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IRG 3: Understanding Nanotechnologies' Risks and Benefits: Emergence, Expertise & Upstream Participation

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To Our Readers

The Societal Implications of Nanotechnology: Origins, Innovation, and Risk // Synthesis Reports of the Center for Nanotechnology in Society at UC Santa Barbara

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UCSB's Center for Nanotechnology in Society (CNS-UCSB), funded as a National Center by the US National Science Foundation in 2005, constitutes an unparalleled national commitment to research and education intended to enhance responsible development of sophisticated materials and technologies seen as central to the nation's economic future. After more than a decade of funding, CNS-UCSB provides a deep understanding of the relationship between technological innovation and social change, illustrated by an unrivaled set of scholarly, educational, and societal outcomes. These outcomes were largely the work of three main Interdisciplinary Research Groups (IRGs): 1) Origins, Institutions and Communities; 2) Globalization and Nanotechnology; 3) Risk Perception and Social Response.

In advancing a role for the social, economic and behavioral sciences in understanding and promoting development of equitable and sustainable technological innovation, CNS-UCSB serves as a solid framework for future social science/ science & engineering (S&E) collaborations at the national center scale. Indeed, successful development of the transformative technologies anticipated by the country's leaders depends on systematic knowledge about complex societal as well as technical factors.

Toward this end, each of the three IRGs has generated a Synthesis Report on the cumulative scholarly results and broader impacts of their nearly 11 years of programmatic research, education and engagement.

This synthesis report *on IRG 3* should be cited as:
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IRG 3: UNDERSTANDING NANOTECHNOLOGIES' RISKS AND BENEFITS: EMERGENCE, EXPERTISE & UPSTREAM PARTICIPATION

I. Introduction & Approach

IRG 3 formed its collaborative, international research group around a core question that was on many governing bodies' minds as they began to pour billions of US dollars into the National Nanotechnology Initiative: Will nanotechnologies experience public backlash and stigma when they are developed and disseminated, and could such a backlash limit the realization of their potential economic and/or social benefits? Understanding the perceived risks and benefits of these emerging technologies and associated social behaviors seemed to present a fairly simple puzzle. However, this seemingly simple puzzle has proved to require a very complicated answer.

We also anticipated that primary focal points of public concern, in addition to central economic issues such as job creation or loss, would be risk, benefit, regulation, trust, responsibility, and justice, the existence of acceptable/affordable alternatives, and scientific uncertainty about the risks. Further, we also suspected that views might vary about particular nanomaterials and their enabled products (glossed as 'application'). We believed that the degree to which experts shared, anticipated, and addressed these concerns would be a powerful predictor of the likelihood of ensuing controversy or backlash.

IRG 3 has thus conducted novel social research on formative nanotech perceived risks and benefits over time through a well calibrated set of mixed qualitative and quantitative social science research methods aimed at studying the views and beliefs about these new technologies by multiple parties. By 'multiple parties' we mean people in numerous different social locations and positions with respect to science and technology (S&T) research and development (R&D)—nanoscale scientists and engineers, nano risk assessment experts, regulators and government agency personnel, industry leaders and workers, NGOs or other social movement and special interest groups,

journalists, and members of the public who differ by gender, race/ethnicity, class, occupation, education, and age, and many other characteristics, as well as nationality. An important aspect of our work is a shared interest in investigating the diversity and nuances of views both within and across these categories of difference. We have pursued this interest because of the demonstrated importance of democratic participation to the success of the innovation system (cf., Dietz & Stern 2008), the ethical imperatives of responsible development and innovation, and the challenges to full participation posed by a large and complex multicultural society such as the US.

Thus, the overarching goals of IRG 3 have been to generate an unprecedented body of new knowledge about the emergent perceived risks and benefits of nanotechnologies and selected other new technologies through a set of linked studies. The scope of the work has included:

- Studying views and social action among multiple stakeholders in the nano-enterprise;
- Developing and documenting methods for public engagement with new technologies in the US and comparative other sites;
- Characterizing expert knowledge and regulatory preparedness for safe handling of these novel properties;
- Tracking media and policy attention paid to nanotech risks and benefits to provide critical evidence of risk signal amplification or attenuation; and
- Disseminating the knowledge gained to an array of critical stakeholders, including scientists and engineers developing these new materials and their enabled systems and products, nanotoxicologists assessing the environmental and health risks they present, the nanomaterials industry, policymakers/

Photo: Risk Specialist Meeting in Santa Barbara in January 2010

regulators, journalists, and diverse US publics and nongovernmental organizations (NGOs)/ civil society organizations (CSOs).

Never before has a class of new technologies anywhere in the world been the focus of such a systematic, long-term, comparative multi-stakeholder analysis of risk perception and societal implications. CNS has made this possible, via the creation of an international, interdisciplinary, state-of-the-art mixed methods research team.

APPROACH

The main theoretical framework for this suite of research projects at inception of the CNS in 2006 derived from the Social Amplification of Risk Framework (e.g., Pidgeon, Kasperson & Slovic 2003), which provides a broad, multi-factorial approach to understanding the evolution of past technological (i.e., human-made) risk controversies. For example, changing public and regulatory views on nuclear power have been exhaustively studied by risk analysts from its highly benefit-centric period of strong public support, through to near absolute technological stigma following the partial meltdown at the Three Mile Island nuclear power plant in 1979 (e.g., Erikson 1994), to current cross-national variance in public support for and opposition to nuclear power plants (OECD 2010), to yet further changes in the wake of the Fukushima Dai-ichi nuclear accident in 2011. However, as our work has demonstrated (Satterfield et al., 2009 and below), nanotech R&D has evolved to the present in the US and abroad with only modest evidence of public awareness, risk aversion, media attention, or widespread protest. As a result, IRG 3 research has moved progressively into more experimental research modes, even as many of the technologies themselves continue to move downstream into wider commercial production and dissemination. This unprecedented lengthy opportunity to study emergent attitudes, beliefs and perceptions is a particular attraction of the nanotechnology context for risk analyses, although it has brought unique challenges as well. As the work has progressed in the absence of once-anticipated risk amplification, analysis also focused on comparisons with other emerging technologies as a means to better understand nanotechnologies' reception.

The term 'risk perception' as we are using it here references cognitive and affective components of risk, which are dynamic and produced through complex drivers. It includes linked concepts such as mental models and templates; but it also focuses on affective responses that are particularly important in 'fast thinking' intuitive responses where knowledge is low. For example, in the context of survey research, risk perception also references deeper cultural values and beliefs that often underpin survey responses but are better probed in systematic qualitative research, especially in an upstream emerging technology context. Risk perception research overlaps with but is not the same as public opinion or attitude polls and surveys. In particular, risk perception research has shown that public perceptions are influenced by a wide array of psychological and social factors that public opinion polls rarely examine (Slovic 2000; Leiserowitz 2006).

Complicating this broad research program are a number of theoretical and methodological challenges. First, in spite of a rich body of comparative literature on perceived risks (particularly US publics') regarding an array of past technologies, the case of nanotechnologies is different in some crucial respects. As indicated above, it has been typified by unusually low public awareness, necessitating the move in our research to what is best understood as 'far upstream.' A case in point is the study of public attitude formation and risk/benefit judgment as they take shape and are produced in an attenuated risk terrain. We thus asked more fundamental questions about how people make sense of novel technologies in the context of many unknowns

NEVER BEFORE HAS A CLASS OF NEW TECHNOLOGIES ANYWHERE IN THE WORLD BEEN THE FOCUS OF SUCH A SYSTEMATIC, LONG-TERM, COMPARATIVE MULTI-STAKEHOLDER ANALYSIS OF RISK PERCEPTION AND SOCIETAL IMPLICATIONS. CNS HAS MADE THIS POSSIBLE, VIA THE CREATION OF AN INTERNATIONAL, INTERDISCIPLINARY, STATE-OF-THE-ART MIXED METHODS RESEARCH TEAM.

THE COMBINATION OF UBIQUITY AND INVISIBILITY OF NANOTECHNOLOGIES, ALONG WITH THE COMPLEX GLOBAL/SOCIETAL CONTOURS THAT MARK THEIR DEVELOPMENT AND DEPLOYMENT, CHALLENGE RISK PERCEPTION RESEARCH IN ENTIRELY UNPRECEDENTED WAYS.

and in some cases unimaginable characteristics and implications. Low awareness has necessitated particularly delicate approaches to how the research and the technologies are framed.

This upstream world (or moment) has also pushed us to consider what comparatively little is known about *benefit perception*, and what nanotechnologies' perceived benefits across different sectors signify. Do, for instance, varied publics have ready-to-go templates for making cognitive sense of this new unknown terrain or are they creating them anew? Nanotechnologies emerged in the social and imaginative realm as largely inchoate risk objects, indeed as a kind of *tabula rasa* risk object(s). Their ubiquity, invisibility and uncertainty suggest consideration as what Morton (2013) has recently referred to as "hyperobjects"—"entities of such vast temporal and spatial dimensions that they defeat traditional ideas about what a thing is." The combination of ubiquity and invisibility of nanotechnologies, along with the complex global/societal contours that mark their development and deployment, challenge risk perception research in entirely unprecedented ways. In addition, the social and political contexts of these molecular sized technologies are complicated by experts whose own judgments of risk and benefit and need for regulation are highly uncertain, particularly regarding longer term, downstream implications and consequences of different nanotechnologies. Together these challenges create a new set of research questions as well as a departure from the usual defaults as to what constitutes risk perception research.

METHODS

Each of these complications and admittedly spirited challenges has, along the way, compelled us to ask a series of thorny methodological questions. What methodological innovations are needed to capture and understand public engagement and thinking as it is unfolding rather than the conventional downstream risk controversy approach where judgments are vastly more solidified, if not polarized? Low public awareness creates particular demands for sensitive framing of risk vs. benefit information. Upstream deliberation has been essential to providing in-depth qualitative data about emergent ideas, values and beliefs. Cross-cultural implementation has required a more thoughtful approach to protocol development and refinement, and critical reflection on researcher-driven effects is essential at every step. We have used a broad set of systematic qualitative and quantitative methods to address these issues, often starting from in depth, qualitative methods such as open-ended inductive interviews and group discussions to learn more about the mental models (Morgan et al. 2001) or cognitive maps or schemata (Casson 1983) that people use to think and talk about technologies. We then use this derived knowledge to build

FIGURE 1. TENDENCY TO AVOID NANO-ENABLED PRODUCTS BY RISK AND BENEFIT FRAMES

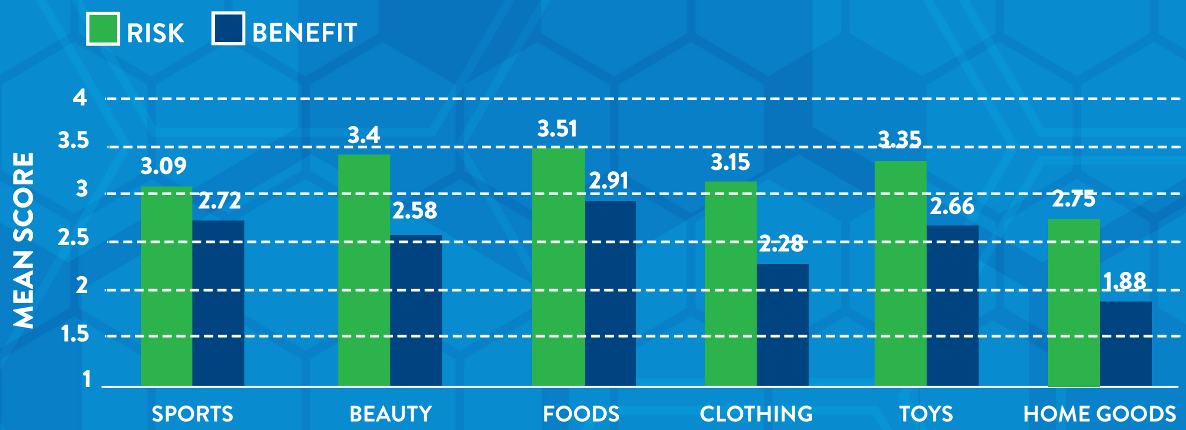


Figure 1. Copeland and Hasell (2014) Framing effects on people's expressed willingness to purchase nanotech applications in the US.

