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CTIA
The Wireless Association®

Wireless and the Environment

A Review of Opportunities and Challenges

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About This Report

The purpose of this report is to explore environmental opportunities and challenges that arise from existing and emerging uses of wireless (licensed spectrum) technology, with a particular focus on the areas of transport, utilities, agriculture, and public services in the U.S. The report was commissioned by CTIA – The Wireless Association® and prepared by BSR.

Please direct comments or questions for BSR to Marshall Chase at mchase@bsr.org, or for CTIA to CTIAMedRel@ctia.org.

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ABOUT BSR
A leader in corporate responsibility since 1992, BSR works with its global network of more than 250 member companies to develop sustainable business strategies and solutions through consulting, research, and cross-sector collaboration. With offices in Asia, Europe, and North America, BSR uses its expertise in the environment, human rights, economic development, and governance and accountability to guide global companies toward creating a just and sustainable world. Visit www.bsr.org for more information.

BSR's Information and Communications Technology (ICT) practice works closely with 34 ICT member companies and other stakeholders, ranging from telecommunications and internet firms to component and hardware manufacturers, several of which are also members of CTIA. BSR has a long history of working with companies in the ICT sector to integrate corporate responsibility into their business strategies.

ABOUT CTIA
CTIA – The Wireless Association® is an international nonprofit membership organization that has represented the wireless communications industry since 1984. Membership in the association includes wireless carriers and their suppliers, as well as providers and manufacturers of wireless data services and products.

The association advocates on behalf of its members at all levels of government. CTIA also coordinates the industry's voluntary efforts to provide consumers with a variety of choices and information regarding their wireless products and services. This includes the voluntary industry guidelines, programs that promote mobile device recycling and reusing, and wireless accessibility for individuals with disabilities.

ACKNOWLEDGEMENTS
BSR would like to thank the BSR and CTIA member companies and other stakeholders who contributed to this report through interviews and other information. Such contributions are cited throughout this report.

All website links cited in this report were confirmed as of September 27, 2011.

Contents

Executive Summary

The world is witnessing tremendous innovation in wireless technologies, leading to significant changes in how humans and machines interact with one another. These new wireless technologies and the changes they support are generating exciting opportunities to address environmental impacts in a range of fields, from agriculture to utilities.

Wireless enables rapid and efficient information exchange with remote, mobile, or otherwise hard-to-reach people and equipment, in ways that were previously difficult, if not impossible. This encourages the collection of much more detailed information, which can be used in new ways by a wider range of users. This growing "information anywhere" environment creates opportunities to benefit the environment in significant ways, including:

» **Matching supply and demand.** Wireless availability of accurate, up-to-date information and communication can be used to focus resources where they are actually needed, and reduce or eliminate excess production or shortages. For example, by knowing when energy or water will be required to meet manufacturing or agricultural needs, utilities and farmers can target these needs more easily.

» **Using less.** Wireless networks are being used to optimize resource inputs so that less is required per unit of a product or service. By monitoring vehicle performance, for example, fleet managers can ensure that vehicles receive needed maintenance to keep them running efficiently, and reduce fuel used per mile traveled.

» **Shifting behaviors.** Wireless infrastructure can actually take the place of existing activities or infrastructure, so that the same job can be done with much lower environmental impacts. For instance, transportation to distant locations to monitor remote equipment might be unnecessary if a wireless communications network is in place.

These opportunities are particularly relevant in four areas:

» Moving People and Goods
» Powering Our Future
» Nourishing People
» Providing Public Services

Moving People and Goods

From fleet managers and logistics providers to truck drivers and private car owners, a lack of good information about vehicles and road conditions creates inefficiencies in America's transport system. These small costs add up to millions of tons of unnecessary carbon dioxide emissions (CO_2, the most common greenhouse gas) and other forms of air pollution, clogged roads, increased costs, and very real human frustration.

Wireless technology can play a variety of roles in ensuring that people and goods get to their destinations on time and efficiently, and help reduce the nearly 40 percent of U.S. greenhouse gas emissions coming from transport. These roles range from offering real-time information about road conditions so drivers can avoid traffic jams or unnecessary stops, to gathering information over time that can be analyzed to improve driving efficiency.

The most significant wireless applications are in areas where people and companies are constantly on the move. For instance, fleet management and telemetrics applications help trucking and logistics companies manage fleets and reduce the number of empty or underutilized trucks on the road (which currently stand at 25 percent and over 50 percent, respectively). Fleet management alone has the potential to reduce CO_2 emissions by about 36 million metric tons (MT) per year, equivalent to annual greenhouse gas emissions from about 6 million passenger vehicles or energy use of 3 million U.S. homes.[1]

Powering Our Future

In traditional energy grids and water utilities, information flow is relatively limited and often occurs infrequently—as evidenced by your monthly electricity bill, which shows total energy used over an entire month, without indicating which appliances used it or when.

Wireless networks increasingly serve as the nervous system of the nation's smart electricity and water infrastructure, connecting users with generators (utilities) and distribution networks. These networks transmit vital information that enables timely and efficient action to support reduced energy use. These applications are a central component supporting the rollout of smart grids.

Wireless technology is crucial in enabling the new two-way communications networks that make smart energy and water possible. Wireless systems connect appliances and devices to smart meters at homes and businesses, and then connect the smart meters to utility companies. Utilities can rely on telecommunications companies and their existing expertise and capabilities to establish and maintain these networks, rather than building networks themselves. These applications are a central component supporting the rollout of smart grids and their potential to save 360 million MT of CO_2 (equivalent to annual

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[1] Carbon emissions calculated using the U.S. Environmental Protection Agency greenhouse gas equivalencies calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html

greenhouse gas emissions from about 70 million passenger vehicles or the energy use of 30 million U.S. homes), and $15 billion to $35 billion by 2020.[2]

Other benefits include: giving customers information and tools that help them make better choices and reduce consumption, and remotely monitoring systems to improve the efficiency and stability of the infrastructure that delivers utilities services.

Nourishing People

Food production is an incredibly important activity in the United States, and the agricultural industry does a remarkable job of efficiently producing food for the country and the world. These activities are not without environmental costs, however: One-third of all greenhouse gases from human activity are attributable to agriculture, and livestock-related emissions alone account for more greenhouse gases than the global transport industry. Eighty percent of fresh water used in the United States is for growing crops or raising livestock. And pressures to use resources for agriculture will grow as the global population expands from 7 billion to 9 billion people by 2050.

Wireless applications can help address these impacts by generating information at a level of detail that farmers never before had access to, enabling highly efficient use of resources and monitoring for negative environmental impacts. Without the need for wireline infrastructure, these solutions are rapidly scalable at increasingly reasonable costs. Key points about wireless use in food production include:

» Wireless applications allow farmers to monitor crop development and livestock management in ways that have never been possible before (such as “dusting” a field with wireless soil monitors, attaching miniature wireless devices directly to plants to monitor growth, or measuring the creation and emission of methane gas in livestock). These applications each provide opportunities to reduce agriculture’s hefty impact on the environment.

» Wireless data provides farmers with actionable knowledge about more precise and resourceful farming techniques. These techniques will affect water and land conservation—several studies suggest water conservation from precision agriculture of 11 percent to 50 percent—and reduce use of fertilizers and pesticides, allowing crop yields to improve while decreasing environmental costs.

Other benefits include: providing never-before-seen data that can now be collected through wireless instruments, the ability to scale up monitoring operations quickly and cost-effectively, and the ability to access remote areas and change monitoring locations on-demand with minimal effort and cost.

Providing Public Services

Government services generate significant environmental impacts—including running fleets of emergency vehicles and garbage trucks that emit millions of tons of CO_2—but also offer exciting opportunities to protect the environment through better information gathering and citizen engagement.

Wireless offers the opportunity to reduce these environmental costs, while enhancing the opportunities to monitor and prevent damage to public

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2 Global e-Sustainability Initiative (GeSI) and Boston Consulting Group, “SMART 2020: Enabling the Low-Carbon Economy in the Information Age, United States Report Addendum,” 2008, p. 18, http://www.smart2020.org/_assets/files/Smart2020UnitedStatesReportAddendum.pdf

environmental resources, from waterways to national forests. Other opportunities also exist, including:

- As more people move to urban areas, wireless technology helps urban planners support and improve the environmental impacts of public infrastructure and services, from roadways and transit to water works and landfills. Smart traffic applications alone could reduce fuel consumption on urban roadways by up to 20 percent.[3]
- As government is pressed to do more with less and to address a range of environmental issues, wireless monitoring is a powerful tool in delivering more efficient and impactful services. Wireless technology—just as in the private sector—enables efficiencies in providing services like waste management.
- Mobile communications encourage dialogue between governments and their citizens about environmental issues. Citizens can instantly report environmental incidents to public agencies just by using their mobile phones and embedded cameras, while governments can more easily provide information to citizens about high-pollution "spare the air" days, water conditions, or other environmental concerns.

Other benefits include using remote sensors to monitor a range of environmental factors that otherwise would be costly and difficult—or impossible—to track, and using on-the-fly information to increase efficiency, and reduce costs and environmental impacts.

