Summary of Decarbonisation Case Studies

Deliverable 3.3

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1 Introduction

The aim of Work Package 3 is to generate insights on non-technical dynamics of innovation processes in the four REINVENT key sectors – steel, plastics, paper, and meat and dairy. In addition to that, cross-sectoral effects, mainly with regard to finance mechanisms, are analysed.

Within Task 3.3, this aim is pursued by means of several in-depth case studies conducted in each sector, including finance. These are based on a mix of methods such as expert interviews, field trips, workshops and desk research. The analysis has been focused on specific interventions for initiating and rolling out an innovation, as well as the initiatives framing and influencing these specific interventions. With an originally planned 15-20 cases, a total of 18 case studies were conducted.

The rationale of this Deliverable is to summarise the results of these case studies carried out by the Work Package team. The Deliverable consists of the following sections:

- Methodology *(Section 2)*
- Summary of the case studies for each sector, including finance *(Sections 3 to 7)*
- Outlook on further work with case study data *(Section 8)*

The Deliverable is intended to be purely descriptive, providing an overview of the case study work and a basis for the analytical work undertaken in upcoming tasks (particularly Task 3.4).

The case studies have been part of a multi-step work process. In Deliverable 3.1, a methodological protocol was devised, laying out an analytical framework for the case study selection and analysis process. It includes a set of selection criteria, a list of five research themes, each containing four to five research questions, as well as templates for case study reports and the sharing of interview data.

Deliverable 3.2 describes the portfolio of 18 cases selected for case study analysis and outlines the reasoning behind this selection. This initial collection of cases included six cases from the steel sector, five from the plastics sector, three from the paper sector, five from the meat and dairy sector, and two overarching finance cases. The cases were chosen based on a set of six criteria: carbon significance, spread across value chain stages, different types of innovations, linkages to other work packages, scale-up and feasibility. This ensured that the case study portfolio reflects a comprehensive mix of innovations and interventions in the key sectors.

After completion of the case selection process, progress, difficulties, necessary methodological and practical changes and preliminary findings have been discussed among the work package team on several occasions, including project meetings (specifically in Lund in October 2018 and in The Hague in March 2019) as well as regular team calls. That way, the case study selection and work process could be regularly re-evaluated, to enable valuable interlinkages with the other work packages and ensure its contribution to the overall objectives of the REINVENT project. Resulting changes in the case study portfolio are outlined in Section 2.

Case studies have been conducted by one or two project participants, based on know-how, experience and access to potential people to interview.

In the meantime, two stakeholder workshops were organised, both taking place in Brussels within a span of four months. The interim workshop, titled "Understanding innovation dynamics for low-carbon transitions in resource-intensive industries, took place on 29th November, 2018. It was held to reflect on preliminary outcomes from the different cases and identify interdependencies between cases within and across sectoral boundaries. 34 participants from industry, policy, NGOs and the scientific community attended. As part of the agenda, selected cases and overarching findings on a sectoral level were presented on posters and discussed in a gallery walk format. These posters included findings from the sector reports composed in Work Package 2. Furthermore Work Package 4 was also integrated into the workshop to draw connections between the case study and the scenario work.

The synthesis workshop took place under the headline "Transition to fossil-free industries: technology pathways and policies" on 18th March, 2019 within the framework of the EU Industry Week. During the workshop about 70 representatives from different industries, national and EU policy institutions, scientific and environmental organisations discussed the decarbonisation potential of different sectors and the opportunities that can arise from cross-sectoral interactions. The event brought together EU-funded projects and national and regional initiatives related to decarbonisation of energy-intensive industrial sectors. In three sessions, insights and findings on electrification and hydrogen, circular economy and biogenic carbon economy and carbon utilisation were presented and intensively discussed. The workshop was co-organised by EASME and the initiative IN4climate.NRW. A poster exhibition on the first results of the REINVENT project was also held in the foyer of the venue. For the case study work, which was already at a relatively late stage at that time, the workshop nevertheless made valuable contributions. Excerpts from two cases were presented and discussed (HYBRIT and biorefineries and bio-CCU).

In addition, there was broad agreement that the establishment of further cross-sectoral solutions for decarbonisation at European and international level is urgently needed and that a common climate and industrial policy in Europe is required for this purpose. The traditional sector boundaries must be overcome in the future.

For each workshop, a report has been prepared outlining the format, agenda and attendance, and summarising key takeaways (see Deliverables 3.4 and 3.5 for the interim and synthesis workshop, respectively).

2 Methodology

The methodological approach for the case study process was defined in the Analytical Protocol (Deliverable 3.1). It included a mixture of primary research (in the shape of semi-structured expert interviews and field trips/workshop participation) and secondary research (including the review of both scientific and grey literature). The amount of primary data to be collected in each case was also outlined in the Analytical Protocol. The follow paragraphs review the data collection process across sectors and cases.

(1) Expert interviews

It was outlined in the Analytical Protocol that case study teams would strive for 8-10 expert interviews per case. This range was exceeded by some case studies while remaining unmet by others. This can be ascribed to different reasons: in some cases, interview access was limited, but other sources (e.g. grey literature) abounded, making a comprehensive case study still feasible. Other cases were abandoned or replaced due to an overall lack of useful data *(see summary of changes to the case study portfolio below).* Yet other case studies proved to benefit from exceeding the quota of 8-10 interviews. In principle, it can be assumed that a sufficient number of interviews were conducted in each case in order to record all relevant dimensions of the survey that relate to the respective case. In total, 135 interviews were conducted. Spread across 18 cases, this amounts to an average of roughly 8 interviews per case. The number of interviews conducted in each sector can be found in Table 1.

(2) Site visits

The methodological protocol also stipulated that each case study should aim to include two site visits. Site visits took different shapes for different cases, including field trips to company offices and factories, attendance of industry conferences and workshops, observation of debates, and visits to related sites (e.g. pertinent regulatory offices or comparable competing production sites). On average, the goal of undertaking two site visits per case was reached. However, similarly to interviews, this average is a result of some cases surpassing this quota, and some cases not reaching it. Again, this is due to different reasons.

In some cases, field trips seemed unnecessary because key figures from considered locations had already been interviewed remotely, and a site visit could not be expected to produce a reasonable amount of additional valuable information. In other cases, site visits would have incurred expenses that were disproportional to any possible added value they may have brought. Other cases lent themselves to more than two site visits because of conveniently dispersed locations or conference visits that would have been undertaken regardless. The number of site visits undertaken for each sector can be found in Table 1.

Sector	Total number of cases	Total number of interviews	Average number of interviews per case	Total number of site visits	Average number of site visits per case
Steel	5	29	6	6	1
Plastics	4	36	9	11	3
Paper	3	10	3	4	1
Meat & Dairy	4	41	10	7	2
Finance	2	19	10	8	4
TOTAL	**18**	**135**	**8**	**36**	**2**

Table 1: Cases, interviews and site visits per sector

Changes to the case study portfolio

A few changes have been made to the portfolio of case studies as it was outlined in Deliverable 3.2. The necessity to allow for such changes (e.g. due to lack of interview access or other forms of data collection) was anticipated and stipulated in Deliverable 3.2. To provide an overview of the updated portfolio, changes are outlined in the following:

The *Carbon2Chem* case, which is located at the intersection of the steel and chemical industries, has subsequently been moved to the plastics section, as interview access was much more abundant on the plastics side, and the intervention's market effects are expected to be higher there as well. The other five steel cases *(Castrip, HYBRIT, MX3D, DOCOL Light Steel* and *Voluntary Environmental Standards)* have remained unchanged.

The *Triodos & Naty* case, which was originally set out to focus on the intersection of plastics and finance, has turned into a pure finance case due to a lack of interview access to *Naty* or other companies receiving investment from *Triodos' Organic Growth Fund*. The *DuraPulp* case ran into similar difficulties, and was consequently switched for *DuraSense,* and moved to the paper section. The remaining plastics cases *(Enerkem, Tierra and Plastic-free supermarkets)* remained unchanged, so that, with the addition of *Carbon2Chem,* a total of four cases were conducted in the plastics sector.

In the paper sector, the *Dewatering* case was abandoned due to issues with both internal coordination and overall data access. The other two paper cases *(Äänekoski Bioproduct Mill* and *SCA Lime Kiln Conversion)* were pursued, adding up to three case studies in the paper sector including the *DuraSense* case.

For meat and dairy, the *FarmDrop* case was abandoned due to a lack of interview access. Work on a similar case study on the *Open Food Network* has since been taken up, but due to time constraints is not yet advanced enough to produce sufficient information for a comprehensive summary within this Deliverable. The other four meat and dairy case studies *(FrieslandCampina Green Bonds, Green Protein Alliance, Oatly* and *Cultured Meat)* were conducted as planned.

As for the finance sector, the *EIB Minimum Quota* case study has run into some difficulties with time constraints and interview data, so that a comprehensive summary could not yet be produced. The *Fossil-free Churches,* however, was carried out as planned. With the *Triodos*

case being moved over from the plastics sector, this still adds up to a total of two cross-sectoral finance cases.

Presentation of Case Study results

The results of each case study were laid out in case study reports, using the template devised in Deliverable 3.1. In addition to this longer-form report, case study authors were provided a template designed to succinctly but comprehensively sum up the main aspects and key insights from each case. The resulting factsheets are the mechanism by which the decarbonisation case studies are summarised and presented in this Deliverable.

In addition to the case study reports and factsheets, the primary data that each case study produced has been recorded using the excel template which was also designed as part of Deliverable 3.1. These data sheets will be made publicly available as part of the Horizon 2020 Open Data pilot.

Not all cases produced all three formats. Some cases ran into problems with interview access or obtaining other kinds of data; they were, however, still of an overall interest for the project, their findings being sufficiently represented in the short factsheet format that a longer report was not necessary. All authors have filled in, or are in the process of filling in, the primary data sheet.

Table 2 provides an overview of the current state of each product for each case study.

Case	Report	Factsheet	Primary Data Sheet
STEEL			
Castrip	Finished	Finished	In progress
HYBRIT	In progress	Finished	Finished
Voluntary Certification Schemes	Finished	Finished	In progress
MX3D	Finished	Finished	In progress
DOCOL Steel	Finished	Finished	In progress
PLASTICS			
Tierra	Finished	Finished	Finished
Enerkem Rotterdam	Finished	Finished	In progress
Plastic-free Supermarkets	Finished	Finished	Finished
Carbon2Chem	Finished	Finished	Finished
PAPER			
Äänekoski	No full report	Finished	In progress
Lime Kiln	No full report	Finished	Finished
DuraSense	Finished	Finished	In progress
MEAT & DAIRY			
Friesland Campina	Finished	Finished	In progress
Green Protein Alliance	Finished	Finished	In progress
Oatly	Finished	Finished	Finished
Cultured Meat	No full report	Finished	In progress
Open Food Network	No full report	In progress	In progress
FINANCE			
EIB Minimum Quota	No full report	In progress	In progress
Fossil-free Churches	Finished	Finished	Finished
Triodos	Finished	Finished	Finished

Table 2: Current state of output from each case study

3 Steel Case Studies

Five case studies have been conducted in the steel sector. The Castrip case looks into a technical process innovation that integrates the casting and rolling steps in steel production. The HYBRIT case study analyses the development of hydrogen direct reduction technology as an alternative to the blast furnace route. A case study analysing a social innovation on the consumption end of the steel value chain looks into Voluntary Certification Schemes in the building sector. Also on the consumption side is the case of MX3D, an additive manufacturing technology for steel that uses robot technology to build large structures. DOCOL Light Steel is a case study of using high-strength steels for lightweighting to reduce the amount of material needed.

3.1 Castrip

Innovation:	**Strip casting in steel production**
Intervention:	**Castrip**
Case Study by:	Annika Tönjes (Wuppertal Institute)
Methodology:	3 interviews, 2 site visits (Limited interview access, especially to actors within Castrip consortium)
Case Study Overview	
Sector(s):	Steel
Value Chain Stage(s):	Production
Type of Intervention:	Technical
Date & Duration:	1985 (ongoing)
Location:	Australia/Japan/USA
Initiating Actors:	BHP (Australia) IHI (Japan)
Actor Constellation:	BHP Steel (now BlueScope Steel; steelmaker initiating R&D) IHI (machine manufacturer partnering with BHP for R&D) Nucor (steelmaker pushing for industrial scale, first to use Castrip technology at their plants) Castrip LLC (joint venture between BHP, IHI and Nucor licensing the technology to steelmakers)
Short Description of Intervention:	When looking at carbon emissions in the steel industry, the focus often lies on the iron- and steelmaking steps in primary steel production, i.e. the CO_2 directly released from the blast furnace and basic oxygen furnace. For secondary steelmaking, it is the indirect emissions caused by an electric arc furnace through the use of electricity generated from the burning of fossil fuels. Often overlooked are the less carbon-intensive but still significant finishing steps that follow, independent of the steelmaking route: casting and rolling. The standard set-up for large integrated steel mills is to have a continuous caster (casting liquid steel into slabs) and a hot-rolling mill (rolling slabs into steel strip). This two-step process not only requires a lot of space, but also a lot of energy. After the casting process, the slabs cool down significantly, and subsequently need to first enter a reheating furnace before being ready for hot rolling. Strip casting is an innovative process that combines the steps of casting and rolling into one. There have been variations of this concept; the Castrip process is a twin-roll strip-casting

	process, in which liquid steel is directly cast between two rolls, usually requiring only minimal additional finishing, depending on the application. This significantly cuts down on energy usage and, as a result, on carbon emissions, energy costs and the capital costs and physical space required for on-site hot rolling. This opens smaller-capacity steel mills up to new possibilities: these so-called 'mini mills' would normally have to outsource the hot-rolling process due to capital and space restrictions. By operating an on-site strip caster they can have the benefit of producing higher value-added products, while cutting down on both process and transport emissions. As one of the major players in the mini-mill sector, American steel company Nucor was a strong force behind bringing the strip-casting technology developed by BHP and IHI to market. The three companies formed Castrip LLC in 2000, and Nucor has since begun operation of Castrip strip caster at two of their sites.
Research Theme Summaries	
1. Innovation History & Dynamics:	The Castrip consortium was one of many in the long race to commercialise strip-casting technology for steel. The idea of a twin-roll strip-casting process for steel is over 150 years old, originally going back to an 1857 patent by renowned English inventor Sir Henry Bessemer. Due to technical difficulties (especially with regard to controlling the rolling speed and temperature in the rotating mould), the concept was taken up and then abandoned several times over the decades. While it was successfully applied to other metals quite early on, the thermal-physical properties of steel continued to pose a strong technical barrier. A new rush to commercialise the technology in an increasingly competitive market led to the emergence of numerous R&D consortia in the 1970s and 80s, the driving force behind which were the steelmakers themselves wanting to reap the economic benefits such a technology could bring. They usually teamed up with either a machine manufacturer or engineering firm to develop different variations of the strip-casting process for steel. Some received initial funding, then ran into financial difficulties when it was time to take their strip casters to an industrial scale. What is more, the emergence of thin-slab casting technology brought about some significant efficiency gains, which meant that further possible efficiency gains were now smaller, reducing incentive to invest in strip casting. Many of these consortia dissolved as a result of this. The R&D partnership that was initiated between BHP and IHI in 1985, however, received a fresh boost when Nucor Nucor became involved in 2000. Strip casting technology is particularly suited to small-scale production of specialty steels, while capacity limits have so far prevented the technology from being scaled up to large-scale carbon steel production. Furthermore, the long lifecycles of existing continuous casters and hot-rolling mills means that the need for replacement, and consequently also the adoption of new technologies like strip casting, is very slow. Some of the initial technical barriers also still remain, preventing the application of the process to certain alloys. A competing strip-casting innovation is the belt casting process developed by SMS, which has been in trial use at Salzgitter since 2012.
2. Governance Arrangements & Agents of Change:	There were numerous R&D consortia working on the development of strip-casting technology. Innovation was strictly driven by steel companies, with support from machine manufacturers, but limited contributions from universities and public research facilities. The R&D consortia monitored each other's activities, and benchmarked themselves against the others' progress. After more and more of them closed down their R&D activities, only three remained: next to what is now Castrip, the other remaining consortia included EUROSTRIP and a collaboration between Nippon Steel and Mitsubishi. There was no public funding for Castrip; initial investment was largely carried by BHP (and some by IHI). Castrip LLC is owned in equal parts by BHP and Nucor, with IHI also holding a small percentage. Nucor carried the investment to get its first Castrip plant up and running. Altogether, estimates suggest that between 1980 and 2000, roughly 1-2% of the global steel industry's annual R&D spending went into strip-casting technology. Some of the competing R&D consortia received some public funding. Interestingly, none of them reached industrial scale, while the ones that did received no (or only minimal) funding. The development of strip casting was mostly driven by the prospect of saving on capital costs (investment for a strip caster is significantly lower than for a continuous caster and hot-rolling mill) and operating costs (especially by cutting down on energy and transport costs). Over strip casting's long innovation cycle, investment in R&D was particularly high

	when energy costs were high, as well as during the steel crises, which strengthened the need for more flexible and more compact process technologies. The other main driver, particularly for Nucor, was to integrate casting and rolling in mini mills, which would open up new market segments for them (e.g. the U.S. construction market for sheet steel). The prospect of turning a profit on thin strip steel at much lower output rates than are required for large integrated mills was appealing in a market that increasingly demanded flexibility. One important occurrence was Allegheny's 1984 claim to have had success in steel strip casting. This helped establish strip-casting technology as an important (and feasible) next step on many steelmakers' agendas, strengthening firm internal support for its development.
3. Transformative Capacities:	Seeing as the Castrip initiative was the first to put their strip casters to commercial use, it can be said that it was quite capable of generating the skills, knowledge and resources required for implementation. The Castrip process's low-carbon qualities were not distinguished by the consortium or the LLC at all. It was marketed as a way to cut costs, particularly energy costs, and as an option for small sites to become competitive in a new segment. It stands to reason, that this innovation would be marketed differently today, as the need for deep decarbonisation has started to appear on the industry's agenda. In fact, there is some evidence for this: Older press releases, news articles and scientific publications do not reference emissions at all. Only more recently (e.g. in announcing the licencing of Castrip technology to the Chinese Shagang Group) has the reduction of CO_2 emissions been mentioned as one of the technology's benefits.
4. Assessment & Evaluation:	Over the years, some estimates on emissions reductions have been made based on the energy savings reported by Castrip. According to these calculations, the Castrip process can reduce CO2 emissions by 80-90% over those from conventional casting and hot rolling. There are currently no estimates on absolute emissions reductions achieved at the plants currently operating a Castrip line; nor are there estimates of potential contributions that could be achieved by upscaling the innovation. So far, some technical limitations prevent such predictions from being feasible, as it is unclear whether the technology will be able to reach larger scales.
5. Uptake & Consequences:	In recent years, Castrip technology has been licensed to steel manufacturers outside of Nucor, in order to help the technology expand. The first of these licensees was Mexican steelmaker TYASA, who built a Castrip line near Orizaba, Veracruz. Chinese steelmaker Shagang has also constructed in Castrip line, and the technology has since sparked interest from British start-up Albion, leading them to consider building a Castrip line. So far, the technology has not achieved upscaling to capacity levels of large integrated steel mills. It will, however, be interesting to see future development as steel stocks saturate in developed countries and more and more steel could be made in smaller, secondary production facilities for which Castrip technology is well suited. The compactness of the technology also opens the industry up to new possibilities in terms of location: production could be set up much closer to customers, and could possibly even be integrated in the factories themselves.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* Strip-casting innovation has spanned 150 years, which is a remarkably long time period even for the slow-moving steel sector. This makes it a very compelling case study, as the influence of market factors (steel crises, energy prices, demand for increased flexibility) and step-wise innovation making processes incrementally more efficient (from ingot casting to continuous casting to thin-slab casting to strip casting) can be observed with unusual clarity. *Key insights from this case regarding …* *Overall decarbonisation:* While the finishing steps of casting and rolling are not the main culprit when it comes to GHG emissions from the steel industry, they can still play an important role in decarbonisation. Their significance will become clearer as deep decarboni-

	sation is achieved in primary and secondary steelmaking (e.g. through hydrogen direct reduction, CCS/CCU and the use of low-carbon electricity), making the need for efficient processes further down the value chain more apparent. *Drivers:* The relentlessness of the steelmakers in wanting to commercialise the technology (and the significant R&D investments that were made) show just how powerful a driver the prospect of cost reductions through efficiency gains can be. Looking ahead, an increase in CO_2 costs could prove to be an equally powerful incentive. What is more, the technology's suitability for smaller-scale production is an interesting driver that could play an important role as future steelmaking shifts more toward secondary production. *Barriers:* Up to this point, the main barriers to the further spreading of strip-casting technology have been related to long equipment lifecycles and technological limitations (some in terms of quality, but mostly in terms of scalability). *Instruments to overcome them:* The technology has already overcome a lot of its initial technical limitations, so continued innovation could prove to solve remaining quality issues. It will be interesting to observe whether strip-casting technology adapts to large-scale steel production, or whether there will be less pressure to do so as smaller, more local production gains importance. *Role of policy:* The bulk of the innovation process took place before decarbonisation entered any political agenda. As an energy-efficient option that could be suitable for any production route, it should be interesting to see if the technology will benefit from such policies in the future. As for public funding, the innovation process does not seem to have been negatively impacted by the fact that it did not receive any. The cost-cutting incentives were sufficient to merit full investment from the involved companies.
Open Questions & Further Research Requirements:	Future research could monitor the on-going development and dissemination of the technology, and address the possibilities for scaling it up to be used in big integrated carbon steel plants, and its application for different steel grades. Will the technology remain limited to small-capacity mini mills? How much of global thin-strip steel production could technically be covered by strip casting? Are there further efficiency improvements that could potentially be realised in the future (e.g. by further decreasing the need for secondary finishing)? What could be the technology's overall contribution to the decarbonisation of the steel sector?

