BROADBAND AS A GREEN STRATEGY:

UNDERSTANDING HOW THE INTERNET CAN SHRINK OUR CARBON FOOTPRINT

VALLEY VISION

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EXECUTIVE SUMMARY

At first glance, “Broadband as a Green Strategy” might seem counterintuitive. Broadband—or high-speed Internet—is part of the Information and Communication Technology (ICT) sector, which is a large consumer of energy and emitter of greenhouse gases (GHG). By 2020, the sector is projected to be responsible for 2.3 percent of total global emissions.[1] The proliferation of smart devices and cloud computing infrastructure, combined with the Internet becoming a foundation for the global economy, assures that power consumption and emissions of the ICT sector will continue to grow.[2] Indeed, ICT is changing dramatically the way people work, learn, play, shop, connect, and mobilize.

Moving beyond a cursory understanding of ICT as a contributor to climate change, the literature indicates it is imperative to understand the role this sector can play as an abatement strategy by driving efficiencies in other sectors. From power and transportation to health care, agriculture, and buildings, broadband-enabled applications such as telehealth, telework, precision agriculture, grid optimization, and e-government offer the potential to reduce projected emissions by over nine gigatons of carbon dioxide equivalent ($GtCO_2e$) by 2020, or approximately 16.5 percent of total global emissions. This represents an abatement potential of at least seven times the ICT sector’s own emissions footprint. Moreover, research indicates ICT-enabled abatement solutions will help address climate change and offer significant economic benefits. These benefits are projected to yield an estimated $1.9 trillion in savings in gross energy and fuel and create 29.5 million new jobs worldwide.[1] The literature further indicates that achieving these results will require thoughtful, integrated planning and policy leadership.

The discussion draft of the Governor’s Environmental Goals and Policy Report (EGPR) indicates California is already on the way to charting a strong climate future through its policies, research, and partnerships. Programs are in place that are achieving emission reductions and putting the state on the path to meeting its 2020 goal for GHG emissions reductions.[3] According to the EGPR, achieving deep emission reductions by 2050 will require that the pace of reductions increase over the coming decades. The research indicates that ICT will serve as an enabling infrastructure for accelerating the pace of reductions.

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[1] Global e-Sustainability Initiative and The Boston Consulting Group, Inc. (2012, December). *GeSI SMARTer 2020: the role of ICT in driving a sustainable future*. Retrieved April 4, 2014 from http://gesi.org/SMARTer2020

[2] Cook, G., Dowdall, T., Pomerantz, D., Wang, Y. (2014, April). *Clicking clean: how companies are creating the green internet.* Greenpeace. Washington D.C. Retrieved April 4, 2014 from http://www.greenpeace.org/usa/en/media-center/reports/

[3] State of California, Governor’s Office of Planning and Research. (2013). *California’s Climate Future: The Governor’s Environmental Goals and Policy Report, Discussion Draft*. Sacramento, CA: Retrieved from http://opr.ca.gov/docs/EGPR_ReviewDraft.pdf

Findings: Overall Trends

The 2014 research summary report, *Broadband as a Green Strategy: How the Internet can shrink our Carbon Footprint,* provides a summary of literature that explores the greenhouse gas emissions reduction potential of broadband-enabled applications. The research indicates a growing global recognition of the potential for ICT to facilitate positive environmental benefits. Several key trends are identified in the research:

> ***Greening of ICT*** – Ensuring that broadband networks and ICTs are highly energy efficient and increasingly powered by renewable energy to the greatest possible extent are important elements of "Broadband as a Green Strategy" policy development.
>
> ***Adopting Broadband as a Green Strategy*** – There is an expanding recognition in the literature that broadband technology should be a deliberate component of energy and climate change policies in order to maximize the desired policy outcomes.
>
> ***Accelerating Pace of Connectivity*** – The transition to a more connected digital world is happening at an ever-increasing pace. Connected solutions will rely on the increasing expansion and adoption of broadband technologies.
>
> ***Integrating Economic, Environmental and Social Impacts*** – On a global scale, government, industry, and scientific research institutions are exploring an integrated view of the environmental, social and economic opportunities associated with ICT. There is a growing global recognition of broadband as an essential infrastructure for realizing 21^{st} Century environmental, economic, and social sustainability objectives.

Findings: Application Focus Areas

A variety of broadband applications was chosen for review to better understand if and how their uses would lessen climate impacts. For example, do online follow-up visits with doctors decrease greenhouse gas emissions because patients are using less fossil fuel for travel to office visits? Each example area was researched to determine how much these effects have been studied, quantified and documented. The findings of this review are summarized below:

> ***Telehealth*** – Often used interchangeably with the terms telemedicine or e-health, telehealth refers to the application of electronic communications and information technologies to support the remote delivery of health care services. This focus area continues to be promising for quantifying and possibly monetizing greenhouse gas emissions reductions related to broadband-enabled telehealth applications. In addition, telehealth is identified in the research as a strategy for climate change adaptation.

Telework – Also referred to as telecommuting or flexible workplace, means working from home or another location away from the office, making use of the Internet, e-mail, and the telephone. This focus area has tremendous potential for displacing greenhouse gas emissions caused by employees commuting to employer sites. There is a large body of work documenting the reduction in vehicle miles traveled achieved through telework. Further empirical investigation to quantify greenhouse gas emission reductions is warranted to validate telework applications as a climate change mitigation strategy.

E-Learning – Also referred to as online or distance learning, means learning conducted via electronic media, typically on the Internet. The literature review did not reveal new research or investigation into the environmental benefits of e-learning; this is an area that may warrant further empirical study.

Smart energy – Smart energy is a wide-ranging categorization of transformational solutions for transition to a low-carbon energy economy. Broadly, this category can be described as ICT at the intersection of energy, information, transportation, and buildings. Smart energy solutions optimize energy use through ICT-enabled monitoring and management systems such as automated controls. For example, smart buildings reduce energy use with ICT-dependent systems to control and monitor a building's mechanical and electrical equipment including heating and cooling, lighting, and power systems. There is tremendous potential for reducing greenhouse gas emissions from buildings through high-efficiency standards for new construction and energy efficiency retrofits for existing structures.

Smart grid – The smart grid enables the two-way flow of energy and information to efficiently deliver a safe, secure and sustainable electric supply. The smart grid describes an ideal state of the electric power system that will be transitioned to over a number of years. Integral to the smart grid infrastructure are the two-way broadband communications networks that enable real-time balance of electric demand, supply, and storage. Unleashing the emissions reductions potential of the smart grid will require forward-looking policy, innovative markets and services, and an integrated regulatory frameworks.

Agriculture – "Precision Agriculture" or "Smart Farming" is the use of innovative technologies applied to the practice of agriculture and farm management with the goal of optimizing returns on inputs while preserving resources. These applications will help improve the efficiency of water and productivity of agriculture. Early research in this area has shown promising results. Advancing the potential environmental benefits of these technologies will require reliable data communications networks in often remote areas not always economically feasible for commercial service providers to serve. This infrastructure investment would likely produce great yields towards California's environmental goals given the large size of the agricultural sector, and the high energy-intensity of the water delivery system in California.

Climate Change Adaptation – Broadband has an important role in helping adapt to minimize the effects of climate change and should be included in government strategies to address global warming. Technologies to improve water-use efficiency are particularly relevant to California due to the continuing risk of water scarcity anticipated with a changing climate.

E-Government – Or online government, utilizes ICTs to provide access to public services when and where they are needed, independent of government offices being open to the public. This application area holds potential for reducing environmental impacts and government costs as well as improving service to citizens. Environmental goals should be intentionally considered in the planning and implementation of e-government initiatives, otherwise the technology deployments may end up working against environmental objectives.

The broadband application areas with the most immediate potential for reduction of greenhouse gas emissions in California are telehealth, telework, precision agriculture, water-use efficiency, and smart buildings. Smart energy solutions, including deployment of smart grid technologies and development of electric vehicle (EV) infrastructure, should continue to be monitored closely and integrated into long-term planning efforts such as the Metropolitan Planning Organizations' Sustainable Communities Strategies pursuant to Senate Bill 375 (Steinberg 2008).

In conclusion, to achieve California's greenhouse gas reduction goals, the research indicates that broadband infrastructure deserves a place in long-term policy and planning as an enabling technology to support climate change mitigation and adaptation strategies. As a result of this research, Valley Vision provides several recommendations to advance the potential of broadband-enabled ICT applications for climate change abatement.

Recommended Actions

These recommendations are offered to policy makers, planners, and researchers at federal, state, regional, and local levels as well as interested stakeholders. Under each category heading below, policy makers, planners and researchers should:

Policy and Planning

- Consider broadband as a critical infrastructure in support of 21st century environmental, economic, and social objectives.
- Include broadband as a deliberate component of climate change strategies to support mitigation and adaptation efforts.
- Coordinate policy and planning for broadband infrastructure across traditional government silos, including energy, transportation, environmental and natural resource protection.
- Align funding and incentives to accelerate broad-based deployment of broadband technology and to drive adoption of climate abatement solutions.
- Offer financing assistance and other mechanisms to encourage the adoption of smart building technologies that will enable significant emissions reductions.

Data and Research

- Collect additional evidence and empirical data quantifying the greenhouse gas emissions avoided through telehealth and telework.
- Leverage Sustainable Communities Strategies as an avenue for developing additional empirical data to quantify the abatement potential of telehealth, telework, and possibly e-learning.[4]
- Inform local government and utility policies and programs with ongoing research into how smart energy solutions can optimize the end-use of energy across major sectors of the economy (e.g., power, transportation, manufacturing, agriculture, and buildings).

Technology and Standards

- Adopt and disseminate common interoperability standards and communications protocols for smart grid applications as they are developed.
- Consider environmental goals intentionally in the deployment of e-government technology initiatives.
- Develop open data and standardized metrics for tracking, monitoring, and reporting performance of the State’s environmental policies and programs.

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OVERVIEW

In 2011, California Emerging Technology Fund (CETF) hired Valley Vision to conduct a review of literature that documented or quantified the greenhouse gas emissions impact of broadband applications. This resulted in a summary of relevant literature; a recommendation to adopt a "Broadband as a Green Strategy" policy focus; and the production of a four-page policy brief that was shared with multiple policy-making stakeholder groups. In 2014, Valley Vision updated the literature review in partnership with CETF, seeking new or refreshed data and information supporting the "Broadband as a Green Strategy" policy focus. This document provides a summary of the relevant literature found in the 2014 research effort.

The 2014 literature search focused on several broadband application areas included in the 2011 literature review. These include telehealth/medicine, telework/commuting, e-learning/education, smart energy, and smart grid. In addition to these focus areas, the 2014 literature search sought to identify new opportunity areas of high potential for broadband-related greenhouse gas emissions abatement. As a result, agriculture, climate change adaptation, and e-government were identified as new opportunity areas. To supplement the literature review, informant interviews were conducted with seven subject-matter-experts and policy leaders to gather current perspectives on emerging "broadband green" opportunity areas and applications.

The 2014 literature review and informant interviews aimed to answer two main questions. First, what new information and research is available to demonstrate the connection between broadband applications and positive environmental impacts, including greenhouse gas emissions reductions? Second, what new or emerging broadband applications should be considered for inclusion in the "Broadband as a Green Strategy" policy-making discussion?