FIGURE 2. DECISION PATHWAY SURVEY

Source: Gregory, Satterfield & Hasell (2016)

EXPERTS CAN AND SHOULD BE PRODUCTIVE AND REFLEXIVE PARTICIPANTS IN PUBLIC ENGAGEMENT. THE CNS AT UCSB PROVIDES HUNDREDS OF EXAMPLES OF SUCCESSFUL EXPERT ENGAGEMENT, FACILITATED BY SOCIAL SCIENCE RESEARCHERS AND BASED ON SOLID SOCIAL SCIENCE EVIDENCE.

quantitative survey instruments to ask well-grounded questions in a systematic and carefully sequenced way, controlling for primacy effects, of much larger and more representative samples.

In essence, we have sought to build a suite of tools where none before existed. Such innovation has included piloting and implementing novel decision pathway survey methods to create a more dialogic and iterative approach to engaging larger and more diverse samples than intensive qualitative deliberative work can yet handle (Gregory, Satterfield & Hasell 2016). At every stage of work, we tested tutorials and styles of survey, interview, and deliberative elicitation by varying both information content and opportunities for information seeking (e.g., breaks in deliberation provided for café-style information seeking across a broad array of sources), to changing the very format and assumption of survey design (e.g., embedding tutorials, using narrative framings so that new information was more readily comprehensible, to altering the order of risk versus benefit information, among other innovations).

Understanding emergent expert judgment is also more methodologically challenging in the upstream moment, and this too was a key focus of our work. Experts are likewise subject to uncertainty in their views on the risks and benefits of the materials and their nano-enabled products, and nanotechnologies represent an infinitely variable class of materials and processes. Full characterization and standardization of these are still in their infancy 15 years into the process, and with very few exceptions, engineered nanomaterials (ENMs) are not yet subject to special regulatory controls in the US; thus regulatory gaps are considerable. Methodological approaches in this situation have included in-depth interviews with elite nanoscientists, survey research across different communities of experts to capture affiliation-based variance, and expert workshops designed to develop decision tools to bridge both uncertainty and regulatory gaps.

In sum, the quantitative methods used in IRG 3 include: standard, psychometric, consumer, and experimental decision pathway phone and web-based surveys of demographically diverse and representative US (and other) publics. Also surveyed was a range of experts including scientists and engineers, regulators, and industry leaders. Experimental research was conducted on factors driving group polarization in emerging nanotech debate, as was longitudinal tracking of print and internet media coverage of nanotechnologies, and longitudinal tracking and analysis of citizen action around nanotech products, research, and development. IRG 3 also has employed systematic qualitative research methods that provide a substantive basis for and validation of quantitative results and include mental models interviewing, expert interviews, expert structured decision making workshops, ethnographic interviews, and deliberative public engagement workshops and

Photo: Nick Pidgeon

focus groups regarding the risks and benefits of specific applications of nanotechnologies and related new technologies. In all research, a focus on application domains was also key, be these environmental or 'green nano,' energy-efficient technologies, medical innovations, or military innovations.

Together, the activities in IRG 3 were designed to comprehensively examine the *situated knowledge, perceptions, and beliefs* of the main actors in the nanoenterprise. By "situated knowledge" we draw on social theory to indicate that knowledge (and imagination) are both shaped and conditioned (but not necessarily determined) by social location and position, and that social values, perception and knowledge production are socially organized and co-produced through dialogue (Stoetzler & Yuval-Davis 2002).

Our research addresses these many issues. In the report that follows we have organized our discussion into 3 main foci: 1) the "problem" of public acceptance; 2) the regulatory challenges of nanotech; and 3) engaging the public: from precaution to responsible research and innovation.

OUR MAIN FINDINGS CAN BE SUMMARIZED AS FOLLOWS:

- Public acceptability of nanotechnologies is driven by: benefit perception, the type of application, and the risk messages transmitted from trusted sources and their stability over time; therefore transparent and responsible risk communication is a critical aspect of acceptability.

- Social risks, particularly issues of equity and politics, are primary, not secondary, drivers of perception and need to be fully addressed in any new technology development. We have devoted particular attention to studying how gender and race/ethnicity affect risk judgments.

- The upstream dominance of benefit perception should not be taken as an indication of continued high public acceptability of nanotechnologies over time. Conclusions regarding current views are tempered by a high level of uncertainty and indicate the above noted malleability, particularly if

Photo: Terre Satterfield

Photo: CNS Director and IRG 3 Leader Barbara Herr Harthorn

benefit-only communication is followed by risk communication. Public acceptability should be viewed as conditional, requiring continued trustworthy actions by government and industry.

- There is almost no sensitivity of publics to differences in the actual engineered nanomaterials, even though toxicological evidence indicates increasingly solid evidence for their differential effects. Therefore, the whole class of nanomaterials is vulnerable in the event that those that more hazardous are not regulated well and so become the basis for stigma or radiating effects.

- Although representatives from the nanomaterials industry demonstrate relatively high perceived risk regarding engineered nanomaterials, they likewise demonstrate low sensitivity to variance in risks across type of engineered nanomaterials, and a strong disinclination to regulation. This situation puts workers at significant risk and probably requires regulatory action now (beyond the currently favored voluntary or 'soft law' approaches).

- All stakeholders in the nano-enterprise, including experts, display dependence in some circumstances on intuitive risk judgments that are at odds with current evidence. Systematic social science research is therefore a critical part of responsible policy and can be used to anticipate where experts most need research and extension support.

- Scientists and engineers, toxicologists, and regulators display significant diversity in their views on the risks of nanomaterials and the regulatory sufficiency of current frameworks for regulating nanomaterials and nano-enabled products. Therefore, a diverse composition of experts is needed in regulatory decision-making bodies in order to capture the full range of these views.

- Those scientists and engineers working most closely with nanomaterials in the early stages of development (e.g., of novel materials and applications) show the highest risk tolerance among experts. The implications for labs and bench science safety among students, postdocs and workers should thus be investigated.

- Among experts, nanotech regulators and federal and state agency personnel express the least confidence in the current regulatory system. There are clearly identified gaps (often large) in regulatory coverage across product lifecycles that contribute to these concerns. The aging regulatory system in place demands systematic policy maker attention and integration across agencies.

- In spite of regulatory and risk assessment uncertainties, diverse expert engagement for development of new tools and approaches can be conducted successfully using current theory and practice in structured decision making. It is critical to implement these now rather than to wait for completed hazard and exposure assessments, particularly given this large and complex class of new materials such as engineered nanomaterials.

- The public can and should be engaged, early and often, in the development and commercialization of new technologies, particularly those with high potential for risk (health, environment, and social) and disruption. European deliberative models have been successfully implemented in the US by CNS and could be scaled up for national deliberation. CNS research has shown that a majority of US publics endorse the core values of responsible innovation.

- Civil society organizations such as NGOs can and should be invited participants and have an increasingly important role to play in safe and responsible development and innovation. Societal experts provide important evidence-based knowledge and understanding for effective facilitation of this process.

- Experts can and should be productive and reflexive participants in public engagement. The CNS at UCSB provides hundreds of examples of successful expert engagement, facilitated by social science researchers and based on solid social science evidence. Federal funders should require such integrated efforts and dedicated resources for all new technology R&D.

- Public participation has been greatly enhanced in the NNI through NSF investment in national societal research and education centers. This approach can and should become an integral part of US technology development, with funding and incentives to develop new methods and approaches, grounded in the best social research practices.

Photo: IRG 3 Graduate Fellows Bridget Harr (Sociology), Louise Stevenson (Ecology, Evolution, and Marine Biology), and Ariel Hasell (Communication) volunteering at NanoDays 2014.

IRG 3: UNDERSTANDING NANOTECHNOLOGIES' RISKS AND BENEFITS

II. Main accomplishments 2006-2016

A. Scholarly Merit - Contributions to Scholarly Knowledge.

1. The "Problem" of Public Acceptability

Background. Government, industry, and science often express concern about presumed lack of public acceptability as a major potential impediment to technological development. This has been the case throughout the development of nanotechnologies, and yet what constitutes acceptability is not as straightforward as it first appears (cf. Devine-Wright 2007; Demski 2011). In the low knowledge context of emerging technologies, we have found that publics are often uncertain rather than assertive or habitually inclined toward risk-averse stances. For example, in our meta-analysis of all nanotech public attitude surveys in North America, Europe and Japan prior to 2009, on average almost half, or 44% of respondents, replied that they "don't know" or are "not sure" about whether the risks outweigh the benefits or the benefits outweigh the risks (Satterfield et al. 2009). Further work has dealt with the low knowledge context of upstream nanotech by careful assessment of knowledge and familiarity in the context of eliciting risk and benefit judgments. Subtle thinking about issues and the construction of preferences are evident as the qualities and conditions of technological implication are revealed. That is, risk perception and technological preferences are appropriately conditional, however much some evidence for the role of other variables (such as affect or trust) is also present.

IN THE LOW KNOWLEDGE CONTEXT OF EMERGING TECHNOLOGIES, WE HAVE FOUND THAT PUBLICS ARE OFTEN UNCERTAIN RATHER THAN ASSERTIVE OR HABITUALLY INCLINED TOWARD RISK-AVERSE STANCES.

Another deceptively simple question is who are nanotechnologies' publics? An early meeting convened by the US National Nanotechnology Coordination Office (NNCO) in 2006 struggled to address this issue in the low awareness context, and many others since then have dealt with publics as 'stakeholders' in very different ways. Some are invited to participate (and speak for wider publics). For example, NISEnet and nano science education approaches have defined 'the public' as the science-interested (and knowledge deficit-ridden) public who seek out and attend science museums and other science education events, including the Nano Days events we have convened annually in the Santa Barbara community since 2006. Survey researchers, ourselves included, have used representative national samples (and quota samples thereof), in the US and

elsewhere, to gather and to some extent speak for those diverse but anonymous people. Our deliberative work has used a similar (but necessarily smaller scale) logic to draw quasi-representative diverse quota samples from the communities in which the deliberations are held.

From a *normative ethics* point of view, the relevant publics are those who might be affected by the development, and so follow the ethic of informed consent (however contingent). But with such ubiquitous technologies or hyperobjects, that is virtually everyone, a universe we have no means to directly and fully engage. Thus, the above means have served as proxies. From an *instrumental* point of view, the publics who may be most strategic to understand and engage with, particularly for a governing body whose mandate includes public acceptance, are those who are most concerned (and vociferous). In the nanotech case that has been a set of key social movement organizations (SMOs)/civil society organizations (CSOs), glossed here as non-governmental organizations (NGOs). For this reason and for their importance as actors in the Social Amplification of Risk Framework (Pidgeon, Kasperson & Slovic 2003), we have mapped the actions of the full English-language NGO nano-active population over the past decade, looking closely at the views of watchdog organizations interested in particular risk scenarios (Engeman & Harthorn 2013; Engeman, Rogers-Brown & Harthorn *in preparation*).

The shifting sands of science journalism, print media, and social media have provided a dynamic and challenging context for research on media coverage and its potential effects on public views on nanotechnologies. IRG 3 has conducted 3 sequential print and social media projects led at UCSB by Bruce Bimber (2006-2010), at Lehigh University by Sharon Friedman (2010-2015), and at UCSB by Ariel Hasell (2014-2016) in conjunction with Galen Stocking and IRG 2. The Bimber-led project at CNS was based on 10 years of nanotech news coverage at the top 10 leading print media outlets in the US in English 1999-2009 and concluded that media coverage of nanotech was quite low overall and episodic compared to other issues, peaked in 2006 in spite of regulatory action and buildup, and that frame analysis (Weaver et al. 2009) showed that like other science journalism, ideas about progress dominated (70% of the nano news as a whole was on progress), while the news on the social implications of nano displayed progress and risk frames at nearly the same volume. Nanotech domains or applications were distributed differently over that decade, with more concrete applications emphasized over time, and journalists only using the progress frame in relation to nano applications in medicine, energy, computers and economy. Notably, in spite of experts' and regulators' emphasis on nanotechnologies for environmental remediation, the "...connection the media draws between nano and the environment seems to be a story of harm and not benefit" (Lively, Conroy, Weaver, & Bimber 2012: 234).

