate and weather. For example, the arctic climate in Alaska, Canada and Russia is a “stable” cold climate, whilst the climate in the south-western Barents Sea is cold with frequent changes in temperature. These temperature variations may create additional challenges. The sub-arctic climate in the Barents Sea is strongly influenced by the warm Gulf Stream originating from the Gulf of Mexico. The possibilities for icebergs are quite remote, even though there is a small possibility of drift ice in the northern part of this area. The geographical area is sparsely populated, but rich in wildlife and fishing resources. This demands additional focus on requirements that need to be considered in the design phase regarding operations, maintenance and support.

**Temperature**

A temperature of 0°C has been cited as the key element in the definition of what should be considered a ‘cold region’. Materials such as metals, plastic and lubricants begin to show the effect of cold temperature on their properties well below 0°C temperature (Freitag and McFadden 1997: page number if possible). Temperatures vary according to location and season. In the Arctic, the coldest months are often January or February (-30°C to -40°C) and the warmest month is July.

For Sub-Arctic areas, the equipment and facilities not only have to be resistant to low temperatures, but also to large variations in temperature during short periods of time.

**Wind**

In the Barents Sea, the phenomenon of ‘polar low pressure’ may occur. The so-called “polar low” storms or “Arctic hurricane” is a shallow, short-lived low pressure centers causing severe weather with heavy snow and strong surface winds that appear suddenly forming over polar seas (Weather online 2014). They may be identified using satellites, but are not easy to forecast and may therefore create huge problems for industrial activities in the Arctic (Gudmestad 2013: page number if possible).

**Icing**

Ice on structures/equipment may cause enormous challenges if maintenance is needed. Depositions of ice glaze and accumulations of wet snow on the surface of facilities, communications and power transmission lines, and white frost formations are often observed.
When designing a plant and a production facility, it would be an advantage to know how the weather is affecting the location (e.g. probability of rain, freezing rain and wet snow, wind direction, frequency of winds stronger than 10 m/s for different air temperatures). This type of information may tell us at which direction and temperature different precipitation events most likely will occur (Drage and Mølmann 2003: page number if possible). In addition, the wave height in combination with strong winds will have an influence on the degree of sea-spray. The design should therefore protect the production facility against the direction where it is most likely to grow ice (see also ABS Guide 2006: page number if possible).

In the early winter 2006, the production facility at Melkøya experienced icing of the equipment due to the storm named “Narve”. For pictures, see http://www.finnmarkdagblad.no/bildeserier_fd/article1920428.ece. The production was closed down for four-five days, and it took nearly one month before operation of the facility was back to normal (Isaksen 2006: page number if possible).

Snowdrift

Snowdrift is another climate factor to consider during the design, construction, maintenance and operation of a production plant. Snow is relatively easily suspended and transported by wind and creates a variety of problems in cold regions. Snow that remains will metamorphose over time into an assemblage of roughly spherical ice grains. Even if the temperature remains well below freezing point, the snow/ice crystals grow due to vapor diffusion and freezing at contact points.

The concentration of snow in the air increases rapidly with wind speed. Snow accumulation at production facilities may be problematic for maintenance and operation work. Wind-blown snow can restrict the access to equipment and instruments, ventilation outlets, and can block doors, rails, stairs, etc.

In situations with snow precipitation and strong wind, the snow crystals will accumulate in low velocity areas near obstacles and create snow depositions. The process is often self-intensifying. Especially during the design and construction of an onshore production facility, possible snow accumulation should be considered thoroughly. A possible efficient solution could be the construction of snow fences (Drage and Mølmann 2003: page number if possible; Freitag and McFadden 1997: page number if possible).

Weather forecasting

The northern region has a poor coverage of weather observation stations (Wergeland 2006: page number if possible). Experiences from the weather stations in the north of Norway show that the weather forecasting abilities are inadequate. The forecast may indicate that a low pressure is building up, but the size, location and strength is hard to predict (Torrissen and Johansen 2006: page number if possible).

Effects of the Arctic environment on operations

The severe arctic climate and remote locations may seriously influence the production goals. The cold temperatures may affect the performance of the materials used in the technical systems, the performance of the operation, maintenance and support personnel. Furthermore, the remote location with less developed infrastructure, less populations and fewer market may affect the organization of operational and maintenance activities and support processes.
Materials

A number of materials such as iron and steel, polymers and plastics, concrete and composite materials experience embrittlement at low temperatures (ABS Guide 2006: page number if possible; Freitag and McFadden 1997: page number if possible). This may cause failures at loads that are routinely imposed without damage in warmer climates. When the brittle transition range falls within the material service temperature, brittle fractures are a paramount concern. Steel and alloys of iron that have been treated to change the crystal structure tend to lose the benefit of treatment when the service temperature is below -10°C. During cold-weather welding, preheating has to be included in welding procedures and careful post-heating is necessary to avoid the rapid cooling of the heat-affected welding zone which often creates a zone of very strong, but also extremely brittle metal.

Seals and gaskets are primarily made of elastomers that can be fabricated for low-temperature service (Freitag and McFadden 1997: page number if possible). However, when some polymers are cooled slowly enough, the resulting crystallization will affect the mechanical properties and sealing capabilities. The consequences may be serious leakages of lubricants, coolants, etc. Highly crystallized plastics are rigid and brittle, making them poor candidates for cold temperature service. Cold temperatures also cause generation of static electricity that can destroy electronic components in computers, control circuitry, etc.

A simple approach for winter concreting is to avoid exposing concrete to freezing temperatures (Freitag and McFadden 1997: page number if possible). New additives for antifreeze and quick set, new materials for high strength, and new techniques for placement promise to extend the range of conditions under which good quality concrete can be produced.

Engines and equipment operating during cold weather are subject to higher wear and increased breakage (Freitag and McFadden 1997: page number if possible). Lubricants are used to reduce friction and thereby wear rates between moving components in dynamic machinery. Their secondary function includes removing particles between moving surfaces and to cool components heated by friction or combustion. Oil becomes more viscous as the temperature falls, thus making it more difficult to supply lubricant to renew the protective oil film.

If the lubricant fails to perform, one will experience increased energy usage, increased wear rates and thereby earlier failures as well as increased number of unplanned corrective maintenance and extended downtime. Routine operations such as steering, starting, braking and operation of controls will require increased energy usage due to inadequate lubrication performance and thereby increased friction. Also the rolling friction in for example bearings will be higher and require increased energy usage in the form of higher fuel consumption, richer air/fuel mixture. Slow uniform warming of the entire engine is desirable during cold weather and of critical importance during extremely cold weather.

A hydraulic system will cease to perform when the temperature drops to a few degrees above the pour-point (Freitag and McFadden 1997: page number if possible). Arctic grade hydraulic fluids should be used and hydraulic hoses must be rated for cold weather use. Some synthetic materials that are acceptable for hot-weather work become brittle and fail under pressure during cold-weather operations.
To avoid freezing and rupture of liquid cooling systems one should use freeze protection for any vehicle that is exposed to temperatures below 0°C.

**Human factors – “Man in the Arctic”**

Wind, snowfall and darkness in combination with low temperature, will reduce the operational effectiveness drastically in a cold climate. Humans were “designed” to operate in a very narrow temperature range, and when we push the limits of that range, we are subject to increasing physiological stress (see also ABS Guide 2006: page number if possible). At low temperatures during the performance of manual tasks humans have reduced cognitive/reasoning abilities and cognitive errors are more likely to occur. In general, as the ambient temperature falls below freezing, the effectiveness of workers declines significantly (Perkins 1996: page number if possible).

More energy is needed to keep the body operating and it tires more quickly. Coordination suffers, the body moves more slowly and productivity decreases. The possibility of making mistakes or being inaccurate will also increase. Extra time must be allowed for all operations when the temperature drops (Freitag and McFadden 1997: page number if possible; Påsche et al. 1990: page number if possible).

**Wind chill**

When exposed to cold temperatures, the rate of cooling and heat-loss for an exposed surface, such as skin, depends not only on the temperature but also on the speed of the wind (Freitag and McFadden 1997: page number if possible). When the wind speed rises, heat generation must also increase or more clothes must be worn to prevent the body’s core temperature from dropping.

In 2001, the National Weather Service implemented a new wind-chill formula to provide a more accurate understanding and useful formula for calculating the dangers from winds and freezing temperatures. The new formula estimates a significant reduction of the wind chill effect (NOAA, 2007). When dealing with exposure conditions, an unheated shelter of any kind is better than being exposed to even the slightest wind. A tent or a tent-like structure around the worksite can improve conditions significantly. If it’s impossible to enclose the work area, frequent breaks at a warm location help to slow performance deterioration. Long, infrequent breaks are not as good as frequent, short breaks in maintaining performance and worker contentment (Freitag and McFadden 1997: page number if possible).

**Clothing**

Heavy clothing is necessary for protection as humans are fairly vulnerable to cold temperatures. Heavy clothes impede motion, and more energy is required for even the most routine chores when dressed in cold weather gear. In a cold climate a person is totally dependent on his/her personal protective equipment. The establishment of proper work procedures and work task training is necessary to perform the work within specific safety and efficiency limits. Even with these preparations, an extremely cold environment represents a work environment that may be hazardous for people’s health. For work requiring a high degree of activity, it is important that the clothing has as good ventilation as possible to reduce the perspiration effect resulting in damp inner clothing and cold injuries (Päsche et al. 1990: page number if possible).
Food intake

One physiological aspect that does not slow down is the appetite. After a full day of work in the cold, the body compensates for the increased energy use and heat loss by increasing the metabolism and the result is a much greater appetite than normal. When supplying rations for outdoor winter activity, the normal amount of food supplies should be increased by factors from 1.5 to 2 times the normal. Warm liquids also help to avoid dehydration that is a frequent problem when working in extremely dry, cold air (ABS Guide 2006: page number if possible; Freitag and McFadden 1997: page number if possible).

 Darkness

Winter in latitudes north of the polar circle is characterized by periods of complete absence of daylight. The darkness reduces the efficiency of workers. The length of periods that the sun is above the horizon at a site is determined by the relative position of the sun, the earth and the location (Freitag and McFadden 1997: page number if possible). At worksites, artificial light is necessary in periods when most of the day is dark. However, it has been a challenge to make light bulbs which have long efficient life and at the same time are resistant to long, cold periods (Dragsund 2006: page number if possible).

Effects caused by the remote location

Transportation and communication are vital to the growth and prosperity in any region. In general the cold regions in the north are not as populated as further south, and the development of roads and railroads is limited. Even where roads exist, winter conditions of ice and snow seriously degrade the effectiveness of transport. The number of adequate airports in these areas is limited, and airplane communication is not as frequent as in other regions in the country. In the Sub-Arctic areas in Norway the situation is better, but the railroad is not developed. Helicopters can be used regularly, but the weather conditions may restrict the frequency.

Transportation

In the Arctic region there are only in Russia shipyards capable of taking on large scale construction projects needed to build large scale production facilities. Fabricated modules will most likely be built in yards far away from the development site. Transportation from the yard to the site has to be taken under serious consideration. Most heavy transportation is carried out using ships and barges. The cost of transportation of the modules will be high, and require careful planning. The capacity to perform repair work is, however, available in Norway and Russia. The physical environment may be rough and unpredictable, and it’s important to be familiar with the differences in seasons. Ice has to be avoided, but also wave heights, wind strength/ direction, as well as icing in harbors and open water have to be considered. The weather-window for transportation is less than elsewhere.

Competence

O&G production facility development and construction requires a lot of equipment and labor. In the Arctic regions, getting enough competence to the area may be challenging. Most likely, there is no one or very few in the area that has experience with such technology and expertise. One solution may be to educate and train local inhabitants, if there are any, in the needed skills. However, most often skilled labor has to be hired in for periods or moved to the development area.
Onshore development in remote areas, as for example constructing/operating process facilities or terminals, will need a large workforce as well. To establish a new society in a remote area will take time, not only to get people to settle down for longer periods, but also to get people to flourish and to keep them there. For extreme remote areas, it may be advantageous to let the workers work in shifts and rotations (e.g. four week rotation).

Communication

Modern communication systems have proven to be very important to the development of the cold regions. A radio-telephone system with microwave and satellite linkage has, for the most part, removed the isolation from even the smallest communities. Telecommunication systems not only permit direct conversation on matters of daily concern, but also carry educational programs and furnish specialized technical advice and remote support to supplement the knowledge of the resident personnel. In case of an accident, medical advice from the closest hospital could easily be given with today’s telecommunication technology.

With the aid of web-cameras and the possibility to transfer medical data directly to experts at the hospital, it is feasible to give medical advice and treatment to offshore installations and to other remote areas. With a similar technique, information and communication technology (ICT), telecommunication systems may be used to provide technical advice and problem-solving during the development period and operation stage. The work processes are improved at the same time as the operational expenses are reduced. Advancement in ICT has made it possible to inspect, supervise, and control processes 24-7 remotely and away from the production or operation site. ICT also enables access to experts located in different parts of the world.

