THESIS FOR THE DEGREE OF LICENTIATE OF PHILOSOPHY

Too Enabling to Fail –
Ethics and Practices in the Legitimation of Nanotechnology

NICHOLAS SURBER

Division of Science, Technology and Society
Department of Technology Management and Economics

CHALMERS UNIVERSITY OF TECHNOLOGY

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Division of Science, Technology and Society
Department of Technology Management and Economics
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 1000

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ABSTRACT

This thesis reads Beck's *Risk Society* in the context of nanotechnology and the politicization of failure in the promise of enabling technologies. It aims to investigate how researchers and innovators legitimate nanotechnology in society. Nanosafety research is the empirical focus, with an approach that builds upon the setting of a Nordic research program. Reflections from STS, in terms of empirical ethics, articulate the conjoining of applied ethics and toxicology in the value-laden endpoint of the (nano)safe society. The thesis exposes three research questions, which broadly correspond to three appended papers. The first question asks how does legitimation crisis in the political economy of research and innovation manifest today? The second question asks how do responsibility practices in responsible research and innovation (RRI) contribute to said legitimation? Lastly, the third question asks how nanosafety researchers reflexively practice anticipation in the legitimation of nanomaterials? The findings are three-fold. First, concerns surrounding legitimation and crisis in the political economy of research and innovation are connected to technoscientific capitalism. Another contribution is the proposal for pragmatism in the European RRI policy community that helps to produce wider legitimation. A third contribution, aiming at the applied ethics of technology, emerges through the study of nanosafety researchers reflexively anticipating the future of nanomaterials. Two further studies are outlined. One will study the Swedish NGO ChemSec, interrogating their ability to reduce the use of toxic chemicals and problematic nanomaterials. The second proposes a field study situated in the Lund-centered nanosafety milieu to explore the implementation of safe-and-sustainable-by-design.

KEYWORDS: risk sociology, nanotechnology, responsible research and innovation, research and innovation policy, political economy of research and innovation, enabling technology, technoscientific capitalism, legitimation crisis, applied ethics, emerging technology

To Alex—
and his slightly dusty copy of Risk Society that will not be returned anytime soon

LIST OF PUBLICATIONS

Appended papers

PAPER I
Karl Palmås and Nicholas Surber
"Legitimation crisis in contemporary technoscientific capitalism"

Published in the *Journal of Cultural Economy*, 2022

Author contribution
Conceptualization, methodology, writing–review and editing

Previous versions
Virtual presentation at 4S, 18 August 2020, as "Sculpting Responsibility through Legitimation: Placing Nano in Wider Sociological Narratives"

Virtual presentation at Nordic STS, 20 May 2021, as "Legitimacy and time in technoscientific capitalism"

PAPER II
Danielle Shanley, Joshua B. Cohen, Nicholas Surber and Shauna Stack
"Looking beyond the 'horizon' of RRI: moving from discomforts to commitments as early career researchers"

Published in the *Journal of Responsible Innovation*, 2022

Author contribution
Conceptualization, methodology, writing–original draft, review and editing

PAPER III
Nicholas Surber, Rickard Arvidsson, Karl de Fine Licht and Karl Palmås
"Implicit values in the recent carbon nanotube debate"

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Author contribution
Conceptualization, investigation, methodology, data curation, project administration, validation, visualization, writing–original draft, review and editing

Previous versions
Presentation at internal Mistra Environmental Nanosafety program meeting, Stockholm, 24 November 2021, as "Tacit values in the recent carbon nanotube debate"

Presentation at Chalmers STS Division Seminar Series, 1 December 2021

TABLE OF CONTENTS

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This licentiate thesis represents a doctoral dissertation only as an ephemeral work in progress. There are already many to acknowledge and express my gratitude, between colleagues, friends, and family.

FIRST, I'll begin with colleagues. I would like to thank everyone at the division of **Science, Technology and Society** with the TME department at Chalmers. I am also grateful for the guest post at the **Environmental Systems Analysis** division and cannot wait to discuss more the implications of policies and regulations surrounding emerging technologies in society. Here, I will emphasize my current co-authors at Chalmers, **Karl Palmås, Rickard Arvidsson** and **Karl de Fine Licht,** with aspirations towards future research collaborations.

I still will admit to not understanding why my supervision team, with **Karl Palmås** at the helm, supported by **Rickard**, and **Per Lundin** as examiner, decided to hire a forest ranger (technically, recreation technician) from his reclusive retreat in the Rocky Mountains. Yes, to be frank, I was not even counting sage grouse for ecologists. I would not call wilderness communication a form of ethnography, but perhaps one day I will return to compose that fieldwork in an increasingly climate-challenged society.

The planning and execution of a creative writing course—during the coronavirus pandemic, no less–has furthermore been significant in shaping my writing perspective(s), with the original idea from **Kjell Vowles** and **Malin Nordvall.** I must also thank **Charlotta Kronblad** for many fascinating conversations about our manuscripts and our collective quest for (re)new(ed) writing styles.

I will soon send a published version of Paper III to the teachers, notably **Martin Persson**, and **Frances Sprei**, of a pivotal doctoral course at Chalmers, in acknowledging their role in inspiring an ethical turn in this project. A parallel acknowledgement is reserved for another course that improved Paper III and another soon to be published (ghost for now) publication, through the kind feedback of **Marco Schirone**.

A critical boost arrived in the form of a delayed and hybrid Research Proposal text and seminar, on 30 October 2020. I simply cannot thank my junior discussant **Barbara Hedeler** and senior discussant **Sverker Molander** enough times for their critical and generative efforts at contextualizing a fledgling version of the project. Now I hope that **Barbara** and **Sverker** take my confession in jest, nevertheless I am sure I will endeavor to return these favors in the adventures to come. One can endeavor, at least.

This project was only made possible by the principal investigators and powers-that-be at **MISTRA**, the Swedish foundation for strategic environmental research, in the creation of **Mistra Environmental Nanosafety, Phase II.** I am grateful for their belief that the more-than-technical aspects of nanomaterials in society deserve greater recognition and, hence, elaboration. I acknowledge the combined sense of discovery and spirit of camaraderie during our years together, especially within ‘Work Package 4’, with **Karl** and **Rickard,** and **Steffen Foss Hansen, Lauge Peter Westergaard Clausen** and **Maria Bille Nielsen** from the Technical University of Denmark. This was merely one piece in a relatively large, interdisciplinary research program. I remain baffled at my colleagues’ patience with the ever-changing nature of this project and its so-called ‘deliverables’.

At this point, I would like to thank the **erstwhile and unnamed mentors** who have intersected with the project. Their support has been illuminative and instrumental in imagining a world where this work can indeed contribute.

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I am also grateful for the process and product of producing a discussion paper, Paper II, during the pandemic. The fellow ‘RRI-a-holics’ involved—**Danielle Shanley, Joshua B. Cohen,** and **Shauna Stack**–might not have written the RRI manifesto as planned, but perhaps we have said something interesting about the state of RRI and the novel idea of collaborating as young researchers across Europe during the chaos of lockdowns. We have collectively learned that one can indeed combine article writing and the spirit of afterwork with enough Belgian beer and institutional Zoom subscriptions.

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SECOND, I must insist in there being a special place for those friends willing to stand by and with a doctoral candidate. I *do* know that there is a world ‘out-there’ beyond responsibility, legitimacy, and nanotechnologies, but they are central in reminding me to experience it. In no particular order (not quite true), I am grateful to **Ludwig** and **Ronja, Ingrid, Melina, Manon, Valentina, Emelie, Kristoffer,** and **Tatiana.**

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–Malmö, 26 March

NOTE *to the reader*

The cover paper, or kappa, that unfolds across the proceeding pages is but a second attempt to perform this project. An initial attempt (Chalmers-speak for Research Proposal) can be requisitioned from the author, with its focus on the place of nanotechnology in the turn to responsibility in European research and innovation policy. This cover paper pivots to the perspective of risk sociology as applied to nanosafety. It holds off and intuits an upcoming focus on expectations, anticipations, and in general, promises, relating to the relationship between nanosafety, engineered nanomaterial regulations, policy and society *writ large.*

Key concepts for the thesis will be introduced in **bold face** and *italics* shall demonstrate *emphasis.*

It is not just that the generalized concept of crisis (economic, legitimation, motivational crises and so on) has lost its theoretical and political acuteness. From different quarters it has been unanimously stated that the project of the interventionist welfare state has lost its utopian energy as it has become established.
Beck (1992, 189)

1) INTRODUCTION

This is a thesis about the risk of failure in nanotechnology and specific nanotechnologies as pivotal instances for enabling technologies. The introduction departs from a vignette depicting the current banking crisis and the prominent role of enabling technologies in contemporary societies. Nanotechnology is then presented in the temporal context of risk governance and its attendant regulations and policy ambitions in Europe. An overall research question for the licentiate is posed, tied together with three specific questions corresponding to the aims of the three appended papers. The remaining structure for this cover paper is then elaborated.

TOO BIG TO FAIL?

The run on Silicon Valley Bank happened on 10 March 2023 (Sanderson 2023). SVB–the largest American bank to collapse since the 2008 financial crisis–saw its clients mostly protected through a Federal Deposit Insurance Corporation (FDIC) organized fund. Instead of an old-fashioned bailout, circa 2008, the FDIC enlisted their wholly bank-financed fund to insure the original amounts in clients' accounts. One thing was immediately clear to the presiding commentariat. Paul Krugman, at the *New York Times*, had no quibbles: "[a]nd yes, it was a bailout".[1] Bailout or not, this was made possible only through classifying the SVB collapse as a "systemic risk". David Z. Morris, over at *CoinDesk*, cannot help but to pontificate on 2008: "that debatable classification conjures another charged term from the mists of crises past: 'Too big to fail'".[2]

Wired magazine reports that most of the 40,000 clients were technology companies, and small 'tech' at that.[3] Small tech or big tech, SVB touched around half of US-based startups. SVB was the bank of choice for high risk, small tech startups. Nanotechnology was also impacted by the crisis at SVB.

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[1] Krugman's commentary is found here: https://www.nytimes.com/2023/03/14/opinion/silicon-valley-bank-bailout.html

[2] The counterpoint from Morris at *CoinDesk*, which is indeed connected to cryptocurrencies, is available at: https://www.coindesk.com/consensus-magazine/2023/03/13/silicon-valley-bank-and-signature-bank-reignite-too-big-to-fail-debate-coindesk/

[3] The full report from *Wired* is here: https://www.wired.co.uk/article/silicon-valley-bank-collapse-fallout#intcid=_wired-uk-bottom-recirc_77741f0d-e0c5-4577-9694-d08863864f27_entity-topic-similarity-v2

One such company, Atomera, held funds there below the FDIC limit.[4] Atomera, as “a semiconductor materials and technology licensing company”, embeds nanoscale technologies into semiconductors. SVB also operated in Europe, with an exclusive focus on startups.[5] For an era of European startups: “[…] it filled a role that no one else would. It was part bank, part networking community, part venture capital firm. In some countries it was a major investor”.

The still developing SVB story signals that this proliferation of small tech (and big tech) is reliant on the logic of enabling technologies. Simply put, **enabling technologies** are new and novel technologies which are promised to be economically essential for the society of tomorrow. Nanotechnologies are at the crux of the promissory note of enabling technologies–one where science, technology, and innovation (1) currently enable (promise) and (2) shall eventually constitute (deliver) a key source of economic growth. Nanotechnologies belong to a class of enabling technologies that are perhaps not yet too big to fail, but their high promises make them *too enabling to fail.* Yet with all the promise comes the issue of risk.

NANOTECHNOLOGY RISK GOVERNANCE

A few weeks before the demise of SVB blanketed news feeds, the big three **nanotechnology risk governance** research programs in Europe met to present their findings at the “Future-proof Approaches for Risk Governance” conference.[6] This was not the aforementioned “systemic risk” that SVB posed to finance, but the types of risk engendered, and governed, by some of its clients producing novel technologies, like nanotech. One signal motif for risk governance was clear: a continuum from chemicals to nanomaterials and onwards to advanced (nano)materials.[7] Chemical substances, together with nanomaterials, are *past, present, and future* (see also European Environment Agency 2013; 2001).

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[4] The press release is at: https://ir.atomera.com/websites/atomera/English/3110/news-detail.html?airportNewsID=0d4aae26-86ad-4dac-993d-32c2dda41fef

[5] Consequences for European startups are sketched in another *Wired* article. See: https://www.wired.co.uk/article/silicon-valley-bank-europe-tech-startup#intcid=_wired-uk-bottom-recirc_77741f0d-e0c5-4577-9694-d08863864f27_entity-topic-similarity-v2

[6] The three programs are Gov4Nano, RISK GONE, and NANO RIGO. This was a hybrid conference with two meeting days. The Paris conference occurred on 24 and 25 January; the online event was 31 January. See: https://nanorigo.eu/2022/09/14/future-proof-approaches-for-risk-governance-lessons-learned-from-nanomaterials/

[7] This is based on the author’s notes and presentation slides from attending this conference.

In Europe, the future-proofing coexists with a suite of policy strategies to reduce toxic chemical use in society in the Chemicals Strategy for Sustainability (European Commission 2020). Calculated for 2021, the global chemicals industry has sales of €4.026 trillion, and Europe accounts for €594 billion, or 15% of the total (Cefic 2023). Industrial chemicals production is projected to double by 2030, however with the estimated European share falling from second to third place. Eurostat reports European chemicals production at 278.9 million tons for 2021; 214.3 million tons are considered harmful to health and 84.3 to the environment.[8] Future chemicals use is to illustrate a "toxic-free hierarchy" with three classes (European Commission 2020, 4–5). The goal is for most chemicals to be "safe and sustainable", but with exceptions granted to "minimize and control", and then to "eliminate and remediate" the worst substances. The ambition, from the European Commission together with industry, is to buttress the economic headwinds with safe and sustainable research and innovations that also make European chemicals more attractive on the global market.

Engineered nanomaterials are part and parcel to this conversation on safety and sustainability. The European market for just nanomaterials has in 2021 been measured at 140 thousand tons, with a valuation of €5.2 billion, according to a recent study (European Chemicals Agency 2022, 12). Projections for 2025 range between 215 and 410 thousand tons and €10 to 14 billion in value (2022, 77–80). To be brief, the nanomaterials market in Europe is growing significantly–in contrast to the state of the chemicals industry. Nanomaterials are still only a small economic piece of the fourth largest "producer" in EU manufacturing (Cefic 2023, 26).

Nanomaterials are now regulated in Europe as an annex (Meesters et al. 2013; Clausen and Hansen 2018; Nielsen et al. 2021; Rudén and Hansson 2010), under the European REACH legislation, i.e., Registration, Evaluation, Authorization and restriction of CHemicals. REACH entered into force in 2008 (Klika 2015) as a paradigm shift towards limiting the blanket use of chemicals across society (Stokes and Vaughan 2013). Nonetheless, **chemicals regulation** itself continues to struggle in this mission (Coria, Kristiansson, and Gustavsson 2022), as witnessed by a subset of ignorance studies

[8] The raw data from Eurostat, retrieved 20 March 2023, are linked here: https://ec.europa.eu/eurostat/databrowser/view/env_chmhaz/default/table?lang=en

(Boullier and Henry 2022; Henry et al. 2021) on the knowledge production and industry influence behind chemical risk assessment.

While nanomaterials are typically short for engineered nanomaterials, toxic-free policies are complicated by the prevalence of natural nanoforms, the non-engineered nanomaterials (see Handy et al. 2008, 303). A seminal indicator here is in the breakdown of plastics into nano and microplastics (Gigault et al. 2021; Kelpsiene et al. 2020; Nature Nanotechnology 2019) through, for instance, weathering. They are a natural, albeit unintended, nanoform.

The market for advanced nanomaterials is much more speculative here. Advanced, or smart nanomaterials, refer to the coming generation of materials that actively respond to different stimuli (Gottardo et al. 2021, 3) instead of just providing passive, but novel, functionalities.

