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Recycling petroleum related knowledge and resources: A case study of channels for knowledge transition and diversification in South West Norway [1]

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Abstract

Gradual diversification of the Norwegian petroleum economy is an important concern for both the Norwegian government and the petroleum industry itself. This paper analyzes the on-going industrial diversification as two separate but interdependent phases depending on the ownership of knowledge and resources: Knowledge transition of publicly available petroleum related knowledge and diversification of privately held petroleum related knowledge and resources. The purpose of the paper is to provide a conceptual model of specific channels for knowledge transition and diversification of petroleum related knowledge and resources. To gain insights in potential channels we use data from a seminar series on opportunities in hydrogen and offshore wind organized by the industry cluster Norwegian Energy Solutions located in petroleum-dependent South West Norway. We use the findings on specific channels to provide policy lessons regarding economic diversification.

[1] Artikkelen er en deleleveranse i FoU-prosjektet «Læringsprosesser fra norskbasert petroleumsvirksomhet» finansiert av Olje- og energidepartementet. Tusen takk til Petter Osmundsen for svært nyttige kommentarer.

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ABSTRACT

Gradual diversification of the Norwegian petroleum economy is an important concern for both the Norwegian government and the petroleum industry itself. This paper analyzes the on-going industrial diversification as two separate but interdependent phases depending on the ownership of knowledge and resources: Knowledge transition of publicly available petroleum related knowledge and diversification of privately held petroleum related knowledge and resources. The purpose of the paper is to provide a conceptual model of specific channels for knowledge transition and diversification of petroleum related knowledge and resources. To gain insights in potential channels we use data from a seminar series on opportunities in hydrogen and offshore wind organized by the industry cluster Norwegian Energy Solutions located in petroleum-dependent South West Norway. We use the findings on specific channels to provide policy lessons regarding economic diversification.

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Introduction

Petroleum activity in Norway started with seismic surveys in the early 1960s. The very first Norwegian petroleum supplier, the logistics company North Sea Exploration Services AS (North Sea), was established in 1965, the year before the first drilling rig was towed across the Atlantic from New Orleans (Pahr-Iversen, 2006). Although activity in the Norwegian petroleum sector has fallen since the peak around 2014/15, the petroleum sector is still a significant part of the Norwegian economy, representing around 10 percent of total private employment (Hernes, Erraia, & Fjose, 2021). In south-western Rogaland petroleum related employment represents 30 percent of total private employment, in the most petroleum-dependent municipalities of Rogaland petroleum represents 30 – 40 percent of total private employment (Hernes et al., 2021). As a result of positive developments in the oil price and temporary petroleum tax adjustments adopted by the Norwegian parliament in June 2020, there is at present a positive outlook for petroleum activity on the Norwegian continental shelf the next few years. At the same time there is a recognition by both public and private actors that petroleum activity will not scale old heights and that petroleum is not the fuel of the distant future. As a result, oil companies and supplier companies, often with prodding and financial support from the government, have initiated activities towards non-oil markets.

Mäkitie, Thune, and Gonzalez (2019) study large supplier companies like Kværner (as of november 2020 merged with Aker Solutions), Aibel, Siem Offshore and the Ulstein group and how these in the last 15-20 years have redeployed capital and competencies towards offshore wind. In 2020 the industrial conglomerate Aker ASA, the mother company of Aker Solutions, established Aker Horizons as a separate business area for "active ownership in companies within renewable energy and green technology to limit and reduce greenhouse gas emission"[3]. Norway's other large EPCI[4] actor, Aibel, has ventured into offshore wind with a strong portfolio related to outfitting converter stations for offshore wind parks[5] and is currently also entering into construction of hydrogen production facilities[6].

The process of economic diversification in the petroleum sector implies the transfer of knowledge and resources to activities beyond operating or servicing petroleum exploration and production. This understanding implies a pool of knowledge and resources derived from petroleum related activities. This pool of knowledge and resources may be private, held by companies directly or by individuals/investors, or public/open for all, residing in knowledge institutions, research institutes or various governmentally funded innovation agencies. The traditional literature on firm diversification is focused on existing firms venturing into new markets with existing or improved products or services with the core theory being the resource-based view of the firm (Thune & Mäkitie, 2019). Research developed within evolutionary economic geography expands on this and argues that diversification of firm knowledge and resources may take place in three ways: through the existing organization, employee spinoffs or labour mobility (Frenken & Boschma, 2007). The literature on cross-industry innovation, knowledge transfer and industry-academia knowledge exchange focuses on the exchange of both private and publicly held knowledge (Fitjar & Rodríguez-Pose, 2017; Hjertvikrem & Fitjar, 2021; Lyng & Brun, 2018; Van Gils & Vissers, 2009). This paper will argue that the on-going economic diversification process must be analyzed as two separate but interdependent phases depending on the ownership of knowledge and resources: a) knowledge transition of publicly available

[3] https://www.akerasa.com/en/investments/aker-horizons
[4] Engineering, Procurement, Construction and Installation. Sometimes a final C is added to include activities within Completion
[5] https://aibel.com/project/dogger-bank-offshore-wind-farm
[6] https://aibel.com/news/new-framework-agreement-for-renewable-hydrogen-projects

petroleum related knowledge; b) diversification of petroleum related knowledge and resources owned by individuals, investors and/or companies.