Science journalism scholars Friedman and Egolf, who began their work in conjunction with a NIRT project based at UCLA, came under the CNS umbrella in 2010 and continued longitudinal analysis of nanotechnology risks in 20 US and 9 UK newspapers 2000-2014. In 2011, as a part of our IRG 3 edited special issue of *Risk Analysis*, they also documented the low coverage of nano in both countries and identified three main narratives over time: runaway technology, science-based studies, and regulation, with recurrent discussion of scientific uncertainty in about half of the articles (Friedman & Egolf 2011). The continued decline in coverage of nano in conjunction with the erosion of science journalism more broadly challenged traditional media studies approaches

FIGURE 3. LIVELY, WEAVER, BIMBER (2012)

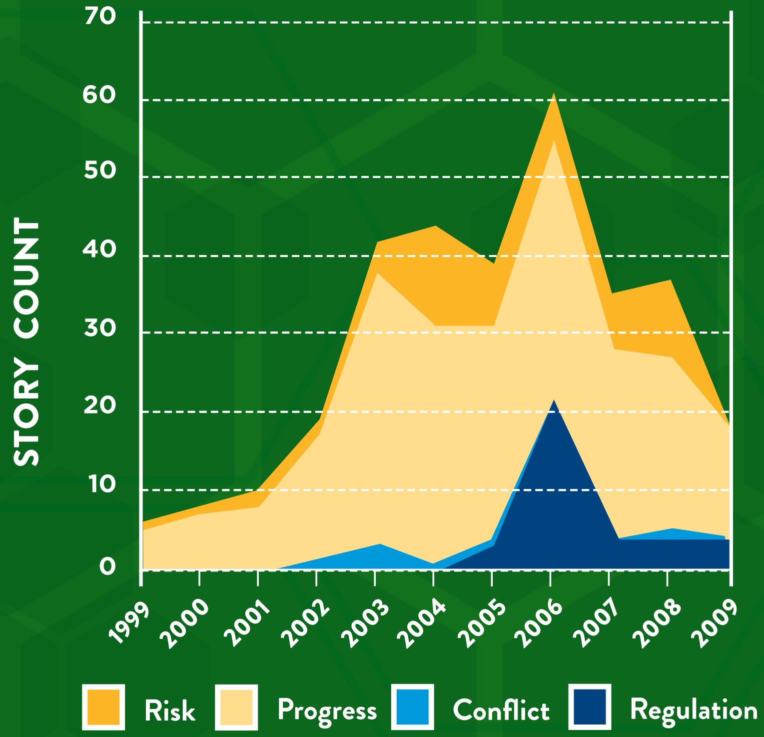


Figure 3. Frequency of Nano Print News Frames 1999-2009

FIGURE 4. BREADTH OF NANO DISCUSSION ON TWITTER

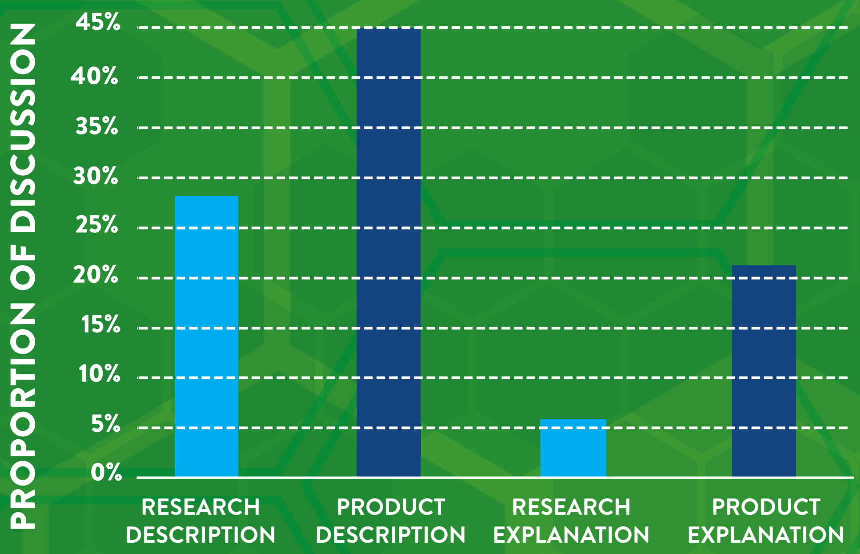


Figure 4. More Description Than Explanation: Larger Focus on Products.

Source: Hasell, A., & Stocking, G. Twitter As A Tool For Public Engagement With Emergent Technologies? Presented At Democratizing Technologies: Assessing The Roles of NGOs In Shaping Technological Futures, Nov 13-15, 2014.

FIGURE 4. TWITTER AS A TOOL FOR PUBLIC ENGAGEMENT WITH EMERGENT TECHNOLOGIES?

Twitter and other social media offer the potential to engage science enthusiasts and connect interested publics. In this study, our two main research questions ask: Is Twitter being used as a tool of interactive engagement between the public and nanotechnology experts? And what proportion of tweets about nanoscience are attempting to explain nanotechnology or engage interested publics?

We look at discussion of nanotechnology and found that, In recent years, there has been an increase in Tweets that describe nanoscience and nanoproducts. However, there is less content that attempts to explain nanoscience in language suited to general audience. Tweets that do attempt to explain nanoscience, tend to focus on nano-based products. We also found a significant Grangers' causality interaction between volume of Research Description Tweets and Research Explanation Tweets, meaning that at times, increase in Description Tweets leads to an increase in Explanation Tweets, while at other times, the opposite occurs.

UPSTREAM BENEFIT AND ACCEPTABILITY RATINGS MAY THUS BE HIGHLY MOBILE, AND THE NANOTECHNOLOGIES CASE DEMONSTRATES THIS PERFECTLY.

(Friedman & Egolf 2012). In 2014-2016, IRG 3 in collaboration with IRG 2 moved to social media with a project by graduate fellows Galen Stocking (IRG 2) and Ariel Hasell (IRG 3). The research uses Forsight by Crimson Hexagon to access the content of all publicly available messages posted on Twitter, focusing on messages related to emergent technologies (nanotechnology and fracking in particular), and examined how public discussion of risk unfolds in social media. A series of projects examined the public discussion of fracking on Twitter by examining tens of millions of messages shared by Twitter users. This project has looked at what types of risk objects were highlighted in public discussions of nanotechnology and unconventional oil and gas development (or 'fracking'), and they found that much of the discussion of nanotechnology is about innovation rather than risk, while about half of the discussion of fracking is risk related. The team has made a series of conference presentations (e.g., Stocking & Hasell 2014, Hasell & Hodges 2015, and Hasell 2016), and has three manuscripts in preparation for peer-reviewed publications.

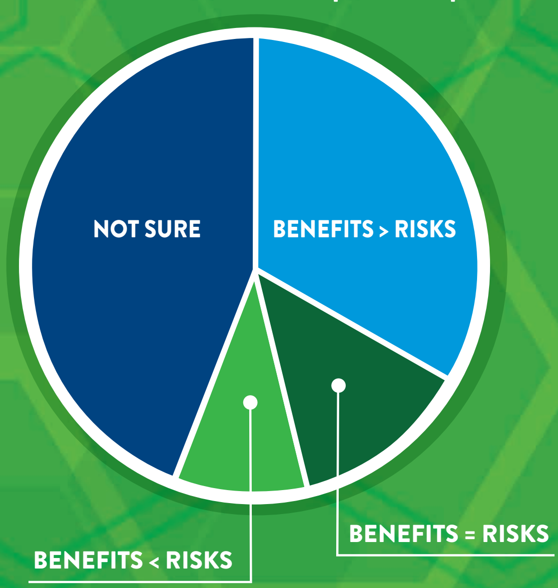
All these studies document very low volume coverage of nano risk issues by media, both traditional print media and social media. This parallel finding from over a decade and a half and across traditional and social media lends strong support to the overall media context of low nanotech risk signal amplification, even with rising risk and regulation issues in play.
In what follows we summarize selected key findings from our work on what drives public acceptability of nanotechnologies.

1.1 BENEFIT MATTERS

Benefit has long been recognized to be a key component of the risk calculus—that which risk perception researchers regard as critical to acceptability judgments (Slovic personal communication, 2007). However, the focus in much risk perception work is on explaining why, retrospectively, risk amplification, technological stigma or harmful attenuation occurred. Such

FIGURE 5.
PUBLIC PERCEPTIONS OF NANOTECHNOLOGY RISKS AND BENEFITS

Based on a metaanalysis of 22 surveys in N. America, Europe and Japan



Source: Satterfield et al. 2009, adapted by Beaudrie questions are key to understanding health risks that might follow, but this focus has also resulted in surprisingly little attention to benefit judgment itself. Unpacking what is meant by benefit perception turns out to be critical for understanding nanotech risk perceptions, and perhaps for all far upstream and poorly understood new technologies?

Our work has consequently provided extensive evidence of the largely benefit-centric views US and UK publics have for nanotechnologies. This effect is powerfully demonstrated in the quantitative meta-analysis of 22 surveys in N. America, Europe, and Japan led by Terre Satterfield and published in *Nature Nanotechnology* (2009), in which approximately 3 times as many respondents judged the benefits to outweigh the risks of nanotechnology as compared to those who thought the risks outweighed the benefits. The more compelling finding in this study, however, we argued was that on average almost half of respondents (44%) were unsure which was the case. We pointed to this finding's importance for potential future malleability of views in this low awareness, risk sensitive context.

Our comparative US-UK deliberative work on nanotechnologies also found surprisingly high levels of overall benefit centricity among participants in both countries, even in the UK where the legacy of risk controversies is high (e.g., GMO and BSE or mad cow controversies). In the case of these deliberations, benefit centricity was predominantly driven by a preoccupation with the technologies themselves, that is, they were assumed to be essentially beneficial until proven otherwise; the sheer novelty of them was often seen in optimistic, even charismatic terms, whereas the risks were overwhelmingly seen as social and/or as pertaining to governance demands (Pidgeon, Harthorn, Bryant & Rogers-Hayden 2009).

This analysis is further supported by our experimental survey research in which provision of longer, more detailed narratives about specific technologies, including those with positively-valenced information, did not produce the kind of benefit centricity evident in deliberation work and meta-analyses cited above (Conti, Satterfield & Harthorn 2011). In our 2011 national US web survey, we further found that the benefit centric views were reversible in the face of risk information, which we interpreted as a betrayal effect. That is, presenting risk information after benefit only information had a more detrimental effect on risk acceptability than the reverse order (Satterfield, Conti et al. 2012).

More recent IRG 3 comparative work on shale oil and gas extraction in the US and UK has driven home the degree to which nanotechnologies in these upstream contexts are essentially placeless—we were discussing technologies that in many cases were still on the S&T drawing boards or even just imagined technological futures, rather than concrete, present and geospatially situated technologies such as unconventional oil and gas extraction. We conclude that much of nanotechnology's benefit 'halo' derives from this, and will remain there, far from our risk detecting sensorium, until waterways are polluted, an explosion occurs, or a transportation spill

ALL THESE STUDIES DOCUMENT VERY LOW VOLUME COVERAGE OF NANO RISK ISSUES BY MEDIA, BOTH TRADITIONAL PRINT MEDIA AND SOCIAL MEDIA. THIS PARALLEL FINDING FROM OVER A DECADE AND A HALF AND ACROSS TRADITIONAL AND SOCIAL MEDIA LENDS STRONG SUPPORT TO THE OVERALL MEDIA CONTEXT OF LOW NANOTECH RISK SIGNAL AMPLIFICATION, EVEN WITH RISING RISK AND REGULATION ISSUES IN PLAY.

happens. We note that chemicals more generally are placeless in this way as well, until a facility/use exists (e.g. Irwin, Simmons & Walker 1999; Bush, Moffatt & Dunn 2001). The critical aspect of this for risk perception is that upstream benefit judgments should not be assumed to be fixed or enduring. Rather, what acceptance there is may well be fragile, and is necessarily contingent, particularly in the nanotech case where awareness is very low and invisibility of the technologies and their footprints is the dominant feature. **Upstream benefit and acceptability ratings may thus be highly mobile, and the nanotechnologies case demonstrates this perfectly.**

