CNS-ASU Report #R11-0001

The Center for Nanotechnology in Society
ARIZONA STATE UNIVERSITY

CNS Systematic Analysis Workshop

Urban Sustainability Syndromes

Arnim Wiek
Arizona State University
School of Sustainability

Rider Foley
Arizona State University
School of Sustainability

June 2011

This research was conducted as part of the Center for Nanotechnology in Society, Arizona State University (CNS-ASU). CNS-ASU research, education, and outreach activities are supported by the National Science Foundation under cooperative agreement #0937591.

NSF

Table of Contents

Tables

Figures

1.0 Introduction

Thematic Research Cluster 2 (TRC-2) within the Center for Nanotechnology in Society at Arizona State University (CNS-ASU) focuses on nanotechnology embedded in urban environments. Nanotechnology is lauded for enabling society to become more sustainable. From Nobel Laureate in Chemistry, Richard Smalley (2006) to Diallo et al. (2011) claims that nanotechnology will address sustainability issues are prevalent in the literature. The American Chemical Society, is focusing a significant amount of research on the issues of using nano-chemistry to address sustainability challenges (Weiss and Lewis 2010).

Claims like these appear to be aligned with sustainability science. But sustainability science has been emerging as a discipline that is problem-focused and solution-oriented (Kates et al. 2001; Clark and Dickson 2003; Komijama and Takeuchi 2006; Jernecke et al. 2011; Wiek, Ness et al. 2012). In the last ten years, sustainability science built upon Rittel and Webber (1973) wicked problem definition in both theoretically and (Ravetz 2006; Seager et al. 2011; Wiek et al. 2012). We are using *urban sustainability syndromes* as a term to define the challenges facing our cities. However, the claims that nanotechnology can address sustainability challenges fails to recognize the true nature of urban sustainability syndromes. There are a number of reasons why this occurs. First, sustainability is narrowly defined as an issue of natural resources (e.g. energy generation). This definition fails to address the social dimension of sustainability, such as hierarchies, justice, and norms (Jernecke et al. 2011; Wiek et al. 2012). Second, the underlying drivers of wicked problems are not addressed by nanotechnology. Societal demand for convenience food and the cultural expectations that fast-food will be available at the drive-in is not addressed through technology. Addressing food production does in no way related to our cultural norms that demand drive-in dining and fast-food service to ameliorate our value of convenience. Third, nanotechnology-based solutions (like many technological fixes) are the initial response, and not considered as part of a suite of solution options. Social and educational programs may prove more efficient in many cases (Sarewitz and Nelson 2008). Fourth, nanotechnologies as the provider of benefits and source of risk is seldom considered. When addressing urban sustainability syndromes, we must ask will the nanotechnology reinforce or make the current situation worse, even as we attempt to solve the problem (Seager et al. 2011). We seek to understand the city environment that nanotechnology will be introduced. Therefore, our first step is to understand the nature of the urban sustainability syndromes.

Cities are now home to more than fifty percent of the world's people and have started to address issues of sustainability through city-based actions (Svara 2011) and as a collective of global cities (C40 2011). Urban centers are the home to regional, state, and national decision-making bodies that comprise a complex network of institutions, resources, and actors taking

actions to identify problems and craft solutions. Ross (2011) denotes that Phoenix is the globe's least sustainability urban region and is ripe for change. The ultimate goal of our research agenda is to prepare research that embeds nanotechnology into a suite of potential solutions to urban sustainability syndromes that warrant consideration and assessment by experts and stakeholders. In this way we attempt to operationalize anticipatory governance within the urban context using the perspective of sustainability science to assess, in real-time, emerging technologies, specifically nanotechnology (Guston, 2008; Karinen and Guston 2010; Wiek, Guston, van der Leeuw, et al. 2012; Wiek, Guston, Frow, et al. 2012).