Both diversification and cross-industry innovation, knowledge transfer and industry-academia knowledge exchange use some kind of medium or channel. This medium or channel may be either formal, like an R&D contract between a company and a research institute, or informal like casual encounters or labour mobility. According to Van Gils and Vissers (2009) these mediums or channels are among the least studied elements of knowledge transfer models. The purpose of this paper is to provide a conceptual model of specific channels for knowledge transition and diversification of petroleum related knowledge and resources. This kind of conceptual knowledge could be very useful for governmental agencies and industry clusters supporting the on-going economic diversification of the Norwegian petroleum economy.

One important instrument in the Norwegian government's policy for economic diversification is support for industry clusters through the innovation cluster program.[7] The Rogaland-based industry cluster Norwegian Energy Solutions was established in October 2018 by a number of Rogaland-based E&P[8] companies, supplier companies, research organizations, banks and innovation support agencies. The focus of NES is on both oil and gas and new possibilities within the renewables sector.[9] Since the inception in 2018 NES has evolved to also include non-Rogaland based companies and NES now represents the entire petroleum ecosystem. We will use data from a NES seminar series on opportunities in hydrogen and offshore wind to propose a number of specific channels for knowledge transition and diversification of petroleum related knowledge and resources.

The paper is structured as follows: The first part presents methodology and data. The second part presents relevant theories on diversification and cross-industry innovation, knowledge transfer and industry-academia knowledge exchange. The third part analyses the case data and uses the analysis to propose a conceptual model of specific channels for knowledge transition and diversification of petroleum related knowledge and resources. The fourth part concludes and presents policy lessons.

[7] https://www.innovasjonnorge.no/no/subsites/forside/om_klyngeprogrammet/
[8] Exploration and Production ('oil companies')
[9] https://www.norwegianenergysolutions.no/

Methodology and data

In this research we are interested in exploring the phenomenon of economic diversification in the petroleum industry. As this phenomenon is not well described in existing literature, a qualitative research strategy seems appropriate (Lyng & Brun, 2020). To study how phenomena takes place, a case study approach is appropriate (Yin, 2014). A case study is not concerned with representing a larger population, the approach is rather on including rich cases representative of the phenomenon or phenomena under study (Eisenhardt, 1989). The case study generalizes empirical findings to theory (Yin, 2014).

As our primary data we will use data from a seminar series on opportunities in hydrogen and offshore wind run by the industry cluster Norwegian Energy Solutions (NES). This methodology is similar to how Lyng and Brun (2018) used data on an industry seminar series to study knowledge transfers between medicine and petroleum.

The members of NES span the entire ecosystem of the petroleum sector and includes sizable numbers of both large, medium-sized and small actors: Most E&P companies active on the Norwegian continental shelf, large and well-established supplier companies, smaller start-ups and employee spinoffs, and finance actors like banks and consultancy companies.[10] We therefore argue that the case of NES is a rich case, highly representative of the phenomenon under study (Eisenhardt, 1989).

In the fall of 2020 NES initiated a seminar series related to possibilities within offshore wind and hydrogen. The aim of the seminar series was to stimulate the development of innovation ideas within renewable and sustainable energy solutions with a stated aim of stimulating collaborations or alliances between cluster members. The target group was stated as “companies with ideas or projects within the relevant topics ocean energy and hydrogen” but participation was open for anyone with an interest in the topics. The seminars were financed by NES and Innovation Norway and there were no fees charged. Originally, all seminars were planned as physical encounters. The first seminar, 27.10.2020, was a physical encounter, albeit with some Covid-19-enduced restrictions, while the next three seminars all were webinars.

Table 1: NES seminar series on opportunities within offshore wind and hydrogen

	27.10.2020	**20.01.2021**	**10.02.2021**	**11.03.2021**
Focus	Trends and markets	Offshore wind	Hydrogen	Summary and way forward
Type of seminar	Physical	Digital	Digital	Digital

The contents of the seminars may be grouped in three: general presentations on technologies and markets, concrete company/project presentations, and discussion sessions in groups and in plural. The data consists of copies of all presentations and personal notes from the discussions and summaries in the final seminar. As the seminars were not recorded, there is no possibility of verbatim quotes of what

[10] https://www.norwegianenergysolutions.no/members

was said. We have obtained permission to use seminar data from both NES on an overall level and from each of the six companies used as case studies.