Addressing Environmental Costs

While the expanding use of wireless technology in the United States clearly presents significant opportunities to improve environmental impacts in a variety of ways, the manufacture, use, and disposal of this technology has an environmental cost in terms of resource use and pollution. As the application of wireless technology expands, both in terms of product volume and geographic placement, the industry will need to continue its efforts to reduce the environmental costs of manufacture, use, and disposal. Ongoing product design efforts for the environment include:

- Reducing material and energy used in production processes
- Reducing energy consumed by products while in use
- Using recycled or other lower-impact materials
- Maximizing the use of existing products and systems
- Safely reusing, recycling, or disposing of products or components

At the same time that the industry addresses these direct impacts, improving the understanding of systems' effects will also be important. For example, some applications of wireless technology may actually displace environmental costs from one location to another, rather than reducing them; in other cases, the reduction of environmental costs may actually create an opening for those costs to rebound in unexpected ways. The industry needs to be mindful of such impacts.

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[3] "Intelligent Traffic Solutions," Siemens AG, http://www.siemens.com/sustainability/en/environmental-portfolio/products-solutions/mobility/intelligent-traffic-management.htm

Looking Ahead

The application of wireless technology has exciting potential in a wide range of areas, especially in its ability to reduce environmental impacts. New applications on the horizon, such as those enabled by machine-to-machine communications, could fundamentally change the way we live, work, and play. We are hopeful that the wireless industry, with the right level of government involvement, will help make this a reality.

Introduction

Odds are that at some point before you began reading this report, wireless technology has already had an impact on your life *today*. Perhaps it was the ability to quickly navigate a traffic jam with a mobile map application, or the convenience of sending a quick text message to let someone know that you're "on the way." It is even possible that you downloaded this report to a mobile device on which you're now reading it.

Applications such as these, and advances in communications technology coupled with rapidly decreasing costs, have resulted in tremendous growth in the adoption of wireless technology. By the end of 2010, there were an estimated 5.3 billion mobile phone subscribers around the world, equivalent to 77 percent of the population.[4] Machine to Machine (M2M) communications, or the "Internet of Things," is the next paradigm shift in wireless communications, and is no longer the stuff of science fiction. Millions of M2M devices have been deployed in almost every industry, and are expected to number 412 million globally by 2014.[5]

In our opinion, three catalysts in particular have enabled this rapid adoption of wireless technology:

- **Remote access.** Wireless sensor networks enable data gathering from remote locations that would be difficult, if not impossible, using wired infrastructure. It also allows easier information distribution to remote users and systems that may not have access to wired networks.
- **Broadband.** Wireless broadband is now common in many parts of the world and the difference between wired and wireless speeds is rapidly diminishing. In some cases, wireless throughout rates already exceed those of wired (legacy) technologies.
- **Lower costs.** Compared with just a few years ago, the costs of hardware, software and services have come down dramatically, and the trend is likely to continue with advances in technology and increasing volumes.

This phenomenal growth in the adoption of wireless technology has enabled availability of "information anywhere", which in turn has allowed people and automated systems to communicate, access services, and make decisions far more quickly and with greater impact. These applications have also benefited the environment as fewer resources are utilized or discarded.

To better understand the promise (and challenges) of wireless on the environment in the U.S., CTIA—The Wireless Association, commissioned BSR, an independent research and consultancy firm, to produce this report. The goal was to see where and how wireless is adopted heavily and what impact it is having on the environment.

We found from our initial research that some of the greatest opportunities for environmental impact lie in the most common activities in business and society:

- **Moving People and Goods.** The U.S. transport infrastructure must meet the needs of a growing and increasingly mobile population while limiting air pollution and greenhouse gas emissions. Transportation sources were responsible for about 40 percent of the greenhouse gas emissions in the

[4] International Telecommunications Union, "ITU estimates two billion people online by end 2010," Press Release, Oct. 19, 2010, http://www.itu.int/net/pressoffice/press_releases/2010/39.aspx.

[5] Cox, Anthony, "Will Mobile M2M create the next 5 billion cellular connections?", Juniper Research Blog, Jan. 19, 2010, http://www.juniperresearch.com/analyst-xpress-blog/2010/01/19/will-mobile-m2m-create-the-next-5-billion-cellular-connections/.

U.S.[6] Transportation is one of the largest sources of environmental degradation, which can be substantially reduced with wireless technology.

- **Powering the Future.** The U.S. utility infrastructure is under severe strain due to ever increasing demand with limited capacity additions. The industry needs to find ways to become more efficient while reducing its own and its customers' environmental footprint, which it is doing through "smart grids".
- **Nourishing People.** Global food production needs to grow by 70 percent by 2050,[7] and as one of the world's breadbaskets the U.S. will play a critical role in meeting these needs. At the same time, agriculture contributes to environmental problems from air pollution to ocean dead zones, but wireless has the potential to play a role in mitigating these effects.
- **Managing Public Services.** Government at every level in the U.S. faces the challenge of anticipating and responding to people's needs for services ranging from alleviating congestion on increasingly busy roads, to encouraging ecosystem stewardship, all while trying to contain costs. There are significant opportunities for governments to improve services, share information and reduce overall environmental impacts, which wireless enables.

At the same time, the increased use of wireless isn't a panacea, and comes with its own challenges. The manufacture, use and disposal of electronics have substantial direct environmental impacts, and these may grow with the expansion of wireless infrastructure.

We welcome your feedback on this report. Please contact the representatives from BSR or CTIA, identified on Page 2.

In the next report, which has also been commissioned by CTIA and will be published in early 2012, we will be looking at the role of wireless on social and economic conditions. We found that particularly in the developing world, wireless applications have enabled tens of millions of people to access financial and health services, or connections to markets, half a world away. These services and connections have enabled people to raise their quality of life or earn higher incomes. We will be taking a deeper look into which applications in different parts of the world are having the greatest social and economic impact.

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6 Northeast States Center for a Clean Air Future, et al, "Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions," October 2009, http://www.nescaum.org/documents/heavy-duty-truck-ghg_report_final-200910.pdf

7 Food and Agriculture Organization of the United Nations (FAO), "How to Feed the World in 2050," http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

"Globalization, population growth, and rampant urbanization are conspiring to overwhelm transportation systems around the world, many of which were built to accommodate a fraction of their current load."

- The Case for Smarter Transportation, IBM (2010)

Moving People and Goods

Section Overview

WIRELESS TRANSPORTATION APPLICATIONS: POTENTIAL IMPACTS
Fleet Management could reduce carbon emissions by 36.1 million MT CO_2
Wireless telemetrics applications significantly improve fuel efficiency
Route management and load optimization reduce wasteful trips for fleets

Introduction: Wireless on the Move

A truck driver sitting in the cab of a fully equipped, wirelessly enabled long-haul tractor-trailer truck looks more like a pilot sitting in the cockpit of a 747 airliner. At the driver's fingertips lie instrument control panels with consistently updated information about real-time vehicle performance, and about how the driver's actions improve or weaken performance en route.

A fleet manager sitting thousands of miles away in the truck's corporate headquarters has an identical real-time view of this information. The fleet manager wirelessly monitors the same updated data about vehicle performance and driver behavior—speed, location, miles per gallon, tire pressure, and average CO_2 emissions over the course of the truck's haul. After a week, a month, or a year, the fleet manager can aggregate data across the fleet and make adjustments to truck routes, load capacity, vehicle maintenance schedules, and driver behavior to improve fleet-wide fuel economy and reduce carbon emissions.

On-board wireless applications such as these are just one example of how wireless technology is helping modern society move goods and people around the country more efficiently while reducing environmental impacts. Complex transportation systems are indispensible to modern society, but the systems have enormous environmental costs, and have become choked with inefficiencies. For instance:

- A long-haul truck driver unknowingly, but consistently, drives too fast, brakes too hard, and idles too long during cross-country trips, costing the company thousands of dollars in fuel per year, while dumping harmful greenhouse gases into the atmosphere.
- Sub-optimal tire pressure on a vehicle due to inaccurate or infrequent measurements reduces the fuel efficiency of the vehicle, leading to reduced miles per gallon (MPG), wasted fuel, and unnecessary pollution.
- A delivery truck breaks down and a fleet manager has no way of knowing that an empty truck two blocks away could be re-routed to pick up the load.

Wireless technology is helping to alleviate many of these inefficiencies to enable smarter transportation. This section highlights two of the most widely adopted wireless technologies in the transportation industry: fleet management systems and telemetrics monitoring systems. It also includes a discussion of how these

One million metric tons (MT) of CO_2 is equivalent to the energy emissions from powering 86,730 U.S. homes in one year.

(Source: U.S. EPA Greenhouse Gas Equivalencies Calculator)

applications aid fleet vehicle routing to reduce environmental impacts in waste management.

Each of these applications demonstrates the ability of wireless technology to support systems that run smarter, more efficiently, and more resourcefully. Specifically, these applications help to:

» **Close Information Gaps**: Wireless technology provides real-time information about the demand, supply, and location of levers in transportation systems, enabling access to key sources of information.

» **Overcome Geographic Barriers**: The transport and logistics industry is not conducive to “wired” monitoring or recording of events. Simply by being wireless, these applications have opened the door to previously unobtainable information about transportation systems.

» **Motivate Behavior Change with Data**: Wireless technology in the transportation industry also has the ability to motivate impactful behavior change. While changing the production of alternative fuels will proceed slowly, changing the way we consume fuel now will be an important step to reducing environmental harm. Wireless technology provides the data that informs this behavior change.

