Visions through the Smelting Furnace

The Story of a Norwegian Smelting Plant towards Carbon-Neutral Ferrosilicon Production

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MA thesis

SUM Centre for Development and the Environment

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Abstract

Ferrosilicon is one of the fundamental building blocks of modern society, yet seldom discussed outside the factory halls in which it is produced. Products from the ferrosilicon industry end up in everything from cars to computers. Finnfjord, a family-owned smelting plant in Northern Norway, is one of the largest ferrosilicon producers in the world, but also one of the largest CO_2 emitters on the Norwegian mainland.

In 2007, Finnfjord adopted a vision to become the world's first carbon-neutral smelting plant. Today, ten years later, and after nearly EUR 100 million worth of investments in technological upgrades, Finnfjord claims to be the most energy-efficient and environmental-friendly smelting plant in the world. The company has received both praise and heavy governmental funding for its innovative solutions, but is still far from reaching its ultimate goal.

This thesis takes an actor-network approach to studying Finnfjord and the many contributors who have been involved at the factory within the last decade. More specifically, the thesis explores how Finnfjord have pursued their vision to become carbon-neutral. Its main contribution is a detailed empirical account of the company's two main ventures since the adoption of the vision – the Energy Recovery Project and the Algae Project – based on interviews with actors both within and outside Finnfjord. The thesis draws on insights from science and technology studies (STS) in order to highlight the complexities of the field Finnfjord operate within, and argues that the production of ferrosilicon is a highly political practice which deserves a more central place in the public debate.

Acknowledgements

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The metal smelting business is full of contagious enthusiasm. I owe at least parts of my fondness for the subject to Boy Kåre Kristoffersen at Enova and Olaf Brastad at Bellona, who have provided me with both philosophical and empirical input along the way. Likewise, the help and interest of Edel Elvevoll at the Arctic University has been indispensable. Takk, alle sammen!

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"What really exists is not things made but things in the making"

William James, 1909

Finnfjord 2011

1. Introduction: Climate Change and Ferrosilicon Production

1.1 A Factory of a Different World

You cannot miss it as you drive by. The industrial grounds of the Finnfjord smelting plant stand out against everything else in the harsh but picturesque Northern Norwegian landscape. Situated at the foot of an open fjord with lush hillsides and naked, snow-covered peaks, the three factory chimneys rising high into the air is the first thing every visitor to the Senja region sees when driving out towards the coast. The contrast between the colossal, grey plant with its rusty-red pipelines, and the rolling, green hills that surround it, is nothing but striking. You get the feeling that whatever is going on within the closed-off factory grounds, it is something of a different world.

In many ways, it is. Finnfjord is one of the world's ten largest industrial manufacturers of ferrosilicon, a necessary component in steel production. Located just a few kilometres outside the little town of Finnsnes, the smelting plant purchases coal and iron at the global market, and uses these to produce the valuable, but energy-demanding product ferrosilicon, which is sold off as solid, hand-sized pellets to manufacturers all over the world. Every year, roughly 100 000 tonnes of ferrosilicon is shipped off by boat from the factory quay. After another global loop, some of the ferrosilicon returns to Finnsnes in the form of finished goods. The steel framework of the town hall, the engines of the cars that ceaselessly speed past the plant, the computers and mobile phones that people use in their everyday lives, the strings of the guitar I carry on my back – all contain traces of ferrosilicon, and would be useless without it.

However, the production and consumption of ferrosilicon also constitutes a major challenge in the face of climate change. In 2007, Finnfjord was considered to be the 14th largest point source emitter of CO_2 on mainland Norway. The same year, the company announced a vision to become the world's first carbon-neutral smelting plant. Today, after more than NOK 800 million of investments, Finnfjord claim to be the world's most energy-efficient and environmental-friendly producer of ferrosilicon. They have installed an energy recovery system able to recycle "up to 340 GWh" of electrical power as a by-product of their ferrosilicon production, and has continued to invest heavily in research and development. Currently, the company is working on an ambitious project to capture and utilise CO_2 to cultivate marine algae for fish fodder.

These innovative ventures have received national attention, and has earned Finnfjord the label “the diamond of Norwegian industry” by Frederic Hauge, founder of environmental NGO Bellona. Nevertheless, despite massive investments and a decade of working towards carbon neutrality, Finnfjord is still the 14th largest CO_2 emitter on the Norwegian mainland, and still consume more electrical energy than a medium-sized Norwegian city. Still, when I began this study, the company was widely praised for their efforts to reduce the carbon footprint of their production.

As a student of sustainable development, the environmental reputation of Finnfjord appealed to me, and at the same time it puzzled me: How could an industry so heavily dependent on an enormous energy supply, and a production inextricably linked to CO_2 emissions, claim to be one of the greenest in the world? The following thesis is an outcome of that question.

1.2 Two Projects: Energy Recovery and the Algae Project

Giving a conference speech in Oslo in January 2016, the CEO of Finnfjord, Geir-Henning Wintervoll, presented the company’s status towards carbon-neutral production.[1] Within the last ten years, he claimed, “Finnfjord has applied measures that correspond to over 90 per cent of our CO_2 emissions”. According to his calculation, Finnfjord was en route to offset their yearly emissions of 300 000 tonnes CO_2. The main venture under the company’s environmental banner had been a large energy efficiency programme – the EGV Project[2] – where the company installed a steam-powered turbine able to regenerate between 30 and 40 per cent of Finnfjord’s total electricity input. This was an unprecedented number for any smelting plant in the world.

Whereas the EGV Project was finalised in 2012, the current flagship of Finnfjord is the ongoing Algae Project. The basic idea is simple: To feed the factory’s CO_2 to carbon-eating microalgae in huge water tanks. The algae use the CO_2 to produce

[1] See Reiseliv i nord (2016)

[2] EGV, Norwegian abbreviation for “energigjenvinning” (energy recycling).

natural oils that in turn can be refined into for example fish fodder or biofuel. In Wintervoll's presentation, the Algae Project could potentially offset as much as 150 000 tonnes of Finnfjord's direct CO_2 emissions, or *half* of the emissions from the factory chimneys. This, combined with the factory's advanced energy recovery system, would effectively *surpass* Finnfjord's climate vision, making the factory not only carbon-neutral but even carbon-*negative*, thus making the factory a net "carbon vacuum cleaner."

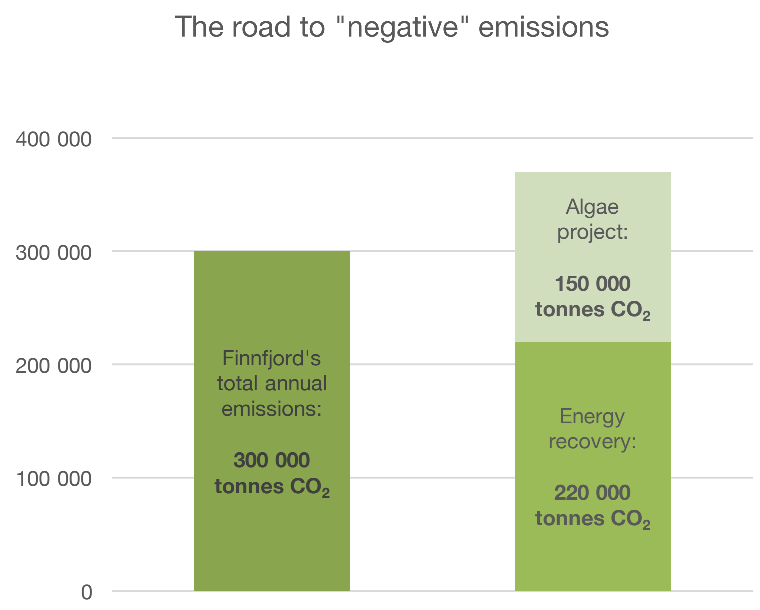

Figure 1*: The road to "negative" emissions, as presented by Geir-Henning Wintervoll at the Nord i Sør conference in Oslo, January 2016. Wintervoll's own presentation also included a third mitigation measure, 20 000 tonnes of CO_2 equivalents "saved" through replacing fossil coal with biogenic charcoal, which, for reasons of space, will not be discussed extensively in this thesis.*

1.3 Ferroalloys of the Past, Present and Future

Finnfjord's forward-leaning attitude has been met with praise in Norway. After nearly 50 years as an oil-driven economy, many have been looking to hydro-powered industry as a future foundation for new workplaces (Tjernshaugen and Langhelle 2009). The Norwegian energy-intensive industries have been eager to align themselves with the *green shift* discourse rather than falling into the same category as the "sunset industries" of the petroleum sector (Fredriksen 2015). The power-intensive industries also have significant political influence by virtue of being cornerstone industries with high export rates and high value creation (Kasa and Malvik 2000, Reve and Sasson 2012).

Finnfjord is been one of approximately a hundred Norwegian businesses encompassed by the EU Emissions Trading Scheme (ETS), where emissions are to be reduced by 43 per cent by year 2030. Success for the ETS is reliant on large technological upgrades – not to say leaps – within the industrial sector. It has even been argued that developed nations must reduce emissions "more than their national potential" (Baer et al 2008, 22, Vuuren et al 2015), effectively becoming carbon-*negative* with time. Seen in this light, the process industries constitute a major challenge, as it seems technically challenging to reduce emissions significantly within the current technological production paradigm (SINTEF 2009).

Ferroalloys, however, are crucial to the way our society works. Steel is an omnipresent material in our daily lives – it is used in infrastructure, transport, packaging, housing and construction. In Norway, it is estimated that between 150 and 300 kilos are consumed each year per inhabitant (World Steel 2015). Moreover, the global demand for steel is growing: Worldwide production doubled from 2000 to 2015, the main driver being developing Asian countries and China in particular. Although it is popular to speak about alternative construction materials such as aluminium as "future materials", the global production of aluminium – around 60 000 tonnes – is still dwarfed by that of steel of 1,6 million tonnes (World Aluminium 2015). It is likely that the demand for steel – and therefore ferroalloys – will continue to be significant in the future.

Globally, Norway is one of the largest ferroalloy producers, but appear small when compared to the real giants. In 2008, the leading ferroalloy-producing countries were China, South Africa, Kazakhstan and Ukraine, who accounted for 77 per cent of the world ferroalloy production (USGS 2010). China alone produce more than half of the world's ferrosilicon (Schnebele 2015).

1.4 Local Fires, Global Currents

Finnfjord is not just an industrial island in a picturesque landscape. The processes taking place at the plant *do* indeed belong to "a different world" in the sense that everything taking place at the factory grounds is connected to the outside world in complex and ambiguous ways. The assemblage of machinery, technologies, people and materials that work together to shape the way the factory works operate locally while at the same time taking part in vast, global structures. The same argument can be used in reverse: Technological development, market forces, national policies and climate change – all these are "global" phenomena which influence the way the factory may operate. Although situated in a remote fjord in Northern Norway, there are many ways in which global currents are present at Finnfjord.

The academic field of Science and Technology Studies (STS) has a preoccupation with explaining linkages of this kind – of how practices and devices work together (e.g. Tsing 2004, Jasanoff 2004, Latour 2005, Law 2009). The STS field aims to connect actors of different kinds through tracing the ways in which they are related to one another. Often, this involves the tedious work of unearthing linkages between actors and events, people and places, sites and situations that might seem separate but are in fact so closely interlinked that it makes little sense to speak about one without mentioning the other.

One of core insights of the actor-network theory (ANT) branch of STS deals with how social phenomena emerge when different actors are *drawn together* and coordinated through processes of *assemblage*. Actor-network accounts highlight the ways in which human and non-human entities come together to form temporal "webs of relations" or *actor-networks*. These networks consist of humans and organisations, but also of physical structures, machines, ideas, nature and animals – all entities that may be said to *act* upon each other through the networks they participate in. In this way, actor-network theory seeks to illuminate the ways in which material objects or settings may constrain, prevent, allow or encourage certain actions to be taken within the network.

The ANT approach provides this thesis with a theoretical entry point to understand the recent development at Finnfjord. Actor-network theory attempts to locate linkages of both the "social" and of "material" kind, and connect "local" and "global" events through showing how these are necessarily products of each other.[3] If the workings of the celebrated smelting plant are indeed "of another world", the ANT approach invites the researcher to study how these connections to the outside world are

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[3] More accurately, ANT proposes a "flat" ontology and rejects the a priori separation of social/material and global/local altogether (see 2.2).

made, and in which ways global currents may be said to be present in the blazing smelting furnaces at Finnfjord.

1.5 Why Finnfjord?

Finnfjord is in many ways a lone bird among. For one, it is family-owned, by contrast to other smelting plants in Norway who are all part of larger conglomerates with considerable industry portfolios, and, with the notable exception of the aluminium producer Hydro, all internationally owned. The standalone smelting plant in Finnfjord is geographically far removed from similar factories and industry clusters – in fact, it is the only industrial manufacturer in the entire county of Troms. In many ways, Finnfjord is an exceptional case which stands out within the industry it is part of. At the same time however, many of the developmental traits observed at the factory can be said to represent – and be of importance to – the Norwegian power-intensive industries as a whole:

Environmental ambitions: Finnfjord have been regarded as early movers in the Norwegian "green shift". Other companies have followed (see 3.1). Finnfjord have both a clearly stated environmental vision and, it seems, a way to transform this vision into reality.

A success story: Finnfjord have received heavy funding from the Norwegian government, and is often highlighted as a best-practice company within their league (ER>ER 2013). The Norwegian state agency Enova (see 4.1) claim that "Norway, spearheaded by Finnfjord and Elkem, has paved the way internationally and promoted highly functional solutions that serve as examples for the rest of the world" (2014, 52). Finnfjord's road towards sustainable production has been deemed to be a success story, so far.

Technology transfer: On a world basis the largest producers of ferrosilicon are found in emerging economies such as China. The innovative technologies and practises developed at Finnfjord could, theoretically, be of importance to the technological development of the smelting industry as a whole, and to similar industries who need to grapple with large amounts of waste heat.

For these reasons, Finnfjord may be a productive doorway to the study of the Norwegian power-intensive industries, and how these are connected to the prevalent issue of climate change.

1.6 Research Question

Confronted with the concern of climate change, it may be tempting to dismiss Finnfjord as an industrial dinosaur for which there is no room in a 2-degree climate scenario. However, it is difficult to envision a future without steel. At the same time, Finnfjord have been portrayed as one of the forerunners of the technological development within the industry. For these reasons, Finnfjord – and the industry they represent – constitute both a problem and solution. This paradox fascinated me tremendously when I started learning about the factory and its recent projects. Moreover, it made me wonder whether the company's ambitious climate goals *have* indeed steered their production towards a more environmentally friendly model.

In the following thesis, I have studied the development at Finnfjord from 2007, when their carbon-neutral vision was adopted, up to 2016, the year when this study was conducted. During this decade, the two abovementioned projects – the Energy Recovery Project and the Algae Project – have spearheaded Finnfjord's climate campaign. The main task of this paper is thus to investigate how these projects came about, and how they have contributed to directing the production at Finnfjord in a more environmental-friendly direction, especially with regards to its carbon footprint. In order to do this, this thesis aims to answer the following research question:

How have Finnfjord pursued their vision to become carbon-neutral?

In order to operationalise this general question, I present a subset of questions that I address in separate chapters. In the first of these chapters, I focus on the material and historical context in which Finnfjord's ambitious climate vision was born. In doing so, I aim to trace historical events that may still be said to influence the ways in which the factory works and develops.

How did Finnfjord's environmental vision come about?

In the subsequent chapters, I describe the ways in which Finnfjord's ambition has materialised into concrete projects. The EGV and the Algae Project will form the empirical core of this paper. They differ in both scope, maturity, commercial and environmental potential. What they have in common however, is the expressed aim at a more environmental-friendly business model, and an explicit linkage with Finnfjord's vision to become the world's first carbon-neutral smelting plant.

How did the Energy Recovery Project take shape?

Through articulating myself in this way, I aim to highlight a central point in the approach of this thesis, namely the joint focus on "social" and "technical" aspects of the shaping of new technologies. Building a technical system requires the *drawing together* of many different actors that shape and influence each other. This is a point I will return to throughout the whole thesis.

Finally, after giving an account of the assemblage of the energy recovery system, the last of this paper's empirical chapters aims to describe the background and the initial stages of the ongoing Algae Project.

How is the Algae Project taking shape?

This chapter is open-ended, since the final outcome of the Algae Project is still uncertain at the time of writing.

The thesis is mainly limited to discussing the two abovementioned projects and how they affect the ferrosilicon production process. Another interesting topic would be to study the ongoing transition from fossil to biogenic coal within the ferroalloy industries, a development currently spearheaded by Elkem (see section 3.1) which has already led to modest emission reductions at Finnfjord (see figure 1). For matters of space however, this will not be discussed at length in this thesis. For the same reason, I will only briefly touch upon emissions from the extraction and production of raw materials (see section 3.2) and upon the role of ferrosilicon (and other by-products) within global commodity chains. As we shall see, metal production is connected to many contemporary debates about climate change, consumption and sustainability. In this thesis however, I will mainly have to focus on the role of Finnfjord and the two projects that have been at the core of their climate mitigation efforts within the last decade.

1.7 Structure of the Thesis

The next chapter gives an overview of the literature, theoretical resources and material I draw on in my analysis. After giving a brief introduction to the field of STS and actor-network theory, I provide a review of relevant literature that deals with technological development and change within Norwegian land-based, power-intensive industries. I combine these insights to a theoretical approach suitable for analysing the "green turn" at Finnfjord as a process of *assemblage,* or a drawing-together of actors in what resembles a network. Finally, I present the research design and the methods I have used to do this.

In chapter 3, I provide an account of the material basis of Finnfjord as a smelting plant, and the historical circumstances that lead to the adoption of the vision to become the world's first carbon-neutral smelting plant. The chapter focuses on Finnfjord's position within the Norwegian process industries, and how the factory historically has sought to adapt to fluctuating surroundings ever since its start-up in the early sixties. Special attention is given to the rise of climate change as the dominant environmental challenge for Norwegian industries. The chapter is chronological in structure, seeking to trace material and social arrangements that are still relevant and present in the way the smelting plant operates today.

Chapter 4 and 5 describe the assemblage of the EGV and the Algae Projects. Chapter 4 focuses on the activities leading up to the 2011 instalment of the energy recovery system, and the challenges that arose both to the project as an isolated measure, and to the working of the factory as a whole. The chapter delineates a network of actors surrounding Finnfjord throughout the process of installing the system. While on the one hand telling a story with a beginning and an end, it also points out some of the many "dead ends" that have *not* led to stable forms or concrete projects. I conclude the chapter with a short discussion about the how the EGV project relates to the vision of becoming carbon-neutral.

In chapter 5, I outline Finnfjord's innovative Algae Project. I say outline because by contrast to the foregoing chapters, the Algae Project is still in its early phases, and will require time and resources to produce a stable network. While chapter 3 and 4 are mainly based on written accounts and interviews, chapter 5 consists of insights from the assemblage process itself, as Finnfjord strive to locate the right partners, technologies and markets to make the project a viable one. Bringing the "organic" domain of Algae production and the "mineral" world of ferrosilicon production together produces a series of interesting connections that both enable and constrain further development of the project. Concluding the chapter, I discuss whether the Algae project is coherent with Finnfjord's vision to become carbon-neutral, and highlight some of the ways in which the vision has been used by campaigning politicians.

In chapter 6, I bring together insights from chapters 3 to 5 by analysing how the environmental ambitions of Finnfjord have shaped the factory's development in recent years, and how it might continue to direct it in the future. The chapter focuses on how Finnfjord's vision is constantly reassembled and upheld, drawing actors together in a process of continual *translation*, and through constant *circulation* of the vision itself between the actors that sustain it. I reflect on the findings I have made throughout the process of writing the thesis, and on the value of approaching a ferrosilicon plant with an actor-network methodology.

Finally, I conclude by suggesting that in order to deal with the environmental impact of ferrosilicon production, we need to understand not just how it is produced, but also how it is consumed.

2. Theoretical and Methodological Approach

In this chapter, I present the theoretical and methodological approaches I have drawn on to investigate Finnfjord's path towards carbon-neutral production. First, I introduce the theoretical resources that have informed the writing of this paper. In the subsequent section, I suggest how the insights from these resources may be translated into a methodological approach to studying processes of assemblage.

2.1 Theoretical Framework

A smelting plant like Finnfjord consists of a wide range of inseparable parts, each adding to the complex whole which is a functioning factory. It is made out of material (the factory, resources, products), processual (technological knowledge, routines), organisational (strategy, communication, markets), environmental (surroundings, society, competitors), social (culture, identity, power, attitudes) and a multitude of other parts. At the same time, all these parts are tightly interlinked with one another in multiple ways. Each practice at the plant consists of both material, social and political aspects.

We tend to treat these things as separate processes and distinct phenomena, and to study them from certain disciplinary perspectives. For example, the fires of the smelting furnace is traditionally the domain of the metallurgist or engineer, while "social" phenomena like culture, beliefs and values have usually been the territory of sociology, anthropology and other social sciences. On a whole, the social sciences have traditionally dealt less with questions of science and technology than the "hard" sciences have (Jasanoff 2004).

Actor-network theory (ANT) is a distinct family within science and technology studies (STS) where it is argued that this division between "hard" and "soft" sciences is both arbitrary, unproductive and, most importantly, rarely adhered to in practice. Within ANT, this "division of labour" is argued to be an outcome of, rather than a precondition for, the ways different academic disciplines have traditionally studied the world (Jasanoff 2004). One central task within the field of STS have been to bridge this gap between the natural and the social sciences – sometimes by rejecting the separation altogether (Latour 2005).

Actor-network theory offers a *practice-based* approach to knowledge production, assuming that nothing has reality or form outside the enactment of relations (Law 2009, 141). ANT encourages students of science and technology to describe the relations that provide a given entity with its distinct identity or role within the *actor-networks* they are part of (Latour 2005).

Within actor-network theory, the world we observe is treated as continuously generated webs of relations. The same can be said about the process of writing a master thesis: Rather than “applying” a theoretical perspective to a set of “raw data”, an academic can be said to consist of elements that have been *drawn together* in a process of exploring the world around us through assembling it, restructuring or re-presenting it in a new way, in order to answer a certain question or perform a certain task (Lahn 2016).

In this chapter, I provide an overview of the literature, resources, insights and material that has been drawn together to form this thesis. First, I give a brief introduction to some of the relevant literature that has been applied to understand the technological development of industrial society in general, and Norwegian power-intensive industries specifically. I continue by providing a thorough review of the academic field of STS and its subsidiary branch of ANT. Finally, I outline the main divergences and similarities in the applied material, and suggest how these insights and resources can be used to shed light on the activities at Finnfjord.

2.1.1 David Nye’s Technological Sublime: The Social Construction of Technology

What kind of factory is Finnfjord? The answer to the question can vary broadly, depending on who you ask. It is a ferrosilicon factory, but also a family-owned cornerstone business, part of the steel production supply chain, an electricity producer, a for-profit organisation, and a major polluter. Both the question and the answer indicate that the factory is presented in terms of *social constructions*: the thoughts, feelings, relations and opinions people have about it. Different people will give different answers. In this way, terms such as “environmental-friendly” and “carbon-neutral” do not only encompass fixed technical properties of the factory, but reflects the interests and values of those actors, as well as institutions that contribute to legitimising accepted interpretation(s) of the terms.