Table 2: NES seminar series on opportunities within offshore wind and hydrogen

Seminar	Topic	Physical presentation	Personal notes
1	Introduction (EY chairman of the board)		
1	The renewables market – the big picture (EY)	x	
1	The renewables market – the regional picture (NORCE and Greater Stavanger)	x	
1	The renewables market – the capital perspective (DnB and DnB Markets)	x	
1	Presentation of the coming seminar series (EY)		
2	Update offshore wind and ocean energy in Norway (Forus Business Park)	x	
2	The global market for offshore wind/ocean energy the next 5 years and beyond (NORWEP)	x	
2	RosenbergWorley and FlexiFloat – what will it take to develop FlexiFloat and establish a supply chain [Case study 1]	x	
2	WindSpider – A Norwegian company with the aim of designing and building a Norwegian wind turbine. What are they working on and what do they need to reach their goal [Case study 2]	x	
2	University of Stavanger on its focus on offshore wind	x	
2	Group based workshops		
2	Inputs from groups and summary		
3	Possibilities in Norway and technological challenges in a new market (VP Low Carbon Solutions, Equinor) [Case study 3]	x	
3	Topeka – emissions free sea transport and distributor in hydrogen supply chains (Project Manager, Topeka/NorSea/Wilhelmsen) [Case study 4]	x	
3	What does it take to build a market for pressurized hydrogen (CEO GreenH) [Case study 5]	x	
3	Plans to produce and distribute green hydrogen and hydrogenbased products (partner Hy2Gen) [Case study 6]	x	
3	"4 questions to the companies", with a focus on development of technology, the market and how fast it will arrive, and blue vs green hydrogen et.c. (EY)		
3	Comments/answers from the companies		
4	Offshore wind activity in the Stavanger region (NORCE)	x	
4	Summary of offshore wind seminar (RosenbergWorley, WindSpider and EY)		x
4	Rogaland in the developer role for hydrogen – Hydrogen green-spots (New Kaupang)	x	x
4	Summary of hydrogen seminar (Topeka/NorSea/Wilhelmsen)		x
4	Summary of NES innovation seminars (Forus Business Park)		x
4	Q&A and comments (EY)		x
4	Summary and closure (NES chairman)		x

Our analysis is structured as follows. We use our study on the literatures on knowledge transition and diversification to identify key conceptual categories to be used in our analysis of the case data (Gioia, Corley, & Hamilton, 2013). We then present and analyze the case data in light of the identified conceptual categories with a focus on identifying a number of specific channels for knowledge transition and diversification of petroleum related knowledge and resources.

Literature review

Knowledge transition

Lyng and Brun (2018) proposes the term knowledge transition for the process of knowledge transfer in cross-industry innovation, defined as a flow of knowledge between two actors where the receiving actor has a different knowledge basis than the sender. Using data from the Pumps & Pipes seminar series on knowledge flows between medicine and oil, they provide a conceptual model that also incorporates the influence of relevant proximities, cognitive, technological and geographical proximities. They propose a conceptual model consisting of three phases, Knowledge Discovery of potentially relevant knowledge, Knowledge Transit of potentially relevant knowledge from one sector to a different sector, and Knowledge Integration of the new knowledge into the acknowledged knowledge base of the receiving sector. They argue that the discovery phase requires cognitive proximity, but not technological proximity, i.e. it requires grasping the basic ideas, while not understanding all the complexities of either petroleum wells/pipelines or the cardiovascular system. If an idea is found sufficiently interesting to become a focus for knowledge transit, the technological proximity will gradually have to increase. Reporting from a pre-pandemic seminar series, they argue for high temporal geographical proximity in both discovery and transit phases.

The discovery phase may consist of both formal activities like educational programs or industry seminars or simply informal meetings. The Norwegian company Shoreline is now a significant provider of services for the global offshore wind industry. The idea for the company was conceived while founder Mr. Ole Erik Vestøl Endrerud was conducting his PhD-studies in offshore technology at the University of Stavanger.[11] The Pumps and Pipes association traces its beginning to a chance encounter on a long-distance flight when a medical doctor and petroleum engineer discovered analogies between the human circulatory system and the pumps and pipes of the petroleum industry. However, some research indicates that one should not give too much emphasis on this kind of casual encounters. Even though the late great British economist Alfred Marshall talked about industry related knowledge residing ‘in the air’ in late 19th century British industry districts, new research indicates that this kind of chance encounters are more of an exception when it comes to relationships leading to innovation (Fitjar & Rodríguez-Pose, 2017).

The transit phase occurs when potentially relevant knowledge has been identified. This phase could consist of further seminars like the ones in the Pumps and Pipes-series, as well as the gathering of new information or establishing of strategic partnerships. Hjertvikrem and Fitjar (2021) argues that knowledge transfers may take place as inter-firm collaboration on projects, monitoring of other firms for inspiration and labour mobility spreading tacit knowledge and information of other firms' activities. They use social network analysis to study channels for knowledge in the petroleum subsea industry in Rogaland and find that these three processes tend to reinforce one another, finding relatively more collaboration between firms that also monitor or recruit from one another. Another potential channel of knowledge transfer is industry-science knowledge transfers. Van Gils and Vissers (2009) develops a typology of knowledge transfer channels according to R&D objective and time span. If the objective is transfer of technical competence and the time span is short, the objectives may be achieved through simply consulting an academic, contract R&D or temporary academic employment. If the time span is longer and/or the focus is on development of products or processes,

[11] https://www.shoreline.no/about-us/our-vision/

concerns of exclusivity influence the choice of channels. Some firms opt for participation in research consortia as a way of keeping themselves informed of scientific developments.