3.2 HYBRIT

Innovation:	**Fossil-free steelmaking through direct reduction of iron ore using hydrogen as reductant (H-DR) and fossil-free mining and pelletisation of iron ore.**
Intervention:	**The HYBRIT project**
Case Study by:	Alexandra Nikoleris (Lund University)
Methodology:	7 interviews, 1 site visit, desktop research. Limited access to interviewees due to reported time constraints and secrecy.
Case Study Overview	
Sector(s):	Steel (Encompassing mining and energy for hydrogen production)
Value Chain Stage(s):	Resource and production
Type of Intervention:	Technical
Date & Duration:	The HYBRIT initiative was publicly announced in April 2016. The pilot phase started on 1 January 2018 and will last until 2024. The whole initiative is planned to last until 2035 when commercialisation is planned.
Location:	Sweden
Initiating Actors:	SSAB
Actor Constellation:	HYBRIT Development AB, a joint venture by SSAB, LKAB, and Vattenfall. HYBRIT Development AB is the 'project leader' and the actor responsible for the H-DR pilot. SSAB and Vattenfall have been the two parties mainly responsible for communication and public relations. LKAB is responsible for the pelletisation trials. Vattenfall is responsible for the hydrogen production and building new capacity for electricity generation and distribution. The Swedish Energy Agency has been the main funding body. The research programme which is part of the initiative involves several actors: Swerim/Mefos, Sandvik, SEI, RISE, Luleå technical university, KTH and Lund University.
Short Description of Intervention:	HYBRIT, acronym for Hydrogen Breakthrough Ironmaking Technology, is a development project with the aim of implementing fossil-free steelmaking in all stages of production; from iron-ore extraction, through pelletisation and reduction (iron-making), to the final steelmaking (in electric arc furnaces). For this to be possible, fossil free electricity production is needed, which will be used for hydrogen production (for the direct reduction of iron ore), for the electric arc furnaces (for melting of sponge iron and adding materials, most notably carbon, to make steel), and for parts of the mining and processing of iron ore (pelletisation). The HYBRIT project consists of several parallel parts. Two pilot plants are being built at the moment, one for direct reduction using hydrogen with steelmaking in an electric arc furnace and one for fossil-free heating technologies for the pelletisation of iron ore). Both pilot plants are run as separate projects from RP1, partially financed by the Swedish Energy Agency with HYBRIT Development AB as the recipient. A research project, called RP1, involving several research institutes and universities (listed above), is studying the potential side-effects and possibilities of implementing fossil-free steelmaking in Sweden as well as specific technological solutions (such as hydrogen storage or the handling of vanadium contamination in the electric arc furnaces). RP1 covers the resource and production stages of the value chain, including system integration and policy strategies.
Research Theme Summaries	
1. Innovation History & Dynamics:	If fossil-free steelmaking as a whole is to be seen as the innovation, this has never been done before. Most of the processes build on established technology and earlier research, including hydrogen production and storage, plasma-heating, and direct reduction of iron ore using hydrogen (which is currently not in commercial use). The innovative aspect of the HYBRIT project is ensuring that all processes rely on fossil-free electricity generation or renewable sources of carbon (biomass) and the scale on which these technologies are being implemented.

	SSAB and LKAB had earlier been involved in the ULCOS programme where direct reduction using natural gas and CCS had been trialled. In the light of Swedish climate policy and the Paris agreement the ambitions of these tests (to reduce carbon emissions by about 50%) did not 'solve the issue'. The first step of HYBRIT was a pre-feasibility study, which concluded that fossil-free steelmaking would be possible in Sweden, meeting few major difficulties. Large-scale hydrogen production and storage is also planned to be built and following the pilot plants, demonstration plants are envisioned before commercialisation in 2042. The mining and pelletisation is not envisioned to be fossil free until 2045. The main challenge identified is the potential lack of financial support and competitiveness on the market. This innovation is probably only viable under conditions of (global) ambitious climate policies, which require more than 80 % reduction of greenhouse gas emissions before 2050, since that would require that at least CCS be implemented on all primary steelmaking. At this stage of the initiative, no unintended consequences can be identified.
2. Governance Arrangements & Agents of Change:	This initiative is organised as a public-private partnership with substantial governmental support. The project is implemented and governed through the formation of a joint venture, HYBRIT Development AB, which is responsible for recruiting the required competence. Required competence is deemed to exist or will be built through the pilot trials and research project. An overall lack of graduate students in the areas of mining and metallurgy might become a problem in the future. Two of the three companies (LKAB and Vattenfall) with joint ownership of HYBRIT Development AB are state owned. The different projects included in the HYBRIT initiative are funded by the Swedish Energy Agency by on average 50 % per project, with a total sum of 598 838 005 SEK. Most of the funding is done through the programme 'Industriklivet' (The Industry Step) which was initiated in 2018 by the government. Political support, not only through ambitious climate targets, but also through financial support is deemed crucial for this initiative to succeed. Ambitious climate targets (the Paris agreement and the Swedish vision of reaching net-zero emissions by 2045) are referred to as the main drivers for why HYBRIT was initiated.
3. Transformative Capacities:	It is too early to assess the extent to which HYBRIT will be successful in generating skills, knowledge and resources for implementing fossil-free steelmaking. The governance structure with close collaboration and the assessment by interviewees does suggest it has the capacity to do so. HYBRIT builds on the vision by the Swedish steel association, Jernkontoret, from 2013, called 'Stål formar en bättre framtid' (Steel shapes a better future) which states that the Swedish steel industry should only contribute positively to society, reducing waste and emissions. It also builds on the aim taken by Swedish parliament to reach net-zero emissions of greenhouse gases by 2045. Communication of the HYBRIT project is aligned with these visions but the key word is 'fossil free' rather than zero emissions. One reason for that is to show that this initiative solves the 'root problem' rather than fixing the emissions. So far there is unequivocal political support and general acclamation in public discourse (social and established media) and HYBRIT is praised as an example of how the 1.5-degree target can be met.
4. Assessment & Evaluation:	HYBRIT has so far mainly been internally assessed and is assessed continuously, through RP1 and the other projects. Metrics for assessment have not been accessible. Evidence of carbon emission reduction is put forward in the feasibility study, which was done 2016-2018. This shows that close to zero emissions of fossil carbon are possible, with an expected reduction by 99 %. The actual carbon emission reductions will depend on how the electricity is produced as well as the carbon balance of biomass which will be used. Wind power is the envisioned power source for HYBRIT and Sweden already has low carbon emissions from electricity production, so the reduction assessment is reliable. Close to zero emissions of fossil carbon dioxide are possible. The emissions from fossil coal are expected to be reduced by 99 %.
5. Uptake & Consequences:	As the HYBRIT initiative is just at its beginning, it is difficult to assess uptake and potential consequences. There is a growing international interest in alternatives to blast furnace steelmaking and hydrogen reduction in particular. Core to the narrative on HYBRIT is that

	this is a 'breakthrough' technology, which will address the problem 'at its root' and it therefore seems hard to incorporate in business-as-usual narratives. It still has elements of the latter narrative, however, in that it sustains the idea of primary steelmaking (iron-ore based). Interviewees deemed primary steelmaking to be necessary during this century because of urbanisation, improved material standards of living and a growing global population, but a growing steel stock (the amount of steel present in society) would make secondary steelmaking (scrap based) the largest steelmaking route after mid-century. Potential social and ecological consequences are mainly related to the amount of extra electricity generation needed for hydrogen production where access to land and disturbance of wildlife habitats might create conflicts. This is connected to the growing interest in electrification in general among many industries and for transportation.
Conclusion & Outlook	
Key Learnings:	HYBRIT is one of a number of initiatives which show that it is possible to make fossil-free steelmaking a reality. Even if the concept is not proven yet, the narrative itself is challenging because it refutes the (formerly) dominant (but decreasingly so) claim that carbon emission reductions could only be met with CCS for the steel industry. A main factor for explaining the success so far for this initiative is the very close collaboration between companies from different sectors and a joint commitment to align to societal goals of net-zero emissions. This builds on well-developed trust and collaborations, especially between SSAB and LKAB, and the conditions of the Swedish steel industry with a high specialisation and close to zero competition between steel companies which enables a joint undertaking such as Jernkontoret's vision. Timing is another factor to explain the success. One of the two last blast furnaces in Sweden is reaching end of life and with today's climate policies investment in a new blast furnace is not deemed to be a good choice. The Swedish conditions, with low-carbon emissions from electricity generation, iron-ore production, and steel production already focused on specialty steel, provide good opportunity to test fossil-free solutions. All assessments done on the feasibility of HYBRIT and the narrative which it produces builds on political commitment to meeting the Swedish goal of net-zero emissions by 2045. Without this goal, support from politics, and the expectation of continued general commitment to meet this goal, this initiative would be very difficult to implement. SSAB has for many years been identified as the top emitter of greenhouse gases in Sweden. The steel sector has been pointed to as one of the 'problematic areas,' which has to some extent contributed to the change of narrative in the steel industry. The actors do not want to be seen as part of the problem, but part of the solution.
Open Questions & Further Research Requirements:	

3.3 Voluntary Certification Schemes

Innovation:	**Voluntary low-carbon building standards**
Intervention:	**BREEAM 2018 New Construction standard (UK)**
Case Study by:	Bregje van Veelen (Durham University)
Methodology:	10 interviews, participant observation at 3 industry workshops/conferences, extensive analysis of grey literature
Case Study Overview	
Sector(s):	Steel
Value Chain Stage(s):	Consumption
Type of Intervention:	Social
Date & Duration:	First BREEAM certification was launched in the UK in 1990. Current version for New Construction (under investigation here) launched in 2018.
Location:	United Kingdom. Although other versions of BREEAM are operational in other countries.
Initiating Actors:	BRE (centre of building science in the United Kingdom, owned by charitable organisation the BRE Trust. It is a former UK government national laboratory that was privatised in 1997.)
Actor Constellation:	BRE Group, BREEAM assessors (responsible for building certification, employed externally) BREEAM associates and advisory professionals (employed by project teams to provide advice before, during or after the assessment) Local planning authorities (decide planning permission) UK Government (building regulations) Wider building value chain constellation (architects, developers, owners, tenants, (sub)contractors, suppliers)
Short Description of Intervention:	The building sector is a major consumer of steel, and we therefore focus on the role this sector can play in reducing emissions from steel. In particular, we analyse the role that industry-led, voluntary standards can play in fostering a reduction of 'embedded emissions': a reduction of emissions associated with the construction (rather than operation) of buildings. We explore this through the case of the BREEAM 2018 New Construction certification scheme, which is operational in the UK. BREEAM NC 2018 is a voluntary scheme that assesses the environmental impact of new commercial buildings. One of the nine categories that the scheme assesses is the impact of building materials, which is the focus of this case. There are five ways in which BREEAM 2018 seeks to reduce embodied emissions. These are primarily social/procedural in nature, e.g. the conducting of Life Cycle Assessment and integrating its outcomes in the design decision-making process; responsible sourcing of construction products; and optimising material use. The scheme has the potential to provide a more robust driver for reducing embedded emissions in building: it has increased the number of credits available in the 'materials' category, and requires developers and contractors to consider material impacts in various ways and at different stages of the building process compared to previous versions of BREEAM. The case shows, while much of the discussion around certification and standardisation revolves around the challenges of measuring embodied emissions, the report shows the challenges around measuring whole life embodied carbon are (1) political

	as well as technical in nature, and (2) only one part of a larger 'implementation puzzle'. However, as the scheme in its current form only came into operation last year, it is difficult to assess its realised impacts.
Research Theme Summaries	
1. Innovation History & Dynamics:	In response to increasing demand for sustainable buildings, a large number of building environmental assessment and green building certification schemes have been created to better identify best practices in green building construction since the 1990s. There are schemes operational on all continents, although most of these schemes only operate in a single country (BREEAM operates in multiple countries, however). To date, BREEAM has been used to certify over 590,000 assessments of buildings across the building life cycle and is being applied in over 78 countries. While many such schemes traditionally focused on operational emissions and impact, BREAM and LEED now also include more extensive assessments of embedded emissions. One of the key reasons why this had not been much included to date is due to the difficulty in developing accurate information of embedded emissions at product and building-level.
2. Governance Arrangements & Agents of Change:	As BREEAM is a voluntary scheme, it is up to a building developer to indicate they would like to have their building certified. In order to achieve a high score, the 2018 scheme makes it essential that the choice of materials is considered early in the building process, and communicated to the multiple other actors involved in the construction process, including design team, contractors, and sub-contractors, and should thus foster greater coordination between actors. At the heart of the assessment/certification are independent assessors, licensed by BREEAM, who assess a new building, submit the required information to BREEAM, and ensure that it meets the quality and performance standards of the scheme. Initiatives by cities such as London and the UK Green Building Council and initiatives to achieve a „net zero carbon" built environment, have also helped to shift the focus from operational to embedded emissions.
3. Transformative Capacities:	Two forms of inertia: (1) whether embedded emissions are at all considered, and (2) if they are, if this is subsequently translated into action. Previous versions of BREEAM were said to address neither form. The 2018 scheme has the potential to address (1) by ensuring developers need to consider embodied emissions, which also means suppliers and other stakeholders need to improve the availability and communication of embedded carbon in different products. However, most points in the ‚materials' category in BREEAM are available for considering different material options, not necessarily implementing the lowest-carbon option. It is therefore unclear if BREEAM will address (2). Also, use of timber in buildings is contested not on environmental ground, but safety: recent legislation that prohibits use of some forms of timber in some multi storey buildings may inhibit the uptake of alternatives. As the low-carbon qualities of materials are not yet made very visible and valued, most developers continue to choose steel and concrete in building structures.
4. Assessment & Evaluation:	There are a small number of evaluations of previous BREEAM schemes, although these mostly focus on motivations for choosing BREEAM, rather than (environmental) outcomes. Despite the development of numerous international standards to measure embedded emissions/conduct Life Cycle Assessments, there also continue to be inconsistencies in measuring embedded carbon, which remains one key barrier to developing an evidence base for the impact of BREEAM – or any other initiative – on carbon emission reductions in buildings. This is partly a social/political (rather than technical question) around the attribution of emissions to different parts of the value chain. Numerous interviews said that schemes such as BREEAM may be useful for clients who don't know much about sustainability or have to use it (see drivers discussed below), but may be too restrictive for those who want to be truly innovative.
5. Uptake & Consequences:	Scaling up: there is potential for replication, but most interviewees agreed that voluntary schemes will never be successful in addressing embedded emissions to the extent needed. However, by assigning more credits for use of products that have

	EPDs (environmental product declarations), BREEAM does have the potential to improve communication of environmental impact of materials further down the value chain, potentially stimulating innovation there. While there was little evidence for additional social or economic impacts, there is a risk that the notion of low- and zero-carbon buildings potentially narrows the notion of sustainable buildings to one that assumes existing political, economic, and social institutions can provide such buildings, rather than requiring more widespread change. Here, the benefit of BREEAM is that developers will need to address multiple (primarily environmental) dimensions, thus also leading to other environmental benefits (e.g. water conservation).
Conclusion & Outlook	
Key Learnings:	*Unique features:* One of a small number of voluntary building certification schemes to consider embedded emissions in construction materials. Requires 'options appraisal', i.e. comparison of different material options, making potential for decarbonisation more legible. However, developers don't necessarily need to act on this to score well in BREEAM, other considerations (e.g. cost) may still be more important. *Key insights from this case regarding …* *Overall decarbonisation:* Direct decarbonisation is difficult to measure. Currently there is no information available (to the author) regarding how much better BREEAM buildings are to non-BREEAM ones, and how much of this possible difference can be attributed to reduction of use of steel (and concrete). *Drivers:* For developers: BREEAM certification as a planning requirement, value increase/higher rent, organisational policy. Technological innovation to measure life cycle emissions has been a driver enabling BREEAM to incorporate embedded emissions in more detail into the standard than before. *Barriers:* Complexity of steel/buildings value chain. Lots of different actors involved, a 'herding cats' problem to get everyone on the same page. E.g. contractors may be incentivised to choose low-cost rather than low-carbon options. In the UK, legislation post-Grenfell disaster both limits use of timber in high buildings, and has (to some extent) led to renewed stigma – developers more reluctant to use it, even if allowed. As a voluntary scheme, BREEAM has to 'move with the market', can't be too far ahead of it or people will not use it. *Instruments to overcome them:* Stimulation of earlier consideration of emissions in buildings/materials meant to ensure those conversations are had between different actors early on, overcoming issue of BREEAM being used as a 'tick box' exercise at the end of the construction process. By stimulating greater development of environmental info (by awarding points for use of products with EPDs), BREEAM stimulates improvement of measurement and provision of environmental data upstream in value chain. *Role of policy:* Most interviewees agreed legislative action is needed. Voluntary schemes alone are insufficient in driving change across the sector. Need updated building standards to drive deep decarbonisation in buildings. Currently, enhanced building regulations are considered by sub-national governments, e.g. Greater London Authority. *Lessons for future innovations:* Most interviewees agreed that previous versions of BREEAM had failed to encourage significant impact (regarding embedded emissions) because it was too easy to use it as a tick box exercise at the end, rather than integrate in decision-making during the construction of building. New version seeks to address this, but too early to tell if successful.
Open Questions & Further Research Requirements:	Further research needed in 2-4 years' time when BREEAM 2018 has been in operation, to see how it has influenced decision-making by developers and other stakeholders. Also: whether improvement of environmental information of products (EPDs, Life Cycle Assessments) will lead to choice of lower-carbon options, or whether other incentives are necessary to do so.

3.4 MX3D

Innovation:	**Wire Arc Additive Manufacturing (WAAM) for Steel**
Intervention:	**MX3D**
Case Study by:	Andreas Pastowski, Georg Kobiela (Wuppertal Institute)
Methodology:	4 interviews, extensive desk research
Case Study Overview	
Sector(s):	Steel
Value Chain Stage(s):	Steel processing (but requirement to consider the whole value chain owing to spill-overs)
Type of Intervention:	Technical
Date & Duration:	Started development of robotic printer for resin in 2012; innovation ongoing
Location:	Amsterdam, Netherlands
Initiating Actors:	MX3D ArcelorMittal City of Amsterdam
Actor Constellation:	MX3D ArcelorMittal City of Amsterdam Autodesk Heijmans Air Liquide Oerlikon Lenovo ABB Plymovent OCAS Delft Technical University
Short Description of Intervention:	Additive Manufacturing (AM) with metals has primarily evolved as Powder Bed Fusion, where objects can be formed out of metal powders using laser or electron beams. However, these processing technologies have their limitations in terms of minor deposition rate and limited size of object resulting from the size of the building chambers required. Nevertheless it has greatly evolved using aluminium and titanium for maximum weight reductions with components for aviation and space missions. Wire Arc Additive Manufacturing (WAAM) combines industrial welding robots, wires for welding and software that translates CAD designs of objects into the movement of welding robots to overcome these limitations. At the same time, wires for welding are cheaper than metal powders. With the bridge project, MX3D and its partners have undertaken an effort to showcase the technical and design potentials offered by WAAM steel processing in the construction sector. This required additional funding to cover the extra cost over a conventional bridge and finding sponsors for this. At the same time, substantial legal requirements had to be fulfilled to provide a bridge for use by the general public. As the end result a fully-welded pedestrian bridge for the City of Amsterdam has been entirely produced by WAAM using stainless steel wire.
Research Theme Summaries	
1. Innovation History & Dynamics:	Primarily developed for rapid prototyping, Additive Manufacturing (AM) has become an industrial processing technology and Wire Arc AM has evolved. Steel is somewhat heavy for

	certain applications (aviation and space) but there are plenty of potential ground-based use cases with vehicles, machinery and construction. The bridge project by MX3D has focused on depicting design options in construction but less on potential impacts on carbon emissions.
2. Governance Arrangements & Agents of Change:	3D printing with metals is high on research agendas and funding is generally available. WAAM with steel has been developed outside the domain of the conventional steel industry by more design-oriented start-ups. However, the bridge project involves specialised industries contributing to the diverse technical set-up of WAAM that would otherwise overstretch the capabilities of a start-up. Thus besides MX3D, various companies have been actively involved. Moreover, the City of Amsterdam has taken an active role in defining the bridge project and provided basic funding equivalent to a conventional pedestrian bridge, while other partners have contributed additional financial resources as sponsors.
3. Transformative Capacities:	Transformative capacities of AM and WAAM with steel rest with likely contributions to decarbonising steel value chains and business cases of the various potential use cases, most of which have not yet been sufficiently explored to date. However, transformative capacities of WAAM are not limited to the steel processing stage. Rather, spillovers to upstream processes and the use phase of steel value chains can be expected. Further on, MX3D will focus more on exploring other use cases of WAAM than on the diffusion of knowledge generated during the bridge project or on upscaling of related products and processing technologies.
4. Assessment & Evaluation:	An assessment of the potential carbon impacts of AM and WAAM involves particular methodological difficulties with steel structures which were impossible to be produced using conventional processing technologies. Moreover, the mentioned spillovers to carbon emissions during other phases of steel value chains increase the complexity of lifecycle-wide analyses and deserve additional projects that are sufficiently focused on such assessments. This mainly refers to the material efficiency of processing as such in terms of energy intensity and logistics related to material efficiency and geographical properties of value chains. Moreover reducing the weight of steel structures may have substantial impacts during the use phase. Thus at its current state of development, the carbon impacts of WAAM cannot sufficiently be assessed.
5. Uptake & Consequences:	As mentioned, WAAM may change the way steel is processed for certain applications. Based on the MX3D bridge project, one area of application is construction. However, ground-based vehicles and machinery may also benefit from lighter loads using relatively cheap steel instead of more costly metals. Beyond production of entirely new products, spare parts and on-site repair may be future core areas of application. So far, no unintended consequences of WAAM have been noticed, which may partly result from its very limited application. Given the early development stage of WAAM, it is highly speculative to assess its social consequences. WAAM mainly requires highly skilled workers for designing the products and translating CAD designs into movement of welding robots. The extent to which lower-skilled workforce might be deployed - amongst other factors - might be affected by the need to apply handcrafted post processing.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* WAAM with steel is a niche of AM with metals. It remains to be seen to which extent AM with metals and specifically WAAM will grow based on crowding out of conventional processing technologies as well as creating new products that previously were impossible to be produced. This Case Study is unique with regard to creating new processing technologies outside the main steel producing companies. However, it basically uses technologies developed for the automotive industry creating new options in steel processing. At the same time it differentiates itself from conventional production by its artistic features, which are not common for the steel industry. The overall decarbonisation of steel processing will not play the most important role for the steel sector as long as primary and secondary steel production is based on fossil reduction agents or electricity produced from fossil primary energy. However this will change during the decarbonisation of primary and secondary steel production that will increase the relevance of remaining potentials for reducing energy intensity. *Key insights from this case regarding …*

	Overall decarbonisation: The decarbonisation of steel processing on its own will not allow delivering decarbonisation of the steel sector as long as primary and secondary steel production are based on fossil reduction agents or electricity produced from fossil primary energy. However, this will change and the relative weight of steel processing for carbon emissions and other SDGs will grow. Notwithstanding this, while carbon-neutral primary and secondary steel production will require some time to be put in place, more efficient processing and use of steel along the value chain can make substantial contributions to reducing the overall carbon emissions of steel value chains. Once all primary and secondary steel production is carbon-neutral, the focus will switch to the attainment of other SDGs. *Drivers and barriers:* Customers, particularly from aerospace companies, are very risk averse. However, AM has mainly developed for these customers resulting from the enormous economic incentives offered by reducing the weight of vehicle components. Steel components are scarce in aerospace vehicles. Steel AM is more focused on components for ground vehicles, machinery and construction, where reducing the weight may not always yield cost reductions that can legitimate the use of relatively costly materials like aluminium or titanium. *Instruments to overcome them:* In the construction sector, WAAM with steel will require clients and architects to change their mind-sets and workflows. Governmental bodies at all levels may use WAAM for specific construction projects that simultaneously deliver an artistic visual appearance and allow for enhancing the range of experience with WAAM in the construction sector. As long as construction projects using WAAM result in cost increases over conventional designs, specific financing schemes will be required. *Role of policy:* Policy needs to assist financing of innovative construction projects that use WAAM. Financing activities in the construction sector should be accompanied by research projects that enable the assessment of the total carbon impact along the value chain and service life of structures processed by WAAM. Beyond the construction sector, financing may be readily available where benefits from the use phase can reduce TCO but there may be a lack of willingness to assess the total carbon impacts along the value chain. *Lessons for future innovations:* Niche projects are crucial for dealing with stakeholders' initial risk aversion. Moreover, such projects are required in order to test public acceptance as well as to generate sufficient experience necessary for creating a business case.
Open Questions & Further Research Requirements:	While steel is a relatively cheap material for early applications of WAAM, it might involve more fundamental issues for achieving WAAM business cases over more costly materials like aluminium and titanium that offer additional weight advantages.