2.0 Workshop Objectives

The workshop objectives are four-fold. First, elicit the urban sustainability syndromes within the Phoenix metropolitan area that currently exist and will persist for the foreseeable near-term (0-5 years). Secondly, prioritize these urban sustainability syndromes and construction of causal diagrams for the top five (5) urban sustainability syndromes. This activity would document the upstream drivers contributing to the urban sustainability syndromes, detail the actions, activities, and behaviors that embody the persistence of the issue, state the perceived and real benefits from those actions and the perceived and real negative impacts and affected people (populations) that result from those actions. The third goal, is to not only to further the singular research objective of TRC-2 but also, to further the goals of the larger CNS research team by training undergraduate and graduate students in the process of planning, structuring, facilitating, and capturing information through experiential learning during the course of the workshop itself. And finally, the team sought to translate information between and among disciplinary researchers in an effort to facilitate future engagement and trans-disciplinary knowledge generation.

These efforts are meant to further the center's goal of exploring new ideas, disseminating information, and seeding future discussions within the context of emerging technology issues, societal impacts, and problem-based thinking. Further, this was an effort to research differently, by framing the research through the orientation of urban sustainability we can better understand the current state of the city environment and therefore take a more grounded approach in scenario construction, visioning exercises, and strategy building that are planned in future research. Additionally, by seeking engagement with the diverse disciplines represented, TRC-2 intends to grow the engagement effort of CNS, building bridges to new research communities. Finally, we sought to play well with the scientists invited and build trust and gain mutual understanding on the issues of concern.

3.0 Workshop Design

Following Sarewitz and Pielke's (2007) supply-demand framework, we conceptualize sustainability problems as demand (as there is a need for society to address them) and nanotechnology as a potential supply (providing solution options). The goal is to identify the overlap between demand and supply, or in other words, *reconcile* to what extent demand for solutions to sustainability problems and supply of nanotechnology actually match (Sarewitz and Nelson 2008). Existing and proposed nanotechnologies have the potential to address a spectrum of challenges, but defining the intersection or overlap between demand and supply means identifying how nanotechnology 'solves' specific problems, with what impacts (intended and unintended), and whether or not other, more sustainable, alternatives exist (Wiek, Guston, van der Leeuw et al. 2012).

In an effort to gain perspective on the urban sustainability syndromes within our bounds, we invited experts in sustainability science, urban planning, environmental justice, social justice, energy planning, natural resource management, and urban governance to a collaborative and trans-disciplinary workshop in February 2011. Fifteen scholars versed in urban planning, urban ecology, social justice, energy, water, climate, and urban geography were invited and chose to attend the workshop to develop urban sustainability syndromes as complex, systemic problems.

Upon entry to the workshop, participants were first introduced both to CNS and TRC-2 broadly with background information and orientation in the plenary. Participants were then provided an overview of the workshop proceedings and expectations from the research team. This introduction and orientation provided context within which the experts were expected to offer their insights and contribute throughout the workshop.

With our investigative lens focused on the Phoenix metropolitan area, of four hundred square miles with 3.8 million residents (US Census 2010), we have seek to formalize a listing of the urban sustainability syndromes that are facing the city in the short-term (zero to five year). This bounds our spatial and temporal dimensions for our research foray into the urban sustainability syndromes present at the time when nanotechnology is starting to emerge into the social fabric and built environments of the city.

The first activity was to elicit an initial listing of urban sustainability syndromes facing the Phoenix metropolitan area in the near-term (0-5 years) horizon. This was conducted in the plenary. Participants were handed a sheet of paper with instructions to write down three urban syndromes, identify the impacts and the affected populations. Participants were given an example of a syndrome that has been researched in detail and this syndrome was illustrated as an example on the handout. Participants spent approximately ten minutes writing

individually. The facilitator then asked participants to voluntarily contribute their examples. A second facilitator captured this on a white board. In plenary, participants continued until all had exhausted their written lists.

After all the urban sustainability syndromes, impacts and affected populations were captured, the participants were asked to reflect on the collective listing and identify and fill any gaps that might be observed. For prioritize the list for the next activity, each participant was given three sticky notes as proxies for votes. Participants were instructed to place their votes next to the syndrome that they felt was the highest priority. This was not a closed balloting session. Once voting concluded and participants took a brief break.