In the knowledge integration phase, the new knowledge is added to the accepted knowledge base of the receiving sector. By the time of Lyng and Brun (2018) there had been no cases of Pumps and Pipes projects reaching this final stage where the new information has been received and integrated into the knowledge base of the receiving sector. But there are important examples from other industries of this kind of 'cross-fertilization'. A number of production processes from the car industry is now well integrated into most manufacturing industries, for instance Ford's assembly line manufacturing, Toyota's lean principles and the general use of robotics (Center for Automotive Research, 2010; Kearney, 2021). An example from offshore petroleum is the technology of slipforming towering concrete constructions that originated in the Norwegian concrete industry but was perfected in the design and construction of the large concrete platforms from the 1970s up until Troll A in 1995 (Larsen, 2018). Slipforming is now successfully integrated as a standard technology of the Norwegian concrete industry and is currently experiencing an offshore renaissance with slipforming of substructures for floating offshore wind turbines.[12]

Diversification

Evolutionary economics sees firms as consisting of organizational routines and evolutionary economic geography describes economic development by changes in the time-space distribution of these firm routines (Boschma & Frenken, 2003; Frenken & Boschma, 2007). In this framework diversification of knowledge and resources can be seen as a branching process where product innovation leads to new routines being generated by recombing and modifying existing routines. Frenken and Boschma (2007) outlines three main processes for such routine replication or diversification. First, routines are replicated within the firm by setting up *new divisions or wholly or partly owned subsidiaries*. Second, routines are partly replicated through *employee spin-offs* (Klepper & Sleeper, 2005). Third, routines are wholly or partly replicated through *labour mobility* out of the existing organization.

There are numerous examples of firm diversification through setting up *new divisions or wholly or partly owned subsidiaries*. The Norwegian company Norsk Hydro first entered petroleum in 1963 through an alliance with the French-led Petronord group and later on established its own petroleum division, which in 2007 merged with Statoil to form today's Equinor. The core theory explaining this kind of diversification is the resource-based view of the firm that focuses on both tangible resources like technological artefacts, financial capital and facilities, and intangible resources like technical knowledge, customer knowledge and managerial capabilities (Thune & Mäkitie, 2019). According to this literature, diversification is potentially highly desirable as it might yield economies of scale if the firm manages to improve capacity utilization and economies of scope if the firm manages to utilize synergies between markets that require similar resources. An example of economies of both scale and scope is how Norwegian shipowners and shipyards diversified into owning, operating and building offshore related vessels and rigs (Ryggvik, 2013, 2015). The Norwegian power utility Lyse managed to diversify into cable-based telecommunication by focusing on its competencies within laying of subterranean cables and its high-quality customer support (Gjelsvik, 2018). It is here important to note that many of the largest Norwegian fortunes owe their existence to successful exits from petroleum related companies. The Kristiansand-based Rasmussen family was in 2001 bought out from a shuttle

[12] https://www.equinor.com/en/news/20210422-next-step-hywind-tampen.html

tanker joint venture with what was then Statoil-owned Navion.[13] The Stavanger-based Smedvig family in 2006 sold their drilling rig and well services company Smedvig Offshore to the John Fredriksen Group.[14]. This kind of investors should be recognized for what they represent, namely diversification of petroleum related knowledge and resources.

There are several perspectives in understanding what drives and affects the process of firm diversification The original perspective on firm diversification argues that since economies of scale or scope are more feasible when more firm resources are present, the extent or degree of available firm resources influences the likelihood of diversification (Thune & Mäkitie, 2019). The second perspective on firm diversification argues that types of firm resources or capabilities influence the likelihood of diversification (Thune & Mäkitie, 2019). Resources may be classified according to degrees of transferability to new markets (Pisano, 2016). Resources that are specific to a given market may reduce the likelihood of diversification and increase the likelihood of focusing on reaping value from existing markets (Teece, Pisano, & Shuen, 1997) while more generic or general-purpose resources may increase the likelihood of diversification (Levinthal & Wu, 2010). The Norwegian-based companies diversifying into petroleum in the late 1960s sported general-purpose resources within shipbuilding, maritime classification, and owning and operating vessels (Blomgren & Quale, 2019; Ryggvik, 2013). A third perspective sees firm resources/capabilities as dynamic and argues that successful diversification depends on making the right investments in market-specific or general-purpose resources/capabilities under conditions of demand and supply side uncertainty (Pisano, 2016). Investments in resources will imply costs if done through corporate R&D, retraining of personnel or acquisitions (Lee & Lieberman, 2010), but less or no costs if done through strategic alliances/partnerships or joint ventures (Lieberman, Lee, & Folta, 2017). Supply side uncertainty will be lower if a company is improving existing capabilities than when it is broadening its repertoire. This may explain why an EPCI-company like Aibel is diversifying into offshore wind through outfitting of sub-stations/converters – requiring existing capabilities within outfitting of and gas structures - leaving design and manufacturing of the HDVC-units and grid-links – which would have required a broadening of its capabilities - to a strategic partner, in this case ABB and Hitachi ABB.[15] Demand side uncertainty may be higher if entry into new markets requires development of new market-specific capabilities (Pisano, 2016) and this may explain why many suppliers try to enter new markets through alliances or strategic partnerships with important end-users or customers. A fourth perspective looks at relative demand conditions and argues that relative demand maturity in current market makes firms more likely to diversify (Wu, 2013). This may explain the current drive for diversification among Norwegian-based oil companies and supply firms.