David Nye has studied how technology and society have co-evolved through history, each affecting the other. He is first and foremost concerned with technological extremes, such as the Golden Gate Bridge or the Moon Landing. Some technologies, he writes, appear as *sublime*, as they provoke “experiences of awe and wonder, often tinged with an element of terror” (1994, xvi). Nye aligns with philosopher Emmanuel Kant, who suggests that the aesthetical properties of an object should be understood as a moral experience – it makes us humans conscious of ourselves in the face of nature. As for sublime objects, they give us “courage to measure ourselves against the apparent omnipotence of nature” (Nye 1994, 7).

Nye builds on Kant’s concept to define a modern, *technological sublime*.[4] He asserts that the history about our industrial society should not only be the history of the engineer. His account of technological development is concerned with the *social* context of technology, of how new objects are understood and integrated into the fabric of social life. Technological objects, he writes, “fuse practical goals with political and spiritual regeneration” (1994, xx).

Central to Nye’s understanding of the sublime is the relationship between humans and nature. “The assumption of human omnipotence has become so common that the natural world seems an extension of ourselves rather than vice versa” (1994, 289). Technology plays a decisive role in this relationship: It becomes *naturalised* in the sense of being viewed as a part of the natural world, a phenomenon to behold in the same way as mighty canyons and creeks.

Norwegian STS scholar Knut Sørensen draws on David Nye’s understanding of the sublime, and argues that the concept it is also relevant in a Norwegian context. For instance, the electrification of Norway throughout the 20th century was not only a piece of impressive engineering, it also marked the construction of modern society. As such, the electrification was a symbolically important project, central to creating the narrative of “building the country” after World War II (Sørensen 2010, 74). We can find similar symbolism in other national projects like the Norwegian Ironworks in Mo i Rana – “the

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[4] A concept which, Nye argues, first and foremost characterises the American society. However, many (e.g. Sørensen (2010) and Sousa (2010)), have argued that the American technological sublime “provides an exciting general conceptual framework which can be used in different scenarios still to be explored” (Sousa 2010, 114). Nye also develops different conceptions and subcategories of the technological sublime that are arguably applicable to other societies than the American one.

flagship of the industrial policies of the Labour Party" (Børresen 1995, 72); the Årdal aluminium plant – "a symbol for the modern Norway" (Asdal 2008, 109); or with a more contemporary example: the Mongstad test facility[5] for carbon capture and storage (CCS) technology – an important "political glue" even without having been realised in its intended form (Tjernshaugen and Langhelle 2009).[6]

Nye's academic project serves as a counterweight to the notion of technological determinism – the belief that technology develops steadily and linearly in an already given direction. Technology, writes Nye, does not consist of "'black boxes' that irresistibly transform the world around them" (Nye 2006, 212). Rather, a technology reflects the imaginative abilities, cultural preferences, and economic or political resources of its makers and users (Bijker 1997, Jasanoff 2004). Technology, then, can be viewed as socially constructed in the sense that it works as an extension to, and repository of, established social interests.

2.1.2 Change and Innovation within Norwegian Power-Intensive Industries

The development of Finnfjord is closely associated with the development of the Norwegian energy sector. Olav Wicken argues that historically, the Norwegian power-intensive industries and the hydro-powered energy sector have developed as "Siamese twins" (Wicken 2011). The electrification of Norway throughout the 20th century occurred alongside largescale industrialisation. The establishment of Finnfjord is also an example of this (see section 3.2). In the recent decade, the production of silicon for solar panels have reinforced this interconnection (Hanson 2011). Concerns have been raised that this mutual interdependence causes innovative inertia and has contributed to an unprofitable expansion of both sectors (Midttun 1988, Narula 2002), but recent liberalisation of the Norwegian power market has to some degree changed this relationship. The current regime is characterised by a more market-based approach, higher electricity prices, global competition and international climate change mitigation efforts (Wicken 2011).

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[5] The Norwegian 'Moon landing' at Mongstad was a government-led attempt to create a full-scale CCS test site adjacent to the Mongstad oil refinery. In total, the government spent more than NOK 7 billion on the project. Bellona leader Frederic Hauge called Mongstad 'the symbol of this government's total failure on climate policy' (Bloomberg 2013).

[6] A similar argument has been made for CCS technology in the United States, see Pollak et al (2011).

Wicken, Kasa and Hanson (2011) argue that a continued high level of energy usage from the Norwegian industry is desirable for the environment. Norwegian power producers may export some electricity surplus to the European market, but because of the limited transmission capacity, they argue that most of the energy will have to be used in Norway. Long-term contracts with the power-intensive industries creates a predictable market, which is necessary for more renewables to be established.

Although water power is largely considered “green” energy, Keith Smith (2011) argues that the Norwegian energy sector is struggling to leave what he terms the *fossil paradigm*. He depicts a situation where established technological practices, infrastructure, knowledge, skills and market patterns together contribute to a “lock-in” of the technological development. Ideas, processes or products that break with these established patterns will struggle to gain acceptance, users, and market shares. Old technologies have usually been improved and refined for a long time after their introduction, making the barrier high for novel technologies to be taken into use. Escaping the fossil paradigm, Smith argues, “requires a complete change of regime” (Smith 2011, 31), through the deployment of technology which radically breaks with the current paradigm.

Staffan Jacobsson builds on Smith and argues that for concrete innovations to take place, there is a need for technological *innovation systems* that accommodate for such innovations. A technological paradigm consists of many innovation systems, defined as “networks of actors” (Jacobsson 2011). In order to break with the fossil paradigm, the current material, social and political systems need to be reshuffled in order to allow for new networks and new actors that base their production on more environmentally friendly technological platforms. Therefore, developing new technology means more than just inventing new technical solutions. To develop new technology is “forty percent development and sixty percent missionary work” (Sørensen 2010, 82) to convince the right people that you have a good solution to their problems. In short, the implementation of new and frame-breaking technology depends on both imaginative engineering and intense political work.

2.2 STS and Actor-Network Theory

Science and technology studies (STS) is a diverse academic field which brings together insights from a number of different academic disciplines to investigate the role of science and technology in society. It is a diverse field. Anthropology and history, law and politics, philosophy and economics, cultural studies and social theory, all have been applied within STS literature (Jasanoff 1995).

One distinct branch of research within the STS family is actor-network theory (ANT). According to STS scholar John Law, actor-network theory "describes the enactment of materially and discursively heterogeneous relations that produce and reshuffle all kinds of actors including objects, subjects, human beings, machines, animals, 'nature', ideas, organisations, inequalities, scale and sizes, and geographical arrangements" (Law 2009, 141). ANT departs from other strands of social science by rejecting a wide range of its established tenets and assumptions. Rather than using pre-established "social" constructs as a starting point for enquiry, such as for example "power", "identities" or "interests", the actor-network approach seeks to describe the case in hand without assuming the existence of such a priori phenomena. Social aggregates like these, it is argued, do not have an independent existence outside the concrete situation in which they are enacted. The actors therefore deserve to be described in its own terms, rather than in the synthesised and abstract language of the analytical social scientist. Within the ANT tradition, the actors' own "theorising" of their work should provide the basis for a study, to allow the actors "as much leeway in defining themselves as that offered by ethnographers" (Latour 2005, 41).

ANT can be viewed as an antithesis to the structuralist programme within the social sciences. Rather than seeking to map out underlying, implicit social structures that shape and sway the world around them, actor-network theory assumes that stable and durable formations are only the exception to the rule and do not have a form or shape outside the situations in which they are enacted (Law 2009, 141). It is *change* and *non-order* that characterise the world we live in, and whenever stable patterns occur, these are exceptions to the rule. Moreover, the mutually exclusive dichotomies that lie at heart of the structuralist tradition, such as langue–parole, global–local or nature–culture, are viewed as the *result* of series of interactions, rather than a "framework" or a "canvas" on which data can be projected. These dichotomies are produced when they are temporarily drawn together in time and space by the entities that give meaning to them. As such, they should not be studied as independent "levels" of reality that can be studied in isolation, but rather an *effect* of social interaction.

In this sense, ANT is what Law calls "an empirical version of post-structuralism" (Law 2009, 145) where temporary order only occurs sporadically and is in constant need of maintenance by the actors involved. Rather than tracing law-like patterns, ANT accounts attempts to trace *the actors themselves*, and describe how different actors may webs of relations through which they provide meaning and function to each other. The term *actor* in this sense involves both human and non-human entities, a point which I will get back to later.

How do these insights contribute to produce a theoretical framework that can be used for academic purposes? In fact, it has been debated whether actor-network theory can be said to be a "theory" at all (Law 2009, Barry 2013). Bruno Latour – who has famously argued both that ANT *isn't* a theory (1998) and later that it *is* (2005) – states that ANT is first and foremost a "negative argument" against the established social sciences. One of the features that characterises the approach is its rejection of theoretical frameworks that can be "applied" to explain a given case (Latour 2005). Traditional social sciences, he argues, take for granted concepts and terms that make no sense unless they are *enacted* and thereby *produced* by social actors. This is indeed what the term "social" *means* to Latour: the drawing-together of actors who *produce* the phenomena that are usually taken for granted within the social sciences: groups, ethnicities, power, hierarchies, knowledge etc. Rather than seeing these as explanatory concepts that can be used to account for a case, Latour argues that these concepts should *themselves* be accounted for, that is, studied as the *effect* of social interaction.

This highlights the preoccupation with practice within ANT. Unless a relation within the network is *enacted* in one way or another, there is no way to trace it and therefore also no way to positively verify that it exists. This is not as much of an ontological argument as it is epistemological, agues Latour. Social aggregates like groups, norms and roles may very well exist, but unless they are enacted, there is no way for the researcher to *trace* them. It is much easier to study the *formation* of social aggregates, as actors are pulled together in a process characterised by uncertainty, fragility, confrontation and controversy. *Group formation*, argues Latour, is much more suitable for study than *groups*. In this way, the main task of the social sciences should not, describe the glue, but *what is being glued* (Latour 2005, 5).

Annemarie Mol (2002) takes the concept of practice one step further, and claims that the logic of actor-network theory also has ontological implications. In her ANTinspired case study of "the body multiple", she shows how multiple body practices produce *multiple bodies*. Reality, she claims, is also enacted. Different practices relating to the same object or concept will produce *different realities*.

This argument can also be invoked to describe the field of ANT itself. Rather than seeking abstract, generalizable knowledge, ANT is grounded in empirical case-studies, and can only be understood in relation to those concrete case-studies and how they work *in practice* (Law 2009, 141).[7] Law defines ANT as a field of literature which seeks a descriptive, rather than foundational, approach to knowledge production, and describes ANT as a set of "tools" or "sensibilities" that can help to grapple with a field of study characterised by uncertainty and controversy. Its aim is not to produce grand theory or generalizable knowledge, but to provide an account or description of the case at hand which does not need an extra layer of "explanation" on top of it.

The research that aligns under the actor-network theory heading is diverse and sometimes even contradicting, but carries a family resemblance in that it lends itself to a number of "sensibilities" that guide their theoretical and methodological approaches. At the core of ANT is a patchwork of case-studies which overlap and intersect, drawing on insights from both each other, from other disciplines, and from the case in hand. Some "classics" within the ANT tradition include the study of fishermen and scallops (Callon 1986b); Portuguese trade ships (Law 1986); the "Pasteurisation of France" (Latour 1988); and feminism and identity politics (Haraway 1991), studies which do not have much in common except their adherence to an actor-network ontology.

How may actor-networks be studied, and what are the "tools" or "sensibilities" that Law is referring to above? In the following section, I outline four characteristic traits of ANT that are relevant to the approach I have chosen for the thesis.

2.2.1 Four Insights from Actor-Network Theory

The notion of *action* is central to the understanding of actor-network theory. ANT proposes that there is no true locus of a given action. Rather, action is *dislocated* in the

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[7] Arguably, this is also true for other academic disciplines, for example most of the natural sciences (Kuhn 1970) where "theory is embedded and extended in empirical practice, and practice itself is necessarily theoretical" (Law 2009, 141). Law also mentions the symbolic interactionist strand of social sciences as a field "embedded and extended in empirical practice" (2009, 141).

sense that every action contains traces of other actions that have occurred elsewhere, in another time or place. In this way, every actor is part of a *network* of other actors. The main task of ANT is *tracing* this network, or, as Law calls it, webs of relations. Importantly, tracing a network does mean to uncover a "thing out there" in the structuralist sense, but rather refers to a *method* of tracing a set of interactions (Latour 2005, 202). As such, actor-network theory is not about unearthing an assumed structure, but "about examining that which enables and constrains action" (Asdal 2011, 222). A consequence of this insight is the way cases are studied. Rather than seeing a phenomenon as a "case of something" within a given theoretical framework, an ANT account seeks to depict the ways in which an entity is connected to other entities in an ontologically "flat" landscape.[8]

Another central insight from ANT is how one might study actor-networks as created through processes of *assemblage* of heterogeneous entities. These processes refer to the abovementioned *drawing together* of people and things that may be said to act upon each other through participation in the network. One interesting, if controversial, feature of ANT is the attention given to non-human entities. Material components contribute to stabilising relations and render them durable.[9] In this way, actors within a network may be objects, sites, humans, machines, visions, documents or animals, or in short: all the things that may be said to *do* things and *act upon* the other entities in the network.[10] This means that for example technologies, infrastructure, ecosystems and everyday objects may be understood as *performative* in the sense that they allow, constrain, encourage, permit, forbid or suggest certain actions to be performed. It does not mean, however, that all actors are "equal" or should be treated

[8] "Flat" in Latour's use of the word does not necessarily mean the world is something "out there" in the sense that reality may be fully uncovered through looking at it from "all angles". Realities, Law argues, are *not* flat. "They are not consistent, coherent and definite" (Law 2007, 605). Rather, "flat" refers to the rejection of the a priori dichotomies at heart of the structuralist tradition.

[9] Latour (2005) uses the study of baboons to justify this claim, describing how the social relations within a baboon family are under constant need of reaffirmation and re-enactment in order to be upheld. The big difference with humans and baboons, he claims, is the way we interact with materials and objects that render stable webs that otherwise would have been a lot more fragile.

[10] For students and researchers at SUM (the institute on which this thesis is being written) the notion of performative objects or technologies should be familiar. See for instance Verbeek (2006) on materialised morality and Wilhite (2008) on social scrips.

like it. It just means that when tracing a network, the analyst should pay attention to all settings that may be thought to enable or constrain actions of certain kinds.

When opening up for both human and non-human actors on our descriptions of reality, we allow the researcher to trace a network through its materiality and its discourses, involving entities that appear to be fundamentally different form each other, but all contribute to the formation of networks through "bringing" their abilities, potentials, desires, connections and perspectives. This *heterogeneity* of a network is crucial to its functioning. Within a post-structuralist ontology, an entity receives its meaning and function from its *difference* (Derrida 1976, Barker 2012) or *incommensurability* with other entities (Latour 2005, 74). As for Finnfjord, the assemblage of engineers, smoke ducts, furnaces, company vision, quartz, monitoring systems, waffles[11], turbines, financial accounts, algae, carbon and so on, is what renders it a stable, functioning system. When tracing the actors through the webs they weave, all these participants in the network may be relevant to understanding the success – or failure – of a network to establish a stable form, and in our case, for Finnfjord's company vision to be upheld.

A third distinctive trademark of the ANT tradition is the preoccupation with *circulation*. Whether illustrated by spices and trade ships (Law 1986), hotel keys (Latour 1991), fish (Holm 2000), scientific facts (Asdal 2011) or documents (Lahn 2016), tracing the circulation of entities within a network is often analogous to describing the interactions that pull it together. Latour suggests that the role of the ANT researcher is not just to "follow the actor", but rather, "what *makes them act*, namely the circulating entities" (2005, 237, my emphasis).

The notion of circulation does not necessarily refer only to physical objects. It can also be concepts, facts, buzzwords or numbers that are shared between actors. As entities circulate, they may take on different shapes or functions as they are encountered in different parts of the web. But since every actor by definition is different, every relation to the circulating entities will be different, giving rise to different *practices* with every step.[12] The notion of *translation* is one of the central concepts within actor-

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[11] See section 2.3.2.

[12] See Mol (2002).

network theory, describing the act of making equivalent terms that are inherently different and sometimes even contradictory (Serres 1974). Within ANT, translation points to the metaphorical work that needs to be done every time two practices meet, simultaneously linking them and rendering invisible the fundamental incommensurability between them (Law 2009, 144). The process of translation is what allows discursive flexibility to entities that work within widely different contexts and in different networks.

The fourth and final insight I will draw upon in the following text, is ANT's emphasis on *accounts*. In every actor-network, some entities will be given prominence while others become hidden from view. This is especially the case for a stabilised network. Latour's (1988) account of the French microbiologist Loius Pasteur may serve as an example of this. Pasteur is widely regarded as a hero of French science, and a "great man" whose discoveries have had a lasting effect on society. However, Latour argues, it is more appropriate to regard Pasteur as a product of everything happening around him at his time. "Farms were turned into laboratories, vaccines made from attenuated bacteria, cattle stopped dying of anthrax, and Pasteur became a great man" (Law 2009, 145). None of these events can be reduced to "causing" one another: Pasteur was not a great man, but a great network.

Following this logic, a network is no stronger than its weakest link.[13] Hughes (1983) uses the car as an example. When all the separate parts function at the same time, they effectively become invisible and produce a stable, *punctuated* network – the car – whose inner workings remain "black-boxed" (Latour 1999) as long as it runs efficiently. However, if one detail is missing or out of order, this may result in the total breakdown of the entire system, revealing the fragility and the heterogeneity of the network which underpinned it. In the same way, actor-networks tend to become "purified" in the sense that certain actors occupy the centre of stage while others are left in the shadows.

This has implications for how an actor-network may be examined, since any stable web of relations will produce less traces to be studied. A good account within the

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[13] No pun intended. This way of putting things shows that the metaphor of a "network" forming around actors is exactly that: a metaphor, which could have been expressed in other ways. Latour discusses this and its implications extensively in his book "Reassembling the Social" (2005).

ANT tradition is one which includes as many parts of the network as possible, and treats each point as a "full-blown actor" (Latour 2005, 120). Latour elaborates on this through distinguishing between *intermediaries* and *mediators*. The former transports force or meaning through the network without modifying its quality or content, while the latter transforms, distorts, adds or subtracts in ways that are unpredictable and cannot be taken for granted. As an example, a computer may be a highly complex machinery which may still function as an intermediary with regards to its function in a network, while a normal everyday conversation may serve to radically change the configuration of the network. A rule of thumb is that a good ANT account involves describing as many mediators as possible, and the complex ways in which they contribute to establishing connections with other mediators.

Moreover, a good ANT account is one which fervently rejects the opportunity of taking "shortcuts", or "jumping" between levels and sites without describing as meticulously and myopically as time will allow for the several ways in which they are interconnected. The virtue of concreteness, in this sense, is not necessarily about describing every interaction as "locally" as possible, but rather to trace the local–global continuum and the ways different levels are connected to the degree that the analytical separation of them do not make sense anymore.[14]

2.2.2 Assembling the Thesis

ANT is not necessarily about granting agency to objects, nor is it simply about "following the actor", as it is often presented. Rather, it suggests scrutinizing with painstaking care every possible relevant connection before moving on to the next (Asdal 2011, 222). An actor-network account seeks to produce a description of the case at hand which pre-empts any need for an explanation (Latour 2005, 137).

But if we follow Law who claims that actor-network theory is not a theory, what insights can "it" contribute with? What "framework" does it provide? First of all, it provides a clear caution about what *not* to do. Pre-established "social" phenomena, it

[14] Then why do we keep referring to global/local and other "structuralist" dichotomies as if they were a priori concepts? STS scholar Sheila Jasanoff coins the term "co-production of knowledge" in order to provide a convincing argument about the "Archimedian point" all sciences have to depart from in her "States of Knowledge" (2004).

proposes, should not be used as explanatory categories, but rather *need to be explained*. Latour suggests that the goal of ANT is exactly this: to describe how social phenomena (that is, heterogeneous networks) are established and upheld through a process of assemblage. Following this, ANT is about following the actors "in their weaving through things they have added to social skills so as to render more durable the constantly shifting interactions" (Latour 2005, 68). This includes moving between objects and events which work together *exactly because* they are different and thereby able to reinforce one another with meaning and function.

ANT also provides us with a clear instruction to follow the actors not just physically, but also with regards to language. "ANT claims to be able to find order much better *after* having let the actors deploy the full range of controversies in which they are immersed" (Latour 2005, 23). In other words, actors have their own meta-language and theories of action. This is one of the fundamental insights to social sciences as a whole – the world we study is already enmeshed in theory. But rather than viewing this as a problem that needs to be solved, the ANT researcher should assume that he is always "one reflexive loop" behind the actors he is studying (Latour 2005, 33), assuming that the actors' own assumptions about what they do is inseparable from what they do. In short, action is always present in theory and theory is always present in in action. Theoretical assumptions are part of what draws actors together. Therefore, Latour proposes an ANT "*infra*-language" whose role is simply to help researchers "become attentive to the actors' own fully developed meta-language" (2009, 49).

Third, the generalising power of ANT does, as we have seen, not reside in the formulation of abstract rules or theoretical frameworks. Rather, generalisability is sought through describing those configurations that may create a stable network. "Some materials", Law writes, "last longer than others. It is easier to imprison people if there are prison walls" (2009, 148). Describing configurations that lead to material, strategic or discursive stability may extend the insights from ANT case studies to go far beyond the specific study in hand.

2.3 Methodological Approach

The main empirical contribution from this thesis is a series of interviews and conversations with people within and around Finnfjord. All have, in one way or another, been involved in the EGV and/or the Algae Project between 2007 and 2016. Most of the material stems from accounts from people who have taken part in activities in and around Finnfjord within the last decade. This poses an immediate challenge with regard to ANT's preoccupation with practice (especially so for the EGV Project which was finalised in 2012): If networks do not have form or shape outside their momentary enactment, how may their assemblage be traced retrospectively? Latour offers a possible way out, suggesting to "feed off the controversies" and incommensurabilities that exist within a network. These, he claims, witness of unsettled heterogeneous networks that are still under formation, and still leave traces of its existence. In the case of Finnfjord, the controversies around the EGV Project are still very much present in documents, newspaper articles, and in the different actors' accounts. Although the EGV system is up and running, there are still conflicts that have not yet been settled and which still influence the ways in which the system works (and sometimes doesn't work). As for the Algae Project, it is an ongoing project which began long before I entered into my study of Finnfjord, and will continue for a long time after this thesis has been concluded. The uncertainties and controversies around the project are very present in the discourse around it, highlighting how the network around it is still taking shape as a process of assemblage of people, organisations, knowledge, algae, technology, governmental regulations and so forth. My main challenge, then, would be to get behind the idyllic picture of Finnfjord as a technological forerunner and environmental pioneer, to gain insight into the processes and events that have given them this status.

2.3.1 The Road to Finnfjord

My starting point for this thesis was neither obvious nor unproblematic. Originally, I wanted to study mobility and globalisation. I was born and raised in a remote fishing village on the island Senja, an hours' drive from Finnfjord. When the first roads arrived in the early 80s, life in the village was transformed overnight. Maps were redrawn, schools moved, people followed, and a the new and profitable industry of fish farming arrived to the region. When I realised how much fish farming would mean to the future development of the area, I considered changing the focus on my thesis from roads to fish. The global networks that act within the fish pens of Senja are astonishing. However, my initial research got me depressed. The environmental challenges connected to the fish farming industry are significant, and there seemed to be little that a sociologist could do about it.