The research effort resulted in over 80 documents reviewed for relevant content. These included papers, reports and publications by scientific and academic research institutions, government and non-profit organizations, as well as industry-produced information. In most cases, research was conducted on articles published between 2011 and the present. In some cases, literature published prior to 2011 was included in this review if the documents were relevant and were not included in the 2011 literature review.

In addition to the review of relevant research, seven informant interviews were conducted with subject-matter and policy experts in the areas of energy, healthcare, agriculture, and education to augment the information found in the research. The findings of these interviews are incorporated into this document under the subjects to which they are related.

OVERALL TRENDS

Greening of Information and Communications Technology (ICT)

The ICT sector has been criticized as a large consumer of electric power and associated producer of greenhouse gas emissions. According to the journal article, *Energy Consumption of Subscriber Devices in Broadband Networks*, the ICT sector consumed approximately eight percent of electricity generated worldwide in 2007 and was responsible for two to two and one half percent of total carbon dioxide emissions (CO_2). [4] Of that total, about four percent was consumed by telecom networks and Internet data centers. Although ICTs in and of themselves are not considered green technologies, the application of ICT to other sectors, in particular transportation, power systems, and industrial control, can leverage energy savings 5-10 times larger than the consumption of ICT itself. In its report, *The Broadband Bridge: Linking ICT with Climate Action for a Low-Carbon Economy,* the Broadband Commission estimates that by 2020 the ICT sector could reduce global emissions from all sectors by 15 percent, representing annual savings of $946.5 billion for companies gaining efficiencies through ICT deployment.[5]

Notwithstanding the climate change abatement potential that could be leveraged through ICT, the literature review uncovered several reports that indicate reducing power consumption and greenhouse gas emissions in this sector are important for addressing climate change as the usage of technology continues to expand globally. This category of literature may be generally referred to as Greening ICT. The paper *Leveraging Advances in Broadband Technology to Improve Environmental Sustainability* explores the direct and indirect benefits of advanced broadband technology on environmental sustainability. [6] Advanced broadband technologies are shown to directly improve the energy efficiency of telecommunications networks. For example, macrocellular base stations are one of the largest consumers of energy on a wireless network; approximately 60 to 70 percent of base station energy is consumed by power amplifiers. Improvements in amplifier design and base station architecture would result in an overall improvement of 33 to 50 percent of the entire base station power consumption. Additional investigations into Greening ICT are being conducted to identify the energy saving potential of green networking technologies,[7] and the energy efficiency potential of advanced wireless networks.[8,9]

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[4] Borzycki, K. (2012). Energy consumption of subscriber devices in broadband networks*. Journal of High Speed Networks*, 18(4), 223-238. doi: 10.3233/JHS-120459

[5] The Broadband Commission. (2012). *The Broadband Bridge: Linking ICT with Climate Action for a Low-Carbon Economy*. Switzerland: Working Group on Climate Change for the Broadband Commission. Retrieved February 25, 2014 from http://www.broadbandcommission.org/Documents/Climate/BD-bbcomm-climate.pdf

[6] Gulati, S. (2013, April 01). Leveraging Advances in Mobile Broadband Technology to Improve Environmental Sustainability. *International Journal of Engineering Research*, 2(2), 66-70. (ISSN : 2319-6890).

[7] Sandhu, S.S., Vihar, S.G. ,Rawal, A., Kaur, P. ,Gupta, N. (2012, February). Major components associated with Green Networking in Information Communication Technology systems. *Computing, Communication and Applications (ICCCA), 2012 International Conference*. doi: 10.1109/ICCCA.2012.6179233.

[8] Gong, X., Hou, W. Guo, L., Zhang, L. (2014, July). Dynamic energy-saving algorithm in green hybrid wireless-optical broadband access network. *Optik - International Journal for Light and Electron Optics*, 124((14), 1874-1881. doi: http://dx.doi.org/10.1016/j.ijleo.2012.05.030

Clicking Clean: How Companies are Creating the Green Internet is a report by Greenpeace, Inc., that examines the power use and energy sources of major data centers and cloud computing infrastructure providers worldwide.[2] Cloud computing refers to the practice of using a network of remote servers hosted on the Internet to store, manage, and process data, rather than a local server or a personal computer. This report notes that there are some positive effects on ICT sector emissions due to cloud computing efficiencies, data center server virtualization, and smart device proliferation (i.e., phones and tablets replacing the use of more energy-intense computing equipment such as personal computers).

According to the Greenpeace report, shifting business online can create significant efficiency gains; however, with global population increasing and the Internet becoming the foundation of the global economy, the energy appetite of the ICT sector will continue to grow exponentially. The report claims that the rapid growth of cloud computing and use of the Internet have produced a collective electricity demand such that if compared to total power demand of countries would rank in the top six. This "country of ICT" consumes more power than Germany as a whole. The report estimates that power consumption in this sector will increase 60 percent by 2020. On a positive note, the report found that leading data center operators have taken key steps toward building a green Internet, particularly those companies that have committed to building a 100 percent renewably powered platform. These commitments are having a profound impact on shifting investment from legacy power generation – oil, coal, gas and nuclear - to renewable energy technologies, and disrupting the status quo among major electric utilities. The report asserts that the Internet *must* be a platform for leading the world to a clean energy future.

In summary, ensuring that broadband networks and ICTs are highly energy efficient and increasingly powered by renewable energy to the greatest extent possible are important elements of "Broadband as a Green Strategy" policy development.

Adopting Broadband as a Green Strategy

Multiple articles and papers published since the 2011 literature review support the position of "Broadband as a Green Strategy." The Broadband Commission report argues that broadband provides a unique opportunity to "spearhead the transition to a carbon-constrained world."[5] The report further asserts that in order to reach its full potential, broadband needs to be a deliberate component of climate change strategy, backed by strong policies in support of economy-wide emissions reductions. Three key areas of opportunity for greenhouse gas reductions identified in this report are smart cities, smart grid, and climate change adaptation. While nations and states may choose to set greenhouse gas reduction targets, it is at the city and metro level where change must be implemented. By 2016, 30 percent of the world's population is expected to live in urban centers, growing to 70 percent of the world's population by 2050. With the anticipated population growth, applying ICT-based innovations,

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[9] Lui, Y., Guo, L., Gong, B., Ma, R., Gong, X., Zhang, L. Yang, J. (2012, March). Green survivability in Fiber-Wireless (FiWi) broadband access network. *Optical Fiber Technology*, 18(2), 68-80. doi: http://dx.doi.org/10.1016/j.yofte.2011.12.002

connected through broadband networks, can lead to multiplier effects that benefit the economy and lead to more connected sustainable communities.

GeSI's SMARTer2020 report released in December 2012 aims to demonstrate how the increased use of ICTs could cut projected 2020 global greenhouse gas (GHG) emissions by 16.5 percent.[1] This is an increase in abatement potential of 16 percent over the analysis from the 2008 SMART2020 report. The updated analysis indicates these GHG emissions can be achieved while also delivering $1.9 trillion in savings in gross energy and fuel and creating 29.5 million new jobs worldwide. The abatement potential of ICT for other sectors is found to be equivalent to more than seven times the ICT sector's own emissions by 2020. The total abatement potential from ICT for other sectors is estimated to be approximately nine gigatons carbon dioxide equivalent ($GtCO_2e$).

ICT-enabled abatement solutions identified in the SMARTer2020 report range across six sectors of the economy: power, transportation, agriculture, buildings, manufacturing, service and consumer. These sectors are referred to as "end-use" sectors. For each end-use sector, solutions are identified that have the potential to reduce greenhouse gas emissions. The table below summarizes the global abatement potential for solutions applicable to each end-use sector.

End-Use Sector	*Abatement Solutions*	*Total Abatement Potential*	*Percent of Total Potential*
Power	• Demand management • Time-of-day pricing • Integration of renewables • Virtual power plant • Integration of off-grid renewables and storage	2.0 GtCO2e	22%
Transportation	• Video conferencing • Telework • Real-time traffic alerts • Apps for intermodal transportation • Asset sharing/crowd sourcing • Integration of EVs • Intelligent Traffic Management • Fleet management and telematics • Optimization of truck route planning • Optimization of logistics networks	1.9 GtCO2e	21%
Agriculture and Land Use	• Soil monitoring/weather forecasting • Smart water • Livestock management • Smart farming	1.6 GtCO2e	18%
Buildings	• Integration of renewables • Building management system • Building design • Voltage optimization	1.6 GtCO2e	18%
Manufacturing	• Optimization of variable-speed motor systems • Automation of industrial processes	1.2 GtCO2e	13%

Service and Consumer	• E-Commerce • E-Paper • Online media • Public safety/disaster management • Minimization of packaging • Reduction in inventory	0.7 GtCO2e	8%

Figure 1: Global abatement potential for solutions applicable to each end-use sector[1]

The SMARTer2020 report includes a detailed study at the national level for six countries, including the United States. The national level studies entail an evaluation of each solution's abatement potential in consideration of factors such as ICT penetration, composition of the economy, climate change awareness, and political willingness to act. For the United States, solutions with the most potential for abatement were found in the power and buildings sectors.

In conclusion, the SMARTer2020 report indicates that the challenge facing many ICT-enabled abatement solutions is the lack of robust policies to address climate change. Concerted action by policy makers is called for to encourage the implementation of these solutions. Specific guidance to policy makers on actions they can take to realize the significant GHG reduction potential is outlined in the report.

The paper *E-commerce and E-materialization: Broadband and Information Technologies Effects on Pollution and Greenhouse Gas Emissions* discusses the significant positive effects the application of broadband technologies can have on the environment. [10] In this report, e-commerce (i.e., commercial transactions conducted electronically on the Internet) is estimated to reduce greenhouse gas emissions by 37.5 million tons per year. Up to 65 percent of emissions from traditional retail shopping are due to consumers traveling to and from traditional retail establishments. E-commerce reduces emissions nationally by up to 30 percent, both from reduced travel and reduced need for traditional retail space. E-materialization refers to the use of electronic communications to replace the need to manufacture, publish, print and ship documents, books, CDs and DVDs.

Numerous examples are provided in Fuhr's paper, quantifying estimates for pollution reduction and greenhouse gas emissions reduction through e-materialization. For example, reduced circulation of newspapers from 1999 to 2009 has saved: 5.7 million tons of solid wastes; 77 million British thermal units (BTUs) of energy; 28 million gallons of polluted water; and 9 million tons of greenhouse gas emissions. This example is notable as the paper industry uses the most energy of any sector outside of the petroleum and chemical industries. In addition to demonstrating the significant reductions in energy use and lower greenhouse gas emissions associated with ICTs and broadband, this paper argues

[10] Fuhr Jr., J., Pociask, S. (2012, June). E-commerce and E-materialization: Broadband and Information Technologies Effects on Pollution and Greenhouse Gas Emissions. *Temple Journal of Science, Technology & Environmental Law*, 31(1), 45. Retrieved from http://connection.ebscohost.com/c/articles/84498265/e-commerce-e-materialization-broadband-information-technologies-effect-s-pollution-greenhouse-gas-emissions

that use of these technologies deserve to be important considerations in the development of comprehensive energy policies.