The literature cited above regards the company as a unit with no regard for possible spatial differences in multi-plant groups. The EPCI company Aibel has 4 000 own employees based out of 8 location in 3 countries, with yards both in Norway and Thailand and engineering offices in Singapore and in 5 different locations in Norway (Mäkitie et al., 2019).[16] Many of these locations have decades long histories as independent companies and have their own unique role within the company. At present Aibel's pivot towards offshore wind seems to be focused out of the Norwegian cities of Haugesund and Asker, implying that there is a spatial element to diversification. Boschma, Coenen, Frenken, and Truffer (2017) looks at diversification at a regional level with a model where a region may diversify

[13] https://www.equinor.com/en/news/archive/2001/08/31/BuyingRasmussensShareInNavion.html
https://www.rasmussen.no/
[14] https://www.smedvig.com/no/
[15] https://www.upstreamonline.com/energy-transition/aibel-and-hitachi-abb-win-major-contracts-for-world-s-largest-offshore-wind-project/2-1-964792
[16] https://aibel.com/company

either by creating its own unique niche *new to the world* or by entering an already existing global regime *new to the region*.

Employee spin-offs happens when former employees of a company establishes companies in same or different industries (Klepper & Sleeper, 2005). Klepper (2007) argues that employee spinoffs is important for understanding the development of Detroit as the capital of the US automobile industry. Employee spin-offs are also found to be an important part of industry development in south-west Norway (Hydle, 2016; Hydle & Meland, 2016). A recent example of employee spin-off is when former Equinor employees established Horisont Energi focusing on green ammonia production[17]. Another example is how former petroleum engineer Svein Kvernstuen founded Beyond within development and production of batteries out of sawdust. The case of Beyonder shows important links between spin-offs and existing companies. First, Mr. Svein Kvernstuen is the son of petroleum founder Ole Kvernstuen that developed and exited two oil services technology companies, Nodeco to Weatherford in 1996 and ResLink to Schlumberger in 2016[18]. Second, just before Christmas 2020 Equinor bought a stake of Beyonder and is now considering using Beyonder as one vehicle to enter the battery market.[19]

Labour mobility happens when former employees move from the existing organization or its wholly or partly owned subsidiaries to other employment in existing or new organisations in the private or public sector. One example of is National Oilwell Varco Chief Technology Officer took on a similar role in the anti-desertification company Desert Control[20]. Frenken and Boschma (2007) argues that while replication/diversification processes in principle may take place both locally or over distance, most will take place locally, an argument that is similar to the discussion of geographical proximities in the literature on knowledge transition. They argue that most employee rotation takes place in the same labour market, most spin-offs locate near parent plant and that most new divisions are created inside existing plants.

From the literature studied above we will argue that the process of economic diversification may be divided into Knowledge transition and Diversification, each with three distinct sub-processes, see figure below.

[17] https://www.horisontenergi.no/
[18] https://www.dn.no/energi/forus/fengliu-lou/svein-kvernstuen/oljeingenior-med-milliardplaner-jeg-ville-ikke-lete-etter-olje-resten-av-karrieren/2-1-923752
[19] https://www.equinor.com/no/how-and-why/etv-news/equinor-ventures-invests-in-beyonder.html
[20] https://www.desertcontrol.com/team

Phases	Processes
Knowledge transition of petroleum related knowledge	**Discovery** of potentially relevant petroleum related knowledge
	Transit of petroleum related knowledge
	Integration into knowledge base of non-oil entity
Diversification of petroleum related knowledge and resources	**Labor mobility from petroleum related companies**
	Employee spin-offs from petroleum related companies
	Existing petroleum related organization providing products and services for non-oil markets

Figure 1: Proposed conceptual model for knowledge transition and diversification of petroleum related knowledge and resources

From the presentation and discussion above we may start outlining possible specific channels for the various processes. Casual encounters, like the chance meeting between a medical doctor and a petroleum engineer, could be one channel for discovery of potentially relevant petroleum related knowledge. Another channel could be participation in education programs, like in the case of Shoreline cited above. Knowledge transfers between academia and industry could be one example of transit of petroleum related knowledge. In the next section we will use data from an industry cluster seminar series to outline a number of specific channels for how these processes occur.

Analysis of case data

Case 1: FlexiFloat and RosenbergWorley

The FlexiFloat concept is a floating foundation for wind turbines and wave energy, resembling a floating carpet of foundations holding a total of 9 wind turbines[21]. The concept was developed by petroleum engineer Einar Sundal when he was furloughed from the EPCI-contractor RosenbergWorley during the oil and gas downturn in 2015. RosenbergWorley is a corner stone company in Stavanger with a history going back to a small mechanical workshop in 1851 and is currently a subsidiary of the Australian Worley group[22].

Mr. Sundal patented the FlexiFloat idea in 2016 and placed the patent in Flexible Floating System AS, owned 90% by himself and 10% by the regional development authority Validé. In 2018 Flexible Floating System entered into a collaboration agreement with RosenbergWorley, Mr. Sundal's daytime employer. RosenbergWorley then helped Flexible Floating System apply for funds from the national innovation support apparatus. In early 2020 RosenbergWorley and FlexiFloat entered into a formal collaboration with the University of Stavanger with an 'industry PhD scholar' working on the project. In December 2020 the IKM Group bought a stake in the technology company Flexible Floating Systems and at the same time entered into a collaboration agreement with RosenbergWorley. If the project comes to fruition, RosenbergWorley, with its yard facilities, will be the chosen EPC-contractor. At present the focus is on qualifying the technology and identifying the necessary subsuppliers. The next step is a demo-project, but this will require entering into a consortium with a partner with the necessary financial muscles.

At the final seminar there was a focus on giving practical recommendations to the projects. FlexiFloat was recommended to continue working on the technological solution, but also to work with finding an end user for the technology.