Furthermore, companies can use emerging technology to improve performance and develop smarter operations, maintenance and support processes (Kumar 2005: page number if possible; Kumar et al. 2006: page number if possible).

Support services

Support is a wide concept, and includes logistics, inventory and infrastructure, information and communication, as well as competence and skills. When aiming for cost-efficiency, these factors are essential throughout the service life of any production facility. In the Arctic region, one should expect the costs of support to be higher. The population is often much lower and the infrastructure less developed. In addition, lack of competence, and needs with regard to transportation of equipment/ modules/ people, spare-parts and inventory management will demand more time and planning.

Inventory

One of the most important tasks, during development and operation, is to maintain sufficient equipment, tools and parts inventories. Supporting a field development project of a large magnitude in a remote location requires careful planning and flexibility.

The geographical distribution of customers is becoming a critical factor in decision-making concerning service delivery strategies, spare parts logistics and inventory management. The distance of the user from the manufacturer, distributor/supplier can bring an additional influence on spare parts management. For remote areas, due to increased delivery time, the inventory has to contain larger amount of spare parts and the inventory also has to contain critical parts that normally could be delivered from the supplier on short notice. To optimize product support, these issues also need to be considered in the design phase by the
Offshore and subsea activities

During the installation and commissioning of offshore facility one will be dependent on that the weather is suitable for the activities planned. Critical activities may have to be performed during the short summer season to avoid risk of job delay or cancellation due to storms or bad weather. However, even during the summer months one face the risk of fog and thereby reduced visibility. Subsea installations are not that affected by the cold arctic climate as the subsea water temperature is not that different from at other locations. However, the installation, maintenance and inspection of subsea systems are critical operations that are affected by the cold temperature and the weather as they are performed from ships or from platforms and often by using remote or operated vehicles (Markeset et al. 2013: page number if possible), (Gudmestad 2013: page number if possible).

Design for the Arctic operational environment

The physical environment, geographical location and regulatory requirements present different challenges regarding the choice of materials, equipment, and support strategies. Technology should be suitable for the specific environment and safety measures should be kept at a satisfactory level as the requirements may be higher than elsewhere (Samarakoon and Gudmestad 2011: page number if possible).

It is the operator’s responsibility to include economic as well as technical considerations in recommending a production facility design solution, taking into consideration the operational environment and geographic location. The economic evaluation will include all aspects related to the costs of development and will; in particular, consider investment costs, operation costs and maintenance costs. Important in this analysis is the selection of equipment based on a production availability analysis (Gudmestad et al. 1999: page number if possible). The aim is to optimize the design in relation to:

- Requirements regarding design or operations given by authority regulations
- Requirements given in various International standards and statutory bodies
- Requirements regarding health, safety and environment
- Requirements regarding safety equipment based on risk analysis and overall safety acceptance criteria
- Project constraints such as budget, realization time, national and international agreements
- Conditions in sales contracts
- Requirements regarding market performance

Reliability is one of the most important aspects to consider for reducing costs. The lower the reliability is, the higher is the probability of failure, accidents, environmental pollution, etc. Due to the severe climate and harsh weather, one may expect that one is not able to predict and design out all possible failures. Furthermore one may expect that failure may have more severe consequences with a higher possibility of negative HSE effects and longer downtime. More frequent failures will increase the safety and health risk of personnel as well as the risk of polluting the environment. In addition, the personnel exposed to cold environment are also affected by the cold environment and may err more in the performance of activities.

To increase the overall failure resistance, a strengthening of some components may be needed, which would lead to increased costs. Thus, from an economical point of view, one
would try to make a design robust enough, considering the time duration and the operational environment, to obtain a reasonable level of reliability.

When designing the maintenance strategies one would like to see that all failures of critical equipment can be predicted so that all failures can be prevented using compensating maintenance activities before the failure event. The failures can for example be predicted using statistical estimates based on experience and historical data. However, one of the problems is that one may lack historical data of how particular machinery behaves in the harsh arctic climate. As an alternative one may try to observe the real time system condition using modern condition monitoring techniques. However, this may not be possible if the failure develops fast or if there is no method of observing parameters usable for predicting failures, or lack of proper sensors.

Through creating excellently designed systems with respect to reliability and maintainability (Markeset 2008: page number if possible; Markeset and Kumar 2003a: page number if possible; Markeset and Kumar 2003b: page number if possible), as well as increasing the use of automation and remote operations, one may be able to reduce the requirements with respect to the workforce and logistics. The identification of factors that may have an effect on the production facility performance may also facilitate more accurate prediction of operational, maintenance and support needs in design phase (Gao and Markeset 2007: page number if possible; Ghodrati 2005: page number if possible; Jardine et al. 2001: page number if possible; Kumar 1996: page number if possible; Kumar et al. 1992: page number if possible; Kumar 1990: page number if possible).

In general, the life cycle cost (LCC) is defined as the total costs associated with the product or system over a defined life cycle. LCC-analysis is an engineering and economical optimizing technique where the main goal is to identify and choose alternatives that generate the highest revenue over lifetime or in other worlds generate the lower life cycle cost (Markeset and Kumar 2000: page number if possible). Some of the factors that may influence LCC in the Arctic regions include:

- Winterization of equipment. This depends on the duration of time the temperatures are below zero
- Functional and ergonomically design of the equipment. It is important to bear in mind that both the equipment and the operator move more slowly in cold temperatures
- Zero environmental spill policy. Produced water from the reservoir should not contain more than 10ppm oil if released to the sea in the Barents Sea, compared to the 30ppm oil content requirement in the North Sea
- The production facility end-of-life/ disposal. Higher cost in remote areas. Less possibility of reusing winterized equipment

**Evacuation and rescue**

Due to the harsh conditions of the physical environment, it may be difficult to grant that the evacuation means are available when needed. Of particular concern are snow and icing that could cause blockage of access to lifeboats, whereby lifeboats in these areas may have to be kept in heated shelters.

Furthermore, there has been an effort in Norway to improve the quality of survival suites to ensure that the arctic immersion suites are self-righting and that they keep up the temperature over a period of 6 hours even if the sea water is at near freezing condition.
Means to ensure evacuation and survival suites in frozen waters are under development, however, the equipment must be qualified for each area under consideration as the requirements will vary in the cold climate regions.

Following evacuation, rescue must be granted. The helicopters used for rescue operations on the Norwegian Shelf will have to be upgraded to reach out to the licenses where exploration drilling is planned on the Norwegian Shelf. Furthermore, emergency landing cites must be identified. The protective area of Bear Island mid-way between Norway and Spitzbergen as well as the drilling rigs or stand-by vessels operating in the area could serve such purpose.

**Discussion and concluding remarks**

The Norwegian offshore industry has little experience with design of O&G production facilities in the cold and harsh environment of the Arctic region. Exploration/drilling rigs have been operative in the Barents Sea for several years, but only the Snøhvit onshore LNG terminal at Melkøya in Hammerfest has been built and operated for some years. The Goliat platform is being built, but has not yet come in operation. Both are located in a sub-arctic environment.

One of the drilling rigs that have experience in the Barents Sea is the Polar Pioneer, owned by TransOcean. The rig is a mobile semi-sub, and has been through substantial reconstruction to resist the cold and harsh environment expected in the Barents Sea. The deck is built-in, and the area where the equipment is located is insulated. In addition, the rig has equipment for de-icing by use of steaming equipment (Torrisen and Johansen 2006: page number if possible). However, the building-in of the deck area creates several restrictions such as crane operations, storage, inspection, etc. In case of gas leakage the ventilation has to be good to avoid increased risk of inhalation and explosion. Explosion panels, opening at low overpressure are often installed to avoid buildup of high explosion pressure in confined modules.

The hull of the Polar Pioneer rig is double, and all pipes are laid inside a heated area between the outer and inner skin to avoid icing (Steensen 2006: page number if possible). Outside pipes are installed with heating cables and insulation. In addition, machines, equipment and sensitive instruments, etc., are built in closures with extra insulation. This makes it much easier to both maintain and work in the area. All the escape openings are electrically heated, the recreational rooms are additionally insulated, and the instrumentation is certified to resist the low temperatures. Both columns and pontoons hold equipment and tanks for storage.

To place the equipment inside heated areas to avoid icing may be a requirement for all future offshore installations, but may be more challenging to achieve for onshore installations. However, one needs to consider if all the equipment inside the heated area still needs to be designed to resist extreme temperatures.

When deciding upon the design for maintenance, operation and support in an arctic climate, there are three main factors to be taken into account, namely:

- The physical environment at the certain geographical location
- The component/system at the location
- The human being who works at the facility at the certain location

Operation, maintenance and support in cold and harsh environments will require a different strategy than that used in more temperate climates and less remote locations. Some periods of the year may for example not be suitable for work outdoors due to the fact that
systems/components may not be accessible because of snow/ice or because the management has decided that workers are not allowed to go outside when the temperature is too low. One solution would be to delay major maintenance to the warmer summer months. However, if something unexpected happens one should be able to resolve the problem to avoid downtime.

Choice of the optimum design of an offshore structure is important because it often determines the price, robustness and reliability of the structure. It is, however, impossible to recommend a generic optimum structural form for a region since each region has its own specific environment with related challenges. In the early phase of the development, studies and observations should be carried out to define the dominating factors for these locations.

The goal is a business that is as profitable as possible, while at the same time prioritizing HSEQ issues. A properly designed working environment is a cost-effective investment in the operation of a production facility and improves efficiency by reducing the time needed for operation and maintenance.

Finally, the operators will always have to deal with other actors such as non-governmental organisations and indigenous people, who may not support the development of the northern region. Political and environmental issues related to the Arctic region will most likely continue to be contentious.

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Crisis management considerations and designs in cold climate areas

OVE NJÅ AND OVE T. GUDMESTAD

Abstract

In this chapter safety design in the petroleum industry and shipping sectors is emphasized, with special concerns being addressed to cold climate environments. The harsh climate, anticipated ecological vulnerabilities and limited experiences from emergency responses are challenging factors for designing appropriate technical safety systems. The uncertainty dimension is vital to this discussion. There exist deterministic approaches that are rather simple and easy to use, which are closely related to the common design practice, based on recognized solutions. Epistemic (knowledge based) uncertainty related to observable quantities, such as whether an accident will occur or not, the capacities of fire segregation, execution time for safe evacuation, dynamics of gas dispersion, magnitude of heat loads, response performances, instability effects etc., are important and should influence the choice of design approach. An approach that reflects features addressed to identify, recognize and realize emergent hazards as well as designs of systems to rescue and evacuate victims from crises occurred.

We will explore structures that are employed to work in/transit through the Norwegian/Russian Delimitation Line Area (DLA) in the Barents Sea in order to develop useful design approaches. This includes specific considerations of accident characteristics. Furthermore we will study effects of different emergency preparedness equipment’s efficiency in cold and freezing climate and emphasize on the challenge of the long distances to shore bases and the limited infrastructure of the Northern regions of Norway and Russia.

Introduction

Great events have small beginnings (Perrow 1984: page number if possible). Crises investigations always reveal circumstances that normally function very well, but in the unfortunate combinations the crisis emerged.

The natural resources in the arctic areas are valuable, for example do fish, meat, oil and gas, minerals and coal deposits as well as the tourist industries and economic viable transport routes attract commercial interests. At present the Arctic is exposed to pressures not seen before, which is indicated by Laurence Smith’s futuristic assessment of the North (Smith 2011: page number if possible). The international agreement on exploration and government of Spitsbergen (Governor of Svalbard, 1920) is an example of the international community’s respect for vulnerable areas in the polar region. Furthermore, Norway and Russia have recently (2011) signed an agreement on the boundary (Delimitation Line) in the Barents region. This agreement enhances the pressure on exploring these areas for oil and gas resources. The potential for major disasters have been addressed by stakeholders for a long time.
In this chapter we discuss the contextual premises for characterizing arctic and cold climate areas. These premises are further connected with industrial and other commercial activities with possibilities for major crises. We analyse past reported major accidents and incidents with potential for becoming major crises in order to illuminate the need to address the performance of the crisis response systems. The concept “crisis response systems” comprise all efforts made by the activity/systems at the sharp end (Arctic), the apparatus provided by other organisations and the society also at the sharp end, and all related efforts at the blunt end (regulatory bodies, enterprise management, crisis operation centers, etc.). Thus, the emergency preparedness definition; “All technical, operational, organisational measures which prevent a dangerous situation that has occurred from developing into an accidental event, or which prevent or reduce the harmful effects of accidental events that have occurred”, is relevant as a starting point. Hence, the responsible decision maker must identify which situations should be labelled dangerous and which situations to be interpreted as accidents.

