Controlling the flow of oil and gas subsea:

A case study of the software OLGA

OLGA is a software program developed in Norway from the 1980s that simulates the flow of oil, gas, water and sediments in pipelines on the seabed. This technology has enabled the transportation of unprocessed oil and gas from below the sea directly to the shore for processing. In so doing, OLGA in its mature form have made reservoirs of oil and gas at deep sea levels commercially viable, and almost rendered the offshore oil and gas platforms unnecessary. As such, OLGA have turned out to be a game changer in the offshore petroleum industry by being the key ingredient for the development of subsea technology. The quest for finding appropriate technology in order to exploit reservoirs at deep sea levels in a commercially viable manner made Norwegian subsea technology and the petroleum service firms specializing on this technologies competitive in the Mexican Gulf, Russia, Nigeria and Brazil.[1]

Statoil, the Norwegian oil company, originally fully state-owned, and one of the main investors in the research and development of OLGA, have calculated that they reduce costs of exploiting a field with approximately 3,3 billion euro by using OLGA.[2] In 2012 Schlumberger acquired the property rights to the OLGA software when they bought the Norwegian software company SPT Group for approximately 682 million euro.[3] SPT Group was the company who commercialized OLGA. At the turn of the millennium, OLGA had a world market share of approximately 90 %.[4] Safe to say, the development of the OLGA software has been a huge success. How was it possible for a new petroleum nation with no experience to develop such an important and innovative technology in an oil economy controlled by a few big multinational companies?

The idea to develop OLGA for offshore petroleum production was conceived in 1979 by two nuclear scientist, just 10 years after the discovery of petroleum resources in the North Sea. Initially, Norway was dependent on foreign oil companies, their expertise and technology, in order to exploit the newly found resources. To develop expertise and technology in order to be more independent of the big multinational oil companies was an

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[1] Ryggvik 2015, p. 4.
[2] Tjelta & Thirud 2005, p. 61.
[3] https://www.tu.no/artikler/mangler-penger-til-a-utvikle-egne-ideer/235921
[4] Tjelta & Thirud 2005, p. 61.

important part of the policy for petroleum that the Norwegian parliament and government agreed upon right after the discovery of oil in the North Sea.

In my paper, I will argue that we need to include five factors in order to explain how and why the OLGA technology was developed. First, Norwegian offshore petroleum extraction provided unprecedented technological challenges, i.e. challenges that the existing international petroleum industry did not have ready answers to. These challenges were connected to the demanding conditions in the North Sea, especially the deep sea levels. Second, Norway set up specific institutional arrangements of its oil economy in order to limit the power of the multinational oil companies, which among many things favoured national research and technology development. Third, the quest for innovations and technology development answering to specific national offshore needs was perfectly timed in order to tap into a reorganization of the national system of innovation in Norway, specifically the Norwegian Institute for Atomic Energy, who was in need of funding through R & D contracts due to political decisions abandoning the ambition of implementing nuclear power in Norway, which also included a change of the institutes name to Institute for Energy Technology. Fourth, agency played a vital role, involving personal connections as well as actions pursuing both personal and institutional interests. Most importantly, for the nuclear researchers it was easy pitching the idea to Statoil for funding to develop OLGA, since the actors on both sides of the table had been strategic actors in establishing both the nuclear research institute and the national oil company – and they all knew the technology from the nuclear research that the idea of OLGA was based on. Fifth, developing OLGA evolved into an interactive venture, where both several oil companies, government agencies and research institutions contributed. Moreover, the software development benefited from the subsequent overall offshore and subsea technological innovations OLGA enabled by contributing with growing empirical input into big data that enhanced the software's reliability and validity. These subsea technological innovations further benefited from the long-lasting traditions of Norway as a sea-nation, and eventually led to an internationalization push at the turn of the 21th century, in which the subsea-technologies and -companies were most successful.

The paper is structured as follows: First, I will briefly depict previous business history research on the petroleum industry, and point to some differences between the Norwegian strand and the general pattern. In addition, I will discuss theoretical framing and methodological challenges of following a business history approach in the study of industry-directed software innovation projects. Second, I provide a brief description of the OLGA software, and the technological context it was developed in connection to. Third, I outline the five explanatory factors I argue needs to be accounted for to grasp why OLGA was developed the way it was one at a time. Finally, I conclude stating that OLGA as a successful innovation project rested on a multitude of institutional and personal factors, who all were perfectly aligned in this specific case, but are not necessarily symptomatic of a perfect system for innovation.

"The new business model" and challenges for doing business history

In business history, politics and the volatile prices has dominated the research on the petroleum industry.[5] Since the global petroleum industry became dominated by the a few large multinationals, the so-called "seven sisters", many originating from Standard Oil, the petroleum industry has for many served as the pinnacle of both big business and multinational corporations.[6] How these large corporations handled organizational challenges has naturally been in focus in the literature.[7] So is the case for the political dimension as the big multinationals has operated in countries with conflicting interests.[8] With high fix costs, price volatility caused by political conflicts, dominance by a few players, the business history research on petroleum industry have focused more on organizational and political issues than technology.[9] This is to some degree mainly the case also for Norwegian petroleum history.[10] In contrast to the international business history tradition, technology has also been a prominent issue in historical research on the petroleum industry.[11]

With the discovery of large oil and gas fields on the Norwegian continental shelf, first discovered in 1969, technological competencies became an important capability for Norwegian petroleum businesses, quite unlike the most common trajectory of European petroleum companies who predominantly were occupied in trading oil.[12] To some extent Great Britain shared the Norwegian path of discovery of petroleum in the North Sea, but the findings on the British side were considerably smaller, which might explain differences in need of technological innovation.

Since Norway in 1972 established a state-owned oil company, as well as ten oil commandments installing a national infant industry policy, the emphases on politics is well

[5] Cfr: Yergin 1991, Jones 2004
[6] Chandler 1990, Wall 1988
[7] Cfr: Hinton 2010
[8] Bucheli ibid., Sluyterman & Wubs ibid., Wilkins 2005ibid.
[9] Priest 2007
[10] Hanisch & Nerheim 1992, Ryggvik 2015, Lie 2016
[11] Nerheim 1996, Engen 2009
[12] Boon 2018

warranted. The quest for gaining technological capabilities have by Norwegian historians not only been investigated as national industrial politics, but also through the theoretical framework of national innovation systems.[13] There existed a close inter-firm cooperation between oil companies and service firms, that also were connected to universities and research institutions as well as the Norwegian government.

At the pinnacle of what we can call a consensus on the Norwegian national system of innovation there is two research institutions: SINTEF, an applied science research institution connected to the Norwegian institute of technology (since 1996 Norwegian University of Science and Technology (NTNU)) and the Norwegian Defence Research Establishment: Both these technical-industrial research institutions were established right after WW2, as part of a national policy inspired by both the British and the American military-industrial complex war efforts, and especially Vannevar Bush' famous "endless frontier" report. According to previous research, these two institutions has been essential for the evolution of high tech businesses in Norway.[14] The case that I bring forth here fits well into this overall picture of the development of the Norwegian petroleum industry, but adds two features not prominent in the existing research: The institute of Energy Technology has not properly been positioned in the Norwegian system of innovations, but only gets briefly mentioned, which does not only underplay the role of how the OLGA software in transforming the petroleum industry, it is symptomatic of how software technology too often have been overlooked.