3.5 DOCOL Light Steel

Innovation:	**Improved process technology and co-design with end users**
Intervention:	**DOCOL Steel**
Case Study by:	Duncan Kushnir, Lund University
Methodology:	5 interviews, extensive literature review (>30 peer reviewed papers)
Case Study Overview	
Sector(s):	Steel (and Automotive)
Value Chain Stage(s):	Manufacturing/Finishing
Type of Intervention:	Process Technology
Date & Duration:	1982 – Present
Location:	Sweden
Initiating Actors:	SSAB
Actor Constellation:	SSAB – producer Vehicle manufacturers – consumer / design and specification for steel Swedish Government – initial financier through guaranteeing a loan Associations (Jernkontoret, Worldsteel) - advocacy as well as knowledge and standards
Short Description of Intervention:	DOCOL steel is a range of steel grades produced specifically for automotive applications. The design objective for all DOCOL steels is to reduce the amount of steel needed for a given part while increasing overall vehicle strength. This is achieved through proprietary improvements in steel manufacturing which give superior material properties that are tuned specifically for individual applications through collaboration with the automotive manufacturers.
Research Theme Summaries	
1. Innovation History & Dynamics:	After a parliamentary decision in 1977, NJA, Domnarvets Jernverk and Oxelösund were merged into a single company, SSAB, with the Swedish State as the owner. One possibility for upgrading Domnarvet was to try and produce extremely high grade steel. The brand of DOCOL steel and idea of targeting the automotive industry was conceived during the Iran oil crisis, first mentioned in the SSAB annual report in 1979 and protected as a brand name in 1980. Producing DOCOL steel required an entirely new process, and the Swedish government was an early supporter of the effort. At first DOCOL comprised only cold rolled steel products, but over time grew to include every type of steel. The turning point according to SSAB was formation of the ULSA consortium with other producers of AHSS and the 1995 ULSA case study on a future vision for how far high strength steels could go to reduce the weight of vehicles and the resulting benefits. Subsequently, there was an increased interest in using AHSS to lightweight vehicles, which has developed and refined more or less continuously to the situation of today.
2. Governance Arrangements & Agents of Change:	DOCOL steel has emerged as one of the six main product brands of SSAB and operates as its own division comprising an entire vertical. DOCOL teams have a one-to-one relationship with many major car manufacturers and customer parts producers. Legislatively, fuel economy standards now exist in most OECD countries, providing one source of constant pressure for lightweighting vehicles. A related institutional change is the spread of vehicle safety regulations, which place specific mechanical needs on certain parts that are not related to lightweighting. These needs for safety and crash resistance are considered by SSAB to now be the second major driver of automotive material design. DOCOL steel appears to follow the general governance model of most advanced steel production: develop the capacity to reliably produce better material qualities, then suggest and market applications, or listen to needs and engineer the appropriate material. The people spoken to at SSAB did not consider it materially different from other advanced steels they

	produce, simply focused on a specific need set of the automotive industry and thus attuned to their processes.
3. Transformative Capacities:	DOCOL initiative has maintained a portfolio of the highest grade of steels available for at least thirty-five years. The transition from the first few cold rolled products to the offerings comprising every type of steel today and sold in increasing volumes into a global market is incontrovertible evidence that the initiative has indeed been successful in generating the skills, knowledge and resources required to implement the product. Decarbonisation was not an explicit focus until later in DOCOL's history, although it is a natural consequence of improving transport energy efficiency. In many ways, this vision is still the one permeating DOCOL and the application of advanced steels in general. "A stronger, lighter, more sustainable world". At first the vision was about resources and the environment in general, but by their first environmental report (2008) it was also linked to climate change. DOCOL proved to SSAB (through sales and demand) that steels specifically targeted at applications in order to use less but higher quality steel was a viable business model. DOCOL was one of the product groups that survived SSAB's reorganization and served as a template on how to market green steel for 'greener applications' that permeates the company today.
4. Assessment & Evaluation:	DOCOL steel is more emission efficient than the global average for steel, but this is mostly due to the unusually pure iron ore in Sweden and the low carbon electricity supply. Many case studies exist documenting the impact of DOCOL steels in reducing the weight of individual components. There are also LCA studies showing the impacts of adopting lighter vehicle frames. DOCOL has without a doubt been successful in replacing steel components with lighter and stronger ones, in many verifiable case studies. There is thus evidence, that with each application, cars are lighter than they would have been and emissions lower than would otherwise have been the case. Yet the case cannot be made that overall emissions have decreased as average vehicle size has increased. SSAB monitors specifically sales volume, but for each grade and application these figures are directly correlated to weight reduction and can be extrapolated to marginal change in fuels consumption. SSAB also does case specific LCA work.
5. Uptake & Consequences:	The increasing sales figures of DOCOL steel directly demonstrate that the initiative is scaling up. The observable increase in AHSS as a percentage of vehicle chassis over time is also direct evidence that the concept of lightweighting is embedded in vehicle design. DOCOL steel has become a major economic pillar for SSAB, and SSAB is largely competitive in the automotive steel market because of premium quality and high standards of assurance. Taking on AHSS in automotive applications early has undoubtedly contributed to this competitive stance. Evidence for the impact is that SSAB, and the Swedish steel industry as a whole are competitive, where many national industries are struggling.
Conclusion & Outlook	
Key Learnings:	*Key insights from this case regarding …* *Overall decarbonisation:* DOCOL steel is more emission efficient than the global average for steel, but this is mostly due to the unusually pure iron ore in Sweden and the low-carbon electricity supply. The overall decarbonisation of the steel sector and the automotive sector are dependent on radical changes in input fuels. Advanced steel has played a huge role in reducing component weight in vehicles, but this contribution has been eaten up by larger vehicles with more accessory systems. Advanced steels may have an important role in EV battery safety. *Drivers and barriers:* Steel and automotive actors are very risk averse. The major barriers are in getting a new steel grade listed as acceptable for use. Ironically, vehicle safety regulation is seen as at least as important a driver as low carbon. Constant innovation in process is considered BAU in the sectors. Steel is very capital intensive. *Instruments to overcome them:* Government guarantees of bonds for the initial equipment was decisive in launching the innovation. Government help in legitimizing new technologies and in creating niches is important. Again, safety regulations were a major driver for DOCOL. In new markets, e.g. SE Asia and India, ability to pay is very constrained, and this is a dominant factor slowing expansion.

	Role of policy: Policy needs at least two tracks in these industries. The first is helping finance capital expenditures for radical innovations such as HYBRIT or EV adoption. The second is to help create acceptability and smooth the process of adoption for new steel grades. SSAB sees future regulations on crash safety for EVs as a major driver for growth in DOCOL. Other efforts include harmonizing and expanding vehicle regulations and standards beyond the OECD. *Lessons for future innovations:* In the steel and automotive sectors, things take decades to change. Demanding higher standards in related fields (e.g. safety) can help.
Open Questions & Further Research Requirements:	How far can steel and lightweighting be taken in vehicles and why is average weight not decreasing? Is new policy needed to make vehicles absolutely lighter? What is the role of advanced steels in accelerating adoption of alternative fuels in the automotive industry? How can policy help create more markets for 'green' steel? Can steelmaking be decarbonised (e.g. HYBRIT)?

4 Plastics Case Studies

Four cases studies were conducted in the plastics sector. Tierra is an innovation on the manufacturing end of the plastics value chain, examining the use of bio-based materials to create a fossil-free outdoor jacket. Enerkem Rotterdam looks at chemical recycling of municipal waste to produce syngas for the chemical sector. Zero-Waste Grocery Stores are an example of a social innovation in the plastics sector, providing consumers an option to forego the use of single-use plastics. Carbon2Chem is an innovation at the intersection of steel and plastics, looking into CCU of the waste gases from steel production and their conversion to methanol for the chemical sector.

4.1 Tierra

Innovation:	**100% bio-based jacket**
Intervention:	**Tierra's deterra-jacket**
Case Study by:	Ludwig Bengtsson Sonesson, Department of Political Science at Lund University
Methodology:	8 semi-structured interviews, 2 field visits (to research & development plant, to outdoor stores in Manchester)
Case Study Overview	
Sector(s):	Plastics
Value Chain Stage(s):	Production/Consumption
Type of Intervention:	Technical
Date & Duration:	Development began around the time of COP21, in 2015
Location:	Sweden
Initiating Actors:	Tierra FOV
Actor Constellation:	Tierra – Consumer-facing manufacturer FOV – Fabric developer Fulgar – Yarn producer
Short Description of Intervention:	After COP21 in Paris, the employees at Tierra had a stated goal of addressing their dependence on fossil fabrics. Ideas of both a 100% recycled product and a 100% bio-based product were raised. Ultimately, the company developed a jacket made out of bio-nylon (castor oil as feedstock) – the novelty of which was its utter lack of fossil-based components, threads, buttons, were either designed away or replaced with bio-based/natural components.
Research Theme Summaries	
1. Innovation History & Dynamics:	There is contention around the ownership of the initial idea of a bio-based jacket. Swedish competitor RÖJK released a similar product using bio-nylon a year before Tierra (but containing virgin plastic materials as well). Choosing the bio-based pathway came down to expertise within the team, one employee had previously worked on a peanut-based fabric. The broader use of bio-based fabrics face several major barriers to adoption: A) Justifying the higher price is often hard as companies in the sector run on tight margins. Recycled polyester has become competitive in price, bio-based run up to 3-4 times the price. B) The availability of fabrics is largely dependant on demand from large buyers, in addition, suppliers demand orders of high volumes. Thus, innovation in small firms is hindered since they can't experiment with new fabrics until the dominant actors on the market have caught

	up. The Swedish outdoor industry has attempted to pool their demands to push suppliers towards recycled, bio-based and biodegradable plastics. C) Clothes can be made from a large number of materials, and each come with their own sustainability issues. Manufacturers struggle to navigate and weight which ones should be prioritised. Bio-based fabrics suffer from the food vs. feed quandary, cotton is water-intense, all synthetic fibres cause micro-plastic pollution and wool faces issues of animal welfare etc. Uncertainty leads to caution and several interviewees indicated that they are waiting for more research before they commit heavily to one solution. D) The outdoor industry relies on *quality* as one of their main selling points. And there is a worry (justified in some cases) that recycled and/or bio-based carry with them a lower quality than virgin fibres.
2. Governance Arrangements & Agents of Change:	The clothing industry has significant inter-firm governance, but rather lax governance on a state level. Some interviewees requested stronger legislation to level the playing field and boost investments in renewable fabrics. Relevant governance arrangements follow: A) The Sustainable Apparel Coalition and its tool *The Higg Index* provides a standardised measurement tool for supply chain sustainability. It gathers actors ranging from H&M to Tierra. B) State-level initiatives in Sweden such as the MISTRA Fashion Futures research program, the Swedish EPA's dialogue on Sustainable Fashion and the Cooperative Platform for Sustainable Textiles provide platforms for interaction and research towards a sustainable clothing industry. C) Textile Exchange, an American non-profit, disseminates best practices relating to fabrics – which results in *Material Snapshots* which give manufacturers an overview of the benefits and drawbacks of fibres. Tierra participates in a TE working group on bio-synthetics with the aim of further developing materials such as the EVO. D) Legislation has focused on chemical contents of DWRs (Fluorocarbons) and there is a sense of impending legislation on micro-plastics among interviewees. The deterra jacket prompted textile firm FOV to replace their entire range of polyester with recycled alternatives and Tierra gained new contacts and knowledge of bio-based clothing details (zippers, buttons etc.)
3. Transformative Capacities:	Textile value chains are infamously long and complex. As FOV were developing the fabric, they had to reach out to manufacturers to iron out issues of country of origin, toxicity and land use change. This resulted in an informational pamphlet detailing the sustainability of the EVO-fabric. However, there is no consensus on where the castor oil actually originates (Brazil, India and China were suggested by interviewees). Tierra (and also their competitor RÖJK) differentiates itself from other clothing manufacturers by focusing on *fossil* and *oil*. They claim the raison d'etre is to reduce oil dependency and oil usage. The term Fossil Free Jacket was often used to describe the deterra product.
4. Assessment & Evaluation:	The LCA of the EVO-fabric (conducted by the company who makes it) showed that the carbon emissions associated with the recycled version of the same material (Nylon) were considerably lower (1,77 CO2-eq vs. 7,36 CO2-eq) while still beating virgin nylon (9,97 CO2-eq) The HIGG index is the most widely used assessment tool within the textile industry, its material index contains more than 80 materials, which are evaluated based on impacts to climate change, eutrophication, water, abiotic resource depletion and toxicity. However, there seems to be a considerable lag between how often the library of materials is updated and how often innovative textiles enter the market. For instance, the only bio-based material found by the researchers was PLA (Polylactic Acid). Further institutionalisation of the Index as a guiding heuristic for firms could both foster the transition to sustainable fabrics or hinder it – depending on the materials featured. As was apparent in other industries, LCA as a method of evaluation is useful but flawed. The uncertainty resulting from the vast amount of assumptions, which have to be made in the evaluation, make this type of detailed comparison difficult. For instance, the idea of a complete phase-out of virgin fossil fabrics does not get recognised in LCAs – if virgin materials have a lower emissions footprint they would show more favourable in the comparison. Outdoor company Houdini has recently adopted a new assessment framework based on the planetary boundaries, which shows potential but is still in early development.

5. Uptake & Consequences:	The issue of whether *deterra* is always fossil-free came up in our interviews. Without the novelty of being the first to make a fossil free jacket, the high material cost and low production volume becomes increasingly hard to justify.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* • Framing as 'fossil-free' is unique in the sector • Majority of actors in textiles are betting on recycling, bio-based materials are quite rare *Key insights from this case regarding …* *Overall decarbonisation:* The Tierra case shows that fossil-free fabrics are a possibility within today's textile sector, if you can make a sturdy outdoor jacket – you could make most garments. Much of the sector is hoping for *full circularity* and dreaming of a closed loop where virgin materials are no more. There is no certainty that that goal is achievable, so as an alternative to fossil fabrics the innovation is key if we still want new clothes on the market. However, for immediate decarbonisation purposes it has issues of scalability and price, which makes a widespread adoption unlikely. *Drivers and barriers:* Drivers: Paris Agreement and intra-firm interest in decarbonisation. Barriers: Cost, supply, material aspects (quality, certain functions), uncertainty of sustainability. *Challenges and instruments to overcome them:* The design of individual garments was identified as a method of overcoming price obstacles (for instance, removing a pocket). Progressive ownership (read not publically traded) seemed to allow more daring innovations and less need for immediate profit. *Role of policy:* The fashion sector is characterised by soft governance without any prominent binding legal requirements (except for some relating to recyclability and chemical use). Many interviewees requested *more* legislation, which would level the playing field and make more sustainable alternatives competitive on the market. *Lessons for future innovations:* Novelty is a powerful tool in the initial launch of an innovation, "The first fossil free jacket" was a powerful vision. Pooling resources within a sector (to show demand towards suppliers) is a way to speed up development processes along the value chain.
Open Questions & Further Research Requirements:	What is the total volume of textiles we are able to allocate biomass to? Why have fossil fuels been politicised while their by-products (for example plastic clothing) have not?

4.2 Enerkem Rotterdam

Innovation:	**Chemical recycling of hydrocarbon wastes (e.g. plastics, biomass)**
Intervention:	**Enerkem – Waste-to-Chemicals project Rotterdam**
Case Study by:	Katharina Knoop, Annika Tönjes (Wuppertal Institute), Ernst Worrell (Utrecht University)
Methodology:	5 interviews: Securing interviews with stakeholders from the private sector was rather difficult. Especially details on the technological aspects of the process are not disclosed publicly. Site visits were not possible as the Rotterdam facility is still in the planning stage and the only existing facility is located in Edmonton/Canada.
Case Study Overview	
Sector(s):	Plastics, Cross-Sectoral
Value Chain Stage(s):	Resource & Production, Consumption & Waste
Type of Intervention:	Technical and Economic
Date & Duration:	2000 (Founding Enerkem Inc. in Canada) - on-going
Location:	Edmonton (Alberta, Canada); potentially Rotterdam, The Netherlands
Initiating Actors:	Enerkem
Actor Constellation:	Financing (Canada): Braemar Energy Ventures, Cycle Capital Management, Fondaction CSN, Fonds de solidarité FTQ, Investissement Québec, National Bank of Canada, Rho Capital Partners, Waste Management of Canada, Westly Group, Valero Energy, Blackrock, Sinobioway (and since April 2019: Suncor) Governance (Canada): Enerkem together with Gov't of Canada (subsidy through WINN program), City of Edmonton Regulation (Canada): U.S. Environmental Protection Agency, Gov't of British Columbia (certification of bio-ethanol as renewable fuel) Rotterdam plant partners: Enerkem, Nouryon (formerly AkzoNobel), Air Liquide, Shell, Port of Rotterdam Rotterdam plant governance: Gov't of Netherlands; Province of Zuid Holland, City of Rotterdam (subsidies)
Short Description of Intervention:	Enerkem (Canada) has developed a (fluidised bed) gasification technology to produce syngas from (hydro)carbon wastes (e.g. biomass, mixed municipal solid waste/MSW, plastics). The technology was patented in 2009. One commercial plant has been in operation in Edmonton (Alberta) since 2015. Since the 1990s various projects have looked at gasification of biomass and wastes to produce syngas (e.g. in the U.S., Europe). In the Enerkem process, the syngas is converted to methanol. Methanol is used as a platform to make ethanol or produce other (intermediate) chemicals. A consortium of Air Liquide, Nouryon (formerly AkzoNobel Specialty Chemicals), Shell, Enerkem and the Port of Rotterdam will build a waste treatment/recycling facility in the Botlek area of the Port of Rotterdam. The project is still in the planning phase.
Research Theme Summaries	
1. Innovation History & Dynamics:	The Enerkem process uses proprietary technology to gasify RDF (Refuse Derived Fuel) to produce synthesis gas, which is converted to methanol after gas clean up. It builds on previous experience with RDF and waste gasification and uses a so-called bubbling fluidised bed reactor. The process is scalable, as it is based on a standardised design of the chemical reactors (train) with a processing capacity of 100,000 tonnes/year. Hence, the capacity can be increased by adding additional trains. The technology was originally developed by Dr. Esteban Chornet at Université de Sherbrooke (Quebec, Canada). He co-founded Enerkem in 2000 with Vincent Chornet (his son). After successfully employing the technology at a pilot plant in Sherbrooke and a demo plant in Westbury, the first methanol at the commercial facility in Edmonton was produced in