RESEARCH QUESTIONS

Overall, this research project investigates how researchers and innovators legitimate nanotechnology in society. The licentiate thesis that follows is concerned with three specific questions.

> (i) In the context of nanomaterials and enabling technology today, how does the problem of legitimacy manifest itself in the political economy of research and innovation?
>
> (ii) How does the present mode of responsibility practices in research and innovation contribute to the current legitimation of science, technology, and innovation?
>
> (iii) How do nanosafety researchers reflexively practice anticipation in order to legitimize and delegitimize the place of nanomaterials in society?

STRUCTURE OF THE COVER PAPER

Following this introduction is a background of theoretical perspectives in the social and natural sciences, stemming from the problem of risk in society (Section 2). The dual development of research and innovation policies and nanotechnology as a key context for emerging technology is thereafter reviewed as previous research informing the thesis topic, culminating in three research frontlines, which guide the present and planned studies (Section 3). Subsequently, there is a brief methodological reflection on exploring empirical ethics in the field of (environmental) nanosafety research (Section 4). Thereafter, the three appended papers are successively introduced, contextualized, and reinterpreted from the vantage point of this thesis (Section 5). Here, three contributions, one per paper, are summarized. Two further studies are then proposed, one on the institutional position and broad outcomes of the Swedish NGO ChemSec, and another on implementing the policy concept safe-and-sustainable-by-design at the nanosafety cluster in Lund, Sweden (Section 6). Future prospects of failure in nanosafety, or the failure of its very future prospects, are considered in a concluding note on the promise of nanosafety legitimizing nanotechnology (Section 7).

2) THEORETICAL BACKGROUND

Theories of risk are central to understanding the progression of nanotechnology and the role of nanosafety research. This section will detail risk as both a sociological and natural scientific (nanosafety) concern through Beck's risk society argument. With a focus on understanding nanosafety as legitimation, risk sociology is reviewed from an etic perspective, whereas progress in nanosafety research is presented in an emic manner. Both perspectives are instrumental to contextualize nanotechnology.

ETIC PERSPECTIVES

This thesis leverages the sociology of risk, concentrated in Beck's *Risk Society*, as the central theoretical fulcrum. The following section will introduce this work, which is expanded upon through the two techno-tragedies of nuclear power and GMOs. Two essential failures, of risk and politics, are revealed. These two cases lead to a review of Beck's theory of politics, sub-politics, as applied to the issue of responsibility in research and innovation. The institutional response of science to risk is developed through the notion of reflexive scientization in the example of toxicology.

The risk society argument

The sociologist Ulrich Beck already declared in 1986 that we were "living on the volcano of civilization" (1992, 17, 76).[9] Blanketed with all the ashfall lies an apocalyptic risk society, our collective present. For Beck (1992, 21), the conceptualization of risk is paramount. His specific articulation starts at,

> *Risk* may be defined as a *systematic way of dealing with hazards and insecurities induced and introduced by modernization itself*. Risks, as opposed to older dangers, are consequences which relate to the threatening force of modernization and to its globalization of doubt. They are *politically reflexive* [original emphasis].

The **risk society** is only partly an industrial society; the alleviation of material scarcity—modernization in other words—loses priority to a risk management of "dealing with hazards". Risks today are thus threats of modernization, "the threatening force", whereas risks yesterday are problematized as "older dangers" to be solved by accumulation, namely, more material wealth. **Risk** and **hazard** (cf. Lofstedt 2011) stand apart from previous eras of danger, in that modernization, for society, maintains its status as solution and becomes problem. Modernization continues to address danger (effect) while also being confronted with itself (side effect): an accelerating **overproduction of risk**. Risk is a prototypical "overflow" (Soneryd and Sundqvist 2021) that cannot be readily solved by modernity.

This is the "volcano of civilization", erupting, albeit with pronounced limits. Because of primary modernization, fewer and fewer perish in the literal eruption of natural and also industrial disaster. This stands in contrast to the frightening statistics emanating from civilizational or modernization risks. Nevertheless, the risk society has dual dimensions. The first is hazard, namely, material pollution, with all the literalism of a volcano. The second here is affect, experienced as anxiety or insecurity in general. This latter aspect speaks to the harm of metaphorical vapors asphyxiating the residents downslope of Beck's volcano of hazard.

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[9] Beck wrote the original *Risikogesellschaft: Auf dem Weg in eine andere Moderne,* in 1986, which was translated from the German for the 1992 version. The full English language title is *Risk Society: Towards a New Modernity*.

Two techno-tragedies

Reflexive modernization must respond to problems of *nature (danger)*, and of *nature and society (hazard)*. In our era of variously defined late capitalism, science and technology fulfills this function, as in the mantra of “fixing society with technology” (Frahm, Doezema, and Pfotenhauer 2021). But, as Beck reminds us, the solutions reflexively engender a new round of problems. Chains of problem-solutions continue under the enduring aegis of techno-economic progress (1992, 45, 200–203). “Risks belong to progress as much as a bow-wave belongs to a speeding ship”.

Two new technologies, amongst other examples, of the late twentieth century encapsulated the growing politicization of progress. These were nuclear power and genetically modified organisms and crops (GMOs). For nuclear power, hazard manifested in the shape of radioactive fallout and its consequences, exemplified by acid rain, radioactive bioaccumulation (Wynne 1992) and outright meltdown (Beck 1992, 60, 177–78). In the political fallout of nuclear power, GMOs highlighted newfound risks in the integration of genetic biotechnologies with agriculture. Similar concerns surrounded the effects of human and animal consumption, together with value conflicts on, for example, the morality of nature and the political economy of global food systems (Wynne 2001). What distinguishes nuclear power and GMOs from research and development in the fully industrial society is arguably their contested economic uptake, showered with occasional protest in society and legal restrictions. These two **techno-tragedies** were, in essence, affronts to progress and early indications of the new possibility of failure.

The sub-politics of responsibility

In the risk society, technological failure is now political. Politics is classified three ways, as either non-politics, sub-politics, or politics. Beck (1992) prefers the term **sub-politics**, to wit, the partial politicization of certain formerly depoliticized arenas. Sub-politics in the risk society captures the translation from the institution of non-politics in the industrial society (cf. van Oudheusden 2014).

The welfare state presided over the zenith of dueling politics in parliamentary democracy (politics as expected) and the non-politics in techno-economic, corporatist pursuits of interest. These extended across various nation states during the first 200 years of industrialization. Politics was reliant upon democratic legitimation and non-politics protected by the established "harmonizing formula" that "technical progress equals social progress", and anyways, "technical progress" is subject to immutable "objective constraints" (Beck 1992, 183–84, 190).

Notwithstanding, the risk society oversees an ostentatious "unbinding of politics". "**Techno-economic innovation**" in Beck's understanding is scathed by the dismantling of so-called "objective constraints", traditionally used to characterize technology development (1992, 186).[10] As these constraints are de-objectified, as in, politicized by risk overproduction, innovation itself is pluralized. The institutional orthogonality of risk to parliamentary democracy results in burgeoning "new political cultures" (1992, 195–200) of participation outside the proper political sphere (cf. Cooke and Kothari 2001).[11] Parliament and voting are not enough to handle the expanding risk overproduction, which is why such politics is increasingly delegated to technocratic expertise. **Society-aligning research and innovation policy** discourses flourish in this preponderance of risk.[12] Furthermore, the "harmonizing formula" is no longer synchronous, as "social progress" is contested by the material overaccumulation triumphed by the welfare state (Beck 1992, 184–87).

The experts also cannot expect *a priori* legitimation in this void of democracy. The sub-politics of responsibility seeks legitimacy across spaces "in which the scope of the social changes precipitated varies inversely with their legitimation" (Beck 1992, 186).

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[10] Beck's conceptualization, surrounding "techno-economic innovation", is a specified functional equivalent to the generalizing catch-all umbrella terms 'science, technology and innovation' or 'research and innovation.' The invocation of techno-economic emphasizes the push for innovation through technological development that is bridled by economic constraints. Alternative conceptualizations to this hegemonic innovation form can be postulated from (van den Hoven 2022).

[11] For a theorization of the institutional gaps induced by the risk society, through the "institutional void" in transgressive policy geographies of risk, see (Hajer 2003).

[12] This conceptualization of a subset of research and innovation policies intends to emphasize specific policies devoted to changing the institutional values of the research and innovation system to better reflect, or align with, society writ large. Two previous discourses are ethical, legal, and social aspects (or implications) (Zwart, Landeweerd, and van Rooij 2014), also referred to as ELSA or ELSI, and anticipatory governance (Barben et al. 2008). For a review of the science-society relationship, one can begin with (Tlili and Dawson 2010; Braun and Könninger 2018). In the Nordic context, the terminology can be compared to norm-critical innovation–see (Fuenfschilling, Paxling, and Perez Vico 2022).

Risk and failure responses as reflexive scientization

Risk overproduction and the politics of technology failure are two paramount issues in the risk society. This is no surprise to Beck. The envisaged response is found in the language of safety, as safety is to risk what wealth is to poverty (1992, 47–49).[13] In Beck's lexicon, scientization is the essential process which then describes knowledge production around risk and relegates the "governance of affect" (Anderson 2007) into tranches of risk governance. Reflexive modernization means that risk is scientized.

The primary—secondary continuum, or "boomerang effect", extends to scientization as well (1992, 23). Beck (1992, 158) clarifies that,

> Scientific civilization has entered a stage in which it no longer merely scientizes nature, people and society, but increasingly itself, its own products, effects and mistakes. Science is no longer concerned with 'liberation' from *pre-existing* dependencies, but with the definition and distribution of errors and risks which are *produced by itself* [original emphasis].

Scientific civilization now confronts the consequences of primary and **reflexive scientization**. This is the problem-solution chain all over again. In the primary stage, problems of "nature, people and society" are solved by scientization. Now, however, science attempts to concurrently solve its very own solutions of the past—and increasingly—its present. Reflexive scientization is the problematization of solutions, if not also combinations of problem-solution chains.

Beck doesn't stop at definitions. The 1980s language of reflexive scientization is refracted onto discourse, replete with terms like "acceptable limits" (1992, 64–69). Acceptable limits propose to delineate what is toxic to humans and the environment at which level or concentration, and by default, also what is non-toxic or harmless. This discourse produces legitimacy by displacing the axiology of harm into the supposedly fact-finding nature of

[13] For a discussion on risk, safety and security, consult (Boholm, Möller, and Hansson 2016). On the topic of nano-safety as nano-security, see Nasu and Faunce (2012).

science. Toxicity and harm become matters of calculation, alone. Ethicists in the risk society can speak of ethics and morality, but not hazard. One consequence is that society consents to the ubiquity of poison, as long as it can be legitimated by the calculative reassurance that a substance is produced and released within the acceptable limit. Little attention is paid to the primary scientization that inaugurates the hazard, because it is, in cruel terms, legitimate hazard.

Two further concerns of epistemology are outlined by Beck: (1) the empirical foundations of toxicology and (2) holistic mixtures of everyday exposure.

First, acceptable limits are generated from scientific studies, for instance *in vitro* and *in vivo*, and then generalized to what could harm humans in society and the environment in realistic settings. In order to know the quantity at which a substance harms humans and the environment, one needs to bring the lab to society and open its mouth for a proper dose-response assessment. Short of a toxicology *on the masses*, the toxicology *for the masses* that is preformed necessarily involves an "acid rain dance" of uncertainty (1992, 64). Acceptable levels—at least the sort that is sourced from toxicology—are mere estimates predicated upon laboratory conditions.

Second, humans and the environment are not exposed to atomistic substances in some sort of solitary confinement but rather in complex mixtures.[14] Poisoning results from the interaction, and lived-in experience, of exposure to mixed cocktails of substances, perhaps even within their individual acceptable limits, in the "out-there" of reality (Latour 2004). The production of acceptable limits furthermore manifests as a legitimation practice. Their fundamental uncertainties are denied and repressed.

EMIC PERSPECTIVES

Toxicology is but one well in the sample tray of nanosafety. To be illustrative, Beck's terminology of reflexive scientization develops along research agendas in the natural sciences of nano(eco)toxicology, environmental fate modelling, risk assessment and life cycle assessment. This is just a

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[14] It is worthwhile to note that in the presiding Chemicals Strategy for Sustainability, there is an emphasis on exactly this problem of understanding this cocktail effect (European Commission 2020, 12).

consideration of the response to environmental implications—itself only one question for the broader problematization of nanoforms in society.

Nano(eco)toxicology

One response to this challenge is in the transition from ecotoxicology to nano(eco)toxicology (Kahru and Dubourguier 2010). In ecotoxicology, substances, or forms, are examined in the lab for their chemical properties (characterization) and the relationship to the biosphere. This is a field that dates to the 1960s (2010, 107) and therefore the origins of the risk society. As concrete chemical forms cannot be exposed to every species, or an entire class of species, representative species are selected instead. Based on the level of the food-web under investigation, the OECD recommends fish, Daphnia or algae (2010, 109–10). Yet nanoforms are no less prolific.

At the nanoscale, nanoforms have physico-chemical properties, essentially a product of their high surface areas, and by extension, their high reactivity. This is why nanoforms and their new behaviors on the small scale break ecotoxicology into nano(eco)toxicology, that is, chemistry is simply not enough (Nel 2006; Dhawan, Sharma, and Parmar 2009). Nanoforms, frequently broken down into nanoparticles, must also be selected to represent their larger cohort. The data is generated for ecotoxicity figures, generally with the intention to add to databases (Juganson et al. 2015) that can address the dual problems of representation, study by study. Another technique is to leverage this data and statistically create species sensitivity distributions that can speak to a range of sensitivities for multiple species and nanoforms, provided sufficient data is available (Garner et al. 2015).

Environmental fate modelling

Studies of the environmental fate of nanoforms reveals another concern beyond ecotoxicity alone (Garner and Keller 2014). Environmental fate references the modelling of ultimate accumulation through the use of reified boxes, or compartments: air, soil, and water (viz. freshwater in lakes and streams and saltwater in the seas). Will a nanoform stay in the air, or land on soil, or drift into a water source (transport) (2014, 3–16)? Will it react and transform with natural organic matter along the way (heteroaggregation) (Garner and Keller 2014, 5–7)? How about other transformations (Garner and Keller 2014, 2–3, 12–16), like sulfidation and oxidation (transformation)? What about nanoforms reacting with each other (homoaggregation) (Garner and Keller 2014, 6)? Could the nanoform dissolve into a colloid (dissolution) (Garner and Keller 2014, 10–12)? Could it stick to the soil or riverbed (sedimentation) (Garner and Keller 2014, 9–10)?

Environmental fate studies are, essentially, either probabilistic (Sun et al. 2016) or deterministic models (Garner, Suh, and Keller 2017; Meesters et al. 2014). Garner et al. (2017, 5541–42) identify three classes of fate models, “steady-state multimedia box models, spatial river/watershed models, and materials flow analysis (MFA) models”, which start from chemical properties and not the novel dynamics of nanoforms. However, nanoforms, usually just engineered nanomaterials, have a few nano-specific fate models, with names like “nanoFate” (Garner, Suh, and Keller 2017), and “SimpleBox4Nano” (Meesters et al. 2014).

General limitations of modelling aside, engineered nanomaterial fate models struggle to accommodate another blind spot. This is the chemicals legacy in the need to make fate models for nanoscale interactions and not simply update from earlier versions envisioned for chemicals (Garner, Suh, and Keller 2017; Meesters et al. 2014; Sun et al. 2016).

Risk assessment

Fate models and toxicity data can be used for the explicitly normative methods of **risk assessment**. Risk assessment is only one component of wider risk management or governance programs. Assessment, in general, aims to determine or quantify levels of risk, whereas management suggests strategies to mitigate risk, and governance asks what society should do about risk. A few examples of risk assessment for engineered nanomaterials are risk quotients, risk categorization and proxy measures. In the end, the current consensus view is in the title of a recent review—"Risk Assessments Show Engineered Nanomaterials To Be of Low Environmental Concern” (Arvidsson 2018). Let’s review how the experts get there.