Upon returning to the plenary, participants were oriented to the next activity through a short (<10 minute) introduction to the causal diagram, orientation and definitions of the categories to be completed (drivers, actions, perceived benefits, negative impacts, and affected populations). See Figure 1 below to review the causal diagram from which the facilitation team worked to orient the participants. Participants were given the option of working on any one of the top three priority syndromes and construct a causal diagram in breakout groups. Participants self-selected one of the three groups, subsequently determined who contributed to which syndrome causal mapping activity. One facilitator from the research team assisted the each breakout group through the process of filling in the blank causal diagrams (see figure 2). The structure and schedule of the workshop are detailed in table 1.

Activities	**Desired Outcome**
Greeting & IRB Compliance Forms	IRB commitments met
Introduction	All participants oriented to the goals of workshop
Questionnaire handed to participants and obesity example is reviewed	Urban sustainability syndromes (activities, impacts, affected population)
Participant-moderator demand sequence: a. Participant expresses a syndrome b. Next participant expresses a syndrome c. Continue sequentially	Facilitated list of urban syndromes
Ranking exercise Participants vote for highest priority on the white board next to the syndrome	Rudimentary ranking of the syndromes to select highest priorities for next activity
Break after ranking	Rest
Causal mapping Have participant break into three groups Start in lower right corner with impacts and affected people and work through map	Causal maps of 6 urban syndromes
Conclusion	

Table 1. Workshop Design. The activities and goals of the workshop are presented.

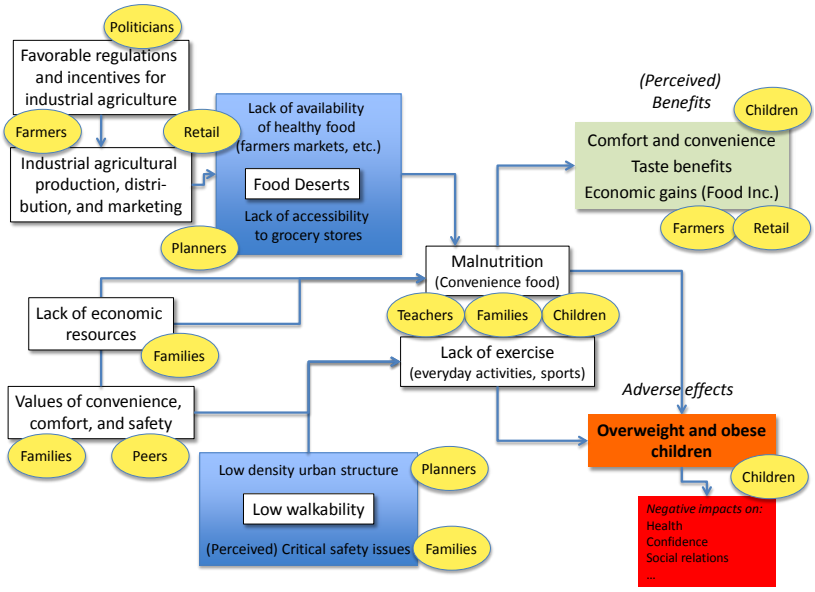

Figure 1. Obesity problem constellation. Figure used to demonstrate and orient participants to the content, flow, and structure of causal diagrams detailing urban sustainability syndromes.