	2015. Enerkem has also developed a new process to convert methanol to ethanol that has been applied in Edmonton since 2017. The Canadian project had been considerably delayed and became much more expensive than originally planned. This was related to a high level of sophistication inherent in building the first commercial-sized trash-to-ethanol facility in the world. As a result, Enerkem achieved its full capacity of converting about 100,000 tonnes of pre-treated MSW into methanol only in 2018. The first plant outside Canada is considered to be built in Rotterdam, The Netherlands. Although initial operation had been planned for 2020, due to delays the final investment decision has been postponed to the second half of 2019. The facility is expected to produce methanol that can be used as feedstock for chemicals (by adjacent sites of Nouryon and Shell). Furthermore, methanol can be blended in transport fuels, thus fulfilling EU requirements on the share of bio-based fuels in transport fuels. Hence, future business of the W2C plant depends on policy developments on EU level as well as regarding the implementation of EU law in the different member states. It could be negatively affected by policy variability as well as uncertainty over future policymaking. This is true for biofuel legislation but also mandatory recycling and MSW reduction rates, which could decrease the availability of MSW as a resource for methanol production.
2. Governance Arrangements & Agents of Change:	In Rotterdam, multiple stakeholders from different sectors are collaborating to implement the Enerkem process of chemical recycling of hydrocarbon wastes. Within the consortium, Enerkem acts as technology provider, lead contractor and equity partner. The Port of Rotterdam provides state-of-the-art infrastructure. In addition, about 2 million tons of municipal solid waste (MSW) are already being shipped to Rotterdam, facilitating the feedstock supply through agreements with waste management companies. Air Liquide acts as a supplier of oxygen and hydrogen and Nouryon participates as a supplier of hydrogen (a by-product of its chlorine production) and a customer of methanol. Shell plans to buy the facility's product, (bio-)methanol. Among the public bodies, the Province of Zuid-Holland and the City of Rotterdam provide financial support. The Dutch Ministry of Economic Affairs and Climate Policy has additionally agreed to develop instruments that help scale up the technology. However, in the decision for the Rotterdam location, public funding played a significantly minor role compared to the availability of private equity capital. Overall, funding the W2C project in Rotterdam appears to be a challenge even though various global players are involved. As in the case of other new technology developments, the risk for financial investors is considered high and thus finding investors turns out to be difficult. As social demand for low-carbon solutions increases, also many companies recognise the need for low-carbon societies and engage in low-carbon innovations to secure their future competitiveness. Thereby, they also prepare for potential future regulation demanding strong climate protection efforts and thus avoid being caught off guard by stringent legislation. A successful commercial application of an innovation could also make the company a frontrunner in the supply of low-carbon technologies. Public institutions supporting innovative projects similarly recognise the need for climate protection measures and are also interested in a prospering local economy including job creation and preservation. Moreover, the use of waste as feedstock counters the (potential) problem of scarcity of landfilling space and fulfils society's desire for increased waste diversion. An Enerkem representative attributed the creation of the W2C project in Rotterdam to policy developments, namely progressive waste policy in particular but also general policy objectives on different levels (EU, national, local). Hence, regulatory developments linked to European and Dutch decarbonisation pathways play a prominent role, but also other drivers such as market trends influenced the decision in favour of the particular project. Those market drivers include e.g. that waste is the most inexpensive feedstock which is abundantly and readily available in all regions (urban and rural) and already collected. On the demand side, there is a consumer pull for renewable and bio-based products, i.e. methanol for fuel use as well as intermediate for "greener" variants of glues, paints, cosmetics etc. Compared to the Enerkem project in Canada, W2C is mainly financed by the joint venture partners' equity capital as well as public grants. The Enerkem-owned Edmonton project also receives public funding. There are, however, many more investors involved, among them venture capitalists, who do not participate in the operational business. The govern-

	ance model of the Rotterdam project thus appears exceptional in the participation of a rather large variety of stakeholders, which are not only investors, but mostly industrial players. Partly, this arises from location-specific aspects, mainly the fact that the companies participating in the operation of the project are already clustered within the Port of Rotterdam. On a more aggregate level, the interlinkage of value chains in the framework of the W2C cooperation could represent a first step towards more industrial symbioses, i.e. the use by one company or sector of by-products, including energy, water, logistics and materials, from another. In the Rotterdam W2C case, the definition mainly applies to Nouryon acting as a supplier of hydrogen, a by-product of its chlorine production. This kind of industrial cooperation holds large emission mitigation potentials and is considered a key measure for the decarbonisation of the energy intensive industry. So far, however, few cooperation projects became reality as different kinds of barriers prevail, such as geographical distance and a lack of trust and knowledge.
3. Transformative Capacities:	So far, the W2C consortium appears successful in generating the skills, knowledge and resources for the implementation of the project. An important step for addressing inertia in this field has been taken by Enerkem with the development of their proprietary technology, which will be transferred to Rotterdam. Furthermore, by bringing together Enerkem, the Port of Rotterdam, Air Liquide, Nouryon and Shell, actors with expertise on different parts of the W2C value chain have been united for this project. While securing funding proves rather difficult, the consortium appears to be capable of generating sufficient financial resources for project implementation. Since the W2C facility in Rotterdam so far only exists on paper, making its decarbonisation potential legible is still rather difficult, especially as it will depend on the composition of the MSW processed at the facility. Consequently, to date the project participants mainly engage in storytelling. The W2C consortium draws the picture of a project which represents a step towards a circular economy where waste becomes the feedstock for everyday products. Enerkem Canada and its collaborating companies also try to highlight concrete cases showing how the general public benefits from its business activity. This comprises the reduction of greenhouse gas emissions, the generation of biofuels used as an alternative to fossil fuels as well as building a sustainable bio-economy. The way in which the W2C partners seek to generate authority and legitimacy for the initiative is closely linked to the vision of a future where waste will be a useful feedstock which can even replace fossil fuels. Towards that goal, the W2C project positions itself as a sole frontrunner being able to actually provide and implement a ground-breaking low-carbon measure. Although potential drawbacks exist, the promise of an applicable solution seems to generate a high level of legitimacy for the initiative. Due to the participation of important multinational corporations and the technological credibility built up by Enerkem in Canada, the generation of authority will probably be successful as well. In Canada, Enerkem further aims at having its facility's 'low-carbon' qualities recognised and assessed by other, possibly impartial institutions. This is realised by product certifications, evaluations of the production process as well as assessments of the company's business model and management in general. Overall, Enerkem Canada appears successful in giving value to its ‚low-carbon' qualities. The awards the company is receiving from industry and its peers show that Enerkem is recognised the way it aims to be.
4. Assessment & Evaluation:	The W2C project is still in the planning phase and public assistance or partnering in the project is limited. Hence, little information is publicly available on the technical, economic and environmental assessment of the Rotterdam plant. The project's economics are strongly influenced by the availability of sufficient MSW, as well as the value of the methanol produced. The delay in the permitting and construction of the facility means that the W2C facility needs to comply with stronger CO_2 emission reduction requirements to be recognised as a bio-fuel (i.e. at least 65% reduction). Since also the composition of the waste will affect the level of CO_2 emissions, it is infeasible to fully evaluate the economics of the project at this time. While the plant in Edmonton complies with Canadian air quality standards, and the produced ethanol is recognised as bio-ethanol by U.S. regulators, the Rotterdam facility is not yet operational. Hence, the technology cannot yet be assessed under European regulatory circumstances.

	Similarly, the W2C plant's potential impact on the climate cannot be assessed at this moment, as this will strongly depend on the composition of the MSW used as input into the plant, as well as on the alternative use of the MSW replaced by the Enerkem plant. Until now, the W2C project has not been publicly or externally evaluated. Yet, in its initial support for the project the Province of Zuid Holland demanded that the Rotterdam facility contributes to at least a reduction of CO_2 emissions by 200 ktCO_2/year while producing at least 180 kt methanol/year. At least 30% of the MSW should come from The Netherlands, which would otherwise be incinerated. Recyclables should have been removed from the MSW before processing, so that the facility would only process post-separation residual waste. To foster innovation, it was expected that the plant should be operational within 24 months, and if this was delayed to over 36 months require sufficient explanation. For the products to be recognised as bio-fuel, European regulation requires that the project achieves a reduction in CO_2 emissions of at least 65%. Similar guidelines do not yet exist for chemical feedstocks. If the methanol would be used to manufacture MTBE (a fuel additive), it should be expected to comply with the same standards. As outlined above, this would require detailed monitoring of both the waste flow, the process, as well as the uses of the produced methanol. The Canadian plant has been evaluated since the start of operations. It was criticised as its operating costs have increased since 2012 but the total waste was constant. Moreover, instead of increasing total waste diverted from landfills has declined. At the same time, Enerkem said that its Alberta Biofuels facility has been meeting the highest quality standards set by the International Methanol Producers and Consumers Association (IMPCA) for the production and sale of methanol.
5. Uptake & Consequences:	As the W2C project itself is still in the planning phase, its operational and commercial feasibility still has to be proven. However, the participating companies are optimistic and believe that the W2C facility in Rotterdam can serve as an example to be imitated worldwide in the near future. Currently, further facilities are being planned in Spain, North America as well as China. When developing the Edmonton site, Enerkem already worked to ensure the potential for expansion. They decided to use a modular manufacturing approach when designing the facility in order to allow for rapid building of new such biorefineries. In case of cooperation, Enerkem provides partners with fabricated modular equipment and handles assembly on site. Additionally, Enerkem licenses its technology to partners. The main criteria for partnerships are the design of public policies, the level of tipping fees and population as well as proximity to petrochemical infrastructure. If its commercial success endures, the Enerkem technology could form the basis for the development of a future economy in which waste serves as a feedstock for different kinds of chemical products and fuels. With regard to the W2C project Rotterdam, due to its forward-looking nature no consequences of its operation could have been identified yet.
Conclusion & Outlook	
Key Learnings:	The Enerkem plant in Rotterdam would convert MSW to methanol, which would be used as feedstock for chemicals or as fuel (additive). Although gasification of MSW is not new and has been studied since the 1970s, few technologies have been successful. If the Enerkem process is successful, the technology would be the first to be so at large scale. While the technology has been licensed for export to e.g. China, the Edmonton plant is still the only operating facility worldwide. The Rotterdam facility would be the second commercial plant to be built worldwide. The initial development and the Edmonton facility were supported by both public and private investments from a variety of backgrounds (e.g. waste management, fuels, equity funding). The Province of Quebec has invested considerably over the whole period (estimated at over C$ 40 million) in the technology. The key driver for the technology is the diversion of MSW from landfilling to produce (bio-)fuels. The Rotterdam plant is primarily funded by private investment (e.g. Nouryon, Shell, Air Liquide). Although its availability is considered limited, public funding is also involved in the initial stages. The main driver for the Rotterdam plant is the trend towards a circular economy (also in policy making) and the search for low-carbon chemical feedstocks as part of the energy transition of the chemical industry.

	This has brought together (semi-)public and private parties, which all see strategic opportunities relating to their core business. The project would lead to new relationships across supply chains. It proves that public policy can be an important driver for low-carbon innovation. Simultaneously, such projects could be negatively affected by policy variability as well as uncertainty over future policymaking.
Open Questions & Further Research Requirements:	It is hard to evaluate the impacts on GHG emissions and its contribution to deep decarbonisation, as the actual impact is determined by a variety of factors. On the input side these are mainly the composition and origin of the MSW residual to be processed, the alternative ways to process (parts of) the MSW, and the efficiency of the process to convert the MSW. On the output side it depends on the actual use of the product and the feedstocks substituted. Given EU regulation and the delay in construction of the plant, the produced methanol can only be recognised as biofuel if the CO_2 emission reduction exceeds 65%. This will only be achievable if the MSW would primarily consist of biogenic material (e.g. organic waste, paper). As the plant will operate on at least 30% domestic waste and up to 70% imported (unsorted) waste, it is unclear if the EU regulatory standard can be achieved. If the methanol will be used as chemical feedstock, EU regulation would not apply, and lower reductions of GHG emissions may be sufficient for the project partners. As competing technologies in the fields of MSW separation and recovery as well as (chemical) recycling arise, it is difficult to evaluate the systemic impacts of the Enerkem process in the European context on technology development, the shift towards a circular economy, and (deep) reductions of GHG emissions.

4.3 Zero-Waste Grocery Stores

Innovation:	**Zero-waste grocery stores**
Intervention:	**Gram (Malmö) and Løs Market (Copenhagen)**
Case Study by:	Jacob Hasselbalch (Lund University) With research assistance by: Ludwig Bengtsson Sonesson, Ekaterina Chertkovskaya, Karl Holmberg, and Sara Ullström (all Lund University)

Methodology:	16 interviews carried out between May 2018 and February 2019
	Focus on the Öresund region, with a field trip to Brussels to examine the European regulatory scene and broader developments within zero-waste
	Site visits to 3 different zero-waste grocery stores and 2 food cooperatives with zero-waste elements:
	- Zero-waste stores
	  ○ Gram, Malmö
	  ○ Løs Market, Copenhagen
	  ○ Yes Future!, Barcelona
	- Food cooperatives with zero-waste elements
	  ○ Färm, Brussels
	  ○ New Leaf Coop, Edinburgh

Case Study Overview	
Sector(s):	Plastics
Value Chain Stage(s):	Consumption
Type of Intervention:	Social
Date & Duration:	First zero-waste grocery stores (in their modern iteration) opened in United Kingdom, Germany, and Italy in late 2000s. Explosive growth in the amount and geographical spread throughout Western Europe starting in 2011, but especially from 2016 onwards.
Location:	Öresund region (Copenhagen and Malmö) – chosen for expedience and two recent openings of zero-waste stores (both in 2016) that received much media attention.
Initiating Actors:	Løs Market (Copenhagen) and Gram (Malmö)
Actor Constellation:	Producers/suppliers: farmers and food producers Distributors/wholesalers: intermediaries between farmers and stores Zero-waste grocery store owners and employees Consumers Competitors (conventional retail): including Coop, Salling Group, ICA Gruppen Regulators: European Union, Danish and Swedish state, municipal and local authorities
Short Description of Intervention:	The purpose of the zero-waste grocery store is to sell retail goods primarily in bulk without the use of plastic or other single-use packaging. They are small grocery stores laid out with inventory and displays to support the use of containers brought from home by the shoppers. They include a scale to weigh containers and the products being bought in bulk. Often, they are financed through crowdfunding and emphasise the local neighbourhood, building relationships to local consumers and suppliers, using social media and blogging to build customer base, and feature membership or loyalty programs.
Research Theme Summaries	
1. Innovation History & Dynamics:	Zero-waste as a lifestyle has been gaining popularity from 2010 onwards. Zero-waste stores have been growing exponentially in Europe, especially in Germany, Italy, Belgium, France. Barriers seen from zero-waste storeowners' perspective include profitability and balancing scalability with commitment to zero-waste principles. Barriers seen from the perspective of conventional supermarkets include hygiene, food waste, investments in existing structures and supply chains, and the role of plastic in facilitating long supply chains. Consumers and retailers want convenience, and retailers want to sell products - sustainability should

	be addressed in food production and in waste management. Packaging experts view the food plus the package as a highly engineered value proposition: it preserves quality. There is a systemic stalemate in moving the entire retail sector to package-free or less packaged models.
2. Governance Arrangements & Agents of Change:	The 'local' is emphasized as the critical scale of operations and governance: local connections to employees, consumers, and producers, and especially to organic producers. There are local food networks, working directly with producers, but also with wholesalers in some cases. Financing is also done locally through crowd funding, especially from local consumers. In the stores, vegetarian products are predominantly sold, and there is a promotion of sustainable lifestyles through non-food products. The zero-waste lifestyle and stores are a form of protest against industrial, globalized food production and overconsumption. Conventional retail instead focuses on plastic strategies and showing consumers that they are taking the packaging challenge seriously - most initiatives focus on bio-plastics, recycling, and the circular economy. Policymakers are looking at the systemic level and organising policy initiatives around the circular economy, trying to move all actors together towards systems with increased recycling rates and more reusable packaging. Much of this is driven by consumption becoming increasingly value-laden. Environmental NGOs raised much awareness on the plastics issue, bolstered by Blue Planet 2. Consumers draw connections from personal consumption habits to plastics in the ocean and pesticides in the environment. This results in forms of sustainable and political consumption. Retailers want to be relevant to young consumers. Meanwhile, packaging experts and companies resist the categorization of packaging as waste, instead arguing that packaging is a part of the product.
3. Transformative Capacities:	Zero-waste stores thrive on the basis of strong social connections to producers, consumers, and the zero-waste movement. A main figure in this movement is Bea Johnson, author of Zero Waste Home. Founders of zero-waste stores stress the importance of the awakening of their own ecological consciousness and personal responsibility as a motivation for establishing their stores. The appeal of the zero-waste lifestyle is a necessary condition for the establishment of zero-waste stores – that appeal, in turn, is sustained by a thriving online ecology of zero-waste bloggers, influencers, authors, and personalities. The concepts of local, organic, and unpackaged goods are inextricable from each other, intertwined with each other. Media and political attention have helped build momentum behind zero-waste stores and initiatives. In contrast, conventional retail is mobilising around circularity instead of zero-waste, mainly because it is understood in terms of incremental moves to realise profits from the waste stream and in packaging. The main obstacle is understood to be a lacking policy framework to support systemic shifts towards the circular economy. The low-carbon qualities of zero-waste stores are not strongly communicated and not a key component of their value proposition. Zero-waste stores are successful when they are highly visible (legible) in local settings and in the media (especially social media), and when their distinction as a sustainable way to shop is recognised and valued by consumers.
4. Assessment & Evaluation:	There are very few assessments of the social, environmental, and economic impacts of zero-waste stores. Experts emphasise the need to do LCAs of food and packaging as a system, and not look only at packaging - the shelf life of food and prevention of food waste are highlighted. At the same time, many experts note the limitations of LCAs and the many assumptions and simplifications that go into producing them, meaning that LCAs are not directly comparable. Zero-waste storeowners are not overly concerned with these assessments or evaluations - in their own words, the stores are understood as social spaces that allow individuals to exercise responsibility towards the collective, and as talking points or concept stores that raise awareness of and promote the zero-waste lifestyle. This makes it harder to assess their impact, because they should not be judged on purely technical terms, but also on their capacity to promote social change and spillover effects. The politicization of plastics and packaging and the attention to these issues within conventional retail are good evidence that some of these social changes and spillover effects are making their impact felt. Rather than metrics of impact, zero-wasters are arguing for absolute reductions to plastic packaging use and waste - in response, retailers are arguing for circular economy initiatives

	where materials are re-used and loops are closed. The key difference is that zero-waste questions the growth paradigm, but the circular economy sustains it.
5. Uptake & Consequences:	There has been significant upscaling of zero-waste stores and activism in recent years, showing exponential growth in the number of stores since the early 2010s. The form that this upscaling has taken is not the expansion of individual stores into bigger stores, but rather a multiplication of many small individual stores opening in new neighbourhoods. In most cases, these are new stores with new owners, but in some cases, the same owners open multiple stores. Upscaling is difficult from the perspective of store owners because it runs the risk of compromising on their values of sustainability: it can be difficult to secure sufficient supply of unpackaged, local, and organic food. Most actors across the entire sector believe zero-waste stores will remain niche, even if conventional retail takes on some elements from the stores (such as more bulk purchase options). Even so, the maintenance and expansion of the niche will put more pressure on conventional supermarkets, which are recognized as the key actors in the supply chain if you want to realize sustainability gains. Business-as-usual has largely been delegitimized: the options presented through the interviews are circular economy or zero-waste, but these have areas of overlap and are not completely mutually exclusive. The circular economy narrative redeems plastics and is pro-growth, while zero-waste problematizes plastics and growth. Bio-plastics are easier to communicate to consumers, but not everyone in conventional retail is convinced that there are sustainability benefits to be realized here - they are less important than the circular economy, and may in some cases be integrated within it. The politicisation of plastics and packaging have led to a large number of plastics strategies and circular economy initiatives being developed by cities, companies, nation-states, and regions. Zero-waste stores and the zero-waste movement have been instrumental in getting this on the agenda.
Conclusion & Outlook	
Key Learnings:	The case study on zero-waste grocery stores has demonstrated the decarbonisation potential of consumer-facing social innovations in the retail sector and how these connect to the REINVENT sectors of plastics and meat/dairy. Zero-waste grocery stores are likely to remain niche actors in the retail sector, and their individual carbon and sustainability benefits at the store-level will therefore not add up to sizeable savings, especially if we consider only the impact on the plastic sector. Most sustainability gains from the innovation are related to how it promotes local food networks, organic production, and vegetarian diets. More broadly, the close connection between zero-waste grocery stores and the zero-waste movement (NGOs, activists, social media personalities) has played an instrumental role in politicising plastic pollution, and it is in large part thanks to them that we are seeing high-level policy and corporate attention to plastics. The response from incumbent actors has been to resist the narrative of zero-waste in favour of a circular economy approach, in which growth is not questioned and the redemption of plastics is possible through increased re-use and recycling. Ultimately, zero-waste stores should be assessed not on technically determined metrics of environmental performance, but on their socially determined capacity to promote ecological citizenship and sustainable consumption among the broader public.
Open Questions & Further Research Requirements:	The right question to ask is not: can zero-waste grocery stores scale up as a business model, but can zero-waste grocery stores create more ecological citizens? Can zero-waste grocery stores bridge the divide between individual and collective action? Probably not. It is primarily an individualizing expression of ecological citizenship and does not actively promote the formation of closer ties among consumers and producers. Commercial relations between consumers and producers are not interrogated, tested, or experimented with. It is still straightforward sales with a mark-up benefiting the store. Where is the collective action? Where is the mobilisation and demand for change? But then again, should this be the responsibility of zero-waste stores? If they are concept stores and talking points for the zero-waste lifestyle, then yes. Key tension between individualising responsibility and promoting collective action for decarbonisation and sustainability.