Risk quotients, dating back to chemical risk assessment (cf. Scheringer 2008), divide a predicted environmental concentration by the no-effect concentration; first with chemical substances, and now with nanoforms (Arvidsson et al. 2011, 246–47). Like with Beck’s acceptable levels, risk is designated as a dichotomy: 1 or higher is a risk and less than 1 is a non-risk.

Realistic attempts to determine risks of exposure from any nanoform, or just with engineered nanomaterials, are, simply put, difficult to impossible. In the world of risk assessment, nature has a problem with "intrinsic overcomplexity" (Arvidsson et al. 2018, 13670). The concept of proxy measures seeks to simplify the overcomplexity by estimating risks of engineered nanomaterials through selected proxies. Arvidsson et al. (2018) review the literature to summarily recommend the two factors of production volume and aquatic ecotoxicity, complete with a two-by-two decision matrix based on these values. The authors suggest (2018, 13676–77) enlisting proxies for when data availability is in question or for the desire to simplify assessment, in comparison to the byzantine nature of fate models.

Risk categorization takes a different perspective. In this tool, exemplified by NanoRiskCat, both "exposure potential" and human and environmental hazards are evaluated for specific nano-enabled products—not nanoforms (Hansen, Jensen, and Baun 2014, 1). Five dots are shown for a nano-enabled product: "[t]he first three dots refer to the qualitative exposure potential for professional end-users, consumers and the environment, whereas the last two refers to the hazard potential for humans and the environment" (2014, 1). Each dot is shaded for high, medium, low, and unknown risk, which correlate, respectively, to red, yellow, green, and grey.

Benefits to consumers, nano producers, and combined businesses include the clear separation of assessing exposure potential and end-use decision-making. This method then offers an alternative to the other more technocratic assessment tools and elucidates the knowledge gaps precluding categorization (2014, 20–21). Consumers can make some degree of an informed decision about which nano or non-nano-enabled products to intentionally use. Nonetheless, a new concern arises in the presence of grey dots emerging from NanoRiskCat labels (cf. Hansen, Hansen, and Nielsen 2020). The underdetermination of risk assessment is made plain—challenging its legitimation.

Life cycle assessment

A final approach, also compounded from other nanosafety tools, is life cycle assessment. Rather than determine ecotoxicity or model environmental fate, life cycle assessment evaluates the environmental impact of engineered nanomaterials. First, the benefits: its formulation encourages wider stakeholder engagement to gather at least the necessary input data and interrogates the holistic impact beyond just risk (Klöpffer et al. 2007, 10–13). All life cycle assessment relies upon the availability of "characterization factors", which "tell the environmental impact per amount of emitted substance", partly a product of those thorny environmental fate models (Arvidsson 2015, 229) and contestable ecotoxicity data (Salieri et al. 2018, 109).

Life cycle assessment proceeds through four stages: (1) goal and scope definition, (2) inventory analysis (inputs and outputs across a given system), (3) life cycle impact assessment (translation from inventories to impacts) and (4) interpretation of the assessment (Hauschild 2005, 82A). Salieri et al. (2018, 108–9) highlight three obstacles for life cycle assessment of engineered nanomaterials, in the "use of an adequate functional unit" that understands the different properties of nanoforms from bulk forms, "the lack of (average) life cycle inventory (LCI) data for the production of the most relevant MNMs in use", and "the lack of characterization factors (CF) for released MNMs".[15]

At a more basic level, the assessments hinge upon the availability and quality of data from an embryonic industry. The effect has been a turn in the literature towards anticipation, in anticipatory (Wender et al. 2014), ex-ante (Roes and Patel 2011), and prospective life cycle assessment (Arvidsson, Tillman, et al. 2018), with the agenda to anticipate (and thereafter evaluate) future scenarios of engineered nanomaterials in society. This perspective embraces the Collingridge dilemma (1982), that is, societal consequences of emerging technologies are unknowable until mature and stable, hence resistant to change, to acknowledge that life cycle assessment is limited by its vary capacity to evaluate. In order to evaluate engineered nanomaterials, high data quality and a resilient capacity needs to be cultivated. By this point in time, the most useful form of evaluation would not be models, but by examining that future society replete with nanomaterials. Still, risk assessment and life cycle assessment aspire to legitimate the release of engineered nanomaterials upon society, frequently by pointing to worrisome examples (see Mueller and Nowack 2008).

[15] MNMs are an abbreviation for manufactured nanomaterials, otherwise referred to as engineered nanomaterials. This is a demarcation from all nanoscale objects or nanoforms.

Nano(eco)toxicology, environmental fate modelling, risk assessment and life cycle assessment, reflexively stress the issue(s) of data. Making, procuring, and evaluating that data is a problem of positivism. Until that data arrives, normative questions abound. Who gets to say when an ecotoxicity score matters? How much uncertainty can be tolerated in the production of a fate model? When is it time to move from Arvidsson's "low environmental concern" to societal concern? What lies beyond the area included in the goals and scope of life cycle assessment? When is nanosafety legitimate?

3) PREVIOUS RESEARCH

The previous research that is derived from the interdisciplinary problematization of risk is divided into two topics for further elaboration. The first topic is in the study of research and innovation policy, in the wake of the risk society argument. The second topic evolves from the design and implementation of nano-technoscience, as seen by the production of nanotechnologies. These two contextualization sections culminate in the articulation of three frontlines to these areas of research that will moreover anchor the planned studies.

RESEARCH AND INNOVATION POLICY

The foregrounding of science, technology and innovation is a policy priority for the future economy. Beck's theory of politics–most significantly in his sub-politics–evinces that legitimation is a persistent problem for techno-economic progress. Research and innovation policy is seen as a central arena that attempts to solve this problem, to secure sustained future growth. This is emphasized in the concept and study of emerging technologies.

Legitimation and the rise of RRI

Research and innovation policy is one target arena to investigate this expansive space of sub-politics. The overriding response to the previous techno-tragedies exhibited in nuclear power and GMOs—to prevent future tragedies–is found in the turn to society-aligning research and innovation policies. Nanotechnologies are, arguably, the first case of new technologies to unfold in this shadow of doubt (Johnson 2004; Owen, von Schomberg, and Macnaghten 2021). Thus, policy-making post-risk society views technological development as not ineffable and inevitable, but socially dependent (Bijker, Hughes, and Pinch 1987), politically reflexive (Winner 1980), and ecologically situated (Ahlborg et al. 2019). If its norms are doggedly challenged, and its deliverables derided as illegitimate, then the (fantastically expensive) modernization projects of nanotechnologies are at risk. In the risk society, the essential background (and existential angst) of risk overproduction means that technologies produce a potential for "backlash," even bordering on failure (Bensaude-Vincent 2021).

Science, technology, and innovation are essentially social institutions like any other (cf. Merton 1974). This consensus view from STS has the consequence that their internal norms should be probed and subject to legitimation. Research and innovation policy, the purveyors of desirable outcomes, should align or at least endeavor to align the legitimate values from democratic society with the internal institutional norms of research and innovation itself. Societal alignment is thus a form of norm-criticism and legitimation repair.

Dating back to the 1990s, the European Commission has utilized its multi-year financial allocation mechanisms—the framework programs—to promote various agendas of alignment; in particular, after the financial meltdown in 2008 (European Commission 2007).[16] A few example policies that aim at this alignment, replete with their own exclusive discourses, are Grand (Societal) Challenges (Kuhlmann and Rip 2018; Välikangas 2022), Mission-Oriented Innovation Policy (Mazzucato 2018) and Responsible Research and Innovation (European Commission 2012; Owen, Macnaghten, and Stilgoe 2012; Sutcliffe 2011; von Schomberg 2010). **Responsible Research and Innovation (RRI)** and its twin, **Responsible Innovation (RI)** (Randles, Tancoigne, and Joly 2022), have seen a lot of attention by both policy-makers, STS affiliated scholars, and the researchers and innovators expected to comply with its demands, in exchange for funding (see Åm 2019). Here, societal alignment is presented in the norm of responsibility.

The first academic discourse, Responsible Innovation, intends to reimagine innovation processes and products in the above mentioned setting of post-

[16] These specific framework programs are created and administrated by the Commission's Directorate General for Research and Innovation, or DG RTD. This thesis is temporally situated in the transition from the eighth program, Horizon 2020, to the ninth, in Horizon Europe. Horizon 2020 officially operated from 2014 to 2020 and evolved into Horizon Europe with a mandate between 2021 and 2027. Worth noting is the long-term increase in budget, rising tremendously with the seventh program during the great recession and subsequent Eurozone crisis. Macq et al. (2020, 4) provide extensive contextualization on the issue.

2008 economic crisis and its corollary in the rising economic and societal importance of technological innovation (Owen, Bessant, and Heintz 2013; Stilgoe, Owen, and Macnaghten 2013). Innovation is thus increasingly relevant for critical reflection in the promotion of alternatives, in line with earlier moves in STS. While explicitly open-ended (for academics), two notable heuristics have been AIRR and AREA (cf. de Saille 2022). The AIRR framework endorses four dimensions of Anticipation, Inclusion, Reflexivity, and Responsiveness, in terms of process, product and purpose questions (Stilgoe, Owen, and Macnaghten 2013, 1570–74). In the UK, there has been an alternative albeit truncated phrasing in Anticipate, Reflect, Engage, and Act (de Saille 2022, 1–2).

The second seminal development in the turn to responsibility arose in the uptake of Responsible Innovation by the European Commission. Responsible Innovation became Responsible Research and Innovation (von Schomberg 2013), and without much thought to the prior relationship between research and innovation (Flink and Kaldewey 2018). As a sizeable priority under Horizon 2020, Responsible Research and Innovation was expounded upon through six keys: engagement, gender equality, science education, open access, ethics, and governance (European Commission 2012).

Emerging technologies

It's not just about the changing state of policy-making, however, but moreover the technologies it intends to produce. Technologies exist at various stages of maturity, as highlighted by the Collingridge dilemma (1982). As they mature, their societal embedding becomes harder to contest. If one wants to change certain technology trajectories—let's say irresponsible– towards more responsible ones, the prototyping should commence with those that are the least developed. These are often seen as **emerging technologies**.

Consistent growth in science and technology, as economic sectors, has translated into new crops of emerging technologies (Seifert and Fautz 2021). So much so that emerging technologies have been subject to problematization and reified into criteria for research. In a recent synthesis, Rotolo et al. (2015, 1828) propose the category for:

> […] a radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous.

Emerging technologies, roughly, are new, with expanding utilization, coherent enough for bounding, and have the future potential for “socio-economic” disruption.

THE FRAME OF NANO-TECHNOSCIENCE

The overarching frame of nano-technoscience is introduced below and reviewed in the new relationship between (nano)science and (nano)technology–through two essential points. Nano-enabled products, alongside constituent engineered nanomaterials, are then presented as a proxy measure for the current economic establishment of nanotechnology. This establishment is then situated in the risk society through the dual critiques of *nanotechnology per se* and as regarding *tangible nanotechnologies*.

Starting from nano-

Nanotechnologies represent a characteristic case to underline the concept of emerging technologies (see Kaplan and Radin 2011). To start, the first essential point is that this farrago of nano- has developed through the prism of nanotechnology and not nanoscience, with the first use in a paper by Taniguchi (1974). Two other key figures in positioning nanotechnology arrived before, in Feynman’s vision (1960) of miniaturization in “There’s Plenty of Room at the Bottom” and after, in Drexler’s imagining of nanotechnology futures (1986), while nanotechnology was being established (cf. Drexler 2004). On the one hand, in the history of science, nano- proceeds as a successor project to materials science (Bensaude-Vincent and Hessenbruch 2004; Eisler 2013). Nanotechnology, on the other hand, has most often been compared to biotechnology (Seifert and Fautz 2021; Seifert and Plows 2014), with the foreboding lessons from previous GMO controversies (Kearnes et al. 2006).

Across STS research, this nano- farrago is generally framed in the hybridized form of technoscience: **nano-technoscience** (Arnaldi, Lorenzet, and Russo 2009; Pellizzoni 2012). Regardless, any discussion of nano-typically begins with the refrain to size. Size-based boundaries help to codify the unique interdisciplinary institutionalization of nanoscience, with combinations of disciplines working together both to study and produce nanoscale phenomena. Precise definitions are manifold for the nanoscale (see Boholm and Arvidsson 2016; cf. Maynard 2011), with a tentative consensus around phrasings like this, in **nanotechnology** as "the understanding and control of matter at 'dimensions of roughly 1 to 100 nanometers, where unique phenomena enable novel applications" (qtd. in Barben et al. 2008, 980; cf. Foss Hansen et al. 2007, 2).

This definition comes from the National Nanotechnology Initiative (NNI) in the US that signaled a consolidation around the term nanotechnology (see Roco 2011; Gallo 2009).[17] The NNI and the many programs that have mirrored its structure elsewhere reveal a second essential point. Structurally speaking, science and technology is to be directed towards economically relevant "novel applications", innovation in other words (Johnson 2004). Nano-technoscience therefore is imbued with the anachronisms in the philosophy of science first, technology second (de Solla Price 1984), and perhaps innovation a distant third (Godin 2006). What is not so anachronistic is in the framing of science, technology, and innovation *all at the same time*.

[17] The NNI has been profiled at various times over its development by, amongst others, Mihail C. Roco, the longstanding nanotechnology enthusiast at the National Science Foundation in the US (Roco 2011, 427–28). The NNI was announced in January 2000 after previous funding efforts focused on smaller research areas than nanotechnology, for instance, "ultra-precision engineering". Funded projects were promoted to both better understand phenomena at the nanoscale and find economically relevant applications. Together with deciding on the term nanotechnology, Roco argues that the more than $12 billion in support between 2000 and 2010 catalyzed similar initiatives in approximately 60 countries by 2004.

Nanoparticles, nanomaterials, and nano-enabled products

Where is the distinction between the earlier emphasis on nanomaterials and nanotechnologies? Specific nanotechnologies involve a manipulation of nanoscale objects for macroscale functionality, commonly referred to as nanoparticles and nanomaterials. Researchers and innovators refine nanotechnologies, which are ultimately aggregated as nano-enabled products for consumers in the marketplace. One does not, in principle, purchase an entire nanotechnology; rather nano-enabled products that utilize their beneficial properties. Nanoparticles are "relevantly measured" in the nanoscale in all three dimensions, whereas nanomaterials refer to one dimension or more (Boholm and Arvidsson 2016, 35–36).

Nanoparticles and nanomaterials are only two commonly manufactured nanoscale objects. These nanoscale objects, nanoforms for short, occur naturally in the environment and are engineered for nanotechnologies, usually distinguished under the unifier of **engineered nanomaterials** (Foss Hansen et al. 2007, 2–4). Nanoscience, therefore, is a result of new research capacities to explore a pre-existing world of very small phenomena (Mody 2010; Erhardt 2003). Nonetheless, nanotechnologies have been developed for several economic sectors, like electronics (Choi and Mody 2009), energy systems (Pidgeon et al. 2009), foods (Alp-Erbay 2022; Sekton 2010), medicine (Contera, Bernardino de la Serna, and Tetley 2020), and textiles (Coyle et al. 2007), for both civil society and the military (Altmann 2004). Today, nano-enabled products tend to mix nanoscale components with (bulk) macroscale objects, hence nano-enabled and not made by nano.

Estimates about nano-enabled products and engineered nanomaterials in society are more explorative than definitive. Since the boon in economic interest for commercializing nanotechnologies that arose in the 2000s, products have been tracked by inventories, "[…] an important resource and bellwether of the pervasiveness of nanotechnology in society" (Vance et al. 2015, 1769). In the US, an early forerunner was the Nanotechnology Consumer Products Inventory (CPI), with a relatively low estimate of 1,814 products, circa 2013. Higher estimates come from the newer European-focused Nanodatabase, based in Denmark (Foss Hansen et al. 2016). The Nanodatabase has surpassed 5,000 entries; their own analysis concludes that applications are clustered around the categories "health and fitness", "home and garden", and "automotive" (Hansen, Hansen, and Nielsen 2020).