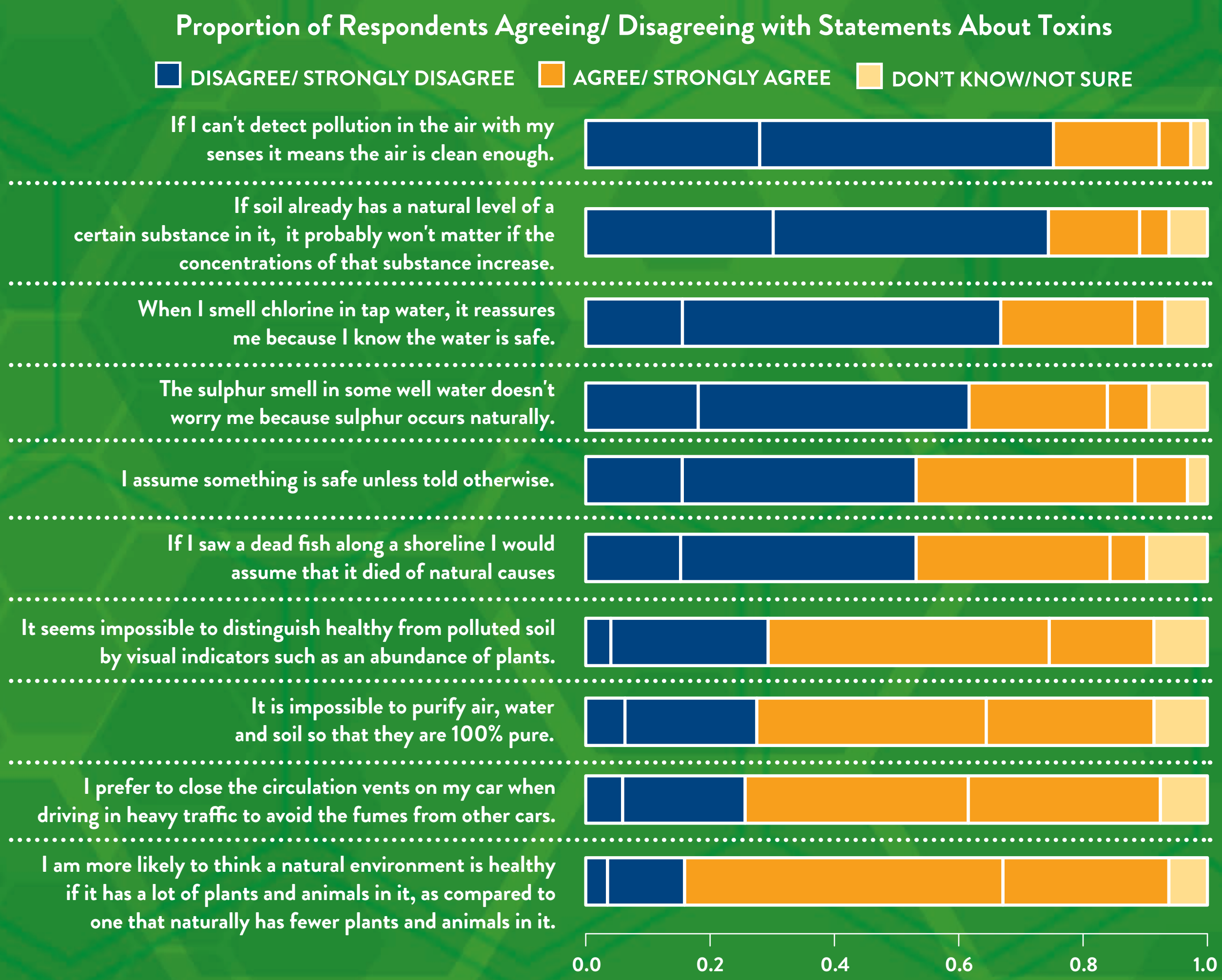
1.2 APPLICATION MATTERS

CNS as a whole and our IRG 3 group made a strategic decision in 2005 not to focus on generic 'nanotechnology' but instead work with its specific applications. This in part is because of our close work with nanoscale scientists and engineers (NSE), many of whom found the generic term problematic or meaningless. And, in part due to Nick Pidgeon's role, we have in general followed the advice of the UK Royal Society in its report on *Nanoscience and nanotechnologies: opportunities and uncertainties* (Royal Society & the Royal Academic of Engineering 2004). As the title indicates, the Royal Society chose to refer to the plurality of nanotechnologies. In following this, we have assumed from the start that differences between technologies—either the engineering nanomaterials (ENMs) themselves or more complex nano-enabled applications—would be important.

IRG 3 has followed specific nano-applications throughout its research design. Both series of nanotech deliberations we conducted (2007, US-UK; 2009, US gender) were structured to systematically compare nano energy applications with nano medical/health/enhancement applications by convening separate workshops on each application. The findings from both sets of studies reveal stark differences in perceived risk by application. The US-UK comparative study found that cross-national differences were dwarfed by strong differences across applications, with unmitigated enthusiasm for energy applications, particularly those emphasizing renewable/new forms of energy rather than energy conservation technologies like energy efficient lighting. By contrast, medical technologies elicited far more nuanced and ambivalent views in participants in both countries, particularly concerning issues of fairness and distributive justice, responsibility, and in the case of human enhancement technologies, significant moral and ethical concerns (Pidgeon et al. 2009). These application effects between energy and health were even more evident in the 2009 gender deliberations in the US (Harthorn, Rogers, et al. 2012; Rogers, Shearer et al. 2012), and food and food packaging applications were viewed with universal mistrust and dislike (Rogers-Brown, Shearer & Harthorn 2011).

IRG 3 survey research has also confirmed strong application effects in experimental design protocols. For example, our 2008 US national phone survey was designed to assess how different nanotechnology applications were viewed by those in/from different social positions. We focused on applications of food, health and energy, and we explored in particular how vulnerability and environmental justice concerns affected acceptability of different applications (Conti, Satterfield & Harthorn 2011). We systematically altered information framing—from fully benefit centric to fully risk centric. We found a nanofood application to be highly unacceptable to survey respondents, even in its most positive, all benefit presentation form. Our national phone survey also found strong application effects, in interaction

FIGURE 6. US PUBLIC AGREEMENT WITH STATEMENTS ABOUT POLLUTION/PURITY



Source: Satterfield, Harthorn, Collins & Pitts *(in preparation)* with other safety and contextual variables, with nano-energy and nano electronic applications seen as highly beneficial, whereas medical and environmental applications were more affected by other contextual variables (Satterfield et al. 2013).

While application has had a noticeable or strong effect on nanotech risk perception in this work, we have somewhat surprisingly found no such effect of the specific type of nanomaterial (ENM). Since carbon nanotubes (CNTs) have been the focus of regulatory action, and regulatory action tends to generate news coverage and risk amplification among other new technologies, we anticipated that there might be more concern about CNTs than other ENMs. However, our 2010 and 2012 national web-based environmental risk perception surveys in which we included ENM types such as CNT as variables provided almost no evidence for effects of the ENM type on public acceptability. This is likely an effect of low awareness and low media attention.

1.3 RISK SIGNAL MATTERS

By contrast, risk signal, the characterization of riskiness, particularly from trusted sources, matters a great deal in publics' risk v. benefit judgments about specific nanotechnologies. We anticipated this in this low awareness/knowledge situation, and therefore built risk signal into all survey protocols from the start as a test condition. By risk signal we mean, the provision of information that indicates experts attribute 'minimal' 'moderate,' 'significant' or 'uncertain' risk. In our 2010 national web-based survey we found that sensitivity to the risk signal, regardless of the particular application, prevailed. This was true across environmental, medical, energy, and military applications using different ENMs (among 8 types). This "dominance" of risk signal was true and affected judgments of acceptability, even when nanomaterials and applications were carefully described (Harthorn, Satterfield et al. 2011; Satterfield, Harthorn et al. *in preparation*). With one exception (an environmental remediation application), the relative ranking of acceptability of 13 of the 14 applications described in the research protocol is positively correlated with the degree of risk attributed to it in the description participants received. This same figure shows the lack of sensitivity to ENM type (see above).

In all our qualitative, deliberative research we also worked strenuously to present technological risks and benefits in as balanced a form as possible, aiming for neutral researcher effects on risk judgments to the highest degree possible. We have expressly *avoided* producing risk amplification (or attenuation) because the aim is to study participants' own emergent perceptions based on their own relatively naturalistic information seeking, uptake and group dialogue. This is even more important in a context where we wish to assess the effects of deliberative thinking and dialogue on the evolving views of the new technologies. Our approach has been well validated in past research and from other sources (Pidgeon, Parkhill et al. 2013; Pidgeon, Demski et al. 2014; Pidgeon, Harthorn & Satterfield *in press*).

Overall, in the upstream situation (low public awareness and knowledge and high scientific uncertainty about risk) that has typified nanotechnologies in the US, UK and elsewhere, lay publics demonstrate high sensitivity and potential malleability in response to information context, be it about benefit, risk, or safety.

1.4 EQUITY AND POLITICS MATTER

Our work has also extensively explored in quantitative and qualitative work how gender, race and ethnicity, and other aspects of identity and social position/social location affect the way people make sense of new technologies and how they behave in deliberative settings. This work builds on prior work on the sociology and politics of gender (Fenstermaker & West 2002), the intersection of social positions and identities (Alcoff 2006; Barvosa 2008; Bauer 2014), and on gender and race/ethnicity as factors in risk perception, particularly the 'white male effect' (Flynn, Slovic & Mertz 1994; Davidson & Freudenburg 1996; Finucane et al. 2000).

We have shown that the 'white male effect' has been misconstrued in a large proportion of studies using or testing this concept (Satterfield, Harthorn, DeVries & Pitts *in preparation*), by which we mean it is often cited as a gender and race effect and not an effect where gender and race are explained by largely socio-political and vulnerability variables. In our nanotech risk perception survey work, gender and race/ethnicity do again predict acceptability, risk and/or benefit judgments (Conti, Satterfield and Harthorn 2011; Satterfield, Conti, Harthorn, Pidgeon & Pitts 2012; Collins et al. *in preparation*, etc.). However, this result is also consistent with the 'white male effect'—that is, it is largely driven by a subset of white men with relatively higher income, education, and more conservative views who are less concerned with technological risks, and/or by a set of nonwhite women whose social-economic status and political world views are in opposition to this.

Our deliberative work has also closely examined gender (and race/ethnicity) effects. Our US-UK comparative nano energy and nano health and enhancement sessions found strong associated gender effects in the nano health and enhancement, but not the nano energy sessions, and as we reported, 'social risks' were far more evident than technological risk concerns, and they focused on distributive and procedural justice issues by participants who were women and people of color in both countries (Pidgeon, Harthorn, Byrant & Rogers-Hayden 2009). Based on this finding,the following set of US nanotech deliberative workshops was designed by Harthorn and Bryant to explore gender effects more closely, with a two application conditions (energy, health) by three group composition (women only, men only, mixed women and men) design:

FIGURE 7.
2009 DELIBERATIVE WORKSHOPS

	Energy/ Environment	Health/ Enhancement
WOMEN ONLY	1	1
MEN ONLY	1	1
MIXED W/M	1	1

Source: Harthorn, Bryant, Rogers and Shearer, *in preparation*

OVERALL, IN THE UPSTREAM SITUATION (LOW PUBLIC AWARENESS AND KNOWLEDGE AND HIGH SCIENTIFIC UNCERTAINTY ABOUT RISK) THAT HAS TYPIFIED NANOTECHNOLOGIES IN THE US, UK AND ELSEWHERE, LAY PUBLICS DEMONSTRATE HIGH SENSITIVITY AND POTENTIAL MALLEABILITY IN RESPONSE TO INFORMATION CONTEXT, BE IT ABOUT BENEFIT, RISK, OR SAFETY.

This project has generated a number of papers exploring the 'white male effect' and views on food risk (Rogers-Brown, Shearer & Harthorn 2014), health and enhancement (Harthorn 2016), technological ambivalence and linked patterns of gender- and race-skewed results (Harthorn, Shearer & Rogers 2011). In one paper (Shearer et al. 2014), we also contextualized participants with 'low risk' views to show that they actually had 'high risk' views when focused on economic risk versus much lower risk views when focused on environmental or health risks. We have studied the highly gendered talk in deliberations—men speak more than women and use more intrusive interruptions; whites use more intrusive interruptions than people of color; women speak more, use more backchannels/ cooperative overlaps, and use more self-disclosure when discussing health and human enhancement applications vs. energy/environment applications, whereas men's patterns of talk do not vary across applications (Denes et al. *in preparation*). Thus, subtle and overt group dynamics play a major role in deliberative settings, largely unexamined before this work. Our work demonstrates that privilege and inequality are often implicated in the social risks people attribute to new technologies (Harthorn, Bryant & Rogers 2009; Harthorn, Bryant, Rogers-Brown & Shearer *in preparation*).