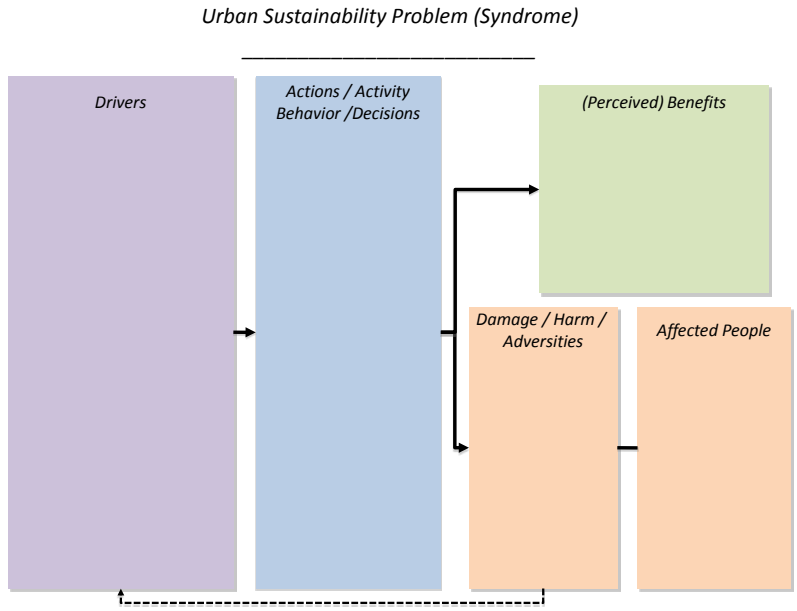

Figure 2. Blank problem constellation. This figure was printed on 24" x 36" paper and participants filled in the structure to capture information about urban sustainability syndromes.

4.0 Outcomes

The workshop yielded numerous first-time introductions within and among the various disciplines of scientists present. This created an environment of both engagement and excitement for the opportunity presented to participants to work collaboratively. The group

quickly grasped both the context of the project and the applicability to place-based urban sustainability syndromes as a starting point for exploration of how technological solutions will become embedded in the urban environment.

Activity 1 Elicitation of Urban Sustainability Syndromes

Moving through the first activity, participants took seriously the task of detailing the urban sustainability syndromes individually, identifying the impacts, and correlating this to the affected people (population). Within the plenary the group members often co-contributed or built upon each other's entries. This at times presented a challenge to the facilitators, how to bound or separate syndromes. Rather than having a singular agglomeration that was all encompassing and indefinable. Although, after one or two urban sustainability syndromes were captured on the white board the group brought new information and trans-disciplinary expertise to bear on the co-production of the raw listing activity. Below in Figure 3, one facilitator captures the contributions on the whiteboard from participants, while another facilitator elicits and moderates the contributions. All participants spoke and contributed content, although contribution was both random and entirely voluntary. At the conclusion of the exercise the facilitator offered a time to reflect upon the entire list and assess the list for gaps. Upon reflection the group realized they had missed three issues and those were expressed and captured prior to moving into the next activity. The raw listing of syndromes, impacts, and affected populations is presented below in Table 2.

	Urban Sustainability Syndrome	**Impacts**	**Affected People**
A	Childhood Obesity	Negative long term health impacts, adverse psycho-social effects, high economic costs	Children in lower socioeconomic groups
B	Marginalization of communities of color	Psycho social effects, lower social standing, access to services, changes in crime, Declining relations between citizens and police	Communities of color, law enforcement, citizens
C	Environmental injustices	Removing opportunities	Lower income communities
D	Highly fragmented, segregated residential areas	Higher crime, unequal access, marginalization, loss of public spaces, community space, less interaction	Lower socio-economic groups, Higher socio-economic groups
E	Lack of access to public space	Health, lack of integration, lack of exposure to outdoors, misinterpretation of private space for public space, fear	Everyone
F	Energy inefficiency, transportation, buildings	Energy inefficiency, social isolation, air quality, rising energy costs, CO2 emissions	Lower socio economic groups
G	High rates of consumption and resulting waste	Waste, energy inefficiency, inequities, poverty-food waste, low labor standards	Everyone
H	Urban sprawl	Automobile dependency, traffic	Populations at urban fringe
I	Air quality	Economic effects, health effects	Current and future citizens

J	Native American Health	Lack of access to services, diminished health	Urban Native Americans
K	Current economic model, development based	Diminished tax revenue, public services, education, lack of development resources	All citizens, lower socioeconomic populations
L	Urban Heat Island Effect	Heat stress problems, energy use, ozone,	Low income groups
M	Account for ecosystem services	Diminished services	current and future citizens
N	Water use	Depletion and rising prices	poor and people on the fringe (the water poor)
O	Food availability, security	Obesity, health, quality of life	Poor, middle class, minorities
P	Energy sources	Air quality, rising costs	everyone

Table 2. Urban sustainability syndromes raw listing. Original concepts expressed by participants of urban sustainability syndromes with impacts and affected populations.