Taken together, these wireless applications have the ability to help improve the way we move things around the country so as to do it more efficiently, more resourcefully, and less harmfully.

ENVIRONMENTAL IMPACT OF TRANSPORTATION INDUSTRY

While rail, air, and shipping are key components of the transportation industry, the backbone is the highway system. Among vehicles that move goods and people on highways, perhaps none are more versatile than trucks. From long-haul trucks to regional moving vans, 29 million trucks hauled over 10.2 billion tons of freight in the United States in 2010.[8] About 2.6 million of these trucks are combination tractor-trailers used for long-haul trucking.[9]

Moving so much stuff around the country comes with a high environmental price. Transportation sources emitted approximately 40 percent of all U.S. greenhouse gas emissions in 2006.[10] Globally, the transport sector accounted for 13 percent of these emissions in 2006, an increase of 130 percent since 1970.[11] Long-haul trucks are the largest CO_2 emitters and fuel users among all trucks, consuming two-thirds of all truck fuel, or 1.5 million barrels of fuel per day.[12] In 2009, long-haul trucks logged about 167 billion miles crisscrossing the United States, emitting an estimated 12.7 million MT CO_2.[13]

8 American Transportation Research Institute, "The Industry," 2010, http://www.atri-online.org/index.php?option=com_content&view=article&id=65&Itemid=76

9 U.S. Department of Energy, *Transportation Energy Data Book*, 30th Ed., June 2011, Table 5.2, http://cta.ornl.gov/data/tedb30/Edition30_Chapter05.pdf

10 Northeast States Center for a Clean Air Future, et al, "Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions," October 2009, http://www.nescaum.org/documents/heavy-duty-truck-ghg_report_final-200910.pdf

11 Asian Development Bank, Narenda Singru, “Special Evaluation Study on Reducing Carbon Emissions from Transport Projects—Evaluation Approach Paper," August 14, 2009, http://www.adb.org/Documents/Evaluation/Knowledge-Briefs/REG/EKB-REG-2010-16/EAP-EKB-REG-2010-16.pdf

12 Northeast States Center for a Clean Air Future, et al, "Reducing Heavy-Duty Long Haul Combination Truck Fuel Consumption and CO_2 Emissions," October 2009, http://www.nescaum.org/documents/heavy-duty-truck-ghg_report_final-200910.pdf

13 U.S. Department of Energy, *Transportation Energy Data Book*, 30th Ed., June 2011, Table 5.2, http://cta.ornl.gov/data/tedb30/Edition30_Chapter05.pdf. Carbon emissions calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator,

Long-haul trucks in the United States emitted about 13 million MT CO_2, the same amount emitted from energy use in every home in the metropolitan area of New Orleans over one year.

Inherent inefficiencies in highway transportation systems exacerbate the environmental damage. Nearly 25 percent of all trucks on the road are empty,[14] and more than 50 percent are less than half-full.[15] Moreover, drivers unknowingly waste billions of gallons of fuel and emit millions of tons of carbon dioxide each year through excessive speeding, improper braking, and unnecessary idling.

Wireless technology is lessening this environmental impact by providing better information to fleet managers and truck drivers, enabling them to reduce wasteful fuel consumption and carbon emissions. This data will also help lower operating costs by lowering fuel consumption and increasing fuel efficiency.

Wireless Fleet Management Systems

ROUTE OPTIMIZATION AND REDUCED ENGINE IDLING

Wireless fleet management systems enable fleet managers to optimize their operations by offering previously unobtainable data in real-time. This leads to surprising improvements in the environmental impact of fleets, particularly by reducing "out-of-route" miles and engine idling times.

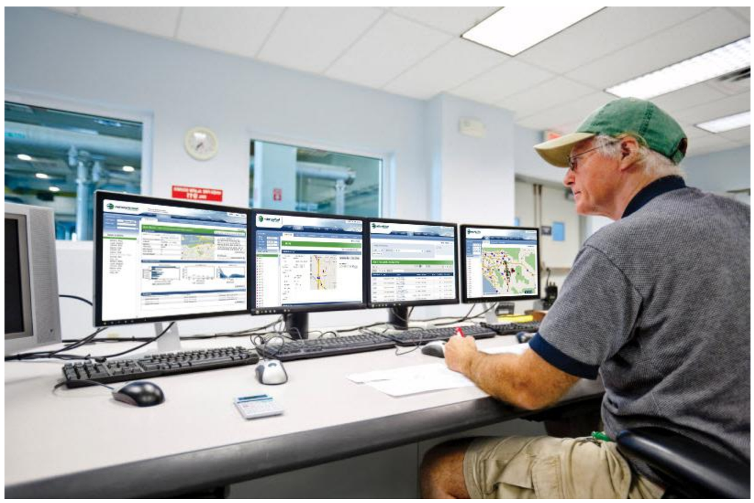

Figure 1: A fleet manager monitors data provided wirelessly including the location, speed, and fuel efficiency of vehicles to optimize routing and lower carbon emissions. (Source: Networkfleet)

Fleet management systems use Machine to Machine (M2M) devices attached to fleet vehicles to record and wirelessly communicate data to a centralized fleet management software system. The data collected includes the position, speed, directional-heading, drive time, stop times, idle times, load weight, and load capacity of each vehicle in a fleet.

All of this data feeds into a centralized software system that allows the fleet manager to optimize vehicle routing. For example, a fleet manager can calculate the most timely and fuel-efficient routes in real-time for vehicles on the road, and

http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

14 GeSI and Boston Consulting Group, "SMART 2020: Enabling the Low-Carbon Economy in the Information Age, United States Report Addendum," 2008, http://www.smart2020.org/_assets/files/Smart2020UnitedStatesReportAddendum.pdf

15 AT&T, "Networking for Sustainability: The Network Offset Effect," December 9, 2009, http://www.att.com/Common/about_us/files/pdf/AT&T_SustainabilityWhitePaper.pdf

SPOTLIGHT:
MEETZE PLUMBING

Meetze Plumbing, a company with 14 trucks, uses a GPS-based fleet management system running across AT&T cellular networks to track each of its vehicles at multiple job sites throughout the day. The system allows fleet managers to accurately identify the closest vehicle to the next job, enabling dynamic scheduling and routing under real-time circumstances. This has resulted in faster and more efficient customer service, as well as reduced driving time, and optimal fuel efficiency. "I really don't know how we ever did business without this tool," says Sam Freeman, Manager of Meetze Plumbing's Service Department.

(Source: AT&T Fleet Management Case Study, Meetze Plumbing)

update these routes to reflect current road conditions and unexpected traffic events, such as accidents or adverse weather conditions. Combining data from other vehicles mounted with wireless sensors, as well as government-generated traffic alerts and weather updates, allows fleet managers to send real-time alerts and updates to the drivers, which improves vehicle efficiency and fuel economy.

LOAD OPTIMIZATION AND REVERSE LOGISTICS

Fleet management systems have also been used successfully for smaller regional fleets that can take advantage of load optimization and reverse logistics. Fleet management software creates opportunities to reduce harmful environmental impacts by using reverse logistics to optimize load allocation for vehicles with spare capacity.

For example, a logistics company with 100 trucks may be scheduled to make 25 deliveries per truck on any given day. Due to unforeseeable traffic conditions or other real-time conditions on the roads, one truck may be able to complete its scheduled deliveries on time, while another truck encounters significant delays throughout the day.

Real-time fleet management software can identify that the two trucks are actually near each other, and the most efficient solution is for the empty truck to help the stranded truck finish the delivery. Both trucks return early, and fuel is saved, resulting in economic gains for the company while also reducing greenhouse gas emissions and air pollution.

Fleet management systems also help to manage fleets that do not have predetermined locations and must respond to unpredictable stops in the field—e.g. plumbers, government utility vehicles, telephone repair companies. Fleet management software can identify the vehicle in the field with the most appropriate location to make an unexpected stop, while using data to account for vehicle location delays, additional stops required, and other unpredictable in-route traffic events.

ENVIRONMENTAL IMPACT

Two of the most important environmental benefits from fleet management systems are in their ability to help reduce "out-of-route" miles and eliminate unnecessary idling time.

"Out-of-route" miles accumulate largely from driver mistakes or error while en route on a delivery, or errant drivers going "off-route" during a delivery. While it doesn't sound like much, research shows that "out-of-route" miles may account for as much as 3 percent to 10 percent of a driver's mileage per year, translating to an additional 500 gallons of fuel required per long-haul truck, and an average additional cost of $2,200 in fuel costs.[16] If these wasted "out-of-route" miles could be eliminated on every long-haul truck by alerting drivers to delivery locations, or alerting fleet managers to errant driver behavior, these systems could reduce greenhouse gas emissions by up to 13 million MT CO_2, and $4.9 billion in fuel savings.[17]

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16 Kenworth Truck Company, "White Paper on Fuel Economy," August 2008, http://www.kenworth.com/FuelEconomyWhitePaper.pdf

17 BSR analysis based on 2.6 million long-haul trucks, assuming 22.2 pounds of CO_2 emissions per gallon of diesel fuel (Source: http://www.epa.gov/oms/climate/420f05001.htm). Equivalencies calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results. Average price of diesel fuel at time of publication is $3.86 (Source: http://205.254.135.24/oog/info/wohdp/diesel.asp).