The case of OLGA is an illustrative example of challenges business historians meet investigating the period after 1970, the so-called third industrial revolution or what William Lazonick has labelled a change from the "old business model" to the "new business model".[15] Accompanying the rise of information technology, the old business model was gradually replaced by new business models, in which in-house R & D projects evolved into inter-firm cooperation and research institutions formed both formal and informal R & D partnerships. This interactive dimension of the new business model represents challenges for business historians, since it necessitates admission to several institutions' and organizations' archives in order to access primary sources if the ambition is to account for every side and actors involved. The traditional way for business historians by going inside the box, analysing one business at a time, may not be sufficient speaking of the new business model. The consequence of investigating one institution at a time, as for instance commissioned history

[13] Engen 2009
[14] Brandt & Nordal 2010, Gulowsen 2000, Sogner 1994, Wicken 1994, Wicken 2009
[15] Lazonick 2010

commonly does, is the emergence of separate silo-narratives that can underplay and/or bias the interactiveness of the histories they portray.

I cannot present a new approach in this paper, i.e. one that are more suitable for the challenges here mentioned, because this paper is mainly based on archives from one institution, the Institute for Energy Technology in Norway. The primary sources used in this paper was collected as part of a commissioned work on this institutions history, a project that was terminated from the institution due to financial insecurity caused by the drop in oil prices in 2015. As such, this paper predominantly follows the old business model, and falls in under the pitfall of silo-narratives, where the primary sources are not collected from all the institutions involved in the object of my research. Without admission, resources and time to consult the involved institutions archives and actors, the historian is left with secondary sources in order to fill the gap. The termination of the commissioned work has, however, given me the opportunity to focus on specific projects rather than depicting a narrative incorporating the whole institution, its activities and people. The possibility to single out projects, technologies or activities may prove to be a fruitful venture in order to capture the interactiveness of the new business models emerging with the third industrial revolution.

The development of the OLGA technology is, hence, a case of software development, and how IC-technology have transformed existing industries. For long, the historical research of the introduction of computers have been characterized by a "hardware bias", i.e. that historians predominantly have emphasized computers – not so much the software making computers useful.[16] There are reasons why software development should be prioritized more in business history. By the 1960s software development was pinpointed as the most important task in order to utilize computers, and make the use of computers more effective.[17] During the 1970s approximately 75 % of the resources in the ICT industries was directed to software development according to calculations.[18] As such, this paper is an attempt to contribute to incorporate software development in business history.

One underlying reason behind the transformation from the old to the new business model is the systemic approach that has followed the evolution of information technology. In fact, systems engineering has evolved to a distinct discipline, as a symptom of the importance of having a holistic approach and the need for integrating different gadgets and system in

[16] John 2014
[17] Boehm 1972, p.2.
[18] Paulsen 2011, p. 11.

order to achieve smooth operations and efficiency.[19] Systems engineering as a discipline has roots to the large technological projects undertaken by the American military-industrial complex connected to the development of nuclear weapons and control of missiles. These technological projects had in common high risks and uncertainties that required complex calculation in which the computers played an important role. As the information technology became common also in civilian use, possibilities to control and simulate large complex systems via computers were opened. Consequently, the systems engineering approach has spread to a wide range of industries, leading up to the recent decades' digitalization frenzy.

The holistic systemic approach does to some degree require inter-firm cooperation, as well as the interaction between various institutions both when it comes to doing business and develop technology. The historical-sociological study on the evolution of large technological systems pioneered by Thomas P. Hughes can be interpreted as the social science answer to systems engineering.[20] I will argue that business historians can benefit from combining the theoretical framework on systems of innovation and large technological systems when investigating business histories in the period of the third industrial revolution and the new business model. These theoretical frameworks share a common emphasis on the interactive dimension, but differs somewhat in this respect. While the systems of innovation approach are more tuned into the interplay and institutionalization of cooperation between organizations and people, the large technological systems approach are setting the spotlight more on the technology in the systems, their reverse salient and flow of goods, gadgets and people. In this paper, I will try to account for both the technological aspects, i.e. the reverse salient in petroleum production that OLGA answered to, with the formal and informal institutionalized settings this technological project developed within.

What OLGA is and does: solving the reverse salient of slugs in offshore pipelines

The OLGA software is an example of a key ingredient in a large technological system, brought forward within a more or less formalized system of innovation, that answered to a severe reverse salient in petroleum production: how to smooth and secure transport unprocessed oil and gas from offshore reservoirs over distance. The problem with transportation of unprocessed petroleum offshore is that the oil and gas comes with water, sand and various sediments. These components tend to lump together when transported in pipes, that eventually will turn into slugs; lumps of all the components that can slow down or

[19] Kossiakoff, Sweet, Seymour & Biemer 2011, Prencipe, Davies & Hobday 2003
[20] Hounshell 1995, Hughes 1983, Summerton 1998

totally stop the flow in the pipes.[21] Consequently, high pressure is needed to transport the slug through the pipes, an action that can have fatal outcomes as these slugs can be quite large and totally destroy the pipes or processing facilities either they are offshore on a platform or a vessel, or on-shore facilities. What the nuclear researchers behind the OLGA software set out to develop was a simulation model, that could predict the flow of all the components in the pipes in order for the petroleum engineers to prevent the emergence of slugs and create a stable flow of goods in the offshore pipelines.[22]

The nuclear researchers' idea was not taken out of thin air; how to simulate, predict and control stable flow of liquids and gas was something these researchers had worked on since the 1950s.[23] The institute for nuclear energy initiated then what they labelled "the rock 'n' roll project", where the ambition was to develop nuclear reactors designed to be used on ships.[24] In this endeavour the nuclear researchers took their base technology, the heavy water reactor (HWR). Their main technological obstacle for inventing a functional nuclear reactor for ships was to secure a stable flow of water and steam in the pipes connected to the reactor in the unstable conditions on sea with various degrees of wind and waves. In order to solve these problems, the nuclear researchers experimented with calculations with basis in the Navier Stokes equation.[25] The Navier Stokes equation was developed in the 19th century that describes the flow of viscous fluids, and as such was well known in the 20th century, and has been included in the exclusive club of "Millennium Problem".[26]

The experiments the nuclear researchers conducted with the Navier Stokes equation in the 1950s and 1960s was directed towards simulating and predicting the flow of two substances, water and gas. Through the experiments, the researchers refined the calculations with empirical data, which they used to build a numerical simulation model.[27] The first project Institute for Energy Technology received funding from by Statoil targeted another form of two-phase flow simulation, i.e. directed towards petroleum transport. But their ambition was to move beyond two-phase simulation models since petroleum reservoirs commonly inhibits both oil and gas.