We interpret the notion crisis management design by adopting Donald Schön’s (1991, p. 79) claim that “design is a reflective conversation with the situation”. Thus, the situation is characterized by cold climate hazard characteristics assessed against the activities subjected for purposes such as oil and gas explorations, tourism or transport. Crisis is understood as “a serious threat to the basic structures or the fundamental values and norms of a system, which under time pressure and highly uncertain circumstances necessitates making critical decisions” (Rosenthal et al. 1989 p. 10), to which the output artifacts; the systems, whether they are dominated by technology or not, are the answer to the reflective conversation. We intend to provide a tool that enables a reflective process to develop crisis management designs in cold climates.

What is meant by Artic areas? Most people intuitively think of the areas close to the North Pole, which is covered by ice. Some define Arctic by the maximum limit of floating ice. However, the exact borders of the Arctic are not definite. Often the concept of Arctic areas is contextual and contingent on the issues that are addressed, for example when discussing Arctic oil & gas activities the contents is related to identified basins which inter alia include areas as far south as the Faroese Shelf and Bering sea (US Outer Continental Shelf) (AMAP 2007). Another measure is related to climate, for example the ten degree isotherm for July, or some define Arctic as the southern border of the permafrost (Bernes 1996: page number if possible). ISO 19906 (ISO 2010) concerns Arctic and Cold Region Areas defined where sea ice may occur. Geographically one could think of Arctic as defined by the Polar circle. The choice are one of many, but as a common understanding, Arctic is characterized by harsh cold climate, large uncertainties of environmental phenomena, scattered human populations and far less human activities than further south.

<FIGURE 11.1. HERE>

The complexity and numerous considerations to be made could be exemplified by the Vassdalen accident on 5th March 1986 causing the loss of 16 soldiers due to an avalanche hitting when they were building a winter road for tanks in Troms county of Norway (NoU 1986: 20). The preparation troop approached an area of the valley with heavy tracked vehicles without proficient knowledge about avalanche hazards, neither precautions nor responses had been consulted neither in the planning phase nor in the execution phase. All weather conditions developed very negatively the week before the exercise (heavy snowfall, strong winds short time before the accident day). The signs were numerous, troop commanders were worried and threatened to neglect orders to enter the area, avalanche experts were consulted very late without a real opportunity to do their job and communications were impeded and
information lost on the way. In the period before the exercise many signs and messages about the avalanche hazards were given but the responsibility to act upon them was not taken. The commanding officers were concerned about the ongoing play and at the top level command (exercise and the brigade) reflections about snow avalanche hazards were down-sized. Organizational complexity in this case is obvious, but also predictability of avalanches and their physical preconditions are challenging (Kleemayr 2004: page number if possible). The avalanche was huge and 31 persons and two belt wagons were transported 100 – 150 m downhill in bad weather (snowfall, -10°C and strong winds). Of the 17 victims buried deep (1-3m) only one survived (he sat close to a belt wagon and had an air pocket). The search and rescue work was extremely complex (Rostrup and Gilbert 1993: page number if possible; Rostrup, Gilbert, and Stalsberg 1989: page number if possible; Stalsberg et al. 1989: page number if possible). The ongoing NATO exercise was stopped and the Norwegian Army has put in place new procedures to avoid hazardous training events during winter time. The following investigations were also criticized for not appropriately addressing responsibilities. The Norwegian Army has also lost soldiers due to drowning when soldiers are crossing unsafe lakes covered with ice (latest incident was on 1st December 2003). In this respect it is necessary to be aware that the ice on a lake may not be homogeneous but will vary in thickness over the lake. In particular near river outlets strong currents may reduce the thickness of ice so bandwagons must avoid these areas and not cross.

This means that emergency preparedness is inherent at all levels, presented by individual attitudes and competence together with organisational, technical and operational arrangements in the harsh working environment and the sector and society involved. Emergency preparedness is every precaution made in order to secure that any situation is handled in a controlled way and the risk is reduced accordingly. Hence emergency preparedness covers all consequence reducing arrangements. This wide definition implies that all arrangements with multiple functions also have functions related to emergency response activities. A pipeline in the Arctic areas accommodating a gas flow serve as a gas flow containment, but it must also be designed to resist extreme external and/or internal loads, and combined with its maintenance/inspection program ensure that the normal operation function is maintained.

Challenges for crisis management in cold climate – characteristics and past events

The climatic conditions in the Arctic areas contain large uncertainties with respect to exceedance probabilities of waves, winds, polar low effects, etc. for operational and design conditions (Gudmestad 2013: page number if possible).

The related challenges that must be taken into considerations are:

- Insufficient data for accurate weather prediction
- Rapid variations in weather conditions
- Harsh weather conditions for long periods at a time
- Harsh weather combined with darkness and low visibility
- Potential for icing and difficult operational conditions for all equipment
- Freezing temperatures making equipment unsuitable, like for example hydraulic equipment and firefighting systems
- Cold polar waters.

Past accidents

Some examples of accidental situations in harsh weather will be discussed in the following??
Accidents caused by wave conditions

The Norwegian Coastal Steamer (Hurtigruten) has been an important institution to tie together the communities along the Norwegian coast from Bergen to Kirkenes since 1893. Accidents have happened, generally in large storms. 15 ships have been lost over the 118 years. Here it should, however, be noted that the ships sail in almost any weather along the partly open coast of Norway (Halvorsen 2011: page number if possible). 41 persons were lost when Sanct Svithun went down on 21st October 1962. The reported cause was a navigation error during strong gale winds and heavy rain. Rescue operations were particularly difficult as the ship was out of course.

It is known that the combined storm surge and the tide can cause considerable flooding as was the case in the Varandey area in northern Russia on July 24th 2010 when the oil treatment and storage terminal located kilometers inland were flooded and the air runway close to the coast was damaged.

Loss of the fishing vessel; the British trawler Gaul (near Bear Island, 8th February 1974, 36 fatalities, see MAIB 1999) and the Norwegian trawler Utvik Senior (17th February, 1978, 9 fatalities, see NoU 2004: 9) have not been fully explained. The most likely causes seem to be large waves potentially combined with low freeboard and icing causing flooding and loss of vessel intact stability.

Accidents caused by Polar low pressures

An important challenge is the lack of predictability of the weather during some parts of the seasons, mainly due to unpredictability of the polar low pressures, which again is partly due to lack of information to establish reliable forecasts. This might lead to long periods with “waiting on weather” (Gudmestad and Karunakaran 2012: page number if possible). In Northern Norway stories about sudden winds that have taken many lives at sea are told. Fishermen could go to sea in calm weather and be surprised by strong winds and snow and there are stories from certain communities where the main part of the male population was lost at sea during these large winds. The famous priest and poet Petter Dass (1647-1707) was working in Northern Norway and tells about fishing settlements losing too many men.

During an incident in February 1848 up to 500 men drowned when fishing off the Lofoten Islands while being surprised by the outbreak of a polar low (Kolstad 2007: page number if possible). According to Kari Wilhelmsen (interviewed by Grønås and Skeie 1999: page number if possible), 56 vessels were lost and 342 people lost their lives in accidents in Norwegian waters in the 20th century. Many of these losses were related to polar low pressures, sudden outbreak of strong winds, often with heavy snow and large waves.

Due to their violent and sudden nature, the polar lows have been the cause of many losses at sea. In the past, polar lows were extremely challenging to forecast. Their small size meant that they easily were hiding between observation points in the Arctic, and they did not have a sufficiently high visibility in the weather prediction models. Also, the physical processes were not well enough described in the models. This led to poor model performance and often false or absent indications in the numerical prognoses, as well as a general lack of confidence among forecasters. Subsequently, the lows were often omitted in forecasts to the public. In recent years, the availability of satellite data (images of cloud structures) and wind data from the sea surface has greatly improved. Satellite data are now assimilated in the numerical
models and, together with a finer resolution; this has led to a higher quality of short range forecasts. Forecasts of potential polar lows are now routinely included in text forecasts of gale warnings, as well as in forecasts for aviation or maritime users. Still, however, there are large uncertainties in these weather forecasts (Wilcken 2012: page number if possible).

An earlier episode which received much attention in Norway was the storm in which seven ships went down off the coast of Eastern Greenland (Vestisen) on 5th April 1952, killing 78. There were 53 vessels in the area for fishing and seal hunting. 5 of the vessels were never found (Alme 2009: page number if possible). Økland (1998: page number if possible) have suggested that an Arctic front lead to strong amplification of the winds parallel to the ice edge. In this area the ice conditions vary very much and unstable weather conditions with strong winds, fog and snow also makes emergency response very difficult.

Accidents caused by ice conditions

The 1952 accident in Vestisen is just one of very many accidents with loss of vessels and loss of lives associated with fisheries and seal hunting near the ice edge in Northern Waters (Alme 2009: page number if possible). In general the older type wooden sealers were not built for large ice load pressure (Aristova and Gudmestad 2014: page number if possible), and the remote locations made rescue operations very difficult. The crew was dependent on their pals on other vessels. On 7th to 9th April 1917 six vessels disappeared with 84 men during a fierce storm. In 1933 (9th to 10th April) seven ships with 13 men were lost and in April 1939 two vessels with 28 men disappeared.

The most dangerous situations were due to ice pressure in northeasterly winds when the open leads in the ice cover closed and in open seas in the case of floating multiyear ice floes on waves. With the introduction of steel hulls only one vessel, “Veslekari” was lost in Vestisen in 1988. The improved performance was also due to less activity and better weather forecasting.

In Russian Arctic Seas a number of vessels have been lost over the years in heavy ice conditions. Many of the records were classified in the Soviet times. Recently, Marchenko (2012: page number if possible) has been given access to old archives and has prepared a monograph summarizing all known events from the Kara Sea to Chukchi Sea. Also steel vessels have been lost and the danger of a floating multiyear ice floe should not be underestimated. Furthermore, parts of the North Eastern Passage are unchartered and sandbanks are shifting location so full attention must be kept when navigating in these waters. The communication system and the possibility for rescue in these distant waters are of concern and it is understandable that Russian authorities require icebreaker assistance for navigating this Passage during periods of dangerous ice conditions.

On the 16th of September 1989 at 23:05, the cruise vessel Maksim Gorkiy ran into an ice floe with full speed 60 nm West of Isfjorden, Svalbard. There were 953 persons onboard, of these 575 passengers; many of these were elders with reduced mobility. The Norwegian Coast Guard vessel KV Senja was called at 00:40 and arrived at 4:00 after having travelled with a speed of 22 knots. The passengers went into lifeboats at 01:30. Then the ship started to take in water and was listing (Kvamstad 2013: page number if possible). Eventually all were rescued due to the lucky situation that the Coast Guard vessel was that close, the weather situation was calm and the rescue was carried out in a professional manner (Hovden 2012: page number if possible). The potential for loss of many lives was eminent. There may be no possibility to rescue all from a cruise vessel in case of an accident in northern waters far from available
emergency equipment. A cruise vessel in northern areas might represent the ultimate challenge and may represent the highest risk in terms of personnel loss.

**Particularly challenging conditions for crisis management**

**Water temperature**

The low temperature of the sea water in cold climate areas large parts of the year causes survival in the cold sea less probable than in more temperate seas. The expected time before exhaustion or unconsciousness decreases sharply when the temperature gets below 4°C and the expected time of survival is in the order of an hour or less. It is therefore necessary to provide the workers on facilities and vessels in cold climate offshore areas with the best survival suits possible. Work has been initiated to provide improved suits and there have proven very useful so the rescue team can have some more time to get to location. It should be noticed that the distance from facilities to shore in northern waters quite often is large, stretching the efficiency of the crisis management team to the limit.

Water temperature and cold exposure during immersion can be life threatening and are often direct cause of fatal accident. Immersion accidents often consist of four life threatening phases – cold shock response, inhibited muscular function/coordination, hypothermia and post immersion (THELMA 2010: page number if possible).

**Spray Icing**

When a vessel is moving in waves and wind, spray icing, caused by water freezing to ice when hitting the vessel, could cause large accumulation of ice on the vessel. Large amount of ice can lead to loss of buoyancy, in particular in case a vessel is overloaded (as may be the case for heavy loaded fishing vessels where the freeboard is low). Furthermore, accumulation of ice on a vessel will lift the center of gravity and lower the GM, the value of the metacenter, which is a measure of the stability of the vessel. Smaller vessels with equipment located high up from the waterline (like fishing vessels) are particularly exposed to dangerous icing situations. Combined with waves the vessel stability can be threatened. It is thought that icing was involved in the sinking of Gaul (see above). Furthermore, as an example, The Lady of Grace, a fishing vessel in Nantucket Sound, sank on 26th January, 2007 due to ice build-up on the decks (USCG 2008: page number if possible).

Another incident is the loss of the Kolskaya jackup during tow in the Okhotsk Sea. The jackup listed, took in water and spray ice accommodated on the legs and deck. Eventually the jackup capsized, leading to loss of 53 crew members (Aristova and Gudmestad 2014: page number if possible).