Figure 3. Facilitation. One facilitator works to capture information expressed by participants, while the other facilitator moderates both the flow and content of information in the plenary.

Activity 2 Prioritization of Urban Sustainability Syndromes

Participants both had fun with and took seriously the task of voting for the highest priority issues. The open and collective nature of the voting system allowed for participants to step back and evaluate potentially emergent winners and loser. The fact that they held three votes each allowed certain people to develop a strategy of withholding votes until the end, when they could have a narrower pool of potential winners from which to tip the balance. Discussion took place actively between the participants and they discussed their votes in a truly open and transparent form of democracy (at least within this workshop setting). In figure 4, participants are observed placing votes at the white board, participants are discussing priorities and others are off-camera observing and waiting to cast final and decisive votes.

Figure 4. Participant Prioritization Activity. This photograph depicts participants placing votes with sticky notes to prioritize the listing of the urban sustainability syndromes.

This activity offered a clear listing among the top five priorities upon which the group reached consensus through this process. After the voting was completed, the question was asked in the plenary, "Does anyone strongly disagree or feel this result is invalid?" by one of the facilitators. With no verbal or non-verbal queues of displeasure with the result an additional layer of consensus building occurred at the conclusion of the activity. The top five (5) urban sustainability syndromes were prioritized as: i. current economic model, development based; ii. marginalization of communities of color – lack of integration; iii. energy inefficiency in , transportation, buildings, and urban form; iv. water use, v. energy sources.

Activity 3 Creation of Causal Diagrams

Participants after receiving an introduction and orientation to the final exercise self-selected to participate in the contribution to creating a causal diagram for each of the top three urban sustainability syndromes. The process of orientation and introduction was well received, with questions of clarification addressing concerns in the plenary prior to the breakout groups. In figure 5, participants are observed engaging with the breakout group moderators and with the causal diagram. Tables 3 shows the urban sustainability syndromes that participants in coordination with facilitators developed.

Figure 5. Break out facilitation. This photo depicts a breakout group moderator engaging with participants while constructing and documenting information on a causal diagram.

Table 3 presents numerous causal relationships between critical drivers (institutions, policy, cultural norms, historical conditions) and the actions taken that contribute to both positive and negative outcomes. The causal relations and constellation framework allow for feedback loops within the individual urban sustainability syndromes. Further, breakout groups expressed causal relations and co-contributing factors and impacts between the separate urban sustainability syndromes. One example is the appearance of "American Dream" in multiple causal diagrams in both the driver category (cultural norm) and in a separate causal diagram as the perceived benefit. Cultural norms and values expressions are certainly co-contributing factors that can manifest within the context of diverse problem-oriented mapping. The inseparability of problem-oriented diagrams from the social, political, technological, and ecological context demands attunement to those co-contributing factors. It is from this place-based orientation that our research can contextualize socio-technical interactions in the greater Phoenix metropolitan area.