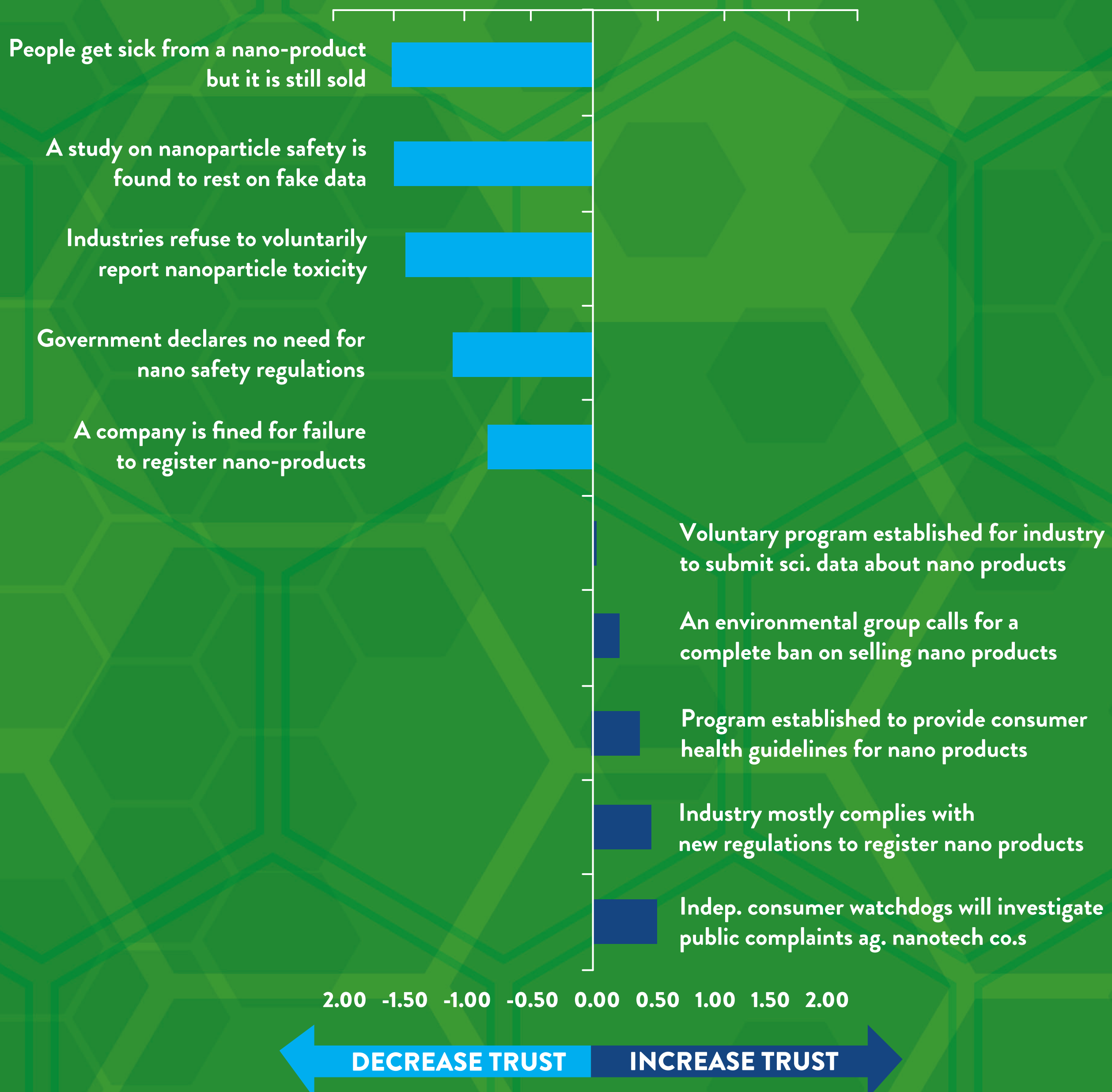
Public views on new technologies thus clearly reflect issues of identity and power, past experiences, and cultural understandings and preferences. Our work strongly argues for the importance of including such factors in research on public attitudes and perceptions.

Our work has also developed theories of trust in risk research. **Trust** is a critical dimension of publics' risk perception, and our results also confirmed the trust asymmetry principle (cf. Slovic 1993) for the nanotech case—that it is much easier to lose trust than to regain it. In our phone survey based on a representative US sample, we extended this work using *realistic examples* of nanotech applications (designed in collaboration with S&E colleagues) (Satterfield, Conti, Harthorn, Pidgeon & Pitts 2012) and discovered:

- A counter finding—that mobility of trust is greatest for those w/ **positive** predispositions to nano—these respondents demonstrated a greater increase in trust when faced w/ proactive risk management actions. We see this as indicating an unusual opportunity for dialogue (and part of the benefit perception research above).

- This same survey did find more mobility of views when bad news about risks ***follows*** good than the other way around, showing experimentally the socially risky aspect of benefit only risk communication

FIGURE 8. TRUST ASYMMETRY IN NANOTECH (US 2008, N = 490)



Source: Satterfield, Conti and Harthorn 2011

Lack of trust, in governments and in corporations, is a recurring theme in all our deliberative research. For example, our US-UK comparative nanotech deliberations found lack of trust clearly associated with risk concerns, and more nuanced cross-national differences with UK participants less trusting of government and US participants more skeptical about the trustworthiness of corporations/business. Lack of trust also obviously intersects with social and political inequality in ways that all responsible governance needs to take account of—those who have experienced environmental and health harms in the past express the greatest likelihood of future harm and vulnerability, and these views are far more widespread among women and people of color (Conti, Satterfield and Harthorn 2011).

1.5 COUNTER-INTUITIVE TOXICOLOGY

In collaboration with the UC Center for Environmental Implications of Nanotechnology (UC-CEIN), Harthorn, Freudenburg, Kandlikar, Satterfield with our students and postdoctoral researchers have pursued a series of studies with more specific attention to the environmental health and safety, environmental values, and intuitive toxicology aspects of ENMs. We have asked in particular if and how nanotechnologies are unique compared with what is known about other technologies, particularly in reference to perceived environmental risks. We hypothesized that since nanotechnologies have many features common to other technologies perceived as high risk, people may have amplified concerns about them if they know about these characteristics. Among these intuitive factors are: invisibility of risk objects, uncontrollability, scientific uncertainty, ubiquity,

perceived toxicity, and risks to future generations. However, intuitive judgments about risk are argued to derive from rapid, "fast-thinking" assessments, heavily informed by affect or emotion in conditions of low knowledge and awareness. We thus also hypothesized that some reliance on one's own sensory apparatus would be at play when 'sensing' hazard, avoiding exposure or assuming that the more material we're exposed to, the greater the hazard. Such intuitive toxicological assumptions may not help us, for example, if nanomaterials cannot be detected through our senses. For these reasons, we explored multiple dimensions of "intuition" and found (Satterfield, Collins, et al., *in preparation*; Satterfield, Harthorn, Collins et al. *in preparation*):

1. Rapid intuitions about different environmental media (e.g., air, water, and soil or those situated within biomes, for example mountain-air, -water or -soil) can be captured and predictive of risk attitudes. Four factors underlying intuitive assessments of environmental media were found, with resilience and tangibility emerging as key.

2. Rapid assessments of the perceived resilience of environmental contexts (e.g., recovers easily from harm) were particularly powerful in predicting the acceptability of nanomaterials.

3. Environmental values also correlate with ideas about resilience and environmental justice, but remain discrete constructs when examined via factor analyses or PCAs (principal components analysis).

4. An index of perceived bodily resilience was also developed as part of the perceived risk survey work, and is predictive of the acceptability of different nanomaterials.

2. Nano Poses a Major Regulatory Challenge

Nanotechnologies have posed numerous challenges to governance and regulation. IRG 3 research has contributed a significant body of work in this important area. **In spite of their arguable importance in the upstream nanotech research context, there have been surprisingly few systematic and longitudinal programs of research on nanotechnology experts outside that reported here.**

PUBLIC VIEWS ON NEW TECHNOLOGIES THUS CLEARLY REFLECT ISSUES OF IDENTITY AND POWER, PAST EXPERIENCES, AND CULTURAL UNDERSTANDINGS AND PREFERENCES. OUR WORK STRONGLY ARGUES FOR THE IMPORTANCE OF INCLUDING SUCH FACTORS IN RESEARCH ON PUBLIC ATTITUDES AND PERCEPTIONS.

FIGURE 9. NANO APPLICATION RISK PERCEPTION RATINGS FOR DIFFERENT EXPERT GROUPS

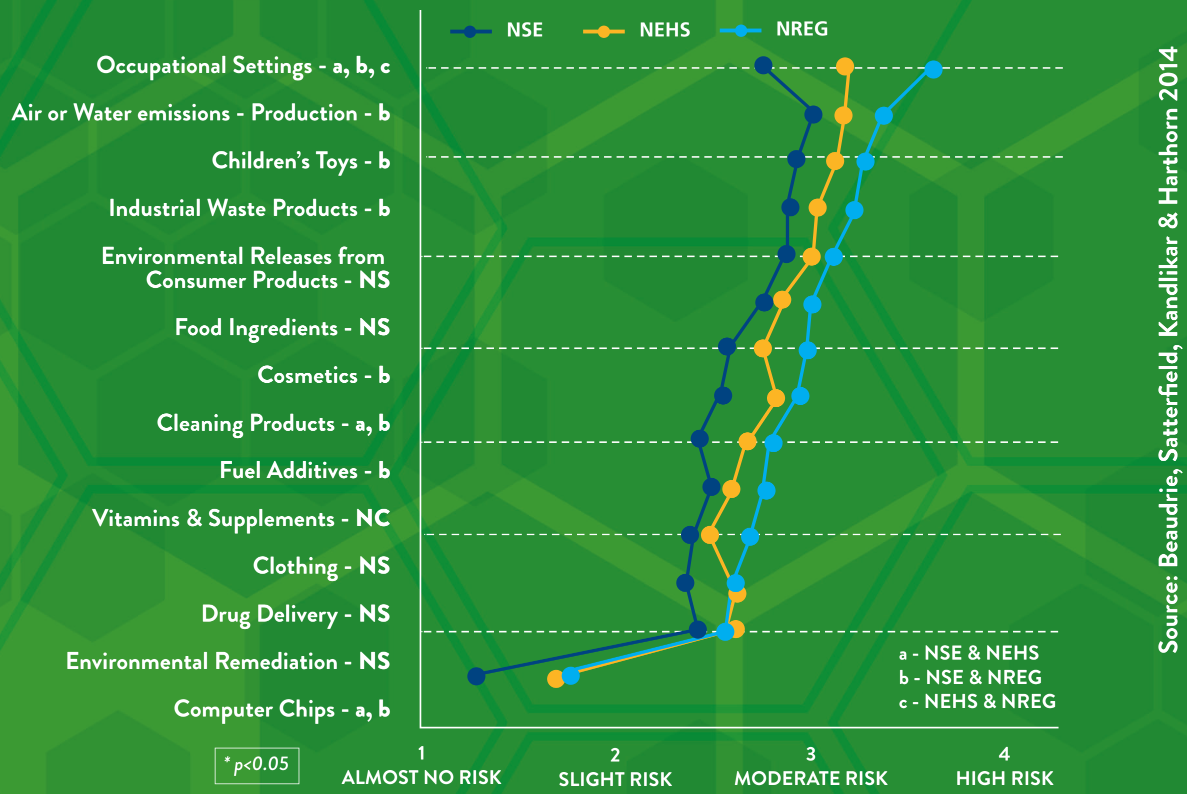
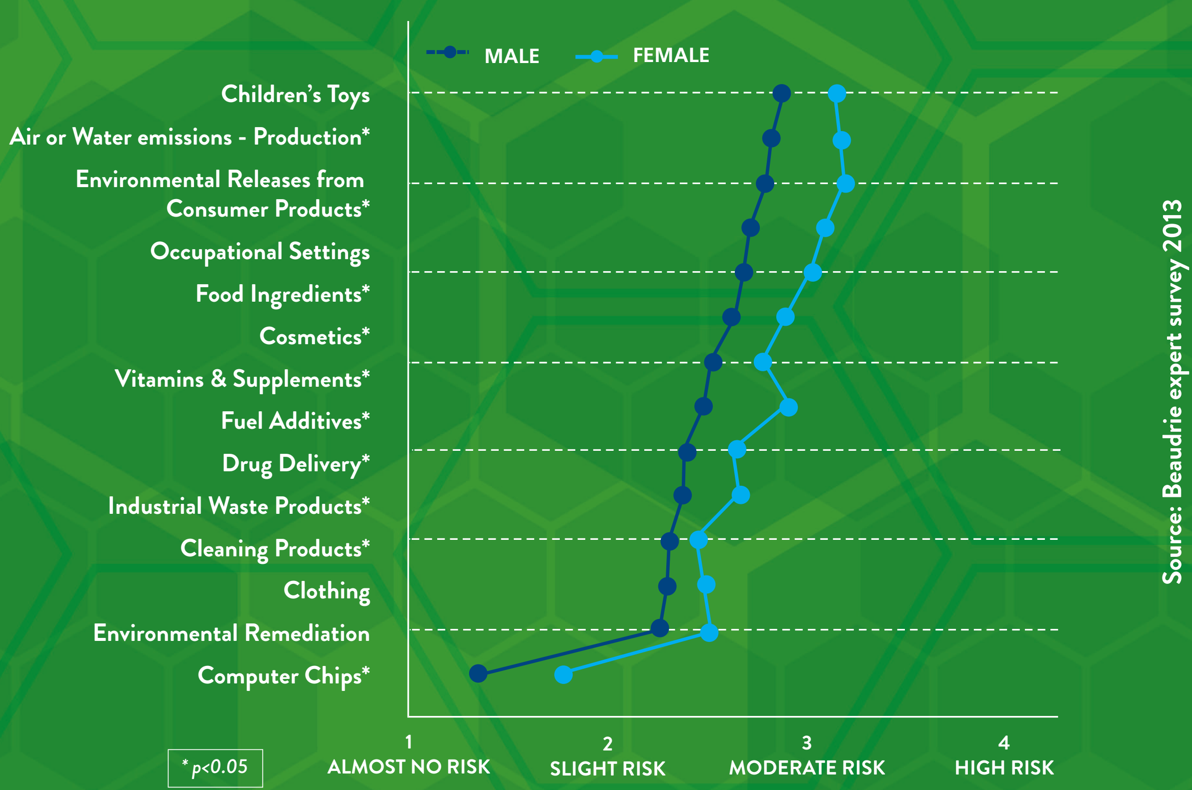