Case 2: WindSpider

WindSpider is a small start-up company within offshore wind technology. The company has its main focus on a crane for more cost-efficient installation and maintenance of offshore wind turbines. While installation and maintenance of fixed offshore wind turbines can be done via jack-up platforms, installation and maintenance of floating offshore wind requires a floating crane vessel. WindSpider's business case rests on helping reduce the large costs of using crane vessels and the potential costs from down-time from unforeseen harsh weather. WindSpider argues that today's offshore wind turbines are basically land based turbines placed offshore and that the company's knowledge of the maritime environment gives them a competitive advantage. The seed studies started in 2015 and feasibility studies and patenting in 2020. In 2021 the focus is on concept development and commercialization. In 2022 the focus will be on testing and qualifying the crane. The company has received financial support from Innovation Norway.

The WindSpider is the brainchild of Mr. Per Olav Haughom, an inventor with a long history working with robotization within natural resource-based industries like hydropower, petroleum and tunneling.

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[21] https://flexifloat.no/
[22] https://www.worley.com/

The company gathers a number of key personnel with extensive experience within robotization and commercialization within the petroleum sector. The company's CEO and part-owner, Mr. Hans Olav Hide, has been a co-founder of three oil service technology companies that subsequently were sold to larger, global industry actors: Roxar that was sold to Emerson; MPM that was sold to what was then FMC; Trac Id that was sold to NOV.

At the final seminar WindSpider was recommended to continue working on their partner network, including finding a customer for the technology. They were also advised to market the product to use for changing of turbine blades, as this might be an alternative or additional market. WindSpider explained that access to customers is one of their main issues right now.

Case 3: Topeka/NorSea/Wilhelmsen

The Topeka project concerns construction of the world's first zero emission hydrogen vessel and establishing a system of hydrogen terminals at the Norwegian offshore bases along the coast.[23] The project is run by the logistics company NorSea Group - Norway's very first dedicated petroleum supplier company established in February 1965 – together with its majority owner, the ship management company Wilhelmsen. The Topeka project has collaborated with the Stord-based industry cluster NCE Maritime CleanTech in securing financial support from both the Norwegian Enova agency and from the EU.[24] The project has engaged important end-users of hydrogen like the high speed craft and car ferry owner Norled and the cruise vessel company Viking Ocean Cruises.

The Topeka project is one part of the larger Aurora Energy project aimed at establishing Europe's first maritime value chain for liquid hydrogen. A production facility for liquid hydrogen will be established at Mongstad, close to Equinor's Mongstad refinery, by a partnership consisting of The E&P company Equinor, the utility BKK and the industrial group Air Liquide.[25] The distribution of liquid hydrogen will be handled by Wilhelmsen and NorSea through the Topeka ship and hydrogen terminals at the NorSea supply bases. The partners in Aurora Energy – Equinor, BKK; Air Liquide, Wilhelsen, NorSea Group, Viking Cruises, Norled, NCE Maritime Cleantech – are engaged in a research project with financial support from the Research Council of Norway. [26]The research project has NORCE Norwegian Research Centre as research partner and the consulting company Gexcon providing technical testing.

Case 4: Equinor

Equinor is one of world's largest E&P companies and Norway's largest company. Equinor recognizes that decarbonizing energy systems requires multiple technologies and the company is at present engaged in a number of interdependent initiatives within CO_2-management, hydrogen and offshore wind. Equinor, Shell and TotalEnergies has established the joint venture Northern Lights for capture, ship-based transport and offshore storage of CO_2.[27] Initially the CO_2 will be captured from Norwegian sources, but Equinor is now working with European CO_2 emitters that also might want to use Northern

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[23] https://www.wilhelmsen.com/media-news-and-events/press-releases/2020/wilhelmsens-topeka-hydrogen-project-awarded-nok-219-million/
[24] https://e24.no/det-groenne-skiftet/i/rgAkre/skal-bygge-verdens-foerste-frakteskip-drevet-av-hydrogen
[25] https://www.offshore-energy.biz/bkk-al-equinor-in-europes-first-maritime-value-chain-project/
[26] https://www.bkk.no/artikkel/3e263b22-84a8-4eb4-8b7b-7617d36f73e2
[27] https://northernlightsccs.com/news/northern-lights-launches-company-dedicated-to-co2-transport-and-storage/

lights for transport and storage. Equinor is involved in production and distribution of green hydrogen in the HyShip/Topeka-project. This project is a partnership between Equinor, the utility BKK, the logistics company NorSea Group and its mother company Wilhelmsen and the industrial group Air Liquide. As the energy system of the future seems to be a mix of baseload sources, flexible sources like hydro and natural gas, and intermittent sources like wind and solar, Equinor is working closely with a number of large European utilities in the UK, the Netherlands and in Germany to integrate hydrogen, natural gas and offshore wind into their energy systems.

Case 5: GreenH

Green H is a relatively small Norwegian company based out of Oslo with as of now only a marginal presence in Rogaland.[28] The owners of Green H has their background in development of small-scale hydro power. Green H together with the Linde industrial group is engaged in developing a facility for hydrogen production in Bodø in Northern Norway. In the seminar Green H presented their plans for setting up a facility for small-scale hydrogen production at Fiskå outside of Stavanger. The business plan is to distribute hydrogen to local aquaculture producers, shipping companies and landbased transport companies. In addition, the plant could produce residual heat to local industry.