This was when I got in touch with a former employee at Finnfjord, who told me something along the lines of "If the world depresses you, you should study what is going on at Finnfjord right now. It will blow your mind." In the coming few days, I would read up on Finnfjord and the Norwegian ferroalloy industry, and noticed that the entire business seemed to have a different mood than the other research topics I had considered researching. Fascinated by the aura that surrounded the factory, I decided to approach Finnfjord with a request about studying their recent development.

In this way, my entry point to the thesis' topic has been guided by the enthusiasm for a greener society in general, and in local efforts to tackling environmental challenges specifically. This comes in addition to the fact that I have been working closely with one of Finnfjord's collaborations partners earlier; have been an active member of the environmentalist group Natur og Ungdom (Young Friends of the Earth) whose main preoccupation within the last decade has been issues of how to grapple with global warming; as well as having deep a fascination for the natural sciences. Seen together, this personal entanglement in the field may be seen as a "problem", but can at the same time be regarded as what STS Donna Haraway calls double or *split vision* (Haraway 1991), emphasising that there are always tensions or frictions within material-semiotic realities and their representations. This implies that "both the social processes that we study and our own take on them are incomplete, uncomfortable, on the move and without resting places where everything can fit together" (Law and Singleton 2014, 381). My curiosity around these issues have lead me to explore many academic strands and connected industries and topics in ways that otherwise may have been regarded as irrelevant to the study. Moreover, the literature that I draw on, the "surplus data" from studying connected fields, and the resources and insights provided by STS literature and the actor-network approach to case studies, have all helped expand and challenge my own perceptions of the field, all adding to the notion of split vision of an inherently complex and contested case.

2.3.2 Getting Inside

To begin with, I had little knowledge about Finnfjord. During high school (from 2003 to 2006, before their "green turn"), I had been studying physics just a few hundred metres from the factory grounds for three years, but still knew very little about the plant and the industry it represented. I did not know that it constituted a major environmental challenge, and had no personal acquaintances on the inside apart from a friend who worked part time there and didn't talk much about it.

However, a former colleague of mine – the one who convinced me to study the company in the first place – had been working as a consultant for the factory administration, and indicated that he would be able to help me get access to the information I needed for the study. I submitted a formal interview request to the company CEO via my friend, where I explained my curiosity and that I wanted to know more about Finnfjord. There was no reply for a long time.

After two months (and a handful of insistent follow-up emails), I finally got an invitation to meet the company CEO in his offices at Finnfjord. The invitation came just three days ahead of the proposed date. I cancelled all my appointments and booked a flight to the nearest airport. Three days later, I presented my thesis outline to the CEO in a meeting room at Finnfjord. In return, I received a thorough 2-hour formal presentation of the company and their current projects. I had prepared a list of thirty-odd questions that I was eager to ask, about everything from organisation structure and budgeting to the chemical process in the smelting furnaces and the behaviour of marine algae in closed tanks. Many of them were still left on the writing pad when our time was up, and the CEO had to rush off to his next meeting.

Back in the reception, I realised that we hadn't appointed any concrete next step to continue my research, and I was not even completely sure that my research proposal had in fact been accepted. Confused, I sat down in the lobby for a while, and I was only about to leave the building when one of the staff members invited me to join them for the weekly Friday waffles.

I remained in the lunchroom for the rest of the day, talking loosely to people from many different levels and branches of the company. The atmosphere in the lunch room was friendly and open, and people gladly introduced me to each other and helped me establish relationships throughout the organisation. By the end of the day, I had gathered a handful of contacts at the company which I thought could be relevant for the thesis. The same afternoon, I met with the administrative manager of the local municipality of Lenvik to discuss Finnfjord's position in the area as an important cornerstone business.

For the next couple of weeks, I kept in touch with the staff members, and through persistently following them up and keeping them updated about my thesis, I was finally assigned an official contact person at Finnfjord for the study, the project manager for the EGV and Algae Projects. Based on the conversations from the first day at Finnfjord, I drafted a “wish list” of people that I wanted to talk to. These were both internally employed at Finnfjord, and external collaborators who had been involved in shaping and/or implementing the environmental vision from 2007. After presenting the list to my contact person, he proposed new people that could be interesting to talk to. With every conversation, new potential informants would emerge. The main challenge would soon be to *limit* the number of sources. It was also important for me not to blindly accept every informant proposed by the company, but rather try to locate informants that would be able to give more critical and independent accounts of the projects.

2.3.3 Following the Actors, Tracing a Network

I decided to mainly focus on the partners *directly* involved at Finnfjord in the two projects: For the EGV Project, the state agency Enova (a state agency who helped finance the project) emerged as the most relevant collaborator. For the Algae Project, The Arctic University (who contribute with the scientific knowledge) seemed like the most interesting partner. My contact person at Finnfjord put me in contact with Enova, but I was asked to “tone down” my interest in the Algae Project because of the “sensitivity p. t.”. Therefore, I did not contact The Arctic University to begin with, but rather focussed my research on the Energy Recovery Project and the events leading up to it. In this period, I did a phone interview with a senior consultant at Enova who had been Finnfjord’s main contact at the agency throughout the EGV Project.

I visited Finnfjord once again by the end of 2015. This time, I conducted an interview with the project manager of the EGV Project and the project engineer at the plant. I was also given a tour throughout the factory, with its quartz piles, smelting furnaces, transport belts, surveillance room, quay, energy recovery unit, laboratories, purification plant (baghouse), offices, lunch room and Algae Project test facilities. It was just as sublime from the inside as from the outside, and vastly “theorised” from before. The processes at the plant were presented as energy flow charts and chemical formulas; the EGV Project through organisation maps and responsibility matrixes; human resources in terms of *lean* production management; the environmental vision as a strategy pyramid, and so forth. Following the actors through their own pre-theorised fields proved challenging but amusing, and after the visit, it took me quite a while to study up on the different subjects seen as relevant by the actors themselves. Meanwhile, I started systematising the interviews and contrasting them to one another.

A few months later, I was invited to participate on a meeting where Finnfjord was to present the Algae Project to its potential collaboration partners within the research and development sector (see chapter 5), where also the dean at The Arctic University was present among the participants. I was thankful for being allowed to participate in this relatively exclusive forum,[15] and offered myself to play a song to open the meeting (I am a professional musician and never travel anywhere without my guitar). The CEO introduced me as their "singing master student" and presented the topic of my thesis to the participants in the room. After the meeting, the university dean approached me and expressed great enthusiasm for my thesis. She invited me to come and see their algae test lab, and when I told her I had been asked to "tone down" my interest in the Algae Project, she insisted firmly. Tempted by this opportunity to learn more, I decided to include the Algae Project in my research. The same week, I did a two-hour interview with the former policy manager at Finnfjord in a café in Oslo.

Mid-January 2016, I visited the algae test lab at the Arctic University in Tromsø. I was introduced to the researchers working at the lab, and to some of the connected projects carried out on the site. I also did an interview with the university dean about their role within the Algae Project at Finnfjord, before we were joined by a well-known Centre Party politician who came by for a coffee and was very enthusiastic about Finnfjord's projects. She agreed to do an interview on the spot.

Later that month, I attended the Enova conference in Trondheim, a large gathering for actors within the sectors of industry, transport and construction. The main issues at the Enova conference are energy efficiency and climate-friendly technology. The conference was attended by both the prime minister and the oil and energy minister, as well as politicians and environmental activists from the whole country. The majority of attendees were CEOs and managers from private firms with high electricity bills. During the conference, I conducted a series of short, semi-structured interviews with both politicians, industry leaders and environmentalist NGO representatives. The

[15] Finnfjord sent personal, non-transferable invitations to 27 people. 32 showed up.

week after, I met with the regional director of Innovation Norway, another of the organisations that had been involved in both the EGV and the Algae Project. This would become the last interview of the data collection period. I figured I had more than enough to chew on.

Throughout this data collection period, not all the accounts I gathered seemed to overlap. At some points, they were even contradictory and conflicting. Moreover, all the informants appeared to be experienced and skilled speakers with a clear agenda. Rather than opposing this agenda (and making myself unpopular), I tried confronting the informants with each other's arguments. In this way, I was able to create a controlled "discussion" where different views would be confronted, thus gaining insight into whether and how different informants' views differed and coincided.

Most of the interviews were recorded and transcribed. If I had doubts or felt uncertain about the details of the conversation, I simply phoned or sent an email to the informants asking for corrections. I believe a flexible research approach like this reduces the risk of misunderstandings and makes a more honest argument in the end.

Throughout the research period, I also conducted a handful of structured interviews, either carried out by phone or in person, with people external to Finnfjord but sufficiently involved to be able to contribute with meaningful insight. The questions in these interviews revolved around Finnfjord's environmental ambitions and the concrete measures that had been taken. During these interviews, I tried to keep my own participation to a minimum, in order not to probe the informants to give certain answers.

Finally, I used the media analysis tool Retriever to look up news articles about Finnfjord from the last 50 years. While my informants naturally wanted to talk mostly about the current projects at the factory and elsewhere, previous media campaigns witness about the many initiatives that never developed into actual realisation. Using media analysis makes it more natural to see current affairs at Finnfjord as a part of the trial-and-failure strategies of the past, and to trace the "dead ends" that the company inevitably had to face in their strive towards carbon-neutral production.

2.3.4 The Researcher is an Actor

Within social sciences, it is common to describe the researcher as a "measuring instrument", and then strive for "reflexivity" in order to approach a sense of objectiveness.[16] Within ANT studies, the researcher is herself understood to be an actor and thus a *co-creator* of the material from where arguments are drawn. Rather than trying to account for the shortcomings of the researcher as an instrument, it is seen as important to *situate* the knowledge produced (Haraway 1991). Therefore, it is important to say a few words about my own perspective on the case of Finnfjord.

First, I grew up in the vicinity, and have friends who have worked at the factory. I recognise its importance as a cornerstone workplace in the area, and through working closely with the Tromsø 2018 team (see Chapter 3) I have also been aware of the environmental programme of Finnfjord since its inception. My personal linkages to Finnfjord, and being a familiar face to most people in the region are factors that undoubtedly have influenced my access to sources and informants throughout the research period. I usually travel with the guitar on my back, and often find myself performing a song or two whether it has been asked for or not. Both in the Algae meeting and in the Enova conference, I was asked to perform as part of the official programme. Through these performances, I got in touch with people who would otherwise be difficult to access. I have generally been met with friendliness and curiosity. Another researcher without my background, profession and personal network would probably have faced significant challenges in getting through to many of the informants in this study.

I also come from an environmental activist background, and have previously been (loudly) sceptical towards polluting industries. Most people probably consider me a radical. Throughout the research period, many of the interviewees confronted me with my own media statements from the past. It is not unthinkable that this may have limited my own access to certain areas, and may also explain the long initial reaction time from the company.

Finally, it should be acknowledged that I did embark on this thesis as an optimist, hoping that the environmental technology developed at Finnfjord might hold

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[16] "The reflexive researcher thinks through his or her own assumptions and how they affect the research project" (Kezar 2003, 401).

some of the potential it promises. Before deciding the research topic or question, Finnfjord's technological development had already impressed me enough to make me want to write this thesis. Personally, I hoped that the development at Finnfjord could contribute to a greener future. To say it with Knut Sørensen's words: "When technology is seen as sublime with respect to the society of the future, it would be nice to be hopeful that the embedding happens in ways that increase the probability that the assumed sublime qualities are realised" (2013, 20).

I have anonymised most of the informants except the Finnfjord CEO. Admittedly, people who are familiar with Finnfjord or their projects may still be able to identify certain informants. However, none of the informants expressed a wish to be anonymous (this was explicitly asked for in all interviews), and I have chosen not to go further in removing personal details.

Through this research project, I have gained insight into processes and facts that are considered industry secrets, and thus should not be made available in this thesis or elsewhere. I have strived to attain clarity about what is considered insensitive information and what is considered inside information, especially with regards to the Algae Project which I was asked to "tone down". To my knowledge, this paper contains no sensitive information.

2.3.5 Informants

Method	Organisation	Representative	Key questions
Semi-structured interviews (2 hrs)	**Finnfjord**	CEO Project manager. Former policy manager	**Key questions**: What was the rationale for investing in energy recovery? Which risks were involved? How did external actors contribute? What distinguishes this project from other energy-efficiency measures? Is the technology transferrable to other actors? What is the rationale behind the Algae Project? How do you envision the coming development of the Algae Project? What barriers and opportunities are the most important to the project?
	Enova	Senior consultant.	
	The Arctic University (UiT)	Professor/dean.	
Structured interviews (1/2 hrs)	**Enova**	Support scheme director.	**Key questions**: What is your impression of the current projects at Finnfjord? What are the environmental benefits of these projects? Is there a demand for the products that Finnfjord are currently developing? How do the projects at Finnfjord influence other actors of the same kind?
	Innovation Norway	Regional director.	
	Troms County	Executive councillor of regional development. Environmental project manager.	
	Nature and Youth (NU)	Local division leader.	
	Lenvik municipality	Administrative manager.	
Unstructured interviews	**Finnfjord**	Consultant. Health, safety and environment manager Project engineer.	
	Friends of the Earth Norway	Consultant.	
	Bellona	Consultant.	
	Political party representatives	SV, SP, AP	
	University of Tromsø	Lab researchers	
	Tromsø 2018	Former business coordinator	

3. A Vision is Born

How did Finnfjord's environmental vision come about? In this chapter, I present some of the events leading Finnfjord's adoption of the vision to become the world's first carbon-neutral smelting plant. The chapter describes the circumstances under which the vision was conceived. I pay special attention to the material and socio-political settings of and around the factory, and highlight some of the early attempts to address the carbon-neutral vision. Perhaps surprisingly, it was a Winter Olympics campaign which turned Finnfjord's vague ambitions of "leaning forward" into a concrete vision of becoming carbon-neutral.

3.1 Background: Ferroalloys – from Sunset to Solution?

Consisting of only a handful of factories, the Norwegian ferroalloy industry employs around 2 500 people and exports products for NOK 18,5 billion yearly.[17] Products from the ferroalloy industry end up in everything from buildings, cars, mobile phones and computers to cosmetics, solar panels, weapons, windmills and pharmaceuticals.

Operating in a global metal market with high competition from strong international players, the Norwegian ferroalloy industry has shown an impressive persistence through a turbulent decade. Wicken (2011) attributes this to the high level of competence within the industry, and the steady refinement of production processes, combined with a high readiness to adapt to suit market demand (Hanson 2011). At the same time, the commercialisation and internationalisation of the Norwegian power system has put pressure on the energy-intensive industries to rationalise their power usage (Wicken, Hanson and Kasa 2011).

This leaves ferroalloys in an interesting position. On the one hand, the production techniques found within the industry are closely associated with both largescale consumption of electrical energy, and CO_2 emissions. On the other, however,

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[17] Finnfjord (FeSi), Elkem Salten (Si), Glencore Manganese (FeMn), Eramet Kvinesdal (SiMn), Elkem Thamshavn (Si), Wacker Holla (Si), Elkem Bjølvefossen (FeSi), Fesil Rana (FeSi), TiZir (TiO_2), Eramet Sauda (FeMn) and Elkem Bremanger (Si / FeSi). Numbers from 2013, presented in the interview with the former policy manager of Finnfjord, now working in another major metal producer, the aluminium giant Alcoa.

there is an increasing global demand for the industry's products. The Norwegian ferroalloy producers can be said to have an advantage to international competitors, since most of its electricity stems from renewable hydropower. It is also a common argument that since Norwegian producers are "green" in comparison to ferroalloys from other nations, it is beneficial to the environment to produce *more* and thereby squeeze out less efficient competitors from the global market:

> The need for steel is increasing, because the world population is still increasing (…) and we cannot deny people not to be poor anymore. The solution is that we must produce more, but with smaller emissions [per unit] (Finnfjord CEO, interview 02.10.15).

In the last decade, there has been a growing attention within the ferroalloy industry to improve production methods while at the same time reducing their environmental impact (Gasik 2013). However, most of the Norwegian process industries are based on old technologies that have matured and improved significantly since their introduction. According to a SINTEF report

> CO_2 emissions [within the industry] are approaching a theoretical minimum level. Without the completely new processes for the production of ferroalloys, there is a very small potential for further reductions per unit produced (SINTEF 2009).

In the same report, the majority of the businesses *themselves* signalled that it would be difficult to reduce emissions by 20 per cent within 2020 – or even by 2050, without reducing production correspondingly. This has lead researchers to suggest that the industry's problems "cannot be solved through incremental changes and innovations. (…) Only completely new processes and raw materials can lead to reduced emissions on a large scale" (Wicken 2011, 225).

Within the same period however, the industry's *image* has undergone a complete makeover. In a recent dissertation about the industry's public profile, long-standing industry consultant in Nordland county Trine Fredriksen writes that "those who work closely with the industry have seen a marked change in the public image of the industry and the attention that it has received only in the last 2 to 3 years" (Fredriksen 2015, 62).[18] From being considered a "sunset industry", stuck in outdated and polluting production forms, Norwegian metal producers are being met with greater positivity and goodwill in both media and political arenas. This change of attitude has also been observed at Finnfjord:

> The industry today has gone from being a problem child, to becoming the solution to a future problem. When I started here [at Finnfjord] ten, twelve years ago, the general mood was that Norwegian industry was something of the past (Finnfjord CEO, interview 03.10.15).

Today, Finnfjord is not alone in having ambitious climate targets for their company. The influential Elkem consortium has adopted a similar-sounding vision to that of Finnfjord, pledging to become carbon-neutral before year 2050.[19] But while the ambitions might sound similar, the different ferroalloy producers have pursued their visions in very different ways:

- **Industrial Ecosystem**: The silicon smelter Fesil and the manganese producer Glencore in Mo i Rana provide district heating and process heat in what they call an "industrial ecosystem" in close integration with other nearby industrial manufacturers and fish farms. A quarter of the excess heat from Fesil's furnaces is reused within this industry cluster (Fesil 2016).

- **Organic Reduction Agent**: The Elkem consortium are currently promoting a project – Carbon Neutral Metal Production – to replace all fossil coal with biogenic charcoal from Scandinavian forests.[20] As of February 2017, it has not yet been decided whether to take the project further than lab-scale testing.[21]

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[18] In 2002, the minister of labour and social inclusion Victor Normann referred to Norwegian aluminium industry as a sunset industry, and stated that "we do not create new businesses by drizzling money over needy companies" (Bergens Tidende 20.11.02). As late as in 2011, economic commentator Per Valebrokk wrote that "Elkem will disappear anyway. (…) Sooner or later they will be closed down and moved to Asia" (E24 11.01.11).

[19] Others have visions that might appear less ambitious – at least at first glance. Eramet commit to "best practice and technology" (Eramet 2016), while Fesil had adopted a goal to "perform with a lowest possible strain on health and environment by efficient operation throughout the value chain" (Fesil 2016).

[20] CNMP will in reality consist of three interconnected parts: A pyrolysis plant for the production of biogenic charcoal, a smelting furnace for the production of (ferro)silicon, and an energy recovery unit similar to that in Finnfjord. In my interview with Finnfjord CEO Geir-Henning Wintervoll, the possibility to use biogenic coal was more or less rejected. "We don't have that much forests here. If we used

- **Energy Recovery**: The Elkem factory at Salten has been granted support from Enova to invest in an energy recovery system similar to that of Finnfjord, but have not decided on whether to invest yet.

- **Hydrogen Reduction**: The titanium oxide producer TiZir in Tyssedal have been granted NOK 122 million to research using hydrogen as reduction agent rather than coal. If successful, they have proposed that they can reduce CO_2 emissions by 90 per cent and energy consumption by 60 per cent.

- **Algae Production**: As we have seen, Finnfjord are working on a possible solution to feel excess CO_2 to algae, which, in turn, produce natural oils that can be used for many products.

However, despite the collective effort to reduce the industry's environmental impact, ferroalloys remain among the most polluting industry in Norway. The total emissions from the 11 factories remain on the same level as on the turn of the millennium, only interrupted by the decline of production in relation to the 2009 financial crisis (see figure 2). Within the same period, the total electricity consumption of the ferroalloy business has remained fairly stable (see figure 3). It was within this context that Finnfjord decided to venture to become the world's first carbon-neutral smelting plant in 2007.

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charcoal, we would have to chop down the whole Northern Norway within the first year. You need an unbelievable amount of wood to make it work" (interview 03.10.16). In spite of this, Finnfjord also do experiment with different amounts and types of charcoal in their furnaces, as it has proved beneficial to the smelting process when combined with fossil coal. Currently, around one tenth of the reduction charge consists of organic material.

[21] It should be noted that the abovementioned SINTEF report considers it technically unattainable to reduce the amount of fossil coal in the ferrosilicon and silicon production processes to below 20 per cent (SINTEF 2009).

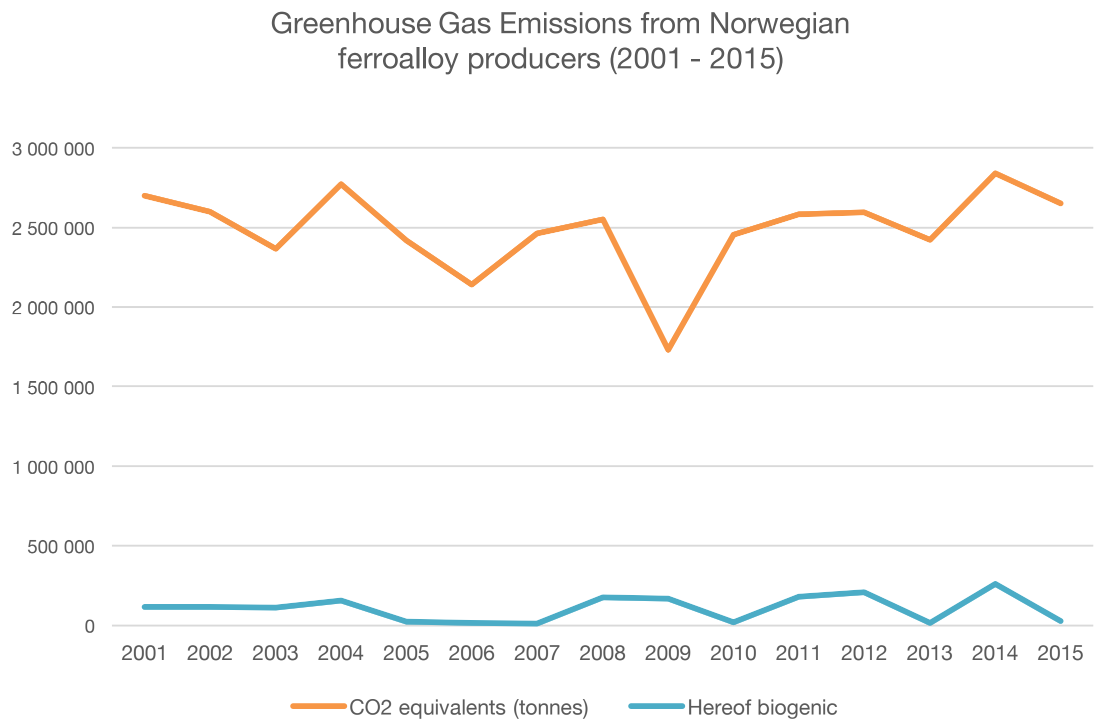

Figure 2: *Greenhouse gas emissions (CO_2 equivalents) from Norwegian ferroalloy producers in the period 2001 to 2015 (Miljødirektoratet 2016).*

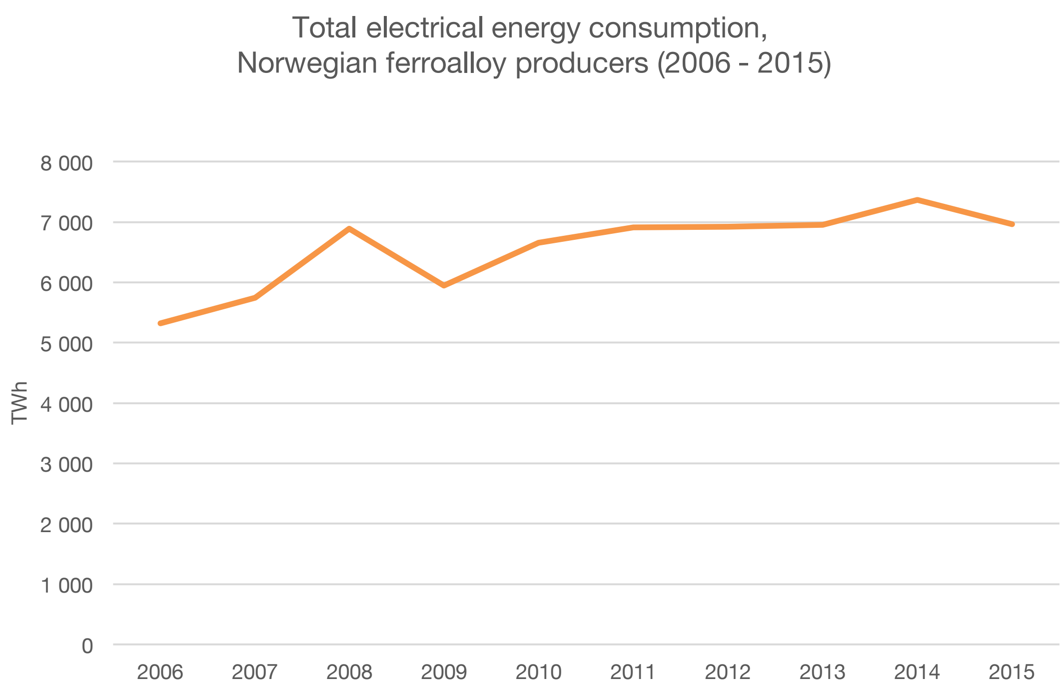

Figure 3: *Total electrical energy usage within the Norwegian ferroalloy industry. The publicly available data do not account for recycled or traded power, which means that the real electricity usage probably has been more stable than the graph implies. For unreported years, values have been extrapolated from means (Miljødirektoratet 2016).*

3.2 Ferrosilicon Production

The core business of Finnfjord is the production of ferrosilicon. The main use for ferrosilicon is within steelmaking, where it is a necessary ingredient both for steel production and steel recycling. Not a single steel type is produced without the use of ferroalloys (Wood and Owen 2005), and about 85 to 90 per cent of all ferroalloys are used in steelmaking (Gasik and Lyakishev 2005).