**Design principles for crisis management**

Safety has traditionally been managed by adopting recognised standards and codes. Standards and codes often prescribe how to develop or they present directly which arrangements to choose in the safety and emergency management, implicitly providing an acceptable safety level. By using this approach, no attempt to express (calculate) the performance of the systems are made. In many sectors performance assessments are part of the technical, operational and organisational safety and emergency management, by employing functional requirements. Functional requirements describe what to achieve instead of what arrangements to be selected. The important question is then how to develop requirements, assess performance and choose emergency preparedness and response arrangements for systems and activities operating in Arctic areas. Ghoneim (2011: page number if possible) is a proponent
for applying recognised standards in Arctic, but has also revealed inconsistencies in the prevailing standards. Lack of experience, novel activities combined with mature knowledge in some relevant fields call for tailor made solutions adapted to actual enterprises or sectors involved. However, performance analyses must be carefully considered with respect to for example relevance of data, modelling and validation.

For all cases with sudden strong winds, possibly combined with snow, immediate crisis response activities would be very difficult. To reduce the risk the authorities have emphasized on the improvements of the weather forecasts. During a cold break in winter of 2012 fishing vessels were not allowed to leave harbors in Finnmark County as the combination of winds, temperatures and waves made vessel icing highly probable with high potential for ships to lose stability.

Specific challenges in the cold region can be exemplified by discussing the Vnukovo Airline crash in 1996. On 29th August 1996 a plane from Vnukovo Airlines in Moscow crashed into Opera fjellet on Svalbard during attempted instrument landing at Longyearbyen airport. 141 persons lost their lives immediately upon the crash. The cause was decided to be wrong navigation in low skies (AAIB/N 1999: page number if possible). Also the communication between the tower and the plane was very difficult due to language problems. As a consequence, approaches to the airport from the eastern direction have become been very careful and in general restricted.

Below are three approaches presented to express and interpret situations for use in crisis response planning. These approaches represent practices from the Norwegian oil and gas industry (Njå 1998: page number if possible).

Detailed descriptions of specific situations

1a) Defined situations of hazard and accident (DSHA)

DSHA relates to a selection of possible events to be dealt with by the emergency preparedness of the activity in question. These situations are partly defined by means of risk analysis based on experience and qualified evaluations. DSHA include the dimensioning accidental events, less extensive accidental events and situations connected with a temporary increase of risk.

1b) Worst case

The worst case approach puts focus on extreme conditions connected to emergency situations. This could be, e.g. extreme weather conditions simultaneously occurring with a fire in a specific area. Only with assumptions governing the design of crisis response arrangements it is believed that the arrangements would function sufficiently. The risk picture obtained from the risk analysis is given less attention, and it will only serve as initial guiding of the development of the extreme situations. These situations could also be directly developed as scenarios or accidental loads, without a risk analysis.

A cluster of specific situations denoted as situation classes.

As opposed to the other two approaches, this approach does not focus on detailed described situations, but classes of situations, e.g. fire or types of fires such as liquid fires or jet fires. Flexibility is sought by focusing on the crisis response arrangements and their functionality. The flexibility of the crisis response arrangements to perform tasks in building crises should be investigated through performance analyses.
The *situation class approach* contains assessments of the crisis response arrangements’ flexibility to function in the class. A class of situations represents a cluster of single situations identified through a various degree of descriptions e.g. the scenarios could be included in risk analyses as a branch in the event tree. Of course, situations more probable to occur than others are not indifferent for choice of crisis response arrangements. Risk analysis could be used to provide information about the proneness of hazards and accidents, but such analyses could also be replaced by scenario-identification without associating probabilities. It is the continuous analysis of the flexibility of the proposed crisis response arrangements that is important, the acting and reacting “forces” communicate, not how probable those novel situations might be. The variability of e.g. the situations or load parameters within the situations could be described by uncertainty distributions. The performance requirements could in this case be gradually developed through performance analyses particularly focusing on consequences to be avoided. A proper crisis response system is dependent on a conscious and active use of performance requirements. There is a need for systematic approaches dealing with performance measures/quantities such as *reliability* (will the systems be there when needed), *effectiveness* (capacity and execution time regarding the systems’ expected functions) and *survivability* (systems’ vulnerabilities to the crisis scenario). Capacity could be related to the evacuation means’ ability to evacuate injured people and execution time could be the related time for carrying out this activity. In a planning process the analyses have to be futuristic, thus it includes uncertainties associated with the performance measures. It is the crisis response arrangements that are the starting point and the issue for the assessments.

As seen in crisis response planning today, the focus has to a large degree been placed on the accuracy and complexity of DSHA descriptions. Requirements, often with an unclear background, are aimed at tasks in these specific situations. This process should be reconsidered by moving towards a flexible *class of situations* approach, in which a systematic development of requirements is included. This way for interpreting situations for use in crisis planning is adopted for the approach for optimising the performance requirements using phase models.

**How to approach and assess performance of emergency response systems**

The Emergency Prevention, Preparedness and Response Working Group concludes that “(I)nfrastucture inadequate for response operations, coupled with the unique environmental difficulties present in polar environment, provide real challenges to risk assessment and mitigation” (EPPR 2011, p. 15). There are major uncertainties about fundamental crisis response issues regarding capabilities in Arctic environments which calls for careful consideration about systems expected to operate in emergencies and their interrelations.

A classification scheme; a model describing the stages of perception of danger to the possible responses to dangerous situations has been developed in order to comply with the emergency preparedness definition. Thus, the model is split in two coherent sub models; (1) *pre accident model* and (2) *post-accident model*. Using this model (classification) as a basis, it can be revised to represent the total crisis response system/organisation.

**Pre-accident model**

The pre accident model focuses on all accident preventive preparations. Being at this stage, the design principles, technology achievements, motivational and competence philosophies related to the personnel, organisational development etc. are important arrangements. The harsh climatic conditions, time spans, ecological vulnerabilities etc must be seen in light of the planned activities, such as oil and gas exploration, tourism or transport. The
communication systems have limited availability in the high north (Kvamstad 2013: page number if possible), which is another type of vulnerability together with physical availability and tracks to reach the facility (Spring and Hansen 2011: page number if possible).

The level of danger could for instance be communicated on the basis of risk analyses, safety meetings, safety audits, statistics and experience data, or signs in close time span for the activity execution, cf. the Vassdalen case above. A conscious practice of danger contemplation characterizes an organisation focusing on high reliability. A suitable contingency design will provide necessary signs to responsible persons in sufficient advance to allow corrective actions to be taken. The presentation of crisis response phases below is partially descriptive, examples to illuminate the concept followed by important issues to consider in designing each phase. Currently Dawson, Johnston and Stewart (2014: page number if possible) are concerned about that there is no central authority to govern the growth of the Arctic expedition cruise industry, in order to supervise and control the level of danger. The need for better weather forecast has been a major concern in the ship traffic emergency system in the Barents Sea, by deploying Wavescan metocean buoys (Mathisen and Bidlot 2011: page number if possible). In general enhanced focus on weather forecasting tools in the Arctic is a prerequisite for crisis management systems designed for the Barents Sea (Barabadi, Gudmestad and Barabadi 2014: page number if possible).

Inspection and preventive maintenance are arrangements that heavily intervene in this process, in the way that hazards will be systematically searched for and removed. However, these measures are not necessarily appropriate since they could mislead the focus onto areas of minor importance. The challenge is therefore to critically examine if the inspection is performed in areas with potential hazards and if the maintenance is carried out on the basis of criticality and reliability aspects of important components. This is part of the objectives of hazard seeking.

- Is the system oriented at danger contemplation, e.g. detection systems, report systems, etc.?
- What inspection schedule is planned?
- What maintenance philosophy is laid down?
- Are the employees trained to seek hazards?

As a summary of an analysis of the Arctic cruise activity, based on Canadian data, concerns about aging and insufficient infrastructure and capacity is raised. There is an aging ship fleet, but also major limitations of SAR resources, salvage and clean-up contingencies (Dawson et al. 2014: page number if possible). A further assessment of their study addressing rapid changes and major uncertainties in the industry make the industry extremely vulnerable if the tourist service providers are not concerned with hazard seeking activities.

Managing safety require a conscious attitude to the level and type of competence needed, either appreciating a flexible and cognitive understanding of systems or accepting a superficial understanding focusing on error signs as sufficient. Hazard recognition is closely related to hazard seeking. Behind hazard recognition there is a requirement to understand the cause and effect relations which leads from those signs and symptoms to the occurrence of the potential disease, accident or disaster. The skills of searching and inspection systems therefore need to be combined with the cognitive, diagnostic function of putting those indicators together and making sense of them.

- Which signs of danger should be expected?
- Are inspection methods capable?
• Are employees trained at fault diagnosis - cause and consequence evaluation?

Very often even when hazards are well known, they are still not recognized as such. Prior to the fatal avalanche in the Vassdalen March 1986, the day before there had been another significant avalanche in the area. However, no one recognized the hazard as being relevant for the troop working in the valley preparing the path for belt wagons.

Assessment of priority and importance of the danger is in the cognitive and affective area, in the sense that motivational factors are as important as the knowledge base. Use of technical safety device systems, such as detectors activating systems that need to be responded or deactivated, put motivational factors aside. However every system needs to be carefully considered due to their coupling with other systems or activities. Lord Cullen (Cullen 1990: page number if possible) reports that the crew on Piper Alpha knew that many sprinkler heads were defect, but nobody found it important to repair. In this case lack of knowledge about potential consequences dominated, but of course the motivational level of the responsible people was not perfect either.

• What makes the situation to be labelled as dangerous?
• Who will communicate the need for action and who will appreciate it?
• What systems assess the priority and importance of specific actions?

Wave-ice interactions (Dumont, Bertino, Sandven and Kohout 2011: page number if possible) are pressing issues in arctic activities for example in the tourism business. A thorough understanding of these effects is of utter importance for the shipping industry challenging interesting spots and areas. The Maxim Gorkiy incident and rescue could have been an extreme case with slightly different wave-ice conditions, in which there were no evidence that the ship-owner had paid much attention prior to the incident (Hovden 2012: page number if possible).

Allocation of responsibility covers the correct acceptance of the responsibility for action by an individual or a technical device. Hale (1984: page number if possible) refer to a questionnaire directed towards supervisors regarding responsibility of taking actions when hazards occur. For 64% of the hazards present, action was regarded by the supervisors as being the responsibility of someone else. This was despite the fact that the supervisors were, according to their enterprises, responsible for everything which happened on the sites which were being inspected.

• Who or what system is responsible for taking action?
• How is this responsibility communicated?
• What kind of decision must be made?

Sydnes and Sydnes (2013: page number if possible) have studied the bilateral oil response regime between Norway and Russia. They claim that the shared understanding and the common interests increase the reliability that a situation will be handled efficiently in the Barents Sea. The basis for their policy analysis is interviews and evaluation reports from exercises, from which they conclude that the involved parties show commitment and operational responsibilities.

As a hazard has been recognized and the responsibility for action has been accepted, it is quite obvious that the knowledge of courses of action must be present. Human knowledge and skills, effectively interacting with functionality of equipment is the bottom clue for obtaining an optimal crisis response system. Appropriate training is needed, with focus on analytical
ability, i.e. cause and consequence consideration, to enhance the knowledge based behavior of responsible personnel.

- What action is needed?
- Is the time horizon critical?
- Is sufficient flexibility provided in the training of humans and/or system designs to identify appropriate actions?

The decision to act is the final part of the cognitive behavior or the system activation. Again, designs of automatic devices could replace the high motivation pressure upon personnel to actually carry out the decision to act. Automation implies standardized courses of action, which does not allow for a weighing of competing courses of action. In many cases weighing is necessary, and in such cases individual cognitive behavior would be preferable.

- What triggers action?
- What consequences to be expected to laps and mistakes?
- How are decisions communicated and instructed?

The final area, ensuring an incident not developing into an accident, is the action sequence which covers the skills necessary to carry out the incident recovery work. This includes performance of maintenance work, response to suddenly arising incidents and removal of technological, organisational and operational aspects that increase the risks.

- Is sufficient skill provided to ensure that the incident do not develop into an accident?
- What equipment is needed?
- Is feed-back of the action sequence given to check that hazard is removed?

Eik and Gudmestad (2010: page number if possible) discussed iceberg management addressing whether an iceberg would be detected, actions considered and proper towing arrangement set up and towing successfully executed prior to collision with an offshore facility. The assessment depended on a lot of quantities such as the distance, shape and size of target, sea state, and personnel and tug master's competence. The complexity to include and simulate the iceberg collision situation, for example in the Shtockman area needs to be carefully considered as part of the crisis management action sequence.

The pre accident model is coherently connected by the critical development of the situation. The remaining dangerous situation will (dependent of time) shift from being a dangerous situation to an accidental situation if no or inappropriate corrective actions are taken. Even though the distinction or limitations between the descriptions of the situations are not clear, an accidental situation should be characterized by the compelling actions to be taken.

