Theoretical Frameworks and Socio-Technical Systems for Fostering Smart Communities in Smart Grid Environments

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Project Summary

INTELLECTUAL MERIT. *The Research Challenges.* Energy sustainability is a theme of national and worldwide importance. Every aspect of our lives relies on energy, and societies as a whole are affected by the energy behavior of its citizens. The development of a more responsible use of energy is one of the most important goals in our society. The challenges of harvesting the benefits of technical innovations such as the *Smart Grid* (overlaying the electrical grid with a computational information system facilitating two-way communication) and *advanced metering infrastructure*s (measuring, collecting, and analyzing energy usage by interacting with smart meter devices) are numerous: (1) most citizens are unaware of new technological developments; (2) information presentation is poorly designed; (3) the social context of individual energy use is ignored, and few interaction and collaboration mechanisms exist; and (4) feedback alone is not persuasive enough to change human behavior. All of these challenges are grounded in the intersection of human behavior (at the individual and social levels) and technology.

Goals and Methods. The two *overarching goals* of the proposed project are (a) the creation of transformative theoretical frameworks and (b) the development of human-centered systems for fostering smart communities in Smart-Grid environments that will turn passive consumers of energy into informed, active decision makers by encouraging and supporting them to change their energy behavior.

For goal (a): This project will explore and create components of a *theoretical framework* for social-computational systems, including: (1) understanding and support of cultures of participation; (2) exploring meta-design as a design methodology to allow people to engage in personally meaningful activities; and (3) implementing incentive structures and reward mechanisms to change human behavior (at the individual and social level). To address and cope with the complexity of such a theoretical framework, this project is based on collaborations with a group of advisors whose expertise is grounded in technology-mediated social participation, behavioral psychology and behavioral economics, eco-arts and eco-visualization, and policy and privacy issues.

For goal (b): This project will explore, design, and assess components of a transformative and integrated *social-computational system*, including: (1) *HYDRA*, a multi-faceted system grounded in the theoretical frameworks and supporting feedback on real-time consumption, simulations, visualization, and the integration of individual and social behaviors (helping as well as competing); (2) OPENEI, a national development effort to create collaboratively constructed information repositories based on cultures of participation; (3) state-of-the-art hardware and software for in-house displays and platforms for *advanced metering infrastructures*. These systems will be developed in collaboration with (1) the leading-edge company *Tendril Networks* (creating advanced metering infrastructure technologies); (2) the *National Renewable Energy Laboratory* (developing OPENEI); (3) *the Sustainability Team and the Campus Community of the University of Colorado* (providing a natural setting to evaluate our developments for formative feedback throughout the project); and (4) the *Fraunhofer Institute (*a research institute in Bonn, Germany, developing a Green-IT framework).

BROAD IMPACT. Beyond the lessons learned from our specific developments, the theoretical grounding of our research will make our methodologies, components, architectures, requirements, and guidelines applicable to a large number of social-computational systems (for example, smart cities and behavior change efforts in health care environments). The *educational impact* will be demonstrated in our collaboration with the *Student Alliance* of the Renewable and Sustainable Energy Institute (RASEI) at the University of Colorado by (1) developing new curricula and interdisciplinary connections among the arenas of finance, technology, policy, science, and law; and (2) preparing students for careers in designing social-computational systems in the energy landscape of the future. The broad intellectual and practical impact of the proposed research is grounded and guaranteed by collaboration with partners well known for their academic expertise and economic success.

The need for appropriate media and communities, awareness, information, and wide-scale development and deployment of Smart Grid technologies is especially important in working toward inclusion and support for *marginal and underrepresented populations* to achieve broad participation, rather than limiting participation to a self-selected group of techno-savvy “early adopters.”

KEYWORDS: smart communities, cultures of participation, meta-design, changing human behavior, behavioral economics, energy sustainability, energy literacy, smart grids, smart meters, HYDRA, OPENEI, eco-arts, eco-visualization, multi-discipline, multi-sector, and multi-national collaboration

Project Description

1 Introduction

Smart-Grid environments are focused on creating and using *information and communication technologies* to support new ways of producing, transmitting, distributing, and consuming electricity. They provide opportunities for citizens to migrate from passive consumers to active decision makers by creating new control and decision-making possibilities. These transformations create foundations for increasing the sustainability of our energy environment.

The fundamental assumption underlying our research is that innovative technologies are *necessary* for these transformative innovations, but they by themselves are *not sufficient*. Without an improved *human* understanding and new mindsets surrounding the use of energy, the promise of Smart Grids will fall short. *Social-computational systems* (SoCS) are needed to allow all citizens to become informed and engaged participants in the energy economy by understanding, acting, deciding, assessing, forming appropriate new social norms, and changing behavior.

Our proposed research will exploit the synergies among *social-computational systems, smart communities,* and *Smart-Grid environments* to mutually enhance and advance these disciplines. Our activities will be embedded in this specific context, and we will explore theoretical frameworks and components and architecture of systems that will contribute to an enriched understanding for the next-generation of social-computational systems in all domains. Throughout this proposal, we refer to two major, interrelated development efforts: (1) HYDRA, a multi-faceted social-computational system developed by our research team (described in Section 8.1); and (2) OPENEI (*http://en.openei.org/*), an open platform and collaboratively constructed repository of information about energy that is the focus of our collaboration with NREL (described in Section 8.2 and in the letter by Enerplex Associates in the Supplementary Documentation).

We will exploit the unique opportunities for collaborations for which we have created the foundations in the context of a one-year SoCS seed grant (the specifics of these collaborations are documented in Section 13 and in the letters from all the collaborators in the Supplementary Documentation). The collaborators are: (1) *Tendril Networks***;** (2) the *National Renewable Energy Laboratory (NREL)*; (3) the *University of Colorado, Boulder*; and (4) the *Fraunhofer Institute* (FIT). Our research will take advantage of the selection of Boulder, Colorado, as the first SmartGridCity™ in the United States in March 2008 by Xcel Energy and NREL, based on its being the home of the University of Colorado and the National Institute of Standards and Technology, as well as on its close proximity to NREL.

2 The Synergy between SoCS and Energy Sustainability

A unique opportunity exists to create a synergy between research in social-computational systems and the Smart-Grid application domain. Our research will demonstrate that (1), on the one hand, for the Smart-Grid effort to live up to its vision and expectations requires support for individual and collective intelligence and social creativity; and (2), on the other hand, social-computational systems face interesting, specific, and unique research questions to cope with the challenges associated with Smart Grids.

2.1 Identifying Shortcomings of the Current Energy Environment

The *Smart-Grid vision* [Department-of-Energy, 2009; Williamson, 2009] combines electrical and smart computational infrastructures by (1) building on technologies in use and under development by electric utilities; (2) adding communication and control capabilities used by utilities to operate the grid; (3) creating feedback with smart metering and energy management systems; and (4) finding the right balance between “automate” and “informate” [Norman, 1993; Zuboff, 1988]. New designs will provide new opportunities afforded by the richer capabilities of the infrastructure (see Table 1), but taking full advantage of their potential will require new mindsets that lead to changes in the way energy end users (as individuals, communities, organizations, and governments) think and learn about how to fulfill energy needs.