Ferrosilicon (FeSi) is an alloy made by mixing molten iron (Fe) with silicon (Si). To do this, the raw materials iron ore (Fe_2O_3) and quartz (SiO_2) are brought together with coal and coke (C) in a smelting furnace, where electricity is used to heat the charge up to almost 2000°C. At this temperature, the carbon (C) pulls out the oxygen from the raw materials, making it possible to mix pure iron and silicon – ferrosilicon – together in the next step.[22]

$$Fe_2O_3 + SiO_2 + C \rightarrow FeSi + CO_2$$

The main by-product from the ferrosilicon process is carbon dioxide (CO_2) which is released as smoke through the factory chimneys.[23] For every kilo of ferrosilicon produced, Finnfjord emits around 3 kg of CO_2.[24] These direct emissions amount to approximately 300 000 tonnes of CO_2 every year (Miljødirektoratet 2016).

Finnfjord's carbon footprint can be divided in three aspects[25] of the production process:

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[22] The explanation above is simplified to the very basics of metal reduction, an essential part of ferroalloy production. In reality, the smelting process is carried out stepwise and at different temperatures, and with additional ingredients to stabilise and optimise the reaction. For a thorough introduction to ferroalloy production, see Gasik (2013).

[23] Another by-product is silica dust – pulverised SiO_2 (also called microsilica) – which was previously considered to be a waste product and a major problem for the local environment. For a long time, the silica dust was released directly into the air, visible as black, heavy smoke. Today it is an important commodity, as it has proven useful for reinforcing concrete. For instance, the Petronas Twin Towers in Kuala Lumpur, which were the tallest buildings in the world until 2004, were built by the use of 4 800 tonnes of silica dust from Finnfjord. In addition to the 100 000 tonnes of the main product ferrosilicon, Finnfjord produce around 20 000 tonnes of silica dust every year.

[24] This is only true for Finnfjord, who produce ferrosilicon with a silicon grade of 75 per cent and around 22-23 per cent iron. Other factories produce ferroalloys of other purities. The CO_2 emissions per tonne produced will vary with the amount of reduction agent (coal) needed.

[25] A potentially fourth and final group of emissions can be said to come further "down the pipe", as Finnfjord's products are used for production of steel, concrete and other industrial products on the global

- **Raw materials**: Emissions from extraction and transport of raw materials (coal, coke, iron and quartz). Eikeland et al. (2001) have estimated that these activities account for roughly 25 per cent of total CO_2 emissions within Norwegian ferrosilicon production, although the actual number varies greatly with type, source, distance, means of transportation etc.

- **Electricity**: Emissions related to the production of electrical energy needed for the smelting process, often referred to as indirect, simultaneous emissions. This is a significant source of emissions in countries where production is based on coal or other fossil energy sources. Since Norwegian industry runs largely on hydropower, the indirect emissions are usually argued to be small.[26] According to a study by Schei et al. (1998), coal-powered ferrosilicon production emits three times as much CO_2 as hydro-powered production. In other words, the source of electrical power is important to determine the carbon footprint of the smelting process.

- **Direct emissions**: Most important however are the *direct* emissions from the production, which at Finnfjord make out roughly 75 per cent of total emissions (assuming that the indirect emissions from electricity production are negligible), or annually around 300 000 tonnes of $CO_{2.}$ These emissions stem from the chemical reaction described above, where coal (C) reacts with the oxygen (O) in the raw materials and forms CO_2 which is released directly into the atmosphere as off-gases.

After the ferrosilicon has been produced, large amounts of waste heat must be dealt with. Some of the heat is managed by pumping fresh sea water into the system, cooling the vulnerable parts of the machinery and then letting the hot water back into the sea.

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market, associated with significant global emissions. In this sense, ferrosilicon can be said to contain "future embedded emissions". However, most emission estimation models do not hold a producer accountable for this category of emissions (see e.g. Ranganathan et al. 2004).

[26] This connects to another debate, about the connection of the Norwegian power grid to that of the EU, a discussion which we for matters of space will not be able to deal extensively with here (see section 6.5).

However, this only deals with around 8 per cent of the heat (see figure 4 below). A much larger proportion is emitted as hot smoke through the factory chimneys. The relative energy flow of ferrosilicon production can be visualised as in the figure below.

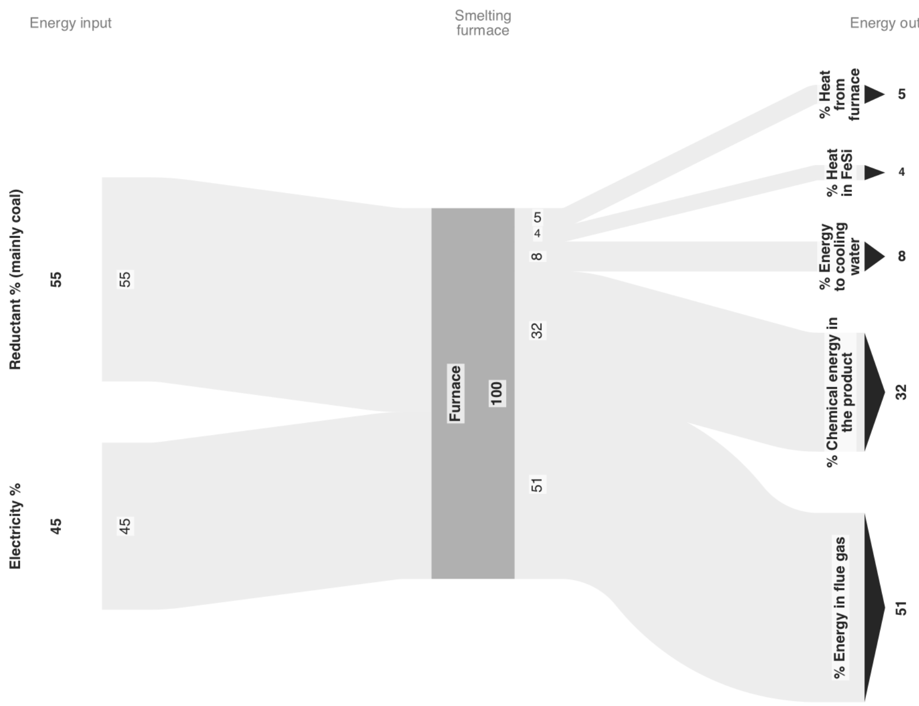

Figure 4: *Sankey energy flow diagram, an example of the ferrosilicon process (exact numbers will vary with equipment type, size of furnace, mix of reducing agents etc.). Approximately half of the energy that goes into the process is released as heat in the off-gases (bottom right arrow). Source: ER>ER (2013) and Finnfjord (2016).*

As shown in the figure, ferrosilicon production is inextricably linked with the consumption of electrical energy – no other energy carrier is technically capable of producing high enough temperatures for the metals to react.[27] Finnfjord estimates a yearly usage of 950 GWh, roughly amounting to fifty thousand Norwegian private households, or around 0,7 per cent of the entire hydropower production in Norway.[28]

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[27] Ferrosilicon with a silicon content up to 15 per cent may be produced in blast furnaces lined with acid fire bricks. Ferrosilicon with a higher silicon content must however be produced in electric arc furnaces (Gasik 2013).

[28] Approximately 130 TWh each year. Enova estimates 20 000 kWh for an average Norwegian household.

The remaining heat required for the metals to react, approximately 1050 GWh yearly, is added through the combustion of the coal which serves as reduction agent. Therefore, the heat waste though the factory chimneys (bottom right arrow on the figure) is often *higher* than the electrical energy added. In other words, while the energy consumption in the ferrosilicon process is indeed large, there is also a notable saving potential if one is able to make use of the unutilised waste heat.[29]

The production process at Finnfjord is highly automated. Heavy machinery performs most day-to-day tasks in tandem with advanced computers and electronic monitoring systems. Most physically hard labour is abolished. The high level of automation requires the workforce to be both knowledgeable about the technology at the plant and skilled with machinery in general. Out of the 125 employees on the factory, 20 have engineer (bachelor) or civil engineer (masters) background, while another 70 qualify as skilled workers through either lower-level education, apprenticeship certificate, or both.[30]

Socially, the distance from the management to the factory floor is argued to be short, and compared to similar industry in other countries, the level of surveillance and supervision is presented as low. The CEO of the factory has a civil engineer background, and is frequently present on the production site (in fact, he lives with his family in the house next door with direct view of the factory from his kitchen window). These factors together, it is argued, makes it possible to produce ferrosilicon with a smaller staff than in similar factories in other countries:

> It is a myth that high wages make us uncompetitive in the global economy. Where Finnfjord employ a hundred, a Chinese ferrosilicon plant would have a thousand people working. That is because the high wages in Norway have forced though robotisation and the development of completely new technology. After all, we have operators, not wheelbarrow drivers (Finnfjord policy manager, interview 05.12.15).

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[29] For a well-written and popularised description of ferrosilicon production and waste heat recovery potential, I recommend Finnfjord's own "Best Practice Framework" presented to the EU Commission after the EGV Project had been completed (see ER>ER 2013).

[30] These numbers are in line with the Norwegian metal sector as a whole (Reve and Sasson 2012, 282). Compared to the rest of the private sector, however, the 14 per cent of the employees with a university degree is far from the national average, which is around 30 per cent (ibid.).

The ferrosilicon production at Finnfjord is highly capital intensive in the sense that it relies on expensive machinery and a skilled workforce. Any disruption of the ferrosilicon production is critical. The two largest furnaces produce ferrosilicon continuously, 24 hours a day. Any halt of production takes days of cooling and re-heating. Simple maintenance tasks can be both costly and time-consuming. It is also a resource-intensive manufacture, in that raw materials (and electrical power) in large amounts are required in order for production to be cost-effective.

The economic situation of the ferroalloy industry has historically been both unstable and unpredictable. Large producers like China and Russia have at times flooded the market with cheap products, making it difficult for producers in less subsidised countries to follow suit. Moreover, the demand for ferrosilicon is closely tied to the demand for steel, which in turn is strongly correlated with global economic growth.

The dependence on electrical energy makes ferrosilicon producers exposed to national energy politics. Whereas the raw materials for production – coal, coke, iron and quartz – are acquired on the international market and thus equally priced to most competing producers globally, electricity prices are nation-specific and can therefore represent the difference between a competitive industry and not. For Finnfjord, electricity is the greatest single production factor, accounting for almost 40 per cent of production costs. Therefore, the company is reliant on a long-term electricity delivery deal with state-owned energy supplier Statkraft. Through this deal, Finnfjord enjoys electricity at below market prices. Nonetheless, it is still vulnerable to price fluctuations.

3.3 The History of Finnfjord

The history of Finnfjord stretches back to July 1953. This was the summer when representatives from the Troms and Nordland regions in Northern Norway decided to construct the Innset power plant, making use of the 185 metres high waterfall between Altevatnet and Innsetvatnet in Bardu, Troms. The decision marked a historic shift within regional power policies, as it was an explicit move away from smaller, local power stations, towards the national practice of large-scale hydropower dams that would provide entire regions with electricity. When construction of the Innset was completed in 1960, it produced a large power surplus within Troms.

Within the same period, the Norwegian government was exploring the possibility of establishing energy-demanding industry in the area to make use of the unused power. They quickly turned towards the metal smelting industry. Initially however, none of the established Norwegian metal producers were interested in taking the risk. When prime minister Einar Gerhardsen threatened to pass the concession on to German interests, six Norwegian companies went together to form Fesil-Nord in Finnfjord, Troms.[31] The factory was officially opened on 15th March 1962, with a total of 132 workers manning the two smelting furnaces. The factory had a turbulent start-up, and after only ten months in operation it was decided to temporarily close one of the two furnaces and fire 40 employees at the plant. Soon after, however, the whole factory was up and running again, and saw a third furnace added to the plant on its ten-year anniversary in 1972.

As a "stepchild" of the six producers, the plant in Finnfjord received less attention than the main factories. During a period of low ferrosilicon prices, it was decided to shut down Fesil-Nord in 1982. However, two colleagues at the plant, Geir Wintervoll and Helge Gørrisen, were allowed to rent the plant for a year. Running the factory with a smaller crew and less expenses, they gathered enough capital to buy Fesil-Nord after a year, and re-established it as an independent company named Finnfjord.

Since then, Finnfjord has remained in the hands of the Wintervoll family, making it the only privately owned ferroalloy plant in Norway today. Since the start-up in 1962, the production capacity has increased from 12 000 to 100 000 tonnes ferrosilicon yearly, which makes Finnfjord one of the ten largest ferrosilicon factories in the world. In the same period, the number of workers at the plant has remained comparably stable, between 80 and 130 employees. In 2014, the turnover at Finnfjord was around 800 million NOK. Today, Finnfjord claim to supply between 10 and 15 per cent of the ferrosilicon consumed in Europe.

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[31] K/S A/S Fesil-Nord was a joint venture between AS Bjølvefoss, Christiania Spigerverk, Elektrokjemi AS, AS Hafslund, Porsgrunn Elektrometallurgi and Tinfos Jernverk.

3.4 Local Pollution and Conflicts

With more than a hundred employees and its economically dominant position in the region, Finnfjord has always been considered a cornerstone industry. Historically however, its position within the local community has also been marked by hostility and opposition. For the three first decades in operation, the plant was closed to visitors and media, and garnered a lot of displeasure from the local community for the thick smoke rising from its tall chimneys. In addition to large quantities of silica dust – which can cause lung diseases and respiratory problems – the plant poured out up to 16 000 kg of sulphur dioxide (SO_2) every day. The hazards of the factory emissions lead to vigorous protests both locally and nationally. In a heated outcry in 1972, a local activist from Friends of the Earth Norway wrote that the factory

> has made the community think expansive and industrial, think about economic growth while smoke from the furnaces lays an impenetrable, suffocating carpet over homes and dying fishing boats. [They] talk about regional development while contaminated air turns pink baby lungs into black, sponge-like remnants (Naturvernforbundet 1972, 48).

These protests have had direct consequences for Finnfjord. More than once, the company's expansion plans have been halted by local discontent. In 1973, a public campaign spearheaded by the local newspaper convinced the local municipality to vote against the establishment of a coke production factory at Finnfjord, although environmental experts agreed that it would have no negative ecological impact (VG, 17.01.73). The hostility was sometimes reciprocated. In 1978, the former Norwegian prime minister and Labour Party leader Trygve Bratteli was denied entry to the factory grounds because he "represented political interests" (VG, 30.09.78).

The 1977 instalment and 1985 upgrading of a "baghouse" to filter out most of the silica dust removed some of the visible emissions from the pipes, and reduced the problem of industrial soot covering local residents' clothes and linens whenever the local winds were unfavourable. The filtering also provided Finnfjord with a by-product, silica dust, which would prove a valuable commodity in the years to come. However, the NO_x and SO_2 problems remained. The factory continued to be in the spotlight for national environmentalist groups, who took to litmus testing the acidity of the snow around the site as well as videotaping the smoke rising from the factory whenever technical problems occurred to the soot filter.

Finnfjord's relationship to the local media has been a contentious issue since the start-up in 1962. In 1989, the factory owners Wintervoll and Gørrisen acquired the majority of the shares of the local newspaper. This led to both protests and ridicule, and people questioned how the paper could be expected to report neutrally on Finnfjord's issues any more. The editor-in-chief withdrew from the newspaper just a few days after.

Throughout the nineties, the friction with the local community subsided, as pollution levels went down and the factory opened up for neighbours and local politicians. Investments in new equipment and purification technology meant that Finnfjord could control their emissions more. During the following decade, the factory reached pollution levels that according to Norwegian Pollution Control Authority (SFT) were not only acceptable, but "surprisingly good" (Nordlys 17.01.97). As late as 2007, an article in the local newspaper portrayed the company as "an environmental sinner" with regards to its CO_2 emissions (Folkebladet 22.02.07), but by and large, throughout the new millennium, most local protests against the smelting plant had abated.

3.5 Power Crisis and Climate Crisis

Besides the aforementioned closing down of Fesil-Nord in 1982, the factory in Finnfjord has experienced financial hardships a number of times. In 1991, China and the Soviet Union dumped cheap ferrosilicon onto the world market, and the factory in Finnfjord was close to bankruptcy – it would probably not have survived without goodwill from its local bank and financial partners. In 2001, the entire plant was brought to a standstill for two months because of plummeting steel prices after the 9/11 attacks.

The ferroalloy market is highly competitive, and connected to other global economic indicators in complex ways. Moreover, international ferrosilicon prices depend on the highly cyclical nature of the steel market:

> It's a cyclical business, so times are always bad. Or, more precisely, every 20 years there are bad times. That's how it works. (Finnfjord CEO, interview 02.10.15)

A cyclical nature does not however mean that it is a *predictable* business. In 2006, the Finnfjord board decided to put a halt to all production for an entire 18 months because of soaring electricity prices in Norway. During this period, it was considered more profitable to simply sell its state-subsidised electrical power, exploiting the company's access to electricity rather than using it to produce ferrosilicon. The factory workers were sent home on paid leave, while the ovens lay cold.

Adding to the difficult market situation in 2006, electricity was expected to become even more expensive. The deal with Statkraft was set to terminate in 2011, and a renewed and equally beneficial electricity contract seemed implausible. By the beginning of 2007, 80 out of 110 employees at Finnfjord were without a day job, and many were, perhaps righteously, pessimistic about the future of the company. Although production in the three smelting furnaces was resumed in 2007 when ferrosilicon prices returned to a profitable level, a sense of urgency remained in the offices of Finnfjord.

At the same time, climate change had risen to the top of the international agenda. Since the introduction of the Kyoto protocol, the factory had increased its production capacity significantly, and the emissions had *doubled*. From emitting 150 000 tonnes CO_2 equivalents in 1991, the number had risen to 300 000 in 2008. This corresponded to almost a third of all carbon emissions in the Troms county, and rendered the factory the 14th largest point source emitter on Norwegian mainland (Nilsen 2011). With the intensifying debate about carbon emissions and climate change, Finnfjord faced yet another challenge in an already difficult situation.

3.6 Leaning Forward

During the first decade of the new millennium, the leadership of Finnfjord was changing, as control was passed on to a new generation. Geir-Henning, the third Wintervoll in line, was appointed plant manager and thereafter CEO of the company. His entry into Finnfjord was by many of my informants described as a turning point for the factory. He was "young, well-educated, and understood that we had to *lean forwards* to gain results", "a modern leader, open and searching, always up to date and always on the phone" and "a visionary, a community builder" (quotes from interviews).

The younger Wintervoll offered a proactive view of business management, urging to lead the company's own development work rather than waiting for new crises to build up and then trying to fend them off, as he claimed had been the strategy in the past. "He reacted with anger against everything that could be regarded as complaining, (…) and rather looked for possibilities within the current conditions. He always asked "How can *we* adjust so that we can survive and even make something positive out of it?" In many ways, that was what made us [at Finnfjord] take up a more *forward-leaning* attitude" (Finnfjord policy manager, interview 05.12.15).

The new CEO proposed that the company, rather than focusing only on its core business of metal production, needed to look around for opportunities to create values in other ways.

> [Before Finnfjord] I worked at Procter & Gamble and was in charge of marketing baby nappies and menstrual pads in the Nordic countries. Then I came to Finnfjord to produce ferrosilicon! The irony is that the two have a lot in common. (…) You have to be curious and interested in what goes on around you. (…) You have to be open to new solutions, you have to look for them (Finnfjord CEO, interview 02.10.15).

With this new philosophy of "leaning forward", Finnfjord wanted to make itself attractive both to the political sphere and to other business initiatives in the region. Not long after Wintervoll took charge of the factory, external collaborations would in large part be what propelled the development of the factory forward.

3.7 Lighting the Olympic Flame

At the same time as Finnfjord's ovens were standing cold due to the electricity crisis, a slightly more optimistic spirit reigned a few miles north, where the city of Tromsø were preparing a proposal to become host for the 2018 Winter Olympics. Having proposed the greenest and most environmental-friendly Olympics of all time, the organisation behind the initiative – Tromsø 2018 – were now searching for potential business partners in the region. Finnfjord was one of the first companies that they got in contact with. According to the business coordinator of Tromsø 2018, the timing of the collaboration suited well with the situation at Finnfjord.

> We wanted clean energy for the Olympic games, and I knew that Finnfjord had plans and a lot of power to sell. It was very easy to get them on board. However, they told us that the national framework [for green energy] was poor. We said we would fix that. [As business coordinator] I wanted to use the Olympics as a means towards that end (Tromsø 2018 business coordinator, interview 08.03.16)

Tromsø withdrew as a Winter Olympics candidate shortly after the collaboration with Finnfjord was initiated, but their business coordinator was soon hired as a consultant at Finnfjord, with the task of following up on the Olympic vision. According to

Finnfjord's policy manager, the initiative from the Tromsø 2018 team was the spark that triggered the environmental ambitions of the company:

> [CEO] Geir-Henning was ambitious and spoke about "leaning forward", but then came a lot of mumbling about technical details and kilowatts and things that people just forget. (…) And then we said "If we are going to be a "lighthouse", we need to have a story to tell!" (…) Through the Olympics, we got something concrete to aim for (Finnfjord policy manager, interview 05.12.16).