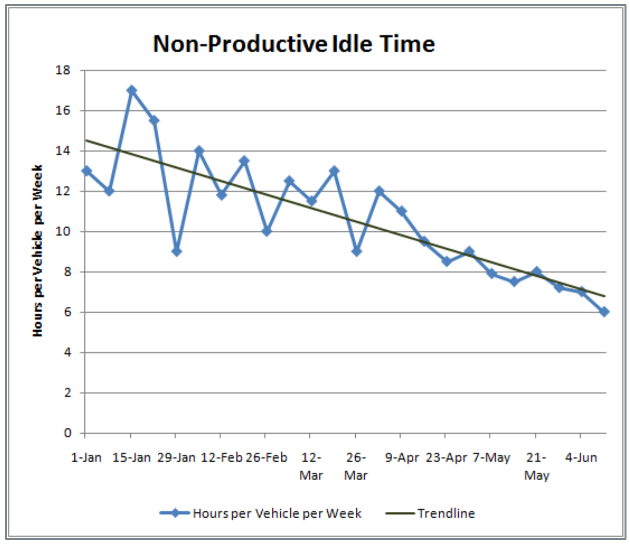

Figure 2: Reduced engine idling with fleet management software. (Source: Telogis, Inc.)

Unnecessary engine idling also takes a heavy toll on the environment, and can be alleviated through fleet management systems. A typical heavy-duty truck burns about 1 gallon of fuel per hour of idling.[18] A typical long-haul tractor-trailer idles as much as 1,400 hours per year, including overnight idling. Applied to every long-haul truck in the United States, the wasted fuel and resulting greenhouse gas emissions could total as much as 3.6 billion gallons and 36.2 million MT CO_2 emitted per year.[19]

Fleet management systems are proving helpful in reducing these environmental impacts. Telogis Inc., a California-based enterprise Software-as-a-Service company, offers a comprehensive location intelligence platform that includes fleet management, multi-vehicle route optimization, work order management and mobile integration. This includes the remote monitoring of engine idling. A Telogis research study showed that by measuring vehicle idling time, and following up with feedback to drivers about reduced engine idling, vehicle idle time was reduced by as much as 50 percent.[20] Adopting this system across a fleet of 3,000 vehicles, one utility company realized savings of over 950,000 gallons of fuel each year, translating to an estimated reduction of nearly 9,000 MT CO_2.[21]

Another study conducted by the U.S. Environmental Protection Agency found that tracking and minimizing the amount of idling on each long-haul truck could save 900 hours of idling per vehicle per year, reducing emissions by about 9 MT CO_2 and saving $3,600 in fuel costs per vehicle.[22] Applying these results to every

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18 New Hampshire Department of Environmental Services, "Diesel Vehicles and Idling," Environmental Fact Sheet 2011, http://www.des.state.nh.us/organization/commissioner/pip/factsheets/ard/documents/ard-46.pdf

19 BSR analysis based on 2.6 million long-haul trucks, assuming 22.2 pounds of CO_2 emissions per gallon of diesel fuel (Source: http://www.epa.gov/oms/climate/420f05001.htm). Equivalencies calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

20 Telogis Fleet Case Study, "Rapid Return on Investment," http://www.telogis.com/benefits/your-roi/

21 Telogis Fleet Case Study, "Rapid Return on Investment," http://www.telogis.com/benefits/your-roi/. Equivalencies calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

22 U.S. Environmental Protection Agency, SmartWay Partnership, "Idle Reduction: A Glance at Clean Freight Strategies," http://www.epa.gov/smartway/documents/partnership/trucks/partnership/techsheets-truck/EPA420F09-038.pdf

long-haul truck in the United States, reduced engine idling could save as much as 23.1 million MT CO_2 emitted per year, and $8.7 billion in fuel costs.[23]

CASE STUDY: NETWORKFLEET, INC.
San Diego-based Networkfleet, Inc. provides fleet management hardware and software, ranging from full-service GPS tracking devices to vehicle diagnostics systems. The fleet tracking software allows fleet managers to gain real-time access to an onboard dashboard of information about fleet vehicles.

Fleet Management Mobile Access

Figure 3: Fleet management data can be accessed remotely via Networkfleet's mobile application
(Source: Networkfleet)

Two of Networkfleet's customers have achieved notable reductions in fuel use and improved fuel economy, leading to reduced CO_2 emissions and cost:

» **The Johnson County, Indiana, Highway Department** installed a fleet management system on 15 vehicles, including 10 heavy dump trucks, three pick-ups, and a minivan. Reduced idling times, reduced speeding, and reduced off-hour usage resulted in 500 fewer gallons of diesel fuel consumed per month—a savings of $15,000 in fuel over the first year, and 5 MT CO_2 emitted per vehicle.[24]

» **Cavalier Telephone**, a telecommunications company based in Virginia, installed fleet tracking software on 112 light trucks to record and analyze speed, idle times, number of stops, and distance travelled. Based on the data collected, the company implemented procedures to reduce unnecessary driving. The policies resulted in a decrease of approximately 5 miles per day per vehicle, adding up to 600 miles per day across the fleet, and nearly 275,000 fewer miles driven throughout the year. Fuel efficiency has increased from 15.3 MPG to 17.3 MPG, creating $37,000 savings in fuel costs per year. In addition, unnecessary engine idling decreased by 10 percent.[25]

Telemetrics Monitoring Systems

While fleet management systems focus on managing entire fleets of vehicles efficiently, on-board telemetrics monitoring systems focus on improving individual driver behavior and vehicle performance.

Telemetrics systems measure a variety of real-time vehicle performance data, including a vehicle's CO_2 emissions, fuel efficiency, speed, miles per gallon, odometer readings, and tire pressure. Some systems even allow managers to remotely control ignition switches.

The data collected from M2M telemetrics devices is collected and sent wirelessly to fleet managers to enable real-time decision making to improve vehicle efficiency. Aeris Communications, for example, is a cellular carrier based in San Jose, California, that focuses on transmitting real-time M2M data from remote mobile devices.[26] Its nationwide cellular systems carry telemetrics data generated by commercial systems, such as long-haul truck drivers, as well as data piped in from consumer telemetrics users and smart grids.

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[23] BSR analysis based on 2.6 million long-haul trucks, assuming 22.2 pounds of CO_2 emissions per gallon of diesel fuel (Source: http://www.epa.gov/oms/climate/420f05001.htm). Equivalencies calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

[24] Networkfleet, "Johnson County Indiana Highway Department," Case Study, http://info.networkfleet.com/rs/networkfleet/images/Networkfleet_Johnson_County_Case_Study.pdf

[25] Networkfleet, "Cavalier Telephone," Case Study, http://info.networkfleet.com/rs/networkfleet/images/Networkfleet_Cavalier_Case_Study.pdf

[26] Aeris Communications, http://www.aeris.com/

Wireless tire pressure monitors could save truckers up to $1,000 in annual fuel costs per vehicle, and cut CO_2 emissions from all long-haul trucks in the United States by 635,000 MT CO_2.

Once received by fleet managers, telemetrics data is then used to encourage more fuel-efficient driving behavior, such as reducing excessive speeding, hard braking, or engine idling. When driven at speeds greater than 50 mph, fuel efficiency decreases significantly: a truck that gets 8 mpg while driving at 50 mph will fall to 6.8 mpg while driving at 60 mph.[27] Another study found that increasing speed from 55 mph to 75 mph results in 39-percent increased fuel consumption and reduces the effectiveness of fuel efficient tires by 27 percent.[28]

The data collected by fleet managers can also be used to extend the life of the vehicle through predictive maintenance. Monitoring each of these factors can have a large impact on fuel consumption and CO_2 emissions. Using wireless devices to monitor tire pressure, for example, can provide a more accurate and up-to-date reading of a fleet's tire pressure, saving money and reducing CO_2 emissions.

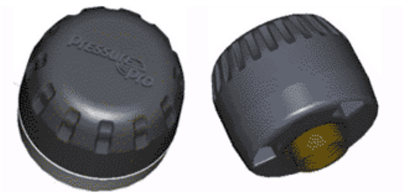

Figure 4: Wireless tire pressure monitors replace valve caps on tires to monitor tire pressure over 12,000 times per day.
(Source: PressurePro)

PressurePro, a wireless tire pressure monitoring company, makes wireless monitoring systems with small devices that screw into each tire's valve stem and replace the valve stem cap.[29] The devices monitor tire pressure up to 12,343 times per day, and are able to detect pressure changes from 10 PSI to 199 PSI, leading to more accurate tire pressure readings. The data is then transmitted wirelessly to the driver, or sent back to a central fleet manager over long-range cellular networks.[30]

Small changes in tire pressure can lead to big savings in fuel consumption. Research shows that every 10 PSI reduction in tire pressure results in a 1-percent reduction in miles-per-gallon.[31] In one case study examining the effect of tire pressure on fuel consumption of typical loaded tractor-trailer trucks, tire inflation pressure at 30 PSI below the optimal tire pressure resulted in a 5-percent loss in a truck's mileage per gallon.[32]

This may not seem like much, but a 5-percent loss in mileage per gallon multiplied across every truck in the United States translates to an extra 1.4 billion gallons of fuel wasted each year, and an extra 635,000 MT of CO_2 emitted—simply because the tires were low on pressure.[33] That adds up to about $2,000 per year in wasted fuel costs per truck.[34] A 16-wheel pressure monitor from PressurePro costs about $1,000 per vehicle ($200 for display, $800 for 16 pressure monitors), which roughly translates to a 2:1 return on investment, not to mention the positive environmental impacts.[35]

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27 Research from Argonne National Laboratories provided to BSR courtesy of Sprint Nextel.