FIGURE 10. EXPERTS' RISK PERCEPTIONS DIFFER BY GENDER



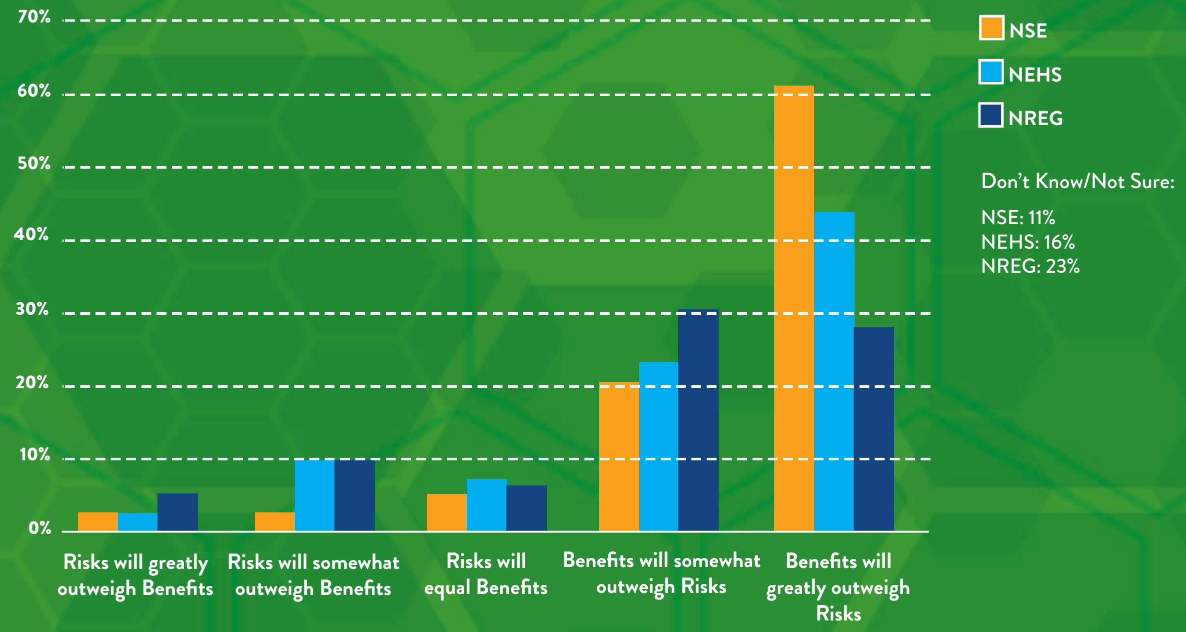
2.1 REGULATORY CONCERN

CNS has conducted leading research on the regulatory capacity of the US government to safely handle the challenges posed by nanomaterials. Beaudrie, Kandlikar, Satterfield and Harthorn began this work thorough analysis of the regulatory process across the full product life cycle (Beaudrie 2010), which identified major gaps and became an award winning science policy publication in *ES&T* (Beaudrie, Kandlikar & Satterfield 2013). A major survey of nanoscale experts followed, sampling nano-scientists and engineers, nano-environmental health and safety scientists, and regulatory scientists and decision-makers. This work clearly demonstrates that among these three groups of experts, those who know the most about the regulatory process—regulators—have the least trust in its preparedness and capacity to handle the challenges of safely and responsibly regulating engineered nanomaterials across the life cycle (Beaudrie, Satterfield, Kandlikar & Harthorn 2013). This work was also the basis for Beaudrie's PhD dissertation, which was completed in 2013.

2.2 EXPERT DIVERSITY

This same survey demonstrated the diversity of views across and within expert groups. Across the groups, benefits are perceived to outweigh the risks generally, but notable group differences are evident (figures 9, 10 and 11). Across 14 different nano-applications (fig. 9 on p. 28) eight significant differences in perceived risk were found. A general pattern of difference also reflected where experts were positioned in the nano life cycle. Specifically, natural scientists and engineers working on nano-materials and processes tended

FIGURE 11. EXPERTS' RISK VERSUS BENEFITS RATINGS FOR NANOTECHNOLOGIES IN GENERAL

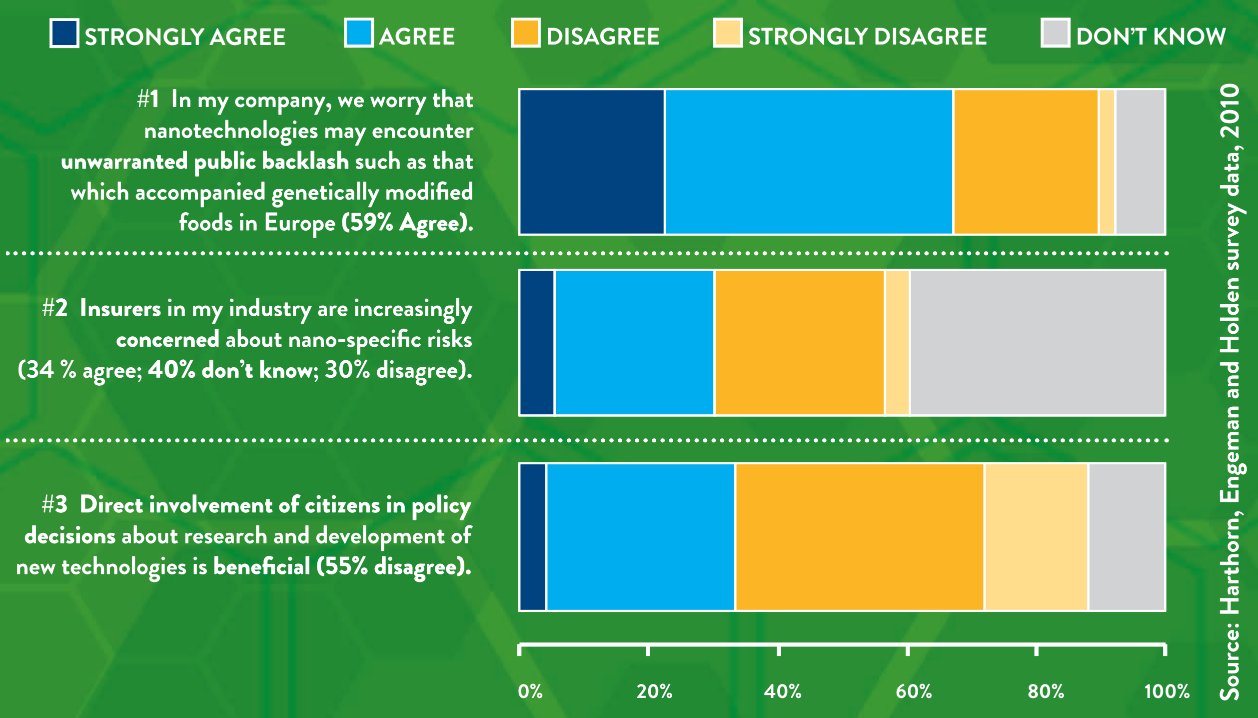


Source: Beaudrie, Satterfield, Kandlikar & Harthorn 2014 to see the risks of nanomaterials as comparatively low, nano environmental health and safety (EHS) scientists see risks as somewhat higher, whereas nano regulators are most inclined to evaluate the risks as comparatively highest. This between group variation is explained in part by perceived novelty of nanomaterials, the perceived uncertainty of the effects of materials, and by those who prefer precautionary versus market-based approaches to governance of these risks (Beaudrie, Satterfield, Kandlikar & Harthorn 2014). In addition, within group differences are evident in that significant gender differences were found in risk ratings for 12 of the applications, with men seeing lower risk and women higher figure 10 on p. 28. Expert differences could affect safety practices and research decisions as well, and experts are less cohesive than they (and we) think. Importantly, this work provides evidence that we all, including experts, display "motivated cognition" about risks that is affected by our social positions, values, and a host of other factors.

2.3 INDUSTRY AT SEA

CNS IRG 3 has conducted two major surveys of ENM risk perceptions and health and safety practices in the international nanomaterials industry. The first study was funded by ICON in 2006 and led by ecotoxicologist/microbiologist Patricia Holden, in collaboration with Harthorn and Conti in IRG 3 and Appelbaum in IRG 2 (Conti et al. 2008). This first study developed a protocol for industry self reporting of an array of EHS program characteristics such as PPE,

FIGURE 12. ENM COMPANY PARTICIPANTS' CONCERN OVER PUBLIC RESPONSE



exposure monitoring, engineering controls, waste disposal product stewardship and risk beliefs. We found uneven practices and distribution of nano-specific EHS practices and expressed need for more guidance on toxicology, exposure and EHS. We implemented a second survey in IRG 3 in 2009-2010 led by Holden and Harthorn to reach a broader international sample, assess the impacts of proliferating nano EHS guidance documents around the world, and probe risk perception and attitudes toward regulation in more detail. We found a surprisingly high degree of risk uncertainty across all ENM types, or moderate to high perceived risk—on average almost three quarters (72.5%) indicated uncertainty or moderate-high risk, without much variance across materials. However, although this kind of uncertainty and high risk translates to greater precaution in other groups, with industry we saw a high degree of preference for autonomy from governmental regulation and a low perceived need for self/other protective action—what we might call a risk management stalemate. A majority (59%) agreed that employees are ultimately responsible for their own safety at work. As shown in Fig 12, we also found industry attitudes toward publics to be negative, reducing prospects for responsible engagement (Engeman et al. 2012, Engeman et al. 2013).

2.4 EXPERT ENGAGEMENT

UBC collaborator Kandlikar published an influential piece pointing to the impossibility of conducting ENM scientific risk assessment using the business

FIGURE 13. RESPONSIBLE DEVELOPMENT OF NANOTECHNOLOGIES

NAS 2006:
"Responsible development [of nanotechnologies] implies a commitment to develop and use technology to help meet the most pressing human and societal needs, while making every reasonable effort to anticipate and mitigate adverse implications or unintended consequences."