Table 1: Comparison of Current Grid versus Smart Grid

Characteristics and Shortcomings of the Current Grid	New Possibilities Envisioned with the Smart Grid
Immense costs are incurred for coping with high demand peaks.	Participants are supported and rewarded for shaving peaks by informed energy consumption.
Single pricing is the only option.	Dynamic pricing structures are implemented for rewarding energy use during non-peak times.
Only total consumption is measured.	Participants are provided with rich data about their use and suggestions for savings.
Is solely an electric grid for passive consumption.	Grid is combined with intelligent infrastructure that motivates and rewards active participants.
Consumption is invisible.	Devices make consumption visible.
Energy is completely individualistic.	Pricing changes based on other people's consumption and infrastructure allow for comparison and competition among consumers.

Large-scale empirical studies (one of the most extensive is by a team led by one of our collaborators [Erhardt-Martinez et al., 2010]) have identified and studied factors and derived initial requirements to empower humans to play more important roles as informed decision makers in future social-computational systems based on the Smart Grid. Table 2 provides a summary of the factors identified and the requirements derived in these studies. These results provide a basis and identify challenges for the research objectives and goals of our proposed research.

2.2 Identifying and Exploring the Relationship between Social-Computational Systems and Smart Grids

The research proposal is grounded in the basic assumption that there is a unique relationship between the objectives of social-computational systems and desirable developments in the energy domain. Energy is being transformed into a domain for which social computing environments represent a unique opportunity for the first time. Everyone (individuals, groups, communities, and nations) is affected by

Table 2: Factors Identified and Requirements Derived for Empowering Humans

Factors Identified	Requirements Derived
Effects of feedback type	*Daily/weekly feedback* and *real-time detailed feedback* generate the highest savings per household (compared to a monthly bill).
Feedback-induced savings and household participation (at different levels: national, state, city, utility, community)	The total amount of energy saved depends on three factors: (1) average household-level *energy savings*; (2) likely level of household *participation*; and (3) higher participation rates with *opt-out designs* (as opposed to opt-in).
Feedback gadgets *alone* are unlikely to maximize household energy savings	Most effective forms of feedback include both *products* (meters, displays, and other devices) and *services* (compilation of data, targeting and tailoring recommendations, tailoring and contextualizing to consumers).
Motivational elements and program effectiveness	Participation is enhanced with motivational elements, such as *goal setting, commitments, competitions, social norms,* and *non-economic incentives.*
Changes in habits, lifestyles, and choices	Most of the energy savings achieved through feedback programs results from *changes in behaviors*, not investments.

Table 3: Synergy between Social-Computational Systems and Smart Grids

Theme	Dimensions of Social-Computational Systems	Smart Grids Developments
Informate (technology designed to include human behavior and actions) rather than automate	Integrated social-computational systems	Smart Grid with a focus on human involvement; foster smart communities
Interaction	New models of social and participatory computing	Smart meters for effective visualizations, simulations, and contextualizations
Infrastructure	Human-computer partnerships (single person, small groups, mass interactions)	Advanced metering infrastructure
Supporting consumers to become active decision makers	Meta-design and cultures of participation	OPENEI and HYDRA: new forms of knowledge creation involving all participants
Assessment	Measurement, variety of user studies	Eco-arts for intelligible and engaging representations
Beyond technology	Beyond usability and sociability: changing human behavior; persuasion	Foster responsible and informed energy behavior; insights from behavioral economics
Policy	Privacy, legal aspects	Cost distributions, different business models, laws
Education	Mindsets focused on social and computational thinking	Energy literacy fostering new mindsets and new forms of interest and engagement

different behaviors toward energy facilitated by new technological developments. Few social standards or norms are yet established, but many research and development projects are actively working on this challenge. Table 3 provides an overview of which specific themes we will explore in the proposed research.

2.3 Defining "Social-Computational Systems" and Extending "SoCS" Research

This section provides answers to specific questions regarding how our project defines "Social-Computational Systems." and how our proposed work will extend "SoCS" research. Our approach combines the advantages and the power of social groups and computational systems to help individuals and groups of people make better decisions. A successful social-computational system should not merely *compute* for social groups, but must also support individuals and smart communities in deciding how to best become active in reducing energy consumption.

Q-1: How will our research increase the understanding of properties that systems of people and computers together possess?

A-1: We will study how to *"informate"* by creating and intertwining technical and social smartness rather than relying only on approaches that *"automate"* (humans treated as passive and compliant) or require *"manual"* intervention (relying on unaided human minds).

Q-2: How will our research develop or contribute to new theories of integrated social-computational systems?

A-2: Our research contributes to new theories with its focus on: (1) *cultures of participation*, in which all citizens are given the opportunity to act as contributors in personally meaningful tasks; (2) *meta-design,* which empowers owners of problems to articulate, elicit, and share their idiosyncratic knowledge; and (3) *change of human behavior*, facilitated by the establishment of social norms and creation of different incentive mechanisms.

Q-3: To what extent does the proposed project and research team span both the computational and social perspectives?

A-3: Our computational perspective is focused on (1) the development of HYDRA (a multi-faceted system based on new technological components and platforms), and (2) the further development of OPENEI (a repository of information about energy). At the social level, our research will transcend the current state of the energy domain, which fosters individual, passive consumption of energy.

Q-4: How and to what extent would the proposed project go beyond simply rebuilding or incrementally improving existing systems?

A-4: Through the growing availability of Smart-Grid technologies, we will analyze, describe, and support the complex interactions that determine how individuals influence and are influenced by social norms, leading to a principled understanding of the mechanisms that underlie social-computational systems in highly complex domains undergoing rapid development.

Q-5: How will our research contribute to the design of systems reflecting explicit knowledge of human cognitive and/or social abilities, new models of social computing, or new algorithms that depend on massive numbers of humans?

A-5: OPENEI (being open to the whole world) will reach its objectives only by involving massive numbers of contributors who need to be supported by systems such as HYDRA to provide tools that let the public see, discuss, reflect, and develop knowledge.

3 Previous Work

The proposed research can build on initial foundations that we have created in our previous work, **including our one-year SoCS Seed Grant,** in the two major dimensions of the proposed research:

- *initial components of a theoretical framework* including (1) cultures of participation providing insights on ways to foster and support individual and collective participation in the resolution of open-ended design challenges [Fischer, 2010]; (2) a focus on lifelong learning, specifically on self-directed learning, learning on demand, and the integration of working and learning [Fischer & Sugimoto, 2006]; (3) collaborative problem framing and problem solving [Fischer et al., 2005; Schön, 1983]; and (4) social production and mass collaboration in peer-support communities [Gorman & Fischer, 2009];
- *systems and architectures relevant to social-computational systems,* including (1) symbiotic, knowledge-based systems to empower (rather than replace) humans [Fischer et al., 1998; Norman, 1993]; (2) table-top computing environments to support social computing and collaboration among communities [Arias et al., 2000]; and (3) next-generation wikis in the context of supporting the research community in the NSF program "Creativity and IT" [Dick et al., 2009].

To pursue these broad objectives in the context of social-computational systems and energy sustainability, we obtained ***a one-year seed grant from the SoCS program***, entitled "Energy Sustainability and Smart Grids: Fostering and Supporting Cultures of Participation in the Energy Landscape of the Future." The research done in the seed grant (and to be done in the next few months) provides the foundations for the greatly refined research agenda of this proposal:

- a deeper understanding of critical issues based on assessments gained from our own studies as well as insights from large-scale assessments [Erhardt-Martinez et al., 2010];
- articulation of more specific objectives and more specific research questions (see Tables 1, 2, and 3);
- considerable enhancement of existing collaborations and creation of new ones: (1) with *NREL* (leading to our focus on OPENEI); (2) with *Tendril* (leading to explicit plans how to take advantage of their products and their infrastructure, allowing us to design and develop HYDRA with more standard and widely available components; and (3) with the *Sustainability Team of the University of Colorado* to collaborate with specific communities in specific physical environments.