In terms of constituent nanomaterials, silver, followed by titanium, titanium dioxide and carbon (for example, carbon black and carbon nanotubes) are the most prolific in the Nanodatabase.

Inventories like the Nanodatabase face significant hurdles in this gap between exploration and definition. For instance, Hansen et al. (2020) caution that most listed product producers do not self-identify their engineered nanomaterials and that reporting bias goes two ways. One issue is in (1) overestimates from businesses making a positive association between a specific product and promises of nanotechnology. Another challenge (2) stems from underestimates in businesses worried about the popular uptake of negative connotations with the association of 'nano' in characteristics like novelty and uncertainty.

Studies on the production of engineered nanomaterials, rather than just data derived from product inventories, provide another statistical viewpoint. Compared to general figures of millions of tons for chemical substances, engineered nanomaterials are reported in no more than the thousands of tons. A prominent survey of industry representatives by (Piccinno et al. 2012, 4–7) reports on global production in terms of tons per year, claiming that titanium dioxide is most common (10,000 tons), with additional metal oxides and carbon nanotubes also prominent (each in the range of 100 to 1,000 tons). Less prevalent in Europe are silver, quantum dots and fullerenes (less than 10 tons). However, the numbers for silicon dioxide vary from negligible (less than 1 ton) to extreme (more than 100,000 tons). This uncertainty–explained by the lack of consensus in demarcating between bulk and nanoscale silicon dioxide–points to the symptomatic underdetermination problem in delimiting bulk from nano.

Another angle to generate production statistics is through modelling flows of engineered nanomaterial life cycles (Keller and Lazareva 2013). The authors base the modelling off another market study (see Keller and Lazareva 2014, 4–5), with major nanomaterial production ranges listed (in decreasing order) as various metal oxides, iron, nanoclays, carbon nanotubes, and finally, far smaller amounts of copper and silver. This study proceeds to map nanomaterial use and release, which is concentrated in Asia, then trailed by Europe and North America (2013, 66–68). To sum up, nanomaterial production is, at a minimum, an order of magnitude smaller than chemical substances. It varies immensely depending on the specific nanomaterial (metal oxides versus the rest). Reporting statistics are limited by the degree of agreement on how to count nanomaterials (or nanoparticles) from their bulk counterparts.

Contesting nanotechnology and nanotechnologies

Nanotechnology inhabits the risk society in three fundamental aspects (cf. Throne-Holst and Stø 2008; Fitzgerald and Rubin 2010). The above overview of actually existing nanomaterials and nano-enabled products points to the first point in the continual *promise of techno-economic progress driving modernization*. This is the endpoint in the maximization of (desirable) goods. Yet these promises co-exist with the undesirable nature of risk. Nanotechnology comes to embody the reflexive logic of both maximization of goods, and minimization of bads. Nano-enabled products contend with nano-enabled risks in a negligible latency period (Beck 1992, 55). Latency becomes simultaneity.

Two further traits develop from Beck's risk distinction between affect and hazard. Concerns started with the angst, that is, affect risk, in the *conceptualization of nanotechnology per se*. Until the 2000s, initial critiques out of anxiety (Joy 2000), termed "speculative nanoethics" (Grunwald 2010; Nordmann 2007) almost *ex post facto*, developed from the science fiction fantasies of nanotechnologies run amok. These are the well-known scenarios of 'grey goo' from the aforementioned Drexler (1986), where (to paraphrase) nanobots eventually devour the planet. The doom and gloom scenarios resonated with the public, notably in the novel *Prey* (Crichton 2003), resulting in an academic discourse seeking to define and separate the science from science fiction of nanotechnology (Bowman, Hodge, and Binks 2007; Kaplan and Radin 2011). What, in fact, can't nanotechnology do?

This first critique is based on nanotechnology as a nebulous constellation of speculation and plausibility. The promises are so large that seemingly anything is possible–up to and including dystopia. Shortly after the science policy and scientific settlement on nanotechnology, a new field of research emerged on the concrete risks (hazards, that is) nanotechnologies suggest for society (Colvin 2003).[18] The turn to risk, traditionally defined, changes the

[18] This research focus has been collected under the terminology of nano-EHS, or environmental, health and safety aspects of nanotechnologies. It can be argued that the

analytical lens to the demonstrable properties of nanotechnologies. Two reports from this period generated lasting momentum: “The Big Down”, from a Canadian NGO (ETC Group 2003) and *Nanoscience and Nanotechnologies: Opportunities and Uncertainties* in the UK (Royal Society and Royal Academy of Engineering 2004). Here, the important qualifier of emerging technologies being “radically novel” is relevant in the colonization of the nanoscale (e.g. Mekel 2006). It is not just more quantitative risk from nanotechnologies–Beck’s risk overproduction–but, crucially, *qualitatively new risks*.

THREE FRONTLINES

Synthesizing the combined theoretical background and two strands of previous research, this sub-section outlines three frontlines vis-à-vis previous research. The first frontline is the movement from the (supposedly past) regulation of chemical substances towards (supposedly present) nanomaterials. The second is in the “implicit ethics” of the risk society that proposes a trajectory from Beck’s reflexive scientization towards safety, as evinced by the case of nanosafety. The third is the outcomes of legitimation practices from nanosafety to nanotechnology. Put together, these frontlines suggest three broad problems that, although not exhausted by this thesis, propose a fertile ground for the two further studies (see Section 6).

How to regulate nanomaterials

Despite the constant focus on the newest emerging technologies in risk governance, chemical substances and nanoforms remain an ongoing regulatory concern. The European Commission expects a rapid transition from the current portfolio of *mostly unsafe and unsustainable* chemical substances to a new generation of *safety and sustainability*. Nanoforms are regulated, essentially, through the regulatory regime of REACH, and are thus not excluded from this policy push. Nevertheless, over two decades of research concludes that nanomaterial properties make the chemicals perspective insufficient for their qualitatively new risks (e.g. Maynard, Bowman, and Hodge 2011; Meesters et al. 2013). This is in plain view of the regulatory truism that regulation is hard policy, or that policy is soft regulation. Moves towards safe and sustainable nanomaterials, and away

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fields of nanosafety and nanotechnology risk governance descends from this period at the turn of the millennium. See (Dunphy Guzmán, Taylor, and Banfield 2006) for an overview of the turn to risk at the NNI.

from the nanomaterials that don't measure up, are also at an infancy stage. The regulator and nanosafety researcher response constitutes the first such frontline.

Between reflexive scientization and (nano)safety

To comply with these regulations, the full force of nanosafety is brought to bear. Beck (1992, 49) only sketches safety as the axiological endpoint of the risk society, with speculative remarks like, "the place of the value system of the 'unequal' society is taken by the value system of the 'unsafe' society". The safe society is the aspirational endpoint for the risk society. In the meantime, the relentless positivism of reflexive scientization and its chain links of problem—solutions beckon, burrowing within nanotoxicology, environmental fate models, risk assessment and life cycle assessment. The latency of side-effects (1992, 34) from nanotechnologies which used to socially distance cause and effect, allowing plausible deniability and "organized irresponsibility" is confronted by reflexive scientization. Nanosafety is funded at the impasse posited by the axiom: our knowledge is just enough to be a problem and not enough to be a solution (cf. 1992, 46–47). A second frontline is in this relationship between reflexive scientization and safety.

Legitimation is at stake. Beck (1992, 28) dismisses the normative usurpation of nanosafety in his theorization of "implicit ethics", asserting that "determinations of risks are the form in which ethics, and with it also philosophy, culture, and politics, is resurrected *inside* the centers of modernization – in business, the natural sciences, and the technical disciplines" [original emphasis]. Nonetheless, "implicit ethics" goes both ways; nanosafety appropriates the value-laden language of safety for positivist methods, without the need to answer to the ethicist (or wider public). Empirical research (and modelling) is thus galvanized with *legitimation by normativity*. Beck (1992, 176) concludes that, "statements on risk are the moral statements of scientized society".

Enabling and legitimating nanotechnology

It's not just nanosafety at risk, either. Nanotechnologies, the paragon of emerging technologies, is referred to as an enabling technology in the European science, technology and innovation policy discourse (cf. Flink and

Kaldewey 2018). Even more enabling are the “key enabling technologies”, so labelled as to “[…] its potential to contribute to economic growth and societal well-being across industrial sectors” (Svendsen et al. 2020, 731), itemizing “micro/nano-electronics and photonics” alongside “advanced manufacturing”, “advanced materials”, “life-science technologies”, “artificial intelligence”, and “security and connectivity.”[19] Nanotechnologies appear primed for utilization, with applications to nano-electronics, advanced manufacturing and as a part of the anticipated turn to advanced materials.

Beyond nanotechnologies, the implication is that science, technology and innovation is a central component of the European project and, by extension, its political economy (cf. Tyfield 2012). Fraser’s “financialized capitalism” (2015) is accelerated by Birch’s preferred term of “technoscientific capitalism” (2020b) as twin motors of the risk society (Birch 2020a). As science, technology and innovation come to dominate investment in Europe, they also become a source of crisis—a crisis potential—for its constituent institutions and the much wider political economy (cf. Habermas 1975). The scope and extent to which the *enabling promise of nanotechnology* can be legitimated through nanosafety is a third frontline. Hence, practices of legitimation link together nanosafety, nanotechnology, in the proposed enabling of technoscientific capitalism.

4) METHOD

The earlier framing of nano-technoscience foregrounds depictions of nanotechnology articulated across STS. STS discussions are briefly reviewed on the topic of adapting ethics research for new technologies. One of the resulting suggestions, empirical ethics, is then used to provide a method to address questions posed by the quagmire of “implicit ethics”, first sketched in the risk society argument. Then, the positionality of the researcher is reviewed as an embedded part of an interdisciplinary nanosafety research program.

[19] Enabling technologies, and emerging technologies, can also be cross-referenced with converging technologies. The idea is that nanotechnologies can form a base platform to integrate with others, like biotechnologies, information, and communication technologies (ICT), or even neurotechnologies. This is just an indication. The discourse is explored further in, for example, (Gelfert 2012), and through contributions to (Kaiser et al. 2010).

THE APPROACH: EMPIRICAL ETHICS

The question left unsaid through Beck's invocation of "implicit ethics" (1992, 28) is in how to study normativity. Exactly who studies normativity, traditionally the domain of ethicists, is extended into the wide-ranging sets of expertise in risk determination, "in business, the natural sciences, and the technical disciplines". What is more, risk producers are joined by norm producers in the relation between emerging technologies and society. Those who study this co-production of risk and norms are generally clustered under the interdisciplinary label of STS. Specifically, normative concerns from nano-technoscience have been grouped under the term "nanoethics" (Allhoff 2009; Ferrari 2010; Ferrari and Nordmann 2010; Gordijn 2005; Johnson 2007; Kermisch 2012), and contrasted with a more scale-independent ethics of "new and emerging science and technology", shortened to NEST-ethics (Swierstra and Rip 2007). The utility and boundaries of nanoethics in the applied ethics of technology is an evolving contention.[20]

These new and emerging sciences and technologies have disrupted their respective institutional structures *and the ethics that evaluates them*. Together with various salvos from STS, one novel proposal is "empirical ethics" (Rehmann-Sutter and Scully 2009, 245–46). Empirical ethics intends to leave the objectivism of distanced judgement via deductive moral frameworks—namely, deontology, virtue ethics, utilitarianism—from the prescriptive tropes of the "acceptability", "desirability", and "novel ethics" frames (2009, 249–50). This is (sociological) ethics "upside-down", with the proviso by Kaiser (2006, 672) to probe "[…] how normative concerns *are* managed by different social actors, rather than discuss how ethicists *should* cope with controversial concerns and visions" [original emphasis]. Ethics can therefore benefit from problematizing "normative concerns" in social settings and establishing an approach of ethics "in the making" (see Johnson 2007).

Empirical ethics is a reflective act. Rehmann-Sutter and Scully (2009, 247) reconnect ethics to science, technology and innovation by concluding,

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[20] These tensions furthermore spillover into the creation and persistence of the notable journal *NanoEthics*. A compromise between scale (nano) and novelty (new-ness) is gleaned from the journal's subtitle: "studies of new and emerging technologies." See: https://www.springer.com/journal/11569/aims-and-scope

> [e]thics, in this conception, is essentially a *reflective loop within* the social processes of innovation and development, not a moral science outside of society. It is not bound to eternal moral principles that serve as a kind of a historically independent Archimedean point, but it needs to proceed pragmatically, taking into consideration the moral understandings of the other participants at a given time and a given place within history, and constantly opening questions about which strategies of action are better contributions to society than others [original emphasis].

In short, constructivist researchers, as would-be ethicists, should treat ethics more like technology. "Moral principles" co-evolve with society and its scholars ought to respond, reflexively, in addressing the scope of ethics itself. Otherwise, business-as-usual, right side-up ethics is a potent legitimation practice in the case of nanoethics. This is an implicitly performative ethics that elides moral uncertainty, which can legitimate nanotechnologies that have a surfeit of explicit unknowns. Right side-up ethics can project moral certainty from other times and spaces—the mythologized "historically independent Archimedean point"–to protect nanotechnologies from political backlash in the extra-technical governance of uncertainty (cf. 2009, 246). Epistemic (and ontological) underdetermination is (also) *axiological underdetermination* for the nanotechnologies.

"Implicit ethics" needs to be made explicit to describe legitimation practices. The key normativity to investigate is risk, and by implication, safety, in this thesis. Legitimation is successful to the degree that normative issues are settled; empirical ethics is therefore a revealing method for scholars interested in the relationship between normativity and legitimation.

ENTERING THE FIELD OF MISTRA ENVIRONMENTAL NANOSAFETY

As a research project, this thesis has been institutionally situated and financially bolstered by the research program Mistra Environmental Nanosafety, Phase II (2019-2023). The program joins the various fields of nanosafety together with researchers at Danish and Swedish universities into six work packages. Hence, the research presented here is, in fact, a contribution to work package 4: "proactive risk assessment, regulation and creation of stakeholder learning alliances".[21] The program also includes industrial sponsors, like TetraPak, that are interested in applying the scientific findings for industry and in raising awareness surrounding nanotechnologies and the environment for a wider public.[22]

The thesis represents a partial result in a reflexive relationship between studying and engaging with nanosafety research from within this interdisciplinary field. However, the thesis engages with the field without presenting (for instance) ethnographic fieldwork–a possibility for later studies. Paper III, presented below, relies upon insights from researchers within the program, which has been discussed at a program meeting in an earlier form. Access to veteran nanosafety researchers, in both their knowledge base and critical perspectives, has been instrumental to setting the stage of nanosafety.

5) COMPLETED STUDIES

Three complete studies are now reviewed, in thematic order. Paper I refers to a review essay of Habermas' (1975) monograph *Legitimation Crisis,* published as "Legitimation crisis in contemporary technoscientific capitalism". Paper II is the discussion paper titled "Looking beyond the 'horizon' of RRI: moving from discomforts to commitments as early career researchers". Paper III is an empirical article exposing "Implicit values in the recent carbon nanotube debate".

PAPER I

Crisis is a recurring concern for political economy. At the contemporary cul-de-sac of "the generalized concept of crisis", political economist Nancy Fraser invokes a reading of Jürgen Habermas, which updates the 1970s-era welfare state exposé *Legitimation Crisis.* In it, she reimagines the "crisis complex", itself a structuralist typology, from rudimentary "displacement" to advanced "metastasization" in a financialized capitalism anchored by the

[21] See the program webpage for more details: https://www.mistraenvironmentalnanosafety.org/work-package-4
[22] This is illustrated in an ongoing series of webinars that began during the pandemic. Gaps between nanotechnology developers, nanosafety research, and communication with the public was foregrounded at the most recent webinar. See: https://www.lu.se/evenemang/creating-trust-nanotechnology-tetra-pak-and-nanosafe4all-webinar

neoliberal state, post-2008 (see Davies 2021). Crisis is complicated. Crisis, if Fraser is correct, is constantly changing form.