The departure from the pre-accident model to the post-accident model is characterized by occurrence of an accidental situation. An accidental situation implies a certain level of harm done. The body or system which perceives the harm must evidently become focused.

Post-accident model

At the point of an accident reorganization into the emergency organisation must take place. This is a critical transition, which has often revealed substantial lacks in the crisis response systems (cf. Piper Alpha accident). When a situation has developed from being dangerous to an actual accident, the question is whether the crisis response organisation is prepared and
able to bring the situation under control. As any prediction of the future, one major problem is to describe the events accurately.

There is no doubt that an accident requires action, and thus the responsibilities of action must be clear, even if the organisation has not been reorganized as expected. The emergency organisation should be designed sufficiently robust to deal with some extent of variability.

- What damage is to be expected?
- Is reorganisation into crisis response organisation carried out smoothly?
- How is the crisis response organisation structured, e.g. with respect to responsibility?

As the accident situation has occurred and the responsibility for action is clear, the knowledge of an appropriate course of action must be present. Human knowledge and skills effectively interacting with functionality of emergency equipment is necessary for dealing with situations, where time factors and accurate performance is a matter of life and death.

- What action is needed?
- Is the time horizon critical?
- Is sufficient flexibility provided in the training of humans and/or system designs for the appropriate actions?

The decision to act is the final part of the cognitive behavior or the emergency system activation. Designs of automatic devices could replace the high motivation pressure upon personnel to actually carry out the decision to act.

- What triggers action?
- What consequences to be expected to mistakes?
- How are decisions to be communicated and instructed?

Even though the Vassdalen avalanche might be seen as a disaster, the victims in the area partly covered by snow did a heroic effort to release their friends. This is the most effective rescue arrangement in all avalanches and this case was no exception. 7 victims partly buried were rescued by their mates (Stalsberg et al. 1989: page number if possible).

Upon the decision to act, the “regular” crisis response activities are to be performed. Usually an action plan is established in order to describe the arrangements for alert, danger limitation, rescue, evacuation and normalization, and meet the goals for these phases:

- **Alert** shall be carried out to ensure a totally effective mobilization of all relevant emergency preparedness resources.
  - Who is to be alerted?
  - Is the alarm equipment designed properly to alert all humans and counteracting resources?
  - Is a system provided to ensure/check that alert is successfully carried out?

Alarm systems encompass all efforts to scramble the dedicated crisis response systems. Whether such systems need to be designed with special precautions have not been subject for critical reflections in the research literature. However, every activity, whether it is oil and gas, fisheries, shipping tourism or else, society is organised with joint rescue coordination centers. Alert is a major response phase influencing the performance of the combat and rescue arrangements, thus special concerns are needed.
Measures for danger limitation shall be implemented to reduce the consequences of an accident that has occurred such that rescue and evacuation can take place in a safe and organised manner, damage from pollution is prevented, and financial loss is kept within defined limits.

- Is the area for the accident sufficiently limited with physical barriers?
- Are active danger limitation resources (external and internal) available in time and have they sufficient capacity?
- What is the escalation potential?
- Are critical conditions identified, e.g. environmental, terrorists, public interference etc.?

There has been extensive research and analyses on how to mitigate oil responses in ice conditions (Ghoneim 2011: page number if possible). In situ burning (Fritt-Rasmussen 2010: page number if possible) and various types of skimming and encapsulating methods has been tested for their efficiencies (Dickins 2011: page number if possible). This is an area which has been given an extreme political focus, thus the societal credibility to recommended solutions is of major importance.

Rescue measures shall ensure that missing persons are found, and injured persons are given necessary first aid and are brought to a safe area for treatment by the health service.

- How is missing persons to be notified and located?
- Is the rescuing equipment sufficient, and is the accident area open for access?
- Where are safe shelters and first aid locations to be settled?
- How are the injured personnel to be prepared for transportation to hospital?

Jacobsen (2012: page number if possible) concludes in his study of available search and rescue arrangements for the petroleum industry in the Barents Sea that it is not advocated at present state to facilitate “all year petroleum activity everywhere in the Barents Sea”. The distances are too large and the capacity of helicopters and vessels combined with the harsh environment would not be sufficiently safe.

Evacuation on and from the plant (installation) shall be carried out in a safe and organised manner in order that all personnel is brought to a safe area.

- Are all evacuation routes available?
- Are necessary evacuation means available in time?
- Is sufficient training given to access and manoeuvre evacuation means?
- Are personnel able to assess prevailing situation and are they familiar with alternative evacuation possibilities?

Evacuation means have been subject for technological developments over the years adapted for the geographical climate conditions, se for example (Hall and Seligman 2011: page number if possible; Jacobsen 2012: page number if possible; Marsden, Totten, and Spring 2011: page number if possible; Ré 2011: page number if possible; Ré and Veitch 2013: page number if possible). Marsden, Totten and Spring recommend: multiple types of craft to provide options for vastly different conditions and more integrated approaches that seeks to balance the weaker components.

Normalization shall ensure that injured personnel are given treatment and care, the environment is restored to its normal condition, and damage to the plant (installation) is stabilized/ repaired.

- How are people involved in the accident followed up?
- How are relatives taken care of?
When an accidental situation has occurred, the consequence mitigation work is not chronological structured in the indicated phases. Phases could be parallel, due to prioritizing of the actions needed. The phases are seldom accomplished in an effective manner, and accident investigations often reveal blamable conditions related to the crisis response arrangements’ performance in these phases. The situations were, e.g. either totally unexpected (no emergency preparedness at all), different to what was expected or the mental, emotional and physical reactions to the accident disturbed performance. Should measures that improve the pre accident behavior be selected in prior to measures that improve the post-accident behavior? This is a matter of the analysis process and in particular defining acceptance criteria and performance requirements. The phase models include all crisis response aspects; Competence and organisations as well as technical systems for direct emergency actions. Hence, the models will be used as the framework in the further methodology development.

Need for further research and development regarding emergency management in the Arctic/ in cold climate

The issue of emergency response; evacuation and rescue in the northern areas is important, though problematic. The distances to hubs make it difficult to reach targets within reasonable times and the weather conditions are on many days very problematic. In addition comes the dark winter without daylight. Discussions about evacuation and rescue in the Barents Sea in Norwegian waters is prepared by Jacobsen (2012: page number if possible). The discussion covers the area south of the Bear Island at 74.5° N and east to 19° E toward the border with Russia to the east. This is the area where Norwegian authorities presently are issuing licenses to the oil and gas industry to explore for oil and gas. Preliminary results were presented by Jacobsen and Gudmestad (2012: page number if possible). Of particular concern is the need to station Search and Rescue helicopters at locations where offshore facilities can be reached and at the offshore facilities. This might also involve stationing of vessels half way between land base and offshore facilities so fuel can be ensured for the flight to the facilities and the return flight to base.

The organization of search and rescue operations in case of disasters in arctic areas is based on Joint Rescue Coordination Centers’ abilities to provide sufficient situation awareness and management of scarce resources. One major concern is mass rescuing of passenger vessels, similar to the case of Maksim Gorkiy. Today there exist no prepared emergency response system that are ready to perform under the probable harsh weather conditions seen in the north, taking survival criteria of passengers as a design criteria. There are work going on within the International Maritime Organization (IMO), but this is long lasting without any conclusion on regulations and guidelines. The International Maritime Rescue Federation (IMRF) has since 2010 organized conferences on mass rescue topics (IMRF 2010: page number if possible).

In this respect we will refer to that the cruise vessel Costa Concordia grounded in calm waters near the island of Giglio west of Italy in the evening of 13th January 2012 after having passed very close to a rock. The vessel had 3 206 passengers and a crew of 1 023 on board. 32 fatalities resulted after the boat listed 80 degrees. Had the captain not set the vessel on the grounds but moved into deeper waters, there would have been potential for several thousand
fatalities. However, “Mit der Dummheit kämpfen Götter selbst vergebens“ (originally attributed to the philosopher F. Schiller).

What should govern the design of the emergency response systems in northern areas is yet to clarify, and worst cases might not be so relevant. However safety considerations must be part of all design phases as well as the operational procedures, such as during all navigation.

Another potential problem in northern waters could arise, even if the greatest care was taken, in case navigation takes place in unchartered waters. This calls for chartering all waters where vessels might traverse. Of potential concern are pinnacles that may need a very dense chartering net to be detected.

It should also be mentioned that radio communication in northern waters is not reliable and this situation poses a threat to all navigation in the northern waters. The communication system is therefore being further developed for this region.

Discussion

There are environmental and human concerns which exhibit slow-burning crisis characteristics (global warming, pollution) but also fast-burning crises (major accidents) which opens up for “Black Swan” considerations (Taleb 2007: page number if possible). In this paper we will not further explore what we do not know that we don’t know (the unknown unknowns), but start with the known disasters in the Arctic and the relationship to the cold climate. This paper must be considered a starting point of obtaining knowledge of hazards in the cold climate and how these challenge the disaster response systems.

A hierarchical structure of performance measures is only useful to us in a decision process with the objective of choosing an “optimal” crisis response system. The decision process depends on several aspects, such as the actual decision makers, the decision arena, the decision problem, and the basis of legitimacy. Suitable performance measures must be looked for, and requirements derived in order to develop and choose the best crisis response system possible. As a basic guideline for selecting performance measures and deriving requirements some ideal premises for the performance requirements are presented;

- They should cover the different crisis response phases: pre accidental phase, alert, danger limitation, rescue, evacuation and normalisation
- They should be adapted to the specific enterprise considered
- They should be expressed in a way that enables checking, i.e. the existing emergency preparedness may be checked against the requirements (using performance analyses)
- They should be logically consistent in the sense that they should not result in biased or unreasonable requirements for some enterprises and systems
- They should contribute to satisfy accepted level of danger (the risk acceptance criteria)
- They should be cost effective
- They should be general, in the sense that they should not favour specific crisis response arrangements
- They should contribute to employees’ and 3rd parties’ (authority and society) perceptions of an acceptable level of danger
- They should balance the wish to obtain improvements (ambition level) and the possibilities for meeting the requirements (realism). “Realism” can be ensured by e.g. application of measured/calculated numbers from comparable activities
They should be dynamic in the sense that they should be revised over time to take into account experience, new information, possible changes in the activities and technological advancements.

They should be simple and easy to understand.

Obviously, it is difficult to meet all these premises for every single crisis response requirement, but they should be regarded as a background guideline (ambition) for requirement derivation. In Norway the oil & gas industry has been the pioneers in setting performance requirements to crisis response arrangements.

Conclusions

We conclude that while most industrial activities in populated areas in the south are accessible and well known, this is not the case in the northern cold climate. As a starting point the known unknowns, which is the well-known risks need to be sufficiently explored. However this is not enough. Efforts should be made to reveal possible totally unexpected issues (“Black Swans”/ unknown unknowns) that might challenge the short and long term consequences for human and environment, but to what extent is it possible to reveal “Black Swans” before they occur? Annerløv (2012: page number if possible) has developed an approach to assess Black Swans. We will further recommend that potential disasters in the cold climates of the North should be classified into t’Hart and Boin’s crisis typology framework (2001: page number if possible) addressing the speed of development and the speed of termination. Such assessments of the arctic systems involved will reveal uncertainties related to systems’ performances and phenomenological knowledge. This is vital for a proper regulation of the northern assets and for all stakeholders involved in the Arctic.

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CHAPTER 12

Offshore Oil and Gas Industry and the Arctic Environment

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Introduction

Environmental impacts are normally classified according to the environmental compartment affected (air, water, and soil), and/or oil and gas industry location (on- or offshore). North East Atlantic oil and gas exploration and production, mainly in the Barents and Kara seas, represents a combined consortia of on- and offshore activities, with likely impact on all three compartments. In addition to permanent and temporary exploration and production facilities, service activities like refining, transport and storage of crude and refined petroleum, production chemicals and technical equipment as well as solid and liquid wastes, should all be included when attempting to describe total environmental risk posed by the industry.

Table 12.1. presents an overall list of main risk parameters, pollution sources and environmental sub compartments negatively affected by oil and gas exploration and production.

In this chapter we will limit our focus to offshore discharges to the marine environment, posing immediate detrimental environmental effects. Furthermore, we also limit our attention to crude oil and refined petroleum products, leaving inorganic ions (heavy metals and inorganic salts), radioactive sources, gases, and solid waste products out of our scope. While this restricted view excludes important hydrocarbon inputs to the marine environment from onshore oil and gas activities, the marine fate and effects of those inputs can be considered similar to offshore discharges as transport and conversion mechanisms are source independent.