4 Results from Prior NSF Research Grants

The proposed research builds upon the results of previous NSF projects that have led to numerous scientific publications and to the development of conceptual frameworks and innovative systems that have been used by other research and industrial organizations as building blocks for their own research. Some of our previous grants most relevant to the proposed research include:

- *G. Fischer and R. McCall,* **"Supporting Collaborative Design with Integrated Knowledge-Based Design Environments,"** *1990-1993 (#IRI-9015441).* This grant was an early attempt to develop environments to support reflective practitioners in different domains with domain-oriented design environments [Fischer et al., 1998].
- *G. Fischer, J. Ostwald, and G. Stahl,* **"Conceptual Frameworks and Computational Support for Organizational Memories and Organizational Learning,"** *1997-2000 (#IRI-9711951)*. This grant focused on developing living organizational memories to support collaborative design [Fischer et al., 2001; Fischer & Ostwald, 2001].
- *G. Fischer and Y. Ye,* **"A Social-Technical Approach to the Evolutionary Construction of Reusable Software Component Repositories,"** *2002-2004 (#CCR-0204277)*. This grant created a deeper understanding of the co-evolution of open source systems and communities [Ye et al., 2004].
- *G. Fischer, E. Arias, H. Eden, and M. Eisenberg,* **"Social Creativity and Meta-Design in Lifelong Learning Communities,"** *2001-2004 (#REC-0106976).* This grant developed initial conceptual frameworks for social creativity and meta-design [Fischer et al., 2004] as well as such innovative technologies as the initial version of the Envisionment and Discovery Collaboratory (EDC) [Arias et al., 2000].
- *G. Fischer, H. Eden, E. Giaccardi, and Y. Ye*: **"A Meta-Design Framework for Participative Software Systems,"** 2006-2009 (#IIS-0613638). This grant in the Science of Design program explored the basic assumption that existing software design methodologies focusing primarily on productivity-driven systems are insufficient to cope with situated uses and fluctuating requirements and therefore require *participative software systems* [Fischer et al., 2009; Giaccardi & Fischer, 2008].

These research grants have employed more than 20 post-doctoral researchers, and during the course of the work, more than 25 PhD students obtained their degrees. The results were published in numerous publications (see References Section).

5 Related Work

Cultures of Participation. Exploring the opportunities and the challenges of cultures of participation is a fundamental and large-scale undertaking. Numerous questions and fundamental transformations have been explored by different researchers in a large number of contexts. Theoretical frameworks have been explored for: (1) *social participation* [Benkler, 2006]; (2) *mass collaboration* [Tapscott & Williams, 2006]; (3) the *democratization of innovation* driven by user communities [von Hippel, 2005]; (4) *collective intelligence* [Malone, 2008] and the *wisdom of crowds* [Surowiecki, 2005]; (5) *migration models* from novices to experts as explored with legitimate peripheral participation [Lave, 1991; Wenger, 1998]; (6) the creation of huge numbers of communities centered on idiosyncratic interests facilitated by the infinite choice provided by the *Long Tail* [Anderson, 2006]; and (7) changes in *intellectual property rights* [Lessig, 2008].

Numerous studies associated specifically with Wikipedia have explored aspects of our research agenda, including what *motivates* consumers to become active contributors [Forte & Bruckman, 2005], support for *collaborators* [Kittur & Kraut, 2008], and the question of *quality and trust* [Giles, 2005; Kittur et al., 2008] resulting from inputs by all interested participants.

A number of reflections and investigations about the *drawbacks* of cultures of participation have raised issues such as (1) whether we will suffer from a new form of "*online collectivism*" that could suffocate authentic voices in mass mediocrity [Lanier, 2006]; and (2) whether the infinite choice will lead to *counter-productive fragmentation* (a modern version of the "Tower of Babel") or there are conditions under which a fragmented culture (with numerous idiosyncratic voices) is better or worse for enhancing learning, discovery, and creativity [Anderson, 2006].

Social-Computational Systems. Some of the fundamental questions associated with social-computational systems are: What will be the relative contributions of humans and computers in such a system? and Is the overall objective to completely automate or rather to informate [Zuboff, 1988]? There is overwhelming evidence that for numerous domains, including expert systems [Winograd & Flores, 1986] and cockpit automation [Billings, 1991], completely automated systems are neither feasible, desirable, nor possible. Our own past research (see Section 3) has been firmly grounded in intelligence augmentation, empowering human beings with intelligent systems rather than replacing them [Fischer et al., 1998; Norman, 1993]. Our proposed research is firmly grounded in the "informate/intelligence augmentation" paradigm—making cultures of participation and human involvement a necessity.

Changing Human Behavior. Research in computer science (and specifically in disciplines such as HCI, CSCW, and CSCL) has migrated from technical objectives to more human-centered objectives. Although concerns about creating usable and useful interaction support and providing engaging user experiences are necessary for social-computational systems, they are not enough for our objectives. We need to understand new dimensions of the problem space and establish new discourses by including insights and results from: (1) behavioral economics [Ariely, 2010]; (2) intervention strategies in environmental psychology [Abrahamse et al., 2005]; and (3) persuasion and persuasive technologies [Cialdini, 2009; Schultz et al., 2007].

Smart Grid. The call by President Obama for the installation of 40 million smart meters and 3,000 miles of smart transmission lines, has created high expectations for an energy revolution, characterized by statements such as: "*The Smart Grid will spawn new Googles and Microsofts, and it is akin to the transcontinental railroad, the phone system, the interstate highway system, and the Internet*" [Berst, 2009]. How realistic these expectations will turn out remains to be seen in the years to come. A large number of utility companies, new intelligent gadget companies (for smart meters and advanced metering infrastructure, or AMI), and IT companies have initiated large-scale experiments in all parts of the world. Parallel to the efforts making Boulder the first SmartGridCity, ***IBM*** has several "smart city" projects around the world, including a traffic management system in London, an electricity grid management system in Amsterdam, and a new project for Dubuque (Iowa), where IBM will bring all of the technologies together to conserve natural resources and slash utility bills and greenhouse gas emissions (for details see: *http://bits.blogs.nytimes.com/2009 /09/17/the-smartest-us-city-is-dubuque/*). ***Google*** has developed PowerMeter (*http://www.google.org/powermeter/*), driven by the slogan: "If you cannot measure it, you cannot improve it." This system makes proprietary data accessible to consumers to allow individuals and organizations to make informed choices about electricity. ***Microsoft*** has developed HOHM (*http://www.microsoft-hohm.com/*) a web-based computational environment bringing people together to save energy and money. Our project will study the impact and relationship of these developments with respect to: (1) whether cultures of participation will (or will not) develop around them, and (2) how the data and experiences collected by these systems will impact and can be integrated into HYDRA.

6 A Brief Scenario: From "How Things Are" to "How Things Could Be"

The following two scenarios illustrate the current state of the energy domain; where it fails to involve, educate, and motivate consumers; and how we aim to improve it.