Later that year, Finnfjord's new vision was formalised by the board of directors: They would aim to become the world's first carbon-neutral smelting plant. A working group was appointed to map out different pathways towards reaching the new goal.

3.8 …with Coal?

The first concrete project under the Olympic banner was launched only a few weeks later. It was in fact an old project, but had now been rewrapped as a "green" initiative. As a joint venture with two other companies, Finnfjord would build a modern and efficient coal-fired power station, complete with carbon capture and storage (CCS) technology. This would be "hitting two birds with one stone": carbon capture and energy production at once. This idea had in fact been proposed before, as an initiative for more predictable energy prices for Norwegian industries (Aftenposten 18.01.07). Now however, it was being re-launched as an environmental measure, with CCS development as the main argument (Nordlys 13.10.07).

The following media campaign called attention to the fact that on a world basis, a new coal-fired power plant was being built every week, but with no CCS in mind. "If we succeed with this project, we will have built the world's first CO_2-neutral ferrosilicon plant" said the general secretary of the Centre Party enthusiastically after a visit to Finnfjord where he was introduced to the project (Nordlys 13.10.07). The strategy of building a coal power plant served as Finnfjord's first concrete *plan* to become CO_2-neutral. The company announced that they were aiming to have the coal plant operative by 2013.

The coal power strategy was short-lived due to a lack of regional CCS infrastructure and a general political reluctance to coal power as a climate initiative. But despite mothballing this first initiative, Finnfjord did not give up on its vision. Shortly after, they approached the Norwegian Energy Fund (Enova) to map the possibilities to increase *energy efficiency* as a way to pursue their environmental ambitions. Within this same period, The Arctic University (UiT) approached Finnfjord with a proposal to explore the opportunity of using marine algae to deal with the company's CO_2 emissions.

Although the coal power project was never realised, it served as an important step in creating the early message of Finnfjord's environmental vision, and in presenting their ambitions to potential supporters and collaboration partners. It also signalled that the "Olympic vision" was not just a moment of short-lived inspiration at Finnfjord's boardroom, but a platform that would direct the company's development ahead. Although it would take many years before the vision would materialise in a concrete project, the early message about Finnfjord's new strategy caused enthusiasm among potential collaborators, and "opened up" Finnfjord to actors that had previously had little interest in the factory:

> It was the [Arctic] *University* to came to *us*, probably because we had announced that we wanted to become the world's first CO_2-free smelting plant, and because we had a lot of CO_2 (Finnfjord CEO, interview 02.10.15).

In this way, the announcement of the carbon-neutral vision was the company's first step to re-establish themselves as environmentally conscious and future-oriented business, a position which would be crucial for Finnfjord to maintain in the years to come.

3.9 Conclusion

In this chapter, we have seen how Finnfjord's vision emerged as a result of many interlinked people, places and events: a highly carbon- and energy-intensive production form; a steady expansion of production capacity throughout the century; the energy crisis and simultaneous climate crisis of 2006; change of management and the adoption of a "leaning forward" philosophy, and finally; the dream of Winter Olympics lighting the fire of Finnfjord's carbon-neutral vision. The first attempt to address this vision was the launch of the CCS project which would secure Finnfjord access to cheap energy while at the same time providing a site for the development of novel, CO_2-related technology. The project was eventually abandoned, but signalled the emergence of a "new" Finnfjord where collaboration partners were welcome, where environment was a key term, and where the management were not afraid of ambitious projects. Soon after, a network was starting to take shape around Finnfjord's environmental vision.

4. The Energy Recovery Project

How did the Energy Recovery Project take shape? In this chapter, I give an account of Finnfjord's installation of a large steam turbine with the potential of recycling up to 340 GWh of electrical energy yearly. I describe the project as a process of assemblage, involving the coming together of a heterogeneous web of actors: people and companies, knowledge and processes, visions and realities, steel and steam, politicians, media and bureaucrats. I also address some of the many "dead ends" that this process has led to, highlighting that the final outcome of the project was by no means given on beforehand. I argue that the project changed significantly from its conception to its completion, while at the same time changing Finnfjord's own rationale for committing to it.

The chapter begins with Finnfjord's turn towards energy efficiency as their main strategy in pursuit of the company's carbon-neutral vision, and describes the processes leading to the emergence of the EGV Project. The main part of the chapter deals with the execution of the project, and the changes that it underwent throughout the process of implementing the technology. I also give an account of the current status of the energy recovery system, which still experiences "growing pains" in the meeting with the day-to-day production of ferrosilicon. Finally, I address at the connections between the EGV Project and the company's carbon-neutral vision, and the assumptions on which such a connection may rest.

4.1 From CCS to Energy Efficiency

After giving up on the coal project, Finnfjord's working group turned their focus towards the possibility of making production more *energy-efficient*, aiming to reduce the factory's *indirect emissions*. One of the ways to achieve this was through making use of the large amounts of heat wasted in the production process. As we have seen, around half of the energy produced within the smelting furnaces was being released into the air as hot smoke. Finding alternative usages for this energy soon became Finnfjord's main strategy to establish a greener production chain.

The "leaning forward" philosophy combined with the this new energy efficiency strategy made Finnfjord rephrase their vision, or at least add another sub-vision to the original one: They wanted to become the world's most energy-efficient smelting plant.[32] Dealing with the company's large electricity usage of 950 GWh yearly was not just a way of addressing the carbon-neutral vision through lowering the factory's indirect emissions. It was also assumed to be good for business:

> We have to be the best in the world on understanding how to exploit the energy in the process, and create value from it. Energy, by definition, is the ability to do work. And work creates value. So our way to do it is to get the energy to where it can do work (Finnfjord CEO, interview 02.10.15)

Making use of excess heat had been discussed at the factory "ever since the fifties" (Finnfjord policy manager, interview 05.12.15). Elsewhere in Norway, industrial waste heat had been used for district heating, industrial processes, as well as for growing flowers, producing fish and keeping public areas free of snow (Tangstad 2013). Also at Finnfjord there had been all sorts of creative suggestions about how to utilise the waste heat: From bio-oil refinement and on-shore halibut farming, to large greenhouse gardens for tomato production and giant "thermos boats" to transport warm water to nearby cities. All these options had been considered in all seriousness.[33] However, none of them had ever been realised.

Among the conventional and tried ways to make use of the waste heat, none were regarded viable. The most efficient method would, in theory, be to use the waste heat to heat up water to provide local buildings with heating. With a system like this, is theoretically possible to recover up to 90 per cent of the electrical power input.[34] However, the internal need for such heating was insignificant, and the only nearby

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[32] This goal was not adopted as an *alternative* to the carbon-neutral vision, but as a *supplement* to it. When the construction of the EGV plant was announced in 2009, it was presented as both an *energy efficiency* measure and at the same time as a *climate measure* (DN 13.01.09). Lowering its energy bill was presented at "the company's most important strategy" (Enova press release 06.05.09).

[33] In fact, so many different ideas had been proposed that when the Norwegian press agency NTB announced – on April Fools' Day in 1989 – that Finnfjord were ready to go into production of tropical fruits like mangoes and papayas (and that the factory director had changed his name from Wintervoll to Sommervoll), the local newspaper Fremover printed the story without ever suspecting that it could be a pun.

[34] Numbers and quotes in the following section are taken from the EEIP Best Practice Framework, co-written by Finnfjord (ER>ER 2013).

town, Finnsnes, had no district heating network. Moreover, the local need for house heating was estimated to be just above 14 GWh, which was only a tiny fraction of the 950 GWh Finnfjord were seeking to offset. This option was dismissed.

Another possibility would be to produce process heat (steam under high pressure in closed systems). This would have the potential of utilising around 75 per cent of the original electrical input. However, this option would require nearby industries who could make use of such an energy carrier. Lacking this industry (and after a series of dismissed attempts to attract or establish it)[35] this option was eventually mothballed.

One option remained, although economically it seemed challenging: The process heat could be used on-site. By feeding heated steam into a turbine, it would be possible to produce electricity, which again could be used in the ferrosilicon smelting process. This *energy recovery* (heat to electricity) process is not particularly efficient, with an effectivity grade of only around 20 per cent, and is also expensive considering the amount of energy saved. Therefore, producing electricity was considered the last option if all other usages should prove unviable. Energy recovery installations already existed in two other smelting plants in Norway: Bjølvefossen, which recycles up to 80 GWh yearly and was the world's first of its kind when it was built in 1977, and Thamshavn, built in the early eighties and recovering up to 180 GWh each year, or around 30 per cent of their electrical energy input. In other smelting plants, producing electricity internally had not been relevant due to low electricity prices. It was simply too expensive. Also at Finnfjord, this technology would be expensive to install, and the risks associated with implementing it were high in comparison to other solutions. Nevertheless, given the increasing urgency of lowering their production costs, the management of Finnfjord saw "a viable business case" (ER>ER 2013, 18) in energy recovery technology and decided to explore the opportunity further.

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[35] This section could have been a lot longer, as Finnfjord's attempts to establish or attract other industries in need of process heat have been many. The most "manifest" attempt was perhaps the 2010 announcement of the establishment of Finnfjord Miljøenergi, a joint venture with Troms Kraft where the aim was to utilise Finnfjord's waste heat to produce wood chips. The wood chips factory was expected to produce up to 100 000 tonnes of biopellet wood chips, and was expected to be finished in year 2012. The initiative was presented as "a result of our work to locate good value chains and an important building block in our plans of energy-efficient and carbon-neutral ferrosilicon production" (Finnfjord press release 2010). The plan was never carried out however. Other options that were considered within this period included the construction of a bioethanol refinery, and the establishment of an industrial cluster, Finnsnes Industripark.

4.2 Enova Support

Early on, Finnfjord approached the state agency Enova[36] to make known their environmental ambitions. Within the Enova organisation, the attitude from Finnfjord was met with great enthusiasm. A senior advisor recalled:

> I remember the first meeting with [Finnfjord CEO] Geir-Henning. He had already calculated what he had to do and what measures needed to be taken in order to reach future energy and climate goals. He was early to dare to set hairy goals (Enova senior consultant, interview 04.12.15).

Another thing that made an impression on Enova, was the involvement from the CEO himself and the local community around.

> He also walks around in an overall and takes part in what is happening on the factory floor. He may not carry wrench and screws, but it wouldn't surprise me if he did. (…) Whenever we have a meeting at Finnfjord, both the mayor and the local businesses show up. That is of course positive to us, to see that they do not only represent their own interest, but that everyone participates (Enova senior consultant, interview 04.12.15).

Enova had never supported an industrial project of this size before, but signalled to Finnfjord that that the large energy savings potential of the factory made it an interesting possibility for the agency. Finnfjord started working on an application to Enova already in 2007, and the two organisations were in negotiations for two years regarding the support scheme (Karlstrøm 2015). Plans were submitted, revised and re-submitted, before a final proposal that suited both parts was agreed upon. According to the policy manager at Finnfjord, the consultants at Enova were actively engaged in shaping the project, and "in reality, applications to Enova were accepted even before they have been sent" (interview 05.12.15).

In 2009, Enova granted the Energy Recovery Project at Finnfjord NOK 175 million, based on a total budget of NOK 512 million.[37] It was the largest single

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[36] Enova is owned by the Norwegian Ministry of Petroleum and Energy and contributes to reduced greenhouse gas emissions, development of energy and climate technology and a strengthened security of supply.

[37] The grant was given as part of Enova's Industry Energy Scheme on the basis of the large energy savings potential. Enova considered the technology to be mature, but risky, and "gave Finnfjord what they asked for" (Enova programme director, interview 27.01.16) in order to trigger the project. When Elkem Salten applied for a similar project some years later, Finnfjord had proven the viability of the technology and Enova's own risk calculations had been readjusted. This is one of the reasons why Elkem

industrial project Enova had ever contributed to, and was expected to save 224 GWh of electricity through recovering waste heat as electricity. The concession was announced in the wake of the global financial crisis, where few industries were willing to take large investment risks. Moreover, it was the first Enova grant to be handed over in an official press conference, at the prime minister's office in Oslo. CEO of Finnfjord, Geir-Henning Wintervoll, recalls:

> Everyone [in the industry] was talking about dismissals and divestments and God knows what, and then we came, some crazy Northerners who wanted to invest half a billion on something completely new. Not many believed in us, and I guess the prime minister needed to show that there are things happening in Norway (Finnfjord CEO, interview 02.10.15)

With the funding from Enova, the Energy Recovery Project reached a rate of return high enough to be considered acceptable by the Finnfjord board. The regional bank SNN granted NOK 300 million in loans for the project. An additional NOK 100 million were obtained in loans from the governmentally-owned Innovation Norway, while the state agency Siva committed to invest NOK 80 million in a new service building, since the old one, standing since 1962, had to be demolished to make room for the energy recovery plant.

With investment support from Enova, Innovation Norway, Siva, and SNN, Finnfjord were ready to go ahead with the project. However, EU regulations require large state subsidies to private firms to be ratified by the EFTA Surveillance Authority (ESA). The ESA evaluation took almost two years before the NOK 175 million Enova concession was authorised. Finally, on 24 March 2011, Norwegian prime minister Jens Stoltenberg put down the foundation stone of the new energy recovery plant.

4.3 Planning and Construction

Almost immediately after the Enova grant had been authorised by ESA, the shovel hit the soil where the energy recovery plant was to be built. Although a lot of questions stood unanswered – like who would deliver the equipment needed, or what the

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Salten were awarded a much higher sum to their project (along with the argument of technological dissemination potential, see section 4.6).

dimensions of the systems would be – the project management gave priority to speed rather than detailed planning. According to the project manager

> We could have developed the plant on paper and waited until we had everything ready, and then done the construction, but then we would probably still be building. (…) When you go ahead and plan the details in parallel with the construction work, you create an effing time pressure for yourself, which again means that things *must* happen efficiently. You're not wasting your time, because you have no time to waste (Finnfjord project manager, interview 27.10.15)

It was decided that the project would be managed internally, rather than outsourcing to one or a few external contractors. The reasons listed were many. First was the "brownfield"[38] nature of the upgrading: Since much of the factory was the same as the one constructed in 1962, it was considered beneficial to involve staff already familiar with the site. Second was the argument of "splitting up" the technical knowledge through using separate consultants, rather than giving away the opportunity for another firm to specialise in energy recovery systems. Third, the number of companies able and willing to undertake a project of this size was presumed to be small, even globally, with perhaps as much as a handful in Europe. Therefore, the competitive element in outsourcing would be weak. Finally, allowing the factory workers to be a part of the upgrading process was thought to create a sense of ownership to the new technology. In this way, the knowledge and insights gained from the process would benefit both day-to-day operation and further development of the plant.

With the assistance from a team of hand-picked consultants, the different components of the new plant were acquired directly from manufacturers after a closed competitive bidding process. Throughout this process, offers and ideas would be negotiated, discussed, adjusted and debated with potential suppliers. The project manager described the bidding as a creative, two-way process where solutions and ideas were used even from suppliers who didn't end up as contracting partners in the project. This was presented as "part of the game", where suppliers release more of their technological insights the closer they are to striking a deal.

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[38] Building on an already developed industrial site, as opposed to "greenfield" construction where you start on scratch.

The technical and economic risk was in part shared between the contracting partners. The engineering company Aalborg, who designed and constructed the boilers,[39] ended up spending over NOK 50 million more than they had budgeted on developing the equipment, thus running with a total deficit on the project. “The price was a real blunder (…) but that’s how it is sometimes when developing a new product. In return we now got expertise and a really good reference” said the CEO then (Nordjyske Stiftstidende 24.05.13).

Although the project was managed internally, a multitude of contractors and sub-contractors participated in the construction of the plant. At the peak, around 1 000 workers entered the industrial grounds every day, and more than half of the day-to-day staff of the ferrosilicon production were at some point involved in the construction works.

4.4 Two Major Innovations

In the preparatory phase, the project group became aware of two possible ways of making the energy recovery process more efficient than what was initially thought to be possible. First, it was proposed that in addition to gathering heat from the hot smoke in the chimney (as had been done in other energy recycling systems) it could be possible to also install steam-leading pipes all the way down to the smelting furnace, where temperatures approach 2 000 degrees. This had not been done in any similar plant before, but was expected to yield a significant amount of extra heat to the energy recovery process. Second, it was suggested that process heat (steam) not used for electricity production (originally intended to be sold to an external industrial partner) could be used to pre-heat the water from which the process heat was being produced, thereby making the energy recovery process even more efficient.

Along with a number of smaller innovations (see ER>ER 2013), these two measures were expected to increase the maximum power production of the steam turbine from 224 to 340 GWh. The technology, materials and expertise required to perform these modifications were considered mature and available. Fitting it all into a ferrosilicon plant, however, was uncharted territory. Compared to the original plan, the

[39] The visually dominant part of the plant, the boiler (also called steam generator) is where the heat in the smoke from the ferrosilicon process is passed on, through heat exchangers, to steam in a closed system.

upgrades represented both major improvements and major risks. Nonetheless, the prospect of being able to recycle nearly 40 per cent of the factory's electricity usage was enough to convince the Finnfjord board. Although it involved increasing the total budget from 512 to an estimated 700 million NOK, the plans went ahead.

4.5 Delays, Overruns…and Success

During the summer of 2012 it became increasingly evident that in order to complete the EGV Project, Finnfjord would need another 80 to 95 million NOK. The overruns stemmed from underestimation of the costs of adapting the existing machinery, furnaces, smoke ducts and turbine building, in addition to larger production shortfalls than expected. Finnfjord applied to Enova for extra funding, but were rejected on the grounds that additional funding at this point "would not contribute to making the project more environmentally friendly than it already is" (ESA 2015). Finnfjord then turned to Innovation Norway, who agreed to grant 16 million NOK as "regional development investment support" (Innovation Norway regional director, interview 07.02.16) to complete the project. This again triggered the necessary bank loans needed for Finnfjord to cover the rest of the cost increase.

However, the aid from Innovation Norway was never disbursed, as ESA decided to open an investigation on whether this could be considered illegal state aid. Once again, the Finnfjord board decided to proceed with their plans, despite the fact that the funds necessary to do so were being held back while the ESA investigation was underway.

When the power generator was finally turned on 20 October 2012, the final bill had ended up on more than 800 million NOK, a total overrun by more than 60 per cent. Not surprisingly, the liquidity of Finnfjord was suffering, and many local suppliers were openly complaining in media about unpaid bills. Some of them claimed to have been forced to take large bank loans to survive as they waited for their money. One of the main suppliers sent a letter to their own creditors apologising that their bills would remain unpaid as long as they were waiting for a "two-digit million sum" from Finnfjord (Aftenposten 27.04.13).

While the EGV Project approached its final stages, newspapers were speculating whether Finnfjord was close to bankruptcy. At the same time, the company CEO arrived in Finnsnes with the brand new NOK 26 million luxury sailing yacht "Lady Be

Good", while public tax numbers showed that he had earned nearly 10 million NOK in personal salaries that year. Characteristics such as "arrogant" and "an economic catastrophe" (Nordlys 27.04.13) appeared in the local press, while Wintervoll refused to agree that anything was wrong – until national press started writing about it. To the newspaper Aftenposten, he commented that "we have tried to explain that our liquidity will be in place as soon as the plant is up and running." When the reporter asked if the contractors could expect to get paid by the end of the year, he replied "Of course. And if they haven't, I suppose they will take to more drastic measures than contacting journalists" (Aftenposten 27.04.13).

Early 2015, ESA made public the verdict of its investigations about the NOK 16 million aid from Innovation Norway. ESA argued that Finnfjord had been determined to bring the project to completion even if they risked bankruptcy by doing so. "The company completed the project in October 2012 without the aid having been disbursed. (…) It appears that the company (…) did not seriously consider stopping" (ESA 2015, §69). Thus, the investigation committee were "unconvinced by the argument that the aid was the trigger for the NOK 80-95 million financing package [from the bank]" (ESA 2015, §72) and that "consequently, the Norwegian authorities are not authorised to implement it" (ESA 2015, €80). The support from Innovation Norway was never paid out.

In the final phases of the project, the situation at Finnfjord appeared dramatic. Nevertheless, the energy recovery plant was eventually brought into operation. Around the country, people had started to take notice of the achievement at Finnfjord. The news agency NTB issued a press release about how Finnfjord were now "recycling half an Alta Power Ptation" (NTB 24.03.11).[40] Technical Weekly Magazine wrote about the "New Moon Landing" that had taken place at the factory, openly comparing it to the failed "moon landing" at Mongstad (TU 07.09.11).[41] Other media followed suit. The

[40] The Alta Hydroelectric Power Station was a highly controversial dam opened in 1987. More than a thousand activists chained themselves to the site when works began in 1982, to protest against the infringement of indigenous people" rights and the consequences to reindeer migration and salmon fishing. The Alta power station produces on average 655 GWh yearly.

[41] The Norwegian "Moon landing" at Mongstad was a government-led attempt to create a full-scale CCS test site adjacent to the Mongstad oil refinery. In total, the government spent more than NOK 7 billion on the project. Bellona leader Frederic Hauge called Mongstad "the symbol of this government's total failure on climate policy" (Bloomberg 2013).

leader of environmental NGO Bellona, Frederic Hauge, described the factory as "a diamond of Norwegian industry" and "one example of those we in Bellona have as heroes" (Nordlys 25.03.11). Finnfjord had survived the process of building an energy recovery plant, with the potential of recycling 340 GWh of electrical power yearly, and with expected annual savings of NOK 130 million (Nordlys 06.11.12).

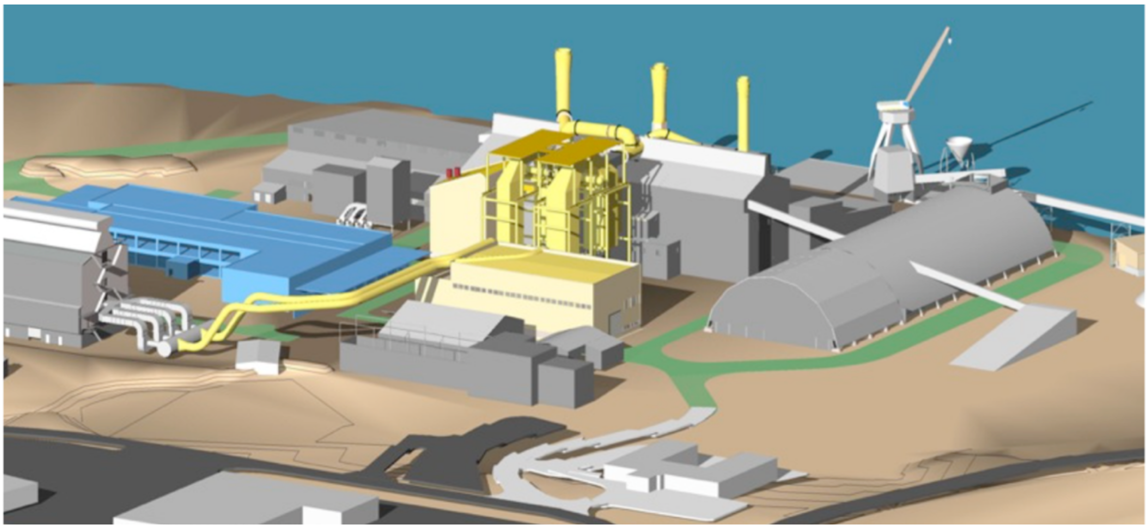

Figure 5: *Finnfjord 2012, with the energy recovery plant (yellow).*

4.6 Dissemination Potential

Among my informants it was generally agreed that there are currently few manufacturers in Norway who can make use of the energy recovery technology developed at Finnfjord.[42] As already mentioned, Elkem's factories in Thamshavn and Bjølvefossen already produce electricity from waste heat in systems that are less efficient, but similar to that of Finnfjord's. Other ferroalloy producers, such as Fesil and Glencore, have chosen strategies where waste heat is utilised in other ways (see 3.1). Among my informants, it was widely argued that electricity prices are currently too low in Norway to make energy efficiency related measures profitable. The situation today is very different from when Finnfjord decided to construct the EGV plant:

[42] I present the ferroalloy and silicon producers here, but the argument is also valid for other Norwegian industries with high energy waste: As for aluminium smelters (who account for almost half of all wasted heat in Norway), their production technique makes their plants unfit for this type equipment. Other power-intensive industries, such as cement, paper and pulp producers, do not attain the high temperatures needed for heat to electricity recycling to be efficient.