	Short Title	Causing Activities and Actors	Underlying Drivers and Actors	Adverse Effects (AE) & Impacted Populations (IP)
Driver-Oriented	Unstable Economy	Hit & Run Development and Developers; Capital mobility by investors; Low cost construction and low wage employers; Box store development by vertically integrated distribution and retail firms;	Image of empty desert needing improvement; Vast land supply; Values of freedom and 'American Dream'; Belief in infinite resources; Zoning codes;	AE: Foreclosure rates, evictions, temporary employment, disposable employees; high vacancy & ghost towns; increased vandalism; lost tax revenue; school closings IP: Minority and lower socio-economic communities
Driver-Oriented	Electric Energy System	Centralized planning with limited redundancy in system; Excessive use based on potentially unlimited supply; Subsidizing fossil fuels; Lack of knowledge about alternatives; Larger homes and dwelling creating demand; inconsistent investment in non-fossil based fuel sources	National grid based on Rural Electrification Policy; government subsidies; Culture of electrical consumption; path dependency; sunk costs in infrastructure; full life cycle costs (social, economic, and environmental) not incorporated into price; national security perception; land-use; tax incentives; building codes	AE: Vulnerability to power outages, based on dependence for heating, cooling, cooking, and water; decreased visibility; increased DALYs from poor air quality; increased carbon dioxide emissions; mining and extraction impacts; transmission impacts (lines, pipes, tankers, and trucks); IP: Lower socio-economic groups; workers with direct exposure; children (lung development); elderly (increased stress on lungs); populations downwind from major sources
Driver-Oriented	Water System	Outdoor landscaping with water intensive flora; Recruiting high water consuming industry (solar and semi-conductors); Investments in water intensive agriculture (cotton); Contractually cheap and guaranteed water supply.	Government subsidies (Reclamation Act), Phoenix as 'Desert Oasis'; Desire for high-tech economic development; Historical allocation of water (Western Water Rights); Direct cotton subsidies;	AE: Increased food costs for transportation, Climate change creating higher drought potential; higher water costs; higher energy costs;
Driver-Oriented	Mobility Patterns	Consumer choice of detached single family homes and large box stores; Willingness to drive long distance; Transportation planning (current and historic); Federal Highway Funding;	Zoning regulations; Relationship to Nature; American Dream – lawns, .25acre lots, garage; development-based profits; values of freedom, privacy, isolation, perceived safety	AE: Psycho-social impacts (stress, decreased social interaction); Ghetto-ization of urban core; Segregation of communities; Reduced air quality; decreased productivity from stress; increased carbon emissions, IP: Residents in abandoned urban core, suburban commuters, elderly lacking mobility, children under 16, disabled persons unable to drive
Adverse effect-oriented	Air Quality	Automobile driving; commuting patterns; expansive highway infrastructure developments; development at urban fringe; fossil based energy production; volatile organic based industrial production	Atmospheric patterns; topography-desert; semi-arid conditions; automobile-oriented transportation; development of emissions producing industries; tillage based agricultural practices	AE: Lung development; increased stress on physiology; increased asthmatic attacks; reduced quality of life; decreased outdoor exercise; development funding threatened by federal agencies;
Adverse effect-	Childhood Obesity	Malnutrition (Convenience foods); Lack of exercise	Food deserts; industrial agriculture practices; agricultural policy; production and distribution system; marketing and branding foods; low recreational opportunity; value of convenience, comfort, and safety; lack of knowledge; racial bias; economic constraints	AE: Early on-set diabetes; cardio-vascular diseases; psycho-social impacts; future educational opportunities and earning potential decreases; increased healthcare costs; increased morbidity and mortality IP: children, especially racial minorities and lower earning socio-economic communities; parents of obese children; society (as supported of healthcare costs) and lost productivity.