How Things Are. Jenny recently started working as a researcher at a lab at the University of Colorado. She often notices that there are lights on and machines running when she's leaving the lab at night, even when she's the last to leave. She has noticed that the lab has a room full of servers even though no one in her lab is doing computing-intensive work and there are only three desktop PCs that require regular backups. She wonders whether this is normal behavior and other labs are similar, or whether her lab is wastefully using electricity and she should do something about it, but she does not know whether the University has established policies governing equipment usage. Despite the fact that she is *very interested in reducing energy consumption, she does not know what to do about it and decides not to do anything.*

How Things Could Be (with HYDRA, a socio-technical system (see Section 8.1) in place). Joe recently joined a lab at the University of Colorado that utilizes the HYDRA system and has developed a community around it. He is not overly interested in energy issues, especially given that he doesn't have to pay for the energy he is using, but his coworkers have made efforts to reduce their energy consumption, so Joe feels compelled to do the same.

Logging into HYDRA, the first thing Joe notices is that the energy consumption per person in his lab is a lot higher than the consumption of other labs in the same building—labs that are of similar age and construction. However, he is not sure what the 150 kWh per month difference really means, or whether it's significant or unusual. He doesn't know why the lab's energy consumption would be higher or what other labs are doing differently to have a lower consumption. As his interest in energy consumption is only peripheral, he decides to just leave things the way they are and not do anything about it.

At the end of the month, HYDRA notifies Joe that his lab consumed half a wheelbarrow, or 120 lb, of coal more than his neighbors and that his lab is on the higher end on the campus in terms of energy usage per person. That amount of coal does seem like a lot to Joe, so he looks into how his lab can reduce its energy consumption. HYDRA allows him to run a quick analysis of the lab's energy usage and reports that its baseline consumption—that is, the consumption that occurs constantly, including times when no one is in the lab—is a lot higher than that of the other labs in the building.

To analyze the baseline consumption, HYDRA asks Joe to fill out a brief survey to describe what devices are running at all times. Joe can think only of the little server the lab uses for nightly backups and enters it. Only as HYDRA specifically asks for the numbers and types of refrigerators, freezers, ventilation and air conditioning systems, as well as other "always on" devices in the lab, does Joe realize that several devices are contributing to the lab's baseline consumption.

From the filled-out survey, HYDRA compares the lab's energy usage with the usage of similar labs in the OPENEI energy database, both on an overall as well as a per-device basis. The comparison shows that Joe's lab has more devices running at night than most labs at the university and that the lab refrigerator is one of the least efficient refrigerators in HYDRA's database. Joe can see that other labs have refrigerators that are twice as efficient as his lab's refrigerator. By choosing the comparison option in HYDRA, Joe sees that switching to one of these more efficient refrigerators would cut the lab's baseline consumption by 25% and reduce the monthly coal consumption by 10 lb.

Next, HYDRA suggests that the lab's servers might be too old, defective, or too powerful for a lab of only five people. Joe again uses the built-in functionality of HYDRA to look for the lab's servers in the OPENEI energy database to compare them to servers other labs of similar size are using. According to HYDRA, most similarly sized labs do not run local servers but use integrated online services to store and back up their data.

Finally, Joe accesses HYDRA's energy simulator to determine the impact of the two changes on his lab's energy usage. The simulator shows that if Joe were to exchange the refrigerator with a more efficient model as well as replace the servers with a cloud-based system, the lab would be using less energy than most labs in his building. Furthermore, Joe's lab would be in the top 10% of labs on campus in terms of low-energy consumption on a per-person basis. Joe saves the simulation and makes it public so that it can be viewed by his coworkers as well as other HYDRA users.

Joe decides that the two suggestions made by HYDRA could be implemented easily, so he sends an email to the lab's supervisor with an explanation of the suggestions and a link to the simulation he created.

Analysis of the Two Scenarios. The current energy environment makes it difficult for consumers to become actively involved and make informed decisions. Not only does Jenny not know how her lab is using energy because consumption is mostly invisible to her, there is no way for her to judge whether her behavior is reasonable as there is no basis for comparison. Energy consumption for Jenny is completely individualistic and abstract, forcing her to remain passive because she has no support for knowing what is the right thing to do.

In contrast, with the support of an advanced social-computational system, Joe is able to see, understand, and judge the energy consumption of his lab. Using the advanced metering devices from Tendril in combination with personally meaningful units and representations such as wheelbarrows of coal, Joe can visualize what energy consumption really means. Showing him comparisons and role models from people in the same building motivates and enables Joe to judge how he is doing. The integration of the OPENEI system allows him to go beyond simply understanding the current state. He can investigate and explore with the collaborative body of information provided by OPENEI users how to become active in using energy more efficiently. The system shows him results, reduces Joe's guesswork in his endeavors to reduce the lab's energy consumption, and provides him with information to change his behavior.

7 Components of a Theoretical Framework

This section describes themes and components of a theoretical framework, grounded in (1) *large-scale empirical studies* and their tentative findings for developments and actions required (see Table 1 and Table 2:); and (2) *initial versions* of theoretical frameworks for cultures of participation [Fischer, 2010], meta-design [Fischer & Giaccardi, 2006], and change of human behavior [Ariely, 2010; Cialdini, 2009; Consolvo et al., 2009]. We will provide evidence that these themes and components will be relevant for social-computational systems in *many* application areas, and is of specific importance to the Smart-Grid vision. These components provide a theoretical foundation for the system developments described in Section 8.

The development of our theoretical framework will be influenced by further data gathering and analysis with a specific focus on: (1) the impact of interactive customer engagement systems to promote the change of human behavior as pioneered by ***OPOWER*** (http://www.opower.com/) and ***GroundedPower*** (now a Tendril company; http://groundedpower.com/new/); (2) broad-based use of new technologies (e.g., as developed by Tendril); and (3) facilitation and encouragement of participation in collaboratively constructed information repositories. (e.g., OPENEI by NREL).

7.1 Cultures of Participation

The industrial information economy has been dominated by large hierarchical organizations with professionals at the top. The networked information economy will be shaped by *prosumers* [Tapscott & Williams, 2006] and *professional amateurs* [Brown & Adler, 2008; Leadbeater & Miller, 2008], defining and creating new, distributed organizational models that will be innovative, adaptive, and low-cost. *Prosumers* and *professional amateurs* are innovative and committed; for them, leisure is not passive consumerism but active and participatory work done to professional standards. They create, discover, learn, and share publicly accredited knowledge. They engage in their activities driven by *intrinsic motivation* [Csikszentmihalyi, 1990], they are willing to accept sacrifices and frustrations, and their idiosyncratic expertise [Anderson, 2006] is often built up over a long career. They are a new social hybrid whose activities are not adequately captured by the traditional definitions of work, leisure, consumption, and production.

Cultures of participation define and are required by Web 2.0 environments [O'Reilly, 2006]. In the proposed research, we will explore the specific aspects of Web 2.0 that are most relevant to the Smart-Grid application domain. For decades, electric power was something the average person did not think much about until it went out. Smart-Grid visions have been reshaping the collective mindset of consumers based on the hope that many will migrate from *passive ratepayers* to *informed, environmentally conscious customers*. With the emergence of the technologies that make Smart Grids possible, technological foundations are created by which customers can become active decision makers by providing them with the information and control they need to actually change their behavior patterns and reduce usage and costs.