28 Research from Argonne National Laboratories provided to BSR courtesy of Sprint Nextel.

29 PressurePro System Details, Tirepressuremonitor.com, http://www.tirepressuremonitor.com/system-details/

30 PressurePro partners with companies, such as Greyhawk Technologies, Inc., to send data remotely in real-time over cellular or satellite networks. Pressure Pro Partners, http://www.advantagepressurepro.com/index.asp?PageTypeId=16

31 Goodyear Tires, "Factors Affecting Truck Fuel Economy," http://www.goodyear.com/truck/pdf/radialretserv/Retread_S9_V.pdf

32 Goodyear Tires, "Factors Affecting Truck Fuel Economy," http://www.goodyear.com/truck/pdf/radialretserv/Retread_S9_V.pdf

33 BSR analysis based on 2.6 million long-haul trucks, assuming 22.2 pounds of CO_2 emissions per gallon of diesel fuel (Source: http://www.epa.gov/oms/climate/420f05001.htm). Equivalencies calculated using the U.S. Environmental Protection Agency GHG Equivalencies Calculator, http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

34 BSR analysis based on 2.6 million long-haul trucks in the United States (Source: U.S. Department of Energy, *Transportation Energy Data Book*, 30th Ed., June 2011, Table 5.2, http://cta.ornl.gov/data/tedb30/Edition30_Chapter05.pdf)

35 PressurePro Pricing Details, Tirepressuremonitor.com, http://www.tirepressuremonitor.com/products/16-wheel-monopole-monitor/.

Through improvements in tracking, routing, and educating drivers, the San Diego Sanitation Department is projected to deliver $10 million in savings over a decade, all while cutting greenhouse gas emissions.

Some companies have implemented driver score cards, and instituted incentive based systems for drivers who produce the most fuel efficient route, which can be monitored and evaluated using telemetrics. At least one company found that drivers have embraced the changes, and instead of pushing back against new driving lessons, they have pushed each other through friendly competition to improve driving performance.[36]

CASE STUDY: UPS

UPS is one of the largest logistics companies in the world. In 2010, it moved 3.94 billion packages across more than 220 countries, with the majority of movement occurring through 99,795 ground vehicles.

UPS has installed a telemetrics system on 37 percent of its U.S. fleet with sensors placed in trucks, providing mechanical and behavioral data about each vehicle. The sensors measure vehicle speeds, turns, idle time, driving in reverse and other driving behaviors that affect fuel usage.[37]

Telemetrics-equipped vehicles saved approximately 90,000 gallons of fuel through the elimination of engine idling time, 590,000 gallons by improving stops-per-mile, and other measures that reduced unnecessary fuel use. Combined with UPS's route optimization software, UPS vehicles avoided driving 63.5 million miles and reduced greenhouse gas emissions by 68,000 MT CO_2.[38]

Wireless in Action: Waste Management Fleets

Garbage collection and waste management systems offer an emerging example of how a suite of wireless applications can reduce harmful environmental impacts. After all, garbage trucks barreling and belching down city streets are not just collecting waste; they are also creating it.

Waste management is a $55 billion industry in the United States.[39] Across all sectors, garbage trucks are estimated to produce an industry-wide total of over 10 million MT CO_2—analogous to the CO_2 emissions from the electricity use of over 1.1 million homes.[40]

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36 Qualcomm, "Performance Monitoring Featuring Fuel Manager Case Study," http://www.qualcomm.com/common/documents/case_studies/Qualcomm-FuelManager-CaseStudy.pdf

37 UPS, "Delivering the World: Sustainability at UPS," CSR Report 2009, p. 41, http://www.responsibility.ups.com/community/Static%20Files/sustainability/UPS_V27_0718_300dpi_rgb.pdf

38 UPS, "Delivering the World: Sustainability at UPS," CSR Report 2009, p. 41, http://www.responsibility.ups.com/community/Static%20Files/sustainability/UPS_V27_0718_300dpi_rgb.pdf

39 Waste Management, Inc., "Waste Management: Think Green," Morgan Stanley Business and Education Services Conference, September 23, 2010, http://www.wm.com/about/investor-relations/events-and-presentations/pdfs/Morgan_Stanley_20100923.pdf

40 Calculation based on INFORM's 2003 estimate of 1 billion gallons of diesel used per year by garbage trucks, EPA emissions equivalencies, and BSR analysis. Deborah Gordon, Juliet Burdelski, James S. Cannon, INFORM, "Greening Garbage Trucks: New Technologies for Cleaner Air," 2003.

BigBelly Breakdown

Figure 5: A solar panel on top of the BigBelly bins power a trash compactor inside the bin, and a wireless sensor alerts collection agencies when the bin is full.
(Source: BigBelly Solar)

The industry's value chain involves a range of activities, from collecting and processing to storing waste. The process starts with waste collection—such as curbside pickup or hauling. Once collected, the waste is typically transferred to a central facility for sorting, treatment, and processing. The waste is then directed to recycling, value recovery, and final disposal.[41] In 2009, 243 million tons of municipal solid waste was thrown away in homes, schools, hospitals, and businesses.[42] This process involves the constant operation of heavy machinery burning fossil fuels, emitting CO_2, and creating litter and effluent.

Along each step of the value chain lies potential for wireless technology to mitigate environmental impacts by reducing inefficiencies, improving allocation of scarce resources, and more effectively handling outliers in the waste management system.

WIRELESS WASTE MANAGEMENT: FLEET APPLICATIONS
The first step in waste management is collection, which involves large fleets of heavy-duty trucks running frequent pickup routes over vast geographies.

Wireless transmissions can be used to more sustainably orchestrate an entire waste collection fleet. Trucks fitted with onboard devices can wirelessly transmit data about pickup route needs and truck locations. Using these data as part of geographic information systems, planners can develop routes that reduce driving distances, avoid traffic, and circulate efficiently among pickup sites.[43] Such measures reduce fuel use and associated emissions.

Fleet management and telemetrics applications also help optimize the efficiency of a waste management fleet on an individual truck level. Data collected and transmitted wirelessly (such as vehicle speed, acceleration, GPS locations, and from RFID-tagged bins)[44] can be used to encourage more fuel efficient driving behavior. Wireless data can also be used to resolve uncertainties and conflicts on truck collections by verifying claims of missed pickups. Managers can avoid sending trucks for extraneous pickups, causing unnecessary pollution and fuel consumption. This reduces extra pickup runs, saving money for municipalities and lowering emissions.[45]

Programs leveraging tracking and monitoring systems produce real benefits for the environment. For example, AT&T worked with the San Diego Department of Environmental Services to develop a Sanitation Truck Monitoring System. Through improvements such as tracking, routing, and improving driver behavior, the system is projected to deliver $10 million in savings over a decade, all while cutting greenhouse gas emissions.[46]

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41 Environment Agency, "Improving Environmental Performance: Sector plan for the waste management industry," Version 1, August 2006, accessed September 27, 2011, http://publications.environment-agency.gov.uk/PDF/GEHO0906BLHF-E-E.pdf

42 U.S. Environmental Protection Agency, "Municipal Solid Waste," http://www.epa.gov/waste/basic-solid.htm

43 Nebojša M. Jovičić et. al, "Route Optimization to Increase Energy Efficiency and Reduce Fuel Consumption of Communal Vehicles," *Thermal Science,* vol. 14, 2010, accessed September 27, 2011, http://thermalscience.vinca.rs/2010/supplement/6

44 Fleet Mind, "Cart Delivery and Management System," http://www.fleetmind.com/waste-recycling-solutions/cart-delivery-management-system/

45 AT&T, "Utilities Case Study: San Diego Environmental Services Department," 2007, accessed September 27, 2011, http://www.wireless.att.com/businesscenter/en_US/pdf/CaseStudySanDiegoWasteManagement.pdf

46 AT&T, "Utilities Case Study: San Diego Environmental Services Department," 2007, accessed September 27, 2011, http://www.wireless.att.com/businesscenter/en_US/pdf/CaseStudySanDiegoWasteManagement.pdf

In Lancashire, United Kingdom, Navman Wireless worked with Neales Waste Management Ltd to develop a tracking and routing system. The system is driving annual fuel cost savings of GBP 50,000 and annual greenhouse gas emissions reductions of 9.7 MT CO_2.[47] These examples highlight the real environmental and financial benefits in using wireless technology to streamline waste pickup.

WIRELESS WASTE MANAGEMENT: TRASH BIN APPLICATIONS

At the point of picking up the actual bins, monitoring devices in trash cans may be used to further improve the waste management process. Such devices can be employed in a number of ways, including monitoring for the presence of hazardous chemicals, substances that require special disposal, or other materials that impede safe and efficient waste collection. One study examined the use of wireless transmitters to monitor for waste that would be hazardous to dispose of in the city's incinerators, such as concrete-based products. Bins were fitted with monitors to detect dense waste that would indicate the presence of concrete.[48] By identifying and flagging hazardous materials, waste management vendors can increase the efficiency of collection, ensure proper disposal of hazardous substances, and minimize environmental risk in the disposal process.