4.4 Carbon2Chem

Innovation:	**CCU (Carbon Capture and Usage) within the steel and chemical industry**
Intervention:	**Carbon2Chem**
Case Study by:	Helena Mölter (Wuppertal Institute)
Methodology:	7 interviews, 2 site visits, 1 industry conference
Case Study Overview	
Sector(s):	Plastics, Steel
Value Chain Stage(s):	Resource & Production
Type of Intervention:	Technical (with organisational elements)
Date & Duration:	2016-2020
Location:	Germany, North Rhine-Westphalia
Initiating Actors:	ThyssenKrupp, Fraunhofer UMSICHT, MPI CEC
Actor Constellation:	Project partners: AkzoNobel, BASF, Clariant, Covestro, Evonik, Fraunhofer Institut für Solare Energiesysteme ISE, Fraunhofer Institut für Umwelt -, Sicherheits- und Energietechnik (UMSICHT), Karlsruher Institut für Technologie (KIT), The Linde Group, Max-Planck-Institut für Chemische Energiekonversion (MPI CEC), Ruhr-Universtität Bochum (RUB), RWTH Aachen, CAT Catalytic Center, Siemens AG, Thyssenkrupp, TU Kaiserslautern, Volkswagen, ZBT Zentrum für BrennstoffzellenTechnik GmbH Funding institution: Federal Ministry of Education and Research (BMBF)
Short Description of Intervention:	Carbon2Chem is a project at the intersection of the steel and the chemical industry placed in Germany (mainly North Rhine-Westphalia) – following the core idea that unavoidable CO_2 emissions from one production serve as the raw material of another, carbon-based production. Thus, there is a reduction of fossil raw materials for the chemical industry. The blast furnace's gases contain, among other things, hydrogen and nitrogen. Carbon is also present in large quantities: as carbon monoxide (CO), as carbon dioxide (CO_2) and as methane (CH_4). Carbon, hydrogen and nitrogen are the basis for many chemical products. The steel mill gas is refined or conditioned to synthesis gas with the help of renewable energy. The result will be basic chemical products (e.g. fertilisers, methanol, polymers). The project was initiated by ThyssenKrupp, Fraunhofer UMSICHT and Max-Planck-Institute and is now encompassing in total 18 partners from industry and research. Besides the investments of the involved partners, the project is funded by the BMBF with €60m for four years. The contribution towards decarbonisation is expected to be a reduction of 20Mt of CO_2 per year. Though this equals 10% of the yearly emissions of industrial processes and manufacturing industries in Germany, it is important to remark that the emissions will be "re-used" by the chemical sector and might be emitted at a later stage of the value chain in case the carbon loop will not be closed. Nevertheless, the chemical industry can reduce the amount of fossil resources as these resources are provided by the steel industry at Carbon2Chem. But a switch towards a fossil-free steel production without blast furnaces might be hampered through the approach of CCU, as the path dependency of the steel industry towards the existing, high emitting blast furnace route, is strengthened.
Research Theme Summaries	
1. Innovation History & Dynamics:	Driven by the steel industry to reduce CO_2 emissions as the prices for CO_2 emissions certificates are expected to rise, ThyssenKrupp got together with the Fraunhofer Institute as well as the Max-Planck-Institute in order to draft a core vision and idea. The innovation has not circulated yet, but it is expected to be implemented at 50 integrated steel mill sites worldwide, including other industrial sectors such as cement in order to use

	their off gases. In addition, it is important to mention that NRW has very good pre-conditions as the steel industry is very connected along the value chain and the chemical industry is of high importance – and both industries are locally close together. Though the success of implementing the project ideas on industrial scale is not clear yet, it is clear that several other – non-technical – innovations arose due to the project's activities: In the businesses itself as they had to learn how to work across different business units; along the businesses as they had to find a common solution and optimum for the processes. Moreover, the organisational set-up and methodology of the project is sending impulses to other cross-sectoral co-operations in NRW. The core challenge – besides technical challenges – of the project was in the phase of initiation, but also while the project is still running, to find a common language for such a huge consortium. As there are scientists and industrial partners involved as well as several business units from within the industrial corporates, it takes time to get a common understanding of processes and working methods.
2. Governance Arrangements & Agents of Change:	The project was initiated and is coordinated by ThyssenKrupp, Fraunhofer UMSICHT and Max-Planck-Institute. 14 more partners from industry and science got involved during the phase of initiation. The partners from science and industry are building a bridge from basic research to the market with Carbon2Chem. The industrial partners are seen as the driving forces – the research partners are supporting on the overarching level. Besides the involved partners, politicians and the energy industry are and were important for the implementation of the project. During the phase of initiation, the partners reached out to the ministry in North Rhine-Westphalia (MWIDE). As a consequence, the project was supported from the beginning by the MWIDE in terms of mental support and to convince the government on a national level. Besides the investments of the involved partners, the project is funded by the BMBF with €60m for four years. A key driving factor for the industrial partners to initiate the project were the expected rising prises for CO_2-emission certificates and thus corresponding higher costs. Moreover, the project follows the aim to ensure the competitiveness of the specific sites of the plants. That's also the reason why the ministry of North Rhine-Westphalia (the region where the core partners of the consortium are based) is strongly supporting the project idea.
3. Transformative Capacities:	The idea of Carbon2Chem is demanding skills on a personal as well as on a technical knowledge level. The first-mentioned comprises a tacit, implicit knowledge as for example skills of working together in new teams, with people from different scientific or industrial backgrounds, working in different working environments, learning organisations or new ways of communication. The second-mentioned is an explicit knowledge on technical processes, products and possible market demands. All interviewees mentioned that the existing technical know-how in the consortium on both sides – research and industry – was and is fundamental for the project. In terms of technical challenges that the project is facing, the interviewees describe the consortium as well set up. The project is generating authority towards the funding institution and towards the public through the financial commitment of the industrial partners. This contribution can be seen as a signal that the project won't remain in the laboratory phase, but that an industrial large-scale implementation is aimed to be reached. The potential of the project to achieve CO_2-neutral steel is made distinct in public. The image of a circular economy is consistently used whereas the usage of the term "Carbon Capture and Usage" (CCU) is not used in broad public dissemination materials. While conducting the case study it was striking that the project consortium's members are not talking about decarbonisation but about CO_2-neutrality.
4. Assessment & Evaluation:	In the Carbon2Chem initiative, the accompanying LCA and economic analysis aims to develop corresponding scenarios that include ecologic and economic criteria. As the emissions of the steel industry have to get assessed very carefully by the steel industry due to CO_2-certificates (ETS), very exact data are already available. The challenge that the project is facing is to combine the steel and chemical industries' resource flows into one assessment: The source of CO_2 will be replaced for the chemical industry - so there are two reductions taking place: Emissions from the steel industry and reduction of fossil resources in the chemical industry. Having said that, the project is still running and not finished yet, and

	neither is the impact assessment of the initiative itself. Moreover, it is a challenge to combine economic and sustainable variables in one assessment which is needed for a successful implementation and up-scaling of the project in the future.
5. Uptake & Consequences:	The core idea of the project is a modular set up whose modules aim to facilitate an implementation of the energy transition. The steel industry hereby serves as an example: This means that the resources which flow into the chemical industry do not necessarily have to come from the steel industry, but can also come from other industries. Thus, the potential to scale up the innovation is very high in case of a successful phase of research and implementation. The project idea is applicable for at least 50 steel sites worldwide according to the project partners. Cross-industrial projects between partners that didn't know each other before are taking place more frequently: Including different corporations' cultures and activities that were formerly unrelated businesses and rather risky. Carbon2Chem can be seen as one part of the puzzle e.g. about the influence on the flexibility of the energy market. Moreover, there might be consequences on the gas market e.g. for methane, as worldwide around 10% of methane might get produced by the CO_2 coming from Carbon2Chem (from the steel site of ThyssenKrupp in Duisburg). This means that a large amount of methane would be on the market additionally and the effects for the chemical market are not clear yet.
Conclusion & Outlook	
Key Learnings:	A key driving factor for the industrial partners to initiate the project were the expected rising prises for CO_2-emission certificates and thus corresponding higher costs. Moreover, the project follows the aim to ensure the competitiveness of the specific sites of the plants. That's also the reason why the ministry of North Rhine-Westphalia (the region where the core partners of the consortium are based) is strongly supporting the project idea. The core challenge – besides technical challenges – of the project was in the phase of initiation, but also while the project is still running, to find a common language for such a huge consortium. As there are scientists and industrial partners involved as well as several business units from within the industrial corporations, it takes time to get a common understanding of processes and working methods. The contribution towards decarbonisation is expected to be a reduction of 20Mt of CO_2 per year. Though this equals 10% of yearly emissions of industrial processes and manufacturing industries in Germany, it is important to remark that the emissions will be "re-used" by the chemical sector and might be emitted on a later stage of the value chain in case that the carbon loop won't be closed. Nevertheless, the chemical industry can reduce the amount of fossil resources as these resources are provided by the steel industry at Carbon2Chem. But a switch towards a fossil-free steel production without a blast furnace might be hampered through the approach of CCU, as the path dependency of the steel industry towards the existing, high emitting blast furnace route, is strengthened. An additional learning from the case is that political actors can act as intermediaries in terms of supporting the initiation and institutionalisation of cross-industrial innovations. Nevertheless, public funding helps to gain authority for such large-scale industrial research programs. To conclude: It needs internal drivers for initiation (as a high willingness and motivation of all included persons), but also external drivers such as expected costs due to rising prices for CO_2-emission certificates. In addition, local factors in terms of proximity of the involved industries are favourable conditions for cross-industrial low-carbon innovations.
Open Questions & Further Research Requirements:	Going forward, it would be interesting to see how the project is further proceeding and which effects on decarbonisation will arise in the end. In addition, will be better to examine the impact on social, environmental and economic factors after an industrial implementation of the project. To conclude, both involved sectors may play an important source of change in the REINVENT sectors. But the pathway of CCU will only lead to an effective carbon reduction if it will be combined with a circular economy in the plastics sector.

5 Paper Case Studies

Three case studies have been conducted in the paper sector. Äänekoski Birorefinery is a case study of technical innovation on the resource and production side of the paper sector, looking into fossil-free pulp production. The Lime Kiln Conversion case study explores the operation of a 100% wood powder-fired lime kiln. DuraSense is an innovative biocomposite made of cellulose fibres, wood particles, and plastic which can be used for a number of different applications.

5.1 Äänekoski Birorefinery

Innovation:	**Biorefinery**
Intervention:	**Äänekoski bioproduct mill**
Case Study by:	Fredric Bauer (Lund University)
Methodology:	2 interviews, desktop research. Limited/incomplete case study due to actors withdrawing from participation.
Case Study Overview	
Sector(s):	Paper
Value Chain Stage(s):	Resource and production
Type of Intervention:	Technical
Date & Duration:	Planning started in 2013, construction was initiated in April 2015, and the bioproduct mill came into operation in August 2017 with a one-year ramp-up, reaching full production in August 2018. In October 2018 the construction of a textile fibre demo plant was initiated, to be finished by late 2019.
Location:	Äänekoski, Finland
Initiating Actors:	Metsä Fibre
Actor Constellation:	Sweco (general engineering consultant), Andritz and Valmet (pulping technology suppliers), EcoEnergy (biogas plant), Itochu (textile fibre partner), Metsä Spring (venture capital and innovation firm within Metsä) and a network of research and innovation partners.
Short Description of Intervention:	The Äänekoski bioproduct mill is a replacement for an old pulp mill in Äänekoski by Metsä Fibre and is the largest pulp mill in Europe. When planning to renew production at the Äänekoski mill, the decision was made to expand significantly, become independent of fossil resources for the operations, and create a biorefinery ecosystem around the mill open for diversification in collaboration with partners or through joint ventures. The bioproduct mill uses wood (mainly softwood) to produce kraft pulp (1.3 million tpa), and a range of byproducts – some of which have been produced in pulp mills previously, e.g. turpentine (3 200 tpa), tall oil (46 000 tpa), and electricity (1 TWh), and some less conventional products, e.g. biogas and sulphuric acid. State-of-the-art technologies were acquired from traditional pulp and paper process technology suppliers Andritz and Valmet. On-site operations (cranes, trucks etc.) are automated and electrified, the lime kiln uses producer gas from a wood gasifier, sulphuric acid is produced on-site, the waste water sludge is used for biogas production by a partner, new wood based textile fibre production is being developed in a joint venture with a partner company. Most technological solutions are not new, but the scale and application domain for several of them (e.g. bark gasification and sulphuric acid production) are, as well as their combination. The aim is further to expand the product portfolio with new products, of which textile fibres from kraft pulp is first in line with a demo plant currently under construction in a joint venture.

Research Theme Summaries	
1. Innovation History & Dynamics:	In 2013 the planning started for revamping and expanding the Äänekoski pulp mill in a small group within Metsä who focused on developing the plant towards a biorefinery, i.e. diversifying the product portfolio towards non-pulp products, and to do this through collaborations rather than developing all side processes and streams within Metsä. A significant risk and barrier was the scale of the application for many of the technologies used, most of which had previously been tested in similar applications but at a smaller scale. The scale also decreased the willingness to take risks, e.g. in making choices for even more innovative technologies. Main drivers for the project were perceived necessity of going into a direction of product portfolio diversification, while simultaneously going against many competitors and not investing in biofuel production processes.
2. Governance Arrangements & Agents of Change:	The main technologies for the conventional pulp production were acquired from the major technology suppliers Andritz and Valmet, aiming for state-of-the art solutions regarding energy efficiency and pushing for non-conventional solutions, e.g. sulphuric acid production from off-gases. The mill has been opened for other firms to invest in processes using available resources, such as biogas from waste water sludge by EcoEnergy, and joint ventures have been formed to market other new products, e.g. textile fibres through a joint venture with Itochu. The development of the fibre production process came out of a previous collaborative research project called Future Biorefinery. A significant share of the 1.2 billion EUR investment – the largest investment in Finish forest industry ever – was secured internally in Metsä, while the majority was loans from EIB (200 MEUR), the EFSI (75 MEUR), and other European Banks. A 32 MEUR investment support was granted by the Finish state for renewable energy and efficiency measures.
3. Transformative Capacities:	Building capacity through networks and acting as an "orchestra conductor" has been an important strategy for Metsä, a strategy which although it can be slow and tedious has reportedly been successful in building up a broader capacity than would otherwise have been possible. Regarding the new textile fibre production, partnering with Itochu was reportedly primarily for reasons of downstream market knowledge and access, as this is a market of which Metsä has little knowledge. The bioproduct mill builds on the competences and resources of the forest and pulp industry that has a long and strong tradition in Scandinavia. The availability of biomass resources in the form of forests – the growth rates of which are increasing – is a significant driver for the industry to develop new products from wood in a carbon-constrained world. Simultaneously, an increasing harvest rate has been challenged as this reduces the carbon sink provided by the forests. Stricter regulations on forest management could hamper the expansion of forest-based bioproducts, a concern raised by the actors.
4. Assessment & Evaluation:	The assessments and evaluations focus on energy efficiency rather than decarbonisation, as the previous mill was already (as most pulp mills) almost fossil-free. Compared to conventional pulp mills where the non-pulp products may correspond to 10% of the revenue, the Äänekoski bioproduct mill earns 20% from other products, the main one being electricity produced from biomass residues (the mill produces 140% more electricity than it uses, compared to a conventional mill that may produce around 50% more than its demand).
5. Uptake & Consequences:	The biorefinery is a widely diffused concept in the pulp industry, where many firms have focused on liquid biofuels as the main new product category. Metsä on the other hand have excluded fuels from the product portfolio and focused their work on structural products, e.g. biocomposites and textile fibres, while using residual resources for energy. Regarding some of the more specific technological solutions scaled up and implemented in the Äänekoski bioproduct mill it remains to be seen to what degree these diffuse within the sector, which will take time as major reconfigurations of mills happen only every few decades.
Conclusion & Outlook	
Key Learnings:	The Äänekoski bioproduct mill is an example of the biorefinery development pathway that has become prominent in the discussion about the future for pulp mill development. It shows that portfolio diversification is still a minor activity, but it receives much attention and interest.

	A network governance model for innovation breaks the traditional sectoral boundary constraints and has seemingly been successful in this case. As the literature has reported many complications for other actors aiming to move towards biorefineries through collaborations, following the developments in Äänekoski over time will be relevant for better understanding such network dynamics. However, the main part of the bioproduct mill is a traditional pulp mill which is fully controlled by Metsä and thus the novelty of the approach and implementation should thus not be overestimated.
Open Questions & Further Research Requirements:	

5.2 Lime Kiln Conversion

Innovation:	**Lime kiln fired with biofuel**
Intervention:	**New lime kiln at SCA Östrand (Bioloop)**
Case Study by:	Lars J. Nilsson and Karin Ericsson (Lund University)
Methodology:	4 interviews with a total of 5 people. Background information from the internet (e.g., press releases) and on lime kilns in kraft pulp mills.
Case Study Overview	
Sector(s):	Paper
Value Chain Stage(s):	Primary pulp production
Type of Intervention:	Technical intervention
Date & Duration:	Project announced 2009 and kiln in operation 2011
Location:	Sweden
Initiating Actors:	SCA
Actor Constellation:	SCA and equipment supplier Andritz. SCA had clear criteria and demands to which Andritz offered a solution in competition with Valmet.
Short Description of Intervention:	The intervention consists of SCA's investment (500 MSEK) in a new wood powder-fired lime kiln at Östrand kraft pulp mill in Timrå. The new powder-fired lime kiln at SCA Östrand replaced two oil-fired lime kilns. The lime kiln is primarily fuelled by wood powder from ground pellets, but also uses gases from the mill (that need to be dealt with anyway), and has oil as back-up in case of problems, upstarts, etc. The pellets are supplied by SCA's wood pellet factory BioNorr in Härnösand, which is only 40 km away. The equipment was supplied by Andritz. Lime kilns are a key process step in the chemical recovery system in kraft pulping. In the lime kiln, calcium carbonate (lime mud) is converted to calcium oxide (re-burned lime mud) via calcination. The lime kiln receives lime mud from the causticizers which prepare the cooking chemicals (white liquor) and then returns calcium oxide to the white liquor preparation. The kiln is a long rotary kiln typically fired by oil or gas to provide a high and stable temperature for the reaction.
Research Theme Summaries	
1. Innovation History & Dynamics:	At the time of deciding to invest in a new lime kiln there were two plants in Sweden that had partial wood/bark-powder firing in converted kilns (Södra's pulp mill in Mönsterås and Kappa Kraftliner in Piteå). However, Östrand was the first ever new-build and new investment for near 100 % wood powder firing. The innovation built on the research on wood powder fired boilers in Sweden and elsewhere, which goes back to the 1980s, and the installation of a number of wood powder burners in converted boilers and CHP plants that previously fired coal. Nevertheless, firing basically 100 % wood powder in a new large lime kiln meant pushing the technical development since there is a chemical process in the kiln and the re-burned lime mud must meet certain quality requirements. Hence, new burners had to be designed and fine-tuned in order to ensure good heat distribution in the kiln, the right flame temperatures and shapes, etc. Excessive temperatures cause refractory damage and over-burned slow reacting lime product. Andritz, who put together the system with lime kiln, grinders, fuel feed, etc., had good theoretical knowledge of wood powder burners, but no previous practical experience of powder burners in rotary lime kilns. SCA had experience of producing and handling wood pellets. An important challenge for this intervention was the handling of large amounts of pellets and powder (about 11.5 ton/h) including explosion risks. However, to secure a stable supply of wood pellets was not a challenge in this case since SCA has a wood pellet factory at a

	relatively nearby site. Moreover, the logistics were already in place with trucks delivering sawdust to the pellet factory from sawmills close to the pulp mill and then going back empty. These could now transport pellets on the way back. As a consequence of the intervention, the wood pellet factory now had a customer with a stable all-year demand totalling 55,000 t/yr (the capacity is 160,000 t/yr) and can thus avoid seasonal storage. The pellet market is otherwise driven by the seasonal demand for space heating. A minor institutional barrier to this intervention concerned the required renewal of the environmental permit for the pulp mill as a result of the lime kiln investment, a process in which the increased NO_x emissions were challenged by the authorities (the NO_x emissions are higher for wood powder burners than oil-fired burners). Based on the good experiences from Östrand, SCA made a decision in 2012 to also invest (490 MSEK) in a wood powder lime kiln at Munksund pulp mill. This time it was together with Valmet who were keen on doing it and getting a show-case/reference. Also Södra decided to invest in a wood powder fired lime kiln at Värö pulp mill in 2012, which was in operation 2015. However, no other investments in wood powder fired lime kilns have been identified apart from Östrand, Munksund and Värö. At the moment, there appears to be greater interest in biogas fired lime kilns where the biogas is produced via thermal gasification.
2. Governance Arrangements & Agents of Change:	The key actors in this intervention are SCA, Andritz and Valmet. Andritz and Valmet (the only two suppliers in the European market) made competing bids for the project. Andritz was chosen primarily because they provided guarantees for the technology. The arrangement was a pretty normal project procurement except both SCA and Andritz were prepared to push technical development. At Andritz the project was managed and carried out by Andritz Finland which appears to be relatively autonomous from the mother company and to have had large degrees of freedom in this project. The investment decision at SCA aligned with their long-term investment strategy and of maintaining a green profile. Some years earlier, plans had been made to expand the mill but the 2008-2009 recession made investments a challenge. In an effort to proceed with expansion plans the lime kiln was identified as the most interesting and profitable investment (the oil-fired lime kilns were unreliable and a bottle neck at the time). The oil price was fairly high at the time and the price of wood pellets was expected to be favourable to oil in the long-term. The synergy to buy wood pellets from the sister company was also recognised. Particular government policies, including the EU ETS, were not important for the investment decision. The financing of the intervention could not be determined from the interviews but SCA is a financially strong company. At both SCA and Andritz, new knowledge and training were required for the handling of wood pellets and powder, which involves explosion risks. The use of wood pellets at the pulp mill entailed new business between sister companies and highlighted the opportunity for synergies within the SCA group. The intervention strengthened the green profile of SCA and provided a stable demand for wood pellets for the wood pellet factory.
3. Transformative Capacities:	The intervention builds on previous skills in SCA (e.g., in producing and handling pellets) and in Andritz (e.g., theoretical background in wood powder burners) but also required new skills to be developed. Although wood and bark powder burners in lime kilns already existed, this was the first ever 100 % full-scale wood powder fired kiln. In particular, the pellet and powder handling required new skills, including in dealing with explosion risks. Although it involved technical challenges, these were judged to be small enough for Andritz to make an offer aligned with the SCA demands for very high availability in what was jokingly referred to as “a full scale pilot”. A key reason for going ahead with the project was that it was profitable with the relatively high oil prices that prevailed at the time, but it was also very much aligned with SCA corporate strategy to be an environmental leader. Both companies see themselves as innovative forerunners. The project was never challenged or questioned from corporate headquarters.

	The project itself has not been used for marketing or branding. For this purpose, environmental goals and emission trends are reported on a more aggregate level.
4. Assessment & Evaluation:	The emission reductions are easy to calculate through the avoided use of oil (17 000 m^3 of oil per year is about 46 kt of carbon dioxide). It is considered a successful project by SCA and Andritz but it has not been evaluated by external actors. The carbon reductions and sustainability are also dependent on sustainable forestry.
5. Uptake & Consequences:	Being or striving to become fossil-free appears to be a strong norm in the Swedish paper industry. This is not the case in other parts of the world. Reducing oil dependence has been on the agenda for decades. The pellet market started mainly for space heating and small boilers. The project increased pellet demand with likely effects on the pellet market and regional bioenergy development. The mill expansion as a whole was expected to generate 600-700 new jobs but mainly upstream and downstream and only a few jobs at the mill itself. The projects at Munksund and Värö may have had similar effects. The project is aligned with and may have strengthened corporate strategy and image as an environmental leader. Forestry effects on biodiversity are always an issue but it is not possible to attribute effects to a single project.
Conclusion & Outlook	
Key Learnings:	The case illustrates the importance of the mill context (e.g., expansion plans), including material and geographical factors (proximity of pellets), path dependency (e.g., pellets market for space heating), and trust between actors in the choice of technical solution. Alternatives to wood powder include gas from gasification, tall oil and bark powder. Mills with less direct access to pellets seem to prefer gasification. Tall oil goes to transport fuels due to strong policy induced demand. Bark powder is slightly more technically challenging than wood powder. Getting away from oil, and doing so profitably, was a key driver and going ahead with decarbonisation has been part and parcel of corporate strategy for a long time. Overall strategy and future expectations are key to strategic investment decisions, and EU-ETS played a very small role in motivating the investment. The innovation may spread to kraft pulp mills in other parts of the world but it is of less relevance to paper mills in Europe. Here, a key option is electrification to replace natural gas used primarily in steam generation for heating and drying. Investments must be profitable to be made – this motivates policy to change relative fuel and electricity prices.
Open Questions & Further Research Requirements:	Electrification options for the paper industry need further research. Electric boilers may be easily installed but more energy efficient options (e.g., high temperature heat pumps and process heat integration) should be pursued.