Our proposed research will contrast the respective *strengths and weaknesses* of systems developed in *professionally dominated cultures* with *systems developed in cultures of participation*. This part of our research will be focused on comparing and analyzing *(1) NREL's "VIBE: Virtual Information Bridge to Energy Efficiency and Renewable Energy"* system (http://vibe.nrel.gov/), an environment constructed by professionals and not open for user contribution, with (2) OPENEI (see Section 8.2). The major limitation of systems such as VIBE is that they are accessible only by professionals, promote consumer cultures, and most participants are neither encouraged nor supported to act as contributors and are more comfortable with simple consumption [Nielsen, 2006].

We will explore mechanisms and support for cultures of participation that will allow consumers not only to access information but to migrate toward roles as contributors and decision makers [Fischer, 2002; von Hippel, 2005]. The openness of systems such as OPENEI will result in much larger information repositories because many more people can contribute their experiences [Raymond & Young, 2001; Shirky, 2008]. Open systems result in substantially larger knowledge repositories as traditional, authoritative content-creation systems, requiring support for data-mining, recommender systems, and other computational systems to become "intelligent" and mechanisms to cope with unreliable and untrustworthy information [Doctorow, 2006; Giles, 2005].

In the context of cultures of participation, we will explore our *first research question:*

RQ-1: How can we foster *richer ecologies of participation* by differentiating, analyzing, and supporting distinct roles: consumers, contributors, collaborators, curators, facilitators, and meta-designers?

Users take different tasks and responsibilities as they progress toward higher levels [Preece & Shneiderman, 2009; Ye & Fischer, 2007]. Most participants will start as consumers, and only a small percentage of these will eventually contribute, collaborate, and act as meta-designers, and thereby be responsible for the content that is shared with everyone [Kittur et al., 2007]. For 2.0 environments such as OPENEI to succeed, it is critical that a sufficient number of participants take on the more active and more demanding roles. Our research will reduce the *funnel effect* [Porter, 2008] (provide encouragements for participants to migrate to more demanding roles) by creating more powerful social and technical environments (such as HYDRA; see Figure 1).

7.2 Meta-Design: Design for Designers

Richer ecologies of participation will be supported by new developments in *meta-design* [Fischer et al., 2004] whose main objective is "design for designers." The meta-design methodology and its supporting substrates are focused on an approach to design that does not eliminate the emergent but rather includes it and makes it an opportunity for more creative and more adequate solutions to problems by empowering users to engage actively in the continuous development of systems rather than being restricted to the use of existing systems. A fundamental objective of meta-design is to create *living socio-technical environments* [Mumford, 2000] in which users can participate actively as co-designers to shape and reshape those systems through collaboration [Kittur & Kraut, 2008; Surowiecki, 2005].

HYDRA (see Section 8.1) will be enriched with substrates in support of meta-design [Fischer et al., 2009]. These substrates will allow local developers and power-users [Nardi, 1993] to engage in end-user development and contributions. A meta-design approach is required for social-computational systems for the following reasons:

- the growing importance of *application-domain knowledge* for most software systems (in this case, all development taking place around the Smart-Grid project) and the fact that this knowledge is held by domain experts rather than by software developers who suffer from a "thin spread of application domain knowledge" [Curtis et al., 1988];
- the need for *open and evolvable systems* based on fluctuating, conflicting requirements, which will lead over time to mismatches between an evolving world and the software systems that model this world [Fischer et al., 2009]; and
- the need to support *communication and coordination* in a richer ecology of participants who have different interests, skills, and background knowledge [Preece & Shneiderman, 2009], requiring support for the *co-evolution of systems, communities, and individuals* [Greenbaum & Kyng, 1991; Nakakoji et al., 2006].

Meta-design underlies the design and evolution of all participatory web ("Web 2.0") environments (e.g.: open source environments, Wikipedia, YouTube; 3D Warehouse, etc. [Fischer, 2010]). The meta-design framework needs to further advance by studying important principles such as consent, conflict, compromises, design trade-offs, and sociability and how they affect human action and decision making in communities [Benkler & Nissenbaum, 2006]. In Smart-Grid design activities, we need to support a balance between *harnessing the collective intelligence of broad populations* versus dealing with unique issues facing a local community versus support for individual participants [Fischer et al., 2005]. Our analyses and developments will try to answer the *second research question:*

RQ-2: How can we foster and support incremental architectures and information repositories that put users into control and that are capable to evolve as technologies become more sophisticated?

7.3 Changing Human Behavior

Technology alone does not determine social structure, nor does it change human behavior: it creates feasibility spaces for new social practices [Benkler, 2006] and it can persuade and motivate changes at the individual, group, and community levels [Consolvo et al., 2009; Fogg, 2002]. Human-centered technologies can change people's lives by (1) making it easier for people to do things, (2) allowing people to explore cause-and-effect relationships, and (3) providing value that cannot be accounted for in monetary terms [Ariely, 2010; Gneezy & Rustichini, 2000].

Assuming, for example, that better learning support will empower stakeholders to be able to contribute—what will motivate them to do so [Csikszentmihalyi, 1996; Forte & Bruckman, 2005; Renninger, 2000; Ye & Kishida, 2003]? We will assess the effectiveness of different reward and encouragement structures, including (a) recognition by the community, (b) acknowledging and featuring the best contributions, and (c) creating awareness of positive examples by similar users. Our research on motivating people to change their behaviors will build on behavioral psychology studies that have shown how providing feedback, goal setting, and tailored information is useful in motivating people to change their behaviors [Locke & Latham, 2002]. Our studies in meta-design [Fischer & Giaccardi, 2006] provided evidence that we become engaged when we can decide and that we value what we make [Ariely, 2010]. Initial empirical findings in our own environment of Boulder as the first SmartGridCity in the US have identified motivational factors governing human behavior in the energy domain [Farhar, 2009] including: (1) practical ("I will benefit from it"); (2) altruistic ("I want to do something helpful"); (3) technical ("I want to know more about what they're doing"); and (4) moralistic ("We should all do what is right"). All of these findings will serve as initial steps to answering our *third research question:*

RQ-3*:* How can we support and foster an alignment of personal motivations and community goals that will result in sustainable behavior change that is personally rewarding and socially responsible?

8 System Developments

Our system developments will be integrated in the multi-faceted, *open, collaborative social-computational system HYDRA* (the name was chosen to signal the multiple facets of the overall development). HYDRA will be based on technologies provided by Tendril and be closely linked with OPENEI, taking advantage of the work of our collaboration partners. Another major research activity undertaken in the context of HYDRA will be the exploration of eco-arts and eco-visualization to provide more informative and more engaging feedback.

8.1 HYDRA: A Multi-Faceted Social-Computational System

HYDRA combines behavioral techniques with human-centered design, computation, and technology to affect energy behavior. It will use smart meters and the advanced metering infrastructure actively developed by Tendril, taking advantage of their open APIs. Our own developments will provide feedback, visualizations, and simulations, and we will create and seed a meta-design environment in which engaged consumer can become active participants and create new information and new tools. It will be closely coupled with OPENEI to bring information and tools from OPENEI into HYDRA and contribute developments done within HYDRA back to OPENEI. Figure 1 provides an overview of the HYDRA system.