Image Source: Harthorn (2013) Nanotechnology Multi-Stakeholder Risk Perception: Implications for Risk Analysis, Risk Engagement, and Communication" Keynote presentation at the NNI R3 Stakeholder Workshop, Wash. DC Sept 11.

as usual, one material at a time approach (Yae-Young, Ramachandran & Kandlikar 2009) and another addressing the importance of alternative methods for expert risk assessment to make risk analysis and assessment progress in the context of scientific uncertainty and regulatory gaps (Kandlikar et al. 2007; Beaudrie and Kandlikar 2011; Beaudrie, Kandlikar, & Ramachandran 2011). This work provided a careful analysis of the risk information needed and research gaps in need of attention as concerns regulatory decision making. They followed this work by conducting a state of the art Structured Decision Making (SDM) expert workshop tailored to the conditions of high complexity and uncertainty, analytic difficulty and high stakes consequences (Beaudrie, Kandlikar, Gregory, Long & Wilson 2014), generating for use in this and parallel emerging technology contexts (Beaudrie, Kandlikar & Ramachandran 2016). **The work demonstrates the importance and feasibility of developing new, methodologically-sound approaches for expert decision making in what can only be called situations of 'regulatory limbo' as is the case for many nanomaterials.**

3. Governance and Public Participation—The Art and Science of Public Engagement

Nanotechnologies in the US have been developed within an official rubric of r**esponsible development, which "... implies a commitment to develop and use technology to help meet the most pressing human and societal needs, while making every reasonable effort to anticipate and mitigate adverse implications or unintended consequences"** (NAS 2006). This ethical vision is articulated in Risk vs. Benefit terms: on the risk side of the equation are environmental and human health risks and hazards, as well as wider social risks and disruption; on the benefit side, technologies that answer needs and contribute good to society.

Although this sounds simple, in practice it's very difficult—how should we weight these different aspects? Whose judgments about both benefits and risks should this be based on? And what processes need to be in place to do the kind of risk analysis and management that incorporates such views? Expert judgment alone is not enough. Democratic public participation is articulated as a key part of responsible development for normative (ethical), instrumental (produce better outcomes), and substantive (incorporate useful information) reasons (Fiorino 1990). So public engagement and participation have been essential elements of the nanotechnology societal implications enterprise at CNS (Roco, Harthorn et al. 2011; Harthorn & Mohr 2012a).

Over the course of the life of the CNS at UCSB, a European model for Responsible Innovation has crystallized. It more explicitly advocates for technological governance that is: anticipatory, reflexive, inclusive/participatory, and responsive (Owen et al. 2013). This language is not yet widespread in US technological governance terms, but we have compelling evidence that US publics strongly share these ethical stances. And, as pointed out in our edited volume, "Novel upstream research and engagement efforts challenge publics and experts to anticipate feelings, judgments, and actions for whole new classes of technologies, and to imagine them as active agents in social contexts that may reproduce, exacerbate, or ameliorate current inequalities, recreancy concerns (Freudenburg 1993), or obstacles to democratic institutions" (Harthorn & Mohr 2012b: 11).

3.1 THE PUBLIC IS READILY ENGAGED

Even far upstream, meaningful discussion has not only been possible but highly productive in the nanotechnologies case. CNS IRG 3 has contributed at a very prominent level to the development of conceptual thinking about the novel processes of upstream engagement associated with the nanotechnology case. Upstream engagement invites selected publics to participate in dialogue about technologies before they are widely researched or known (Pidgeon & Rogers-Hayden, 2007; Rogers-Hayden & Pidgeon 2007; Rogers-Hayden & Pidgeon 2008). Corner and Pidgeon conducted a systematic comparative review of 18 nanotech deliberation projects in N. America and Europe and found that the ones that 'worked' shared these characteristics (Corner and Pidgeon 2012):

- They produced informed judgment, rather than intuitive, 'fast' thinking among participants, that is, actual deliberation took place;
- Benefit centricity was quite widespread;
- But also, they found *latent ambivalence* on the part of publics that was unaffected by increased knowledge and awareness and had as key elements: skepticism toward government & industry; concern about who represents the public's interests; and significant questions about the need for the new technology/product at all.

In the latter case, Corner and Pidgeon (2012) argue that latent ambivalence "is really about the social context in which a science is conducted, rather than the risks of the technology itself" (and we found this in our own comparative US-UK deliberations). In the latter, concern focused on the social rather than technical side of risk, no matter how much technical info or expertise we provided. We have argued that these new upstream models for successful nanotech upstream engagement can serve an important function in "broadening the scope of public involvement in decision making about science and technologies" (Harthorn & Mohr 2012:11).

IRG 3 nanotechnology public engagement protocols and success have also served as the foundation for a series of highly successful public engagements in the UK to dialogue on such controversial new technologies as climate geoengineering (Pidgeon, Corner et al. 2012; Corner, Parkhill and Vaughan 2013; Pidgeon, Parkhill et al. 2013), and in the US and UK to discuss shale gas and oil extraction (Thomas et al. 2016; Partridge et al. 2016). They have also served as the model for extensive public engagement work in the UK on public values and acceptability of energy system change (Parkhill, Demski et al. 2013; Pidgeon, Demski et al. 2014; Demski, Butler et al. 2015) and on climate change (Corner, Markowitz and Pidgeon 2014). **These studies demonstrate the leverage value of CNS foundational research on public engagement and citizen dialogue about nanotechnologies' risks and benefits.**

3.2 ENGAGING ORGANIZED PUBLICS

CSOs (Civil Society Organizations—a broader term than non-governmental organization) or SMOs (Social Movement Organizations) constitute an important type of public often overlooked in calls for "upstream engagement" which invites participation from individual publics in dialogue about technologies before they are widely researched or known (see Corner and Pidgeon, 2012; Pidgeon and Rogers-Hayden 2007). Researchers have argued that public engagement projects, rather than creating spaces for public partnership in shaping technological development, may serve as exercises in earning public trust in science experts (Irwin 2006; Wynne, 2007). SMOs, however, deliberate nanotechnology in less controlled contexts, through the web, with the media, and within their communication networks. As "uninvited publics" (Wynne, 2007), SMOs are participating in as well as facilitating upstream engagement, and they are well-positioned to influence public perceptions, particularly in the context of low public awareness of nanotechnology. In comparison to unorganized publics, CSOs have better structural and financial resources to conduct research, issue reports, and communicate their views to the media, policymakers, and industry. Additionally, some CSOs could be understood to represent wider publics in dialogues with government and industry leaders (Engeman, Rogers-Brown & Harthorn 2016).

To investigate CSO involvement in nano, we (grad fellow Engemen and Harthorn, with sociologist Earl) have studied their actions since 2010, building a global database of 233 organizations that have expressed interest in or concern about nanotechnology in English, 101 of whom we identified as 'nano-engaged'—doing more than just endorsing other groups' nano-focused actions. Preliminary findings demonstrate that nano-engaged CSOs targeted government institutions in their pursuit of increased EHS funding, product labeling, and government oversight. Some researchers have argued that, in regard to emerging technologies, CSOs are filling the void left by governments in the wake of neoliberalism (Hess et al., 2008). Despite a seeming lack of trust in government agencies to safeguard consumer and environmental safety, the nano-engaged CSOs in this study, in seeking desired outcomes, targeted government agencies and policymakers, rather than targeting industries directly as might be anticipated based on research in science and technology studies (see Hess et al., 2008).

Photo: IRG 3 Graduates & Postdocs, 2011

3.3 PUBLIC PARTICIPATION

Our work shows that ***public ideas and values about responsible development*** include 4 factors: 1) the role of the public in tech development, 2) their views on equity and power, 3) their belief in issues of informed consent to move forward with development, and 4) their levels of trust in institutions in the context of nanotechnology. We take this to show that publics do have a well defined and somewhat overlapping set of understandings about responsible development, and that those who feel development is not happening responsibly in these terms are less likely to find environmental exposures of MNM acceptable (Harthorn, Collins, Satterfield and Hanna *in preparation*).

Our work on equity and politics as key drivers shows that gender is just one of many factors that can drive perception and interaction; and we found that group interactions (including multi-stakeholder ones) are socially very complex and difficult to decipher. More work on this and tools for such analysis are badly needed.

B. Broader Impacts - Contributions to Society

Because of our focus on risk concerns, our work has been of significant interest to science and engineering (S&E), to the nanomaterials industry, to policymakers and regulators, as well as to members of the wider publics in the US, Canada, and the UK and EU where the 3 team leaders are based. Via engagement with state, national and international governing bodies and agencies, to S&E audiences, to toxicologists and industrial hygienists, to the nanomaterials industry, and to local and regional communities, science museums, schools, colleges, community colleges, business

groups, and civil society groups, CNS's impacts will continue beyond the typical academic venues of disciplinary conferences and journal publications. We have also been covered in the national presses of US, UK, and Canada. Comprehensive listings of all our relevant presentations from 2005 to 2016 are available on the CNS website: http://www.cns.ucsb.edu/presentations

Here we just provide a few of the more recent highlights.

In Jan 2010, Harthorn, Pidgeon and Satterfield convened a Nano Risk Perception specialist meeting in Santa Barbara, drawing the world's leading risk perception experts from the US, Canada, UK, Switzerland, Germany, and Portugal to deliberate the contours of emergent nanotech risk perception, debating issues such as novelty, equity and fairness, gender and risk perception, media coverage, comparative risk objects, and national and international risk governance issues. We published an overview and a set of papers from the meeting in a special issue of the highly regarded journal *Risk Analysis* (Pidgeon, Harthorn & Satterfield 2011).

Since 2008 when it was founded, IRG 3 has collaborated with the UC Center for Environmental Implications of Nanotechnology at UCLA, one of the two NSF/EPA national centers in the US dedicated to research, education and outreach on the ecotoxicology of nanotechnology. Harthorn has been a member of the CEIN Executive Committee since 2008, and from 2008 to 2014, she led the only societal implications research group in the Center, which included Freudenburg, Satterfield and Kandlikar, along with our students and postdocs, to conduct a series of research projects on environmental risk perception of nanotechnology. This has resulted in a series of high impact publications and ongoing engagement of science and society issues within the CEIN, including joint research, education and outreach activities (e.g., Holden et al. 2016).

IRG co-leader Nick Pidgeon, with his Understanding Risk Research Group at Cardiff University, has been a leader of societal risk research initiatives in the UK on nanotechnology as well as GMOs, climate engineering, and energy. He was awarded an Honorary Fellowship of the British Science Association in 2011, and an MBE (Member of the British Empire) in the 2014 Queen's Birthday Honours for his services to climate change awareness and energy security policy. He is a social science advisor to the UK Department of Environment, Food and Rural Affairs and to the Department of Energy and Climate Change, and he is regularly called to provide testimony to the government and the Royal Society on risk related issues, including, for example, a presentation to House of Commons Science and Technology Committee inquiry on the regulation of geoengineering in London, United Kingdom, January 2010.

In Winter and Spring 2010, CNS Director and IRG 3 leader Barbara Harthorn made a series of presentations as part of the 10-year assessment of progress in the NNI. This included providing testimony on societal implications research to both the US President's Council of Advisors on Science and Technology (PCAST) and to the National Academies of Science in their separate evaluations of the NNI, and overview keynote presentations to the Revisioning Nano2 conference, Evanston, IL, March 9-10, 2010 and to the NNCO EHS Capstone conference, Washington, D.C., March 30-31, 2010.

The second IRG 3 survey of the ENM Industry in 2009-10 resulted in a series of presentations to government and industry: Grad Fellow Engeman to the Nanotech 2010 Exhibition and Conference, nanotechnology working group, National Institute of Advanced Industrial Science and Technology (AIST), Tokyo, Japan, March 8, 2010; Engeman & Bren School MSEM student Baumgartner video conference presentation on industry views of EHS risks to the Nanotechnology [Industry] Colloquium (invited by Applied Nanotechnology, Inc.), Austin, TX, March 8, 2010, and to the California Department of Toxic Substance Control (DTSC) at UCSB-CEIN, Santa Barbara, CA, April 15, 2010 and by co-leader Holden in the Nanotechnology VI: Progress in Protection conference, California Department of Toxic Substance Control (DTSC), Los Angeles, CA, October 13, 2010; Harthorn also gave a Keynote Address on this work at the NIOSH Nanotech OHS & Medical Surveillance, Keystone, CO, July 21-23, 2010.