Wireless bin monitoring systems can also be used to monitor compactor systems for problems. In the case of issues such as compactor failures or hydraulic fuel leaks, an alert is sent to the system monitor. The overseer can then react quickly to avert costly and harmful problems that would lead to waste buildup and spills. Furthermore, some issues may be resolved remotely, preventing maintenance trips for simple fixes.[49]

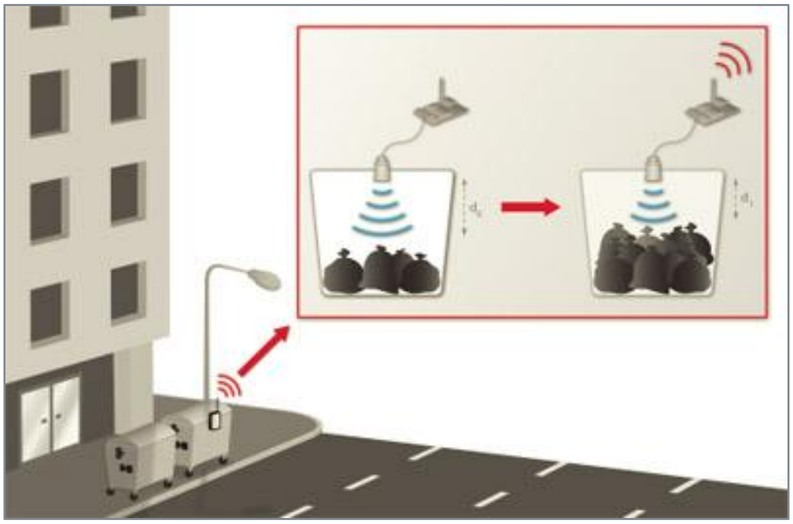

Figure 6: Wireless monitors inside trash bins monitor when a bin is full, reducing wasteful trips to collect it. (Source: Libelium)

Wireless waste bin monitoring also enables dynamic optimized routing to increase waste management efficiency. Wireless monitors can assess how full a bin is and transmit that information to a central dispatch system. This enables real-time routing to eliminate unnecessary pickup trips, as well as overflowing bins that lead to debris entering local environments.[50] One study of dynamic scheduling and routing systems found tremendous benefits in lowering operating

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47 Navman Wireless, "Neales Waste Management Ltd," Case Study, http://www.vehicle-tracker.org.uk/Neales.html

48 Alberto Rovetta, et. al, "Early Detection and Evaluation of Waste Through Sensorized Containers for a Collection Monitoring Application," *Waste Management* 29 (2009).

49 One Plus, " Waste Compactor Remote Alarms and Diagnostics," Case Study, http://www.onepluscorp.com/hauler/products-AlertPlus.asp

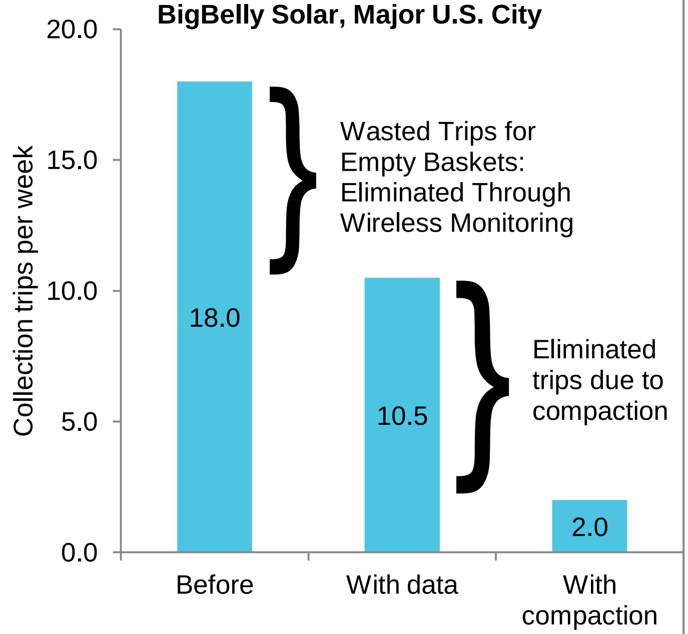
50 One Plus, "Waste Fullness Optimization with Web Reporting," Case Study, http://www.onepluscorp.com/hauler/products-WasteEdgeWireless.asp

In Portland, Oregon, BigBelly systems are expected to cut CO_2 emissions by 25,000 pounds per year.

costs, decreasing collection and hauling distances, and reducing container collection compared to static collection policies that many operators use.[51] This more efficient routing reduces fuel consumption, decreases costs, and keeps cities cleaner.

CASE STUDY: BIGBELLY SOLAR WASTE MANAGEMENT SOLUTIONS
One illustration of the impacts wireless mobile technology can have on waste management is BigBelly Solar. This system deploys solar-powered, trash compacting waste receptacles and recycling bins with wireless alert technology. The bins feature a closed chamber into which passersby place garbage, which is then shunted into the compactor. As the level of trash rises, an electric eye detects it and initiates the compactor. Once the compactor gets near capacity, the wireless monitoring system sends an SMS message to a central dispatch. From there, the information can be incorporated into a dynamic route optimization system to direct a truck to make the pickup, avoiding unnecessary pickups when bins are not full.

Figure 7: Reduced Collections from BigBelly Solar, Major U.S. City



(Source: Data provided to BSR by BigBelly Solar)

A recent BigBelly study in a major U.S. city demonstrated that using wireless data to inform bin pickups reduced weekly collections by over 40 percent, from 18 trips to 10.5. Compaction obviated an additional 8.5 trips per week, for a total of 89 percent fewer trips with the wireless BigBelly system.[52] This significantly reduces congestion from unnecessary truck traffic and reduces CO_2 emissions. The fully-enclosed containers also decrease litter by preventing overflow.[53]

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[51] Ola M. Johansson, "The Effect of Dynamic Scheduling and Routing in a Solid Waste Management System." *Waste Management* 26 (2006).

[52] BSR conversations with BigBelly Solar; data provided to BSR by BigBelly Solar.

[53] BigBelly Solar, http://bigbellysolar.com/

Wireless Opportunities to Reduce Environmental Impacts: Vehicle Miles Traveled

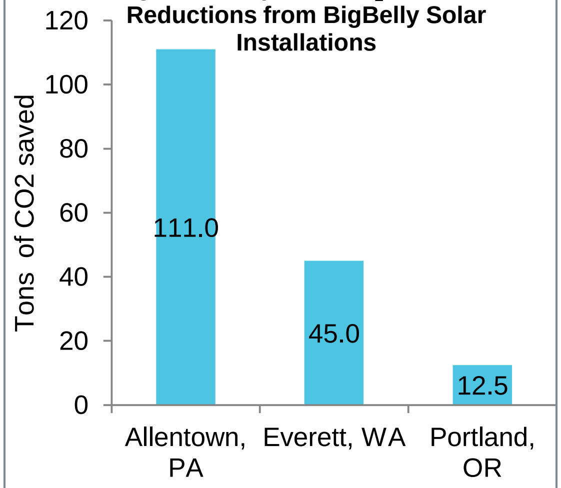
Matching Supply and Demand: Use of wireless to understand where transportation is needed and where it isn't (for example in waste collection) reduces vehicle miles traveled and related environmental impacts

Using Less: Wireless monitoring can improve vehicle performance, decreasing fuel use per vehicle mile traveled

Shifting behaviors: Wirelessly transmitted information may actually take the place of vehicle trips

More than 10,000 BigBelly units have been sold to over 750 customers in 30 countries. In Philadelphia, one of several U.S. customers, the installation of 500 BigBelly units was projected to reduce both collection frequency and annual operating costs by 70 percent. The cumulative cost savings were forecasted at $10 million over 10 years—a 70-percent savings compared to the existing system of wire mesh bins.[54] BigBelly reports that after one year all initial goals have been met. The wireless monitoring system even drove an additional reduction of 2.5 collection trips per week.[55] On the other coast, Portland, Oregon's BigBelly system is expected to cut CO_2 emissions by 25,000 pounds per year.[56]

Figure 8: Projected CO_2 Emission Reductions from BigBelly Solar Installations



(Source: Media coverage of installations)

Looking Ahead

Wireless solutions will continue to help close information gaps, overcome geographic barriers, and motivate behavior change throughout the transportation industry, resulting in significant economic and environmental benefits.

Applications on the horizon include M2M sensors mounted on cars that collect data on weather, traffic congestion, current road conditions, and other real-time information, and communicate with the sensors in other passing cars to provide summaries of current traffic conditions.[57] This technology could support predictive traffic mapping, in which drivers input their destination into the devices, and software calculates system-wide trajectories to be mapped and updated in real-time. The system could then calculate more efficient routes for all drivers, based on intended destinations.

54 BigBelly Solar, "City of Philadelphia Case Study: Cost-Savings from Solar-Powered Compactors for Trash and Recycling," Case Study, http://bigbellysolar.com/files/CaseStudy-Phila-Full-06-09.pdf

55 BSR conversations with BigBelly Solar; data provided to BSR by BigBelly Solar.

56 Portland Business Alliance, Portland Adopt-A-Belly Program, http://www.portlandalliance.com/downtown_services/big_belly.html

57 IBM Smarter Cities, "Smart Traffic," http://www.ibm.com/smarterplanet/us/en/traffic_congestion/ideas/index.html

Powering Our Future

Section Overview

WIRELESS UTILITIES APPLICATIONS: POTENTIAL IMPACTS
Fewer power plants required to meet peak electricity demand
Reduced energy used by consumers
Reduced water loss through household and infrastructure leaks

Introduction: The Utilities Nervous System

When we turn on the faucet, we expect water; when we plug in an appliance, we expect electricity. Utility services are omnipresent and effortless in most Americans' lives. Yet the country is increasingly aware of the rising environmental, resource, and financial costs of supplying and powering daily life. Electricity generation has enormous environmental impacts, and clean water supplies are increasingly under strain. The nation is looking for better ways to deliver the utilities services on which we reflexively depend.