Research and innovation is one such location for the reimagined crisis complex. The logic of society-aligning research and innovation policy post-2008 is expressed at length by Máire Geoghegan-Quinn, then European Commissioner for Research, Innovation and Science. At a 2012 conference, she declares,

> [t]he dialogue between science and the rest of society has never been more important. As the Europe 2020 Strategy makes clear, to overcome the current economic crisis we need to create a smarter, greener economy, where our prosperity will come from research and innovation. Science is the basis for a better future and the bedrock of a knowledge-based society and a healthy economy. After ten years of action at EU level to develop and promote the role of science in society, at least one thing is very clear: we can only find the right answers to the challenges we face by involving as many stakeholders as possible in the research and innovation process. Research and innovation must respond to the needs and ambitions of society, reflect its values, and be responsible […] (2012, 1).

The agenda is clear: research and innovation are now a problem for the state. Paper I seeks to reflect on this very settlement—two generations after Habermas' landmark *Legitimation Crisis* (1975) and one generation after Beck's *Risk Society* (1992). Building on recent scholarship in the political economy of research and innovation (Birch 2020a), attached to a reengagement with Lyotard's original proposed understanding of technoscientific capitalism (1984, 45–46), is this crux that research and innovation is "the bedrock of a knowledge-based society and a healthy economy".[23] Research and innovation matter to STS scholars, that much is plain; however, political economists should additionally take note.

[23] The political economy of research and innovation (PERI) approach is loosely defined. Similar terms are the political economy of technoscience (Birch 2013), political economy of science (Tyfield 2017) or Marxist studies (Moore 2020) of science and technology, viz.

Reading in between the lines of Geoghegan-Quinn's speech, the vision of the preferred contemporary European state is a post-neoliberal, "knowledge-based" state. Beck and his company in the English-language introduction (Lash and Wynne 1992) notably renounce Habermas' outlook on the political economy as no longer prescient. This is the "generalized notion of crisis" critique that still stings political economy and structuralist analysis (Beck 1992, 189). Today, nonetheless, in the slow, post-2008 dissolution of the neoliberal state, Beck's retort (1992, 187–89) against the Habermassian crisis complex—based on his notion of individualization and weakening influence of the state on society–seems misplaced. The state is back in a new managing role.

The *industrial cum risk society* reveals another layer as a *research and innovation society*. For Geoghegan-Quinn, "prosperity will come from research and innovation," and that prosperity must be legitimate, in four axiomatic ways: "(1) needs and (2) ambitions of society", to (3) "reflect its values", and (4) "be responsible." Responsible research and innovation may be other things, but it is pre-positioned as *de rigueur legitimation practice*.

PAPER II

Placed at the end of the long decade of Responsible Research and Innovation in Europe, Paper II reviews and reflects on legitimation crises in the research and innovation policies of RI and RRI. We respond to the long-promised revolution of RRI—that very opening up (Stirling 2008) and aligning of science (viz. research and innovation) to society–emblematically proclaimed by policy-makers like Geoghegan-Quinn. Essentially, there is an aura of disillusionment between scholars and policy-makers in the dearth of evidence for a responsibility revolution in the research and innovation system.

The problematic revisits tensions in between perspectives of revolution or evolution in these often zealous agendas. A lingering concern for the (STS inspired) *part* policy-making, *part* intellectual framework pipeline is captured through Zwart et al.'s (2014) refrain: "old wine in new bottles". Five discomforts (Chadwick 2021) are identified, in (1) "the hype", (2) "the

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Marxist STS (cf. Hamlin 2007). A specialization has been proposed under a cultural political economy of research and innovation (Tyfield 2012), that presents a possible agenda for a later dissertation.

public(s), (3) “the bubble”, (4) “the politics”, and (5) “the message”. Subsequently, there is a transition from lines of critique to lines of commitment, from the authors to the wider RRI and society-aligning research and innovation policy communities. In it, we explicitly commit: (1) “to challenge our assumptions”, (2) “to think about the mechanics of change”, (3) “to expand our horizons”, (4) “to foster cooperation and care”, and finally (5) ”to keep calm and carry on”.

This ‘manifesto’, which can be interpreted through pragmatism (see Cohen and Gianni 2023), has thereafter been commented upon in the initial *Journal of Responsible Innovation* by Coenen (2022), de Saille (2022), and Van den Hoven (2022).

PAPER III

Carbon nanotubes are a signal achievement of early efforts in developing nanotechnologies and commonly manufactured in society (Mody 2010). The societal and ethical challenges for nanotechnology writ large have been the taproot of society-aligning research and innovation policies, exemplified above (post-2008) with RRI (Shelley-Egan and Bowman 2018). In Paper III, we connect these two dots and pose a question—albeit tacitly. How do scientists see responsibility vis-a-vis carbon nanotubes? Put differently, do they believe that they can be made responsible?

The paper explores this reflexivity and anticipation in practice through the quiet debate that emerged over the course of 2019 and 2020 on regulating carbon nanotubes. At the end of 2019, the Swedish NGO ChemSec announced the placing of carbon nanotubes onto its Substitute-It-Now (SIN) list, which they claim is followed by the chemicals industry and adjacent companies (Hansen and Lennquist 2020).[24] The SIN list is moreover designed to evaluate chemical substances with the exact criteria of the European chemicals legislation REACH in the Substances of Very High Concern candidate list. The intuitive implications are two-fold. One, economic actors will voluntarily change their behavior to reduce or eliminate their usage of carbon nanotubes across their product life cycles. Two, carbon nanotubes

[24] ChemSec is a hybrid form of an NGO with partial government funding, based in Gothenburg, Sweden. The NGO offers other services to clients, like the chemicals industry, beyond just SIN. The overriding aim is to bolster “the change to safer chemicals.” https://chemsec.org/about-us/

will soon (someday) be regulated under REACH towards minimization. Either way, the era of unfettered carbon nanotube development is over and perhaps for other nanotechnologies as well.

Nanosafety researchers do not, all in all, agree with ChemSec's assessment. This quickly turned into a series of comments for and against limitation in the journal *Nature Nanotechnology* (Fadeel and Kostarelos 2020; Hansen and Lennquist 2020b; Heller et al. 2020; "The Risks of Nanomaterial Risk Assessment" 2020). Realizing that this allegedly technical discourse was itself disclosing a conversation on ethics and values (Swierstra and Rip 2007), we deployed a mixed, multifaceted methodology. First, suitable articles were culled from a Scopus search to identify pre-existing interest in the normative concerns of carbon nanotubes. Second, a final sample was analyzed through content analysis to deconstruct their arguments on substitution. Third, the tool of argument mapping (see Sharkey and Gillam 2010) was applied from the content analysis to produce multiple mind-maps, or visual brainstorming figures. Fourth, the argument maps were spliced together with value maps that associated underlying end values to each argument.

Two camps, or broad positions, were identified in the results. The yes/substitute camp contains three arguments: the hazard argument (carbon nanotubes are hazardous according to REACH), the asbestos argument (carbon nanotubes are comparable to asbestos), and the regulatory feasibility argument (regulating carbon nanotubes as one nanomaterial/chemical substance is most feasible).

The no/business-as-usual camp consists of six arguments. One, the case-by-case argument says that carbon nanotubes are too disparate to be regulated in the aggregate. Two, the science-based regulation argument is that regulation should be predicated on (and only on) scientific knowledge. Three, the precautionary argument asserts that the carbon nanotubes industry follows a precautionary mindset and does not require further regulation. Four, the lack of standardization argument finds that differing approaches to standardization of the safety research makes the resulting studies summarily inconclusive. Five, the safe-by-design argument counters that carbon nanotubes should instead be made safe by modifying their hazard profile and likely exposure conditions. Six, the progress argument warns that emerging technologies like carbon nanotubes, symbols of necessary progress, will struggle to promote their safe evolution, as a product of the endangered investment.

Three separate end values motivate the debate, (1) environmental protection and human safety, (2) good science and (3) technological progress. Both camps propose their positions, intermittently, as guarantors of safety with carbon nanotubes as ambivalent “risk objects” and “objects at risk” (Boholm and Corvellec 2011, 5–6). Good science is promoted by the no camp as the source point of the necessary rigor to inform regulatory decision-making. Technological progress—here in the belief that carbon nanotubes, can, should and will be made safe–divides the camp across the schism between (unbridled) progress and (bridled) precaution (see Munthe 2020; Hansson 2020).

Abstract, intrinsic values are one thing. A seminal implication to value-laden debates on regulating emerging technologies, bolstered by this case on carbon nanotubes, is that value perceptions drive decisions—explicit actions–to safeguard certain values over others. This is the crucible of Beck’s earlier “implicit ethics”. What is more, two paramount value endpoints for the risk society, safety, and techno-economic progress, enter the discussion.[25] Safety and progress serve to create a legitimating sheen, in the dismal sense that, “[…] there was and remains no alternative. The necessity, the non-decidability of technological ‘progress’ becomes the bolt securing the process to its democratic (non-)legitimation” (Beck 1992, 187). Put into Beck’s framing, the two camps reveal themselves as a precautionary safety-then-progress (no camp) and an investment-oriented safety-through-progress (yes camp.)

[25] Good science can be related to Beck as well. In chapter 7 of *Risk Society* (1992, 155–81), Beck develops a detailed critique of science in the risk society from science as an Enlightenment project to the 20th century response by the Frankfurt school (see e.g. Horkheimer and Adorno 2002). Scientization is the response to risks, which is increasingly insufficient, with declining legitimation potential. His focus is on fragmentation at the institutional level and in the knowledge production of science. A unifying, monolithic belief in science is not developed in relationship to safety and techno-economic progress. Instead, techno-economic progress (see chapter 8) is the overarching belief system that legitimates continued risk overproduction (1992, 183–235). For society, good science is not a resilient end value, but it does elucidate the value topography separating the institution of science from society writ large. Good science does not intend to be responsible research and innovation (see van Hove and Wickson 2017).

Failure or not, progress is the *sub-terrain of legitimation*, visible in the conflictual puttering of otherwise quotidian legitimation practice. It is little surprise that the regulatory debate of carbon nanotubes *problematizes safety in lieu of progress*. There is no counter-progress in this subterranean sub-politics. The rhetoric of progress does not lend itself to alternatives, in comparable fashion to the ill-fated supporters of would-be irresponsible research and innovation (Flink and Kaldewey 2018, 20). Carbon nanotubes do not represent a failure of RRI because there is no proposed alternative techno-economic paradigm—simply read again from the remarks of Máire Geoghegan-Quinn at the European Commission. Rather, the failure is found in the evidenced lack of an alternative institutionalization of (precautionary) safety-then-progress (cf. Saldívar-Tanaka and Hansen 2021).

CONTRIBUTIONS

Put together, these studies generate three novel contributions. First, Paper I evaluates the political economy of crisis in terms of legitimation in the new economy of science, technology, and innovation. In this way, crisis is connected to the imbroglio of "technoscientific capitalism." This is a contribution to the new subfield in the political economy of research and innovation. Second, Paper II adds to the current reflective moment of RRI from the vantage point of 'Early Career Researchers'. In focusing on a degree of ambivalence and naivety within the RRI community, the outcome is an argument towards pragmatic approaches to aligning research and innovation with society. This is a contribution to the interdisciplinary nexus of RRI and critical policy studies. Third, Paper III details the reflexive and anticipatory role enacted by nanosafety researchers through the recent controversy surrounding the specific nanomaterial carbon nanotubes. Implicit values are revealed to understand the mobilization of two opposing camps of otherwise similar researchers in safeguarding certain values over others. This is a contribution to the applied ethics of technology.

6) FURTHER STUDIES

> In the process, all the conditions become, first, *structurable*, and second, *dependent on legitimation*. […] But then the central issue becomes, not only *what* is investigated, but also *how* it is investigated, that is, with what approach, scope of thought, end points and so on

> with respect to the increase or avoidance of industrialization risks.
>
> Thus there are fundamentally *two options* confronting each other in dealing with civilizational risks: removing causes in primary industrialization, or the secondary industrialization of consequences and symptoms, which tends to expand markets. To this point, the *second* route has been taken almost everywhere (Beck 1992, 175) [original emphasis].

Two further studies are proposed to complete the doctoral dissertation. The earlier frontlines from Section 3, namely, (i) the regulatory transition from chemical substances to nanomaterials, (ii) the value-laden arc from reflexive scientization to (nano)safety, and (iii) enabling and legitimating nanotechnology in society, are scheduled points of departure. To investigate this “secondary industrialization of consequences and symptoms”, the work of ChemSec is the first point of departure. Moreover, attempts at “removing causes in primary industrialization” will be addressed by investigating the nanosafety cluster in Lund, Sweden.

GOTHENBURG STUDY: SECONDARY INDUSTRIALIZATION

ChemSec is established as an organization of concern throughout the course of Paper III.[26] On the one hand, their institutional position suggests a certain filling of the risk society’s “institutional void” in covering the multi- and transnational distribution of risk and corporate structure, beyond a usual suspect like the European Chemicals Agency or the European Environment Agency (Hajer 2003). On the other hand, they are situated at the confluence of regulating chemical substances and nanomaterials: first in reviewing carbon nanotubes and, more recently, graphene (Mumberg et al. 2023). ChemSec purports to anticipate future regulations and hence prepare its clients against undesirable future scenarios.

Additional insights from the sociology of expectations (e.g. Borup et al. 2006; Brown and Michael 2003; van Lente 2012) and finance (e.g. Beckert 2016;

[26] The organization has published a review of the crisis in East Palestine, US, that began in February 2023. See: https://chemsec.org/one-thing-we-can-learn-from-the-ohio-chemical-disaster/

2020) are postulated as an approach to articulate ChemSec's work as an anticipatory practice towards risk mitigation and future financial stability. Yet, the organization's modus operandi is to investigate substances and nanomaterials that are already produced and of societal relevance—hence the expanding market of "consequences and symptoms." These anticipatory outcomes and its relational position to their clients will be questioned through a combined approach of interviews, document, and discourse analysis.[27]

LUND STUDY: PRIMARY INDUSTRIALIZATION

Beck's exhortation to "removing causes" is expressed today in concepts like co-creation (Robinson, Simone, and Mazzonetto 2020; Voorberg, Bekkers, and Tummers 2015), co-design (von Busch and Palmås 2023) and value-sensitive design (Garst et al. 2022). The crux is to design away the bad (toxins) while also aiming for that elusive societal alignment, with Geoghegan-Quinn's earlier refrain to "as many stakeholders as possible". Safe-by-design (Kelty 2009; Ishmaev et al. 2021) and safe-and-sustainable-by-design are instead concepts primarily oriented to rendering design processes in the eponymous manner, notably with engineered nanomaterials (Brennan and Valsami-Jones 2021; Gulumian and Cassee 2021).

The practical implementation of these concepts are underway at various sites across Lund, in particular at the research center NanoLund and multi-stakeholder platform NanoSafe4All.[28] A central question to explore is how, who are making, and to what extent are engineered nanomaterials presented to be made safe and sustainable, including circularity (see Hansen et al. 2022)? How, where, and when do value conflicts in these areas manifest (e.g. Bouchaut et al. 2021)? This case study, an amalgam of interviews, document analysis and optimistically fieldwork participant-observation, might extend into the Swedish national platform for nanosafety, SweNanoSafe.[29]

[27] ChemSec maintains an aggressive public or client relations campaign, presumably in part to promote its mission. One can follow their email outreach or watch their humorous attempts to anthropomorphize chemicals on their website. https://www.youtube.com/watch?v=jZqrrgDIdQc
[28] For more information on NanoLund, see: https://www.nano.lu.se/. NanoSafe4All is an upstart initiative that works partially within the Mistra Environmental Nanosafety Program Phase II, with an emphasis on Lund-based collaborations beyond academia. This is an emerging cluster that the author is placed to directly observe.
[29] SweNanoSafe has established interest in the principles of safe-by-design and circular economy (SweNanoSafe 2021; 2022). SweNanoSafe is also related to the Mistra Program,

7) CONCLUDING NOTE

Nanosafety, amongst other things, is about the pursuit of safer engineered nanomaterials. Why emphasize the pursuit and not speak of outcomes? This is not only because of Ulrich Beck's edict–*statements on risk are the moral statements of scientized society*–in the necessarily public morality of nanosafety. Ethics and morality underscore the sub-political response to risk overflows, that is, the constant challenge for technical containment in moral domains. The pursuit of nanosafety is also dogged by its own technical limitation, in the *partial project of reflexive scientization*. Nanosafety is the quietly shouting literature of "[d]espite significant advances in analytical methods, it is still not possible to measure the concentrations of ENM [engineered nanomaterials] in natural systems" (Sun et al. 2016, 4701).