[21] Interview with Kjell Bendiksen, former director of Institute for Energy Technology and inventor of OLGA; cfr: IFE & SINTEF 2008.
[22] Interview with Kjell Bendiksen.
[23] Interview with Kjell Bendiksen.
[24] Njølstad 1999
[25] Interview with Kjell Bendiksen.
[26] Hosch 2018
[27] Interview with Kjell Bendiksen

In order to make a numerical model really useful for offshore pipelines, the nuclear researchers faced two major challenges. Firstly, transport of unprocessed petroleum offshore entailed more than two substances, namely water, oil, gas and sediments. In their lingo, they needed to take a step from a two-fase to a multi-phase flow simulation model. The second challenge in going from two-fase to multiphase simulations was the fact that the multiphase flow simulation needed to account for the pressure of deep sea levels, and the ups and downs of the seabed. Consequently, they needed to calculate new algorithms, and make a new simulation model. In order to do so, they required to obtain new empirical data on the flow of oil, gas and water to refine their numerical calculations. After complicated and conflicted negotiations, Exxon funded the construction of a test loop in Trondheim where SINTEF run tests on a grand laboratory scale of Institute of Energy Technology's calculations, which provided useful empirical data for developing the algorithm before moving the software full scale offshore.[28]

With the decision to construct a test loop, the project expanded in funding, scope, as well as actors and institutions involved. Originally, the project was initiated by two nuclear researchers, Dag Malnes and Kjell Bendiksen, at the Institute for Energy Technology with funding from Statoil.[29] The test loop finalized in 1983, however, was funded by Exxon with 10 million euro, who declared that the test facilities was a gift to the Norwegian state.[30] From that point of, the OLGA project became a joint venture, funded by shifting groups of oil companies as the project continued, and the research was conducted as a joint venture between the two competing Norwegian technical-industrial research institutions Institute for energy technology in the Oslo region and SINTEF in Trondheim. The test loop was constructed in Trondheim, after a decision made by the Norwegian government. Receiving empirical data from experiments conducted in the 1-kilometre-long test loop helped the research team to refine the simulation model, consequently making the simulations more reliable and the model more refined. The software provides the users with real-time calculations and predictions of the flow of goods in the pipelines.[31]

OLGA, as briefly depicted above, inhibits the key features of both the "new business model" R & D innovation projects, systems of innovation approach and large technical systems approach; the OLGA software answered to a major reverse salient, i.e. the problem

[28] IFE & SINTEF 2008
[29] Njølstad 1999
[30] IFE & SINTEF 2008
[31] Interview with Kjell Bendiksen; cfr: ibid.

of stable transport of unprocessed oil and gas; evolved into an interactive R & D project involving a wide range of researchers, research institutions and investing oil companies; technology based on numerical calculations creating an algorithm designed through a software enabling both simulation and real-time observations. In the next sections, I will go into more detail on how and why this software was developed in Norway, a young petroleum nation still dependent on the dominating multinational oil companies, but with ambitions to promote a national oil industry. I will go about this by dividing the narrative in five different, but mutually dependent and related explanations. The division into five explanations brakes with a chronological narrative, but is done to highlight the analytical differentiation of the five explanations.

Special technological challenges on the Norwegian continental shelf

To comprehend how OLGA transformed the international petroleum industry, we need to understand the challenges it originally was designed to answer to. Oil companies encountered new challenges when the oil and gas reservoirs on the Norwegian continental shelf was discovered at the turn of the 1970s. The Norwegian continental shelf is very deep, with sea levels up to 600 meters' depth. Many of the biggest reservoirs was at depths on more than 200 meters.[32] The seabed is characterized by steep hills and bumpy terrain as the sea depth close to shore are so deep. Moreover, wind and weather conditions in the rough North Sea lays extra challenges on safety and stability on operating platforms and vessels.

Internationally, it was said that extraction of oil and gas was not cost effective at sea levels deeper than 200 meters. This calculation stemmed from technological transfer via companies with experience from offshore petroleum production in the Mexico Gulf.[33] Before 1970, 173 metres was the record sea depth of developed offshore petroleum fields. Since the existing petroleum technology was insufficient for a large part of the big reservoir findings on the Norwegian continental shelf, a window of opportunity opened up for existing Norwegian offshore and construction firms to enter into the market of petroleum service firms. This window of opportunity widened as a consequence of the Norwegian governments explicit policies to protect and facilitate the evolution of national petroleum industry and competence.[34] Out of this context, Norway set out to develop concrete platforms in order to safely and cost-effectively produce oil and gas at the deep sea levels and demanding

[32] Institute for Energy Technology (IFE) archives. Box Petroleum technology 1973-1980. Minutes from meeting with Statoil 10.5.1978.
[33] Engen 2009, p. 194.
[34] Ryggvik 2015, p. 12;

conditions in the North Sea. The Norwegian concrete platforms, labelled condeep platforms, became a success sparked by increasing oil prices in the 1970s. Consequently, Norway developed a growing offshore supply service industry.[35]

During the 1980s it became evident, however, that the Norwegian petroleum industry was struggling, with rising costs and declining oil prices threatening the future of Norwegian oil and gas business. The development of ever bigger and advanced concrete platforms was increasingly perceived as a financial liability.[36] This technological development peaked in 1995, when the biggest concrete platform "Troll" was finalized with the impressive height of 472 meters, placed at a spot with 303 meters' sea depth. By then, a new technological path was opened up rendering the concrete platforms obsolete. Troll was the last field build with platform-based technology on the Norwegian continental shelf.[37] After Troll, petroleum fields in Norway was constructed with some sort of subsea-technology, meaning that the extraction of oil and gas happened at the seabed and then transported either to a platform or vessel that received unprocessed oil and gas from several reservoirs, or that the unprocessed oil and gas was transported onshore for processing.