According to the *UK Broadband Impact Study,* the availability and use of faster broadband is expected to result in significant positive environmental impacts including the savings of 2.3 billion kilometers of car-trip commuting replaced by telework; 5.3 billion kilometers of car-trip business travel replaced by video and online collaboration tools (equal to 9 percent of the UK's current business travel); and 1 billion kilowatt hours (kWh) of electricity saved annually through broadband-using firms shifting part of their server capacity onto more energy-efficient public cloud platforms. [11] The study estimates these savings would translate to 1.6 million tons of carbon dioxide equivalent (CO_2e) annually by 2024 (equal to 0.3 percent of the UK's current greenhouse gas emissions).

In summary, there is a greater policy and research focus supporting the connection between broadband and greenhouse gas reduction and "Broadband as a Green Strategy" than there was three years ago in the previous literature review. More information is available now, providing both quantitative and qualitative data, on the environmental impacts of broadband. Broadband is recommended as a deliberate component of energy and climate change policies in order to maximize its potential for supporting the desired policy outcomes.

Accelerating Pace of Connectivity

"The Internet of Things" was an emerging technology trend identified by the management consulting firm McKinsey & Company in 2010. By 2013, the explosive growth of connected devices prompted McKinsey to rename this phenomenon "The Internet of ALL Things" in its report *Ten IT-enabled Business Trends for the Decade Ahead*. [12] Connected devices include smart phones, tablets, personal computers, sensors and actuators that connect and feed into, and/or receive data from communications networks such as the Internet. More than 12 billion devices around the world today are connected to the Internet. The number of connected devices is expected to proliferate at astounding rates, with estimates ranging from 50 billion devices to more than a trillion within the next decade. This level of connectedness has the potential to transform activities in transportation, healthcare, energy, agriculture and government, among other sectors. In a related article, experts from the Institute of Electrical and Electronics Engineers (IEEE) predict that 60 percent of cars will be connected to the Internet by 2025.[13] Similarly, a Broadcom blog post states that analysts are predicting that 100 percent of cars will be

[11] Department for Culture, Media, and Sport. (2013, November). *UK Broadband Impact Study, Impact Report*. United Kingdom. Retrieved from https://www.gov.uk/government/publications/uk-broadband-impact-study--2
[12] Bughin, J., Chui, M., and Manyika, J. (2013). *Ten IT-enabled business trends for the decade ahead.* McKinsey & Company, McKinsey Global Institute. Retrieved March 11, 2014 from http://www.mckinsey.com/insights/high_tech_telecoms_internet/ten_itenabled_business_trends_for_the_decade_ahead
[13] IEEE. (2013). *The Need for High Speed: IEEE experts predict 60 percent of the vehicles on the road will be Internet-enabled by 2025*. Posted to http://www.ieee.org/about/news/2013/28_august_2013.html

connected by 2025.[14] The article anticipates a new era of vehicle-to-person (V2P), vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication, commonly known as V2X. According to the article, V2X communications promise "quantum improvements" in road and traffic safety by alerting drivers to upcoming road hazards, accidents and traffic jams.

According to the McKinsey report, linking machinery, equipment, and other physical assets with networked sensors and actuators allows not only the capture of data and performance management, but enables machines to collaborate and act on new information independently. In a transportation network, for example, the system can be optimized by sensors picking up traffic data and actuators coordinating traffic signals based on the number and movement of vehicles in a city. The report highlights examples of transformational opportunities in government, healthcare, and education that will emerge as the world becomes a more connected digital place. Government examples highlighted include the provision of e-government services, such as the ability to pay taxes, parking tickets and other fees, or obtain documents, licenses and permits online. Healthcare opportunities highlighted include telehealth applications as well as self-monitoring of medical conditions such as high blood pressure. In the realm of education connectivity is driving opportunities for new student-paced pedagogies and new education delivery mechanisms, including e-learning applications that support both student learning and teacher professional development.

In summary, the transition to a more connected digital world is happening at an ever-increasing pace. Connected solutions will rely on the increasing expansion and adoption of broadband technologies.

Integrating Environmental, Economic, and Social Impacts

The literature search found an expanding global recognition of the positive environmental impacts of broadband access and adoption. Positive environmental benefits notwithstanding, they are not necessarily viewed as a primary driver. Despite the fact that the parameters of the literature search specifically looked for views on environmental impacts of broadband, a great deal of the literature was found to reference an integrated discussion of economic, environmental and social impacts. The *UK Broadband Impact Study* is one example.[11] As stated in the report, "central to…the study has been the development of an integrated model of the projected economic, social and environmental impacts associated with faster broadband…and of those impacts attributable to the current set of publicly funded interventions to improve broadband quality and coverage." The report establishes the viewpoint that broadband is a necessary infrastructure for national competitiveness in the 21st Century.

In many cases, economic benefits were seen as a primary driver with environmental and/or social impacts as secondary co-benefits. The CSIRO report, *Smart Farming: Leveraging the Impact of*

[14] Murry, S. (2014, March 10). *Timothy Lau in ECN: Connected cars promise "quantum improvements in road and traffic safety*." Message posted to http://blog.broadcom.com/automotive-technology-2/timothy-lau-in-ecn-connected-cars-promise-quantum-improvements-in-road-and-traffic-safety/

Broadband and the Digital Economy, is indicative of this viewpoint. [15] While carbon reduction goals are specifically called out as part of Australia's national goal for the future of the agricultural sector, the economic benefits of this initiative are the primary driver. The Utah Broadband Project is another example. The project is a collaborative effort between the Governor's Office of Economic Development, the Utah Public Services Commission, and the Utah Department of Technology Services. The project promotes the use of broadband for economic benefit in multiple sectors, including agriculture. [16]

In summary, on a global scale, government, industry, and scientific research institutions are exploring an integrated view of the environmental, social and economic opportunities associated with ICT. There is a growing global recognition of broadband as an essential infrastructure for realizing 21st Century environmental, economic, and social sustainability objectives.

SUMMARY OF FOCUS AREAS

Telehealth

Telehealth, often used interchangeably with the terms telemedicine or e-health, refers to the application of electronic communications and information technologies to support the delivery of health care services including remote health monitoring and consultations as well as managing and sharing digital health information.[17] The current literature indicates the field of telehealth is important both for its environmental and economic value.

From an economic perspective, telehealth is a large and quickly growing market opportunity. Dedicated device and software markets were estimated at $843 million in 2012 and projected to reach $2.9 billion by 2019. The mobile health care market was valued at $1.4 billion in 2012, and is expected to reach $1.5 trillion by 2019. This growth will be due in part to the use of seven billion smart phones and four and a half billion tablet devices globally.[18]

From an environmental perspective, the paper *Climate Change and eHealth: a Promising Strategy for Health Sector Mitigation and Adaptation,* indicates that the health care sector is the second largest

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[15] Griffith, C, Heydon, G, Lamb, Lefort, L, D, Taylor, K, Trotter, M and Wark, T. (2013). *Smart Farming: Leveraging the impact of broadband and the digital economy*, CSIRO and University of New England. Retrieved from http://24green.com/wp-content/uploads/2013/08/Smart-Farming-leveraging-the-impact-of-broadband-and-the-digital-economy.pdf

[16] State of Utah. (N.D). *Broadband benefits the agricultural sector*. State of Utah Broadband Project. Retrieved February 25, 2014 from http://broadband.utah.gov/resources/agriculture/

[17] Davidson, C., Santorelli, M. (2009). *The Impact of Broadband on Telemedicine* (A Report to the U.S. Chamber of Commerce). Advanced Communication Law & Policy at New York Law School. Retrieved February 26, 2014 from http://telehealth.org/wp-content/uploads/2013/11/BroadbandandTelemedicine.pdf

[18] PR Newswire. (2013, September 16). *Global Telemedicine and M-Health Convergence Market Shares, Size, Strategies, and Forecasts, Worldwide*, 2013 to 2019 Forecast and Analysis in New Research Report at Researchmoz.us. Albany, NY: Retrieved from http://www.prnewswire.com/news-releases/global-telemedicine-and-m-health-convergence-market-shares-size-strategies-and-forecasts-worldwide-2013-to-2019-forecast-and-analysis-in-new-research-report-at-researchmozus-223896141.html

consumer of energy of all U.S. industrial sectors. [19] Globally, the health care sector is estimated to contribute from three to eight percent of greenhouse gas emissions in developed countries. In the report *The Energy Burden and Environmental Impact of Health Services* published by the *American Journal of Public Health*, these figures are reiterated, along with a more detailed description of specific estimated emissions associated with multiple aspects of health care delivery (e.g., hospitals and clinical buildings, surgery, anesthetic gases, etc.). [20] The paper concludes that "although reducing health-related energy consumption and emissions alone will not resolve all of the problems of energy scarcity and climate change, it could make a meaningful contribution." The paper recommends that further empirical investigation be conducted related to the greenhouse gas emissions reductions associated with telehealth.

A more recently published report provides empirical evidence and quantified greenhouse gas reductions empowered through telehealth delivery. The *Journal of Health Services Research & Policy* published the study *Teleconsultations Reduce Greenhouse Gas Emissions*.[21] The study was conducted in the Portuguese region of Alentejo, and compared a group of patients receiving remote consultation services with a control group of patients receiving traditional face-to-face medical consultations. For more than 20,000 patients over a 7-year period between 2004 and 2011, total travel distances and the direct and indirect greenhouse gas emissions for face-to-face patients was compared to the associated emissions that would have resulted had telehealth services not been available.

The study concluded that "the availability of remote care services can significantly reduce road travel and associated emissions." Results demonstrated that telehealth consultations led to a 95 percent reduction of emissions, avoidance of 455 tons of greenhouse gas emissions, and elimination of 2,313,819 kilometers of travel. The greenhouse gas emissions reductions were equivalent to 22 kilograms of CO_2 per patient. The study recommended that greenhouse gas emissions reductions be considered in technology assessments and economic evaluations, a practice which is not common today. The authors proposed monetizing the value of the emissions reductions as a way to facilitate their inclusion in economic evaluations, and mentioned that the pollution "allowance" value of California's Cap-and-Trade program, starting at approximately $10 per allowance in 2013, was far from the meaningful value of 50 euros defined by the Kyoto Protocol as the price needed to drive low-carbon investments.

The California Telehealth Network (CTN) is connecting over 800 California healthcare providers in underserved areas to a state- and nation-wide broadband network dedicated to healthcare. CTN is deploying a web-based scheduling tool (e-ceptionist) that will not only improve scheduling efficiency, but also enable the CTN to measure and track vehicle miles avoided due to use of the telemedicine

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[19] Holmner, A., Rocklov, J., Ng, N., Nilsson, M. (2012, June 5). *Climate change and eHealth: a promising strategy for health sector mitigation and adaptation*. Global Health Action. doi: http://dx.doi.org/10.3402/gha.v5i0.18428
[20] Brown, L., Buetter, P., Canyon, D. (2012). The Energy Burden and Environmental Impact of Health Services. *American Journal of Public Health*, 102(12), 76-82. doi: 10.2105/AJPH.2012.300776
[21] Oliveira, T., Barlow, J., Goncalves, L. Bayer, S. (2013, August 14). *Teleconsultations reduce greenhouse gas emission. Journal of Health Services Research & Policy Report*, 18(4) 209-214. DOI: 10.1177/1355819613492717

consultations. The collection of this data will create the potential for quantifying emissions for a carbon trading system.[22]

In summary, telehealth continues to be a promising application for quantifying and possibly monetizing greenhouse gas emissions reductions related to broadband-enabled telehealth delivery. In addition, telehealth is identified in the research as a strategy for climate change adaptation.