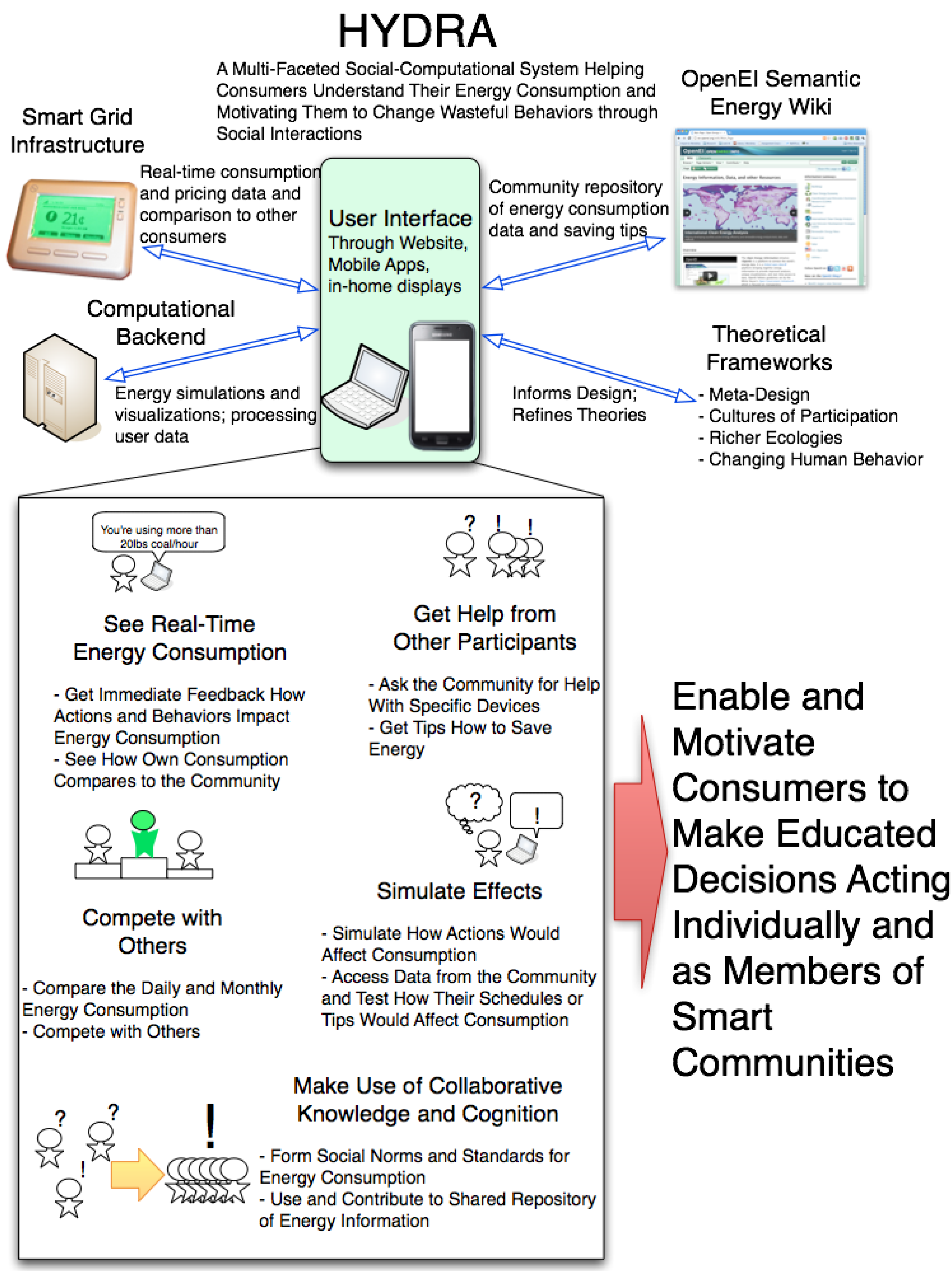


Figure 1: HYDRA: Architecture, Linking with other Developments, and Specific Components

HYDRA fosters migration to active roles (*RQ1*) by showing new users how other users became active and by giving positive examples. Participants can assume different roles from reader to asker to energy-adviser.

To better understand *RQ2*, we are building a system that allows users to create and use visualizations and simulations to explore their own and others' energy consumption. It is being built as a meta-design environment that allows all users to modify and extend the functionality when needed. The software allows them to explore how exchanging devices or changing behaviors impacts their energy consumption and how their own consumption compares to other consumers. By integrating data from OPENEI, users can look up their own devices and simulate how different devices in the OPENEI database would impact the energy consumption over longer periods of time.

To address *RQ3*, the software backend includes a social hub for all HYDRA users, where the information from the different sources—for example, smart metering devices, OPENEI data, simulations—is being collected, analyzed, and put into a social context so that users are shown information and recommendations that are relevant to them. The focus in on positive examples and role-models from similar users to effectively motivate consumers to also adapt certain behaviors [Cialdini, 2009].The system also generates aggregated as well as individual statistics and pushes these to the consumers' devices and applications to generate awareness of their own energy consumption, social norms, and activity by other users. These data can also be used to run competitions within the HYDRA community that focus on reducing energy consumption.

8.2 OPENEI: The Open Energy Information initiative

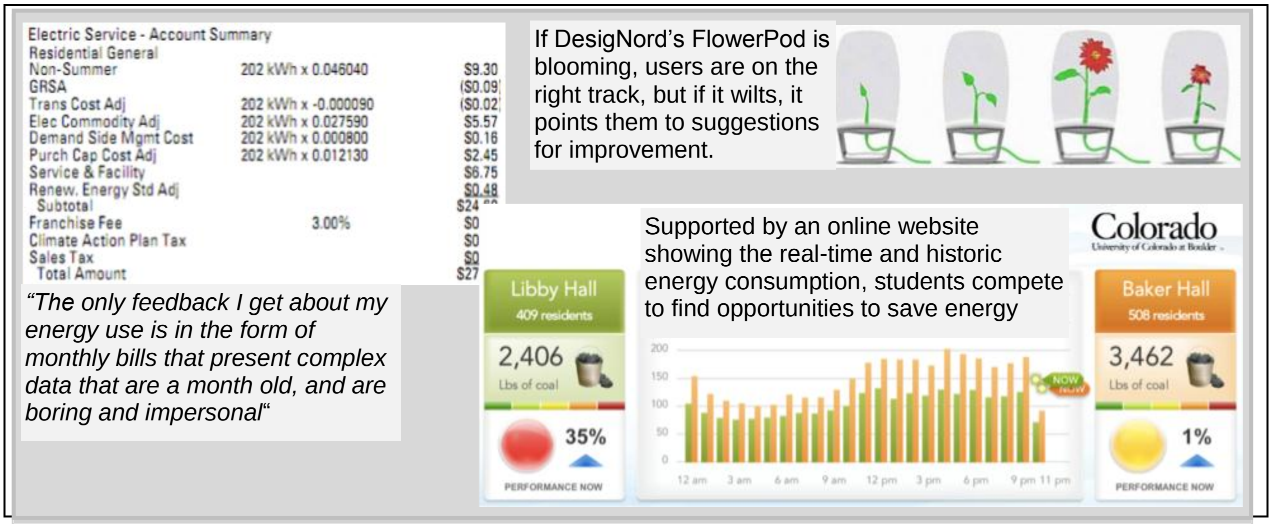
NREL is the lead developer of the Department of Energy's Open Energy Information (OPENEI; www.openEI.org), an open-source collaborative web platform that will make DOE resources and open energy data widely available to the public. OPENEI is a semantic wiki focused on transparency, collaboration, and participation. The expected large-scale impact of OPENEI was expressed by Secretary Chu of the DOE:

> *This information platform will allow people across the globe to benefit from the Department of Energy's clean energy data and technical resources. The true potential of this tool will grow with the public's participation – as they add new data and share their expertise – to ensure that all communities have access to the information they need to broadly deploy the clean energy resources of the future.*

We will integrate OPENEI into HYDRA (see letter from Jamey Woods in the Supplementary Documentation) by allowing users of HYDRA to access OPENEI from within all HYDRA systems, including in-home displays, mobile apps, and the HYDRA website. Thanks to the underlying semantic wiki structure, OPENEI data can be displayed in many different forms and used for simulations and calculations within the HYDRA system. OPENEI will be extended and expanded to act as a user-contributed repository of energy data information for a variety of commercial and residential electronic devices. HYDRA users will be able to use the OPENEI infrastructure and data to simulate or calculate how switching to a different device might influence their energy usage, to identify popular devices, and to share their own measurements with the public. OPENEI is being used as the central collaborative memory for HYDRA users and can assist individuals in understanding their own energy usage and identifying differences to other users.

To answer *RQ1*, we will be using access and usage logs from OPENEI to analyze how user behavior, especially frequency of visits and involvement are influenced by the activity and behaviors of others. Based on the initial data analysis, we will perform semi-structured interviews with users of OPENEI and HYDRA.

We will analyze how the OPENEI ecology of participation is evolving over time. These data will help us to further refine our understanding of this ecology of participations and its different levels. OPENEI will inspire our work, and our theoretically guided developments will also allow us to add and evaluate new tools in OPENEI.



8.3 Eco-Arts and Eco-Visualization: Providing Meaningful Feedback and Encouraging Competition among Communities

A major finding mentioned in Table 2 emphasizes the effects of feedback type, namely that *daily/weekly feedback* and *real-time detailed feedback* generate the highest savings per household (compared to a monthly bill). Figure 2 illustrates this as follows: (1) the image (left side) shows a standard bill about energy consumption from a utility company obtained once a month (which most people find unintelligible); (2) the "Flower Pod" (right side, top) is an artistic illustration showing in a qualitative way the energy consumption in real time; and (3) the graph (right side, bottom) shows the competition between two dormitories at CU Boulder.

The research in our SoCS seed grant has shown that it is not enough to provide individuals with some feedback about their energy consumption (which they experience as meaningless, dull, and complex). Even though it is necessary to measure energy, measurements by themselves are insufficient to change behavior. Energy consumption needs to be visualized, socialized, and made understandable for consumers in order to motivate behavioral changes.

This leads to our *fourth research question:*

RQ-4: Which computational mechanisms will provide the best feedback for people to understand the information, to believe that they are capable of making a difference, and to motivate them to take action?

In collaboration with our advisor Marda Kirn, we will try to answer *RQ4* by developing (and providing tools for others to develop) *eco-arts* and *eco-visualizations* by combining art and technology to understand energy consumption (at the individual and the social level) and experimenting with new media art that displays the real-time usage of electricity to develop new strategies to conserve energy in the home and workplace [Holmes, 2007]. We will develop dynamic media supporting exploration and computational decision making (e.g., strategies for managing appliance use) along with interaction mechanisms that can be exploited and mastered by all participants. We will identify factors that affect an individual's ability to curtail energy usage (e.g.: create incentives, other than monetary, that affect an individual's commitment to conserve resources and develop effective visualization strategies to communicate energy consumption data.)

9 *Research Methodology*

Our research methodology will evolve our initial frameworks about meta-design and cultures of participation, broadly grounded in insights from different disciplines (and supported by the associations with our collaborators and advisory board members). This evolution will be based on iterative system development efforts surrounding HYDRA with building blocks from Tendril's open APIs and integrative elements from OPENEI. We will engage stakeholder participants, extend requirements, design and build, deploy and assess—performing these steps in multiple cycles. The insights gained from this process will be used to extend or reshape our theoretical frameworks as well as refine the HYDRA system.

As we engage in these activities, we will explore interesting questions regarding obtaining energy usage data for each participant, how comprehensive that data collection is, how individuals interpret their usage data, how trends influence behavior, how seasons and their different energy requirements shape behavior, and how collaboration and community influence behavior and the judgments that people make.

The core settings for application to practice, user feedback and experience, and assessment will be twofold:

- An initial effort will encompass a research building on our campus, the Discovery Learning Center which houses several research laboratories, including our own Center for LifeLong Learning & Design (L^3D). We will instrument selected labs with meters, sensors, and controls that will be integrated with the HYDRA system and will work with participants from those labs to pursue the following objectives: (1) minimizing electricity consumption without reducing the quality of the environments; (2) accessing learning opportunities to become knowledgeable about energy sustainability; (3) providing comprehensible feedback without overburden participants with technical details; (4) supporting and rewarding active decision making and behavior change; and (5) creating social interactions focused on energy sustainability (e.g., competition among different units, labs, neighborhoods).
- A second effort will entail the recruitment of volunteers from the Boulder community to install the necessary hardware and software in their homes and create a similar small community based on residential users.

Assessment activities will include data from interactions within HYDRA, ethnographic studies and interviews with participants, and specific information feedback drawn from targeted interventions.

10 Educational Implications

Our Center for LifeLong Learning & Design has been engaged in long-term efforts (see support by previous NSF grants in Section 4) to educate future generations of scientists, engineers, and designers. The proposed project will engage *graduate and undergraduate students* as apprentices not only to "learn about" socially intelligent systems and Smart-Grid environments, but also to "learn to be" members of collaborative scientific communities engaged in advancing these environments. Over the last ten years, L^3D has developed a highly successful *Undergraduate Research Apprentice Program* (*http://l3d.cs.colorado.edu/urap/index.html*). We will request supplementary funds by applying to *NSF's Research Experiences for Undergraduates (REUs*) each year to support these students.

We will develop curricula and define guidelines for two literacies: *social-computational systems literacy* [Fischer, 2009] and *energy literacy* (*http://www.energyliteracy.org/*).

We will promote interdisciplinary collaborations between students and practitioners from computer science and from energy related disciplines by closely collaborating with the *student alliance* of the Renewable and Sustainable Energy Institute (RASEI) at the University of Colorado (*http://rasei.colorado.edu/index.php?id=341*). This alliance brings together graduate and undergraduate students from different disciplines, such as information technology, energy technology, policy, science, law, and business to take advantage of their interests for energy. The alliance is creating a curriculum for a certificate in "Energy Sustainability" (including many topics related to Smart Grids).

The need for appropriate media and communities, awareness, information, and wide-scale development and deployment of Smart Grid technologies is especially important in working toward inclusion and support for *marginal and underrepresented populations* in order to achieve broad participation, rather than limiting participation to a self-selected group of techno-savvy "early adopters" who could bias the development of technology solutions toward a subset of potential consumers who are like themselves, but not reflective of mainstream concerns. Our involvement with the *El Pueblo Mágico* after-school effort at Sanchez Elementary School in Lafayette, Colorado, works to engage students in fostering energy awareness and responsibility.