The subsea technological path has evolved in two steps. From 1996 to 2006, the pioneering period of subsea-technology, the recipient of unprocessed oil and gas was vessels. This technological step paved the way for successful internationalization steps by the biggest Norwegian offshore service firms.[38] Previous historical research have emphasized the business opportunities and technological artefacts and systems brought forward in cooperation with the oil companies. The software that radically changed the technological possibilities, and paved the way for the subsea-solutions from the 1990s have not yet been incorporated in the historiography. In fact, the first step towards subsea technology was taken with the Troll field, because this was the first real trial of the OLGA software.[39]

With Troll, Statoil and its partners experimented with different subsea-solutions with the OLGA software as technological cornerstone, because the software opened up for transportation of unprocessed oil and gas.[40] The Troll field was not only a large field, it also consisted of several smaller fields that would not be commercial viable using platform technology.[41] Thus, this field represented a golden opportunity to test transport of

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[35] Ibid., p. 13.
[36] IFE archives. Box Petroleum technology 1973-1980. Letter from NTNF to IFE 17.3.1980. IFEs arkiv.
[37] Technology development on the Norwegian continental shelf, presentation by Statoil.
[38] Christensen & Rinde 2009, Sogner & Petersen 2014, Nerheim 1996
[39] Askim 2013
[40] Interview with Kjell Bendiksen; cfr: IFE & SINTEF 2008, Askim 2013
[41] Interview with Kjell Bendiksen

unprocessed petroleum from the smaller fields to the central platform instead of constructing several platforms. Consequently, the last technological leap was reached with the fields Snøhvit and Ormen lange opened in 2006 and 2009, which are developed without platforms, where unprocessed petroleum is transported directly from the seabed in pipes to the shore – distances of respectively 147 and 120 kilometers.[42]

OLGA enabled cost effective extraction of oil and gas at deep sea levels many kilometres from the shore even in periods with low oil prices. As a consequence, oil companies and companies reliant on the platform technology went through restructuring processes – some disappeared such as Norwegian Contractors, the constructors of concrete platforms. As OLGA was exported internationally, the software has opened up new opportunities for oil and gas extraction offshore globally.

Institutional arrangements favouring national innovation

Since the discovery of petroleum on the Norwegian continental shelf, the Norwegian state implemented an infant national petroleum policy, meaning that they actively used protectionist measures in order to secure the emergence of a national petroleum industry in all areas.[43] In 1979, a new step was taken making investments in Norwegian R & D part of the protectionist policies, when the Norwegian government established the so-called "Goodwill agreements".[44] These agreements were connected to the Norwegians systems of concessions, regulating the operators on the Norwegian continental shelf, stating that oil companies investing in Norwegian R & D received goodwill points, making them more likely to win a concession.[45]

Moreover, the government made R & D investments deductible in the tax system. The corporate tax for oil companies was in 1975 set at 78 %, so making R & D investments deductible meant in practice that the Norwegian state sponsored 78 % of R & D investments in the petroleum sector.[46] Simultaneously, Statoil gave up the ambition to build up a large R & D department to do extensive in-house technology development. Altogether, these steps both gave strong incentives for investments in Norwegian research and technology development in the petroleum sector, and represented a golden opportunity for Norwegian research institution to tap into the large investments made. During the 1980s the existing

[42] Interview with Kjell Bendiksen; cfr: Askim 2013, IFE & SINTEF 2008
[43] Engen 2009, Ryggvik 2015
[44] White paper, Dokument nr. 8:103 (2001-2002).
[45] Engen 2009, p. 193.
[46] Ibid., p. 194.

Norwegian research institutions received approximately half of the R & D investments made by oil companies.[47] The major players were SINTEF, Institute for Energy Technology and Rogalandsforskning (a regional research institute located in the Norwegian oil capitol Stavanger).

Spurred by the mid-1980s price fall in oil prices, the quest for innovation and new technologies was intensified in Norway. The technological paradigm established around the condeep platforms was costly, both in terms of construction and production on field. The platforms were large constructions, and demanded high employment, as well as large bureaucracies.[48] Facing lower oil prices, the fear of the costs connected to the Norwegian petroleum technological paradigm grew proportionally.[49] Consequently, another institutional arrangement was established to increase innovation. Inspired by the British CRINE program, the Norwegian government implemented a similar program called NORSOK. The underlying ambition of NORSOK was to reduce costs connected to fields with 50 %. This was supposed to be achieved by encouraging more competition, interaction and cooperation between the various actors connected to the petroleum industry.[50] In effect, the ambition was to break free from the technological path-dependency of the condeep platform technological paradigm.

The institutional arrangement established at the beginning of the 1980s thus promoted efforts towards innovation, as well as both competition and cooperation between actors. These institutional setups enabled the OLGA project to grow from an initial “crazy” idea to be a joint venture, shared by both Institute for Energy Technology and SINTEF, Statoil, EXXON, Connoco Phillips and other oil companies. Without these institutional incentives to invest in Norwegian R & D, and interaction between actors, the OLGA project would probably not have been carried out in the same scale, and would most likely not had the same national and global technological and commercial impact.

Timing: reorganization of Norwegian technical-industrial research

The development of subsea-technology in Norway benefitted from what had happened in Norwegian research previously, combined with some reorganizations of the technical industrial research institute sector. After WW2 the first steps was taken towards establishing an applied research institute sector in Norway.[51] In general, the motivation for building up

[47] Ibid.
[48] Ibid.
[49] IFE archives. Box Petroleum technology 1973-1980. Letter from NTNF to IFE 17.3.1980. IFEs arkiv.
[50] Engen 2009
[51] Wicken 1994, Sogner 1994

research institutes outside of the universities was partly based on lessons learned from Norwegians observing the British and American military-industrial complexes during WW2, as well as a growing belief in applied scientific research as a key to modernization and economic growth following Vannevar Bush' famous report "Science, the endless frontier".[52] Moreover, the motivation was based on a conviction that Norway, and its businesses, were too small to fund and conduct the research and development needed.[53]

The institutes established the first decades after WW2 differed in organization and purpose. Some were directed to specific purposes, like the Norwegian Defence Research Establishment, Institute for Atomic Energy, Institute for geology and Institute for Marine Research. Others were more general, like the competing SINTEF in Trondheim, connected to the Institute of Technology, and SI (Central institute for industrial research) in Oslo. The activities of these institutes were coordinated by a public national research council.[54] The tradition of nationally coordinated research efforts had both an institutional effect on the development of subsea-technology, since there existed some sort of tradition for cooperation and coordination of research efforts. In addition, the development of subsea-technology benefitted from the knowledge and competence generated in several of the existing research institutes.

During the 1960s, the government followed the recommendations from OECD and the director of the Norwegian research council, and increasing their funding and efforts to promote industry directed research. The prior research efforts had been subject to criticism, and a government-initiated report pointed out that the organization of applied research did not reap desired results due to too weak connection between the research institutes and the industrial sector; they claimed the research institutes emphasized their scientific aspirations too much and operated more as closed circles than bridges from the scientific communities to the industrial sector, while the industrial sector were criticised for not showing interest to the possible rewards services from the research institutes could reap.[55] Consequently, the government initiated a policy of indicative planning, in which the research council indicated preferred technological projects and business opportunities.[56]

During the 1970s several conditions changed, as in most of the western countries. Norway experienced deindustrialization following the rise of industrial production in Asia

[52] Amdam & Bjarnar 1999, Brandt & Nordal 2010
[53] Collett & Skoie 1981
[54] Ibid.
[55] Ibid.
[56] Sogner 1994

and low-cost countries. The research policies were once again subject of criticism, and by the 1980s the coordination of the research institutions became more market-oriented.[57] Coincidentally, the nuclear research program conducted by the Institute for Atomic energy underwent a radical change at the same time. The institute changed name to Institute for Energy Technology in 1980 as a consequence of the Norwegian government's decision to abort the planned introduction of nuclear power in Norway in 1979.[58] To prepare the introduction of nuclear power stations in Norway was the most important purpose of establishing this institute, and without its mission, the institute were transformed to be more similar to SINTEF as a contract-funded industry directed research institute, with a specific orientation towards energy technology.