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Telework/commuting

According to telework.gov, a website that facilitates the Telecommuting Act of 2010 for U.S. Federal Government employees, the terms “telecommuting” and “flexible workplace” are now generally referred to as telework.[23] The concept refers to the practice of working from home or another location away from the office, making use of the Internet, e-mail, and the telephone. Many information sources identify employer savings and employee satisfaction as key benefits of telework, while recognizing the promising potential for greenhouse gas reductions as an environmental co-benefit.

The Broadband Commission report refers to telework or “smart work” as meaning teleworking, flexi-working, virtual or telepresence conferencing, and flexi-office as a climate change mitigation strategy.[5] The report provides an overview of a study conducted by Swedish telecom operator TeliaSonera, the goal of which was to reduce business and car travel, and limit the need for office space. Using 2001 as a baseline, the study found that by 2007, telework initiatives reduced CO_2e emissions by 40 percent per employee per year (over 2.8 tons CO_2e per employee). Scaling results to the country level, the study anticipated that similar initiatives could reduce Sweden’s total CO_2e emissions by two to four percent, and suggested that scaling results to a global level could reduce global emissions by the same order of magnitude of two to four percent worldwide.

Published by the *International Journal of Research Engineering*, the paper *Leveraging Advances in Mobile Broadband Technology to Improve Environmental Sustainability*, discusses the “enormous potential” for reducing the use of natural resources and emissions of greenhouse gases through telework and video conferencing to replace car-based commutes and business travel.[6] The paper contends that high-speed communications are needed to provide the user experience required to achieve the full potential of these reductions.

The *UK Broadband Impact Study* estimates that increased telework, encouraged through the availability of faster broadband, would reduce the UK’s annual commuting distance about 2.3 billion kilometers by 2024, equivalent to two percent of the country’s total annual commuting distance for car travel.[11] The study estimated that more than half of the carbon savings from reduced commuting and office energy use would be offset by increased emissions from domestic space heating for home-based teleworkers.

[22] Information courtesy of Eric Brown, California Telehealth Network.
[23] Telework.gov. (n.d.) U.S. Office of Personnel Management and U.S. General Services Administration. Retrieved from http://www.telework.gov/tools_and_resources/training/employees/scorm/et/et/te_01_01_0040.htm

With the rebound effect of home-based workers taken into consideration, the net annual savings in CO_2e emissions through increased telework is anticipated to reach 0.24 million tons of CO_2e by 2024. In estimating the impact of faster broadband on business travel, the study estimated the net carbon impacts associated with reduced business travel to be 1.1 million tons of CO_2e by 2024. An additional benefit of reduced business travel would be savings of 5.3 billion kilometers of car travel annually, equal to nine percent of the UK's current total annual business travel.

Global Workplace Analytics is an organization that conducts independent research and consults on emerging work place issues and opportunities. [24] A recent white paper published by the organization examines the obstacles and opportunities of a fully deployed U.S. Federal Government employee telework program. The white paper estimated that if 32 percent of eligible Federal employees were to telework at the same frequency as existing Federal teleworkers, the environmental benefits would include an annual reduction of up to 200,000 tons of greenhouse gases and savings of 5 million barrels of oil.[25]

Connected Tennessee is a public-private partnership studying the impacts of high-speed broadband-enabled telework in Tennessee from a social, environmental, and economic perspective. Their report, *Telework and the Broadband Super Highway,* published in 2012, argues that increasing the availability of high-speed Internet across the state, thus increasing opportunities for telework, can benefit the environment, boost economic growth, and provide a better work-life balance for employees across Tennessee. [26] The report states that the Nashville-Murfreesboro commute is the longest in the country. The average 200 hours per year of rush hour travel in any of the fifty largest U.S. cities is compared with the typical Nashville rush hour travel time of about 280 hours per year. According to the report, all four major cities in Tennessee rank among the top 25 U.S. cities for carbon emissions per capita as a result of these long commutes. Connected Tennessee estimates that by working from home full-time instead of commuting, a Nashville employee can save approximately $2,300 per year in auto-travel expenditures (gas, maintenance, and tires) and produce approximately 9,480 fewer pounds of CO_2 emissions per year.

The World Wildlife Fund and the Carbon Disclosure Project published a joint report in 2013 titled *The 3% Solution: Driving Profits through Carbon Reduction*. [27] The authors assert that companies encouraging their employees to travel less by car and plane would result in positive impacts to the environment as well as economic value. Assuming that employees work from home one day a week, reducing car travel by seven percent and air travel by ten percent, the carbon reduction impact could be as much as 65 megatons of CO_2e with a corresponding economic value of $25 billion (present value) by 2020. These figures assume investment in flexible working arrangements, car-pooling services, video and teleconferencing equipment and support for on-site electric vehicle charging.

[24] Global Workforce Analytics (n.d.)http://www.globalworkplaceanalytics.com/
[25] Lister, K., Harnish, T. (2013, August). *Federal Telework: Obstacles and Opportunities*. Retrieved February 27, 2014 from http://www.globalworkplaceanalytics.com/whitepapers
[26] Connected Tennessee. (2012). *Telework and the broadband super highway*. Retrieved March 19, 2014 from http://www.connectedtn.org/sites/default/files/connected-nation/Tennessee/files/tn_teleworking_0512.pdf
[27] World Wildlife Fund and The Carbon Disclosure Project. (2013). *The 3% Solution: Driving profits through carbon reduction*. Washington DC. Retrieved March 24, 2014 from https://worldwildlife.org/projects/the-3-solution

In a policy brief prepared for the California Air Resources Board, researchers from the University of California, Davis, and the University of California, Irvine, reviewed the empirical literature on the impacts of telecommuting. Reductions in vehicles miles traveled (VMT) from telecommuting "appear to be substantial," according to authors, both for workers who work from home and those who work from a central 'telecenter.' For home-based workers, VMT was reduced by 90.3 percent. For center-based telecommuters, VMT reductions ranged from 62 percent to 77 percent. The authors noted that none of the studies reviewed provide direct evidence for telecommuting's impact on greenhouse gas emissions, though several studies estimated the impact on energy use. Translating VMT reductions into estimates of greenhouse gas emissions reductions depends on the nature of the VMT eliminated (e.g. speeds, acceleration, deceleration, times vehicle is started, etc.) and the types of vehicles owned by telecommuters. Apart from these considerations, greenhouse gas reductions would be "expected to be similar to VMT reductions, if vehicle fleet composition and driving patterns are unchanged."[28]

In summary, telework is an area that has tremendous potential for displacing greenhouse gas emissions caused by employees commuting to employer sites. There is a large body of work documenting the reduction in VMT achieved through telework. Further empirical investigation to quantify greenhouse gas emission reductions is warranted to validate telework applications as a climate change mitigation strategy.

E-Learning

E-Learning, also referred to as online or distance learning, means learning conducted via electronic media, typically on the Internet. The 2014 literature review did not reveal new research or investigation into the green benefits of e-learning. Knowledge experts in the education field indicated that while there seems to be a logical connection between greenhouse gas emissions reductions through e-learning due to avoided miles traveled, ICT deployment in education is driven by reasons other than environmental concerns. Knowledge experts interviewed by Valley Vision indicated that they were not aware of any intentional efforts to study this connection to date.[29]

Much of the current literature on broadband in education focuses on the need for technology and communications to improve educational opportunities and outcomes. *The Broadband Imperative: Recommendations to Address K-12 Education Infrastructure Needs*, a report published in 2012 by The State Educational Technology Directors Association (SETDA), discusses the driving need for more broadband in education in order to ensure all students have access to educational tools and resources

[28] Handy, S., Tal, G., and Boarnet, M. (2013, December) *Policy Brief on the Impacts of Telecommuting Based on a Review of the Empirical Literature*. Policy brief for the California Air Resources Board. Retrieved March 19, 2014 from http://www.arb.ca.gov/cc/sb375/policies/telecommuting/telecommuting_brief120313.pdf

[29] Information courtesy of Cindy Kazanis and Michael O'Niell, California Department of Education; and Jeff Layne, California State University, Chico.

needed to be college and career ready by 2015 and beyond. [30] Another report published by SETDA in 2008, *Empowering Teachers: A Professional and Collaborative Approach*, submits that one of the barriers to sustainable professional development is access to technology. [31] The report recommends that information technology staff members be included in the planning process so that broadband and access issues are addressed during the planning and implementation processes of professional development training. The report further recommends increasing access to online learning and professional communities for teachers to provide any time, any place learning for teachers, as well as access to the opportunity to collaborate with peers and share knowledge on best practices and technology integration strategies.

The report *ICTs and Climate Change Adaptation and Mitigation: the Case of Ghana* includes a brief reference to e-learning as an adaptation strategy, referencing a 2008 study by Open University in the United Kingdom that found, "on average, the production and provision of the distance learning courses consumed nearly 90 percent less energy and produced 85 percent fewer CO_2 emissions than the conventional campus-based university courses." [32] This information was used to support the assertion that universal broadband access would allow educational content to be delivered direct to local schools and homes thereby limiting the need for travel to distant schools or cybercafés. The report further claimed that educational content delivered over ICT networks can be used to raise awareness and build capacity on climate change.

McKinsey & Company, in its report *Ten IT-enabled Trends for the Decade Ahead,* noted that Internet and information technology tools have largely transformed the way companies interact with customers, engage talent, and manage operations. While these changes have improved productivity in the private sector, they have largely bypassed the government and education sectors. The report asserts that over the next decade the ten identified IT-enabled trends "will combine to force educators to rethink models of learning and embrace new platforms and modes of teaching." Among the anticipated changes are: new pedagogies that will make learning more adaptive and allow students to learn at their own pace; new delivery mechanisms, including smart phones and tablets entering the class room to deliver personalized content; and new forums for teacher development and collaboration.[12]

To supplement the literature review, Valley Vision conducted a number of informant interviews with knowledge experts in the education field. One interview was with Cindy Kazanis, Director of the Educational Data Management Division at the California Department of Education. During the interview, Ms. Kazanis indicated that teacher professional development may be an area to further explore the potential linkage of reduction of greenhouse gases with e-learning. As more teachers are able and choose to complete their required professional development training online, vehicle trips to a

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[30] Fox, C., Waters, J., Fletcher, G. and Levin, D. (2012). *The Broadband Imperative: Recommendations to Address K-12 Education Infrastructure Needs*. Washington, DC: The State Educational Technology Directors Association (SETDA).