Yet this is an expensive pursuit. Nanotechnology development across the globe has long been earmarked, both privately and publicly, in the many billions of US dollars (Miller and Wickson 2015, 485–86). This is to say nothing about the synchronous investments towards multi-platform technological convergence. Nano(eco)toxicology researchers, as one area of nanosafety, and itself a diminutive piece in the nanotechnology puzzle, expect that "[…] toxicity testing on just the nanomaterials currently commercially available may take decades to complete and require the investment of over US$1 billion" (2015, 499). Miller and Wickson, in their foundational critique of the nanomaterial risk assessment paradigm, underline that this was in 2009. Nanotechnology will be a mature economic industry by the time that nano(eco)toxicologists can feel safe to bookend their textbooks. Nanotechnology will also be, if promises are kept, no small part of Geoghegan-Quinn's definition of progress: "[…] a better future and the bedrock of a knowledge-based society and a healthy economy". As long as nanotechnology can promise progress, *the subterrain of legitimation*, 1 billion dollars for nano(eco)toxicology is a small price to pay.

akin to a larger and mature venture like NanoSafe4All. It is based out of Karolinska Institutet in Stockholm, Sweden.

8) REFERENCES

Ahlborg, Helene, Ilse Ruiz-Mercado, Sverker Molander, and Omar Masera. 2019. "Bringing Technology into Social-Ecological Systems Research—Motivations for a Socio-Technical-Ecological Systems Approach." *Sustainability* 11 (7): 2009. https://doi.org/10/ghhn5z.

Allhoff, Fritz. 2009. "On the Autonomy and Justification of Nanoethics." In *Nanotechnology & Society*, edited by Fritz Allhoff and Patrick Lin, 3–38. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-1-4020-6209-4_1.

Alp-Erbay, Esen. 2022. "Nanomaterials Utilized in Food Packaging: State-of-the-Art." *Food Engineering Reviews*, June. https://doi.org/10.1007/s12393-022-09318-y.

Altmann, Jürgen. 2004. "Military Uses of Nanotechnology: Perspectives and Concerns." *Security Dialogue* 35 (1): 61–79. https://doi.org/10/bcrgcb.

Åm, Heidrun. 2019. "Limits of Decentered Governance in Science-Society Policies." *Journal of Responsible Innovation* 6 (2): 163–78. https://doi.org/10/gj7sjq.

Anderson, Ben. 2007. "Hope for Nanotechnology: Anticipatory Knowledge and the Governance of Affect." *Area* 39 (2): 156–65. https://doi.org/10/dw7nc8.

Arnaldi, Simone, Andrea Lorenzet, and Federica Russo. 2009. *Technoscience in Progress: Managing the Uncertainty of Nanotechnology*. Amsterdam: IOS Press. http://site.ebrary.com/id/10331648.

Arvidsson, Rickard. 2015. "Life Cycle Assessment and Risk Assessment of Manufactured Nanomaterials." In *Nanoengineering*, 225–56. Elsevier. https://doi.org/10.1016/B978-0-444-62747-6.00008-7.

———. 2018. "Risk Assessments Show Engineered Nanomaterials To Be of Low Environmental Concern." *Environmental Science & Technology* 52 (5): 2436–37. https://doi.org/10/ggjtmz.

Arvidsson, Rickard, Anders Baun, Anna Furberg, Steffen Foss Hansen, and Sverker Molander. 2018. "Proxy Measures for Simplified Environmental Assessment of Manufactured Nanomaterials." *Environmental Science & Technology* 52 (23): 13670–80. https://doi.org/10/ghphvn.

Arvidsson, Rickard, Sverker Molander, Björn A. Sandén, and Martin Hassellöv. 2011. "Challenges in Exposure Modeling of Nanoparticles in Aquatic Environments." *Human and Ecological Risk Assessment: An International Journal* 17 (1): 245–62. https://doi.org/10/cg2nmr.

Arvidsson, Rickard, Anne-Marie Tillman, Björn A. Sandén, Matty Janssen, Anders Nordelöf, Duncan Kushnir, and Sverker Molander. 2018. "Environmental Assessment of Emerging Technologies: Recommendations for Prospective LCA." *Journal of Industrial Ecology* 22 (6): 1286–94. https://doi.org/10/gfjcv9.

Barben, Daniel, Erik Fisher, Cynthia Selin, and David H Guston. 2008. "Anticipatory Governance of Nanotechnology: Foresight, Engagement, and Integration." In *The Handbook of Science and Technology Studies*, edited by Edward J. Hackett, Olga Amsterdamska, Michael E. Lynch, and Judy Wajcman, 3rd ed., 23. Cambridge, Mass: MIT Press.

Beck, Ulrich. 1992. *Risk Society: Towards a New Modernity*. Theory, Culture & Society. London ; Newbury Park, Calif: Sage Publications.
Beckert, Jens. 2016. *Imagined Futures: Fictional Expectations and Capitalist Dynamics*. Cambridge, Massachusetts: Harvard University Press.
———. 2020. “The Exhausted Futures of Neoliberalism: From Promissory Legitimacy to Social Anomy.” *Journal of Cultural Economy* 13 (3): 318–30. https://doi.org/10/gjrgsg.
Bensaude-Vincent, Bernadette. 2021. “From Nano Backlash to Public Indifference: Some Reflections on French Public Dialogues on Nanotechnology.” *NanoEthics* 15 (2): 191–201. https://doi.org/10/gmw48p.
Bensaude-Vincent, Bernadette, and Arne Hessenbruch. 2004. “Materials Science: A Field about to Explode?” *Nature Materials* 3 (6): 345–47. https://doi.org/10/dzf3sp.
Bijker, Wiebe E., Thomas P. Hughes, and Trevor J. Pinch, eds. 1987. *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology*. 12. pr. Cambridge, Mass.: MIT Press.
Birch, Kean. 2013. “The Political Economy of Technoscience: An Emerging Research Agenda.” *Spontaneous Generations: A Journal for the History and Philosophy of Science* 7 (1): 49–61. https://doi.org/10/gg7mth.
———, ed. 2020a. *Assetization: Turning Things into Assets in Technoscientific Capitalism*. Inside Technology. Cambridge, Massachusetts: The MIT Press.
———. 2020b. “Technoscience Rent: Toward a Theory of Rentiership for Technoscientific Capitalism.” *Science, Technology, & Human Values* 45 (1): 3–33. https://doi.org/10/gft8ns.
Boholm, Åsa, and Hervé Corvellec. 2011. “A Relational Theory of Risk.” *Journal of Risk Research* 14 (2): 175–90. https://doi.org/10.1080/13669877.2010.515313.
Boholm, Max, and Rickard Arvidsson. 2016. “A Definition Framework for the Terms Nanomaterial and Nanoparticle.” *NanoEthics* 10 (1): 25–40. https://doi.org/10/f3n954.
Boholm, Max, Niklas Möller, and Sven Ove Hansson. 2016. “The Concepts of Risk, Safety, and Security: Applications in Everyday Language.” *Risk Analysis* 36 (2): 320–38. https://doi.org/10/f3mxss.
Borup, Mads, Nik Brown, Kornelia Konrad, and Harro Van Lente. 2006. “The Sociology of Expectations in Science and Technology.” *Technology Analysis & Strategic Management* 18 (3–4): 285–98. https://doi.org/10/cwqzcz.
Bouchaut, Britte, Lotte Asveld, Ulf Hanefeld, and Alexander Vlierboom. 2021. “Value Conflicts in Designing for Safety: Distinguishing Applications of Safe-by-Design and the Inherent Safety Principles.” *International Journal of Environmental Research and Public Health* 18 (4): 1963. https://doi.org/10/gmw5b6.
Bowman, Diana M., Graeme A. Hodge, and Peter Binks. 2007. “Are We Really the Prey? Nanotechnology as Science and Science Fiction.” *Bulletin of Science, Technology & Society* 27 (6): 435–45. https://doi.org/10/dqm58s.
Braun, Kathrin, and Sabine Könninger. 2018. “From Experiments to Ecosystems? Reviewing Public Participation, Scientific Governance and the Systemic Turn.” *Public Understanding of Science* 27 (6): 674–89. https://doi.org/10/gksj69.

Brennan, Maurice Edward, and Eugenia Valsami-Jones. 2021. “Safe by Design for Nanomaterials—Late Lessons from Early Warnings for Sustainable Innovation.” *NanoEthics* 15 (2): 99–103. https://doi.org/10/gm3p4z.

Brown, Nik, and Mike Michael. 2003. “A Sociology of Expectations: Retrospecting Prospects and Prospecting Retrospects.” *Technology Analysis & Strategic Management* 15 (1): 3–18. https://doi.org/10/djthh2.

Busch, Otto von, and Karl Palmås. 2023. *The Corruption of Co-Design: Political and Social Conflicts in Participatory Design Thinking*. New York: Routledge.

Cefic. 2023. “The European Chemical Industry Facts and Figures 2023: A Vital Part of Europe’s Future.” The European Chemical Industry Council, AISBL. https://cefic.org/a-pillar-of-the-european-economy/facts-and-figures-of-the-european-chemical-industry/.

Chadwick, Rachelle. 2021. “On the Politics of Discomfort.” *Feminist Theory* 22 (4): 556–74. https://doi.org/10.1177/1464700120987379.

Choi, Hyungsub, and Cyrus C.M. Mody. 2009. “The Long History of Molecular Electronics: Microelectronics Origins of Nanotechnology.” *Social Studies of Science* 39 (1): 11–50. https://doi.org/10/b6wvxr.

Clausen, Lauge Peter Westergaard, and Steffen Foss Hansen. 2018. “The Ten Decrees of Nanomaterials Regulations.” *Nature Nanotechnology* 13 (9): 766–68. https://doi.org/10/ggjtm2.

Coenen, Christopher. 2022. “Against Bureaucrapitalism: A Response to Shanley and Colleagues.” *Journal of Responsible Innovation*, March, 1–4. https://doi.org/10.1080/23299460.2022.2055993.

Cohen, Joshua B., and Robert Gianni. 2023. “Democratic Experimentation with Responsibility: A Pragmatist Approach to Responsible Research and Innovation.” In *Putting Responsible Research and Innovation into Practice*, edited by Vincent Blok, 40:57–77. Library of Ethics and Applied Philosophy. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-14710-4_4.

Collingridge, David. 1982. *The Social Control of Technology*. Repr. London: Pinter.

Colvin, Vicki L. 2003. “The Potential Environmental Impact of Engineered Nanomaterials.” *Nature Biotechnology* 21 (10): 1166–70. https://doi.org/10/b4srhp.

Contera, Sonia, Jorge Bernardino de la Serna, and Teresa D. Tetley. 2020. “Biotechnology, Nanotechnology and Medicine.” *Emerging Topics in Life Sciences* 4 (6): 551–54. https://doi.org/10/gn7hg7.

Cooke, Bill, and Uma Kothari, eds. 2001. *Participation: The New Tyranny?* London; New York: Zed Books.

Coria, Jessica, Erik Kristiansson, and Mikael Gustavsson. 2022. “Economic Interests Cloud Hazard Reductions in the European Regulation of Substances of Very High Concern.” *Nature Communications* 13 (1): 6686. https://doi.org/10.1038/s41467-022-34492-2.

Coyle, Shirley, Yanzhe Wu, King-Tong Lau, Danilo De Rossi, Gordon Wallace, and Dermot Diamond. 2007. “Smart Nanotextiles: A Review of Materials and Applications.” *MRS Bulletin* 32 (5): 434–42. https://doi.org/10.1557/mrs2007.67.

Crichton, Michael. 2003. *Prey*. New York: Harper Collins Publishers.

Davies, William. 2021. “The Revenge of Sovereignty on Government? The Release of Neoliberal Politics from Economics Post-2008.” *Theory, Culture & Society*, April, 026327642199945. https://doi.org/10/gjpmps.
Dhawan, Alok, Vyom Sharma, and Devendra Parmar. 2009. “Nanomaterials: A Challenge for Toxicologists.” *Nanotoxicology* 3 (1): 1–9. https://doi.org/10/c7jx2t.
Drexler, Eric. 1986. *Engines of Creation: The Coming Era of Nanotechnology*. Anchor.
Drexler, K. Eric. 2004. “Nanotechnology: From Feynman to Funding.” *Bulletin of Science, Technology & Society* 24 (1): 21–27. https://doi.org/10.1177/0270467604263113.
Dunphy Guzmán, Katherine A., Margaret R. Taylor, and Jillian F. Banfield. 2006. “Environmental Risks of Nanotechnology: National Nanotechnology Initiative Funding, 2000–2004.” *Environmental Science & Technology* 40 (5): 1401–7. https://doi.org/10/bbttxd.
Eisler, Matthew N. 2013. “‘The Ennobling Unity of Science and Technology’: Materials Sciences and Engineering, the Department of Energy, and the Nanotechnology Enigma.” *Minerva* 51 (2): 225–51. https://doi.org/10/f4zjjz.
Erhardt, David. 2003. “Not-so-New Technology.” *Nature Materials* 2 (8): 509–10. https://doi.org/10/cmw4vd.
ETC Group. 2003. “The Big Down: Atomtech: Technologies Converging at the Nano-Scale.” Winnipeg.
European Chemicals Agency. 2022. *Study of the EU Market for Nanomaterials, Including Substances, Uses, Volumes and Key Operators*. LU: Publications Office. https://data.europa.eu/doi/10.2823/680824.
European Commission. 2007. *Taking European Knowledge Society Seriously: Report of the Expert Group on Science and Governance to the Science, Economy and Society Directorate, Directorate-General for Research, European Commission*. Luxembourg: Office for Official Publ. of the Europ. Communities.
———. 2012. “Responsible Research and Innovation: Europe’s Ability to Respond to Societal Challenges.” European Commission.
———. 2020. *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Chemicals Strategy for Sustainability Towards a Toxic-Free Environment*. https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:667:FIN.
European Environment Agency. 2001. *Late Lessons from Early Warnings: The Precautionary Principle, 1896-2000*. Edited by Poul Harremoës, David Gee, Malcolm MacGarvin, Andy Stirling, Jane Keys, Brian Wynne, and Sofia Guedes Vaz. Environmental Issue Report, no. 22. Copenhagen, Denmark: European Environment Agency.
———, ed. 2013. *Late Lessons from Early Warnings: Science, Precaution, Innovation*. EEA Report, 2013:1. Luxembourg: Publications Office.
Fadeel, Bengt, and Kostas Kostarelos. 2020. “Grouping All Carbon Nanotubes into a Single Substance Category Is Scientifically Unjustified.” *Nature Nanotechnology* 15 (3): 164–164. https://doi.org/10/ggntt6.