5.3 DuraSense

Innovation:	**Biocomposite**
Intervention:	**DuraSense**
Case Study by:	Fredric Bauer (Lund University)
Methodology:	Four interviews, three site visits, one trade fair, desktop research. More interviews were planned but were later cancelled by interviewees.
Case Study Overview	
Sector(s):	Paper/plastic
Value Chain Stage(s):	Resource and production
Type of Intervention:	Technical
Date & Duration:	Innovation project for biocomposites initiated in 2014, first products made from DuraSense launched 2018.
Location:	Sweden
Initiating Actors:	Stora Enso
Actor Constellation:	Stora Enso Local SMEs with expertise in plastic converting
Short Description of Intervention:	Biocomposites are composite materials usually consisting of a biobased fibre mixed with a plastic. Biocomposites are used in a range of applications, such as automotive panels and upholstery, noise insulating panels, and indoor furniture. Recent estimates for Europe are that more than 30 compounders are active in the area of biocomposites and together produced more than 100 000 tonnes in 2018. In an effort to diversify into new products, Stora Enso focused on biocomposite as an opportunity with large potential and developed DuraSense, which is a biocomposite made of cellulose fibres, wood particles, and a plastic which may be a bioplastic, recycled plastic, or fossil based plastic. DuraSense was mainly developed in-house by a small team, after engaging with different external stakeholders to understand market requirements and potential. To test the material and its properties in different downstream applications the team started collaborating with local SMEs with expertise in plastic converting.
Research Theme Summaries	
1. Innovation History & Dynamics:	In 2014, following the closing down of two paper machines (in 2012 and 2013) in Hyltebruk in south-western Sweden and the laying off of almost 300 employees, a new analysis of diversification opportunities concluded to focus on biocomposites. In 2017 the decision was made to invest in a commercial scale compounding unit for the production process in Hyltebruk, a 12 MEUR investment which allows for the production of 15 000 tonnes per annum of DuraSense. This unit is currently the largest biocomposite compounding unit in Europe, although it is a small unit compared to manufacturing units for plastics. In mid-2018 the first set of consumer products were launched, a range of kitchen utensils by Orthex. Also disposable cutlery has been launched and other products are being developed.
2. Governance Arrangements & Agents of Change:	Decreasing markets for traditional products (newsprint in the case of Hyltebruk) forced Stora Enso to look for new opportunities, which coincided with increasing interest in green materials such as biocomposites in several markets. Current policies and regulations are dismissed as direct drivers for the development. The development was done in collaboration with local firms, although not through any formal partnerships or joint ventures. The initiative has led to Stora Enso making two major investments in a production facility and a competence centre for biocomposites. According to public information these investments total 19 MEUR, of which 12 million were for the production facility. No information has been disclosed on how the investments were financed. The initiative also led to the filing of several patents in the area of biocomposites and their manufacturing, codifying the

	knowledge produced in the innovation project. The initative also led to the founding of a new subsidiary within Stora Enso focusing on biocomposites.
3. Transformative Capacities:	Investing in new knowledge through the recruiting of new research engineers was crucial to building up capacity to work with the new area. The restructuring of work in the team, from a structure focused on continuous production to one focused on rapid decision making was important for moving the project forward. When realising that some competences needed for taking the project to a marketable product were missing, collaborations were formed, which added necessary capacity. The visibility of the biobased content, by including coarse wood fibres in the biocomposite, attracts attention and makes the renewable properties legible. The value of this is accentuated in the products which do not use pigmented plastics but retain the wood-based colour. Recycling is recognised as a key concern, but most interviewees recognise that plastic recycling schemes and policies are almost completely focused on plastic packaging, which is most likely not what DuraSense will be used for, thus distancing the innovation a bit from the recycling discourse.
4. Assessment & Evaluation:	The main assessment of the decarbonisation potential relies on the substituted volume of plastics by wood fibres in the biocomposite, which is up to 50% but depends on the application requirements. The carbon footprint depends on the polymer used in the biocomposite but it is reported to be up to 80% lower than conventional plastic when using a biobased polymer, which currently is biobased poly-ethylene.
5. Uptake & Consequences:	The biocomposite business is now a separate business organisation within Stora Enso, not only due to its low carbon properties but also due to the fact that it is a type of product that lies outside of the regular business activities of the firm which mainly deals with sawn wood, pulp, board, and paper. The low carbon properties of all these products are promoted in the communication of the firm – in this way the narrative around DuraSense thus closely follows the business-as-usual narrative. DuraSense has reached commercial production in a facility with a production capacity of around 15 000 tonnes per annum, which is the largest capacity for biocomposites in Europe. It is thus in itself a scaling of biocomposite production, although the actual production is yet unknown, but assumed to be far from the full capacity.
Conclusion & Outlook	
Key Learnings:	The DuraSense case showcases several trends identified and discussed within Reinvent: the move towards biobased raw material resources to substitute for fossil ones; industries diversifying and crossing traditional boundaries; the value of collaboration along the value chain for successful innovation in new areas. The case shows how a window of opportunity was created for the initiative in a situation when the main actor was under severe pressure, forcing them to look for new opportunities, combined with a growing interest for alternatives to traditional plastics in some markets. The increasingly intensified discourse around plastics and their negative environmental effects supported the initiative throughout the development process. The case shows how two sectors are approaching each other, however not through partnerships between global firms but rather through very local processes building on trust and proximity rather than a quest for a global market from the start through a jont venture or similar scheme. If and when the market for biocomposites in general and DuraSense in particular matures, the type of partnerships needed to grow may of course be completely different, which is also acknowledged by the main actor.
Open Questions & Further Research Requirements:	The opportunity to integrate biocomposites into a circular system for production and use of plastics is largely unexplored but raises questions when it comes to standardisation and recycling. As it thus far seemingly is a material used in niche market applications, the role of strategic partnerships for decarbonisation remains interesting to explore in this context.

6 Meat and Dairy Case Studies

Four case studies were conducted in the meat and dairy sector and are summarised in this chapter. Friesland Campina's Green Schuldschein is a case study at the intersection of the dairy and finance sectors, analysing the company's use of the financial instrument of the green bond. The Green Protein Alliance is a social intervention on the consumption end of the meat and dairy value chain, promoting the partial substitution of animal protein with plant protein. The Oatly case encompasses both production and consumption, focussing on the substitution of cow's milk with plant milk made from oats. Cultured Meat looks into a technical innovation for meat alternatives, investigating the possibilities of lab-grown meat.

6.1 Friesland Campina's Green Schuldschein

Innovation:	**Green Bonds**
Intervention:	**FrieslandCampina Green Schuldschein**
Case Study by:	Bregje van Veelen (Durham University)
Methodology:	8 interviews, attendance at 2 industry workshops/conferences
Case Study Overview	
Sector(s):	Meat & dairy
Value Chain Stage(s):	Finance
Type of Intervention:	Social
Date & Duration:	2016 - present
Location:	The Netherlands
Initiating Actors:	FrieslandCampina (dairy company) and various international banks
Actor Constellation:	FrieslandCampina – issuer Green Bond. Involved collaboration between their supply chain, sustainability and finance departments Various banks (e.g. Rabobank, ING) - intermediaries, arrangers Vigeo Eiris – intermediary, provider second opinion Investors (unidentified) Sustainable dairy actors – e.g. Duurzame Zuivelketen in the Netherlands, International Dairy Federation
Short Description of Intervention:	FrieslandCampina is the first non-German issuer of a 'green' Schuldschein, through which it raised €300 million of investment, as part of its strategy to diversify its funding. It is also the first 'green' debt instrument issued by a dairy company. FrieslandCampina is a Dutch multinational dairy cooperative that controls approximately 75-80% of the dairy market in the Netherlands. Therefore emission reductions within this company's value chain have the potential to contribute significantly to emission reductions of the Dutch dairy sector as a whole. In the case of FrieslandCampina, proceeds will be used for three types of projects, which connect to the three pillars of the company's *Nourishing by Nature* purpose: • Reduction of environmental footprint of production factories • Sustainable farmer development • Development of healthier products This case study is primarily concerned with the first set of projects, as the others do not have an explicit focus on decarbonisation. The reduction of the company's environmental footprint is part of its *route2020* strategy. The majority of the money raised (80-90%) will be used to improve environmental footprint and train farmers. Projects financed by the Schuldschein cover a wide range of projects, although these fall within three larger on-going projects, all focused on reducing emissions from the company's processing factories. It is

	important to note, however, that the company used the money to re-finance some of these projects, rather than putting an additional €300 million towards sustainability.
Research Theme Summaries	
1. Innovation History & Dynamics:	This section focuses specifically on the history and dynamics of *Green Schuldscheine*, the financial instrument deployed by FrieslandCampina to fund their low-carbon projects. Schuldscheine originate from the German market, where they have been used since the 19th century. Although there is an increasing internationalisation on both the investor and issuer side, approximately three-quarters of Schuldscheine issued in 2015 were issued by German institutions. While Schuldscheine have a long history, the first *green* Schuldschein was only issued in 2016. There is, however, a growing demand for them, reflecting a general growth in demand for green investment products. +/- 50% of these products are invested in by investors specifically interested in green or sustainable investments, the other 50% by ‚normal' institutional investors. Despite this optimism, there is an on-going debate in the wider green bond sector regarding the balance between upscaling the number and value of green bonds coming to market, while also maintaining integrity of the sector (i.e. ensuring there is no ‚greenwashing').
2. Governance Arrangements & Agents of Change:	The process of issuing of the Schuldschein can be conceptualised as a multi-stakeholder collaboration. Within FrieslandCampina, it involved the company's sustainability, supply chain and finance departments, with the latter taking the lead. The issuance of a Schuldschein involves close cooperation between FrieslandCampina and several international banks (Rabobank, ING Bank, BNP Paribas, Unicredit, and Raiffeisen Bank International) who provide advice to the issuer regarding how to structure the offer to ensure that it is both 'green' and of interest to their investors. FrieslandCampina also hired French company Vigeo Eiris to provide a second opinion, which is an external assessment to determine whether the proposal can be truly classified as ‚green', and enabling investors to assess a project's risk and return before investing. The provision of a second opinion is thus key to legitimising the initiative. Resultant changes: The Green Schuldschein offered an additional means through which to raise finance on favourable terms that goes into the 'general finance pot' but which has the added value of allowing FC to demonstrate leadership on sustainability. It did not, however, significantly change the company's operations nor provide *additional* carbon savings.
3. Transformative Capacities:	What is most noticeable is the framing of the initiative as *non-transformative*. As explained previously, FrieslandCampina repeatedly stated that the €300 million raised does not provide additional funding for low-carbon projects, and that the projects funded through the green Schuldschein would have been implemented either way. Furthermore, the focus on reducing emissions from its factories enabled FrieslandCampina to make decarbonisation legible, without upsetting its 18000+ member farmers. The dispersed ownership of farms also makes it difficult to direct centralised investment from institutional investors towards farmers. Furthermore, FrieslandCampina's actions should also be seen in the context of the company's strategy that assumes a continued growth in milk production, thus favouring technological change in its factories over transformative change along its value chain. While Vigeo Eiris played an important role in providing authority and legitimacy for the initiative, this did not necessarily entail making the low carbon qualities of the initiative distinct. Rather, Vigeo's role was in making the governance qualities of the issuer distinct and giving those value (i.e. how reliable is the issuer, rather than how much carbon will be saved).
4. Assessment & Evaluation:	Assessment and evaluation of the initiative has primarily been undertaken by Vigeo Eiris, the intermediary hired by FrieslandCampina to provide a Second Party Opinion on its Schuldschein offer. But, the assessment does not quantify GHG emissions reductions. Rather, as part of the second party opinion, Vigeo Eiris evaluates the *resources allocated* by the issuer to manage the GHG emissions for example. As such, the evaluation is more concerned with the procedural dimensions of low-carbon governance, than with quantifying its outcomes. It had not yet evaluated the initiative post-issuance to determine whether FrieslandCampina has done all the things it said it would do, so little is known about the actual impact of the initiative. Within FrieslandCampina, the main challenges identified are (1) the design of holistic metrics that also account for other environmental factors (biodiversity, animal health, etc.); and (2) their inclusion in subsequent decision-making within the company.

5. Uptake & Consequences:	Scaling up: Since FrieslandCampina other dairy companies have also issued Green Schuldscheine, and the Green Bond market as a whole is continuing to grow. The Climate Bond Initiative is also developing new standards for agricultural green bonds to standardise the way in which impact is measured. Visibility: The final challenge identified within FrieslandCampina is not necessarily the design of impact metrics, but their inclusion in subsequent decision-making. It is here that employees saw the greatest room for improvement. While it was not expected that the metrics for measuring climate impact will change significantly in the future, it was expected that the ways in which metrics are used may change. Other consequences: The technological measures implemented should also be seen in a wider context where FrieslandCampina expects continued growth in the volume of milk produced and processed, at least until 2020. Thus, the focus on technological measures potentially avoids some of these difficult trade-offs between decarbonisation, farmers' livelihoods, and the place of the 'iconic' dairy sector in Dutch society and the national economy.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* FrieslandCampina's internal structure is interesting: it consists of two ‚prongs': the cooperative (the farmers) and the company (which buys the milk from the farmers and is wholly-owned by the cooperative). This means it has (theoretically) more influence over its upstream value chain, but it remains difficult to realise change at the farm-level. The dispersed ownership of farms (e.g. family-owned) makes it more difficult to direct finance that way, it is easier to invest it in ‚big' projects, wholly owned by the company (such as factories). This makes it difficult to direct green finance in the agricultural sector to the part of the value chain where most (70-80%) of the emissions emerge *Key insights from this case regarding …* *Overall decarbonistion:* FrieslandCampina's factories only make up a small proportion of the company's emissions. While these have been reduced, this is not necessarily as a result of the Green Schuldschein (which was used to re-finance the projects rather than provide new finance), and the majority of the company's emissions (from farms) remain untouched. The use of ‚green' financial instruments to refinance existing projects rather than fund new projects does not seem completely unique in the financial sector. *Drivers:* Green Schuldscheine issuance was a means for FrieslandCampina to display/signal its 'green' credentials to the outside world, legitimising the company's practices and potentially pre-empt the introduction of future, stricter regulation. *Barriers:* see above note re dispersed ownership. *Instruments to overcome them:* There may be ways for FrieslandCampina to issue a Schuldschein and then spend the money on reducing emissions on farms, but from a governance-perspective this is more challenging, meaning it may be more difficult to raise investment (because seen as more risky). *Role of policy:* FrieslandCampina is anticipating the future introduction of stricter regulation to ensure the agricultural sector contributes to national carbon reduction targets. By trying to show it is reducing emissions already, the company hopes regulation for the dairy sector will be less strict.
Open Questions & Further Research Requirements:	Due to the lack of access to investors to interview, no information was gathered about their motivations, and why they had become interested in the Schuldschein, although other interviewees alluded that they are likely to be more driven by the risk/return model of a Schuldschein, than the 'green' measures suggested by FrieslandCampina. Further research that addresses some of the drivers and barriers for investors to invest in 'green' finance instruments/projects would be helpful.

6.2 Green Protein Alliance

Innovation:	**Private governance initiative to promote dietary change**
Intervention:	**Green Protein Alliance**
Case Study by:	Maria Tziva (Utrecht University), Simona Negro (Utrecht University)
Methodology:	21 semi-structured in-depth interviews, 2 site visits (plant-based product exhibition Veggie World, London, April 2017; Green Proteins Summit, Wageningen, October 2017). *The GPA is an on-going initiative. This analysis takes into account developments up until January 2018.*
Case Study Overview	
Sector(s):	Meat and dairy
Value Chain Stage(s):	Consumption
Type of Intervention:	Social
Date & Duration:	Founded in 2016 and on-going
Location:	The Netherlands
Initiating Actors:	The Planet (Het Planeet) DuurzaamDoor programme - Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland (RVO)) New Foresight
Actor Constellation:	Members: Alpro, Appel, Bonduelle, Boon, Dutch Soy, the Dutch Weed Burger Garden Gourmet, GoodBite, Grow, HAK, Intersnack, Jumbo, Marley Spoon Menken Orlando, Next Foods, Oljik, Purple beehive, Quorn, Rotterzwam, So Fine, Unilever, Vivera, Zeewaar Partners: Drift, Dutch cuisine, HAS Hogeschool, Luis Bolk Institute, Milieu Centraal, Ministy of Economic Affairs (EZ), Natuur & Milieu, Rabobank prof. AH Kersten (WUR), Voedingscentrum, Albert Heijn
Short Description of Intervention:	Meat and dairy production contributes significantly to climate change. Meeting the EU 2050 emission reduction targets will require the deep decarbonisation of the EU agri-food sector. Large mitigation potential still exists in reducing meat and dairy consumption. However, due to uncertainties related to the impact of demand-side food regulations, such as consumption taxes on food, and strong industry opposition, governments are reluctant to introduce demand-side regulatory measures that would regulate consumption. The wider diffusion of low carbon innovations, such as a wide range of plant-based protein products, could contribute to an accelerated dietary shift and disrupt meat and dairy consumption. The Green Protein Alliance (GPA) is a multi-stakeholder partnership, which consists of firms from the complete supply chain of plant-protein products, and partners including the Ministry of Economics, the Dutch Nutrition Centre and NGOs. It aims to change the protein consumption balance in the Netherlands to 50:50 protein (plant:animal) by 2025 by providing a space for sector organization activities, including setting sector-wide product standards, inspiring product development partnerships and new product market introductions and implementing consumer awareness campaigns and education initiatives.
Research Theme Summaries	
1. Innovation History & Dynamics:	The GPA was launched in 2016. Initially 14 firms across the supply chain of plant-based protein products, including incumbent retailer Albert Heijn, invested in the initiative and officially became members. In 2017, the GPA organised a public event to introduce GPA and present its strategic plan, the Green Growth Plant. The overarching vision of a healthier and more sustainable food system was recognized as guiding the activities of the members in the alliance.

<table>
<tr><td></td><td>The plan committed the GPA to set specific standards for plant-based products to comply with the dietary guidelines of the Dutch Nutrition Centre. All members of the GPA committed to efforts that aimed to make plant-based products the “easy” choice for consumers.
The event introduced two initiatives for the long-term development of the plant-based protein sector including a subsidy scheme for the development of innovative plant-based protein products and a partnership between two producers of plant-based protein products and a university of applied sciences to train students for the needs of the plant-based products industry.</td></tr>
<tr><td>2. Governance Arrangements & Agents of Change:</td><td>The alliance is governed by a governing board consisting of four representatives of different plant-based protein product firms and has an official spokesperson.
The different members and partners of the GPA have diverse roles. Producing firms have a role in product innovation, in co-operating and in sharing knowledge. The role of business-to-consumer firms, such as retailers and food service firms, includes providing consumers with more opportunities to purchase and consume plant-based protein products. The partners have a role in developing and sharing credible dietary information for healthy and sustainable diets. All members and partners have a role in communicating the shared message of striving for a healthy and sustainable food system.</td></tr>
<tr><td>3. Transformative Capacities:</td><td>Models for sustainable sector transformation developed by the consultancy firm New Foresight were the underlying principles in the development of the GPA. New Foresight’s approach stipulated a set of interventions to leverage the positive drive firms in a sector have to develop in order to transform markets towards sustainability. These interventions relate to the structuring of supply, demand and the environment of the sector. Public and private stakeholders need to work together towards a coordinated tailor-made plan.
In the case of the transition to plant-based protein consumption, first several barriers for plant-based protein demand, supply and the environment of the sector were identified. To overcome those barriers, the shared message for a healthier and sustainable food system and the goal of 50:50 (plant:animal) protein consumption by 2025 were set and the Green Growth Plan was introduced.
The low carbon quality of the initiative was communicated in most of the GPA activities. It was made distinct by quantifying the impact the GPA goal will have on CO_2 emissions. Particularly, it is argued that achieving the goal of 50:50 (plant:animal) protein consumption will lead to the reduction of CO_2 emissions by 5200 kton. In the case of the GPA, apart from low carbon qualities, the overall health benefits of the initiative were also made distinct. The GPA argues that by achieving 50:50 (plant:animal) protein consumption, the nutrition of Dutch consumers will be brought more in line with the proposed dietary guidelines for healthy diets, of the Dutch Nutrition Center.
The models of market transformation resonated with the initiators and the GPA members and partners. Hence, it significantly contributed to making the potential of the initiative legible and the establishment of the GPA possible.</td></tr>
<tr><td>4. Assessment & Evaluation:</td><td>The first impact assessment of the GPA was included in the Green Growth Plan published in 2017. The impact is measured through the number of members and partners in the GPA, their market share percentage in the Netherlands, the number of new partnerships for product development and the number of new products and meals. The detailed quantified measures are illustrated in table 1. Additionally, the Green Growth Plan argues that in 2016, there has been a 16% increase in the consumption of plant-based protein products.
<table><tr><td>14 founding members</td></tr><tr><td>16% increase in the consumption of plant-based proteins in 2016</td></tr><tr><td>8 new plant-based protein products have been introduced in retail and recipe boxes</td></tr><tr><td>50% of Dutch retailers represented</td></tr><tr><td>80% of plant-based protein producers represented</td></tr><tr><td>12 new partnerships have been forged</td></tr><tr><td>6 new market parties are affiliated</td></tr></table>Table 1, Summary of GPA impact</td></tr>
<tr><td>5. Uptake & Consequences:</td><td>One of the most important perceived successes of the GPA was that the initiating actors managed to develop a partnership, for the promotion of plant-based protein consumption,</td></tr>
</table>

	between important actors in the agri-food sector. The constellation of the members and partners in the GPA was perceived as a central factor in influencing protein consumption. All members and partners have a particular role in order to achieve the goal of 50:50 plant 50:50 (plant:animal) protein consumption by 2025. Moreover, over the course of its implementation, the GPA managed to attract new members such as Unilever, one of the largest agri-food firms globally and Jumbo, one of the largest retailers in the Netherlands. Therefore, the potential impact of GPA projects is growing. In terms of broader environmental impacts, due to lower land use, the environmental impact of a plant-based diet is significantly lower than the impact of a diet based on meat and dairy products. Finally, although animal products are good sources of a range of essential nutrients including protein, diets characterized by high animal product intake have been associated with health risks including cardiovascular disease and colorectal cancer. Therefore, a decrease in the average consumption of meat and dairy products can have important benefits for human health.
Conclusion & Outlook	
Key Learnings:	The novelty of the GPA lies in the scope of the initiative. It is the first multi-stakeholder partnership in the Netherlands and among the very few worldwide which aim to change the protein consumption balance by promoting plant-based protein products. In this respect, it comprises a step in building the necessary conditions for increase in the consumption of plant-based protein products and ultimately a more sustainable protein consumption balance. A large body of scientific literature argues that reducing meat and dairy consumption can have a significant impact on the decarbonisation of the food sector. Private governance initiatives, such as the GPA, are important in promoting food consumption transitions mainly for two reasons. First, demand-side hard regulations in food are almost completely absent and the sector is regulated to a large extent by such hybrid and private governance initiatives. Second, the role of each different organization in multi-stakeholder partnership is important for the implementation of regulation because different actor groups bring in different crucial resources and capabilities. Finally, the case illustrates that the promotion of emerging industries, such as the plant-based protein industry is more likely to secure the necessary support of important stakeholders than the restriction of existing industries. It also offers interesting growth opportunities for mature sectors. Therefore, it can comprise an avenue to bypass lock-in in the industrial sectors and promote decarbonisation.
Open Questions & Further Research Requirements:	Further research could focus on the impact of broad hybrid and private governance initiatives for decarbonisation and whether they adequately promote transition pathways.