Sources of petroleum to the marine environment

Hydrocarbons enter the marine environment by release of petroleum oil or gas. Offshore sources include: natural seeps, accidental oil spills and oil and gas blow outs, leakages from production, transport and storage facilities, dissolved and dispersed hydrocarbons in produced water, oil residuals on drill cuttings and muds, non-combusted hydrocarbons fallout during flaring and mud burning and installation drainage and ballast water. Environmental concerns are to a large extent limited to the liquid and dissolved petroleum fraction as the gaseous components are volatile and escape to the atmosphere. Our current knowledge on worldwide releases is based on probability estimations combining some basic assumptions, like natural seepage rates, unregistered spill frequency and leakage rates and quantifications limited to case areas (Wilson et al. 1974: page number if possible; Schmidt-Etkin 2011: page number if possible). Natural oil seeps have been known since ancient times (Levorson 1954: page number if possible) and do account for a significant fraction of hydrocarbons released to the environment (Kvenvolden and Cooper 2003: page number if possible; Smith 1968: page
number if possible). In a recent review by Schmidt-Etkin (2011) the annual worldwide release of oil has been estimated to about $2\times10^6$ tons/year of which about 30% is due to natural seepages, 6-8% originates from municipal and industrial land runoff, 21-49% transportation (including operational and accidental spills) and 2-3% atmospheric precipitation. Offshore exploration and production amounted to 1-2% in the same study, however a single accident like the Mocando, Gulf of Mexico spill that happened just after this was published would change that to 35%, indicating the uncertainty and variability of these estimates.

Wilson et al. (1974: page number if possible) estimated the annual oil release to the arctic environment to be about 450–1700 tons of the total marine input of 200-600x10^3 tons. Hence a relatively small operational or accidental input in this region would change significantly the overall inputs. In order to assess the environmental impact of such events, understanding the fate of oil in marine environment is essential. Therefore, in the following paragraphs we focus on describing the mechanisms involved in shaping the fate and effect of accidental oil spills. Fate and effects of the alternative sources listed above would normally imply the same, or a subset of the same mechanisms.

**Oil spills – Environmental fate**

The effects of marine oil spills first reached the public through the media attention following the Torrey Canyon accident 18 March 1967 whereby about 130 000 tons of crude was released to the British channel killing more than 15 000 seabirds and smearing close to 300 km shorelines (Smith 1968: page number if possible). While most spills are very small (70% < involve releases of less than 30 kg oil), the rare but larger spills account for the bulk of inputs to the marine (60% <), and represent the environmental risk of immediate concern (Schmidt-Etkin 2011: page number if possible). Spills may occur from various activities related to exploration and production, shipping and land based transport, pipeline transport, storage and refining. Environmental risk assessment of oil spills involves an evaluation of the probability and environmental consequences imposed by the spill. While the former is outside the scope of this text (see IMO (2010) for details), environmental consequences, primarily linked to fate and effect of the individual constituents and the oil phase itself, are discussed in detail. Figure 12.1. shows major mechanisms involved in oil phase transport and conversion in marine environments.

Evaporation of volatile and semi-volatile compounds from the surface oil slick is a major mechanism transferring hydrocarbons from the sea to the atmosphere (Fingas 2011a: page number if possible). Volatile compounds, like short chain alkanes, alkenes and cyclo-alkanes along with monoaromatics will evaporate within hours depending on their volumetric fraction, sea and air temperature, and wind conditions. About 80% of all volatiles disappear within days (Fingas 2011b: page number if possible). Even though evaporation models exist for a large range of crude oils, the process may lead to formation of solid or tar like “skins” at the surface of spills due to accumulation of resin and heavy constituents, resulting in retarded evaporation that is difficult to predict. Simple models, adequate for typical marine conditions, have lately been proposed and their main sensitivity is towards time and temperature (Fingas 2011b: page number if possible). As temperature in the arctic is significantly lower compared to temperate seas, evaporation under arctic spill conditions is likely to deviate significantly to more temperate experiences as both evaporation and skin formation will be more pronounced.
A secondary effect of volatilization causes the remaining slick properties like viscosity, flash point and density, to change significantly, altering its physico-chemical fate and biological effects.

Another surface linked conversion mechanism is the photo-oxidation (photolysis) of hydrocarbons by radiation dependent formation of reactive oxygen species that converts hydrocarbon to short chain acids alcohols, ketones and aldehydes (Payne et al. 1987: page number if possible). Photo-oxidation of certain polyaromatic hydrocarbons (PAHs) and thiophenes causes formation of degradation products with significantly higher toxicity compared to their hydrocarbon origin, while also generally increasing biodegradation (Maki et al. 2001: page number if possible; Lee 2003: page number if possible; Plata et al. 2008: page number if possible). Under arctic summer conditions, photo-oxidation may therefore be significant due to light intensity and radiation time.

Depending on the chemical composition of oil, wave and mixing conditions, oil and water will mix and form discontinuous but relatively homogenous mixtures called emulsions (in case of water droplet in the oil phase) or dispersions (oil droplets in a continuous water phase). Emulsions are formed in several ways. Unstable emulsions are formed by entrapment of water droplets retained by viscosity forces. Semi-stable emulsions form when asphaltenes and resins in the oil interact by weak chemical surface forces in addition to viscosity retention. If sufficient polar resins and asphaltenes are present, stable emulsions may form (Fingas and Fieldhouse 2009: page number if possible). Emulsions are often named according to their physical similarity to chocolate mousse, either as oil mousse or just mousse. Emulsions increase in volume (due to water entrainment) and dramatically in viscosity, making cleanup operations difficult and limited (Fingas 2011b: page number if possible). In addition, degradation processes and evaporation are in general reduced (Fingas 2011c: page number if possible). Models for prediction of emulsion formation and behavior have been proposed taking oil composition, viscosity and density as input data (Fingas 2014: page number if possible). It is thought that this is sufficient for predictions, and that special arctic factors are implicit. Dispersion of fine droplets of oil into water is caused by wave action or turbulent currents, and the smaller fractions < 20 μm are stable for relatively long residence times. Surface active compounds originating from the oil, released by marine organisms or actively sprayed onto the slick as a means of oil spill cleanup strategy will stabilize and promote formation of stable dispersions. As dispersion will enhance the surface to volume ratio (oil-water interphase), surface dependent processes, like biodegradation, particle adsorption and dissolution, will proceed faster, and increase the rate of observed removal of surface oil. Also, dispersion stimulates transport of spilled oil into the water column reducing exposure to surface organisms.

Components of significant solubility in water (1 ppm <), such as C1 to C8 alkanes, cycloalkanes, one and two-ringed aromatics, phenols and acids constitute the water accommodated fraction (WAF) of oil in water. Solubility is limited (WAFs typically account for < 1% of total hydrocarbons in crude oil on water tests (Southworth et al. 1983: page number if possible; Faksness et al. 2003: page number if possible) and even though single compounds have considerable solubility, much lower concentrations are found in the presence of crude oil phases, typically 0.1–0.5 ppm (Grahl-Nielson 1987: page number if possible; Baker et al. 1990: page number if possible). The low dissolved concentrations are explained by diffusive and advective spreading. However, soluble hydrocarbons represent the bioavailable fraction of hydrocarbons in crude oil water mixtures, and also represent the acute toxicity of to meio- and micro fauna in sea water (Patin 1999: page number if possible). Hence, even though dissolved hydrocarbons do not represent the major fraction in oil spill – marine water systems, their role in conversion and effects is of uttermost importance. Similar to evaporation,
dissolution also contributes to changing the continuous oil phase physio-chemical properties, ageing the oil into a more viscous and dense oil with implications for cleanup strategies.

Sedimentation by high density aged crude oil residuals, or oil sorbed to suspended particulates represents a process of deposition of spilled oil to bottom waters and sediments. Sorption to suspended particles occurs close to shorelines and coastal regions and may occur during any stage of the oil spill ageing process. Sedimentation due to ageing is the result of all processes leaching volatile light fractions, leaving the heavy fractions to accumulate until the specific gravity of the residual becomes higher than seawater.

Wind driven drift, tidal and oceanic currents represent the major horizontal spreading mechanisms of surface slicks. In calm waters, spreading due to buoyant pressure and interfacial tension forces drives horizontal transport and formation of a thin surface slick. Thickness of the final slick depends on the oil characteristics, wind and wave pattern as well as ageing and mixing of oil and water. Normally, slicks are thinner towards the edges, leading to a characteristic “fried egg” shape. While the surface of oil slicks move about 1-3% of wind speeds up to 10 km/h, the deeper layers drift slightly to the right due to the Coriolis effect (typically 10° to 20° at 1 to 1.5% the wind speed; (Reed et al. 1990: page number if possible; Fingas 2011b: page number if possible). During strong winds, wave mixing intensity causes slicks to be entrained into mixed waters and follow Ekman drift. A range of spill drift and spreading models have been developed for trajectory forecasting by implementing wind drift, surface currents, tidal currents, along with vertical dispersion and advection (Galt 1997: page number if possible; Marta-Almeida et al. 2013: page number if possible; Liu and Sheng 2014: page number if possible) providing adequate tools for oil spill contingency decision makers (Galt 1997: page number if possible; Reed et al. 1999: page number if possible). Models for trajectory predictions have also been developed for ice conditions (Droztowski et al. 2011: page number if possible).

Uptake, conversion, and mineralization by living organisms are commonly known as biodegradation. By and large, the major group of organisms responsible for biodegradation in most environments (including the marine), are the bacteria (Atlas and Bartha 1998: page number if possible). In addition, other microorganisms, like fungi and yeasts, also degrade hydrocarbons (Head et al. 2006: page number if possible). Normally not regarded as biodegradation, uptake and conversion by higher organisms, mainly through detoxification metabolism, also contribute to the overall removal of hydrocarbons. Potentially, all components in crude oil are biodegradable (alkanes, alkenes, cyclic aliphatics, aromatics, PAHs, resins, etc.) however, their biodegradability is limited by bioavailability and kinetics (Head et al. 2006: page number if possible). Bacterial uptake of hydrocarbons is directly linked to the bacterial growth process, whereby hydrocarbons serve as primary substrate. The growth process is stoichiometrically linked to uptake of nutrients and an electron acceptor, which under aerobic conditions is molecular oxygen. Generally, hydrocarbons used for growth is restricted to the dissolved fraction (Harms et al. 2010: page number if possible; Parales and Ditty 2010: page number if possible), but bacteria has shown to develop aggregates, known as biofilms, at surfaces of oil droplets (Grimaud 2010: page number if possible). This latter mode of growth reduces transport limitations, but does not involve direct oil phase uptake. Stimulation of bacterial growth by addition of limiting nutrients, especially nitrogen and phosphorous, is a known strategy for enhanced biodegradation of oil spills, first tried out in large scale field applications during the Exxon Valdez accident in 1989 (Pritchard and Costa 1991: page number if possible; Atlas and Hazen 2011: page number if possible). Biodegradation rates increased to up to 1.5% reductions per day (mass) but reduced as the easily biodegradable fractions got depleted and slow bacterial growth on the more insoluble heavier fractions took over (Bragg et al. 1991: page number if possible). This is a general
pattern seen in natural biodegradation and bioremediation studies, and it contributes to the ageing process described for evaporation and dissolution; as time proceeds, oil slicks become denser, more viscous and chemically more inert. This has implications for oil spill management and decision making, and choice of remediation strategies and cleanup technologies. Along with evaporation and dissolution, biodegradation and bioremediation are important removal mechanisms for the fate and effects of oil spills and released hydrocarbons. Biodegradation is also the only mechanism presented that actually remove the hydrocarbon from the environment by complete mineralization. In extreme environments, like the low temperature arctic and deep sea, biodegradation is thought to be the main process controlling environmental fate (Bragg et al. 1991: page number if possible). Hence, adequate knowledge of this process is of uttermost importance in order to predict environmental risk and actively remediate hydrocarbon pollution.

As mentioned above, fate and effects of other sources of marine discharges of hydrocarbons are controlled by the same mechanisms influencing the oil spills. Leakages and release of drainage and slop water follow the same transport and conversion pattern, while release of produced water and ballast water from hydrocarbon storage installations introduce mainly dissolved and dispersed hydrocarbons prone to water column transport, evaporation and biodegradation conversions. Fate and effects of oil sorbed to drill cuttings, or present in mud is subjected to immediate sedimentation. Slowly, dissolution and biodegradation convert these hydrocarbons, or they get buried in the sediment strata.

**Marine effects of hydrocarbons**

Up till now we have focused on environmental fate of hydrocarbons released to the marine, and limited our discussion on effects. In addition to effects caused by hydrocarbons, additional environmental effects of offshore oil and gas exploration and production must be recognized, ranging from inorganic chemical discharges and chemical leaching from structural components, to seismic habitat disturbances. Our scope limits this section to environmental effects caused by hydrocarbon releases.

Biological (on organism levels) and ecological (community level) effects is a large research field and we will summarize current knowledge of importance for sound environmental management and policy makers. The common perception of oil in the environment physical is oiled and dead macrofauna including sea birds, fish and marine mammals. The media and social effects of oil spills (especially) are also outside the scope of this short review, but should not be forgotten. In fact, several authors including industrial interest organizations claim the social and public perception of oil spills to be more dramatic than the actual environmental effects. This is speculative and tendentious, but should still be regarded in environmental management.