> In 2008, everyone agreed – the power business, the analysts – about one thing, and that was that prices would remain high in the future. And now, in 2015, that is an argument that we have abandoned long ago (Enova senior consultant, interview 04.12.15).

It was a widely accepted view among my informants that currently, electricity is simply so cheap that it makes no sense to recycle it. Moreover, since Norwegian electricity stems largely from hydropower, prices are not affected by international climate policies or the EU carbon market. In sum, there are currently weak economic incentives to save energy for Norwegian power-intensive industries.

However, the really big players in the ferroalloy industry are located in countries where energy recovery technology could have a huge impact with regards to CO_2 footprint. In China, who produce more than half of the ferrosilicon on the world market, much of the production is coal-based. If a system like that of Finnfjord's was installed in a coal-fired ferroalloy factory, its total CO_2 emissions would immediately be cut by at least a quarter (Schei, Tuset and Tveit 1998). However, many of my informants doubted that Finnfjord's technology would be applicable to the bulk of international ferroalloy producers today. The main reason for this is the complexity of the technology:

> I am quite sure that the energy recovery plant at Finnfjord – a very complicated plant – would never have worked if it was installed in another country. I really do not believe that (Enova senior advisor, conversation 04.12.15)

This was an opinion that I met among many people within the industry. It was argued that many important features that made the EGV Project possible are unique to Finnfjord and to Norwegian metal producers. Such features included the high level of trust within and between organisations; the low social barriers; the advanced automation technology; the long tradition of handling unwanted pollutants; and the competence of the workforce. Additionally, Finnfjord's internal handling of the Energy Recovery Project had invoked a unique sense of ownership for the workers on the plant, where "everyone had to adapt, adjust and learn" (ER>ER 2013, 20). This sense of "ownership" was argued to be crucial to the success of the project.

> It is actually so complicated that all the operators have to be "co-owners" of the company for it to work. I remember from the very start, on the opening day of the plant, everyone was wearing t-shirts saying "We got the power!" I

> did. The prime minister did. The workers did. Everyone was treated the same way (Enova senior advisor, conversation 04.12.15).

For these reasons, there was a general belief among my informants that a similarly complex plant would be challenging to construct among the vast majority of metal smelters worldwide. It was not just the technical knowledge which would have to be transferred, but the whole organisation culture, including the low distance from the manager's offices to the factory floor, the independence of the individual workers, and the technological insight of the operators.[43] In the words of Finnfjord's policy manager:

> China's problem is that they are not able to learn the technology. They own Elkem, so it should be unproblematic [to transfer it]. (…) Their problem is with what they cannot buy. Their problem is their own workforce, the competence there (Finnfjord policy manager, interview 08.12.15).

To sum up this section, the national potential for using Finnfjord's specific technology is, in one brutal word, limited. Several features of the technology makes it unlikely for it to find its way to a large number of industrial sites worldwide in the nearest future.

Against this, it could be argued that "the nearest future" for a metal manufacturer has a different meaning than in everyday speech. An investment within this business can take up to a decade to recoup, and new technical equipment is often acquired with a 50-year perspective in mind.[44] With a global scope, and in a 50-year perspective, saving up to 40 per cent of energy among alloy manufacturers worldwide is after all *a lot* of energy. Perhaps not enough to label it a moon landing, but undoubtedly sufficient to make it worth striving towards.

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[43] This might help explain why it has taken Elkem Salten so long to reach a decision about what to do with the grant from Enova to construct an energy recovery system like Finnfjord's. While Finnfjord were granted NOK 175 million purely based on their potential energy savings, part of the argumentation to award Elkem twice the amount, NOK 350 million, was the technological dissemination potential. Elkem is owned by Bluestar, a Chinese state-backed international corporation with a comprehensive industry portfolio, controlling smelting furnaces that globally consume more than 5 TWh of electrical energy yearly. Previously, Elkem was owned by the Norwegian investment group Orkla. According to one of my informants, "Elkem were really celebrating the day Bluestar bought them". Orkla's only objective, she said, was short-term surplus for its shareholders, whereas Bluestar was interested in using Elkem factories in Norway as a site for technological development. "We could be close to developing revolutionary technology, only to be told that Orkla would rather invest their money in marketing a new type of pizza". With the new Chinese owners, Elkem have made significant investments in technological upgrades, and are currently running their Carbon Neutral Metal Smelting scheme with an ambition to become carbon-neutral by year 2050.

[44] As we have seen, it took more than 30 years from Thamshavn's then-revolutionary energy recovery plant was built until Finnfjord also decided to construct one.

4.7 Growing Pains

As smoke, steam and electrons started flowing through the factory, following completely new routes from 20 October 2012, it did not only mark the completion of one of the largest industrial projects carried out on mainland Norway within the last decade; it also rendered invisible much of the work that had gone into producing it. Its controversies, its doubts, its conflicts, its risks and its many "dead ends" were outshone by the impressive piece of engineering and political work which had gone into assembling the plant.

However, despite the impressive achievement, the delicacy of the new system soon became clear, as the EGV plant was not immediately compatible with the rest of the factory. Frequent shutdowns; periods of intense maintenance; faulty parts and leakages; trial-and-failure attempts to understand the workings of the "new" smelting plant; all these have been recurrent issues since the EGV system was set in motion. For example: Whereas off-gases from the furnaces were previously too hot for handling (600 to 700 degrees), they were now so cool (160 to 170 degrees) that the acidic SO_2 within the smoke would cause corrosion within the plant. As a consequence, the EGV system could not be run at full steam until the problem was solved.

This is only one of many examples. The second time I visited the smelting plant, I asked the project engineer about a specific part of the factory. "What does this one do?", I asked, pointing at a pipeline that ran from somewhere to somewhere through the newly installed EGV system. "Nobody knows", he laughed. "It is so complicated that nobody knows unless they bring a map up here."

Our tour around the factory had to be called off ahead of time because of a situation where feed water from the smoke hood was leaking onto the charge in the largest of the three furnaces. The resulting loss of pressure in the steam pipes did not only reduce the capacity of the EGV system significantly, it could also be dangerous to both machinery and staff within the factory. Previously, situations like this had led to uncontrolled explosions in the production hall. Instabilities like these bore witness of how complex and untested a system like the EGV plant was. After four years of getting used to the new factory, many of the "growing pains" of the plant were still causing major disruptions in day-to-day production.

Another issue was that the EGV system only reduced the factory's *indirect* emissions through lowering its need for electrical energy. The direct emissions from the factory chimneys – and importantly, the emissions for which the factory were accountable to the EU ETS – were still the same, around 300 000 tonnes of CO_2 a year. If Finnfjord's vision to become carbon-neutral was to be upheld, it was *these* emissions that needed to be dealt with. After mothballing the coal power plans however, Finnfjord had sidelined themselves with regards to development of CCS. The technology was still considered an interesting opportunity, but would have to be developed externally; it was considered "more of a vision than something we can put a date on yet" (Finnfjord CEO, Teknisk Ukeblad, 09.07.11). Within the same period however, CCS technology seemed increasingly unlikely to become available in the nearest future. In 2013, the Norwegian CCS prestige project at Mongstad was abandoned, while many of the EU's CCS pilot projects were scrapped even before building had begun. Finnfjord's strategy needed renewal in order to seem realistic.

The next chapter will deal with Finnfjord's attempt to get "back on track" towards carbon-neutral through the emerging Algae Project. First, however, let us consider how the EGV Project may be said to relate to the company vision of carbon-neutral production.

4.8 Energy Efficiency and Carbon Emissions

How does Finnfjord's EGV Project "answer" to the company vision to become carbon-neutral? In the following section, I will address two core issues of the energy recovery plant: its actual efficiency, and its claim to contribute to smaller CO_2 emissions from Finnfjord's production.

First, efficiency. So far, I have only cited Finnfjord's own official number of "up to 340 GWh" yearly when referring to the EGV system's energy recovery potential. This is the maximum yield if everything at the factory is working flawlessly. As we saw in the last section, however, that is far from the case. The system's *actual* yield is considered inside information at Finnfjord. Therefore we can only do approximations based the information we have. But let us try.

In order to approach a production of 340 GWh yearly, all ovens at Finnfjord must be running at full power nearly 365 days a year.[45] All technical support systems

[45] More accurately around 95 per cent of the time, 350 days a year.

have to be working as they should, year-round, without large maintenance periods or power blackouts (which is not uncommon in the area). Even the *weather* has to be good, as outside temperatures determine how much energy may be squeezed out of the factory off-gases (see section 4.7). For these reasons, and due to the many instabilities and technical hiccups that have occurred since the instalment of the system, it seems unlikely that the actual energy production on the site has yet approached the maximum potential of 340 GWh yearly.

Second, emissions. It remains open to interpretation whether the EGV system does "in fact" contribute to Finnfjord's vision of becoming carbon-neutral. The project has been presented as a *climate* initiative by both Finnfjord and its partners, both prior to the project and after its completion. The claim to this rests on the assumption that power saved at Finnfjord may replace emissions elsewhere in Europe:

> Of course, we don't emit less CO_2 from our chimneys. But the power that we *do not use* replaces power produced elsewhere, and that is often coal power or a "European Mix" of everything produced in Europe. That gives us a CO_2 effect of 220 000 tonnes (Finnfjord CEO, interview 02.10.15)

While this claim may be argued to be problematic in many respects (and I will argue that it is[46]), the "actual" emission reductions from the EGV Project remain difficult to pin down as *one* number. It depends largely on which assumptions one makes about the project, and about the impact it is assumed to have on other actors.

In fact, the climate effect of the project can be argued to be zero – 0 tonnes CO_2 – since most of Finnfjord's electricity comes from "green" hydropower anyway. As for the argument of replacing power produced elsewhere, this is also a complicated claim. The complexity of the power market, the limited transmission capacity of the Norwegian power grid and the vast distances to the European continent makes it difficult to assess how much of Finnfjord's energy is "really" used elsewhere.

While most of my informants rejected this view of zero climate effect, the policy manager at Finnfjord agreed that

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[46] The claim about replacing 220 000 tonnes of CO_2 is based on the assumption that the power not used at Finnfjord replaces "marginal power" in European countries that otherwise would have been produced with a CO_2 component of 0,67 tonnes of CO_2 per MWh. Given the technical difficulties described in section 4.7, the limited need for power in the region, the vast distances to the European power grid, and imperfections of the energy market, it seems to me like a bold claim.

you can of course *choose* to see it that way. There are people who think this whole energy efficiency thing is a sham, and that we should just go on using as much power as we can here in Norway. But what you're asking about, is basically a *political* calculation (Finnfjord policy manager, conversation 09.05.17)

Finnfjord's policy manager highlights an important point here, namely that assessing the "actual" effect of the EGV Project is largely a *political* task. The assumptions one has to make in order to do so will inevitably touch upon questions of values and expectations about how society responds to a project like Finnfjord's. How the power "not used" at Finnfjord may be used elsewhere is a question whose answer involves considering the electricity usage of other power-intensive industries; private household consumption; continental transmission cables; green certificates; the electrification of the petroleum sector, and so on.

To extend this claim about the political nature of numbers: I have argued above that the indirect emission reductions from Finnfjord's EGV plant may be significantly smaller than 220 000 tonnes CO_2 yearly. On the other hand however, the number can also be argued to be *larger* than the CEO's claim, since Finnfjord's increased competitiveness may be assumed to squeeze out less efficient ferrosilicon producers from the world market. This was a commonly held view among the people I interviewed. Through increasing efficiency within Norwegian industries, one could contribute to the climate by outperforming more polluting factories elsewhere.[47] This focus on *efficiency* and *productivity* rather than emission *reductions* is a central part of for example Enova's agenda:

Our mission is not to reduce the total amount of energy used in Norway, but to make sure that the energy is used more *efficiently*. That means to produce *more* goods and services for the *same* amount of energy. There's a quite important difference there[48] (Enova consultant, conversation 04.12.15).

[47] I write "elsewhere", but almost everyone I interviewed explicitly talked about *China* as the one, big Elsewhere of ferrosilicon production.

[48] It should be noted that while Enova previously was mainly a tool for increasing energy efficiency and energy security, it's current mandate has been extended to also involve projects that may contribute to address Norway's commitment to reduce national emission by 40 per cent within 2030 (see www.enova.no).

I could have given more examples, but will have to stop here. What I have tried to say is that while the 220 000 tonnes of CO_2 assumed to be “saved” yearly by the EGV Project may seem to rest on a problematic argument, so is *every* attempt to pin down *one* number. Assessing the “real” emission reductions from the EGV Project is an inherently political question to which there is no real answer.

4.9 Conclusion

In this chapter, I have shown how the difficulties of addressing the factory’s direct emissions made Finnfjord turn towards *energy-efficiency* as their main strategy, in an attempt to bring down their *indirect* emissions through using less electricity to produce the same amount of ferrosilicon. I have given an account of the instalment of an energy recovery system which, at least on paper, has the capacity of recycling up to 340 GWh of electrical energy, and which significantly lowers the factory’s electricity needs. In the concluding section, I addressed the connection between Finnfjord’s EGV Project and their carbon-neutral vision, arguing that it is difficult to assess the “real” emission reductions resulting from the project, since any such assessment involves assumptions that go far beyond the realm of neutral calculations.

5. The Algae Project

How is the Algae Project taking shape? In this chapter I present the second large project that has spearheaded Finnfjord's carbon-neutral campaign, the Algae Project. The project emerged as a potential way for the company to get "back on track" towards carbon-neutral production, but has also been characterised by uncertainty and disagreement about both its technological foundation and its commercial potential. Throughout the chapter, I focus on the reshuffling of actors in order to open up for new and productive connections to take place, and the previously untried circulation of carbon between the mineral and the organic worlds through an incorporation of fossil carbon in what is presented by the actors as "the bioeconomy."

I first give an introduction to the biology and commercial potential of microalgae, as presented by the researchers at the Arctic University. The second part of the chapter deals with the attempts to establish a research and development network around the university's knowledge on algae, and the controversies and potential conflicts arising from these attempts. I address the linkages that connect the Algae Project to Finnfjord's carbon-neutral vision. Finally, I describe how Finnfjord's proactive philosophy has attracted not just researchers, bureaucrats and algae, but also campaigning politicians, to the plant.

5.1 Arctic Algae

In 2011, three marine researchers at the Arctic University in Tromsø (UiT) penned an article in a regional newspaper, titled "What if we cultivated the sea on land?" In the text, the researchers presented the status of a research area with a long-standing tradition at the university, but which had, they claimed, received little attention outside of academia.

> One of the most fascinating aspects of so-called basic research is that it can suddenly reveal an enormous potential which could not have been be predicted. (…) A good example is the study of marine microalgae, which has been carried out by "nerdy" scientists for more than a hundred years. (…) At the University of Tromsø, microalgae have been mass produced on lab-scale for about 25 years (Nordlys 18.06.11).

According to the three scientists, global demand for alternatives to fossil fuel had drawn their attention to new ways to make use of old knowledge. Now, the Arctic University were looking to exploit their knowledge on microalgae.

Microalgae are eukaryotes – small, unicellular plants – which operate either alone or in colonies. Their size varies, from a few micrometres and up to almost half a millimetre, where single organisms are barely visible to the naked eye. Microalgae do not have leaves, stems or roots, and are specially adapted to a liquid environment. They are physiologically and genetically very complex. Their genome is 10 to 50 times larger than humans, and may differ with as much as 60 per cent between species.

Microalgae need light, water, CO_2, nitrates and phosphates to grow, and use these nutrients to produce lipids (natural oils), proteins and carbohydrates, which make up the main components of the organism's mass. Microalgae form the lowest trophic level of the marine food chain. Nearly all the organic material that humans extract from marine environments (fish, scallops, etc.) are originally produced by microalgae further down in the chain. The most productive species can, under ideal conditions, double their weight within 24 hours (Thrush et al. 2006).

Globally, marine algae produce roughly 50 per cent of the oxygen in the Earth's atmosphere. Because global air currents transport CO_2 towards the North and South Poles, algae in the polar regions have adapted to absorbing larger amounts of CO_2 than their relatives around the equator. Preparing for the long and dark winters, these algae produce large amounts of natural oils – lipids.

Through decades of studying marine algae, the researchers at UiT claimed to have identified a strain of "arctic algae" which had proved especially proficient at transforming CO_2 into lipids. Another distinguishing feature was their size. The algae studied at UiT were particularly large compared to algae types that were usually used for cultivation. Farming these types of algae would be "a little like farming cattle instead of flies" (algae lab researcher, conversation 13.01.16).

Cultivating algae in an industrial environment was not a new idea. In East Asia the growing and harvesting of seaweed has long traditions. Microalgae has also been cultivated in Norway for start feed for fish larvae. However, the researchers claimed that their "arctic algae" had features that would make them superior to other variants used in conventional microalgae farming around the world.

Towards the end of the article, the researchers asserted that it would be "particularly beneficial" if algae production could be established close to existing industry with abundant access to CO_2 and heat. Finnfjord was explicitly mentioned in the article as one of the possible providers of this. The writers summed up with a rhetorical question: "Could it be that we are seeing the beginning of a substantial biotechnical industry in Northern Norway?"

5.2 FENOMA

Although the article was one of the first public hints of the Algae Project, this topic had been discussed internally at UiT for a long time. Although only casually mentioned in the article, Finnfjord had in fact been part of this discussion for many years.

Two years earlier, in 2009, UiT had proposed a large R&D project practically oozing with ambition. In the proposal to the Research Council of Norway, UiT sketched out the contours of FENOMA[49], a business–research innovation centre which would include farming of micro- and macroalgae (seaweed); production of lipids, proteins and carbohydrates; and excess-CO_2 removal both from industrial waste gas *and* the ocean itself (!).

Finnfjord's role in the project would be to facilitate the algae production, by installing a 250 000-litre transparent tank where microalgae would be cultivated by use of waste heat and CO_2 from the ferrosilicon production. Several other private firms would be included in the centre, each with a designated role within a hypothetical supply chain. In parallel with research-driven product development, a marketing group would investigate how FENOMA's produce could be made into commodities on the open market. The biological flexibility of the algae and the combined knowledge of the involved partners in the project would make it possible for all parts of the production chain to adjust to market demand. The university dean claimed that "This is one of the best projects we have ever made. (…) There are 200 000 different microalgae species, and we have only looked at 70-80 of them so far. (…) Honestly, I believe that it is only our imagination that limits the possibilities if we just produce enough biomass" (interview 14.01.16).

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[49] Food and Energy from Northern Marine Algae (see University of Tromsø 2009).

The proposal stressed that it had to remain open what the commercial output of FENOMA would be, depending on the development of the project and the market response to these novel products. It was, after all, a complete break with the current production paradigm, and it would take time for the new products establish on the free market. Nonetheless, the opening chapter offered a wide range of possibilities:

> The year is 2030 and the employees of one of the refineries of Algoil ASA, are having lunch. (…) The technical manager is having her algae soup and a green pill against the flu, while the director eats cereals enriched with bioactive ingredients from microalgae. The marketing director has a small sushi wrapped in algae, rich in carbohydrates, proteins, omega-3, vitamins and minerals that will keep her going through the busy afternoon. She jumps into her hybrid micro-car running on solar energy and biofuel from the waste treatment plant. (…) This scenario is not science fiction, but represents real examples of the role algae may have in our society. The objective of FENOMA is to start and facilitate these processes.

Despite the ambitious plans, the application was turned down by the Research Council. In the refusal letter, the business aspect of the proposal was considered risky, as the algae technology was still young and troublesome, and the market threshold was considered high, with fierce competition from already established products such as fossil fuel and fishmeal. The strongest caveat was however the lack of technical detail in the plan. Why should FENOMA succeed where so many others had failed? After thirty years of worldwide research on microalgae and their commercial usages, how would FENOMA become a breakthrough? One of the members of the panel wrote: “The approaches described in this proposal are based largely on non-specific and over-optimistic ideas. (…) I can have little confidence that the team will succeed (where so many others have failed) in cultivating either microalgae or macroalgae on a commercially viable scale.” Later, similar funding applications would also be rejected on similar grounds.

5.3 Old News or Revolutionary Technology?

The FENOMA concept was also met with opposition from established scientists on the field. Senior researchers at the Norwegian University of Life Sciences (NMBU) indirectly confronted the project in an article printed in Dagens Næringsliv, a major business magazine. In the article, they criticised the lack of scientific backing to the initiative, as similar attempts, they claimed, had shown a far too low yield to be economically viable. According to their own studies, a realistic production of microalgae in Norway would be a scarce 5 to 6 kilogram per square meter. With regards to CO_2 capture, they wrote, a football pitch of algae-producing bioreactors would offset no more than 30 cars yearly, not exactly a breakthrough within climate technology. The main bottleneck, they claimed, was the access to light:

> For the microalgae to absorb CO_2, you need light, and a lot of light. Regrettably, this seems to be systematically ignored. (…) Absorbing industrial CO_2 emissions by use of plants/microalgae are old news in Norway. We have been through it before. (…) We have realised that cultivating microalgae for producing fish fodder solely on the basis of energy from light is unrealistic, at least for the next few years (DN, 11.06.15).[50]

Despite the scepticism from research institutions, the regional office of Innovation Norway once again showed interest in one of Finnfjord's projects. In September 2014 it was announced that Innovation Norway would help finance a pilot project, contributing with NOK 7 million to construct a small-scale, 6 000 litre tank on the Finnfjord industry grounds, with the sole purpose of finding out whether the algae cultivated at UiT for three decades could survive in the industrial environment of Finnfjord. Finnfjord agreed to set aside NOK 12 million for the experiment, while the rest of the project, around NOK 21 million, was to be financed by UiT and public funds from the Troms County.

At this point it was estimated that Finnfjord could potentially get rid of as much as 20 per cent of their CO_2 through algae production. However, the project had now departed significantly from the FENOMA concept launched six years earlier. The macroalgae part – and consequently the ambitions of removing CO_2 from seawater – had been dropped completely due to technical obstacles. Most of the commercial partners had pulled out, most because of the lack of public funding (one major partner stating that they would rather return to their "core business" of extracting fossil oil). The scientific basis for the project had changed too, as the algae species at the core of FENOMA had been dropped in favour of new (and more promising) specimens.

Early spring 2015, a pilot reactor was installed at the Finnfjord factory grounds. The first test results indicated that production in the reactor was far higher than the

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[50] Researchers Mortensen and Gislerød refer to their own research on the field, see Mortensen and Gislerød (2015).