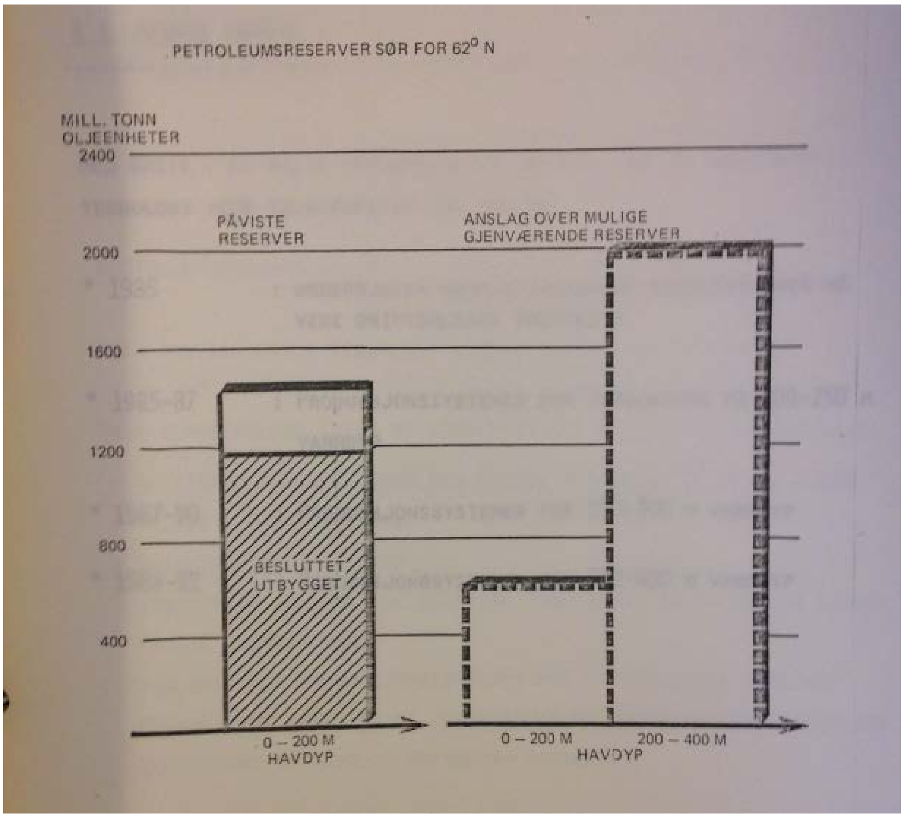
The institute had enjoyed special prerogatives since its establishment, receiving more government funding than all other Norwegian research institutes altogether until the mid-1960s, as well as almost total freedom in their research.[59] From the 1960s, however, pressure was laid on the institute increasingly, as the prospects of the nuclear power plan became ever more uncertain and the other research institution was critical of the institutes privileged position. The governmental funding to the institute was reduced 50 % in real prices from 1965 to 1980.[60] Thus, the institute were in need to increase their contractual research accordingly in order to keep their staff and level of activity. During the 1970s the institute gradually realized that they possessed unique competencies industrial firms were eager to acquire: ability to design software to simulate and control industrial processes.[61] The instalment of the "goodwill agreements" were in this context a golden opportunity for the reshaped institute for energy technology.

Personal connections

The institute for atomic energy was in fact the first research institute that Statoil met with in 19798 the year when Statoil gave up plans for building up a substantial in-house R & D department and the establishment of the "goodwill agreements".[62] At the meeting Statoil presented their main technological challenges for the directors from the Institute for Atomic Energy. The most important issue Statoil stressed, was the fact that most of the big reservoirs

[57] Ibid.
[58] Njølstad 1999
[59] Ibid.
[60] Ibid.
[61] IFE archives. Minutes from board meetings year 1977. *Samarbeidet mellom Institutt for Atomenergi og Scandpower*, memo to the board, 5.12.1977
[62] IFE archives. Box Petroleum technology 1973-1978. Minutes from meeting with Statoil 10.5.1978.

discovered were located at depths between 200 and 600 meters below the sea surface. Statoil were in need of finding technologies that made petroleum production at deep sea levels commercially viable.



The directors of Institute for Atomic Energy circulated the minutes from the meeting to their researchers. Two researchers, Dag Malnes and Kjell Bendiksen, launched from this context their idea of a software to simulate and control the multiphase flow of goods in pipelines.[63] Dag Malnes was an experienced nuclear engineer, who had been part of the two-phase flow projects at Institute for Atomic Energy in the 1960s. Kjell Bendiksen was newly recruited to the institute in 1979, and was a physicist specialized in computer algorithms.[64] Together they discussed the possibility to design a software for simulation and control of the flow in petroleum pipelines based on the Navier Stokes equation and earlier calculations made by the institute in the 1960s. Their vision was that this software would enable oil companies to transport unprocessed oil and gas directly from the seabed onshore. This idea was well appreciated by Statoil, who provided funding the two researchers. In 1980 the first version of OLGA was completed, and the results was promising.[65]

[63] Interview with Kjell Bendiksen
[64] Interview with Kjell Bendiksen
[65] Interview with Kjell Bendiksen

It was not a coincidence that Statoil bought in to the somewhat "crazy" idea from Malnes and Bendixen. As mentioned earlier, transport of unprocessed oil and gas was seen impossible because of the risk that slugs would appear and damage the expensive equipment and cause dangerous accidents. The strategic actors in both Statoil and Institute for Atomic Energy did, however, know each other well, and their longlasting connections entailed a context of mutual trust. The managing co-director of Statoil who lead the meetings with Institute for Atomic Energy, Henrik Ager-Hanssen, was prior to his appointment employed at Institute for Atomic Energy, where he also initiated and became director of the company Scandpower intended to commercialize technology developed at Institute for Atomic Energy, a company who in the 1990s commercialized the OLGA software.[66] Moreover, Henrik Ager-Hanssen had lead the research on nuclear reactors for ships in the 1960s.[67] Thus, he was very familiar with the Navier Stokes equation, and how it could be used for simulations and control of multiphase flow of viscous substances.

At the strategic levels, there existed close personal connections between Statoil and Institute for Atomic Energy. Both Institute for Atomic Energy and Statoil was born out of the same elite circle in Norwegian industrial politics. Especially two persons was instrumental in this respect, namely Jens Christian Hauge and Finn Lied. Both had been part of the Norwegian resistance movement during WW2, Hauge as the leader of it. As the Norwegian labour party controlled parliament for nearly two decades after WW2, it meant that strategic actors connected to the labour party had great power to affect policies. Hauge and Lied belonged to a closed circle of power that laid premises for the government's policies. Hauge was minister of defence in 1948, and forced through the establishment of the Institute for Atomic Energy, while Finn Lied became chairman of the institutes board, a position Lied also had in 1979. The same duo was the architects behind the establishment of the state-owned oil company Statoil. Hence, it was not coincidental that Ager-Hanssen turned to the Institute for Atomic Energy first, as well as it was not a coincident that Statoil wished to take the leap of faith to gamble on a project transferring technology from the nuclear sector to petroleum.