6.3 Oatly

Innovation:	**Oat-based dairy analogues**
Intervention:	**Oatly**
Case Study by:	Ludwig Bengtsson Sonesson (Lund University)
Methodology:	10 semi-structured interviews, site visit to Oatly plant and Oatly office.
Case Study Overview	
Sector(s):	Meat/Dairy
Value Chain Stage(s):	Production/Consumption
Type of Intervention:	Technical and Social
Date & Duration:	Initiated in the early 1990s (on-going)
Location:	Sweden
Initiating Actors:	Rickard Öste Lund University
Actor Constellation:	Lund University – Research Svensk Sädesförening – Initial Investment Lantmännen AB – Early investor Skånemejerier – Industrial Partner Rickard Öste – Founder Forsman & Bodenfors – PR-Firm Verlinvest – Investor China Resources - Investor
Short Description of Intervention:	Oatly produces oat-based dairy analogues for an international market. Through a patented enzyme process, they manufacture an oat-base, which is then processed into a diverse set of products (milks, yoghurts, cream etc.). The innovation itself came in the early 90s, but it was not until 2012 that Oatly really took off. A new CEO, Toni Petterson, was adamant that the product was not just for those who were unable to process dairy – but for all who made the choice not to drink it due to its environmental impact. This re-framing also brought with it a new look and attitude to the packaging, with "Wow No Cow" branded on the front, and humorous text by copywriter John Schoolcraft. This antagonistic approach spurred a law-suit from the Swedish Dairy Lobby which put the dairy discussion as a headline item in the papers - "The Milk War" was brewing. While Oatly lost in court, they were now a household name and have been growing ever since. A new ownership in 2016 took them to both the US and China and in 2018 they reportedly outsold dairy milk in some stores.
Research Theme Summaries	
1. Innovation History & Dynamics:	Oatly's story can be divided into five acts: Early Innovation, Commercialisation, the birth of Oatly, Change and Globalisation. The innovation spun out of research on lactose intolerance at Lund University and an offer of small funding to develop a value-added product based on oats. The enzyme was developed and patented and the rest of the 90s were spent partnering with a range of established actors to take it to market (Lantmännen, ICA, Friggs). After the Lantmännen partnership collapsed, 'Oatly' was born, new investors acquired and an uncon-ventional partnership with dairy producer Skånemejerier started. However, the oat milk was sidelined and to gain independence, Oatly built their Landskrona manufacturing plant in 2006, a big step. A steady but slow growth lead to the recruitment of Toni Petterson, the "change" process and the current rebellious positioning of Oatly. Key takeaways: • Initial demand created by research on lactose intolerance. Increasing eco-trend/cli-mate change awareness created second wave of demand. • Plant milks are not new, they are very old innovations, but Oatly's ability to pick up on societal trends and appeal to new demands is their strength.

	• Early circulation focused on baristas and spread fast. Has established itself as THE alternative to milk in coffee shops/hotel breakfasts/offices (in Sweden). • Major barrier has been production capacity. Strict demands on purity of product makes outsourcing hard. • The cultural hegemony of dairy in many western countries is both a barrier and a driver – there needs to be a ruler for a rebel to emerge. • Oat demand is increasing, will make their production more valuable for farmers.
2. Governance Arrangements & Agents of Change:	Oatly has and continues to benefit from their close connections with Lund University. It birthed the initial innovation and is now involved in ScanOats – developing the oat breeds of tomorrow. The discussion on livestock's impact on climate change, spurred both by reports (FAO Livestock's long shadow), popular culture (Cowspiracy etc.) and the vegan movement, enabled the vision of a "post-milk generation". The EU School Milk Subsidy was contested by Oatly, but so far – no institutional change has occurred. Interviewees indicated several regulatory barriers (regulation on organic products differing from dairy to plant milks, subsidy systems, not being allowed to call their products "milks") but also a *lack* of governance – demanding a roadmap for Sweden's booming plant-based industry (no mention of it in current food strategy). Key difference in governance compared to other plant milks is idea of target audience (everyone) and tone of voice (rebellious). Traditional marketing of plant milks signals empathy, softness, harmony and cleanliness. Several rounds of finance – founder & his brother key in shaping future of Oatly. Acquisition by Chinese and Belgian firms enables global expansion and contention for Asian and American markets. Interviewee indicated that every new product is an innovation in itself. To replicate the repertoire of dairy products available on the market requires time and money. *Växtbaserat Sverige*, a lobby organisation founded by Oatly attempts to balance the dominance of livestock agriculture in Swedish farmers' lobby. Only certain plant-based producers allowed, notably not those who also deal in livestock – driven by fear of conflicting agendas.
3. Transformative Capacities:	Oatly addresses the inertia of dairy culture in their PR-campaign against school milk. Through advertisements (print & digital) and the publication of a book with rebuttals of the most common arguments for dairy milk. Oatly uses the concept of 'the Oatly way' to make decarbonisation legible, in graphical illustrations they show how grains go directly into milk instead of passing through a cow. Although simplified (cows grazing is not mentioned) – the message is effective. The company uses events as a form of lab, most notably the Way out West music festival. After Oatly became a sponsor, the festival is now meat and dairy free – which Oatly capitalised on in an ad campaign which encouraged the rest of Gothenburg to also give up milk for 72 hours. This technique of futuring, defamiliarising 'the festival' and reimagining it as a meat/dairy free zone allows the attendees to experience a post-milk society. Oatly's cooperation with farmers are another way to gain legitimacy for the project. Together with Adam Arnesson, sheep-farmer in central Sweden, they produced an 'old-fashioned' oat milk made from heirloom oats. They showed that by incorporating more plants into his crop rotation he increased revenue while decreasing emissions. Oatly is currently recruiting 10 more farmers to do similar experiments as part of a EU research project. The low-carbon qualities are (together with taste, 'local' and 'rebellious') highly articulated in Oatly's sales tactic. Their latest initiative prints the Carbon Footprint of their products on the packaging.
4. Assessment & Evaluation:	In their newest initiative "Food industry: show us your numbers!", Oatly encourages their competitors to disclose the emissions footprint of their products. This focus on numerical assessment and evaluation is contentious, as no consensus on *what* and *how* impact from milk should be assessed exists. The most prevalent arguments are 1) that assessments must look at a systematic level and also include other values, such as preservation of pasture lands, bio-diversity and cultural

	importance; 2) that emissions must be put in the perspective of the nutritional content of the product; 3) that a distinction be made between emissions from fossil fuels and methane/NO_2 emissions from agriculture due to their differing life spans in the atmosphere. An attempt to bridge this divide was made in a study of how oat milk could be integrated into the Swedish farming landscape while still preserving the protein output of current systems. This has not been widely publicised because of its complexity – in marketing, Oatly favours LCAs as they paint them in a better light and are easier to communicate.
5. Uptake & Consequences:	Oatly has certainly put plant-based milks on the map for many, both in Sweden and internationally. However, causality between Oatly's success and the diversity of brands and products in the market segment is hard to establish. There is a worry that the idea of Oatly as a 'good company' (their phrasing) will fade as they grow and expand into international markets. They repeatedly note the importance of being a small and independent actor with ties to the local food system – something, which works when the primary production is in Landskrona but is harder when now it opens a factory in New Jersey.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* • Unique marketing approach • Leveraging legal battles with incumbent regime in a public forum • The creation of a movement around a product *Key insights from this case regarding …* *Overall decarbonisation:* Plant-milks provide a way for consumers to maintain current dietary patterns while decreasing their emissions footprint. However, they need to exist within a sustainable food system, with significantly decreased animal agriculture. Due to financial inertia, many farmers do not have the margins to transition their production, thus there needs to be a governed transition to achieve a decarbonised sector. *Drivers and barriers:* This case study enforces the beliefs that an innovation in itself is not enough to start a low-carbon transition. Oatly started in the 90s, but only when their imaginary fit with societal desires for decreased emissions and researchers were pointing to the environmental impacts of livestock could they be said to have a real impact on the sector. Another key takeaway is that it seems that regulatory barriers can be turned into springboards if portrayed as unjust, given that the actor in question is deemed credible as a rebel/minor player. *Challenges and instruments to overcome them:* The story of Oatly is also the story of modern advertisement. Companies increasingly act as *ideological parasites*, riding the wave of trends (in this case eco-friendly consumption and veganism) and express this in their advertisement. To overcome financial barriers, consumers are paying a markup to achieve a certain image – consumption has become an act of rebellion. This movement building or creation of publics serve to break through inertia. *Role of policy:* Today, policy in the EU or at a Swedish level does not seem to aide the decarbonisation of meat/dairy – but with the CAP under revision at the time of writing it is too early to say for certain. As the agricultural transition is vitally important for nations' wellbeing, the role of policy should be to ensure a food system which can achieve international commitments (Agenda2030, Paris Agreement etc.) while supplying ample food to its citizens. *Lessons for future innovations:* A product-level innovation can't just rely on moral superiority or a compelling story – it must fulfil the services of its high-carbon contender. For Oatly that meant it had to taste good, blend effortlessly with milk and come in a varieties of shapes and mediums. Interviewees testified that they only switched to their own product when it could blend with coffee, and that consensus among consumers was that taste was the primary factor for choosing Oatly.

Open Questions & Further Research Requirements:	

6.4 Cultured Meat

Innovation:	**Meat analogues**
Intervention:	**Cultured (lab-grown) meat**
Case Study by:	Richard Lane (Utrecht University), Mark Cooper (Lund University)
Methodology:	2 semi-structured interviews, attendance at Good Food Institute annual conference, extensive desk research. Commercial sensitivity and access, alongside coordination difficulties, limited interview possibilities, the speculative nature of this technology prioritised desk research.
Case Study Overview	
Sector(s):	Meat/Dairy
Value Chain Stage(s):	Production
Type of Intervention:	Technical
Date & Duration:	Food products not yet commercially available. 2013 saw the first presentation of a burger made using muscle fibres produced in vitro.
Location:	Initially the US & The Netherlands, now global
Initiating Actors:	Mark Post (vascular physiologist), Peter Verstrate (food technologist) – Mosa Meats Founders Dutch Ministry of Economics, Agriculture and Innovation – research funder Uma Valetti (cardiologist), Nicholas Genovese (stem-cell biologist), Will Clem (restaurateur/biomedical engineer) –Memphis Meats founders IndieBio – San Francisco based biotech accelerator program – start-up developer
Actor Constellation:	Cultured meat startups: Mosa Meats, Higher Steaks (EU); Memphis Meats, Just, Wild Type, Finless Foods (San Francisco); Supermeat, Aleph Farms, Future Meat Technologies (Tel Aviv); Shiok Meats, Avant Meats, Integriculture Inc. (East Asia) Finance and business development providers: Business accelerators - IndieBio, Y-Combinator; Mission oriented Venture Capital managers – New Crop Capital, 50 Years, Coller Foundation, Stray Dog capital; High net worth Private Investors – Bill Gates, Richard Branson (Memphis Meats investors); Sergey Brin (Mosa Meats investor); Agro-industrial food companies - Tyson, Cargill, PHW Industry and third sector organisations: The Modern Agriculture Foundation; The Good Food Institute; Next Nature Network; New Harvest
Short Description of Intervention:	Cultured meat is an example of the new field of cellular agriculture of which there are two general types: (1) Tissue engineering e.g. the production of cultured meat and leather which takes cells or cell lines from living animals and cultures these in vivo in order to produce maximum useable tissue output from minimal tissue input. (2) Fermentation based agriculture e.g. the biofabrication of familiar animal products such as gelatine, egg white, collagen using non-animal inputs, typically genetically modified bacteria, algae or yeast. Cultured meat begins with the removal of starter cells from an animal by biopsy. These cells can be of different types, from embryonic stem cells to fully differentiated muscle cells. Most companies use satellite cells, e.g. adult stem cells. Biopsied cells are isolated and placed in a culture media within a bioreactor. The growth medium provides the required nutrients and growth factors to enable cell proliferation. Once a desired number of satellite cells has been produced, culture conditions can be altered to induce cellular differentiation. Protein synthesis is accomplished by the use of an appropriate scaffold, such as a collagen-based hydrogel enabling the development of muscle fibres. For a minced-meat like product these fibres can then be harvested and assembled.
Research Theme Summaries	
1. Innovation History & Dynamics:	The in vitro cultivation of muscle fibres was first undertaken in 1971 with research into the growth of Guinea Pig aortic smooth muscle. In the 1990s NASA took an interest in in vitro grown meat as a possible protein source for astronauts during long space voyages. In 2002,

	the organisation funded experiments at Touro College in New York that produced fish "fillets" from goldfish skeletal muscle cells. The first in vitro meat patent was filed in 1999 in the Netherlands. A 2005 collaboration between three Dutch universities - Utrecht, Amsterdam and technical University Eindhoven funded by the Ministry of Economics was followed by a 2010 collaboration between Utrecht University and Wageningen University on in vitro meat, funded by the Ministry of Economics, Agriculture and Innovation. August 6, 2013 saw Maastricht University's Mark Post present the first lab meat burger (costing £220,000) and go on to found Mosa Meats in 2015 with Peter Verstrate (previously with Dutch sausage producer Stegeman). San Francisco based start-up Memphis Meats was founded in 2015 by Uma Valeti, Nicholas Genovese and Will Clem. In March 2016, they produced the first lab-grown meatball at a cost of $18,000 USD per pound. A year later, they produced sample quantities of poultry products in the form of chicken nuggets and duck a l'orange, priced at $6,000 USD per pound. Currently cultured meat start-ups and companies are rapidly proliferating, particularly in San Francisco, Israel and Asia. These are focusing on producing both meat (e.g. Just, Memphis, Mosa, Supermeat, Aleph Farms), fish (e.g. Finless Foods, Shiok Meats, Avant Meats) and cell culture scaling products (Higher Steaks, Integriculture Inc., Wild Type).
2. Governance Arrangements & Agents of Change:	Cultured meat production currently occurs within a developing market modelled along the lines of Silicon Valley's 'disruptive innovation'. As a form of Biotech start-up, cultured meat companies frequently draw from publically funded research within the academic sector. E.g. Mark Post and Peter Verstrate occupy positions at Maastricht University and their company, Mosa Meat was spun out of research funded by the Dutch Ministry of Economics, Agriculture and Innovation. Start-ups are also fostered through business accelerators – Memphis Meats is one of five cultured meat and protein start-ups to have gone through the IndieBio programme. The further development of potential products and start-ups is financed via high net worth private investors and multiple venture capital funding rounds where investment is undertaken on the basis of future value streams. This process is supported by several third sector organisations providing awareness raising and marketing, networking, direct and indirect funding (e.g. The Modern Agriculture Foundation, The Good Food Institute, Next Nature Network, also New Harvest). Importantly New Harvest provided the funding for the earliest and most positive speculative LCA of cultured meat undertaken by researchers at Oxford University. This remains the most widely referenced study on potential positive climate and environmental impacts of cultured meat in comparison to livestock meat production and is frequently referred to in journalistic accounts, corporate advertising and web content as simply 'The Oxford Study'. Increasingly, agro-industrial conglomerates are either directly investing (e.g. Tyson Foods Cargill in Memphis Meats; Cargill in Aleph Farms) or directly partnering (Just partnering with Eurovo and PHW Gruppe for European distribution of its cultured scrambled egg; Supermeat partnering with PHW Gruppe).
3. Transformative Capacities:	Transformative capacities are made visible by the use of narratives focusing on the future impacts of increasing meat consumption on the climate, environment, human health and animal welfare. Figures from the FAO's 2006 report *Livestock's Long Shadow* and its 2011 World Livestock report are widely referred to in corporate advertising and online marketing, as well as in industry events such as the Good Food Institute's annual conference and in reporting on the development of the cultured meat sector. These figures reinforce the impact of meat production and consumption, and the inevitability of increasing consumption due to increasing global population and per capita incomes. Narratives of efficiency and inefficiency are frequently deployed by all market participants as a means to discursively separate meat production from animals. The 1931 essay by Winston Churchill entitled 'Fifty years hence' with its quote: "We shall escape the absurdity of growing a whole chicken in order to eat the breast or wing, by growing these parts separately under a suitable medium" is frequently used within the cultured meat sector as a kind of foundational mission statement. In fact, one of the San Franciso based Venture Capital funds - an investor in Memphis Meats, among other cellular agriculture and biotech start ups - is called Fifty Years after this quote.

	In this way, cultured meat is presented as a primary means to address climate change in the meat and dairy sector, as well as contribute to reduced antibiotic use, public health and sustainable resource management, while avoiding the necessity for consumption reductions and broad dietary changes.
4. Assessment & Evaluation:	Given that cultured meat products do not yet exist commercially, assessments of cultured meat production remain uncertain and are based largely on speculative Life Cycle Analyses. Cultured meat could reduce non-CO2 greenhouse gas emissions and reduce land use. Energy use in comparison to meat production is unclear, while there could be reductions in water use and ecotoxicity. Tuomisto (2011) found cultured meat could produce 78-96% reduction in greenhouse gas emissions, 99% less land use, 82-96% less water use, but only 7-45% less energy use (higher than poultry). Mattick et al. (2015) & Smetana et al. (2015) found cultured meat could have a lower environmental impact than beef, but higher impact than pork, chicken and plant-based proteins. In reviewing these studies, Lynch & Pierrehumbert (2019) noted that following caveat: "Replacing cattle systems with cultured meat production before energy generation is sufficiently decarbonized and/or the more optimistic production footprints presented here are realized (assuming they can be), could risk a long-term, negative climate impact".
5. Uptake & Consequences:	So far, no commercially available cultured meat products have been produced, however both Memphis Meats and Mosa Meats have a target market launch of 2020-21 – offering products to restaurants (not direct to consumers). Just claims that it will be able to launch a cultured chicken nugget product in Asian restaurants during 2019. Further uptake is dependent upon overcoming technological and cost barriers to scaling production, the development of appropriate regulatory frameworks and addressing issues around consumer perception and acceptance. However, the cultured meat sector as a whole has been successful in capturing widespread attention and focus as a response to the problem of meat consumption. E.g. The MIT Technology Review listed the 'cow-free Burger' in its 2019 report on 10 technological breakthroughs that it believes will have a large future global impact, while the World Economic Forum recently released an 'Alternative Proteins' White paper as part of its: 'Meat: the future' series. This success is both dependent upon and creates the conditions for predictions of significant market growth. A 2018 BusinessWire piece predicted the global meat substitutes market to be worth $46 billion by 2020, while a recent report by Barclays suggested this could grow to $140 billion within a decade, gaining a 10% market share of the $1.4 trillion global meat market. This has the effect of both spurring continued investment in cultured meat start-ups and clearly framing the solution to the problems of meat consumption as one of providing alternative proteins - technological replacements to current meat production. This narrows research, investment and policy foci in ways that partly preclude consideration of broader dietary changes. It also naturalises intensive CAFO-based livestock production, which now accounts for over three quarters of all global poultry production and over a half of global pork production. This obscures the potential positive impact of alternative means of livestock production.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* • Unique technologically focused approach • Specific market form: the biotech start-up, as the vehicle through which research, investment, market development and regulatory lobbying is undertaken • The simultaneous naturalisation of meat consumption and redefinition of meat according along functional and efficiency lines *Key insights of this case regarding …* *Overall decarbonisation:* Long-term decarbonisation of meat production through the development of cultured meat products is reliant upon decarbonisation of primary energy production. Replacing cattle systems prior to a broad spectrum shift to renewably produced electricity risks a potential increase in GHG emissions. Within the current model of cultured meat production, its naturalisation and legitimation of western levels of meat

	consumption may further reinforce the growth of intensive livestock practices globally and result in absolute increases in GHG emissions - with cultured meat products remaining additional. *Drivers and barriers:* Key drivers include increasing global meat consumption and the widespread recognition of its negative impacts. The creation of a new commodities and assets through the development of promissory narratives around future value streams and returns on investment. Animal welfare concerns driver for mission-oriented Venture Capital investment. *Instruments to overcome them:* Barriers include specific technical challenges around: (i) affordable growth medium – including the removal of animal products from this in the form of Foetal Bovine Serum; (ii) the production of texturally complicated tissue requiring bioreactor innovation; (iii) production scale-up. Consumer perception and acceptance frequently reported as barriers. Simultaneously unsettling the "naturalness" of current meat production methods, while focusing on a narrative of "taste, cost and convenience" present the R&D and marketing responses to this. In the EU, Novel Food Regulation, product labelling, GMO regulation and Good Manufacturing Practice regulations may present key barriers to commercial development, and will be on-going sites of lobbying activity from the livestock industry. The development of an appropriate Intellectual Property regime is key to current investment and valuation of cultured meat companies. *Role of policy:* European low-carbon innovation within the meat & dairy sector is largely reliant upon appropriate CAP revision and a food and health regulatory structure capable of fostering dietary changes, novel food products, and alternative agricultural and meat production practices. It is imperative that policy is developed within a holistic perspective, and in line with the precautionary principle, recognises potential unintended side effects. *Lessons for future innovations:* The case of cultured meat offers important lessons around potential future structuring of meat production systems, and the effectiveness of market driven, speculative investment lead innovation pathways. Key here is the recognition of potential broader impacts of novel technologies, including consideration of whether these are likely to remain additional to, and possibly reinforce existing high-carbon production mechanisms in the short to medium term.
Open Questions & Further Research Requirements:	Open questions remain regarding impacts on farming sector & geographical relocation of bioreactors; impact of reduced animal feed imports on global trade; potential for widespread employment destruction in the livestock sector with only partial job replacement via high-skilled employment; issues over control of food production, market concentration and food security.