NMBU scientists claimed was theoretically possible. Together, the research leader from UiT, Hans Chr. Eilertsen, and Finnfjord CEO, Geir-Henning Wintervoll, penned an official response:

> We believe [their claim of] a yearly yield of 5-6 kilos per square meter was very hasty and based on lacking knowledge about other ongoing projects. (…) In our experiment, this number showed to be more than 200 kg/m^2 (DN, 09.10.15).

In other words, the algae partners at Finnfjord claimed that their “arctic algae” were growing 40 times faster (!) than conventional microalgae, and were celebrating an unofficial “world record in algae cultivation” (Finnfjord press release, 04.05.16). Whether an exaggeration or not, these were numbers that caught people’s attention.

5.4 The Algae Meeting

On the 4th of December 2015, Finnfjord together with UiT hosted a presentation of the Algae Project. According to the invitation leaflet, the aim was to “display the results and further potential of the Algae Project, [and to] find out how UiT and Finnfjord in collaboration with national and regional support programmes can (…) maintain the momentum of a promising collaboration between business and research”. To the meeting, they invited three governmental agencies – Enova, Innovation Norway and The Research Council of Norway – as well as representatives for the regional government and the management of one of the largest salmon farms in the area. Geir-Henning Wintervoll introduced the meeting by presenting Finnfjord’s vision to become the world’s first smelting plant without CO_2 emissions. The Algae Project now posed as the main venture under this banner. And, he proudly asserted, the project was advancing much faster than anticipated:

> This summer we only had one question, which was “Will the algae survive an industrial environment?” In this respect, this meeting is one year too early. We have progressed two years in one year! (…) Some estimates say that we might be able to get rid of as much as 50 per cent of the CO_2!

Wintervoll asserted that the biotechnical insight of UiT combined with the industrial process knowledge at Finnfjord would make the two perfect collaboration partners for a project like this. Moreover, he remarked, the production at Finnfjord fit hand in glove with the cultivation of “Arctic algae”, since they depend on a certain amount of silica and iron to grow, both of which there is plenty in the off-gases from ferrosilicon production. Closing his introduction, Wintervoll revealed the plans ahead: To construct two tanks of an industrial scale – 3 to 5 million litres – with a budget of NOK 10 to 20 million over a period of two years.

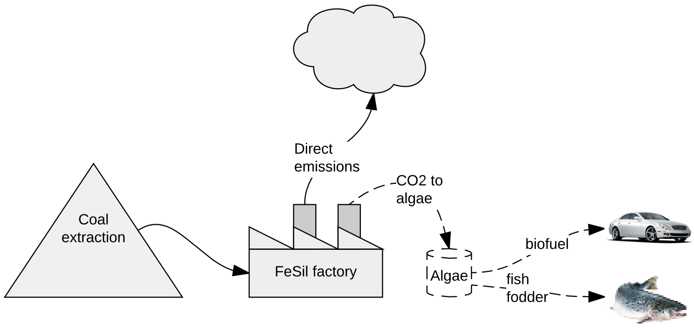

Figure 6: *A possible route for the carbon processed at Finnfjord.*

Later in the meeting, the different state agencies were invited to give short introductions of their current strategies under the heading "The Algae Project is a part of the bioeconomy of the future." This term, "the bioeconomy", was not a word I had heard in any previous presentations of the project, but in this meeting it figured as a keyword in most of the presentations. Innovation Norway presented their newly adopted strategy where sustainability and "value chains based on renewable raw materials" was now on top of the agenda. In this presentation, the bioeconomy was defined in opposition to the petroleum economy: "Somehow, we have to replace all those things that we currently have obtained through the petroleum industry". The Research Council presented the organisation's key objective as "innovation in the economic sector, and sustainability for society as a whole". They asserted that "in the bioeconomy (…) we will need to produce more biomass, we will have to harvest more, we will have to refine better and smarter, and focus on sustainability and cyclic economies". They also called attention to a handful of similar projects around the world that could function as sources of inspiration, collaboration partners, or competitors to the Algae Project. No one, the Research Council asserted, had yet been able to produce algae in large enough volumes to make them competitive against fossil or agrarian products.

Finally, Enova presented their potential role in the project. In contrast to their role in financing and shaping the EGV Project, Enova's official mandate had been extended in 2012 from purely energy-related projects to also dealing with novel, climate-friendly technology.[51] “If the potential here is indeed to reduce emissions by fifty per cent, that is, of the direct emissions, that would be relevant for a programme like ours”.

After each introduction, the floor was opened for discussion and questions. The main caveats from the attendants regarded the biological and technical feasibility of the Algae Project, referring to the scarce results from similar attempts. Representatives from Finnfjord and UiT tried to reassure the meeting attendants that the scientific and technological basis for the project was promising, and unique to any other previous attempt. Moreover, the energy recovery unit at Finnfjord represented a distinguishing factor that was argued to make the factory particularly suitable for algae cultivation.

> Rather than having off-gases that vary between 200 and 300 degrees, we now have off-gases of a relatively constant temperature. That makes it a lot easier to use our installations for new things, for example algae cultivation (Finnfjord project manager, interview 28.10.15).

In this way, the EGV Project was now presented as a stepping-stone for the Algae Project to take place. It was an assumption which was shared by many of the people I spoke to. “If they succeed at the Algae Project, then it is at least partly a consequence of the things they have already started” (Enova senior consultant, interview 04.12.15).

However, the really ground-breaking feature of Finnfjord’s model was not the production of algae itself, but the integration of the “mineral world” and the “organic world” within the one and same industrial site. Stepping over this barrier would represent an unprecedented move, from one production paradigm to another, from an industry where carbon is a waste product, to an industry where it is one of the building blocks.

5.5 Into the Bioeconomy?

“The bioeconomy” was a recurring theme in the discourse around the Algae Project. In interviews and presentations, “the bioeconomy” was envisioned as an emerging

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[51] According to the mission statement from the Norwegian Ministry of Oil and Energy, Enova’s mission unto 2020 is to promote 1. reduced GHG emissions that count towards Norway’s reduction pledges for 2030, 2. increased innovation within energy and climate technology adapted to the transition to a low-emission society, and 3. strengthened national energy security through flexible and efficient usage of effect and energy (Enova 2017).

business field with great opportunities for both financial and environmental gain. The UiT dean summed the topic up in this way:

> [In the future] we have to replace the mineral oils so that we won't release 400 million years old CO_2. So there is a lot of things that we use for food today, that we have to use for technical products – plastic, and yeah, you name it. We have to produce a whole lot more biomass in the future, so these projects that we are involved in today is only to build knowledge to prepare for that society. (…) We have to use the biomass in a new way to survive in the future. And that is what the bioeconomy is (UiT dean, interview 14.01.16).

The bioeconomy was often presented as a radical antithesis to the current, "fossil" economy. Another feature that most of the informants shared, was its cyclical nature. In contrast to the fossil economy, the bioeconomy would be based on organic, renewable raw materials.

All the informants shared the view that Finnfjord's current project represented a turn towards the bioeconomy. Moreover, the bioeconomy featured as a more or less inevitable trend, something that would arrive sooner or later, and that today's businesses could choose either to ignore it, or adapt to it. A Centre Party representative described Finnfjord as a forerunner in the transition towards the bioeconomy:

> Finnfjord have shown that this is possible. Now there'll be pressure on other businesses to recycle energy and capture CO_2. Finnfjord have developed a national model for how to bring our industry into the new era. (…) 20 years from now we will look back and see that it all started here. And then it is important that we do not make the green shift, the bioeconomy, and all this, too narrow – Finnfjord must be a part of it! (Centre party politician, interview 14.01.16)

This quote highlights a common concern among my informants, namely the fear of a "too narrow" understanding of the bioeconomy. While the term mostly figured as a description of industries based on renewable raw materials – like the wood processing industry and the marine sector – it was argued that it was crucial to also include traditionally "fossil" businesses, such as Finnfjord, in the emerging bioeconomy. How this was to be done, was an open question, but the Algae Project was widely regarded as one of the most promising ways to bring the two spheres together.

5.6 Disagreement and Optimism

Although the early phases of the Algae Project have been described as promising, many participants around Finnfjord considered there to be major obstacles to be overcome before the project could be realised. One related to the biology of the algae: The project depends on identifying a species which produces useful substances efficiently – much more so than conventional algae today. Another challenge was to industrialise the process, that is to capture CO_2, grow algae continuously and harvest the biomass in an efficient manner. A third concern related to health and preventing harmful substances from the ferrosilicon process to accumulate within the algae. Finally, being able to refine the biomass into a competitive product on the open market is by no means a given. In short: The steps ahead are long and many.

It also remains an open question what the algae will be *used for*. In the FENOMA vision from 2009, the actual usage areas of the biomass produced was only addressed in loose terms. Seven years later, Finnfjord CEO Geir-Henning Wintervoll stressed the importance of “keeping all doors open” to avoid excluding potential usage areas in the future:

> It is crucial to establish a value chain that we can earn money on as fast as possible. If you can’t make money, it will never work. Salmon fodder is currently our main goal (…) but the most important thing is not to close any doors, to dismiss any opportunities, and that is difficult (Finnfjord CEO on algae meeting 04.12.15)

The Finnfjord CEO proposed a number of potential future usages for the algae: in fish fodder; as nutrients in human food; replacing fossil fuels; and as a source for medicines. Producing salmon fodder was considered as the most realistic usage, while fuel production was mostly presented as a fallback strategy if other uses should fail.

The alternative of producing biofuel, however, was opposed by everyone I spoke to at the university. According to one of the lab technicians, just the thought of using marine oil as fuel “should be considered a crime” (conversation 14.01.16), since the oils have so many other potentially beneficial usages. The university dean was of the same opinion:

> To produce biofuel? God forbid! To use things that could have become food and medicine and nutrients, to burn it like oil, that would be a pity (University dean, interview 14.01.16)

Although it is too early to say what the outcome of the Algae Project may be, it seems that "keeping all doors open" will continue to be the official policy for still quite a while. That might be a necessary approach. Even if Plan A of producing fish fodder succeeds, it is by no means a given that Finnfjord will be able to establish algae fodder as a product on the open market. One significant challenge is the mere *quantities* of fodder needed in a fish pen:

> *If* they succeed – and I really mean *if* – *if* they can turn as much as *half* of their CO_2 into biomass, which would be extreme, they still won't be anywhere *near* of providing enough fodder [for even a small salmon farm]. It's literally just a drop in the ocean (Algae meeting participant, conversation 05.12.15).

Still, as I concluded my fieldwork at Finnfjord, optimism reigned around the project and the potential it was thought to hold for the future. The promising test results from the pilot project had given confidence to the people working with the project, and provided the project with an aura of optimism both in and around Finnfjord. After the success of the EGV Project, the management expressed great impatience about continuing the development of the plant. As the project manager expressed it: "We have never been readier for something new than now, right after!"

5.7 Circulating or Short-Circuiting?

If we approach the Algae Project in the same way as with the EGV Project, what do we find? How does the project connect with the carbon-neutral vision? As we have seen, it was initially assumed that algae cultivation could reduce Finnfjord's emissions by perhaps as much as 20 per cent. Already a year later, the technology was said to have the potential of removing "up to half" of the factory's emissions. It was within this context that Finnfjord CEO Geir-Henning Wintervoll stated that his factory in fact had the potential to become carbon-*negative* in time.

Still, both the biological and technological basis on which the Algae Project rests are contested. Moreover, it remains an open question what the algae may actually be used for in the future. What follows is that assessing the "true" potential of the Algae Project is just as difficult as with the EGV system. To exemplify this, I want to address an aspect of the Algae Project that was little discussed among the participants in the network around Finnfjord, namely the question about what happens with the carbon *after* it leaves Finnfjord in the form of microalgae.

As we have seen in chapter 5, one of the key notions of "the bioeconomy" was a circular economy based on renewable raw materials. This is at odds with Finnfjord's current mode of production: Their main source of carbon is *fossil* coal. Even if the CO_2 from the factory chimneys may turned into fish fodder or biofuel, the *carbon* itself doesn't disappear. It just takes on another form.

While it remains uncertain what the algae at Finnfjord may be used for in the future, all the imagined usage areas involve either combustion into CO_2 or consumption by humans or animals. Thus, as illustrated in the figure below, the final destination for the carbon is the same as before, namely the global carbon cycle. Instead of being released through the factory chimneys, the carbon is "bypassed" through organic products. The end result – even when bypassed through algae – will eventually be the same. In this sense, the total "carbon output" of the factory may still be said to be 300 000 tonnes.[52]

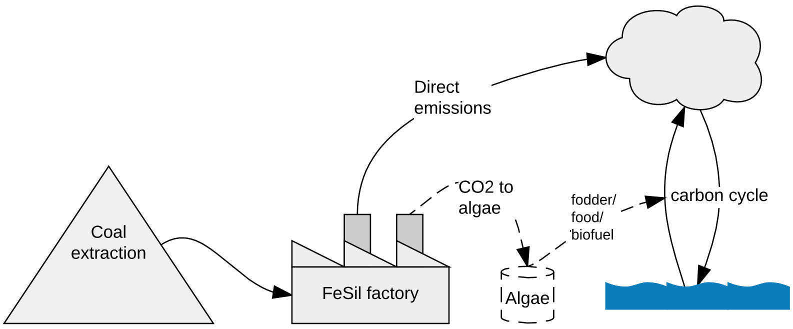

***Figure** 7: Algae cultivation "bypassing" carbon into the carbon cycle. While the direct emissions are accountable to the ETS, the conversion into organic compounds such as fish fodder and biofuel is not.*

However, as with the assessment of the EGV system, establishing the "real" effect of the Algae Project cannot be considered a "technical" task. On the one hand, emission reductions may be significant if the algae replace fossil energy sources, for example

[52] As with the EGV Project, this argument could be extended to involve global connections that go far beyond what I am able to cover in this thesis. One example is how the Algae Project aligns with the European carbon market. While *direct* emissions from the factory chimneys are accountable to the ETS, the carbon tied up in lipids or other organic products is *not*. Following the logic of the ETS cap-and-trade market, the carbon not released by Finnfjord will probably be released elsewhere.

fossil fuels.[53] On the other, if the plan of producing fish fodder is made into reality, the main competitor on the market may very well be fishmeal, which itself is an organic product from a renewable source – fish.[54] In this scenario, the "fossil" algae from Finnfjord could be outperforming "organic" sources of food, leading to a net *increase* of carbon in the global carbon cycle.

These are thought experiments that make little sense until they are actually tried in practice, and without making assumptions about the consequences they have for society around them. As with assessing the "actual" consequences of the EGV Project, this too seems like a fundamentally political task rather than a technical assessment. Whether carbon is in fact circulating through Finnfjord, or merely "short-circuiting" the good intentions of the bioeconomy through taking the path of least political resistance, is open for interpretation.

5.8 Enter Politicians

Finnfjord has in recent years become a popular destination for ministerial visits and political gatherings. Since 2012, more than 70 Norwegian parliament members have paid the factory a visit, the majority speaking enthusiastically about what they learned there. Such as the leader of the Norwegian Labour Party, who visited the plant early 2016:

> They have adapted in a way which bears witness to the advanced competence in Norwegian industries. (…) Their vision is to become the world's first without CO_2 emissions, and in time to become carbon-negative. This is profitable, good for the climate, and it is technically feasible. (…) [They are] on the road towards a win-win; reduced emissions AND production of marine proteins for a growing world population" (Jonas Gahr Støre on his Facebook page 15.03.16)

This kind of praise for Finnfjord's achievements have come from both sides of the political spectrum. In the interviews I conducted, it could seem like the admiration of Finnfjord was not necessarily based on direct knowledge about the company or the

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[53] At least it these are more carbon-intensive than the practice of feeding algae with coal. This is a tricky comparison, to say the least.

[54] A large proportion of the fodder given to farmed fish comes from, exactly, fish that is not considered suitable for human consumption. Needless to say, fish meal is a product with its own environmental footprint, again underlining the complexity of the question in hand.

industry itself, but on a general perception of the business as "leaning forward" and environment-minded. Many of the politicians I spoke to expressed a positive attitude to the company without knowing very much about the details.

One of my informants, a senior politician within the Labour Party, said he was impressed with the recent development at Finnfjord:

> They have made production more efficient, they have reduced their emissions. (…) We should perhaps ask why the rest of the industry isn't doing the same thing.

When I asked him to elaborate on which concrete measures he thought of as most beneficial to the climate, he replied:

> Now, I don't know all their numbers, but *I assume* that they have positive numbers also on that [environmental] bit, with sales… (He hesitates) …and do things that combine business, environment and climate. I hope they succeed; I think that is needless to say! (Labour Party politician, interview 14.01.16, my emphasis)

Whether knowledgeable about the technical details of the factory or not, being part of the transition at Finnfjord has been associated with political prestige. The Finnfjord CEO told about a recent ministerial visit from the Oil and Energy Department. The minister was particularly interested in the Algae Project. After an inspection of to the algae test facilities, the management sat down with the minister to discuss the possibility of developing the project further:

> He asked "How much will this cost?", and I answered that we'll get far with 120 million… *And you could see* the disappointment on his face! You know, they have so much money to spend, and want something grand. They want to be able to say "This is a *billion* investment!" And then I thought bloody hell, I won't be so honest next time (Finnfjord CEO, interview 02.10.15).

One of the consultants at the factory agreed that "next time we should just add a zero to the budget, although the project will be the same", hoping that increased expenditure would lead to increased interest from campaigning politicians. Still, it seems the factory has gotten the attention of quite a few already.

5.9 Conclusion

In this chapter, I have given an outline of the early stages of Finnfjord's innovative Algae Project. The project proposes to link the "mineral" and the "organic" value chains by converting CO_2 to fish fodder or fuel. Although the initial test results have been promising, there are many uncertainties and controversies surrounding the project, both with regards to its technological feasibility and its commercial potential. Moreover, I have argued that it is difficult to assess the project's connection to the carbon-neutral vision, since the production model it proposes implies a significantly different understanding of the term "carbon-neutral" from the first environmental projects undertaken at Finnfjord. Whether algae cultivation is indeed a way of crossing over from the fossil economy to "the bioeconomy", or rather represents a "short-circuiting" of the global carbon cycle is up for discussion. Nevertheless, the project has attracted strong actors from very different spheres, both from researchers, sea farmers, oil companies and the medical industry, as well as politicians, bureaucrats and journalists.

6. Finnfjord Towards Carbon-Neutral?

In this chapter, I draw together insights from the case-study of Finnfjord and the theoretical and analytical resources reviewed earlier. I focus on how the different practices relating to Finnfjord's vision may be said to produce different realities through a process of translation, and how this process has drawn together networks of actors that have served to define and uphold the company vision throughout the last decade. I argue that the circulation of the vision itself is one Finnfjord's greatest success factors in creating their environmental reputation. Finally, I reflect on the implications this has in the context of a master thesis, and what we can learn from approaching a factory like Finnfjord with an actor-network perspective.

6.1 One Vision, Multiple Practices

In the previous chapters, we have followed Finnfjord in their search of less carbon-intensive technology, examining many of the solutions that have been proposed – coal power, fish farming, thermos boats, biopellet production, CCS, seaweed cultivation, district heating, organic reduction agents – and two projects that have (at least partially) been implemented: the EGV and the Algae Project. The chapters have been an attempt to delineate an actor-network forming around Finnfjord's carbon-neutral vision. In a sense, there have been *many* – many visions and many networks. In the following section, I argue that the recent development at Finnfjord can best be understood as separate processes that are linked in complex and contradictory ways through the company vision.

It is roughly 10 years since Finnfjord adopted its vision to become the world's first carbon-neutral smelting plant. Throughout this decade, the vision has been standing firmly at the core of the company's activities. At the same time, the strategies for attaining the vision have changed significantly. To begin with, it was CCS technology which was seen as the key to carbon-neutral production. Later, it was the EGV Project which served as the company's climate flagship. Today, the Algae Project spearheads their continued campaign towards carbon-neutral ferrosilicon production. However, these are not just different strategies towards reaching the company goal. At the contrary, they imply very different understandings of what the goal itself might mean.

The different "solutions" to the problem of carbon emissions propose radically different understandings of the term "carbon-neutral" itself.

To illustrate: The purpose of CCS was to store carbon within deep geological formations, thus making the factory carbon-neutral in the sense that it "returns" the carbon to the Earth's crust. By contrast, the EGV Project had a very different approach to the carbon-neutral vision. Through the EGV Project, Finnfjord assumed to replace continental coal-based power through freeing up Norwegian hydropower. It was a more indirect, and perhaps also more problematic, claim to emission reductions. Finally, the Algae Project involves a third and again very different understanding of carbon-neutral, since, as argued in Chapter 5, the total carbon output of the factory will not necessarily be reduced through the project as long as its main source of carbon is fossil coal.

Rather than appearing as *one thing*, Finnfjord's environmental vision has changed throughout the process of reaching it. To the company management, this "vagueness" was presented as one of Finnfjord's success factors, since it has granted the company flexibility when transforming the vision into concrete measures:

> We at Finnfjord have managed to produce more than just a lot of nice graphs. We have *done* a lot. You cannot just keep talking, you have to *do* something. And that isn't necessarily what you had envisioned. That may not be possible. Visions are quite loose (Finnfjord CEO, interview 02.10.16).

A central insight from actor-network theory is that different practices generate different material realities (Mol 2002). As we have seen above, Finnfjord's vision may be *one* in theory, but in practice it is *multiple* because there are many practices relating to it. With every network taking shape around the factory, a different understanding of the vision has been produced: In collaboration with the Tromsø Olympics and as part of a larger discourse on climate and carbon emissions it first appeared as a CCS project; later, with influence from Enova, Innovation Norway and other actors involved in the EGV Project, it came out as an energy-efficiency programme; and today what may be shaping around the Algae Project is a particular understanding of "the bioeconomy". In other words, the CCS plans, the EGV Project and the Algae Project are not different "answers" to the same question about how to become carbon-neutral. Rather, the different projects answer to the settings (material, discursive, strategic etc.) that allow or restrain certain paths, and thereafter charge the question with different meanings.

What follows is that Finnfjord's vision is singular and multiple at the same time. This connection between the vision and Finnfjord's many attempts to address it may be understood as a process of *translation* (Serres 1974, Law 2009), or the two-way process of connecting different practices and terms through *making them equal*. The great differences between the individual projects are rendered invisible through a "betrayal" (Law 2009, 145) of the incommensurability between them.

This does not mean that they do not belong together. Maintaining a loose vision may, with the words of Law, be understood as a way to "move terms around, about linking and charging them" (Law 2009, 145) as part of a deliberate strategy to form or uphold relations between actors. This is reminiscent of Asdahl's study of the circulation of scientific facts, where facts are moved around in order to "do work and create political effects" (Asdahl 2011, 233). The "betrayal" of the translation is *productive* in the sense that it brings together actors that otherwise would not find common ground. The actors bring their own ambitions, competencies, networks and skills, assembling Finnfjord's vision as a plethora of practices through which the vision may circulate. In this sense, Finnfjord's loose vision works "precisely because these [practices] are irreducible to one another" (Law 2009, 152). It is the *multiple* material-semiotic enactments of the company vision that have served to uphold and stabilise it as *one*. Seen this way, Finnfjord's vision is the *effect* rather than the *cause* of their projects within the last decade.

My study of Finnfjord started with a seemingly paradoxical question: How can a factory so heavily dependent on electric energy, and a production inextricably linked to CO_2 emissions, claim to be one of the greenest in the world?