The nuclear researchers at the Institute for Atomic Energy was not alone thinking along these lines. In both France, Italy and Great Britain researchers were trying to use the two-phase technologies from their nuclear facilities in order to prevent the slugs in petroleum

[66] IFE archives. Minutes from board meetings 29.5.1971.
[67] Njølstad 1999

pipelines at the same time.[68] They struggled, however, because what seemed to solve the slug problem in laboratories did not work on industrial scale. In fact, Exxon was in 1980 planning to build up test facilities in Great Britain in order to conduct two-phase flow research.[69] Their plan was to build a bigger test loop with pipelines in order to avoid the problems the others had with scaling up from laboratory to industrial scale.

Consequently, the Norwegian research institutions started to compete in order to attract the planned Exxon investments to Norway.[70] SINTEF in Trondheim tried to formulate a research project on their side, while the rest of potential candidates, Institute for Energy Technology, Rogalandsforskning and Christian Michelsens Institute, formed an alliance to have the size and competence mix to match SINTEF who benefitted from their affiliation with the Institute of Technology. The Institute for Energy Technology had the software and simulation skills, and had already designed the OLGA software, which gave the alliance an upper hand. Rogalandsforskning, being located in the oil capitol of Norway Stavanger, possessed the most specialized petroleum competencies, while Christian Michelsens Institutt, located in Bergen, was the oldest of Norwegian research institutes outside the universities, established prior to WW2, and had the longest tradition of marine and industrial research.

Exxon evaluated the research proposals coming from Norway, which benefitted from the newly instated "goodwill agreements" making the planned investment cheaper, and found both Norwegian proposals more attractive than their original plan with test facilities in Great Britain.[71] The alliance' proposal was Exxon's favourite. So, Exxon decided to abort their original plan, and instead finance a test facility for two-phase flow research in Norway. As their plan changed, it was then inevitable that the research was going to be conducted by Norwegian researcher adapted to the conditions on the Norwegian continental shelf – not as an Exxon venture. That was the conditions for the "goodwill agreements". Thus, Exxon "donated" the test loop that was built to the Norwegian government.

As it was clear that Exxon was going to give substantial investments in two-phase flow research, that in practice would make Norway the hub in this field with the largest test facilities, the matter was subject to political conflict in Norway. Exxon, originally wishing to fund the alliance' proposal, meaning that the test facility would be located in Stavanger, turned to the Norwegian Petroleum Directorate asking for advice on the location. Matters

[68] Askim 2013; Brev fra NTNF til IFA av 17.3.1980. IFEs arkiv. Arkiv 1975-1992. Boks 0424 Petroleumsteknologi 1973-1980.
[69] Ibid.
[70] IFE archives. Minutes from board meetings 1980-1981; ibid.
[71] Ibid.

concerning locations of large investments of national importance typically becomes heavily debated in Norway, because it is a long-stretched country, scarcely populated and policies keeping activities and population dispersed have great impact. In the location struggle, Trondheim won.[72] Exxon still wished to go forth with the alliance' proposal, so a compromise was made, entailing that SINTEF and Institute for Energy Technology would cooperate on the research project. They divided the responsibilities, so that Institute for Energy Technology was going to design and develop the OLGA software, while SINTEF was going to run tests in the test loop providing empirical data. After a struggle between Institute for Energy Technology and SINTEF over property rights, which involved Statoil who previously held the property rights to OLGA, the two institutions managed to co-operate smoothly, when Statoil gave up their property rights to the versions created after 1982.[73]

To summarize the importance of personal connections, the close ties between strategic actors in both Statoil and Institute for Atomic Energy was vital for bringing the idea to adapt the two-phase flow models developed in connection with the institutes prior research from the drawing board to funded research. Especially since the co-director of Statoil himself was familiar with this line of research. On the other hand, the competitive nature of the relation between SINTEF and Institute for Energy Technology did not prevent them to join forces when district politics of Norway located the test facilities in Trondheim even though Exxon preferred the other research proposal. District politics was another playfield in Norwegian politics, governed by other mechanisms and actors that were architects behind Institute for Atomic Energy and Statoil. Moreover, as the combined research milieu of Norway, helped forward by the "goodwill agreements", won the battle making Exxon funding the Norwegian alternative instead of the British, the Norwegian researchers was coupled with an international research community in a more concrete fashion than before, which provided new personal connections, insights and possibilities to spread their research efforts outside of Norway.

Interaction, feedback and longlasting offshore-tradition

The test loop in Trondheim was completed in 1983, making the OLGA project entering a new phase. From that point of, it was no longer a venture between Statoil and the Institute for Energy Technology, but the project grew to include SINTEF on the research side, as well as several oil companies including the Norwegian Statoil, Hydro, and the foreign Exxon,

[72] Ibid.
[73] IFE archives. Box Petroleum technology 1981-1992.

Conoco Phillips, Texaco, Mobil, Petro Canada and Getty Oil.[74] Between 1984 and 1996 SINTEF and Institute for Energy Technology cooperated on the research, projects that continually was renewed with various industry partners, Exxon and Statoil at the core. In 1996, SINTEF and Institute for Energy Technology split ways. SINTEF received funding from Conoco Phillips to develop a competing software to OLGA, while Institute for Energy Technology constructed a smaller test loop at their facility Kjeller just outside Oslo.[75] Consequently, Scandpower, the institutes company for commercialization overtook the property rights for OLGA, who swiftly dominated the global market for simulation and control of multiphase flow in petroleum pipelines.

The 1-kilometre-long test loop constructed in Trondheim was instrumental in making OLGA a global success. Through the cooperation between the software development at Kjeller and the tests run in the test loop, OLGA received feedback from a scale that resembled the length that the software first was tested upon.[76] The interaction between calculations in the simulation software and the tests run was crucial for the success of the OLGA project, because the interplay between refinement of the simulation model and feedback from the empirical data increased the software's reliability and validity. Making a representation of "real-world problems" in an algorithm and software comes with a series of problems. Pipelines below sea, especially the bumpy terrains of the North Sea seabed, provided extra challenges speaking of securing a stable flow of oil, gas, water and sediments. Thus, it was vital to reach a level of accuracy that surely would prevent the formation of slugs in the pipelines.