Extensive literature on toxicological effects of hydrocarbons to marine organisms exists. It is not easy to extract conclusions upon concentration and effect levels from the overall literature as some studies report no effects at considerable hydrocarbon concentrations, while others report significant metabolic and/or ecological disturbances at even trace levels. Some of this variability can be related to vast differences in methodologies, experimental and environmental factors and sampling conditions. It also reflects the very large possible response range of complex marine organisms and communities. Patin (1999: page number if possible) proposed using a combination of concentration-response curves, median LC$_{50}$ and EC$_{50}$ concentrations (lethal and ecologically effective concentrations, respectively) for standardized tests and risk assessment evaluation. In a summary of literature data looking at bacterio- and phytoplankton, macrophytes, crustaceans, fish and bivalves, the same author conclude that LC$_{50}$ of early development stages are significantly lower than mature
organisms, with WAF ranging from 10–100 µg/l for early stages, and 0.1–10 mg/l for developed organisms. No observable effect (NOEC) concentration of dissolved hydrocarbons was found in the range 0.1–1 µg/l (Patin 1999: page number if possible). Details regarding different organisms and specific hydrocarbon compounds and production chemicals are now available giving more specific and precise information on effects and effect concentrations (Holdway 2002: page number if possible). Linking toxicity to specific hydrocarbon groups, Bakke et al. (2013: page number if possible) recently linked effects of produced water discharges to the concentration of alkylated phenols, and PAHs. Taking into account dilution and body burden exposure, they concluded physiological effects on cod and edible mussels to be limited to 1-2 km from produced water discharges of North Sea conditions. Sensitive stages are not, however, restricted to early life stages, but also include periods of metamorphic changes, reproduction and periods of metabolic stress like starvation (Anderson 1985: page number if possible). Environmental factors also affect threshold and lethal dose concentrations, and especially temperature seems to be an important factor (Anderson 1985: page number if possible; Robertson 1998: page number if possible). When it comes to ecosystem level responses, linking hydrocarbon discharges to observable effects on for instance fish stocks or sea mammals distributions, it becomes extremely difficult (Holdway 2002: page number if possible; Shigenaka 2010: page number if possible; Bakke et al. 2013: page number if possible). The problem is partly linked to experimental or observational methodologies and data analysis uncertainty. In additions, extrapolation onto community level effects is very difficult as alternative factors explaining observed responses cannot be ruled out (Hjermann et al. 2007: page number if possible). A possible route towards population and/or community level environmental effect management strategy is application of molecular biomarker responses, and proteomic, metabolomics and/or genomic methodologies (Hansen et al. 2013: page number if possible; Jager and Hansen 2013: page number if possible).

Management of hydrocarbon wastes and accidental discharges

The primary decision in oil spill management is whether to actively remediate, or leave the fate of spills to natural degradation processes as described above. For active fighting, technologies for remediation of oil spills are numerous and have been recently reviewed in Fingas (2011d: page number if possible). These include physical measures, such as booms, skimmers, sorbents, in-situ burning, sprinkling and flushing, suction and manual removal. Application of chemicals is another option for treatment of oil spills. Often combined with physical and/or biological measures, these are: Dispersants and washing agents, emulsion breakers and inhibitors, solidifiers, sinking/ballast agents, adhesive skimming enhancers, bacterial co-substrates and fertilizers. Finally, addition of biologically active phases for stimulated biodegradation (bioremediation) includes: Addition of sewage sludge, wastewater treatment plant activated sludge, pure or enhancement cultures, genetically modified microorganisms and freeze dried powders of bioactive potential (unknown composition). Selection of oil spill cleanup method is often dictated by parameters of the local environment, governmental regulations and public perception, as well as crude oil characteristics, degree of ageing (the time window), accessibility and secondary safety, human health and ecological risk.

For non-accidental discharges, such as produced water, slop water and drill cuttings including muds, technologies for on- and off-site treatment has been developed and adopted. Produced water treatment includes hydro-cyclones, centrifugation, filtration, flotation, adsorption and absorption techniques (Fakhru’l-Razi et al. 2009: page number if possible). Novel technologies are still considered, however, new developments are now moving towards zero
emission management involving 100% re-injection (Garland and Hjelde 2003: page number if possible). Re-injection techniques has also been developed for drill cuttings and mud disposal, and is thought to be the only environmentally sound disposal option on the Norwegian arctic continental shelf (Nagel and McLennan 2010: page number if possible).

Environmental issues related to Oil & Gas activities in the Arctic Ocean

The Arctic Ocean plays an important role in the regulation of global climate and it is also an important source of economic and cultural value. Due to climate change, sea its ice extent has been reaching minimums in the last six years (in 2007 and again in 2012) and sea surface temperature on the ice edges has been measured to exceed the long-term average. As a result, the Arctic Ocean has become a rapidly changing environment challenging its inhabitants (AMAP 2010b: page number if possible; PAME 2013: page number if possible). Future prospects of increasing Arctic offshore oil and gas activities bring further stressors introduced previously. Additionally, the increase in temperature will likely enable an ice-free transportation route to be established in the North-East passage, allowing for both oil and gas transportation and other transportation of goods by ship on the Arctic continental shelf (ACIA 2004: page number if possible). This implies that the general increase of pollution arising from shipping traffic will increase together with the risk of an oil spill. Levels of oil transportation from ports and terminals in north-western Russia already reached 13 million tons by 2009 and exceeded 15 million tons by 2010. Predictions suggest this capacity to reach up to 100 million tons per year during the next 5-10 years (Bambulyak and Frantzen 2011: page number if possible).

The major concern regarding hydrocarbon releases originate from their well-known toxic effects as mentioned in the previous part of this chapter. Species in the vicinity of accidental spills are directly exposed to this hazard, and humans may experience indirect effects through food obtained from polluted areas. In those parts of the Arctic region, where large fish resources are being exploited by the fishing industry, environmental protection and food safety become closely related issues. The Barents Sea is an excellent example for such area (Stiansen et al. 2009: page number if possible). Besides focusing attention to highly valuable regions it is important to keep in mind, that the marine environment is very dynamic. Transportation of large water masses to great distances (e.g. through currents) and other mixing mechanisms take place continuously, making it easy for even point source pollutions to be carried to large distances (Schlosser et al. 1995: page number if possible). Pollution can also become dispersed as contaminants are transferred through the marine food web, between ecosystem members at different trophic levels. In this context, for example, migrating species of the Arctic represent a risk for carrying pollution to and from the area. The Arctic nations have in the last decades recognized the importance of establishing thorough knowledge about the current functioning of the Arctic ecosystem, including geographical, oceanographical, chemical and biological features. Although the ecosystem of the Arctic Ocean is still the least explored of all oceans due to limited accessibility, challenging climate and logistic difficulties, Arctic Council working groups have compiled extensive data about its status in recent years (AMAP 2010a: page number if possible).

The Barents Sea ecosystem as an example

The Barents Sea is considered as a moderately productive ecosystem which is capable of producing substantial fish stocks due to its size. The foundation of the ecosystem consists of microscopic phytoplankton (algae) which utilize the energy from the sunlight and assimilate inorganic carbon (i.e. carbon dioxide) into cell material. Just like trees on terrestrial environments, algae are the most important primary producers in the Barents Sea and in other
parts of the Arctic Ocean (Word et al. 2008; page number if possible; Stiansen et al. 2009: page number if possible; Arneberg et al. 2013: page number if possible). As light is essential for their growth, algae blooms are limited to spring and summer seasons and relatively shallow water depths. Although algae blooms have been recently observed under sea ice, the increase of ice free open water surfaces favours enhanced phytoplankton growth. As Figure 12.2. shows, major consumers of these microscopic organisms are tiny zooplanktons which create a link towards higher level organisms, such as different fish species. The arrows represent the direction of the energy flow. Zooplankton members are called “keystone” species in the Arctic marine food webs. Without them the ecosystem would collapse as energy cannot be transferred further up from the primary producer level. Hence zooplankton (and algae) must be considered in environmental monitoring of the arctic in order to spot potential dangers that can effect valuable fish populations. Figure 12.2. can be used to detect the many interdependent relationships characterizing the arctic ecosystem. As all species are directly or indirectly connected, Ecosystem Based Management (EBM) has been recognized as the most useful framework for risk assessment and decision making in the fishing industry (Stiansen et al. 2009: page number if possible; Arneberg et al. 2013: page number if possible).

Status of the environment and sensitivity of Arctic species

There have been already substantial amounts of oil and gas produced in the Arctic region. With technological developments, better understanding of pollutant fate and effect, and stricter regulations, current activities are far less dangerous than in the beginning of the Arctic oil era (AMAP 2010a: page number if possible). As a result, hydrocarbon levels in the Arctic Ocean are low, except for areas where natural petroleum sources are present (AMAP 2007: page number if possible). Ecotoxicological assessment of prior activities are rare, the majority of ecotoxicological studies assessing the effect of oil industry related chemicals originate from temperate areas (Bakke et al. 2013: page number if possible). A number of studies used native Arctic species to elucidate ecotoxicological effects and some set out to establish the sensitivity of Arctic species in comparison to temperate ones (Skadsheim et al. 2009: page number if possible; Bechmann et al. 2010: page number if possible; Hansen et al. 2011: page number if possible). Their conclusions suggest that Arctic species are sometimes more, sometimes less sensitive to tested pollutants under laboratory conditions compared to temperate ones (Camus and Olsen 2008: page number if possible; Hatlen et al. 2009: page number if possible). The obtained data is not yet substantial for solid conclusions. Moreover, it is not yet clear whether the observed moderate toxicity levels are a result of arctic specific environmental features or unique adaptation of the species, hence, overall it is too early to conclude about the sensitivity of Arctic species (Hjermann et al. 2007: page number if possible). Most likely, the response mechanisms of individual organisms, such as metabolism of pollutants, can be expected to be mostly the same in Arctic species. The real vulnerability of the Arctic ecosystem to even localized oil spills comes from biological features as: (1) extreme seasonality of biological production (most production occurs in summer when there is daylight), (2) seasonal aggregation of marine animals (locally high diversity and abundance in certain times of the year), (3) short food chains, and (4) migration of species from and to the Arctic.

Fate of oil spills in the Arctic environment

Currently, hydrocarbon levels in the Arctic are low and over half of the existing hydrocarbons originate from natural seepages (for example nearshore Beaufort Sea, along the coast of
Baffin Island at Scott Inlet, at Buchan Gulf). The largest threats to the Arctic Ocean are considered to be accidental oil spills.

Unique characteristics, i.e., permanently cold temperature, extreme seasonal light/dark cycle and the presence of seasonal and permanent sea ice, affect oil weathering processes in the Arctic region. In general, due to low temperatures, most weathering processes described earlier in this chapter occur slower under Arctic conditions compared to warmer environments. This could ideally increase the so called “time window” or “window of opportunity” for response that allows for efficient cleanup measures. On the other hand it also slows down natural recovery mechanisms, such as biodegradation by bacteria. Darkness makes it difficult to detect oil spills during the winter, requiring technology adapted to such conditions. Ice covered waters can be inaccessible hindering any response, and the presence of partial sea ice complicates oil distribution. The following paragraphs describe the effect of these features in more detail, discussing their influence on previously introduced weathering processes.

Effect of temperature

Most types of crude oils, except for the lightest paraffinic ones, have a pour point higher than the mean temperature of the Arctic Ocean. Below pour point, oils begin to solidify. This implies that for example surface spreading will become very limited. As a result of limited spreading, oil spilled in cold water occupies smaller area and forms thicker layer (Potter et al. 2012: page number if possible). Spreading of oil on the water surface normally enhances other processes such as evaporation, dissolution as it facilitates the formation of a large and thin layer. Consequently, under cold conditions, these processes also slow down. Decreased evaporation rate prevents small molecular weight alkanes and aromatics, such as benzene, toluene, ethyl-benzene and xylene (BTEX) from escaping into the atmosphere quickly, thereby making it more likely for these components to be dissolved (Fingas 2011a: page number if possible). This is not favourable for marine life as BTEXs are very toxic. Dissolution rates are generally reduced at low temperatures as a result of thermodynamic laws. Dispersion is known to be dependent on viscosity, which is directly linked to chemical composition of the oil and also to its weathering state (NRC 2005: page number if possible). Moreover, dispersion has been shown to be temperature dependent as well, most likely due to increased viscosity at lower temperatures (Li et al. 2010: page number if possible). Srinivasan et al. (2007: page number if possible) found that dispersant efficiency was almost two times lower at 5 compared to 16 °C provided sufficient mixing energy. Biodegradation is also among those processes dependent on temperature, metabolic processes of all living organisms tend to occur slower at reduced temperatures. Nevertheless, cold-adapted hydrocarbon degraders have been shown to be able to degrade oil under arctic conditions even in sea ice (Brakstad and Bonauinet 2006: page number if possible; Brakstad 2008: page number if possible; Brakstad et al. 2008: page number if possible; Brakstad et al. 2009: page number if possible; Lo Giudice et al. 2010: page number if possible). In a recent study, microorganisms from the Chukchi Sea were found to degrade both fresh and weathered crude oil in the presence and absence of Corexit 9500 at −1°C with oil losses ranging from 46–61% and up to 11% mineralization over a 60 day test period (McFarlin et al. 2014: page number if possible).