[31] Fox, C. (2008). *Empowering Teachers: A Professional and Collaborative Approach*. The State Educational Technology Directors Association (SETDA). Retrieved February 24, 2014 from http://www.setda.org/?attachment_id=956

[32] Ospina, A., Bueti, C., Dickerson, K., and Faulkner, D. (2012). *ICTs and climate change adaptation and mitigation: the case of Ghana.* University of Manchester and the International Telecommunications Union.

central location to complete training will be reduced. Ms. Kazanis also thinks there is anecdotal evidence to support the availability of broadband in schools with a reduction in field trips, which would translate into reduced transportation-related emissions, but had no empirical evidence or statistical data to offer.

From a technology standpoint in K-12 education, the major focus right now is on implementing the on-line assessment corresponding to the new Common Core curriculum standards adopted throughout California. Beginning in the 2014-2015 school year, the new online assessment will replace the paper-based Standardized Testing and Reporting (STAR) test used to gauge student achievement in previous years. California is currently testing the new Common Core assessments in order to understand what the technology needs and gaps may be when the state's 3.3 million K-12 school children transition to the online assessment. Moving forward, this will be an important area to monitor to ensure schools have the necessary bandwidth to implement effectively the new online assessments.

A second interview was conducted with a knowledge expert in higher education. Mr. Jeff Layne is the Director of Distance Education at the Center for Regional and Continuing Education with California State University, Chico. Mr. Layne indicated that the University offers several online degree programs that have been put in place to expand access to a university education. Mr. Layne provided some data related to online learning at Chico State from 2006 to the present. As of the fall 2013 semester, 153 students were enrolled in online courses leading to completion of an online degree program. It is unknown how often these students would have traveled to campus if these courses were not offered online. Mr. Layne noted, "It would be interesting to have definitive information regarding online courses and whether students are reducing the number of trips they make to campus." Other factors that need to be understood to determine environmental impacts of distance education are how frequently the class meets, the travel modes of students - whether they walk, bike, carpool, etc. - and what type of vehicles they drive.

In summary, the literature review did not reveal new research or investigation into the environmental benefits of e-learning; this is an area that may warrant further empirical study.

Smart Energy

Smart Energy is a wide-ranging categorization of transformational solutions for transition to a low-carbon energy economy. Broadly, this category can be described as ICT solutions at the intersection of energy, information, transportation, and buildings. This is a burgeoning field with a multitude of private sector companies developing products to capture market opportunity and major universities creating cross-sector research initiatives. Smart energy solutions optimize energy use through ICT-enabled technologies and automated controls.

Columbia University has created a Smart Cities Center. The Center will conduct research to develop and monitor sustainable urban infrastructure and buildings, calculate and communicate optimal transportation routes under congested conditions, and improve the power supply through smart grid technology. Ubiquitous sensing devices are envisioned to monitor everyday activities in a crowded urban environment and identify opportunities for maximizing efficiency in energy usage.[33]

The Massachusetts Institute of Technology (MIT) has launched the City Science Initiative at the MIT Media Lab. The initiative provides the opportunity for interdisciplinary research networks to join together to improve the design, livability and understanding of high performance urban environments. The initiative is working with strategic partners from industry and government to develop targeted research projects and living lab deployments around the themes of urban design, mobility-on-demand, energy, big data, responsive technologies, and integrated live-work environments. The mission of the initiative is to develop urban strategies that improve livability and creativity. In addition, these strategies should result in 100 times reduction in CO_2 emissions and 10 times reduction in traffic congestion compared to business as usual scenarios. City Science will provide new insights into creating a data-driven approach to urban design and planning by leveraging advances in data analysis and sensor technologies. The six interdisciplinary research themes City Science researchers will initially focus on include mobility networks, electronic and social networks, and energy networks.[34]

At Stanford University, the Precourt Institute for Energy has a similar cross-disciplinary research approach. The institute's Precourt Center for Energy Efficiency (PEEC) focuses on the demand side of energy markets and economically efficient reductions in energy use or energy intensity. PEEC's research focus includes buildings, transportation systems, behavior, modeling, and policy. One of the center's many research projects focuses on wireless sensor technology for energy use automation and optimization in residential and commercial buildings. According to PEEC, energy efficiency is the bridge to a low-carbon future. While low-carbon energy technologies are being researched, invented, and deployed, the largest reductions in greenhouse gases over the next 10 to 20 years will come from the more efficient use of electricity, oil, and natural gas. In modern economies, energy efficiency has the potential to reduce greenhouse gas emissions by as much as 25 percent. Cutting energy waste would provide an economic boost by reducing costs without impacting comfort or productivity.[35]

Energy use in buildings is a major source of emissions.[1] Although newer construction has become more energy efficient, energy waste abounds in older buildings due to inefficient heating and cooling, lighting, and other power systems. "Commercial structures offer particularly good opportunity to reduce energy costs because of their size, their long-term occupants, and their typically more sophisticated building managers," according to the GeSI Smarter2020 report. As described in the report, there are four key ICT-based smart building strategies for optimizing energy use: (1) building design, (2) building management system, (3) renewable energy integration, and (4) voltage optimization.

Building management systems (BMS) are ICT-dependent systems to control and monitor a building's mechanical and electrical equipment including heating and cooling, lighting, power systems, fire systems, and security systems. The BMS serves as a connection point to onsite renewable energy resources. Renewable energy integration refers to adding renewable energy systems on-site such as a

[33] See http://idse.columbia.edu/smart-cities
[34] See http://cities.media.mit.edu/
[35] See http://peec.stanford.edu/people/index.php

solar photovoltaic system or a combined heat and power system. Renewable energy integration may also include power purchase contracts for offsite renewable energy supply. Voltage optimization is an energy saving method that reduces the voltage of electricity supplied to a building's equipment; it reduces energy waste by balancing phase voltages. Because financing is frequently a barrier to adopting these systems, the Smarter2020 report recommends policy makers should consider rebates for ICT-enabled upgrades, and "more controversially, should institute a CO_2e tax or permit system to encourage more green technologies."[1]

In summary, smart energy is a wide-ranging categorization of transformational solutions for transition to a low-carbon energy economy. Broadly, this category can be described as ICT at the intersection of energy, information, transportation, and buildings. Smart energy solutions optimize energy use through ICT-enabled monitoring and management systems such as automated controls. For example, smart buildings reduce energy use with ICT-dependent systems to control and monitor a building's mechanical and electrical equipment including heating and cooling, lighting, and power systems. There is tremendous potential for reducing greenhouse gas emissions from buildings through high-efficiency standards for new construction and energy efficiency retrofits for existing structures.

Smart Grid

The Smart Grid: An Introduction, published by the U.S. Department of Energy, provides an overview of the smart grid and why it's important for the nation's future. The term smart grid refers to an electric grid allowing for the bi-directional flow of electricity and information. The smart grid is an ideal future state of the electric system that will be transitioned to over many years. Today's electric grid was designed for the one-way flow of electricity from a central generation plant down the line to the consumer of that electricity. While two-way communications and self-healing networks have long been the norm in the private sector for critical enterprise data and communications networks, this level of intelligence has not applied to the electric grid. In many situations today, one must call her electric power provider to notify of a service outage.

In the introduction to the book *Broadband Networks, Smart Grid and Climate Change*, the author discusses the communication and control systems layer that is essential for making today's electric grid smart. [36] The author asserts that the use of broadband networks, sensors, smart meters, and software will enable two-way flow of electricity and information that will reduce greenhouse gas emissions, improve coordination of energy supply and demand, and provide superior system performance at lower costs. In summary, the book proffers that policy makers around the globe have recognized the traditional carbon-intense mode of energy is outdated. The approach on how to achieve an economic, environmentally sustainable, and secure energy supply is not clear due to the breadth and complexity of the issues, according to the author. Build out of the smart grid faces numerous technical, policy, and market issues. The emergence of new smart grid services and products calls for experimentation,

[36] Noam, E., Pupillo, L., Kranz, J. (Eds.) (2013). *Broadband Networks, Smart Grid, and Climate Change*. New York, NY: Springer.

governmental rules that enable innovative services, and the adoption of forward looking policy and regulatory frameworks that promote the transition and consider the energy supply system as a whole.

Deployment of smart grid technologies will move today's not-so-smart grid in the direction of the future intelligent grid required to power the 21st century economy, one which is becoming increasingly digital and connected.[37] Smart grid technologies include smart meters, devices, and sensors. They also include advanced technologies for regulating voltage in transmission and distribution, which is important for balancing system operations and reducing energy loss.

Intelligent two-way communications are embedded in the smart grid and act in real-time to coordinate the behavior and actions of all the actors and components on the system to efficiently deliver safe, secure, and sustainable electric supply. In 2012, the National Institute of Standards published its *Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0*.

The graphic shown in Figure 2: Conceptual Reference Diagram for Smart Grid Information Networks [39] is the conceptual reference diagram for smart grid information networks. [39] It depicts the many components and actors associated with the smart grid and demonstrates the complexity of the two-way information and communications networks required to support smart grid operations. The various actors on the system include markets, electric power generators, regional systems operators, distributed energy resources, electric power customers, and energy services providers. These actors must be connected through high-speed communications networks to enable real-time balance of electric demand, supply, and storage.

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[37] U.S. Department of Energy. (n.d.). *The Smart Grid: An Introduction* (DE-AC26-04NT41817, subtask 560.01.04). Retrieved March 10, 2014 from http://energy.gov/oe/downloads/smart-grid-introduction-0