Ferrari, Arianna. 2010. “Developments in the Debate on Nanoethics: Traditional Approaches and the Need for New Kinds of Analysis.” *NanoEthics* 4 (1): 27–52. https://doi.org/10/dgz8qm.
Ferrari, Arianna, and Alfred Nordmann. 2010. “Beyond Conversation: Some Lessons for Nanoethics.” *NanoEthics* 4 (2): 171–81. https://doi.org/10/cbjfgt.
Feynman, Richard P. 1960. “There’s Plenty of Room at the Bottom.” *Engineering and Science* 23 (5): 22–36.
Fitzgerald, Scott T., and Beth A. Rubin. 2010. “RISK SOCIETY, MEDIA, AND POWER: THE CASE OF NANOTECHNOLOGY.” *Sociological Spectrum* 30 (4): 367–402. https://doi.org/10/fjcrk2.
Flink, Tim, and David Kaldewey. 2018. “The New Production of Legitimacy: STI Policy Discourses beyond the Contract Metaphor.” *Research Policy* 47 (1): 14–22. https://doi.org/10/gcsmtg.
Foss Hansen, Steffen, Britt H. Larsen, Stig I. Olsen, and Anders Baun. 2007. “Categorization Framework to Aid Hazard Identification of Nanomaterials.” *Nanotoxicology* 1 (3): 243–50. https://doi.org/10/dc6qtb.
Frahm, Nina, Tess Doezema, and Sebastian Pfotenhauer. 2021. “Fixing Technology with Society: The Coproduction of Democratic Deficits and Responsible Innovation at the OECD and the European Commission.” *Science, Technology, & Human Values*, March, 016224392199910. https://doi.org/10/gjhdtr.
Fraser, Nancy. 2015. “Legitimation Crisis? On the Political Contradictions of Financialized Capitalism.” *Critical Historical Studies* 2 (2): 157–89. https://doi.org/10/gg7mcv.
Fuenfschilling, Lea, Linda Paxling, and Eugenia Perez Vico. 2022. “Norm-Critical Innovation as a Way Forward for Responsible Innovation? Evidence from a Swedish Innovation Policy Program.” *Journal of Responsible Innovation* 9 (3): 371–97. https://doi.org/10.1080/23299460.2022.2112817.
Gallo, Jason. 2009. “The Discursive and Operational Foundations of the National Nanotechnology Initiative in the History of the National Science Foundation.” *Perspectives on Science* 17 (2): 174–211. https://doi.org/10/dxtmxx.
Garner, Kendra L., and Arturo A. Keller. 2014. “Emerging Patterns for Engineered Nanomaterials in the Environment: A Review of Fate and Toxicity Studies.” *Journal of Nanoparticle Research* 16 (8): 2503. https://doi.org/10/f589x9.
Garner, Kendra L., Sangwon Suh, and Arturo A. Keller. 2017. “Assessing the Risk of Engineered Nanomaterials in the Environment: Development and Application of the NanoFate Model.” *Environmental Science & Technology* 51 (10): 5541–51. https://doi.org/10/f98vk9.
Garner, Kendra L., Sangwon Suh, Hunter S. Lenihan, and Arturo A. Keller. 2015. “Species Sensitivity Distributions for Engineered Nanomaterials.” *Environmental Science & Technology* 49 (9): 5753–59. https://doi.org/10/f7cxc7.
Garst, Jilde, Vincent Blok, Léon Jansen, and Onno S. W. F. Omta. 2022. “From Value Sensitive Design to Values Absorption – Building an Instrument to Analyze Organizational Capabilities for Value-Sensitive Innovation.” *Journal of Responsible Innovation*, May, 1–28. https://doi.org/10.1080/23299460.2022.2069994.

Gelfert, Axel. 2012. “Nanotechnology as Ideology: Towards a Critical Theory of ‘Converging Technologies.’” *Science, Technology and Society* 17 (1): 143–64. https://doi.org/10/f4b23t.
Gigault, Julien, Hind El Hadri, Brian Nguyen, Bruno Grassl, Laura Rowenczyk, Nathalie Tufenkji, Siyuan Feng, and Mark Wiesner. 2021. “Nanoplastics Are Neither Microplastics nor Engineered Nanoparticles.” *Nature Nanotechnology* 16 (5): 501–7. https://doi.org/10.1038/s41565-021-00886-4.
Godin, Benoît. 2006. “The Linear Model of Innovation: The Historical Construction of an Analytical Framework.” *Science, Technology, & Human Values* 31 (6): 639–67. https://doi.org/10/bgdjz9.
Gordijn, Bert. 2005. “Nanoethics: From Utopian Dreams and Apocalyptic Nightmares towards a More Balanced View.” *Science and Engineering Ethics* 11 (4): 521–33. https://doi.org/10/c4hdhf.
Gottardo, Stefania, Agnieszka Mech, Jana Drbohlavová, Aleksandra Małyska, Søren Bøwadt, Juan Riego Sintes, and Hubert Rauscher. 2021. “Towards Safe and Sustainable Innovation in Nanotechnology: State-of-Play for Smart Nanomaterials.” *NanoImpact* 21 (January): 100297. https://doi.org/10/gh7r4t.
Grunwald, Armin. 2010. “From Speculative Nanoethics to Explorative Philosophy of Nanotechnology.” *NanoEthics* 4 (2): 91–101. https://doi.org/10/dqrcpc.
Gulumian, Mary, and Flemming R. Cassee. 2021. “Safe by Design (SbD) and Nanotechnology: A Much-Discussed Topic with a Prudence?” *Particle and Fibre Toxicology* 18 (1): 32, s12989-021-00423–0. https://doi.org/10/gmw487.
Habermas, Jürgen. 1975. *Legitimation Crisis*. Translated by Thomas A. McCarthy. Boston, Mass: Beacon Press.
Hajer, Maarten. 2003. “Policy without Polity? Policy Analysis and the Institutional Void.” *Policy Sciences* 36 (2): 175–95. https://doi.org/10.1023/A:1024834510939.
Hamlin, Christopher. 2007. “STS: Where the Marxist Critique of Capitalist Science Goes to Die?” *Science as Culture* 16 (4): 467–74. https://doi.org/10/bvtnw4.
Handy, Richard D., Frank von der Kammer, Jamie R. Lead, Martin Hassellöv, Richard Owen, and Mark Crane. 2008. “The Ecotoxicology and Chemistry of Manufactured Nanoparticles.” *Ecotoxicology* 17 (4): 287–314. https://doi.org/10/cdh2cz.
Hansen, Steffen Foss, Rickard Arvidsson, Maria Bille Nielsen, Oliver Foss Hessner Hansen, Lauge Peter Westergaard Clausen, Anders Baun, and Alessio Boldrin. 2022. “Nanotechnology Meets Circular Economy.” *Nature Nanotechnology* 17 (7): 682–85. https://doi.org/10.1038/s41565-022-01157-6.
Hansen, Steffen Foss, Oliver Foss Hessner Hansen, and Maria Bille Nielsen. 2020. “Advances and Challenges towards Consumerization of Nanomaterials.” *Nature Nanotechnology* 15 (12): 964–65. https://doi.org/10/ghnj4g.
Hansen, Steffen Foss, Laura Roverskov Heggelund, Pau Revilla Besora, Aiga Mackevica, Alessio Boldrin, and Anders Baun. 2016. “Nanoproducts – What Is Actually Available to European Consumers?” *Environmental Science: Nano* 3 (1): 169–80. https://doi.org/10/ghcmr7.
Hansen, Steffen Foss, Keld Alstrup Jensen, and Anders Baun. 2014. “NanoRiskCat: A Conceptual Tool for Categorization and Communication of Exposure

Potentials and Hazards of Nanomaterials in Consumer Products." *Journal of Nanoparticle Research* 16 (1): 2195. https://doi.org/10/ghphvm.
Hansen, Steffen Foss, and Anna Lennquist. 2020a. "Carbon Nanotubes Added to the SIN List as a Nanomaterial of Very High Concern." *Nature Nanotechnology* 15 (1): 3–4. https://doi.org/10/ggq4mw.
———. 2020b. "SIN List Criticism Based on Misunderstandings." *Nature Nanotechnology*, May. https://doi.org/10/ggzr35.
Hansson, Sven Ove. 2020. "How Extreme Is the Precautionary Principle?" *NanoEthics* 14 (3): 245–57. https://doi.org/10/ghmkg5.
Hauschild, Michael Z. 2005. "Assessing Environmental Impacts in a Life-Cycle Perspective." *Environmental Science & Technology* 39 (4): 81A-88A. https://doi.org/10/d698w8.
Heller, Daniel A., Prakrit V. Jena, Matteo Pasquali, Kostas Kostarelos, Lucia G. Delogu, Rachel E. Meidl, Slava V. Rotkin, et al. 2020. "Banning Carbon Nanotubes Would Be Scientifically Unjustified and Damaging to Innovation." *Nature Nanotechnology* 15 (3): 164–66. https://doi.org/10/ggntt5.
Horkheimer, Max, and Theodor W. Adorno. 2002. "The Concept of Enlightenment." In *Dialectic of Enlightenment: Philosophical Fragments*, edited by Gunzelin Schmid Noerr, translated by Edmund Jephcott, 1–35. Cultural Memory in the Present. Stanford, Calif: Stanford University Press.
Hove, Lilian van, and Fern Wickson. 2017. "Responsible Research Is Not Good Science: Divergences Inhibiting the Enactment of RRI in Nanosafety." *NanoEthics* 11 (3): 213–28. https://doi.org/10/gg2kr5.
Hoven, Jeroen van den. 2022. "Responsibility and Innovation." *Journal of Responsible Innovation*, March, 1–5. https://doi.org/10.1080/23299460.2022.2050570.
Ishmaev, Georgy, Pieter E. Vermaas, Dick Hoeneveld, and Pieter van Gelder. 2021. "Safe by Design Regulation for Academic Experimentation and Value Conflicts: An Exploration of Solution Directions." *International Journal of Environmental Research and Public Health* 18 (4): 1554. https://doi.org/10/gmw5b7.
Johnson, Ann. 2004. "The End of Pure Science: Science Policy from Bayh-Dole to the NNI." In *Discovering the Nanoscale*, edited by Davis Baird, Alfred Nordmann, and Joachim Schummer, 217–30. Amsterdam ; Washington, DC: IOS Press.
Johnson, Deborah G. 2007. "Ethics and Technology 'in the Making': An Essay on the Challenge of Nanoethics." *NanoEthics* 1 (1): 21–30. https://doi.org/10/dhp3q5.
Joy, Bill. 2000. "Why the Future Doesn't Need Us." *Wired*, April 1, 2000. https://www.wired.com/2000/04/joy-2/.
Juganson, Katre, Angela Ivask, Irina Blinova, Monika Mortimer, and Anne Kahru. 2015. "NanoE-Tox: New and in-Depth Database Concerning Ecotoxicity of Nanomaterials." *Beilstein Journal of Nanotechnology* 6 (August): 1788–1804. https://doi.org/10/ghphvj.
Kahru, Anne, and Henri-Charles Dubourguier. 2010. "From Ecotoxicology to Nanoecotoxicology." *Toxicology* 269 (2–3): 105–19. https://doi.org/10/bxgw3v.

Kaiser, Mario. 2006. “Drawing the Boundaries of Nanoscience — Rationalizing the Concerns?” *Journal of Law, Medicine & Ethics* 34 (4): 667–74. https://doi.org/10/fw77xz.
Kaiser, Mario, Monika Kurath, Sabine Maasen, and Christoph Rehmann-Sutter, eds. 2010. *Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime*. Vol. 27. Sociology of the Sciences Yearbook. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-90-481-2834-1.
Kaplan, Sarah, and Joanna Radin. 2011. “Bounding an Emerging Technology: Para-Scientific Media and the Drexler-Smalley Debate about Nanotechnology.” *Social Studies of Science* 41 (4): 457–85. https://doi.org/10/c25v35.
Kearnes, Matthew, Robin Grove-White, Phil Macnaghten, James Wilsdon, and Brian Wynne. 2006. “From Bio to Nano: Learning Lessons from the UK Agricultural Biotechnology Controversy.” *Science as Culture* 15 (4): 291–307. https://doi.org/10/cb48km.
Keller, Arturo A., and Anastasiya Lazareva. 2013. “Predicted Releases of Engineered Nanomaterials: From Global to Regional to Local.” *Environmental Science & Technology Letters* 1 (1): 65–70. https://doi.org/10/gf66c7.
———. 2014. “Predicted Releases of Engineered Nanomaterials: From Global to Regional to Local: Supporting Information.” *Environmental Science & Technology Letters* 1 (1). https://doi.org/10/gf66c7.
Kelpsiene, Egle, Oscar Torstensson, Mikael T. Ekvall, Lars-Anders Hansson, and Tommy Cedervall. 2020. “Long-Term Exposure to Nanoplastics Reduces Life-Time in Daphnia Magna.” *Scientific Reports* 10 (1): 5979. https://doi.org/10/ghkbg8.
Kelty, Christopher M. 2009. “Beyond Implications and Applications: The Story of ‘Safety by Design.’” *NanoEthics* 3 (2): 79–96. https://doi.org/10/fjnzvt.
Kermisch, Céline. 2012. “Do New Ethical Issues Arise at Each Stage of Nanotechnological Development?” *NanoEthics* 6 (1): 29–37. https://doi.org/10/bdmb2k.
Klika, Christoph. 2015. “Risk and the Precautionary Principle in the Implementation of REACH: The Inclusion of Substances of Very High Concern in the Candidate List.” *European Journal of Risk Regulation* 6 (1): 111–20. https://doi.org/10/ghr9bk.
Klöpffer, Walter, Curran, Mary Ann, Frankl, Paolo, Heijungs, Reinout, Köhler, Annette, and Olsen, Stig Irving. 2007. “Nanotechnology and Life Cycle Assessment. A Systems Approach to Nanotechnology and the Environment: Synthesis of Results Obtained at a Workshop Washington, DC 2–3 October 2006.” European Commission, DG Research, jointly with the Woodrow Wilson International Center for Scholars.
Kuhlmann, Stefan, and Arie Rip. 2018. “Next-Generation Innovation Policy and Grand Challenges.” *Science and Public Policy* 45 (4): 448–54. https://doi.org/10/gd4kqc.
Lash, Scott, and Brian Wynne. 1992. “Introduction.” In *Risk Society: Towards a New Modernity*, by Ulrich Beck. Theory, Culture & Society. London ; Newbury Park, Calif: Sage Publications.

Latour, Bruno. 2004. “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern.” *Critical Inquiry* 30 (2): 225–48. https://doi.org/10.1086/421123.
Lente, Harro van. 2012. “Navigating Foresight in a Sea of Expectations: Lessons from the Sociology of Expectations.” *Technology Analysis & Strategic Management* 24 (8): 769–82. https://doi.org/10/ggdtzn.
Lofstedt, Ragnar E. 2011. “Risk versus Hazard: How to Regulate in the 21st Century.” *European Journal of Risk Regulation* 2 (2): 149–68. https://doi.org/10/gkhpp9.
Lyotard, Jean-François. 1984. *The Postmodern Condition: A Report on Knowledge*. Theory and History of Literature, v. 10. Minneapolis: University of Minnesota Press.
Macq, Hadrien, Élise Tancoigne, and Bruno J. Strasser. 2020. “From Deliberation to Production: Public Participation in Science and Technology Policies of the European Commission (1998–2019).” *Minerva*, April. https://doi.org/10/ggwsq2.
Maynard, Andrew. 2011. “Don’t Define Nanomaterials.” *Nature* 475 (7354): 31–31. https://doi.org/10/bdjfpz.
Maynard, Andrew, Diana Bowman, and Graeme Hodge. 2011. “The Problem of Regulating Sophisticated Materials.” *Nature Materials* 10 (8): 554–57. https://doi.org/10.1038/nmat3085.
Mazzucato, Mariana. 2018. “Mission-Oriented Research & Innovation in the European Union: A Problem-Solving Approach to Fuel Innovation-Led Growth.” Luxembourg: Publications Office. https://data.europa.eu/doi/10.2777/36546.
Meesters, Johannes A. J., Albert A. Koelmans, Joris T. K. Quik, A. Jan Hendriks, and Dik van de Meent. 2014. “Multimedia Modeling of Engineered Nanoparticles with SimpleBox4nano: Model Definition and Evaluation.” *Environmental Science & Technology* 48 (10): 5726–36. https://doi.org/10/f545qt.
Meesters, Johannes AJ, Karin Veltman, A Jan Hendriks, and Dik van de Meent. 2013. “Environmental Exposure Assessment of Engineered Nanoparticles: Why REACH Needs Adjustment: Environmental ENPs and REACH.” *Integrated Environmental Assessment and Management* 9 (3): e15–26. https://doi.org/10/ggjtm3.
Mekel, Michele. 2006. “Nanotechnologies: Small Science, Big Potential and Bigger Issues.” *Development* 49 (4): 47–53. https://doi.org/10/br579r.
Merton, Robert K. 1974. “The Normative Structure of Science.” In *The Sociology of Science: Theoretical and Empirical Investigations*, 4th ed. Chicago: Univ. of Chicago Pr.
Miller, Georgia, and Fern Wickson. 2015. “Risk Analysis of Nanomaterials: Exposing Nanotechnology’s Naked Emperor.” *Review of Policy Research* 32 (4): 485–512. https://doi.org/10.1111/ropr.12129.
Mody, Cyrus C.M. 2010. “Institutions as Stepping-Stones: Rick Smalley and the Commercialization of Nanotubes.” Studies in Materials Innovation. Chemical Heritage Foundation.
Moore, Kelly. 2020. “Capitalisms, Generative Projects and the New STS.” *Science as Culture*, December, 1–16. https://doi.org/10/ghpc8k.