The GreenH case did not explicitly touch upon using petroleum related knowledge and resources. But it may be presumed that if the project will come to life, it will need to recruit personnel with petroleum related competencies.

Case 6: Hy2Gen

The Hy2Gen group is a European company established in 2015 to engage in production of green hydrogen and green hydrogen-based products like biomethanol, green ammonia, etc.[29] At present the company is engaged in hydrogen initiatives in both Norway, France and Canada. The company's very first hydrogen initiative was in Norway and came into being as a result of an "accidental meeting" with their Norwegian business developer and a Norwegian local politician. The company's business developer for the Nordic companies, Mr. Thor Magnus Rovik, has 2 decades of international experience from business development in the oil and gas business, from both the Norwegian champion Equinor and the smaller E&P company Rocksource. Hy2Gen is currently working on possible green hydrogen production in multiple Norwegian locations.

[28] https://greenh.no/
[29] https://hy2gen.com/

A conceptual model of channels for recycling petroleum related knowledge and resources

Based on our discussion of the literature and analysis of case data, we will now propose a list of 9 possible channels for knowledge transition and diversification of petroleum related knowledge and resources.

Phases	Processes	Channels
Knowledge transition of petroleum related knowledge	Discovery of potentially relevant petroleum related knowledge	1) Casual encounters
		2) Educational programs
	Transit of petroleum related knowledge	3) Meeting places/Cluster activities/Innovation facilitation
	Integration into knowledge base of non-oil entity	4) Research programs/Industry-university collaborations
Diversification of petroleum related knowledge and resources	**Labor mobility from petroleum related companies**	5) Labour mobility to non-oil entities
	Employee spin-offs from petroleum related companies	6) Employee spin-offs
	Existing petroleum related organization providing products and services for non-oil markets	7) Employee spin-offs in strategic partnership with existing petroleum related organizations
		8) Existing organization providing products and service for non-oil markets
		9) Existing organisation in alliance or joint venture with partners, suppliers and/or customers

Figure 2: Proposed conceptual model of nine specific channels for knowledge transition and diversification of petroleum related knowledge and resources

Casual encounters: Our discussion of the literature and our case data points to a role for casual encounters in discovering potentially relevant petroleum related knowledge. As has been mentioned earlier, the Pumps & Pipes association came about as a result of such an encounter. Hy2Gen's first hydrogen initiative came into being as result of an "accidental meeting" between their Norwegian business developer and a Norwegian local politician. The idea for the FlexiFloat technology came about when the founder was furloughed. *Educational programs:* The FlexiFloat case points to ideas being refined, but not discovered through academia-industry partnerships. In the discussion of the literature we discussed how the idea for the offshore wind services company Shoreline came about during the founder's PhD program in offshore technology at the University of Stavanger. We therefore include educational programs as one channel for discovering potentially relevant petroleum related knowledge. *Meeting places/Cluster activities/Innovation facilitation:* Lyng and Brun (2018) points out the importance of the seminar series Pumps & Pipes for discovering *and* transiting petroleum related knowledge. The NES seminar series that this paper studies is one concrete example of how meeting places/cluster activities may be used to present ideas and connect potential partners. The Topeka case points to the importance of the industry cluster NCE Maritime CleanTech in helping secure funding from Enova and the EU. FlexiFloat received support from the innovation support agency Validé in its establishment.

Research programs/Industry-university collaborations: The model of Lyng and Brun (2018) makes a distinction between the process of transiting knowledge from one petroleum actor to a non-petroleum actor and the process of integrating the petroleum related knowledge into the knowledge base of the non-petroleum actor. For developing the FlexiFloat case RosenbergWorley set up an internal team that included and "industrial PhD scholar" at the University of Stavanger. RosenbergWorley's internal team also received technical support from professors at the University of Stavanger. The Topeka case entered into a research collaboration with NORCE Norwegian Research Centre and the consultancy Gexcon to develop the technology. We therefore propose that these kinds of programs/collaborations serve both as knowledge transit and as knowledge integration.

Labour mobility to non-oil entities: The Hy2Gen and WindSpider cases both show the importance of labour mobility of personnel with various petroleum related competencies, either technical competencies or business development competencies. *Employee spin-offs:* Both FlexiFloat and WindSpider are cases of employee spin-offs, that is companies founded by personnel with experience from petroleum related companies. *Employee spin-offs in collaboration with existing petroleum related organizations:* Both FlexiFloat and WindSpider started as employee spin-offs that soon entered into strategic partnerships with existing petroleum related organizations, either as investors and/or strategic partners. In the case of Wind Spider some of the founders have made fortunes from selling petroleum related companies and may thus be considered petroleum related investors. As we have shown earlier, the literature on diversification points to alliances or strategic partnerships as a way of reducing supply-side uncertainty and costs/investments in cases where a company has to gain access to new capabilities. However, both FlexiFloat and WindSpider point to the need to also enter into collaborations with potential customers/end-users.