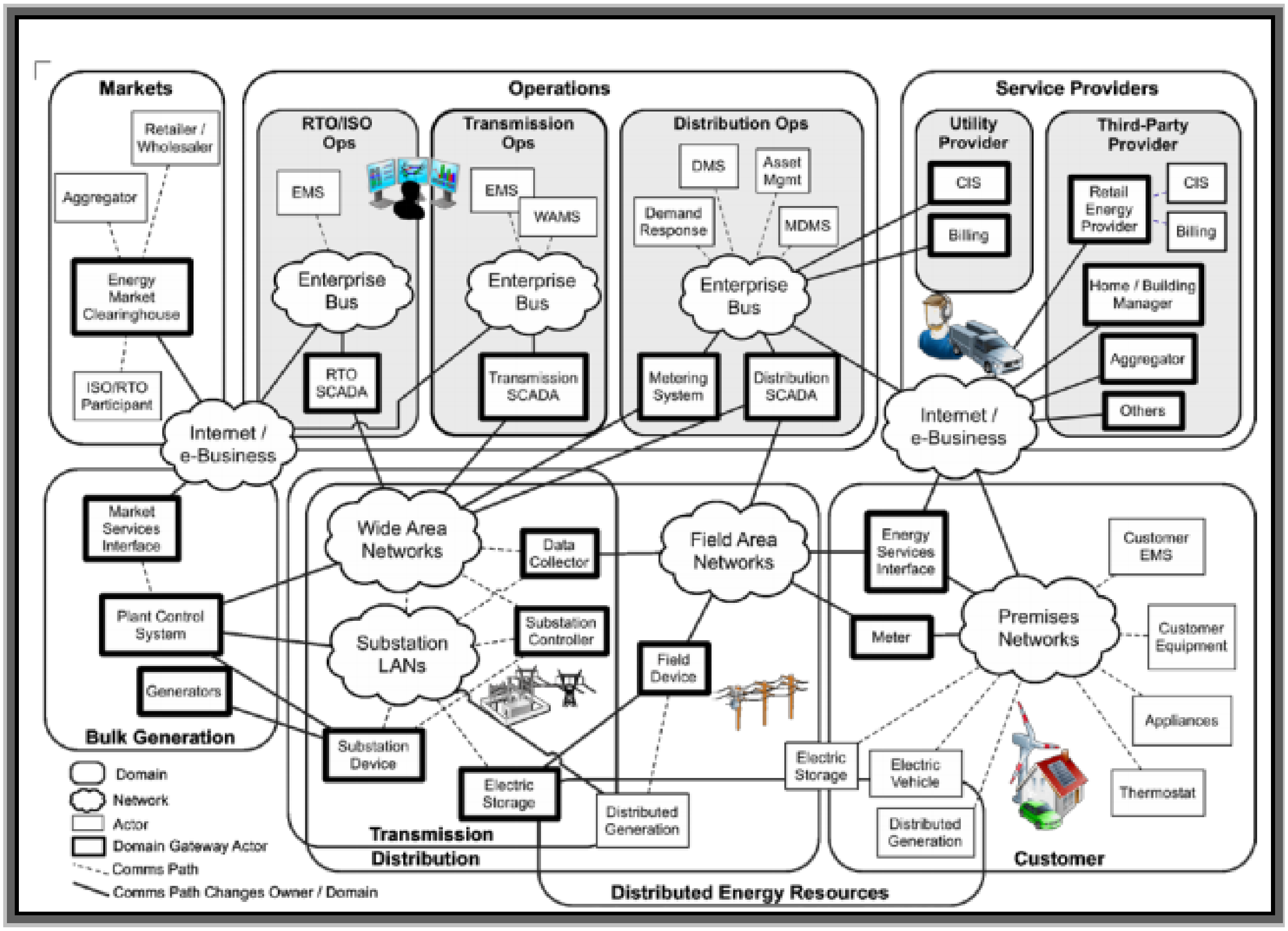

*Figure 2: Conceptual Reference Diagram for Smart Grid Information Networks*Error! Bookmark not defined.

The report *Environmental Impacts of Smart Grid* published by the National Energy Technology Laboratory for the U.S. Department of Energy, analyzes the technical potential for key areas of smart grid impact. [38] These include demand response (DR), demand management (DSM), renewables integration, distributed storage, electric vehicles, and distribution efficiency. An evaluation of the existing research on environmental impacts for each area is reviewed and summarized. The report focuses on the particulate and gaseous emission pollutants produced as by-products of the generation of electricity and it reviews the environmental impact of smart grid infrastructure. The reports notes that a smarter grid will empower many benefits, including improved power demand response, more intelligent outage management, better integration of renewable resources, and advanced electricity storage systems. These benefits rely on the two-way power flow and integrated communications integral to the smart grid. The report concludes that the smart grid will ultimately give consumers and

[38] U.S. Department of Energy. (2011). *Environmental Impacts of Smart Grid* (DOE/NETL-2010/1428). Retrieved February 27, 2014 from http://www.netl.doe.gov/energy-analyses/pubs/EnvImpact_SmartGrid.pdf

utilities more control which will help consumers manage their energy usage and help utilities better manage peak demand spikes and power outages. The smart grid will help improve the efficiency of the electric power system and decrease the intensity of its greenhouse gas emissions.

The article *Putting the 'Smarts' in the Smart Grid: A Grand Challenge for Artificial Intelligence*, published in the journal *Communications of the ACM*, notes that the future smart grid presents many challenges for power systems engineering, telecommunications, and cybersecurity. [39] The article covers core concepts of the smart grid, including distributed intelligence, automation, and information exchange, that have long been the focus of research within the computer science and artificial intelligence fields. From an artificial intelligence standpoint, the article discusses challenges to the smart grid core concepts that must be overcome in order to realize the full potential of its benefits. These challenges include the integration of distributed renewable resources and electric vehicles that need to communicate with the smart grid in order to balance supply and demand and the real-time cost of providing service.

A major policy focus for California is the deployment of electric vehicle (EV) infrastructure. EVs present an enormous challenge to the electric grid from the power demand side. A typical household may use between 20 - 50 kilowatt hours (kWh) of electricity a day, while an EV may consume more than 32kWh in just a few hours to charge its battery. On the demand side, EVs will place a significant increased load on the power system if the vehicles are not communicating with the grid about optimal times and locations for charging. On the supply side, EVs provide a potential benefit to the grid by allowing surplus power to be dispatched and stored in electric vehicles batteries. Two-way broadband communications will facilitate these transactions. Distributed renewable resources likewise require two-way communications with the grid in order to balance intermittent supply and to dispatch surplus power to storage systems for later use. In conclusion, the article states that a fundamental rethinking and reengineering of the electricity grid is required to reduce reliance on fossil fuels and move to a low-carbon economy that provides energy security and mitigates the impacts of energy use on the environment.

Connecting Smart Grid to Climate Change is an industry white paper produced by Silver Spring Networks. The authors suggest that the smart grid can serve as a foundation to help the electric sector reduce greenhouse gas emissions by 0.7 gigatons CO_2e by 2030, or five to nine percent of total emissions using 2005 as a base year. The white paper provides policy recommendations including a "network-first" approach to building out the smart grid infrastructure. Rather than building out a separate network infrastructure for each new category of device and application, the authors propose there are substantial benefits in using the lessons learned in building out the Internet, applying a unified network approach to smart grid deployment. The paper claims cost savings supported by avoiding redundant communications systems will vastly accelerate the deployment of new applications and devices. In addition, the paper states that unifying core communications platforms and using open, standards based approaches (e.g., Internet Protocol) can help utilities quickly deliver integrated back

[39] Ramchurn, S., Vytelingum, P., Rogers, A., Jennings, N. (2012, April). Putting the 'smarts' into the smart grid: a grand challenge for artificial intelligence. *Communications of the ACM*, 55(4), 86-97. doi:10.1145/2133806.2133825

office systems for smart grid applications, avoiding critical bottlenecks in delivering these new utility functions.[40]

Smart grid deployment by the Sacramento Municipal Utility District (SMUD) has resulted in energy loss reductions on the supply side of one to two percent through application of conservation voltage reduction (CVR) technology. Future uses of the smart grid will enable opportunities for more localized control on the demand side, for example automated controls for street lighting, energy efficiency and demand reduction programs. SMUD is currently conducting research and has several projects in the demonstration stage. Barriers to smart grid deployment include interoperability standards and communications protocols that are still in development for smart grid applications, including grid-to-grid communications protocols and grid-to-device protocols. Information and network security will be key concerns as build out of smart grid infrastructure continues.[41]

In summary, the smart grid describes an ideal state of the electric power system that will be transitioned to over a number of years. Integral to the smart grid infrastructure are the two-way broadband communications networks that enable real-time balance of electric demand, supply, and storage. Unleashing the emissions reductions potential of the smart grid will require forward-looking policy, innovative markets and services, and integrated regulatory frameworks.

NEWLY IDENTIFIED OPPORTUNITY AREAS

The updated literature review revealed several new focus areas that have a nexus with "Broadband as a Green Strategy." These include agriculture, climate change adaptation, and e-government.

Agriculture

Smart farming and precision agriculture are new terms that appear in the literature. These terms are somewhat interchangeable and refer the use of innovative technologies applied to the practice of agriculture and farm management with the goal of optimizing returns on inputs while preserving resources. According to Valley Vision's interview with knowledge experts from the U.S. Department of Agriculture, these practices hold great potential for helping California farmers improve water-use efficiency and adapt to the impacts of climate change.[42]

Water-use efficiency is particularly relevant for California not only because of the 2014 drought, but also because of the continuing risk of water scarcity anticipated with a changing climate. In the context of climate change, the water-energy nexus has a double impact for California due to the high volume of energy consumed in the state's water delivery systems. Water delivery accounts for 20 percent of

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[40] Jung, M., and Yeung, P. (N.D.). *Connecting Smart Grid to Climate Change*. Silver Springs Network White Paper. Retrieved February 27, 2014 from http://www.silverspringnet.com/pdfs/SSN_WP_ConnectingSmartGrid-1109.pdf
[41] Information courtesy of Obadiah Bartholomy, Sacramento Municipal Utility District.
[42] Information courtesy of Robert Machado and Robert Tse, U.S. Department of Agriculture.

California's total energy consumption.[43] In contrast, the national average for energy consumption in water systems is 13 percent.[44] The Climate Change Scoping Plan pursuant to Assembly Bill 32 (AB 32)—The California Global Warming Solutions Act of 2006—identifies water-use as a sector requiring significant amounts of energy. It sets goals to use cleaner energy to treat and move water and to work towards higher efficiency.

In the arid San Joaquin Valley the BlueTech Alliance aspires to seed an industry centered on the region's large agricultural sector and the pressing need to reduce the energy intensity of water. The BlueTech Alliance is a nonprofit focused on identifying market opportunities for water and energy technologies. As part of the alliance, the Water, Energy and Technology (WET) Center—located at Fresno State University—serves as an incubator for innovative technologies designed to reduce the energy intensity of the water system.[45] Sectors aligned with water technology, renewable energy, air quality, and agriculture technology are targeted with a goal of making the region a world center of water and energy research, innovation and application.

Researchers at the University of California, Davis, are investigating an affordable, long-range wireless network that provides farmers with data to allow the use of more precise inputs such as water and fertilizer. This project is funded under a grant from the U.S. Department of Commerce Economic Development Administration. According to research scientist Bob Coates, "The world around us is becoming more connected. In the many years I've worked in this field, technology has improved dramatically and prices have fallen. Battery-powered wireless networks can measure almost anything in our environment. With the 'Internet of things' gaining momentum and a drought in California, the time is right for a more affordable, customizable, cloud-connected wireless network solution for precision agriculture and environmental monitoring."[46]

The country of Australia has been a leader in research on water-use efficiency because of their experience with severe drought. According to an article in the *Telecommunications Journal of Australia* highlighting commercial applications of broadband, "sensor-web irrigation offers the possibility of saving vast quantities of water and averting salinization at a time when climate change and current practices threaten the viability of irrigated agriculture."[47] According to the article, sensor web-irrigation management is an application that requires broadband access on farms. Three fundamental realities that undermine the efficient use of water are discussed in the article. These include: (1) difficulty in knowing when crops are being over-watered *[under-watering is generally obvious],* (2) difficulty in getting water to the farm when needed by crops *[not a trivial problem given manual irrigation systems*

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[43] Glick, D. (2011, August). How Saving Energy Means Conserving Water in the US West. *Scientific American*. Retrieved from http://www.scientificamerican.com/article/how-saving-energy-means-conserving-water/

[44] Green, T. (2013, July 10). *The energy cost of water*. Message posted to http://www.utexas.edu/opa/blogs/research/2013/07/19/the-energy-cost-of-water/

[45] See http://bluetechalliance.org/2013/12/fresno-state-water-and-energy-technology-incubator-gateway-to-blue-tech-valley/

[46] UC Davis Child Family Institute for Innovation and Entrepreneurship. (2014, January 21). *The promise of precision irrigation.* Retrieved from http://gsm.ucdavis.edu/spotlight-story/promise-precision-irrigation.