With the advent of smart grids, wireless networks increasingly serve as the nervous system of the nation's utilities infrastructure. They connect users with utilities and distribution networks, transmitting vital information about the state of the system while enabling responses to that state. This is significantly different from traditional grids, where information flow is much more limited and occurs slowly. In traditional grids it might by extremely difficult or impossible to gather the information and mobilize the responses that the smart grid makes possible with the click of a mouse

These smarter utilities offer powerful opportunities to improve environmental impacts. With smart energy (and water) grids, utilities and consumers can gather new, myriad, and near real-time data that makes it possible for consumers to make better choices about their resource use. The data also allows utilities to put resources to work more efficiently. Furthermore, this information helps parties to detect outliers and quickly remedy problems, from inefficient appliances to system-wide spikes. In fostering these improvements, wireless technology is helping power daily life and the future of the nation—more efficiently, with lower resource use, and with greater stability.

These benefits of smart grid technology, often enabled by wireless, are apparent in a variety of applications:

- "Vampire" appliances suck energy even when they are turned off or in standby mode. Smart meters help consumers identify and reduce their households' stealth energy users, thus helping the environment while saving money.
- Electricity typically costs the same 24 hours a day, even though peak use incurs greater financial and environmental impact. Many utilities simply do not have the data to make pricing more granular. Real-time smart meter data enables variable pricing and encourages off-peak use, thereby promoting better use of resources and reducing demand for peak energy.

"The Smart Grid will be characterized by a two-way flow of electricity and information to create an automated, widely distributed energy delivery network. It incorporates into the grid the benefits of distributed computing and communications to deliver real-time information and to enable the near instantaneous balance of supply and demand at the device level."

– Electric Power Research Institute, 2011

» Water leakage accounts for five to seven billion gallons of water loss per day in the Unites States.[58] Wireless monitoring is being used to detect and remedy leaks quickly to reduce these losses, save money for water companies, and conserve a critical resource.

This section will explore how wireless technology is playing an important role in enabling sustainability improvements in utilities. It will focus primarily on smart energy grids and smart water management.

Wireless and Energy Smart Grids

In 2008, the United States consumed over 4,156 Billion kWh of electricity, or 13,600 kWh of electricity per person.[59] Generating the country's electricity accounted for 39 percent of all U.S. CO_2 emissions in 2009.[60]

Now imagine reducing that number by even a small fraction: the environmental benefits would be significant. Such a vision is not fancy; there are clear solutions to drive such reductions. Even better, these solutions save money for consumers and provide a financial benefit to utilities.

Collectively, these solutions are referred to as smart grids. The U.S. Department of Energy provides a basic definition of the smart grid:

> The smart grid is the electricity delivery system, from point of generation to point of consumption, integrated with communications and information technology for enhanced grid operations, customer services, and environmental benefits.[61]

Smart grids, then, incorporate many different facets and technologies. Among them:

» **Appliances** can wirelessly communicate with smart meters to provide data about their electricity usage and patterns

» **Smart meters** installed in homes and businesses allow two-way communications to collect, store and organize data; exchange information; and possibly enable remote management

» **Infrastructure and monitoring** tools can be placed throughout transmission networks to monitor and manage infrastructural systems

» **Centralized coordination** technology enables utilities to better use information in managing the grid to increase efficiency and stability

58 "Drinking Water," Report Card for America's Infrastructure, accessed September 27, 2011, http://www.infrastructurereportcard.org/fact-sheet/drinking-water; Bevan Griffiths-Sattenspiel and Wendy Wilson, The River Network, "The Carbon Footprint of Water," May 2009, http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf; "Water Loss Control – Efficiency in the Water Utility Sector," Alliance for Water Efficiency, accessed September 27, 2011, http://www.allianceforwaterefficiency.org/Water_Loss_Control_Introduction.aspx.

59 The World Bank, "Indicators," accessed September 27, 2011, http://data.worldbank.org/indicator

60 U.S. Environmental Protection Agency, "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009," chapter 3, April 2011, http://www.epa.gov/climatechange/emissions/downloads11/US-GHG-Inventory-2011-Chapter-3-Energy.pdf

61 U.S. Department of Energy via Karen Herter, Environmental Defense Fund, "Evaluation Framework for Smart Grid Deployment Plans," June 2011, http://www.edf.org/sites/default/files/smart-grid-evaluation-framework.pdf

Together, these applications create huge environmental benefits. Through improved electricity planning, distribution, efficiency, and conservation, smart grids greatly advance efforts to use less energy, and use it more effectively.

With several smart grid technologies available and increasingly strong imperatives to use them, utilities are now beginning to roll these systems out on a large scale. In doing so, many are finding wireless technology to be a critical part of these smart grids, driving environmental, societal, and financial benefits.

THE ROLE OF WIRELESS: SMART GRIDS ENABLE TWO-WAY COMMUNICATIONS

Alongside the nation's myriad "LOL" and "will be home late" SMS dispatches, smart grids send and receive transmissions that crucially affect the nation's energy infrastructure.

In many smart grid systems, wireless technology plays an important part in carrying the data and instructions that enable the smart grid's two-way communications. Technology providers like Consert and SmartSynch are partnering with major mobile telecommunications providers like Sprint, AT&T, T-Mobile, and Verizon to bring smart grid services to utilities nationwide.

Wireless can play different roles in these systems. The two most common configurations are a mesh network or a point-to-point network. In a mesh network, smart meters relay information among each other and among local nodes that then wirelessly transmit batches of data to the central system. Often, these systems use radio frequency transmissions among meters and nodes, then use cellular transmissions for the backhaul. The second common configuration is a point-to-point system, where the smart meter itself has a cellular chip in it that communicates directly with the central system.

These wireless systems carry information and instructions between homes and the utilities. These transmissions enable sustainability benefits through three major modes:

» **Peak demand management:** When electricity use spikes, the additional demand can force utilities to procure additional energy. They typically do this by purchasing more energy at greater expense, or by relying on inefficient generators. Smart grids help remedy this situation in two ways. First, smart meter information helps utilities better anticipate and meet demand. Second, smart meters provide tools that—within parameters set by each individual customer—utilities can power down specific appliances in the home in a practice called "load shedding." For instance, if nobody is in the house and the user has set system parameters to allow it, the air conditioner could be automatically adjusted to mark the target temperature at 80 degrees instead of 70 degrees, thus cutting the amount of HVAC energy needed in the home. These efforts can obviate the need to run generators and procure extra power at financial and environmental cost.

» **Energy conservation:** Smart meters can provide detailed information to consumers about how they are using electricity. Consumers can then use simple web and mobile interfaces to set programs for their home energy use to reduce energy and minimize costs. For example, if a user is at work during weekdays, he or she could program the smart meter to power down the home's water heater and save energy.

» **Lower service emissions:** Smart meters in the home and remote monitors on power lines can be used to quickly identify power outages and infrastructure problems. Without this technology, utility workers literally have to drive around and visually search for problems, wasting fuel and electricity.

Additionally, remote meter reading virtually eliminates the need for fleets of meter reading service vehicles.[62]

A number of current programs illustrate wireless smart grid technology in action, including:

» Texas New Mexico Power (TNMP) is in the process of deploying 231,000 wireless-enabled smart meters following a smaller successful pilot. By leveraging existing wireless networks, TNMP avoids building any major new communications network infrastructure.[63]

» CPS Energy of San Antonio, Texas, currently looks to roll out cellular-enabled smart meters to 140,000 customers. CPS Energy is using the smart grid information to develop a "virtual peak plant" to manage energy demand spikes.[64]

CASE STUDY: DUKE ENERGY, SMART GRIDS, AND WIRELESS

Duke Energy serves 4 million customers over 47,000 square miles. Now the company is working to serve its customers with a new digital grid communications network.