Existing organization providing products and service for non-oil markets: In many ways this is the classic case of firm diversification, a company setting a new division to serve a new market. One example of this will be how NorSea and Wilhelmsen plans to use their existing organizations for operation of logistics bases and ship management respectively. As we have seen from the literature on diversification, there is relatively little risk in using the existing organization when merely expanding existing capabilities, in this case expanding existing capabilities within general logistics and ship management. *Existing organization in alliance or joint venture with partners, suppliers and/or customers:* From our case studies it seems like most petroleum related companies engage in some kind of alliance or joint ventures when diversifying into a non-oil market. The prime example here is how Equinor is teaming up with both different E&P companies, industrial groups and/or utilities to make inroads into new markets. One of these alliances is our Topeka case where the consortium includes both suppliers, research organizations and possible end-users of the technology. The FlexiFloat and Wind Spiders cases are examples of pure industrial partnership with, as of yet, no end-user included in the partnership. The active use of alliances and strategic partnerships is in line with the diversification literature that sees this as a way of reducing supply-side uncertainty, reducing costs/investment and gaining access to market-specific capabilities.

The discussion above has focused on knowledge transition and diversification within industrial settings and with a focus on financial capital, but the results may also apply in other settings and with other forms of capital. One example is knowledge transition within international law, where international law principles related to petroleum has been applied in relation to seabed mining (Eide, 2021). Another example is further applications of safety management principles from the petroleum activity. Another example could be diversification of petroleum related real estate like when a former quarry for sand to offshore constructions is developed into a facility for land-based aquaculture.[30]

[30] https://tytlandsvikaqua.no/omoss/

Conclusions and policy lessons

The purpose of this paper was to provide a conceptual model of specific channels for knowledge transition and diversification of petroleum related knowledge and resources, i.e. we aimed to highlight specific channels for recycling petroleum related knowledge and resources. This kind of conceptual knowledge could be very useful for governmental agencies and industry clusters supporting the on-going economic diversification of the Norwegian petroleum economy. To gain insights in potential channels we used data from a seminar series on opportunities in hydrogen and offshore wind organized by the Rogaland-based industry cluster Norwegian Energy Solutions. As the members of NES spans the entire ecosystem of the petroleum sector and includes sizable numbers of both large, medium-sized and small actors, the case of NES is a rich, highly representative case of the Norwegian petroleum industry. Our analysis highlights the following 9 channels for knowledge transition and diversification of petroleum related knowledge and resources: *1) Casual encounters; 2) Educational programs; 3) Meeting places/Cluster activities/Innovation facilitation; 4) Research programs/ Industry-University collaborations; 5) Labour mobility to non-oil entities; 6) Employee spin-offs; 7) Employee spin-offs in collaboration with existing petroleum related organizations; 8) Existing organization providing products and service for non-oil markets; 9) Existing organization in alliance or joint venture with partners, suppliers and/or customers.*

Here we will discuss our results by dividing the highlighted channels into three distinct groups, each with specific lessons for governmental agencies and industry clusters supporting the on-going economic diversification of the Norwegian petroleum economy.

The first group consists of channels that governmental agencies and industry clusters need to be aware of, but which they cannot influence. This group also consists of channels that historically have been considered inherently local

It is difficult to plan for *casual encounters*, but it is important to note that this is one source of discovering potentially relevant petroleum related knowledge. In the past one would have argued that this kind of encounters were inherently local, but this is changing with the advent of virtual meetings. It is also difficult to plan for *labour mobility*, but governmental innovation officials and industry clusters must be aware of this powerful channel for transferring petroleum related competencies to either the public sector or non-oil private companies. Labour mobility is traditionally inherently local, but this may also change with the advent of more remote working.

The second group consists of channels that the government may support directly as these channels are wholly or partly governmentally funded.

Partly governmentally funded *industry clusters* have been one important policy for promoting collaborations and a gradual diversification of the economy. The findings in this paper points out their importance in both providing meeting places, helping create strategic partnerships/alliances and helping provide financing. Starting from the early 1970s a number Norwegian universities started setting up *educational programs* with a particular emphasis on petroleum related applications, for instance programs in offshore/marine technology (Hanisch & Nerheim, 1992). At present a number of these programs are now being refashioned in a more general manner, like when programs in Offshore technology is rebranded Marine technology. But these programs will for a long time be a useful source for discovering petroleum related ideas or concepts. *Research programs/Industry-University collaborations* have a role in helping transit and integrate petroleum related knowledge. An important actor here is the petroleum related research institute sector which is now gradually diversifying their competencies.[31]

The third group consists of channels that governmental agencies may support indirectly, e.g. through innovation agencies or partly governmentally funded industry clusters

Employee spin-offs has been found to be a very important phenomenon, particularly *employee spin-offs in partnership in partnerships with existing petroleum related organizations*. Existing petroleum related organizations could take a role as investor or strategic partner. In practice the roles as investor and strategic partner may be a bit blurred as investors not only provide funding, but also tends to have a seat on company boards providing valuable business insights. The classic case of firm diversification is when an *existing organization sets up a division to provide products and services for a new market*. This study has shown that this is most likely when diversification implies merely expanding existing capabilities for new markets. In most cases the *existing organization will enter into some kind of alliance or joint venture with partners, suppliers and/or customers*. This points to the paramount importance of helping existing petroleum related organizations setting up strategic partnerships or alliances with partners, suppliers and potential end-users of their products and services.

[31] https://www.sintef.no/en/latest-news/2021/major-wind-research-centre-kicks-off-its-activities/

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