[47] Cebon, D. and Lodders, A. (2012). Broadband applications and commercialization: Hospital-in-the-home and water management. *Telecommunications Journal of Australia*, 62(2): 30.1-30.7. Available from http://tja.org.au.

can extend for miles and water orders must be placed weeks in advance], and (3) difficulty in determining the amount of water needed *[depends on weather conditions such as temperature, humidity, wind and rain, as well as soil moisture conditions].*

Broadband-enabled information systems can be used to increase the efficiency of irrigation in two ways: first, by making the distribution system more efficient; and second, by watering plants according to their needs. Optimized water-use efficiency is made possible with ubiquitous broadband networks capturing data from plants, the soil, the atmosphere, irrigation systems and satellite observations, providing an integrated water management system that corresponds to the needs of crops in real-time. In a trial of sensor-web irrigation on an Australian dairy farm, scientists were able to obtain water savings of 23 percent. Moreover, the trial also demonstrated a 74 percent increase in the economic productivity of water in horticultural applications.[47]

Sensor-web technologies provide the backbone for effective water management systems. They enable integration of large volumes of local and regional data and allow farmers to better model and act on climate and weather conditions. Long-range weather forecasts, local conditions and local soil moisture content, combined with remote sensing, weather data, and system status information, are used to predict future conditions and guide action.[47]

Broadband and the Sustainable use of Water Resources is another paper that explores the concept of water-use efficiency. This paper advocates for precision irrigation delivered in an Internet-based service model ("Irrigation-as-a-Service") to improve water-use efficiency for the purposes of adapting to a changing climate and meeting increased global demand for water.[48] A pilot project conducted in Australia's Goulburn Valley in 2007 demonstrated promising results, including water savings of 23 percent per season, water productivity improvement of 27 percent, and increase in gross margins of 38 percent.[48]

National Information Communications Technology Australia Limited (NICTA) has been established through the Australian Government's ICT Centre of Excellence program. According to NICTA, agriculture accounts for more than 70 percent of total fresh water consumption across the globe and water-use efficiency in the industry is often less than 50 percent.[49] For every liter of water taken from a reservoir, only half is delivered to crops.[49] Increasing competition for fresh water and a changing climate are stressing water supplies globally. Working in partnership with the University of Melbourne and Victorian water authorities, NICTA designed and built a wireless sensing and control platform called NICTOR™. These devices are used to measure crop water requirements in real-time, and to control canal gates and pumps to deliver the right volume of water to the plant when it is required. Promising outcomes of two of these trials are shown in Figure 3: Results of NICTA Dairy Trials.[49]

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[48] Saleem, S., Wicks, B., and Dassanayake, K. (2009). *Broadband and the sustainable use of water resources. Telecommunications Journal of Australia*, 59(1), 2.1-2.12. doi:http://arrow.monash.edu.au/hdl/1959.1/788254
[49] Department of Broadband, Communications, and the Digital Economy. (2013). *National ICT Centre of Excellence: improving water-use efficiency*. Australia. Retrieved February 25, 2014 from http://www.archive.dbcde.gov.au/2013/september/what_is_the_digital_economy/australias_digital_economy_future_directions/final_report/appendix_case_studies/national_ict_centre_of_excellence_improving_water_use_efficiency

Trial Description	Results
Dairy trials employing flood irrigation for dairy pasture production	• 26 percent less water used through an irrigation season measured in megalitres of irrigation water; • 27 percent improvement in water productivity measured as an increase in tons of pasture produced per megalitre of irrigation water; • 38 percent improvement in gross margin measured in dollars earned per hectare.
Horticulture trials employing drip irrigation for 'Pink Lady' apple orchard	• 73 percent increase in gross returns measured in dollars earned per hectare; • 74 percent increase in economic water productivity measured in dollars earned per megalitre of irrigation water.

Figure 3: Results of NICTA Dairy Trials[49]

The Common Scientific and Industrial Research Organization (CSIRO) is the federal agency for scientific research in Australia. CSIRO's Sustainable Agriculture Flagship has set a national goal to increase the productivity of the agricultural and forestry sectors by at least 50 percent by 2030, and reduce net carbon emissions per unit of food and fiber by at least 50 percent between 2013 and 2030. The National Research Flagship Programs are focused on scientific solutions for advancing the nation's most challenging problems. Australian farms have faced a range of challenges including the impact of drought. According to the CSIRO report, *Smart Farming: Leveraging the Impact of Broadband and the Digital Economy*, access to timely information over the Internet has become an essential tool for Australian farmers.[15] While the Internet has been available to farmers for over a decade, there is a confluence of developments made possible by the rollout of Australia's next generation broadband network and the growing impact of the digital economy. These impacts are expected to drive transformation in the agricultural sector through innovative digital services that help the sector meet its productivity and sustainability goals. These developments include:

- Low cost and ubiquitous sensor technology that will connect into an 'Internet of things,' collecting information on crops, livestock, water, and weather, making sector-wide analysis possible.
- Spatially-enabled mobile sensors for characterizing the landscape of farms and measuring changes in biomass.
- Video-conferencing systems increasingly in use, bringing remote veterinary and other agricultural advisory services to farms, many of which can be supported by in-place sensor technology.

CSIRO, in collaboration with the University of New England has established a series of smart farming initiatives throughout the country to demonstrate and evaluate the impact of these developments. The organization is currently evaluating several projects in which sensors have been deployed to monitor soil moisture, temperature and livestock. Another CSIRO project is adaptive water resources management for irrigation and environmental protection. This project will provide real-time monitoring and prediction of stream flow and other environmental indicators, which will be linked to scheduling of water extractions and releases by irrigators. A major output of these projects for farmers, water regulators, and other stakeholders will be a user-tailored online dashboard of real-time information that can assist in making decisions on water management. [15] It's important to note that while carbon reduction goals are specifically called out as part of Australia's national goal for the future of the agricultural sector, the economic benefits of this initiative are the primary driver.

Similarly, several articles and reports discussed the economic benefits of broadband for agriculture. The Utah Broadband Project, a collaborative effort between the Governor's Office of Economic Development, the Utah Public Services Commission, and the Utah Department of Technology Services, is one example. The project promotes use of broadband for economic benefit in multiple sectors, including agriculture. According to the project's website, broadband will help Utah's agricultural sector, including farmers and food processors, compete in a global digital economy.[16] New applications and technologies such as cloud computing infrastructure will help farmers better manage various aspects of their farms, from inventory management to chemical monitoring or tracking worldwide markets. These applications increase the need for high-speed Internet access.

The Impact of Broadband on U.S. Agriculture: An Evaluation of the USDA Broadband Loan Program also focuses on the economic impacts of broadband for farmers. [50] The evaluation found that high-speed Internet access boosts farm revenues by six percent and profits by three percent. Several factors were shown to lead to higher revenue or lower costs, thus increasing farm profits. First, access to high-speed Internet can increase the diffusion of better management practices, helping farmers produce the same amount of output with fewer inputs. Second, access to the Internet allows farmers to search for new customers which may lead to an increase in crop production. Finally, using the Internet, farmers can find more cost effective supplies such as seeds, fertilizers or farm equipment which helps reduce input costs.

In summary, new precision agriculture and smart farming applications will help improve irrigation efficiency and agricultural productivity. Early research in this area has shown promising results. Advancing the potential environmental benefits of these technologies will require reliable data communications networks in often remote areas not always economically feasible for commercial service providers to serve. This infrastructure investment would likely produce great yields towards the California's environmental goals given the large size of the agricultural sector and the high energy-intensity of the water delivery system.

Climate Change Adaptation

Broadband has an important role in helping countries adapt to minimize the effects of climate change. According to the report *ICTs and Climate Change Mitigation and Adaptation: The Case of Ghana*, the capacity of ICT to mitigate the harmful effects of climate change imposes a responsibility on policy makers to promote the technology as a strategy to combat the issue.[32] The report suggests that ICTs are playing an increasing role in predicting, identifying and measuring the impacts of climate change. It

[50] Kandilov, A., Kandilov, I., Liu, X., Renkow, M. (2011). *The Impact of Broadband on U.S. Agriculture: An Evaluation of the USDA Broadband Loan Program*. Retrieved February 25, 2014 from http://ageconsearch.umn.edu/bitstream/103634/2/KKLR_AAEA_2011.pdf

further asserts that ICTs can be key enablers of mitigation and adaptation in vulnerable sectors such as cocoa production, forestry and infrastructure. As stated in the report, ICTs can help reduce GHG emissions in a variety of sectors, and contribute to making broadband infrastructure broadly available in developing countries without adding to carbon emissions. Mitigation strategies called out in the report include using ICTs to: improve waste management; increase efficiency and renewable energy; raise awareness, educate, and build capacity on climate change; and increase remote healthcare access. From an adaptation standpoint, the report indicates that ICT tools hold significant potential as enablers of change and transformation for areas of vulnerability. Those areas include agriculture, food security, water resources, and human health.

Climate change adaptation will require smart planning for providing access to real-time data for climate monitoring and early warning systems, according to the report *The Broadband Bridge: Linking ICT with Climate Action for a Low-Carbon Economy.*[5] The report highlights the following examples where broadband plays a valuable role in climate change adaptation.

> *Addressing Climate Risks* - China Mobile is helping poor farmers address climate change induced challenges through applications such as automated monitoring and control systems, automatic drip irrigation, wireless water quality monitoring, and water conservation.[50]
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> *Remote Weather Monitoring* - In China, remote transmission of meteorological data provides timely and accurate forecasts of disastrous weather conditions for farmers. This data is collected through 1,100 monitoring stations in Xianjiang and delivered to farmers in remote areas. In Africa, weather is critical for the 3.5 million people living along Lake Victoria in East Africa. The Weather Info for All Initiative (WIFA) is mobilizing public and private partners to provide reliable weather information to vulnerable communities affected by poverty and climate change. The project is rolling out 5,000 weather observation stations throughout Africa, reusing infrastructure at existing and new mobile sites. The stations are expected to dramatically improve information essential to predicting and coping with climate shifts.[50]
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> *Early Warning Systems* - Broadband communications and technologies are particularly valuable in disaster management.[50] ICT-based early warning systems are providing people with alerts and information regarding threats such as hurricanes, floods, and other 'extreme weather events.' Additional applications of these systems could be improved water catchment management at the community level, enhanced storm warning notification systems at the regional level, and informed farmers who optimize seed planting time at the ground level.
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> *Protecting Human Health* - Climate change can impact human health in a variety of ways; examples include altering the geographic range and seasonality of certain infectious diseases, disturbing food production ecosystems, and unexpected weather changes or extreme weather events. Preliminary illustrations of transformative solutions enabled through broadband technologies include telehealth applications such as digitization of medical records and remote consultation and intervention. These systems can bring down the costs of delivering services, especially in the event of pandemics and new health challenges where local knowledge might

not be sufficient. They can also improve communication with groups vulnerable to heat waves, such as the elderly and disabled. [50]

The paper *Climate Change and e-Health: a Promising Strategy for Health Sector Mitigation and Adaptation,* authored by health scientists at Umea° University in Sweden, explores the topic of telehealth and climate adaptation in further detail. The paper postulates that telehealth "has the potential to help societies significantly adapt and reduce their vulnerability to climate change."[19] Several adaptation strategies, including their strengths and limitations, are discussed in the paper. These strategies include application of telehealth in disaster response and provision of point-of-care diagnostic tools. The paper recommends strengthening public health surveillance using mobile technologies and promoting knowledge, awareness and preparedness among the public, volunteers, and health workers in regions with a high degree of vulnerability to climate change. In conclusion, the paper argues that telehealth is a promising strategy to combat and adapt to climate change, and that health information technology should be included in national and global strategies to address global warming.