Mol's ontological extension of the actor-network approach may help answer this question. In her case study of the *body multiple*, she argues that each practice related to the body generates its own reality. Following this argument, a translation between practices does not necessarily produce a single, coordinated network or a single reality. Most of the time, translations between practices produce *multiple realities*, or "chronic multiplicity" (Law 2009, 152). Following Mol, the term "carbon-neutral", as well as its material representations, is a fundamentally complex entity which may produce a vast web of relations, each connection relating to the term in complex and incommensurable ways.

This implies that the term "carbon-neutral" is not itself a neutral term. It cannot be assessed through "technical", incontestable methods. What appears to be technical and "actual" also involves judgements and attempts to interpret and change reality (Asdal 2008, 114). As argued earlier, Finnfjord's two main projects throughout the last decade have not yielded any "actual" results with regards to carbon emissions. The question, as well as the answer, is inherently political.

6.2 A Heavy Industry

Actor-network theory reminds us that action is *dislocated* and distributed in both time and space. In this section, I argue that Finnfjord's development must be understood as heavily influenced by an already existing order, namely the material reality of the factory itself.

In chapters 4 and 5, I have described many of the participants who have contributed with form and function to the EGV and Algae Projects, and who have served to link the projects to Finnfjord's environmental vision. However, these participants all have to relate to an already existing (and arguably durable) assemblage: the factory itself. No matter how forward-leaning one's philosophy is, chances are that previous and less environmentally minded philosophies will also have their say.

To recapitulate: The current version of the smelting plant is constructed in successive layers "on top of" the original factory from 1962, each upgrade and adjustment adding to the complexity of the plant. In this way, many of the decisions made during the factory's construction years are still present in the way Finnfjord works today, *acting* forcefully upon the quartz, iron, workers, local environment and company vision even today, fifty years after.

This argument can be taken even further back, to 1953. What makes the factory *act* is not only the workers manning its equipment, the global demand for steel or the engineers who design and assemble the plant. So far in this thesis, I have given little attention to one of the central actors at Finnfjord, namely the *power* that enables the whole factory to operate. It is the stream of electrons from Norwegian mountain reservoirs which gives life to the factory. The power that flows through the smelting plant produces many of the economic ("the ability to do work"), social ("the need for steel is increasing") and environmental ("replaces power produced elsewhere") rationales for Finnfjord's activities.

However, actor-network theory reminds us that relations between actors are always ambiguous: *enabling* action also involves *restricting* it. The history of Finnfjord is often presented as beginning in 1953, when the construction of the Innset hydropower dam was agreed upon, creating the regional power surplus which formed the political rationale for establishing the factory in Finnfjord. This, the fact that the infrastructure around the plant – as well as the plant itself – has already been assembled, is a precondition for the industrial development in the region.[55] Constructing a new and similar plant today, even with state-of-the-art technology, would be politically impossible. Likewise, changing the way it operates is a heavy task. Using ANT language, the regional power surplus *wants* to be used, just like the electric arc furnaces in Finnfjord *want* to use it. Among all the actors involved at Finnfjord, the electron is, quite literally, among the most powerful.

This naturally has implications for the company's ambitions to reduce their environmental impact. While the vision from 2007 is indeed ambitious, the material configuration of the smelting plant is, to a large degree, what dictates the enactment of the vision. In a world of fragile bonds, the smelting plant in Finnfjord has proven stubbornly stable. Compared to the constantly shifting world of expectations, norms, public policies and visions, the factory's concrete walls and steel ducts make out a nearly immutable system. If technology is indeed "society made durable" as Latour (1991) puts it, then parts of the factory represent a historical period – the 1950s and 60s – in which climate change was barely conceived as a potential problem yet.

This might help explain why, after 10 years of restructuring and more than NOK 800 million spent on technological upgrades, the road to being carbon-neutral (in the sense of not contributing to climate change), still seems long and windy for Finnfjord. The company is still the 14th largest point source emitter on Norwegian mainland, and will probably remain so in the foreseeable future.

These claims are not new to those working within the industry itself. As we have seen, industry leaders have claimed that even modest reductions within the next decades are unlikely (SINTEF 2009). As mentioned earlier, technical equipment within the

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[55] Asdal addresses this issue in her account of the environmental issues of the Norwegian metal smelting industry. Many factories were constructed without assessing the environmental consequences of their production. Once the issue of local pollution arose, she argues, "the fact that the factories already existed, that they had a reality, was crucial in questions about how to deal with them" (Asdal 2011, 60).

metal business is often acquired with a 50-year perspective, with a 10-year recoupment plan, and with expectations of large, periodical fluctuations in the steel market.[56] The initiatives we are observing at Finnfjord and in the ferroalloy industry today, may represent a "marked change" (Fredriksen 2015, 62) in the *attitude* of the companies, but it will take time to change the technological basis, production processes and the environmental footprint of the industry.

6.3 Black-Boxing the Carbon

With the "leaning forward" philosophy and the adoption the carbon-neutral vision, Finnfjord has explicitly attempted to avoid any affinity with "sunset industries" of the petroleum sector and other non-renewables. This turn has involved the enrolment of a whole new set of actors who agree to tell a new and different story about what it going on within its factory grounds. It is a story about novel technology, about a flexible and open-minded organisation, about a supportive local community and about state-of-the-art production techniques that are not to be found anywhere else in the world. The network forming around Finnfjord do two things to provide the company with its identity as a forerunner of technological development: First, the network is *punctuated* through a series of accounts that all lend their capabilities, insights, resources and credibility to Finnfjord, making it appear as if the smelting plant and its management are the *prime movers* within the network. In reality, its development is enabled, steered, restricted and justified by the network of actors surrounding it, upholding it and constituting what it means to be a prime mover at all.

Simultaneously with the punctuation of the network, some aspects of Finnfjord's production are being "black-boxed" and consequently hidden from view. For example, the EGV plant is invariably presented as producing "up to 340 GWh yearly". As we have seen, this claim may be technically correct, but is probably far from the actual production of the system. By presenting the EGV plant purely as a number, focusing on its outputs and not its internal complexity, it is reduced to an individual node within the factory (Callon 1986a), appearing as a "closed chapter" in the history of the smelting

[56] It is worth remembering that Elkem's company vision is carbon-neutral production within year 2050.

plant. This obfuscates the system's "growing pains", as well as fact that the it could have been even more efficient than it is:

> We still have the potential to take out more heat and optimise further, and if we had money, then of course we should have done more, no doubt about that. But then again, we did a lot (Finnfjord project manager, interview 27.10.15).

As we have seen, "up to 340" has become the operative number for anyone referring to Finnfjord's electricity consumption. In this way, the focus is drawn towards the amount of power which is *not used* at the plant, rather than the actual number of electricity consumed – "at least 610" or "almost a whole Alta Power Station". While reductions has become what Finnfjord *do* in many people's eyes, the remaining environmental issues at the factory disappear from the discourse around the plant. Change is given prominence over durability, fluidity over foundation, projects over permanence.

In the accounts given of the Algae Project, the black-boxing takes a different form. Here, *the carbon itself* disappears from the discourse where the "arctic algae" enter. As we have seen above, many of the actors involved in the projects at Finnfjord assume that by feeding the CO_2 to microalgae, the problem disappears. However, the carbon doesn't disappear, it only takes a detour through organic products before ending up in global circulation. This "short-circuiting" of the global carbon cycle enables the coal at Finnfjord to transgress the boundary from "fossil" to "organic", and to become a resource rather than a waste product, as it "disappears" from view when entering into organic products.

The carbon here works as a metonym for the factory as a whole. The Algae project tells the story of Finnfjord's entrance into the bioeconomy, while the reproduction of carbon-based ferrosilicon process becomes hidden from view. The fact that Finnfjord's source of carbon is non-renewable fossil coal was never addressed by any of my informants. Likewise, the fact that the seafood industry *is already a bioeconomy* by the actors' own terms was never discussed by any of the people I interviewed.

These processes reveal an actor-network at work. While the actors in and around Finnfjord give prominence to the company's technological "moon landing", the flexible and productive "arctic algae" and the inevitably oncoming "bioeconomy", they simultaneously downplay the problems and instabilities of the EGV system, the uncertainty and controversies around the Algae Project, and the inevitable CO_2 emissions resulting from the factory's ferrosilicon production. While the discourse around Finnfjord tells the story of rapid progress, path-breaking technology and an elastic organisation, it at the same time obscures the fundamental processes at heart of the plant, the building from 1962 and the many limitations that lie both within Finnfjord and in the networks currently surrounding it.

6.4 Surviving on the Vision

With the account given above, it seems difficult to explain how Finnfjord may have been portrayed as a forerunner, rather than a failure. If it is so hard to address its core problem, *the process of producing ferrosilicon itself*, shouldn't the networks around the factory crumble and fall apart in disillusionment?

Bruno Latour provides the student of science and technology with methodological advice about how to trace the shifting networks around an actor. He encourages the ANT writer to follow "what makes [the actors] act, namely the circulating entities" (2005, 237). The starting point for this thesis was Finnfjord's adoption of the vision to become the world's first carbon-neutral smelting plant. But while the efforts to meet with this ambition take a long time to implement, the vision is still there, ten years after its adoption. How can the vision still be so vigorously present in the company's activities when the act of pursuing it has proven to be so challenging?

More than anything else, it is the *vision itself* which circulates and can be said to "do work and create political effects" (Asdal 2011, 233) within and between the actors gathering around Finnfjord. While I have argued above that the road ahead towards carbon-neutral production may be long, the vision itself has created a strong pull around Finnfjord, attracting a vast array of other actors that have served to reinforce and uphold the vision itself, despite the difficulties of turning it into concrete projects that effectively answer to it:

> So far they haven't actually reduced their emissions, so Geir-Henning has to survive on his visions. A community builder, that's what I would call him
> (UiT dean, interview 13.01.16)

As we have seen, Finnfjord's vision has been adapted to "do work" for very different players throughout society: The Finnfjord management, Enova representatives, workers on the plant, local media, activists, expert communities, fish farm managers, the EU commission, the Lenvik municipality, ministers and senior politicians, competitors and partners, the Tromsø 2018 Olympic team, researchers, bureaucrats, national press, subcontractors, think tanks, state agencies and environmental NGOs – all have incorporated Finnfjord's company vision into utterly different contexts, and for very different purposes. In this way, the vision itself may be said to flow throughout the networks spanning around Finnfjord, changing and transmuting with every step and effectively *drawing the actors together*. It does not do so by itself, however. Rather, – and this is one of the fundamental insights from actor-network theory's "negative argument" (Latour 2005) – it is *produced* through the constant attention and reaffirmation from the actors who surround it. Thus, Finnfjord's carbon-neutral vision cannot be separated from its enactment, and the enactment does not (only) take place within the factory grounds, but in the relations that form around it.

Seen from this perspective, Finnfjord's vision is a fragile construction. It has not yet been manifested physically or rendered stable. The many networks around Finnfjord define and uphold the company vision in temporary and delicate ways, through processes of translation that are more vulnerable than they might appear. For example, it is difficult to imagine that the costly and complicated EGV Project – and thereby the main venture under the carbon-neutral banner so far – could have taken place without the significant contributions from Norwegian state agencies like Enova and SIVA. Likewise, the whole Algae Project might go down the drain if the collaboration partners are unable to locate a species of microalgae which is suitable for cultivation within a ferrosilicon factory. This might be down to pure chance. As Hughes (1983) reminds us, the most efficient way of locating the components of a network, is to study the breakdown of networks that fail. The many controversies and uncertainties that surround Finnfjord's pursuance of their vision renders some of these components visible, at least for now.

To sum up this section, Finnfjord's carbon-neutral vision has served as the discursive component for a number of practices within and around Finnfjord throughout the last decade: It has figured as energy-efficiency measures; as the site for passing politicians; as a premise for technological development; as a part of the "bioeconomy"; as the topic of a master thesis; as an Olympic lighthouse project; as a "green shift" forerunner; as a motivation for exploiting knowledge on algae, et cetera. The vision's "loose" interpretation, as well as the various actors being willing and able to approach it from very different angles, has made it possible to maintain it throughout what has been a turbulent, but also successful decade for Finnfjord.

6.5 Actor-Networks and Loose Threads

What can we learn from approaching a company like Finnfjord in material-semiotic mode? On the one hand, it is frustrating to admit that the complexities and contradictions that lie at heart of this thesis are just that: complex and contradictory. Actor-network theory does not propose a way to "solve" these. On the contrary, it argues that complexity and contradiction are inevitable – even *necessary* – components of all social activities. What actor-network theory *does* allow the researcher to do, is to examine material-semiotic configurations that enable or restrict certain actions (Asdal 2011), that lead to material and/or discursive stability (Law 2009), and that can be assumed to render some social ties more durable than others (Latour 1991, Latour 2005). In the sections above, I have outline the major findings of this thesis: That Finnfjord's many attempts to address the vision have, in practice, produced *many visions* that partly overlap but also contradict each other; that the already established orders around Finnfjord render it difficult and time-consuming to establish new ones; and that the circulation of the vision is itself is what pulls the actors together around the factory in Finnfjord.

But then what? Where do we go if we cannot make singular, "true" claims about Finnfjord's development? What have we learned?

In one sense of course, we have learned a lot. By following Finnfjord's vision through its many manifestations, flowing out from the factory grounds and forming an impressive network around it, we have gained knowledge about how it may be possible to steer a heavy and well-established industrial system in a more sustainable direction. At the same time, we have learned just how heavy such a process can be, and just how many actors that may have to be involved when trying to change established orders that have taken the form of steel and concrete.

On the other hand, we have mainly been "studying up rather than down" (Law 2009, 150), describing a process which should mostly be known by most people working in and around Finnfjord already. A study within the actor-network family is itself a way to "move terms around", rendering durable an account which itself may be contested and challenged. My account inevitably leaves many loose threads to be picked up by others, and many interesting questions remain unaddressed. What happens to the power that Finnfjord "does not use"? How can the factory get rid of its "growing pains"? Will the energy recovery technology be adaptable to other plants of the same kind? How will the Algae Project develop further? Is "the bioeconomy" just another buzzword, or does it signal the dawn of a new era for Norwegian industries? These are just a few of the threads that would have to be followed in order to get a "complete" answer to the thesis' research question.

A chronic issue within actor-network studies is the question of where to stop. If everything social is by definition interconnected in a multitude of momentary webs, isn't the "zoom" we apply to a case at least partly arbitrary? Researchers within the ANT field have tried to deal with this dilemma in different ways. Latour argues that the actors themselves, through their own actions and theories, provide the scaling needed. "Either the sociologist is rigid and the world becomes a mess or the sociologist is pliable enough and the world puts itself in order" (Latour 2009, 184). At the same time he contends that the main limitation to a good actor-network account should be the sheer lack of space (2009, 148). Others remain vague on this point, perhaps because it is one of the fundamental dilemmas of a poststructuralist epistemology, a field characterised by deferral, relationality and of fluidity (Derrida 1976, Barker 2012). Law contends that in order to describe the world, researchers (and their readers) have to acknowledge that research will always be messy and heterogeneous – in fact it *needs* to be messy and heterogeneous in order to grapple with the multiplicity of the world we live in (Law 2007). While the account I have given of Finnfjord's development within the last decade has attempted to pull together *some* of its loose threads, I will have to leave others in a messy state.

Messy and heterogeneous are words that fit to describe my study of Finnfjord, at least if certain and incontestable answers is what you are after. The "zoom" we apply is crucial for assessing the success of Finnfjord's CO_2 mitigation efforts so far. For example, we may accept the company CEO's claim that the implementation of the EGV and Algae Projects "correspond to" emission reductions of 370 000 tonnes CO_2 (see section 1.2), but as I have argued earlier, this claim mixes together very different understandings of the term "reduction" and what kind of "carbon-neutral" it implies (see section 6.1). Even if we accept the claim, these reductions still do not account – neither in numbers, nor in practice – for emissions from raw material extraction and transport (see section 3.2), or from emissions further down the assembly line. In other words, the "total" emissions of Finnfjord are also very difficult to assess. If we zoom further out, we may consider the role Finnfjord's products play in global commodity chains, for example when ferrosilicon from the plant is made to produce steel for bridges, buildings or weapons; when silica dust is blended into concrete to construct skyscrapers in Malaysia; or when lipid oils are mixed with Brazilian soy to produce fodder for salmon farms which in turn export fresh fish by plane to the emerging markets in Shanghai or New York.

These examples illustrate how difficult it is to stop once you have picked up a thread that may lead around the entire globe and back again. The actor-network approach may be argued to lack the necessary tools to connect and generalise our findings. The ant's account, it may be said, will always be partial and incomplete. However, it can be argued to be the more honest approach to producing knowledge in a world where connections are – as we have seen in this study – heterogeneous and complex, and where every actor must be assumed to act under contradicting forces producing simultaneously occurring realities. The world is a messy place. Rather than "tidying it up" through turning to abstract theory, I have tried to tell a story about a Northern Norwegian ferrosilicon producer's winding and uncertain path towards carbon-neutral metal smelting. I have shown how different enactments of Finnfjord's vision have produced different understandings of what "carbon-neutral" means.

We could have done it the other way around, by providing a theoretical definition of "carbon-neutral" along with the research question, then "testing" the definition on Finnfjord's own projects. I believe the result would be disappointing. The assumptions one has to make in order to whittle down the "carbon-neutral" term to an operational size would make it impossible to encompass all the activities at Finnfjord within the last decade. We would find ourselves "aiming at a moving target" (Law and Singleton 2014). We would either presume that our theoretical assumptions were wrong, or conclude that Finnfjord's pursuit of carbon-neutral has been either "failed", "confused" or even "hypocritical". By separating theory and action, the translation processes which currently glue the many actors around Finnfjord together, would break down.

In practice however, they don't. Politicians, media, researchers and industry representatives keep swarming towards Finnfjord to learn, participate, describe and influence. Every day, Finnfjord's vision is reassembled into new forms, new representations and new understandings that reinforce, contradict and oppose each other, thereby keeping the vision alive. It was for this reason, namely that it *works,* that the smelting plant caught my interest in the first place.

One might claim that these contradictions reveal the impossible ambition of the vision itself, and that Finnfjord's many attempts are "really" just a way postpone the sunset. However, this is not what I have found. I have met with a company who persistently work towards a more environmentally friendly production, and who cling to a "loose" vision in order to keep all doors open in a complex world where you have to be ready for new and unexpected possibilities that may present themselves where you least expect it.

In a sense, Finnfjord have already adapted to the notion that "carbon-neutral" will have to be *performed* on a stage which is not set by the company itself, and together with actors who may not share much apart from a desire to get involved in projects that are considered good for the environment. Moreover, Finnfjord have realised that new actors – organisations, funding partners, technology, undiscovered strains of algae – may appear unexpectedly and change the game overnight. Visions are loose, and both the EGV and the Algae Project have evolved significantly after their inception, and will both continue to do so in the future. If there is a lesson to be learned from applying actor-network theory to a smelting plant, then it is that our knowledge of the world is never complete.

Throughout the thesis, I have claimed that many of the questions surrounding Finnfjord's environmental ambitions are "inherently political". By now, I hope to have made clear what this means. If describing a case is "always an ethically charged act" (Law 2009, 155), then the same is certainly true about passing a judgement on the ferroalloy industries' position within society. In this thesis, I have tried to pick up some of the threads around Finnfjord's EGV and Algae Projects and describe how these are connected to the company's environmental vision. Some of the threads will remain loose, and may be picked up by anyone. Hopefully it is someone who acknowledge – and appreciate – the complexity of the field Finnfjord operates within.

7. Conclusion

In this thesis, we have followed Finnfjord on the road from being one of the most polluting industries in Norway to … still being one of the most polluting industries in Norway. Ten years after the adoption of the vision to become the world's first carbon-neutral smelting plant, Finnfjord releases the same amount of CO_2 through its chimneys. The company has however installed a ground-breaking energy recovery system which significantly lowers their electrical energy input. Today, Finnfjord claim to be the most energy-efficient and environmental-friendly smelting plant in the world. They are currently working on the promising Algae Project, where they plan to use CO_2 to produce fish fodder.

In this thesis, I have given an account of the two above-mentioned projects. I have described their emergence, and how they have been carried out (so far) by actors within and around Finnfjord. I have discussed the two projects' claim to the label "carbon-neutral", analysing their complex and partly problematic assumptions about how electricity and carbon circulate through society. Finally, I have argued that assessing the success of the projects is not just a technical task, but an inherently political question to which there are no true answers.

Throughout the process of becoming carbon-neutral, Finnfjord's vision has been readjusted a number of times – if not on paper, then at least in practice. While the carbon-neutral vision seemed clear enough when it appeared in 2007, Finnfjord's numerous attempts to address it have implied very different understandings of what it means to be "carbon-neutral" altogether. I argue that the vision has attracted a certain type of actors – politicians, media, novel technology, NGOs, "the bioeconomy", state agencies, arctic algae – to Finnfjord, translating the vision into a multiplicity of practices that only partly overlap. This multiplicity explains how Finnfjord can be many things at the same time: a forerunner into the green shift, a major polluter, an aspirant to the bioeconomy, an enormous energy consumer, a problem and a solution – all at once. The carbon-neutral vision provides roles, identities and functions to the actors around Finnfjord, who in turn contribute to upholding and reaffirming the vision as a heterogeneous assemblage. In this thesis, I have explored some of the material, discursive and political sides of this assemblage throughout what has been a turbulent, but arguably successful decade for Finnfjord.

I have argued that the reason for Finnfjord's success is the *circulation of the vision itself*. It has been incorporated to "do work and create political effects" (Asdal 2011, 233) for actors that operate far beyond the factory grounds. The vision has figured in various forms throughout local and national media; in Enova's annual reports; in Bellona's praise for the Norwegian industries; and in the stone halls of the EU commission in Brussels. One of its most obvious political effects is that it has portrayed Finnfjord – and the Norwegian smelting industry – as future-oriented, environment-minded and forward-leaning. At the same time, it obfuscates the seemingly inescapable fact that ferrosilicon production will remain a hugely carbon-intensive and environmentally problematic industry in the foreseeable future. It may be long until we see "truly" carbon-neutral ferrosilicon. At the same time, shutting down Norwegian smelting plants may have adverse effects, as new producers emerge Elsewhere in order to answer to market demand.

So where does this leave us? Throughout this thesis, I have given little attention to what is arguably the main driver of global emissions from ferrosilicon production, namely ferrosilicon *consumption*. The global demand for steel, we are reminded, has nearly doubled within the last 15 years. Whereas the sublime technology and awe-inspiring development at Finnfjord makes it the perfect candidate for a case-study of metal smelting, its splendour renders invisible the daily, mundane experiences we have with its many products. They, too, are networks – well-functioning, established, and *silent* assemblages that form the very fabric of our everyday lives. This thesis has been written on a device containing ferrosilicon, just like the tape recorder, aeroplane, guitar strings and waffle iron that were crucial to assemble it.

You cannot miss it as you drive by. The towering chimneys of the smelting plant in Finnfjord stand out against the picturesque Northern Norwegian landscape. But it is easy to overlook the 2 kg of ferrosilicon that make your car hang together, the 3 grams of Silgrain® that make your iPhone work, or the silica dust gluing together the bridges you have to cross to get home. Any debate about the metal smelting industry needs to consider not only how their products are made, but also how they are put to use – tracing the webs they weave between the blazing furnaces of Finnfjord, and our own fingertips.

Ferrosilicon pellets from Finnfjord

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