Adverse effect-	Environ-mental Justice	Industrial production of goods	Cost cutting measures; reactive government policies; incentives for industrial production; perception of safety; value of consumer-rights; values of comfort; values of utility maximization and specialization	AE: Impacted groundwater, impacted air (localized and globalized); biological impacts; exposure risks (ingestion & inhalation); decreased property values; decreased trust; geographic stigmatization; racial biases; IP: Residents, City (lost tax revenue), State and Federal Governments (remediation expenses reflect opportunity costs)
Adverse effect-oriented	Lack of Social Cohesion	Legislative mandates to address illegal aliens (SB1070); Employer sanction law (SB300); Building gated communities; historically derived white entitlement to land and water, resources; City investments (socio-geo-spatial discrimination)	Racial bias of legislature; States rights based legislature; Legacy of discriminatory housing policies; Active segregation by age and race; Axiom that people cluster by race;	AE: Immediate removal (within 48 hours) if arrested; Abandoned property; no representation; increased stress; decreased quality of life; increased health care costs (no preventative health care sought); hostility toward law enforcement; IP: Communities of color, predominantly non-white Latinos; Undocumented People
Adverse effect-oriented	Consumer Waste	Desire for inexpensive goods; Shopping as recreation; Consumer choice of products; Mediated desire; Fetisization of products; Poor labeling and information delivery; willful ignorance; desire to be 'in'; gifting as expression of religious beliefs	Culture of consumption; maximization of utility draw from Smyth; Subsidization for trade and transportation of goods; Designed product obsolescence; Media and marketing efficacy; Religious basis for consumption; Disconnection from production modes; competition in market; public policy to consume for national security	AE: Landfill-based land use; off-gassing methane, carbon dioxide; degradation of air quality; leakage of landfill effluent; Loss of dollars from local economy; Globalized wealth transfers; Stigma of poverty, being left out of consumption culture IP: Communities near landfill; local businesses and craftsmen; lower socio-economic communities; non-Christian based religious communities
Adverse effect-oriented	Urban Heat Island (UHI)	Road paving with black tar and concrete; Thermal heat adsorbing construction materials; Black or dark colored roofing materials; Urban form and building orientation	Automobile-oriented transportation network; Cheapest prices construction materials are chosen without regard to UHI; Lack of urban forest that would both reflect sunlight and provide cooling transpiration at night; Urban planners have not historically considered UHI;	AE: Higher cooling bills; increased mortality and morbidity; decreased levels of outdoor recreation; reinforcing driver of automobile reliance – too hot/ no shade to walk to bike; Urban ecology impacted by elevated temperatures and decreased flora for ecological integrity and services. IP: Lower earning socio-economic populations; Young children and elderly; residents in areas of sparse urban forests or plants; Residents near highways or un-shaded roadways where residual heat generates higher night-time temperatures;

Table 3. Top ten urban sustainability syndromes. This table details the top ten urban sustainability syndrome, listing key drivers, activity, behaviors, decisions, benefits, damage, adversities, and affected people.

5.0 Conclusion

The activity structure, focused on outcomes, offered an opportunity to achieve the stated goals of the workshop; i. elicit the current to near-term urban sustainability syndromes in the Phoenix metropolitan area; prioritize those urban sustainability syndromes; and construct problem constellations (causal diagrams) for the top five urban sustainability syndromes. Understanding the context and dynamics of the current urban sustainability syndromes facing the greater Phoenix metropolitan area will allow the research team, in collaboration with stakeholders, to evaluate the ability for technology to attenuate these issues in future scenarios. Further, the problem-orientation of this workshop allows for comparison against the functional solutions presented by nanotechnology applications.

In the process of accomplishing these goals, the workshop also achieved many of the larger CNS-ASU goals, not explicitly stated to participants; i. training undergraduate and graduate students in collaborative and co-knowledge generation workshop preparation, execution, and synthesis; ii. demonstrated and translated, in real-time, information between and among formerly isolated and independently oriented disciplinary actors; iii. exploration new ideas, disseminated information and seeded future engagement through constructive and coherent activities; iv. framed urban sustainability in a context both available and understandable to the participants; v. the workshop built new bridges across campus to disciplines previously not engaged by CNS-ASU.

In summary, the explicit goals set by the research team for the workshop were met through the structure and execution of activities. The pre-workshop planning effort to consciously orient each activity toward an outcome that lead naturally into the proceeding activity provided strong continuity and content. This continuity and content allowed for smooth transitions between activities offering progressively deeper levels of engagement from both participants and facilitator-researchers. Herein, this initial engagement opportunity provided both the participants and the research team a space to build trust and co-generate knowledge in a cooperative and open setting. It will be our express intent to build upon this trust and co-generation of knowledge throughout the term of the project and expand the network of interested and contributing parties to “Nano in the City” and to CNS as a whole entity. The knowledge created within this workshop with contextualize and orient the research team to the environment into which nanotechnology will emerge and subsequently alter the current socio-technical systems and interact with the problem constellations expressed in the dynamic urban sustainability syndromes.

6.0 References

Clark, W. C., & Dickson, N. M. (2003). Sustainability science: the emerging research program. *Proceedings of the National Academy of Sciences of the United States of America*, *100*(14), 8059-61.