California Water Code Section 10541 requires that all Integrated Regional Water Management (IRWM) Plans address climate change by evaluating the adaptability of water management systems to climate change and by considering GHG emissions of all identified programs and projects. In the *California Santa Ana Watershed Basin Study,* a greenhouse gas emissions calculator was developed as a tool to support climate change analysis for 20 different projects across the area's watershed basin.[51] The calculator helps decision-makers explore the links between water resources, energy, and GHG emissions in evaluating projects.

The Wineville Regional Recycled Water Pipeline and Groundwater Recharge System Upgrades project was one of the projects evaluated using the GHG calculator. In this project, two existing groundwater recharge facilities and a constructed wetlands would be outfitted with automated control gates and upgraded power supply with automated control logic. The recharge facilities would remotely link through a new communication network to approximately 19 recharge sites and seven recycled water stations in the regional system. The results estimated the project would reduce imported water by 4,500 acre-feet per year (AFY), increase the groundwater supply portfolio by 3,000 AFY, and increase the self-supplied water portfolio by 1,500 AFY. In addition, implementing the project would result in an estimated reduction of greenhouse gas emissions by 12 percent through 2050 when compared to the baseline of the study area.

Water-use efficiency, as discussed in the agriculture focus area, is a subject referenced heavily in the literature with respect to climate change adaptation. Reducing the amount of water needed to grow crops or serve population growth is highlighted as an important strategy for adapting to climate change.

[51] U.S. Department of the Interior, Bureau of Reclamation. (2013). *Greenhouse Gas Emissions Calculator for the Water Sector User's Manual: Santa Ana Watershed Basin Study, California Lower Colorado Region* (Technical Memorandum No. 86-68210-2013-03). Denver, CO: Technical Services Center. Retrieved from http://www.usbr.gov/WaterSMART/bsp/docs/finalreport/SantaAnaWatershed/TechMemo2-GHGCalculatorUsersManual.pdf

In summary, the literature indicates broadband has an important role in helping adapt to minimize the effects of climate change and should be included in government strategies to address global warming. Technologies to improve water-use efficiency are particularly relevant to California due to the continuing risk of water scarcity anticipated with a changing climate.

E-Government

E-Government, or online government, utilizes ICTs to provide access to public services when and where they are needed, independent of government offices being open for business. In the research paper, *Identifying and Quantifying the Indirect Benefits of Broadband Networks: A Bottom-up Approach,* the indirect benefits of e-government are evaluated and quantified. [52] The thesis of this paper is that indirect benefits should be quantified in evaluating the cost of upgrading existing services to next-generation, fiber-based services. These upgrades may not be economically viable for service providers based solely on the direct revenues from customer subscribers due to the high upfront costs of the upgrade. If indirect benefits, including social benefits, are quantified in the cost-benefit analysis, the business case for service upgrades, such as deployment of fiber to the home, improves. To test the hypothesis, a bottoms-up model for evaluating benefits was built and applied to two European cities, Ghent in Belgium and Eindhoven in the Netherlands. The indirect benefits of e-business and e-government applications were examined and compared for both cities and benchmarked against results of other similar research projects.

With regard to e-government, two main types of services were evaluated. The first type includes all transactions in which citizens need to connect with an administrative center such as tax filings, license applications, and fee payments. The second type of service evaluated was providing online information and resources for citizens such as newsletters or city information. The indirect benefits of these services were found to be reallocating time for administrative personnel, saving time and travel costs (both fuel and parking costs) for citizens, decreasing consumption of paper and mailing of materials, avoiding traffic jams and accidents, reducing CO_2 emissions from travel, and improving service convenience for constituents. The highest value effect for e-government applications was found to be the travel-related gains attributable to reduced travel time and cost. These gains had co-benefits of reduced greenhouse gas emissions through travel avoided.

As mentioned in the section on e-Learning, the report by McKinsey & Company references government as one of the sectors in which the transformational benefits of information technology has been less apparent than for companies in the private sector. The reports states that over the next decade, transformation of government services at all levels is possible through the use of ICTs. The report anticipates the transformations in government will come from the implementation of "e-services" which will enhance service delivery and reduce waste while optimizing resources, saving costs, and improving citizen engagement.[12]

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[52] Van der Wee, M., Verbrugge, S., Sadowski, B. Driesse, M. Packavet, M. (2012, February 05). Identifying and quantifying the indirect benefits of broadband networks: A bottom-up approach. *Telecommunications Policy*. doi: http://dx.doi.org/10.1016/j.telpol.2013.12.006

In the U.S., the Federal Government has had an online government mandate for more than a decade with the passage of the E-Government Act of 2002 (Pub.L. 107–347, 116 Stat. 2899, 44 U.S.C. § 101, H.R. 2458/S. 803). Improving government efficiencies and accountability and reducing costs are noted provisions of this legislation. Much of the current literature examines the success, or lack thereof, of government technology implementations that have seen cost overruns rather than the cost savings expected. According to the Office of E-Government and Information Technology within the Office of Management and Budget, the information technology advancements that have transformed how private sector companies serve their customers have not been realized by the Federal Government. The Department states on its website, "The Federal Government largely has missed out on that transformation due to poor management of technology investments, with IT projects too often costing hundreds of millions of dollars more than they should, taking years longer than necessary to deploy, and delivering technologies that are obsolete by the time they are completed."[53] Cloud computing infrastructure is now being touted as a way for governments and educational institutions to streamline technology and gain efficiencies in delivering e-government and e-learning services.[54, 55]

While cloud-based service models may streamline efficiencies and costs of e-government services, they will also require more bandwidth and more ubiquitous access to broadband. The paper *Environmental Sustainability in the Age of Digital Revolution: a Review of the Field,* published in the *American Journal of Humanities and Social Services*, puts forth the importance of intentionally integrating sustainability goals into the delivery of e-government services in order to avoid unplanned negative environmental impacts. [56]

In reviewing the field, the author found reports predicting that the energy use of cloud services accessed via wireless networks will grow up to 460 percent between 2012 and 2015. In terms of greenhouse gas emissions, this is equivalent to 4.9 million new cars on the road. Proponents argue that ICT has abatement potential seven times higher than the sector's own footprint. These emissions reductions would be achieved through ICT-enabled efficiency gains in other sectors, including government. However, the author of the paper found that relatively few studies focus on how e-government programs are architected to facilitate a low-carbon environment.

The author argues that e-government initiatives need to reflect government environmental priorities and explicitly include environmental sustainability as a key strategic objective. Otherwise, e-government projects and priorities may become counterproductive and misaligned with environmental goals. The paper further contends that governments need to establish sound policies

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[53] See http://www.whitehouse.gov/omb/e-gov

[54] Eggers, W. (2011, January 31). *Cloud Computing in Government Explodes*. Governing: The State and Localities. Posted to http://www.governing.com/blogs/bfc/cloud-computing-government-explodes.html

[55] Ghazizadehy, A., (2012, March 27). *Cloud Computing Benefits and Architecture in E-Learning*," Wireless, Mobile and Ubiquitous Technology in Education (WMUTE), 2012 IEEE Seventh International Conference. doi: 10.1109/WMUTE.2012.46

[56] Al-Khouri, A. (2013). Environmental sustainability in the age of digital revolution: a review of the field. *American Journal of Humanities and Social Sciences*. DOI: 10.11634/232907811301192

and incentivize practices to align e-government objectives with social requirements for more environmentally responsible use of ICTs.

In summary, e-government applications hold potential for reducing environmental impacts and government costs as well as improving service to citizens. Environmental goals should be intentionally considered in the planning and implementation of e-government initiatives, otherwise the technology deployments may end up working against environmental objectives.

CONCLUSION

The research indicates a growing recognition of the potential for broadband to enable positive environmental benefits. While the use of information and communication technologies (ICTs) results in a significant consumption of energy and production of greenhouse gas emissions, research indicates that they hold the potential to reduce emissions in other sectors by a factor of seven times their own emissions footprint. These results will not be achieved without thoughtful, integrated policy development and planning.

The literature also reveals an expanding recognition of broadband as an enabling infrastructure for existing and emerging technologies that help reduce greenhouse gas emissions in the energy, transportation, agriculture, water, health care, and government sectors. In order to support California's greenhouse gas reduction goals, broadband infrastructure deserves a place in long-term policy and planning as an enabling technology to support climate change mitigation and adaptation strategies.

The broadband application areas with the most immediate potential for reduction of greenhouse gas emissions in California are telehealth, telework, precision agriculture, water-use efficiency, and smart buildings. Smart energy solutions, including deployment of smart grid technologies and development of EV infrastructure should continue to be monitored closely and integrated into long-term planning efforts such as the Metropolitan Planning Organizations' Sustainable Communities Strategies pursuant to Senate Bill 375 (Steinberg 2008).

RECOMMENDED ACTIONS

As a result of this research, Valley Vision provides several recommendations to advance the potential of broadband-enabled ICT applications for climate change abatement. These recommendations are offered to policy makers, planners, and researchers at federal, state, regional, and local levels as well as interested stakeholders. Under each category heading below, policy makers, planners and researchers should:

Policy and Planning

- Consider broadband as a critical infrastructure in support of 21st century environmental, economic, and social objectives.
- Include broadband as a deliberate component of climate change strategies to support mitigation and adaptation efforts.
- Coordinate policy and planning for broadband infrastructure across traditional government silos, including energy, transportation, environmental and natural resource protection.
- Align funding and incentives to accelerate broad-based deployment of broadband technology and to drive adoption of climate abatement solutions.
- Offer financing assistance and other mechanisms to encourage the adoption of smart building technologies that will enable significant emissions reductions.

Data and Research

- Collect additional evidence and empirical data quantifying the greenhouse gas emissions avoided through telehealth and telework.
- Leverage Sustainable Communities Strategies as an avenue for developing additional empirical data to quantify the abatement potential of telehealth, telework, and possibly e-learning.[4]
- Inform local government and utility policies and programs with ongoing research into how smart energy solutions can optimize the end-use of energy across major sectors of the economy (e.g., power, transportation, manufacturing, agriculture, and buildings).

Technology and Standards

- Adopt and disseminate common interoperability standards and communications protocols for smart grid applications as they are developed.
- Consider environmental goals intentionally in the deployment of e-government technology initiatives.
- Develop open data and standardized metrics for tracking, monitoring, and reporting performance of the State's environmental policies and programs.