Mueller, Nicole C., and Bernd Nowack. 2008. “Exposure Modeling of Engineered Nanoparticles in the Environment.” *Environmental Science & Technology* 42 (12): 4447–53. https://doi.org/10/ctz5wf.
Mumberg, Tabea, Steffen Foss Hansen, Anders Baun, and Rickard Arvidsson. 2023. “Assessment of Graphene-Based Materials against the Substances of Very High Concern Criteria.” Scientific Report E2023:001. Division of Environmental Systems Analysis: Chalmers University of Technology, Department of Technology Management and Economics.
Munthe, Christian. 2020. “Precautionary Principle.” In *International Encyclopedia of Ethics*, 1–10. American Cancer Society. https://doi.org/10.1002/9781444367072.wbiee550.pub2.
Nature Nanotechnology, ed. 2019. “Nanoplastic Should Be Better Understood.” *Nature Nanotechnology* 14 (4): 299–299. https://doi.org/10/ggjtmj.
Nel, A. 2006. “Toxic Potential of Materials at the Nanolevel.” *Science* 311 (5761): 622–27. https://doi.org/10/fwrp92.
Nielsen, Maria Bille, Anders Baun, Aiga Mackevica, Amalie Thit, Inger Odnevall Wallinder, Julián Alberto Gallego, Lauge Peter Westergaard Clausen, et al. 2021. “Nanomaterials in the European Chemicals Legislation – Methodological Challenges for Registration and Environmental Safety Assessment.” *Environmental Science: Nano* 8 (3): 731–47. https://doi.org/10/gjn4qt.
Nordmann, Alfred. 2007. “If and Then: A Critique of Speculative NanoEthics.” *NanoEthics* 1 (1): 31–46. https://doi.org/10.1007/s11569-007-0007-6.
Oudheusden, Michiel van. 2014. “Where Are the Politics in Responsible Innovation? European Governance, Technology Assessments, and Beyond.” *Journal of Responsible Innovation* 1 (1): 67–86. https://doi.org/10/ggcm3c.
Owen, Richard, John Bessant, and Maggy Heintz, eds. 2013. *Responsible Innovation: Managing the Responsible Emergence of Science and Innovation in Society*. Chichester, UK: John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118551424.
Owen, Richard, Phil Macnaghten, and Jack Stilgoe. 2012. “Responsible Research and Innovation: From Science in Society to Science for Society, with Society.” *Science and Public Policy* 39 (6): 751–60. https://doi.org/10/f4jbzv.
Owen, Richard, René von Schomberg, and Phil Macnaghten. 2021. “An Unfinished Journey? Reflections on a Decade of Responsible Research and Innovation.” *Journal of Responsible Innovation*, July, 1–17. https://doi.org/10/gmc7qk.
Pellizzoni, Luigi. 2012. “Strong Will in a Messy World. Ethics and the Government of Technoscience.” *NanoEthics* 6 (3): 257–72. https://doi.org/10/gf658p.
Piccinno, Fabiano, Fadri Gottschalk, Stefan Seeger, and Bernd Nowack. 2012. “Industrial Production Quantities and Uses of Ten Engineered Nanomaterials in Europe and the World.” *Journal of Nanoparticle Research* 14 (9): 1109. https://doi.org/10.1007/s11051-012-1109-9.
Pidgeon, Nick, Barbara Herr Harthorn, Karl Bryant, and Tee Rogers-Hayden. 2009. “Deliberating the Risks of Nanotechnologies for Energy and Health Applications in the United States and United Kingdom.” *Nature Nanotechnology* 4 (2): 95–98. https://doi.org/10/b75bc5.
Randles, Sally, Elise Tancoigne, and Pierre-Benoît Joly. 2022. “Two Tribes or More? The Historical Emergence of Discourse Coalitions of Responsible Research

and Innovation (Rri) and Responsible Research and Innovation (RRI).” *Journal of Responsible Innovation*, June, 1–27. https://doi.org/10.1080/23299460.2022.2061306.
Rehmann-Sutter, Christoph, and Jackie Leach Scully. 2009. “Which Ethics for (of) the Nanotechnologies?” In *Governing Future Technologies*, edited by Mario Kaiser, Monika Kurath, Sabine Maasen, and Christoph Rehmann-Sutter, 27:233–52. Sociology of the Sciences Yearbook. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-90-481-2834-1_13.
Robinson, Douglas K. R., Angela Simone, and Marzia Mazzonetto. 2020. “RRI Legacies: Co-Creation for Responsible, Equitable and Fair Innovation in Horizon Europe.” *Journal of Responsible Innovation*, November, 1–8. https://doi.org/10/gk669w.
Roco, Mihail C. 2011. “The Long View of Nanotechnology Development: The National Nanotechnology Initiative at 10 Years.” *Journal of Nanoparticle Research* 13 (2): 427–45. https://doi.org/10/bv6vsm.
Roes, AL, and MK Patel. 2011. “Ex-Ante Environmental Assessments of Novel Technologies–Improved Caprolactam Catalysis and Hydrogen Storage.” *Journal of Cleaner Production* 19 (14): 1659–67. https://doi.org/10.1016/j.jclepro.2011.05.010.
Rotolo, Daniele, Diana Hicks, and Ben R. Martin. 2015. “What Is an Emerging Technology?” *Research Policy* 44 (10): 1827–43. https://doi.org/10/f7xnbr.
Royal Society and Royal Academy of Engineering. 2004. *Nanoscience and Nanotechnologies: Opportunities and Uncertainties*. London: The Royal Society : Royal Academy of Engineering.
Rudén, Christina, and Sven Ove Hansson. 2010. “Registration, Evaluation, and Authorization of Chemicals (REACH) Is but the First Step–How Far Will It Take Us? Six Further Steps to Improve the European Chemicals Legislation.” *Environmental Health Perspectives* 118 (1): 6–10. https://doi.org/10/cqn589.
Saille, Stevienna de. 2022. “New Horizons, Old Friends: Taking an ‘ARIA in Six Keys’ Approach to the Future of R(R)I.” *Journal of Responsible Innovation*, March, 1–5. https://doi.org/10.1080/23299460.2022.2050592.
Saldívar-Tanaka, Laura, and Steffen Foss Hansen. 2021. “Should the Precautionary Principle Be Implemented in Europe with Regard to Nanomaterials? Expert Interviews.” *Journal of Nanoparticle Research* 23 (3): 70. https://doi.org/10/gjkkh2.
Salieri, Beatrice, David A. Turner, Bernd Nowack, and Roland Hischier. 2018. “Life Cycle Assessment of Manufactured Nanomaterials: Where Are We?” *NanoImpact* 10 (April): 108–20. https://doi.org/10/gf64qc.
Sanderson, Katharine. 2023. “What the Silicon Valley Bank Collapse Means for Science Start-Ups.” *Nature* 615 (7953): 569–70. https://doi.org/10.1038/d41586-023-00778-8.
Scheringer, Martin. 2008. “Environmental Risks of Nanomaterials.” *Nature Nanotechnology* 3 (6): 322–23. https://doi.org/10/bdn5r6.
Schomberg, René von, ed. 2010. *Understanding Public Debate on Nanotechnologies: Options for Framing Public Policy: A Report from the European Commission Services*. EUR 24169. Luxembourg: Publ. Off. of the European Union.

———. 2013. “A Vision of Responsible Research and Innovation.” In *Responsible Innovation*, edited by Richard Owen, John Bessant, and Maggy Heintz, 51–74. Chichester, UK: John Wiley & Sons, Ltd. https://doi.org/10.1002/9781118551424.ch3.

Seifert, Franz, and Camilo Fautz. 2021. “Hype After Hype: From Bio to Nano to AI.” *NanoEthics* 15 (2): 143–48. https://doi.org/10/gmw48s.

Seifert, Franz, and Alexandra Plows. 2014. “From Anti-Biotech to Nano-Watch: Early Risers and Spin-Off Campaigners in Germany, the UK and Internationally.” *NanoEthics* 8 (1): 73–89. https://doi.org/10/f6pd5f.

Sekton, Bhupinder. 2010. “Food Nanotechnology - an Overview.” *Nanotechnology, Science and Applications*, May, 1. https://doi.org/10.2147/NSA.S8677.

Sharkey, K., and L. Gillam. 2010. “Should Patients with Self-Inflicted Illness Receive Lower Priority in Access to Healthcare Resources? Mapping out the Debate.” *Journal of Medical Ethics* 36 (11): 661–65. https://doi.org/10/dsxzp5.

Shelley-Egan, Clare, and Diana M. Bowman. 2018. “Nanotechnologies: The Catalyst for Responsible Research and Innovation.” In *Nanotechnology Environmental Health and Safety*, 33–55. Elsevier. https://doi.org/10.1016/B978-0-12-813588-4.00003-8.

Solla Price, Derek de. 1984. “The Science/Technology Relationship, the Craft of Experimental Science, and Policy for the Improvement of High Technology Innovation.” *Research Policy* 13 (1): 3–20. https://doi.org/10/d6rbzz.

Soneryd, Linda, and Göran Sundqvist. 2021. “Leaks and Overflows: Two Contrasting Cases of Hybrid Participation in Environmental Governance.” In *Democratic Situations*, edited by Andreas Birkbak and Irina Papazou. Mattering Press.

Stilgoe, Jack, Richard Owen, and Phil Macnaghten. 2013. “Developing a Framework for Responsible Innovation.” *Research Policy* 42 (9): 1568–80. https://doi.org/10/f5gv8h.

Stirling, Andy. 2008. “‘Opening Up’ and ‘Closing Down’: Power, Participation, and Pluralism in the Social Appraisal of Technology.” *Science, Technology, & Human Values* 33 (2): 262–94. https://doi.org/10/cfpsn5.

Stokes, E., and S. Vaughan. 2013. “Great Expectations: Reviewing 50 Years of Chemicals Legislation in the EU.” *Journal of Environmental Law* 25 (3): 411–35. https://doi.org/10.1093/jel/eqt024.

Sun, Tian Yin, Nikolaus A. Bornhöft, Konrad Hungerbühler, and Bernd Nowack. 2016. “Dynamic Probabilistic Modeling of Environmental Emissions of Engineered Nanomaterials.” *Environmental Science & Technology* 50 (9): 4701–11. https://doi.org/10/f8m9c9.

Sutcliffe, Hillary. 2011. “A Report on Responsible Research & Innovation.” Matter.

Svendsen, Claus, Lee A. Walker, Marianne Matzke, Elma Lahive, Samuel Harrison, Alison Crossley, Barry Park, et al. 2020. “Key Principles and Operational Practices for Improved Nanotechnology Environmental Exposure Assessment.” *Nature Nanotechnology* 15 (9): 731–42. https://doi.org/10/gg95tj.

SweNanoSafe. 2021. “Toward Safe and Sustainable Nanotechnology Innovation.” 2021:6. Institute of Environmental Medicine: SweNanoSafe and Karolinska Institute.

———. 2022. “Safe and Sustainable by Design: A Prerequisite for Achieving a Circular Economy.” 2022:1. Institute of Environmental Medicine: SweNanoSafe and Karolinska Institute.
Swierstra, Tsjalling, and Arie Rip. 2007. “Nano-Ethics as NEST-Ethics: Patterns of Moral Argumentation About New and Emerging Science and Technology.” *NanoEthics* 1 (1): 3–20. https://doi.org/10/bdw4df.
Taniguchi, Norio. 1974. “On the Basic Concept of Nano-Technology.” In *Proceedings of the International Conference on Production Engineering*. Vol. Part II. Tokyo: The Japan Society of Precision Engineering and International Institution for Production Engineering Research.
“The Risks of Nanomaterial Risk Assessment.” 2020. *Nature Nanotechnology* 15 (3): 163–163. https://doi.org/10/ggntt4.
Throne-Holst, Harald, and Eivind Stø. 2008. “Who Should Be Precautionary? Governance of Nanotechnology in the Risk Society.” *Technology Analysis & Strategic Management* 20 (1): 99–112. https://doi.org/10/fgkmqv.
Tlili, Anwar, and Emily Dawson. 2010. “Mediating Science and Society in the EU and UK: From Information-Transmission to Deliberative Democracy?” *Minerva* 48 (4): 429–61. https://doi.org/10/bftc9g.
Tyfield, David. 2012. “A Cultural Political Economy of Research and Innovation in an Age of Crisis.” *Minerva* 50 (2): 149–67. https://doi.org/10/f33vnn.
———, ed. 2017. *The Routledge Handbook of the Political Economy of Science*. Abingdon, Oxon ; New York, NY: Routledge.
Välikangas, Anita. 2022. “The Uses of Grand Challenges in Research Policy and University Management: Something for Everyone.” *Journal of Responsible Innovation* 9 (1): 93–113. https://doi.org/10.1080/23299460.2022.2040870.
Vance, Marina E, Todd Kuiken, Eric P Vejerano, Sean P McGinnis, Michael F Hochella, David Rejeski, and Matthew S Hull. 2015. “Nanotechnology in the Real World: Redeveloping the Nanomaterial Consumer Products Inventory.” *Beilstein Journal of Nanotechnology* 6 (August): 1769–80. https://doi.org/10/brg2.
Voorberg, W. H., V. J. J. M. Bekkers, and L. G. Tummers. 2015. “A Systematic Review of Co-Creation and Co-Production: Embarking on the Social Innovation Journey.” *Public Management Review* 17 (9): 1333–57. https://doi.org/10/gfb7zv.
Wender, Ben A., Rider W. Foley, Troy A. Hottle, Jathan Sadowski, Valentina Prado-Lopez, Daniel A. Eisenberg, Lise Laurin, and Thomas P. Seager. 2014. “Anticipatory Life-Cycle Assessment for Responsible Research and Innovation.” *Journal of Responsible Innovation* 1 (2): 200–207. https://doi.org/10/gjspcd.
Winner, Langdon. 1980. “Do Artifacts Have Politics?” *Daedalus* 109 (1): 121–36.
Wynne, Brian. 1992. “Misunderstood Misunderstanding: Social Identities and Public Uptake of Science.” *Public Understanding of Science* 1 (3): 281–304. https://doi.org/10/b5sswt.
———. 2001. “Creating Public Alienation: Expert Cultures of Risk and Ethics on GMOs.” *Science as Culture* 10 (4): 445–81. https://doi.org/10/dw8ht6.
Zwart, Hub, Laurens Landeweerd, and Arjan van Rooij. 2014. “Adapt or Perish? Assessing the Recent Shift in the European Research Funding Arena from

'ELSA' to 'RRI.'" *Life Sciences, Society and Policy* 10 (1): 11. https://doi.org/10/ggjtms.