C40 Cities (2012). *About us.* Retrieved 30 March 2012, from http://live.c40cities.org/about-us/

Diallo, M., Brinker, C. J., Scott, N., & Murday, J. (2011). Nanotechnology for sustainability: environment, water, food, minerals, and climate. In M. C. Roco, C. Mirkin, & M. Hersam (Eds.), *Nanotechnology Research Directions for Societal Needs in 2020* (pp. 145-173). London: Springer.

Guston, D. H. (2008). Innovation policy: not just a jumbo shrimp. *Nature*, *454*(August), 5-6.

Jerneck, A., Olsson, L., Ness, B., Anderberg, S., Baier, M., Clark, E., Hickler, T., et al. (2010). Structuring sustainability science. *Sustainability Science*, *6*(1), 69-82.

Karinen, R., & Guston, D. H. (2010). Governing Future Technologies: Nanotechnology and the Rise of an Assessment Regime. In M. Kaiser, K. M, M. S, & C. Rehmann-Sutter (Eds.), *Toward Anticipatory Governance: The Experience with Nanotechnology* (pp. 217-232). Dordrecht, NL: Springer.

Karn, B. (2005). Overview of Environmental Applications and Implications. How does nanotechnology related to the environment? Or why are we here? In B. Karn, T. Masciangioli, W.-xian Zhang, V. Colvin, & P. Alivisatos (Eds.), *Nanotechnology and the Environment: Application and Implications* (pp. 2-6). Washington, D.C.: American Chemical Society.

Kates, R. W., Clark, W. C., Corell, R., Hall, J. M., Jaeger, C. C., Lowe, I., Mccarthy, J. J., et al. (2001). Sustainability Science. *Science*, *292*(5517), 641-642.

Komiyama, H., & Takeuchi, K. (2006). Sustainability science: building a new discipline. *Sustainability Science*, *1*(1), 1-6.

Ravetz, J. (2006). Post-Normal Science and the complexity of transitions towards sustainability. *Ecological Complexity*, *3*(4), 275-284.

Rittel, H.W.J., & Webber M.M. (1973). Dilemmas in a general theory of planning. Policy Sciences 4, 155-169.

Sarewitz, D, & Pielke Jr, R. (2007). The neglected heart of science policy: reconciling supply of and demand for science. *Environmental Science & Policy*, *10*(1), 5-16.

Sarewitz, Daniel, & Nelson, R. (2008). Three rules for technological fixes. *Nature*, *456*(7224), 871-2.

Seager, T., Selinger, E., & Wiek, A. (2011). Sustainable Engineering Science for Resolving Wicked Problems. *Journal of Agricultural and Environmental Ethics*.

Smalley, R. (2006). Nanotechnology and Our Energy Challenge. In L. E. Foster (Ed.), *Nanotechnology: Science, Innovation, and Opportunity* (pp. 13-17). Upper Saddle River, NJ: Pearson Education Inc.

Svara, J. H. (2011). The Municipal Year Book 2011. In J. C. Cotnoir (Ed.), *Cities* (pp. 43-60). Washington, D.C.: ICMA Press.

Weiss, P. S., & Lewis, P. A. (2010). Sustainability through Nanotechnology. *ACS Nano*, *4*(3), 1249-50.

Wiek, A., Guston, D. H., Frow, E., & Calvert, J. (2012, in press). Sustainability and anticipatory governance in synthetic biology. *International Journal of Social Ecology and Sustainable Development*.

Wiek, A., Guston, D.H., van der Leeuw, S., Selin, C., & Shapira, P. "The nano-enhanced city, sustainability challenges, and anticipatory governance." *Journal of Urban Technology* (2012 under review).

Wiek, A., Ness. B., Brand, F. S., Schweizer-Ries, P., & Farioli, F. (2012). From complex systems analysis to transformational change: A comparative appraisal of sustainability science projects. *Sustainability Science*, vol. 7 (Supplement 1), pp. 5-24.