11 Evaluation and Assessment

Assessment of community interaction and practice must involve an open process of design and evaluation that is woven into the fabric of a community's evolving processes and activities [Carroll & Rosson, 2007; Miskelly & Fleuriot, 2006]. To evaluate our developments, we will assess the use and impact of our environments in the context of the everyday practice and real-world settings of our collaborating partners and communities. Our advisors Karen Ehrhardt (from a social science perspective), Marda Kirn (from an artist perspective), and Kevin Doran (from a policy perspective), are experts in the evaluation and assessment of energy-related issues and will provide major support and advice. This part of our research will also greatly benefit from our international collaboration with the Fraunhofer Institute (see letter in the Supplementary Documentation for details).

Our design approach is based on the assumption that technology development alone is not sufficient to make a community more engaged [Mumford, 2000]. We will triangulate quantitative and qualitative data by combining HYDRA usage data, energy consumption data, pre- and post-questionnaires, and unstructured interviews of the HYDRA users. We will use the Experience Sampling Method [Csikszentmihalyi et al., 1993] with users of HYDRA to answer questions about individual and collaborative engagement, control, and competition. To make sense of the quantitative data, we will make use of interaction graphs [Wilson et al., 2009] and bi-directional social network analysis [Goggins et al., 2010] to better understand the impact other users and their behaviors have on individuals and how social norms are being formed [Friedkin, 2001]

12 Results, Deliverables, and Dissemination

We will develop guidelines into how social and technical interventions can support the components of our theoretical framework. HYDRA will provide useful lessons, prototypes, and guidelines for designing social-computational systems that will foster and support more informed and responsible attitudes and actions toward energy sustainability. We will make source code broadly available wherever possible to interested developers. We will publish our research in academic journals and present it at academic conferences. In addition to merely educating the public about Smart Grids, the project will actively engage the public in the process of applying its knowledge to social decision making. This public engagement will provide numerous benefits, such as improving public attitudes toward energy sustainability and increasing the quality of scientifically informed social decision making.

13 Coordination Plan: Research Collaborations and Partnerships

The proposed project will (1) be *multi-disciplinary* (socially intelligent systems and Smart Grid), *multi-sector* (academia, industry, and public), and *international* (close collaboration with a German research center); and (2) involve *graduate and undergraduate students* in the preparation and engage them in making contributions to the theoretically grounded design, development, and assessment of social-computational systems. The research teams of PIs, advisors, and collaborating institutions (academia, companies, research laboratories, and cities) brings together interdisciplinary expertise in computer science (specifically, social computing, open living, knowledge-based computational environments, and intelligent support systems for lifelong learning) and in the revolutionary energy developments centered on the Smart Grid.

13.1 PIs and the Center for LifeLong Learning & Design

Gerhard Fischer (PI) is a Professor of Computer Science, a Fellow of the Institute of Cognitive Science, the Director of the *Center for LifeLong Learning & Design (L^{3}D), and a member of the CHI Academy.* He has worked and published extensively and has been the PI of numerous research grants in the following research areas: lifelong learning, design, organizational memories and organizational learning, meta-design, and social creativity. He will be responsible for the *overall scientific and educational quality of the grant* and for managing the collaboration of the complex web of participants.

Hal Eden (Co-PI) will provide *leadership for all technical developments* associated with HYDRA needed to study the research questions raised. He will develop embedded measurement, assessment, and feedback components.

The Center for LifeLong Learning & Design as a whole is uniquely positioned to explore and provide new insights into these issues based on (1) our long-term focus and experience in designing and assessing theoretically grounded innovative, complex socio-technical systems to support consumers as active contributors and lifelong learners and (2) unique collaborations with national and international research laboratories, companies, and public institutions;

13.2 Collaborating Organizations

For further information on these organizations, see the letters in the Supplementary Documentation.

Tendril Networks (*http://www.tendril.com*), a local Boulder company, will assess the usefulness and usability of our theoretical framework, and will test some of HYDRA's prototype components in an industrial context. In return, we will take advantage of the Tendril Residential Energy Ecosystem (TREE) in our developments.

The **National Renewable Energy Laboratory (NREL)** (*http://www.nrel.gov/*) is exploring a broad spectrum of innovations for our energy future [NREL, 2009]. The core theme for collaboration is to apply our theories of meta-design and cultures of participation to further advance OPENEI developments.

The **University of Colorado** with its different laboratories and communities (such as the Renewable and Sustainable Energy Institute (RASEI) (*http://rasei.colorado.edu/*) and its new educational programs relevant to social-computational systems and energy sustainability will serve as testbed for technological developments and smart community building.

The **Fraunhofer Institute (FIT), Bonn, Germany** (*http://www.fit.fraunhofer.de/*) is working in two areas of particular importance for our collaboration: (1) developing a *Green-IT framework and infrastructure*; and (2) performing *action research and ethnographic studies* to evaluate the use and impact of smart-metering devices and displays. We will share methods and results and will organize a joint international symposium.

13.3 Advisors

Our proposed research represents an important and timely systemic problem requiring insights from multiple disciplines. The work in our *one-year seed* grant (Section 3) allowed us to establish collaboration with researchers representing different perspectives. For further information from these advisors, see the letters in the Supplementary Documentation. These researchers will serve on our advisory board (specific details are articulated in the letters) by contributing to the following perspectives:

- *technology mediated social participation*: Ben Shneiderman (University of Maryland; computer science) [Shneiderman, 2009];
- *environmental psychology and behavioral economics*: Karen Ehrhardt-Martinez (University of Colorado; Renewable and Sustainable Energy Institute) [Erhardt-Martinez et al., 2010];
- *policy and laws*: Kevin Doran (University of Colorado Law School) [Doran et al., 2010]; and
- *eco-arts and eco-visualization*: Marda Kirn (Director, EcoArts, Boulder; *http://www.ecoartsonline.org/*).

14 Timeline

Our research methodology determines the work plan for our project:

- In **Year 1**, we will focus on building the major components of HYDRA. We will recruit participants from the Discovery Learning Center, instrument the environments, and deploy HYDRA to test its efficacy and guide iterative design. We will begin assessment, ethnographic studies, and intervention activities with the DLC participants.

- In **Year 2**, we will continue our activities with the DLC participants, including refinement of HYDRA based on feedback and analysis of assessments. We will recruit residential participants and deploy HYDRA along with needed infrastructure. We will expand the online interaction to include both of these communities and continue assessment efforts across both sets of participants.
- In **Year 3**, we will perform interviews with all users of the system, continue to collect data from system usage, and perform rigorous analyses of the data. Transcending our specific developments, we will derive refined requirements for further developments and general findings, guidelines, and recommendations for social-computational systems and cultures of participation [Fischer et al., 2009]. During Year 3, we will also organize an *international symposium* with the Fraunhofer Institute.

Throughout all three years, we will incorporate new technologies as they are developed in the Smart-Grid context, and we will refine our requirements and developments for HYDRA on an ongoing basis.

The goals described in this proposal are very ambitious for a three-year university-based research project. They are feasible and achievable based on:

- our previous work in socially intelligent systems, specifically in our one year seed grants supported by the SoCS program (see Section 3); and
- the synergy of all the different organizations that have agreed to collaborate with us in this project (see Letters in the Supplementary Documentation).

15 Summary of Intellectual Merit and Broad Impact

These two areas are described in the Project Summary.

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