The CNS at UCSB, along with the CNS at ASU and the NanoCenter at University of South Carolina was a co-founder of a new international professional society, the Society for the Study of Nanoscience and Emerging Technology, in 2008. Harthorn has been a lead board member, organizer, program committee member, and fundraiser for the organization through its first five years, including serving as the co-organizer of the annual meeting in Nov 2011 in Tempe, AZ, with Dave Guston at the CNS at ASU. Nick Pidgeon and CNS National Advisory Board member Ann Bostrom both gave plenary keynote addresses on emerging technologies and risk perception at the 2011 meeting.

In Nov 2014, Harthorn and Engeman of IRG 3 were the lead organizers of a large international conference on *Democratizing Technologies: Assessing the Roles of NGOs in Shaping Technological Futures* held at UCSB in Nov 2014, along with IRG 2's Appelbaum and an interdisciplinary committee of interested faculty and students at UCSB. The conference builds on IRG 3's work on civil society organizations as critical stakeholders in responsible innovation and development of new technologies by asking how NGOs/CSOs engage with and against new technologies around the globe, and the implications of NGO watchdogs for emerging tech governance. The team co-authored a full report on the conference that is available at (Han et al. 2015): http://www.cns.ucsb.edu/sites/www.cns.ucsb.edu/files/demtech/Democratizing%20Technologies%20Conference%20Report.pdf

IRG 3 HAS BENEFITED GREATLY FROM THE CONTRIBUTIONS OF UNDERGRADUATES, GRADUATE STUDENTS, AND POSTDOCS.

Photo: CNS community college interns.

All IRG 3 grads and postdocs at UCSB have participated annually in NanoDays public education meetings held annually in local Santa Barbara communities—thousands of local school children and their families were reached through these activities; the events were co-organized with the UCSB California NanoSystems Institute and the NNIN.

Harthorn was an invited speaker at a Congressional Briefing on ‘Nanotechnology Policy: Evolving and Maturing’ American Chemical Society, Washington, DC, October 9, 2015 in which she argued for the critical importance of policy maker attention to IRG 3 identified regulatory gaps, reported on public ambivalence about medical nanotechnologies due to distributive justice concerns, and the ongoing potential for a shift away from public acceptance if there is not open and responsible governance.

IRG 3 researchers have provided insight into effective science communication strategies. Harthorn served on the planning committee and was an invited keynote speaker at the 2013 NNI Risk 3 Stakeholder Workshop in Washington, DC in September 2013 (Fadel, Morita and Mayfield 2013). Pidgeon was an invited participant at the 2nd NAS Sackler Colloquium on Science of Science Communication, and his talk was published in their special issue of PNAS on this topic (Pidgeon et al. 2014). Harthorn served as an invited ethnographic observer, and closing speaker at the US-EU nanoEHS Communities of Research (COR) Scrimmage and meeting at the National Science Foundation, June 6, 2016. https://nanoehs.enanomapper.net/.

IRG 3’s team at University of British Columbia led by Satterfield and Kandlikar, in conjunction with Decision Research’s Gregory, have engaged in highly specialized outreach to the technical S&E community, conducting research on the US regulatory oversight on nanomaterials across the product life cycle. On Aug 13 2013 Nanowerk ran a piece on their work http://www.nanowerk.com/spotlight/spotid=31804.php. And their former student and postdoc, Beaudrie, has taken a lead role in the international Society for Risk Analysis, heading the Nanomaterials Risk Specialty Group, engaging with the American Chemical Society (Aug 2014), organizing a 2-Day Expert’s Workshop on Alternative Testing Strategies for Nanomaterials with members of the Society for Risk Analysis in Denver, CO, September 15-16, 2014, and presenting to SETAC North America (Society for Environmental Toxicology and Chemistry) in Nov of that year.

IRG 3 has benefited greatly from the contributions of undergraduates, graduate students, and postdocs have contributed greatly to this effort; they have also greatly benefited from their participation in this large, collective research enterprise. We have had wonderful outcomes for students and postdocs in the job market, even those completing degrees at a particularly difficult time (see separate participant listed separately for a full list). A few selected examples show the array of career paths CNS IRG 3 experience has provided:

- **Mary Collins** went on from pre-doctoral and brief post-doctoral researcher positions in CNS and UC CEIN at UCSB to a 2-year postdoc at SESYNC, the national ecology center at University of Maryland, and then directly into a tenure track position in Fall 2015 in Environmental Health at SUNY EFT, Syracuse; she continues collaboration in the CNS with Harthorn and Satterfield.

- IRG 3 Science fellow **Shannon Hanna** worked on the same CNS/UC CEIN environmental risk project at UCSB, then moved to

Photo: Nano-enabled antimicrobial teddy bear

NIST (National Institute of Standards and Technology) where he continues postdoctoral work on the environmental characterization of engineered nanomaterials

- IRG 3 Social Science fellow **Christine Shearer** worked on the gender nanotech deliberation project with Harthorn and Rogers-Brown, both as a pre-doc and postdoctoral researcher at UCSB, then went on to a postdoc at UC Irvine in climate science, and now is pursuing her career as a reporter and climate change activist/writer in the nonprofit sector with CoalSwarm.

- **Christian Beaudrie**, see above—completed his doctorate at UBC on CNS/UC CEIN research on regulatory risk perception and management, has moved into the environmental consulting business with Compass Resource Management in Vancouver.

- GIS expert **Indy Hurt** worked in IRG 3 with Harthorn as a fellow on public deliberation and spatial analysis, completed her PhD at UCSB in geography, and moved directly to Apple headquarters in a development position in their mapping initiative. She recently moved on to work on developing open source map technology with Mapzen.

Many of our former students and postdocs continue their collaborative work in the CNS long after graduation, as you can see from the IRG 3 full publication list on the website at: http://www.cns.ucsb.edu/publications.

IRG 3: UNDERSTANDING NANOTECHNOLOGIES' RISKS AND BENEFITS

Key Findings, References, Participant List

Key Policy-Related Findings From Our Research

- Public acceptability of nanotechnologies is driven by: benefit perception, the type of application, and the risk messages transmitted from trusted sources and their stability over time; therefore transparent and responsible risk communication is a critical aspect of acceptability.

- Social risks, particularly issues of equity and politics, are primary, not secondary, drivers of perception and need to be fully addressed in any new technology development. We have devoted particular attention to studying how gender and race/ethnicity affect risk judgments.

- The upstream dominance of benefit perception should not be taken as an indication of continued high public acceptability of nanotechnologies over time. Conclusions regarding current views are tempered by a high level of uncertainty and indicate the above noted malleability, particularly if benefit-only communication is followed by risk communication. Public acceptability should be viewed as conditional, requiring continued trustworthy actions by government and industry.

- There is almost no sensitivity of publics to differences in the actual engineered nanomaterials, even though toxicological evidence indicates increasingly solid evidence for their differential effects. Therefore, the whole class of nanomaterials is vulnerable in the event that those that more hazardous are not regulated well and so become the basis for stigma or radiating effects.

- Although representatives from the nanomaterials industry demonstrate relatively high perceived risk regarding engineered nanomaterials, they likewise demonstrate low sensitivity to variance in risks across type of engineered nanomaterials, and a strong disinclination to regulation. This situation puts workers at significant risk and probably requires regulatory action now (beyond the currently favored voluntary or 'soft law' approaches).

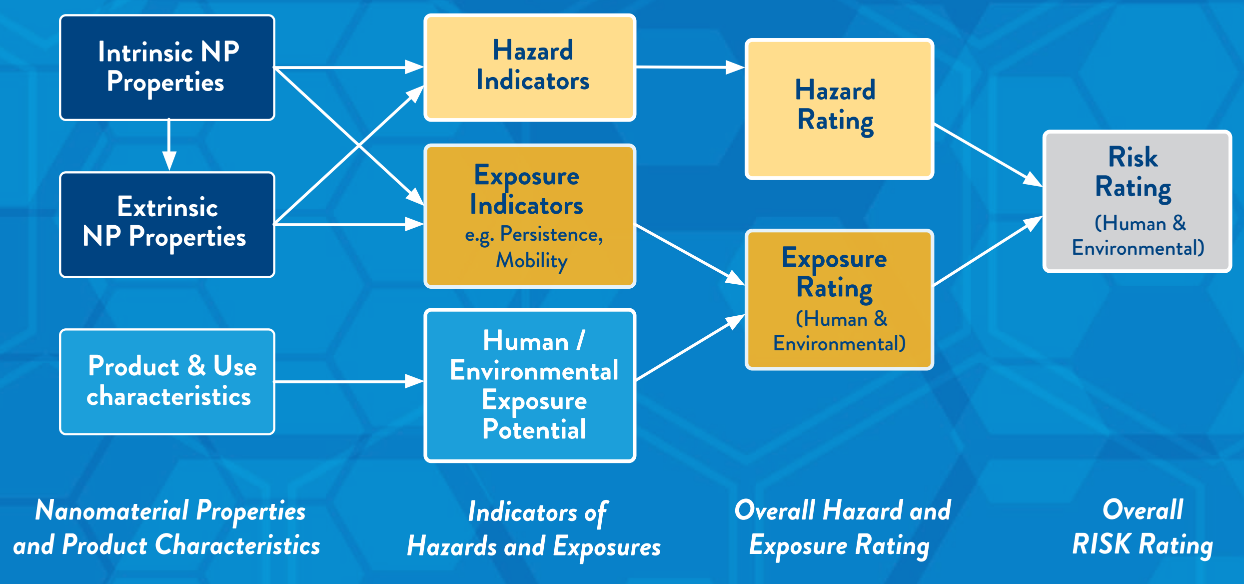
- All stakeholders in the nano-enterprise, including experts, display dependence in some circumstances on intuitive risk judgments that are at odds with current evidence. Systematic social science research is therefore a critical part of responsible policy and can be used to anticipate where experts most need research and extension support.

- Scientists and engineers, toxicologists, and regulators display significant diversity in their views on the risks of nanomaterials and the regulatory sufficiency of current frameworks for regulating nanomaterials and nano-enabled products. Therefore, a diverse composition of experts is needed in regulatory decision-making bodies in order to capture the full range of these views.

- Those scientists and engineers working most closely with nanomaterials in the early stages of development (e.g., of novel materials and applications) show the highest risk tolerance among experts. The implications for labs and bench science safety among students, postdocs and workers should thus be investigated.

- Among experts, nanotech regulators and federal and state agency personnel express the least confidence in the current regulatory system. There are clearly identified gaps (often large) in regulatory coverage across product lifecycles that contribute to these concerns. The aging regulatory system in place demands systematic policy maker attention and integration across agencies.

FIGURE 14. NANOMATERIAL RISK SCREENING TOOL



Source: Kandlikar, Beaudrie, Gregory, Long & Wilson 2015

- In spite of regulatory and risk assessment uncertainties, diverse expert engagement for development of new tools and approaches can be conducted successfully using current theory and practice in structured decision making. It is critical to implement these now rather than to wait for completed hazard and exposure assessments, particularly given this large and complex class of new materials such as engineered nanomaterials.

- The public can and should be engaged, early and often, in the development and commercialization of new technologies, particularly those with high potential for risk (health, environment, and social) and disruption. European deliberative models have been successfully implemented in the US by CNS and could be scaled up for national deliberation. CNS research has shown that a majority of US publics endorse the core values of responsible innovation.

- Civil society organizations such as NGOs can and should be invited participants and have an increasingly important role to play in safe and responsible development and innovation. Societal experts provide important evidence-based knowledge and understanding for effective facilitation of this process.

- Experts can and should be productive and reflexive participants in public engagement. The CNS at UCSB provides hundreds of examples of successful expert engagement, facilitated by social science researchers and based on solid social science evidence. Federal funders should require such integrated efforts and dedicated resources for all new technology R&D.

- Public participation has been greatly enhanced in the NNI through NSF investment in national societal research and education centers. This approach can and should become an integral part of US technology development, with funding and incentives to develop new methods and approaches, grounded in the best social research practices.

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IRG 3: RISK PERCEPTION AND SOCIAL RESPONSE

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