7 Finance Case Studies

Two cross-cutting finance case studies have been conducted. Fossil-free Churches examines divestment as a financial instrument to foster decarbonisation. The Triodos case study looks into an ethical bank's Organic Growth Fund as an instrument for financing green innovations.

7.1 Fossil-free Churches

Innovation:	**Divestment**
Intervention:	**Fossil fuel divestment by faith-based actors in the UK, Belgium and Sweden**
Case Study by:	Bregje van Veelen (Durham University)
Methodology:	14 interviews, participant observation at 3 workshops, observed 2 debates on divestment
Case Study Overview	
Sector(s):	Finance
Value Chain Stage(s):	Finance
Type of Intervention:	Social
Date & Duration:	Innovation start date: 2012. Intervention: Church of Sweden first large church to divest in 2014, The Belgian Bishop Federation decided to divest in 2017, and the Church of England and Scotland expanded their divestment strategies in 2018.
Location:	Divestment started in the US. Location of all institutions who have committed to divest is online on gofossilfree.org
Initiating Actors:	350.org, committed individuals within churches.
Actor Constellation:	Churches and faith-based organisations (e.g. Church of England, Church of Sweden, Belgian Bishops Congress, Church of Scotland). Within these organisations key actors are a mix of sustainability-focused actors, and the Churches' investment bodies. Faith-based campaign organisations (e.g. Operation Noah, Green Faith, Ecokerk) Other environmental campaign organisations (e.g. Go Fossil Free Sweden) Financial sector/institutional investment intermediaries (e.g. PRI, TPI, ClimateAction100+) Asset managers (implementation/intermediary)

Short Description of Intervention:	The financial sector has an important role to play in financing the move to a zero-carbon economy by shifting investment from high-carbon to low-carbon industries and innovations. In this case study I look at the different approaches institutional investors – in particular faith-based actors (i.e. churches) – take in addressing climate change through their investment practices, outlining the differences between a moral and risk-based approach and the resultant different implications for investment practices and the potential for the REINVENT sectors to be either positively or negatively affected. The total investments held by churches are relatively small. However, churches have long been at the forefront of screening out particular investments that they deem at odds with their beliefs. They are also currently at the forefront of divestment campaigns, and their actions may serve as an indication of where others will follow. Faith-based actors currently adopt a mix of two approaches: some favour divestment (withdrawal of investment from high-carbon companies) while others favour to engage with these companies instead in an attempt to encourage them to align with the Paris Agreement targets. Divestment has largely adopted a sector-based approach, focussing on upstream fossil fuel companies. Therefore, the impact on REINVENT sectors has been minimal. Furthermore, based on the interviews it seems unlikely divestment will spread further down the value chain, with all interviewees favouring engagement over divestment from downstream companies. However, approaches that focus on the alignment of investments with a 2-degree scenario might be a means to move past current approaches which focus on excluding upstream fossil fuel companies, and also affect other high-carbon companies including those in the REINVENT sectors.
Research Theme Summaries	
1. Innovation History & Dynamics:	Faith-based actors have a history of ethical investment that dates back to the 19th century. When campaigns to divest from fossil fuels began in the mid-2000s it was thus not surprising these actors were among the first to become involved, as they had both the moral mandate and the implementation tools to do so. Currently, faith-based actors make up almost 30% of all institutions that have committed to divest. There is limited evidence whether divestment can be a 'proven technology' in realising carbon reductions: while the immediate financial impact might be small, it may help to destabilise the assumption that high-carbon investments are safe and profitable. Key barriers to divestment as a strategy (especially for REINVENT) are the challenges in distinguishing "bad" from "good" companies, either for divestment or low-carbon reinvestment purposes.
2. Governance Arrangements & Agents of Change:	The divestment debate has been driven by (1) a history of ethical investment; (2) increased recognition of the financial risks associated with fossil fuel investment, and (3) growing calls for climate action by faith leaders. We distinguish between 2 main approaches/discourse coalitions, which represent different governance arrangements. The first is 'divestment as moral obligation', a more activist approach grounded in contestation, which connects churches to (secular) NGOs and movements such as GoFossilFree. The second is 'divestment as risk mitigation', which has emerged from the financial sector itself, and is an approach grounded in collaboration/engagement, primarily through transnational ethical investment initiatives such as ClimateAction100+, and Principles for Responsible Investment. Sometimes this division plays out within single institutions, where environmentally-minded employees or clergy may call for divestment, but churches' investment bodies favour an engagement approach. We also see some churches adopting a mix of approaches, e.g. divest from the 'worst' sectors (coal, tar sands), while engaging with oil, gas and other high-carbon companies.
3. Transformative Capacities:	Churches' investment bodies generally hire external fund managers to manage their investments. As relatively small investors, they sometimes rely on what investment products others offer, and making changes to investments (such as divestment from certain sectors) requires a coordination of multiple actors down the 'investment chain'. To make decarbonisation legible churches (uniquely) refer to theology to underpin the need for climate action. Their moral standing is also said to give them additional leverage and influence in society, enabling them to legitimise divestment as an ethical investment approach. To make low-carbon qualities distinct, the intervention largely relies on the adaptation of a sectoral approach to distinguish between high- and low-carbon sectors, which largely neglects the REINVENT sectors (either as sites of high-carbon practices or low-carbon alternatives), as

	these are seen as either too complex to define as high-/low-carbon, or deemed not to be 'at the root of the problem'.
4. Assessment & Evaluation:	In terms of those who have decided to divest from fossil fuels, there appears little evidence what difference this has made to the carbon content of their portfolios. Transnational initiatives which focus on the alignment of companies' or investment portfolios' emissions are especially valuable in developing the tools that can help assess whether progress towards alignment with a 2-degree scenario is made. Various initiatives are currently trialling methodologies to do so. Current limitations include the accuracy of the data provided by companies, and that the data disclosed is currently often too limited to enable investors to assess how companies are performing against a 2-degree scenario.
5. Uptake & Consequences:	Divestment is becoming increasingly mainstream, with a growing number of mainstream financial institutions also committing to divest from (some) fossil fuels, while others are participating in a growing number of transnational investors' initiatives that seek to encourage companies to align their activities with a 2-degree scenario. The latter can also shift the focus from a small number of 'green/low-carbon' products or 'sin/high-carbon stocks' to a more comprehensive analysis of entire investment portfolios and the role they can play in addressing climate change. The focus on climate change has, however, come to overshadow other environmental and social considerations (e.g. gender diversity, human rights) in churches' investment decisions. Others feel that opening up the debate around climate finance encourages more investors to take non-financial criteria into account when making financial decisions, which may have a positive knock on effect on other social and environmental dimensions, for example through the growth in ethical investment products. However, again, it appears too early to tell what the effect might be.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* The use of moral arguments (often grounded in theology) to argue the need for climate action among investors. The governance structure of churches means that its clergy and members have a reasonable amount of influence over how churches' money (endowments, pensions) is invested. Churches are at the forefront of trialling both divestment and engagement strategies with high-carbon companies/sectors. *Key insights from this case regarding …* *Overall decarbonisation:* Direct decarbonisation is difficult to measure. While news articles indicate the pressure from divestment begins to be felt in the coal industry, the impact on REINVENT sectors is currently minimal. *Drivers:* The importance/effectiveness of the moral argument for climate action; having a history of ethical investment and thus often already having the right tools to take climate change into consideration in investment decisions. *Barriers:* complexity of investment chain, coupled with small size of church investments, can make it difficult to realign different actors along investment chain; many in churches prefer 'orderly' over 'radical' change. *Instruments to overcome them:* Transnational initiatives that connect different investors and other financial actors to coordinate action. Instruments to assess 2-degree alignment are seen as grounded in science rather than 'radical' activism. *Role of policy:* Divestment campaigns and actions focus primarily on financial actors not policy makers. However, its framing of fossil fuel/high-carbon investments as 'risky' is grounded in the idea that policy makers will bring in stricter regulation for high-carbon sectors, especially post-Paris. *Lessons for future innovations:* Too early to tell the success of different approaches (divestment, engagement), and therefore difficult to indicate lessons for future innovations in this sphere. However, to enact change in REINVENT sectors, divestment/low-carbon investment needs to move beyond upstream fossil fuels and implement tools that recognise high-carbon assets (and low-carbon alternatives) in a diversity of sectors.
Open Questions & Further Research Requirements:	Assessing an investment portfolio's alignment with a 2-degree scenario offers the opportunity to assess and evaluate the climate impact of all investments. However, such approaches are only in their infancy and the quality of data provision will need to be improved before such approaches can be applied widely and accurately. It would be worth following

	up in a few years' to assess their impact on reducing the carbon footprint of the companies / investors' portfolios involved. More detail is also needed on companies' responses to the withdrawal of investments as a result of divestment campaigns.

7.2 Triodos

Innovation:	**Ethical banking**
Intervention:	**Triodos Organic Growth Fund**
Case Study by:	Bregje van Veelen (Durham University)
Methodology:	5 interviews, attended 3 industry conferences. Difficulty finding interviewees willing to be part of the research.
Case Study Overview	
Sector(s):	Finance
Value Chain Stage(s):	Finance
Type of Intervention:	Social
Date & Duration:	Since 2014
Location:	Netherlands
Initiating Actors:	Triodos Bank
Actor Constellation:	Triodos Bank (initiator) Institutional investors (investing in fund) FEBEA, Global Alliance for Banking on Values (international networks for 'Green Banks')
Short Description of Intervention:	This case study report analyses the Organic Growth Fund, an investment fund offered by Dutch Ethical Bank Triodos, and how it contributes to decarbonisation in the REINVENT sectors. In mainstream banks, 'green' innovations will need to compete on the same terms as others, which can be challenging at the innovation stage. In contrast, ethical banks, albeit generally small in size, are at the forefront of integrating economic and more-than-economic concerns when deciding how to lend or invest their money. Triodos has grown into one of the largest ethical banks in Europe, and is one of the few ethical banks to offer investment products, which enables them to not only provide long-term finance to companies operating in the green/sustainable economy, but also act as active shareholders on the boards of these organisations. The Organic Growth Fund is one mechanism through which the bank finances investment in green sectors, especially companies operating in the agricultural value chain. It is a private equity fund established by Triodos Investment Management in 2013. It seeks to provide long-term capital to a small number (currently five) companies operating in the sustainable consumption arena, primarily in the food sector. It invests in companies across the value chain, from ingredient sourcing to distribution and retail, who combined sold close to €184 million worth of goods in 2017. The fund is solely open to institutional investors and has net assets of close to €50 million (in 2017), 75% of which is invested in the five companies included in the portfolio. Further details on the fund are to be found in section 3.1 of the case study report. Although ethical banks are at the forefront of taking socio-environmental outcomes into consideration when making financing decisions, they only make up a small proportion of the banking landscape. While this thus has the potential to help innovative green companies to grow, the number of companies invested in by Triodos is very small, meaning their cumulative impact will be limited. Secondly, when we look at what ethical banks are doing, it is not only that they are small, but also not explicitly focused on decarbonisation. While for example the Triodos Organic Growth Fund invests in companies that operate in the food & plastics sector, decarbonisation is often not a main aim, and climate/ decarbonisation impact is often not measured, thus making it difficult to quantify the climate impacts of ethical bank finance.
Research Theme Summaries	
1. Innovation History & Dynamics:	Triodos is often identified as being at the forefront of ethical banking in Europe. Triodos define themselves as a Sustainable Bank, that only finances initiatives and companies that make a positive social, environmental or cultural contribution. The bank was founded in the

	Netherlands in 1980 and is now one of at least 34 European ethical banks. Unlike many other European banks, many ethical banks have gown significantly since the 2008 financial crisis, benefiting from the emerging distrust in mainstream financial institutions. To facilitate the growth of ethical banking, a number of international collaborative initiatives emerged, particularly through the establishment of FEBEA and GABV. Green and ethical banks also collaborate directly, for example Danish bank Merkur Andelskasse offers some of Triodos's investment funds to its own customers. As ethical lending usually involves comparatively small sums of money (compared to equity investments), it means that this form of finance is particularly suitable to fund smaller companies, for example small-scale renewables, organic farms, or those producing or selling sustainable consumer products at a smaller scale. While this form of lending is thus primarily suitable for smaller producers and retailers, the provision of investment funds also allows Triodos to invest in companies with larger capital requirements.
2. Governance Arrangements & Agents of Change:	The Organic Growth Fund can be best characterised as a single sector initiative. It was initiated by Triodos and its impacts are also evaluated by Triodos itself through its internal assessment methodology. While Triodos does collaborate with other ethical banks, either directly or through organisations such as FEBEA and GABV, and finances other organisations, these collaborations do not directly impact the *initiative,* which was developed by Triodos alone*.* Triodos did identify a number of drivers that explain (1) why it has set up the Organic Growth Fund, and (2) why the OGF focuses specifically on companies involved in sustainable consumption, rather than for example renewable energy. The immediate driver demand from the organic food sector, where one of the companies Triodos already worked with was seeking long-term investment, but no-one was offering this. According to Triodos, the provision of long-term equity (OGF) enables companies to prioritise longer-term development over short-term profits. Due to the lack of participation from companies invested in, we unfortunately have no data on the changes experienced there as a result of the OGF. Looking beyond Triodos, to help the ethical banking sector grow, the Global Alliance for Banking on Values developed an investment fund to fund investment in ethical banks, to help them grow. Collaboration between Triodos and other banks directly also helps the sector to offer products of a scale that a single bank may not be able to offer.
3. Transformative Capacities:	The Triodos Organic Growth Fund started with €25.3 million in capital, which had doubled to €52 million in 2018. The structure of the OGF is particularly important for addressing inertia. The fund has a somewhat 'odd' structure: it provides long-term private equity investment, but investors can step out of the fund. It addresses the problem that companies need long-term investment, but investors want to be able to step out after five to seven years. In other words, the fund has been placed between equity investors and companies seeking equity investors to address the mismatch in timescales. The Organic Growth Fund is also indicative of the trend among ethical banks to fund companies engaged in promoting sustainable consumption (as explained in section 1), such as through organic food or promoting a circular economy. It focuses on food, textiles and personal care, which Triodos sees as 'a maturing and rapidly expanding market segment, which is key in the transition to a sustainable economy'. For the purposes of REINVENT, it is potentially interesting to ask whether this spread of environmental concerns into new arenas strengthens action on decarbonisation (even if carbon reductions may be an unintended consequence of some of these projects) or dilutes it (by drawing attention away from areas where the largest reductions can be made). One of the key ways in which ethical banks generate authority and legitimacy is their commitment to transparency. However, the lack of quantification of key impacts – even more so among smaller ethical banks – is increasingly seen as being in contrast with their commitment to transparency and may hamper their ability to attract new forms of ‚green' or ‚climate' finance. Finally, regarding the question of making low-carbon qualities distinct: it is important to recognise that many ethical banks, including Triodos's OGF, generally do not focus on making *low-carbon* qualities distinct. Rather, they consider climate impact one aspect of the social and environmental qualities that they seek to promote.
4. Assessment & Evaluation:	It is unclear if or how Triodos measures its environmental impact, or progress towards the goal of environmental sustainability. The same is also true for the other ethical banks referred to in the interviews. None currently appear to measures the carbon or environmental impact of their portfolios. When asked why, interviewees generally pointed towards the

	burden this would impose on them, and the companies they invest in. Especially as ethical banks tend to invest in smaller companies, asking for detailed reporting would put an unnecessarily high burden on them, and/or would lead to incorrect information reported. As explained in the previous section, this is, however, slowly starting to change, not least because of greater societal demand for a more rigorous assessment of these banks' impacts. There are therefore now also initiatives emerging through banks themselves, but industry organisations such as FEBEA and GABV appear to play a particularly important role in improving the measurement and communication of their ethical banks' impacts. The GABV has been particularly active on this front by developing a Scorecard. The Scorecard allows banks to self-assess, monitor, and communicate their progress on delivering values-based.
5. Uptake & Consequences:	As interest in the green and socially responsible sectors grows, not only have ethical banks seen a growth in customers, but also a growth in competition. In 1995 Triodos's two green funds accounted for 100% of the green investment funds in the Netherlands. In 2009, Triodos held 10% of the overall market. There is room for growth by expanding into emerging markets, including Eastern Europe, where social lenders can help to create new enterprise (but mostly focused on social, not environmental, outcomes. There may, however, also be divergences in the objectives of individual banks and the organisations (GABV/FEBEA) that represent them. While the latter seek to broaden the impact of ethical banks, the former are more interested in deepening their impact. From a carbon perspective, ethical banks can also play an important role in scaling up innovation through offering networking opportunities for the companies they invest in. For example, Triodos tries to bring the companies within its Organic Growth Fund together to share experiences and ideas for best practice. Most ethical banks also appear to have additional social or economic benefits (e.g. seeking to transform banking practices more broadly), but again, these are often difficult to quantify.
Conclusion & Outlook	
Key Learnings:	*Unique features of this case:* Triodos's Organic Growth Fund is also rather unique for a number of reasons: (1) its focus on sustainable consumer products rather than renewable energy as a means of making a positive environmental impact; (2) the size of the companies it funds; and (3) its coverage of the whole supply chain. Its ‚Evergreen' structure (see point 3 above) is also unique and can help overcome inertia by allowing investors to leave the fund, without interrupting investment in the companies' part of the fund. *Key insights from this case regarding …* *Overall Decarbonisation:* The potential for decarbonisation is currently limited due to (1) the small size of the ethical banking sector, and (2) the broader focus on ethical banking which often does not prioritise decarbonisation, at least not outside the energy sector. *Drivers:* The financial crisis acting as a positive driver for ethical banks, opening up space for alternative practices. Going forward it will be interesting to see if the growing demand among institutional investors for 'green' investment products will (positively) impact Triodos' fund and other funds offered by ethical banks, or whether such investment will go to mainstream banks who are beginning to offer green investment products. *Barriers:* Many smaller ethical banks lack the expertise to develop equity finance; are too small to make such products viable; and/or are subject to stringent banking regulation which limits the amount of money they can invest. *Instruments to overcome them:* For example Merkur bank (ethical Danish bank) offers some of Triodos' investment products because it is too small to develop its own. Such collaborations could thus help overcome some of the above barriers.
Open Questions & Further Research Requirements:	The emerging attention for the SDGs – both as a communication/impact measurement tool, and as a possible framework for making financial decisions – does however indicate a more holistic approach that takes both social/economic/and environmental impact of companies into account. Going forward, it would be especially interesting to see how Triodos will integrate the SDGs in its financial decision-making; how that changes the sectors/projects invested in; and how the different priorities of the SDGs will be balanced in financial decision-making.

	Also: whether growing focus on ‚green' investment among institutional investors will benefit ethical banks, or whether such investment will mostly be directed to/through mainstream banks/institutions.

8 Outlook

The case studies constitute a rich empirical material which gives an overview of decarbonisation innovations in the four sectors. As the case study work has reached its conclusion, there are two main ways in which the produced output will be put into use when going forward in REINVENT:

(1) Publication of data and results

In addition to the results published in this report, the data collected during interviews and site visits and recorded in the primary data excel sheets will be made publicly available as part of the Horizon 2020 Open Data Pilot.

We will explore options for the factsheets of case studies developed for this Deliverable to be redesigned in order to make them more illustrative and accessible for public dissemination. The exact format and mechanisms used for dissemination are still subject to internal discussion.

(2) Further work within REINVENT

The work that has been completed over the course of Task 3.3 will feed into other work packages (e.g. the creation of narratives for Work Package 4), as well as the remaining tasks of Work Package 3. The case study work provides the basis for the comparative analysis of innovations in Task 3.4, and for the impact assessment in Task 3.5.

In Task 3.3, analytical work remained mostly on the individual case level, focusing on different value chain stages and only partially taking a sectoral view. The next logical step is to bring the work to a sectoral and cross-sectoral level. At the same time, the focus of the analysis (which, for the purpose of case studies, comprised various research themes) is narrowed to non-technical drivers and barriers of low-carbon innovation, thus returning to the key theme of Work Package 3.

For this purpose, in Task 3.4 a comparative structured analysis of the case studies' results is being conducted. The objective is to derive an evidence-based scheme of non-technical drivers and barriers of innovations and on potential influencing factors for future low-carbon innovations. Currently, a small team representing the different participants' expertise is conducting a content analysis, screening case study reports, the innovation database and innovation biographies (Work Package 2) for different categories of drivers, barriers, instruments, activities and cross-industrial interdependencies. For this purpose, a first set of sub-categories was derived from previous work (including the used categories from the innovation database from Work Package 2 and the analytical protocol from Task 3.1). After a first round of analyses, these categories have subsequently been revised by the team to ensure they comprehensively represent the findings from the content analysis. The next step is to cluster and categorise the identified drivers and barriers on a sectoral level in a mapping process. The results from the content analysis and mapping process will then be discussed in a virtual internal workshop, where a set of hypotheses will be developed. Against the backdrop of these hypotheses, the identified drivers and barriers will be presented, discussed and evaluated in a focus group format including both REINVENTers and external stakeholders with sectoral

expertise from industry, research, policy and NGOs. This focus group event will take place in mid-September, leaving the Work Package team sufficient time to revise and augment their results with the findings from the focus groups. This work will then result in Deliverable 3.6, a report outlining the drivers of low-carbon innovation.