The first real trial of the OLGA software was as mentioned before on the Troll project at the beginning of the 1990s. The construction of the Troll field was at the same time the peak of the condeep platform technology paradigm and the starting point for the subsea-technology paradigm. In the first phase of the Troll project the giant condeep platform was constructed. When the Troll field was discovered it was the largest finding of gas reservoirs in the North Sea. Processing of the gas offshore, as well as transport from the field, represented huge costs. The involved companies and the Norwegian authorities debated solutions, many sceptical to try the OLGA multiphase flow technology.[77] Eventually, decisions were made that enabled a full scale trial of the OLGA software. Firstly, gas from

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[74] Askim 2013
[75] Ibid.
[76] IFE & SINTEF 2008
[77] Troll project. Norwegian petroleum directorate

the Troll field, were Statoil was the main contractor, was transported semi-processed, i.e. water and gas, onshore to a new gas processing facility at Kollsnes outside of Bergen, a distance of 60 kilometres.[78] Secondly, and more important, unprocessed gas was transported from a small satellite-field connected to Troll directly to the Oseberg field, a distance of 50 kilometres. This gas injection project from Troll to Oseberg (TOGI), contracted by Hydro, was a pioneer project for subsea-technology.[79] The Oseberg field had prior to this been developed for oil production, and the gas from Troll was intended to enhance the effectiveness of oil production. Oseberg was Hydro's first main construction concession. Hydro, then Norway's biggest industrial corporation established in 1905, originally privately owned, but after WW2 partly state-owned, was Statoil's Norwegian competitor. In Hydro's view the fully stateowned Statoil was unfairly winning major concessions from the state for political reasons. The construction of the Oseberg field, however, turned out to be a technological and organizational success.

The satellite gas field of Troll was located at 300 metres depth, and due to severe disaster connected to deep water diving previously, installation of drilling was not an option done manually. Thus, the preferred technological option was to use remote operating vessels in the installation. As such, the gas injection project evolved to a pioneer project of subsea-technology, in which remote operating vessels were in use, the flow of unprocessed gas was monitored and controlled by computers using OLGA, and received on a remote controlled installation at the Oseberg field – all operations were monitored and controlled via computers. Hydro's project manager has in aftermath declared that OLGA was a necessary condition for conducting this project.

In the context of the needs to reduce costs in construction and operations, Hydro managed to do so much better than Statoil had done after the decisive oil price drop in 1985. It seems that the gas injection from Troll to Oseberg played an instrumental role in their success. Estimates states that the gas injection increased the overall oil recovery by approximately 7%. The importance of the Troll-Oseberg gas injection project was, however, not so much its commercial aspects. Rather, it was a demonstration of the potential of OLGA and subsea-technology. It opened doors and possibilities to exploit the potential of the software and further subsea-technology development. The first full-scale operation of OLGA in combination with other subsea-technology was also instrumental in receiving empirical

[78] Troll project. Norwegian petroleum directorate
[79] Askim 2013

data from full-scale operations enhancing the reliability and validity of the simulation model. Moreover, this project was also a door opener for oil service firms to enter into subsea-technology. The subsea-installation that received the gas from Troll was contracted by the Norwegian branch of ABB. Eventually, both the Kongsberg Group, Aker and Kværner joined the subsea-technology paradigm, which by the 2000s laid the foundation for successful internationalization efforts bringing the subsea-technology global. As this technological paradigm was developed based on the OLGA software, OLGA subsequently dominated the global market.

Conclusion: Successful innovation, but not successful systems

The OLGA software is a story of successful innovation brought forth by researchers and institutions in Norway, who initially had little knowledge, experience and power within the petroleum industry. In this article I have argued that we need to account for five factors in order to explain this successful innovation. In my view, all explanations are equally necessary and mutually dependent. Firstly, the specific technological challenges the Norwegian continental shelf inhibited, with its deep sea environment coupled with steep seabed and rough waters, constituted conditions never before handled by the petroleum industry. As such, the specific technological challenges on the Norwegian continental shelf created a need for technological innovation. It was of course not given that the innovations would come from Norway; the research and development could easily have been carried out by multinational oil companies and experienced researchers.

This brings us to the second explanation: The Norwegian government and parliament installed institutional arrangements with incentives and regulations that enabled a national petroleum industry to grow, as well as incentives favouring investments in research and development conducted by Norwegian research institutions. The findings of oil and gas on the Norwegian continental shelf were so massive, and the oil price high enough at crucial moments, that the national petroleum industry had opportunities to grow, and the multinational oil companies saw opportunities for high profit even with the protectionist and nationalist policies pursued by Norway.

Timing is in itself an important explanation, and not only speaking of the price changes. Even if Norway installed policies favouring national innovation projects, and also possessed unprecedented technological challenges, it was not evident that Norway had the competencies needed to solve the technological challenges. Here lies the important of timing as the third explanation. At the moment when the “goodwill agreements” were implemented the technological-industrial research institutions in Norway were undergoing changes, and seeking to find new outlets for their knowledge and competencies. This was especially true for the Institute for Atomic Energy, who lost their purpose as the Norwegian government decided to abort the planned construction of nuclear energy plants in Norway in 1979. Nuclear scientists possessed the crucial competencies on viscous liquids flow, as the failed Italian, French and American attempts show. Without the aborted Norwegian nuclear plans, it is not certain that these researchers would be available. Fourthly, the personal connections between Statoil and Institute for Atomic Energy was instrumental in providing the trust and familiarity that such a risky research project was committed to and funded. It certainly helped that Statoil's assistant managing director had headed the research project that was the foundation for the OLGA software.

Quickly, the OLGA project expanded, and became a joint venture including several oil companies and both Institute for Energy Technology and SINTEF, which brings us to the fifth explanation. The interactive dimension the project grew into as the test loop funded by Exxon was constructed in Trondheim paved the way for the inclusion of both more empirical data and more competencies into the project and the refinement of the simulation model. Moreover, the collaboration across institutions and borders increased the likelihood of use of the software. The interactive dimension went beyond the OLGA project, as the OLGA software became the technological key to brake the condeep platform technological paradigm that had evolved in Norway. Getting free from the condeep platform technological paradigm became paramount in Norway in the 1980s after the price fall, because the condeep platform represented too high costs especially since the future reservoirs to be developed was at deeper sea depths. Beginning with the Troll field, OLGA enabled pioneer development in subsea-technology where oil companies, oil service firms and research institutions collaborated on finding new solutions.

Taking all explanations together, OLGA seems as an illustrative example of third industrial revolution innovations. Software-development is at the core of technological development, enabling businesses and people to make use of computers effectively, replacing manual operations. The development of technology is not done by one firm, or institution, but as part of an interactive collaboration between a wide range of people and institutions. And the new technology provides opportunity for new entries of smaller businesses in competition against previously dominating giants. The Norwegian institutional arrangements and the evolution of a national petroleum industry points towards the growth of a national innovation system. Previous research has certainly analysed this development as such, although many have overlooked the importance of Institute for Energy Technology. The case of OLGA, however, does not fit neatly into a description of a national system of innovation. The national dimension is of course important as the five explanations indicates. But as the OLGA project grew with the construction of the test loop in Trondheim, the project broke the national borders, not only by including foreign investment, but also in the sense that it no longer was a project aiming to primarily answer to Norwegian challenges; it became more of a global project in which funding, people, knowledge, experiences and the aims of the project were no longer exclusively Norwegian. Moreover, the technological foundation of the OLGA software, and thus the subsequent subsea-technologies, rested on decades with government funded research in nuclear technology.