Effect of darkness

Darkness mainly represents difficulties for tracing and tackling the spilled oil. Regarding oil weathering, only photo-oxidation is directly affected. None or limited photo-oxidation implies that formation of water soluble and toxic compounds are retarded and oxidized “skin” on the
surface of the slick will likely not build up. In the summer season, the opposite effect can be expected (Barron et al. 2003: page number if possible).

**Effect of ice**

As Figure 12.3. illustrates, oil can be distributed in several different ways on, under, among and in ice. Accessibility of oil for recovery under different ice concentrations and coverage are limited. Ice sheets (or pancakes) can also behave as booms which collect and contain the oil in which case contingency might become easier (Brandvik et al. 2006: page number if possible). This effect of sea ice can be utilized for in situ burning, where a substantially thick oil layer must be developed to reach ignitability.

Oil in pack ice evaporates even slower than from cold open water due to thick film formation. Ice coverage (as of % of surface occupied by ice) in particular appears to significantly influence the extent of evaporative loss of hydrocarbons (Brandvik and Faksness 2009: page number if possible). Oil encapsulated in ice will not evaporate at all (Potter et al. 2012: page number if possible). Emulsification and dispersion are generally retarded under icy conditions as brash or pack ice dampens wave action which would provide the mixing energy necessary for these processes. Oil encapsulated in ice were shown to diffuse down to the bottom of the ice sheet to a very low extent, which means that water soluble components are not likely to be leaching out from the ice (Faksness et al. 2011: page number if possible).

< FIGURE 12.3. HERE >

**Strategies to tackle oil spills in the Arctic**

The Arctic is one of the most challenging environments when it comes to oil spill response therefore prevention becomes even more important (Rossi 2013: page number if possible). The remoteness and harsh climate makes it extremely difficult to respond to disaster quickly. Oil spill cleanup can be a particularly great challenge during the winter months when sea ice may cover transportation routes and there is no daylight. Detailed planning and extreme preparedness is therefore essential (PAME 2009: page number if possible; The PEW Charitable Trusts 2013: page number if possible). Equipment needs to be stored on site when distances are too long to get the necessary cleanup measures to the area quickly and personnel need to be trained to be able to use the equipment. So far, no major oil spills have occurred in the Arctic offshore. Experience from spills in more temperate climates and a number of small scale field studies carried out in Arctic waters serve as a knowledge base for oil spill contingency and response (Brandvik et al. 2006: page number if possible). The remaining area for development is to improve the ability to deal with oil spills in ice and in complete darkness in case of winter operations.

All response strategies require the understanding of the location, mass balance and movement of the spilled oil. In poor light conditions and in poor weather, remote sensing tools, such as vessel-based or airborne remote sensing systems, are necessary. Monitoring the fate of oil after an incident usually includes the usage of advanced modelling tools and sampling of the area (Singsaas and Lewis 2011: page number if possible). As concluded earlier, oil is expected to undergo slower weathering in ice which can be an advantage for certain types of oil spill scenarios. Yet, the “window of opportunity” is limited and rapid decision making is required to make use of it. Oil fate models serve as aid for such decision making. The most widely used model in the Norwegian sector is the Oil Spill Contingency and Response (OSCAR) model, developed by SINTEF (Reed et al. 1995: page number if possible). OSCAR has been adapted for modelling oil in ice in 2009 (OSCAR version 6.0). Future developments of the model will likely make it an essential tool for response planning.
The three major response strategies which have already been assessed for their efficiency under arctic conditions during the Oil in Ice Joint Industry Program (JIP) were: (1) mechanical recovery, (2) dispersant use, and (3) *in situ* burning. Research developments regarding this area are described in detail in the JIP report published by SINTEF and also discussed extensively in “Spill response in the Arctic offshore” by Potter et al. (2012: page number if possible). Further information about projects carried out under the Oil in Ice JIP can be found on SINTEF’s website (http://www.sintef.no/Projectweb/JIP-Oil-In-Ice/Publications/). Latest developments, guidelines and research findings related to response strategies under Arctic conditions can also be found on the website of the Arctic Response Technology JIP (http://www.arcticresponsetechnology.org/). Here we include a selection of interesting conclusions from these works.

Mechanical recovery using traditional booms proved to be little efficient under icy conditions. Instead, new prototypes of skimmers have been developed specifically for working under partial ice cover and test results have been promising. Dispersant use have been shown to have an increased “window of opportunity” for application at higher ice coverage (approximately 1.5 day compared to maximum 12 hours without ice), however, this time window is still shorter than that of more temperate scenarios (Brandvik and Faksness 2009: page number if possible). *In situ* burning has also been suggested as a viable alternative, in fact, it is considered the highest potential response strategy under Arctic conditions. Ignitability of oil slicks depends on mainly the concentration of light and volatile components in the residual oil and the water content emulsified into the oil. High ice coverage which enables retention of volatiles and blocks emulsification appeared to be suitable for the application of *in situ* burning as it facilitates thick slick with high concentration of volatiles remaining (Fritt-Rasmussen and Faksness 2011: page number if possible). Oil trapped under ice for the winter season can still be ignitable when it surfaces during spring melting and hence be burned. The major drawback of this strategy is the massive soot production and release of partially oxidized hydrocarbons in the air. Risk assessment must balance the negative effects of air pollution from *in situ* burning with the achievable ecological benefits to the marine ecosystem.

**Need for harmonized standards of operation**

As the Barents Sea is an area of common interest for Norwegian, Russian and other parties both with respect to fish resources and oil and gas resources, it is of great importance to agree on rules for operation and harmonize standards. There are several activities centred around developing guidelines and regulations for preparedness and response in the Arctic under the work of Emergency Prevention Preparedness and Response (EPPR) and Protection of the Arctic Marine Environment (PAME) working groups of the Arctic Council. A recently established Arctic Council Task Force appears to be a good way to begin addressing the challenge of Arctic Marine Oil Pollution Prevention on an international level by providing an arena for extensive and direct communication and collaboration between the Arctic nations. A more “local” forum in the Barents Region for discussion and cooperation, the Barents Euro-Arctic Council (BEAC), has been established in 1993. Its major aim is to "provide impetus to existing cooperation and consider new initiatives and proposals.”

Industrial parties are generally very optimistic and trust modern technology to prevent disasters. The scientific opinion is more pessimistic and does not trust the human factor involved in the process. Most of the oil spills in history have been induced by human error and under tough conditions like in the Arctic, workers are under even more stress compared to other offshore platforms due to difficult weather conditions which makes them more prone to
mistakes. Hence, Arctic offshore facilities and working conditions have to be designed accordingly after careful evaluation of health and safety parameters.

Health and Safety in the Arctic

Health, Safety and Environment (HSE) is a focus area for offshore activities, and is paid special attention for work in the harsh and cold environments of the North. HSE work includes health- and environmental protection, working environment and safety. The work should be proactive in order to avoid incidents which may be serious or fatal in these regions. Important climatic factors have to be taken into consideration as temperatures, wind, icing, polar low, uncertain weather forecasts and dark polar nights. Some focus area for offshore work in arctic regions are paid special attention, such as number of working hours and rest periods on the installations, preparedness for long transportation distances with helicopters in case of injuries (Jacobsen and Gudmestad 2013: page number if possible), effect of darkness with respect to work processes and ability to sleep, low temperatures which affects physical and concentration problems, handling of equipment in cold environment, and aspects of use of chemicals under these conditions.

Guidelines are given in an International Association of Oil & Gas Producers (OGP) report (OGP 2008: page number if possible) and challenges for work in extreme climates with respect to health are given in other reports (Dahl-Hansen et al. 2000: page number if possible; Knardahl et al. 2010: page number if possible; Thelma 2010: page number if possible). Work in both elevated and lowered temperature give a higher risk to accidents as the outside temperature moves away from the optimal temperature at 17 °C. Normally, the heat produced by doing physical activities is removed by wind chill. Thus, both the temperature and wind are important factors for cooling the body. For colder regions a too high wind chill index (WCI) will cause problems (CANDAC 2014: page number if possible). The effect of wind on perceived temperature is illustrated in Figure 12.4. A frostbite guide gives the following consequences based on the efficient temperature shown in Figure 12.4.:  

\[
> -27 °C: \text{Low risk of frostbite for most people} \\
< -28 °C: \text{Increasing risk of frostbite for most people within 30 minutes of exposure} \\
< -36 °C: \text{High risk for most people in 5 to 10 minutes of exposure} \\
< -44 °C: \text{High risk for most people in 2 to 5 minutes of exposure} \\
< -55 °C: \text{High risk for most people in 2 minutes of exposure or less}
\]

< FIGURE 12.4. HERE >

In addition the humidity is important. Clothes should therefore have the ability to transport sweat from the skin to outer layer of the clothes. An inner layer of non-absorbing material as e.g. polypropylene filaments and wool as a moist absorbing, but still insulating material is therefore preferred used. The outer material should be able to protect against wind and water. New technology has given smarter cloths. The material could be Phase Change Materials (PCM) which can regulate the heat transport through the cloths, heat conducting materials with an energy recourse and materials with sensors measuring temperature, humidity and heart rate. In addition to good insulation for the feet, arms and body it is very important to protect the head and neck region with scarf and face mask to avoid a substantial heat loss. Insulation of tools reduces the heat loss direct to the metal from the hands and power tools,
cranes and other support will help reducing the need for individual work. A lower temperature will affect the ability to work properly, which will increase the risk of accidents. The optimal skin temperature for hand and fingers are 32-36 °C, and below that the function is slower and less precise. Overall, it is extremely important to have sufficient clothes, and to keep the hands and feet warm. Under cold conditions the extremities will swell and become painful.

Freezing may be divided into three phases (OGP 2008: page number if possible):

1. degree: Freezing without peeling and blistering, but with color change of the skin

2. degree: Blistering and peeling of the skin with pain and a violet color of the skin

3. degree: Freezing with blackening and death of skin tissues, which gives pain and numbness

If body temperature becomes lower than 35 °C the situation is defined as hypothermia. Bodily responses to cold are included in Table 12.2. A report prepared for the Petroleum Safety Authority, Norway, relates to work in cold environment (Thelma 2010: page number if possible) and a report with extensive literature review was compiled by Stami for similar conditions on land (Knardahl et al. 2010: page number if possible). The most extreme situation on a platform is immersion accidents where a person falls in the water.

A series of medical papers related to petroleum industry and health were published in Norway in 2004. It was reported that a very limited number of papers had been published related to offshore petroleum work, and thus medical doctors had very limited knowledge on this area. A focus was given to shift work and accidents (Bjørkum et al. 2004: page number if possible). An increase in number of accidents was reported due to shift work, and especially due to work in night shift. The shift work disturbs the body’s natural rhythm, hence regular rest periods need to be organized. Sleep disorders are frequently registered as a result of shift work, especially for the night- and early morning shifts (Pallesen et al. 2004: page number if possible). The risk of failures is highest in the period 3:00 to 4:00 am in the night, and it becomes even higher with the longer working periods and periods far since the last rest period (Folkard and Tucker 2003: page number if possible; Tucker et al. 2003: page number if possible). The melatonin metabolite is a good indicator of a sound day rhythm. The acrophase of the melatonin metabolite was not changed for day shifts. For night shift the acrophase of the melatonin metabolite was delayed, and normal after 4-7 days. For lighter periods, i.e, in spring the adaption period from night to day was much shorter. Artificial light exposure gave also a positive effect with respect to adaption time to day shift. In order to get a good sleep other stimuli as physical activities, noise, light and coffee should be avoided. Regular 12 hours night work for, e.g, 14 days is better than having a swing shift, as the awake period is became better with longer night periods (Parkes 1994: page number if possible; Barnes et al. 1998: page number if possible; Bjorvatn et al. 1998: page number if possible; Bjorvatn et al. 1999: page number if possible; Gibbs et al. 2002: page number if possible).

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CHAPTER 13

Winterization of onshore plant facilities

PER-ARNE SUNDSBØ
Part 4

Scenarios
CHAPTER 14

Scenarios for the Development of the Petroleum Industry in the Barents Sea as a Joint Norwegian-Russian Petroleum Province
Glossary

Acute toxicity
Alkanes
Alkenes
Bioaccumulation
Biodiversity
Bioremediation
Community
Cyclo-alkanes
EC₅₀
Ecosystem
Ecotoxicity
Environmental impact
Environmental risk
Eutrophication
Saprobiation
LC₅₀
Meiofauna
Microfauna
Monoaromatics
Photo-oxidation
Polyaromatic hydrocarbons (PAHs)
Population