The institutional arrangements, or system of innovation, that the OLGA project evolved as a consequence of has received critical remarks several times. Lots of money was spent on R & D which never materialized in successful innovations. The success of OLGA were as such more a case of perfect alignment of many factors, rather than a planned or systemic success.

Amdam, R. P. & Bjarnar, O. (1999). Networks and the Diffusion of Knowledge: The Norwegian Industry Committee in New York during the Second World War. *Business and Economic History, 28*(1), 33-43.

Askim, A. K. (2013). *Mellom industri og vitenskap: Etableringen av SINTEFs Flerfaselaboratorium i lys av teknologiavtalene* (Master Master thesis). Norges teknisk-naturvitenskapelige universitet, Trondheim.

Boehm, B. W. (1972). Software and Its Impact: A Quantitative Assessment. Santa Monica: RAND Corporation.

Boon, M. (2018). *Multinational Enterprise and Transnational Regions : A Transnational Business History of Energy Transition in the Rhine Region, 1945-1973 Multinational Enterprise and Transnational Regions*.

Brandt, T. & Nordal, O. (2010). *Turbulens og tankekraft. Historien om NTNU*. Oslo: Pax.

Bucheli, M. (2010). Major Trends in the Historiography of the Latin American Oil Industry. *The Business History Review, 84*(2), 339-362.

Chandler, A. D. (1990). *Scale and scope: the dynamics of industrial capitalism*. Cambridge: Belknap Press.

Christensen, S. A. & Rinde, H. (2009). *Nasjonale utlendinger : ABB i Norge 1880-2010*. Oslo: Gyldendal akademisk.

Collett, J. P. & Skoie, H. (1981). *Teknisk-industriell forskningsorganisasjon i Norge 1945-80: prinsipiell debatt og hovedlinjer i utviklingen. Vedlegg til utredning om offentlig støtte til teknisk industriell forskning og utvikling i Norge*. (8200706443). Oslo: Universitetsforlaget.

Engen, O. A. (2009). The development of the Norwegian petroleum innovation system : a historical overview. I J. Fagerberg (Red.), *Innovation, path dependency and policy: the Norwegian case* (s. s. 179-207). Oxford: Oxford University Press, 2009.

Gulowsen, J. (2000). *Bro mellom vitenskap og teknologi: SINTEF 1950-2000*. Trondheim: Tapir.

Hanisch, T. J. & Nerheim, G. (1992). *Fra vantro til overmot?* (Vol. 1). Oslo: Leseselskapet.

Hinton, D. D. (2010). Introduction. *The Business History Review, 84*(2), 195-201.

Hosch, W. L. (2018). Navier-Stokes equation. *Encyclopædia Britannica*. Hentet fra https://www.britannica.com/science/Navier-Stokes-equation.

Hounshell, D. A. (1995). Hughesian history of technology and Chandlerian business history: Parallels, departures, and critics. *History and Technology, 12*(3), 205-224. doi: 10.1080/07341519508581885

Hughes, T. P. (1983). *Networks of power : electrification in western society, 1880-1930*. Baltimore: Johns Hopkins University Press.

IFE & SINTEF. (2008). Flow. 25 years of multiphase subsea transport of oil and gas *https://www.sintef.no/globalassets/sintef-petroleum/brosjyre/brochure_flow.pdf*.

John, R. R. (2014). The computer boys take over: computers, programmers, and the politics of technical expertise. *Business History, 56*(5), 846-847. doi: 10.1080/00076791.2013.764040

Jones, G. (2004). *Multinationals and Global Capitalism: From the Nineteenth to the Twenty First Century*: Oxford Scholarship Online.

Kossiakoff, A., Sweet, W. N., Seymour, S. & Biemer, S. M. (2011). *Systems Engineering : Principles and Practice* (2nd ed. utg. Vol. v.67). Hoboken: Wiley.

Lazonick, W. (2010). Innovative Business Models and Varieties of Capitalism: Financialization of the U.S. Corporation. *The Business History Review, 84*(4), 675-702.

Lie, E. (2016). Context and Contingency: Explaining State Ownership in Norway. *Enterprise & Society, 17*(4), 904-930. doi: 10.1017/eso.2016.18

Nerheim, G. (1996). *En gassnasjon blir til* (Vol. B. 2). Oslo: Leseselskapet.
Njølstad, O. (1999). *Strålende forskning : Institutt for energiteknikk 1948-1998*. Oslo: Tano Aschehoug.
Paulsen, G. (2011). *Betwixt and between : software in telecommunications and the programming language Chill, 1974-1999*. BI Norwegian Business School, Oslo.
Prencipe, A., Davies, A. & Hobday, M. (2003). *The Business of systems integration*. Oxford: Oxford university press.
Priest, T. (2007). *The offshore imperative : Shell Oil's search for petroleum in postwar America* Vol. no. 19.
Ryggvik, H. (2015). A Short History of the Norwegian Oil Industry: From Protected National Champions to Internationally Competitive Multinationals. *Business History Review, 89*(1), 3-41. doi: 10.1017/S0007680515000045
Sluyterman, K. & Wubs, B. (2010). Multinationals and the Dutch Business System: The Cases of Royal Dutch Shell and Sara Lee. *The Business History Review, 84*(4), 799-822.
Sogner, K. (1994). *Fra plan til marked : staten og elektronikkindustrien på 1970-tallet* (Vol. nr 9, 1994). Oslo: TMV-senteret.
Sogner, K. & Petersen, T. (2014). *Strategiske samspill : Kongsberg gruppens historie 1987-2014*. Oslo: Pax.
Summerton, J. (1998). Stora tekniske system. I P. Blomkvist & A. Kaijser (Red.), *Den konstruerade världen. Tekniska system i historiskt perspektiv*. Stockholm: Brutus Östlings Bokförlags Symposium.
Tjelta, S. & Thirud, Å. P. (2005). *Norwegian petroleum technology: a success story*. Trondheim: Norwegian Academy of Technological Sciences
Wall, B. H. (1988). *Growth in a changing environment : a history of Standard Oil Company (New Jersey) : Exxon Corporation : 1950-1975*. New York: McGraw-Hill.
Wicken, O. (1994). *Elektronikkentreprenørene: studier av norsk elektronikkforskning og -industri etter 1945*. Oslo: Ad notam Gyldendal.
Wicken, O. (2009). *The Layers of National Innovation Systems: The Historical Evolution of a National Innovation System in Norway*.
Wilkins, M. (2005). Dutch Multinational Enterprises in the United States: A Historical Summary. *The Business History Review, 79*(2), 193-273. doi: 10.2307/25097027
Yergin, D. (1991). *The Prize : The Epic Quest for Oil, Money & Power Prize*.