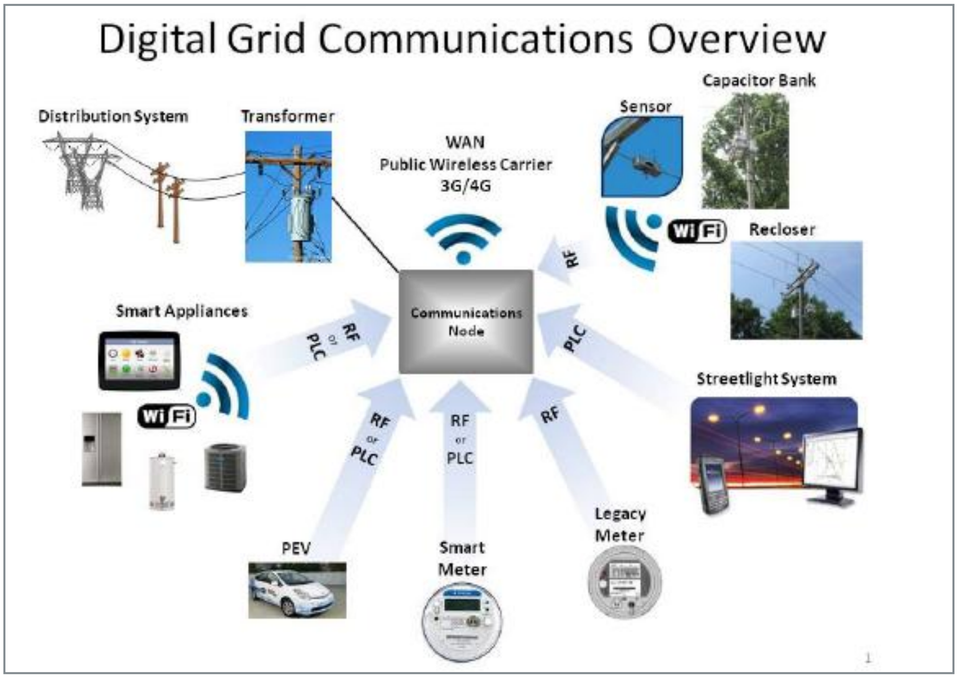


Figure 9: Duke Energy Digital Grid Communications Overview and Reasons for Selecting Public Wireless Carriers (Source: Duke Energy)

To help build out its smart grid infrastructure, Duke Energy is turning to a public wireless carrier to establish a Wide Area Network (WAN) utilizing 3G or 4G

62 BSR conversations with AT&T, Texas New Mexico Power, Consert, and CPS Energy, September, 2011.

63 BSR conversations with Texas New Mexico Power, September 2011; GigaOM, Katie Fehrenbacher, "SmartSynch Raises $25M for the Cellular Smart Grid," February 23, 2011, http://gigaom.com/cleantech/smartsynch-raises-25m-for-the-cellular-smart-grid/; Qualcomm, "The New Role of Cellular Networks in Smart Grid," (materials presented at Greentech Media webcast, "The New Role of Cellular Networks in Smart Grid," September 6, 2011).

64 Qualcomm, "The New Role of Cellular Networks in Smart Grid," (materials presented at Greentech Media webcast, "The New Role of Cellular Networks in Smart Grid," September 6, 2011). BSR conversations with CPS Energy, September 2011.

technology (see Figure 9). Duke Energy's system is using a network of local communications nodes collocated with distribution to gather and process data—thousands of nodes are already deployed. Nodes will gather data from a variety of sources such as smart meters, legacy meters, Wi-Fi-enabled smart appliances, electric vehicles, and streetlight systems. The nodes will then take this data and transmit it over the wireless WAN for gathering, processing, and action. Flexibility, financial considerations, speed of deployment, and the opportunity to leverage wireless carrier expertise are all among the reasons why Duke Energy selected this network model to build their smart grid.[65]

CELLULAR TECHNOLOGY BENEFITS SMART GRIDS

Wireless technology presents several strengths in the development of smart grids. These strengths facilitate utilities' quick and impactful deployment of smart grids, which rapidly lead to environmental benefits.

Wireless enables utilities to build a smart grid system and capture its environmental benefits without having to build and maintain a proprietary, private network. In explaining Duke Energy's decision to use existing, public wireless networks for its smart grid, David Masters, Manager, Technology Development, wrote, "Duke Energy has no desire to be in the communications business. We need to harness already existing expertise and capabilities that the wireless networks provide in designing, building, and maintaining the communications."[66] Wireless enables utility companies to bring smart grid technologies to life without incurring the time, expense, and headaches of building telecommunications networks on their own.[67,68] By leveraging wireless networks already in place, utilities can drive sustainability improvements by testing and deploying smart grids expeditiously and at scale.

Wireless networks are also useful because they rely on industry-wide telecommunications standards to maintain and develop the network. By hewing to existing public network standards, companies can employ broadly used technology and equipment, rather than being locked into maintaining and purchasing products for a proprietary network infrastructure.[69]

Additionally, as telecommunications companies innovate and deploy new technology, utilities can readily upgrade without having to invest in overhauling a proprietary network.[70] The utilities can thus harness telecommunications companies' existing standards, research and development, and network improvements. This is especially valuable given the pace of change in

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65 Duke Energy, David Masters, "Duke Energy: Developing the Communications Platform to Enable a More Intelligent Electricity Grid," February 2011, accessed September 27, 2011, http://www.duke-energy.com/pdfs/OP-David-Masters-SmartGrid-Comm-Platform-02-01-11.pdf

66 Duke Energy, David Masters, "Duke Energy: Developing the Communications Platform to Enable a More Intelligent Electricity Grid," February 2011, p. 8, accessed September 27, 2011, http://www.duke-energy.com/pdfs/OP-David-Masters-SmartGrid-Comm-Platform-02-01-11.pdf

67 This public networks approach holds many benefits for telecommunications companies, as well. Among them, it provides wireless carriers with a steady flow of income, insulated from fluctuations that occur with consumer churn. GigaOM, Katie Fehrenbacher, "The Cellular Smart Grid Grows Up," May 27, 2010, http://gigaom.com/cleantech/the-cellular-smart-grid-grows-up/.

68 *Smart Grid News*, "Smart Grid Communications Smackdown: The Cellular Companies' 'Combine-and-Conquer' Strategy," October 19, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications/Smart-grid-communications-smackdown-the-cellular-companies-combine-and-conquer-strategy-3163.html

69 Qualcomm, "The New Role of Cellular Networks in Smart Grid," (materials presented at Greentech Media webcast, "The New Role of Cellular Networks in Smart Grid," September 6, 2011).

70 GigaOM, Katie Fehrenbacher, "The Cellular Smart Grid Grows Up," May 27, 2010, accessed September 27, 2011, http://gigaom.com/cleantech/the-cellular-smart-grid-grows-up/

telecommunications and utilities' ballooning data requirements.[71] By making maintenance and upgrades easier, wireless technology can help make smart grids effective at delivering the information needed to generate environmental benefits.

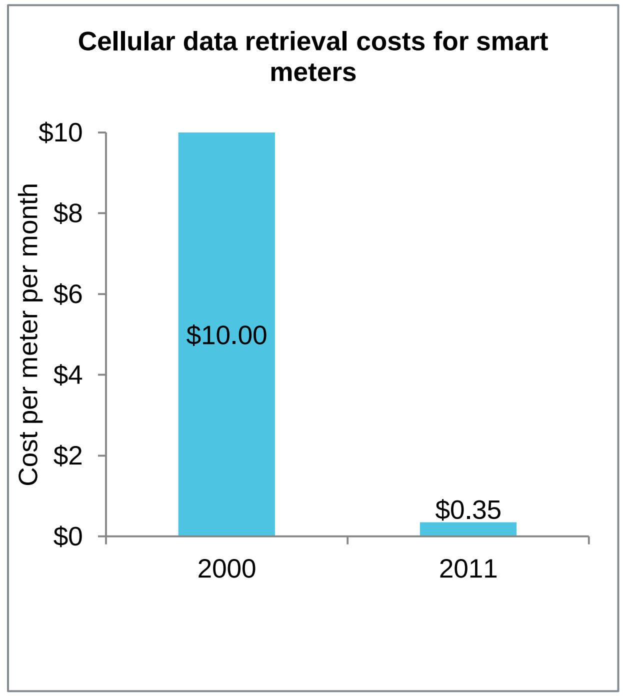

Figure 10: Drop in cellular data retrieval costs (Source: SmartSynch)

Furthermore, wireless networks' coverage, reliability, and capacity make it possible to reach many customers and carry a range of data. Cellular networks' broad coverage means that smart grids can reach massive audiences. This is partly because smart meter transmitters use large, sophisticated antennae two to four times more powerful than a typical cell phone, making the connection more reliable.[72] In a recent pilot program by Texas New Mexico Power, wireless meter readings had a 99.96-percent success rate,[73] and smart grid solutions provider Consert noted, "[I]f every water, gas, and electrical meter in the US (totaling around 300 million meters) were to send data in 15-minute intervals, the aggregate of the data would occupy only 0.00018 percent of the data a typical carrier transfers across its network on a daily basis."[74] This provides significant headroom for growth in smart grid data flow on public networks.[75] It is also important to recognize that smart grid data can be carried on a dedicated network channel, separate from teenagers' torrents of texts.[76]

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[71] GigaOM, Katie Fehrenbacher, "Verizon Brings the Smart Grid to the Cloud," February 2, 2011, accessed September 27, 2011, http://gigaom.com/cleantech/verizon-brings-the-smart-grid-to-the-cloud/

[72] *Smart Grid News*, "Smart Grid Communications Smackdown: The Cellular Companies' 'Combine-and-Conquer' Strategy," October 19, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications/Smart-grid-communications-smackdown-the-cellular-companies-combine-and-conquer-strategy-3163.html; Consert, "Cellular Networks: The Future of Smart Grid Technology," January 7, 2011, accessed September 27, 2011, http://www.consert.com/articles/cellular-networks-the-future-of-smart-grid-technology

[73] *Smart Grid News*, Jesse Berst, "Smart Grid Technology: Cellular Emerges As a Viable Communications Choice," May 5, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications_News/Smart-Grid-Technology-Cellular-Emerges-As-Viable-Communications-Choice-2300.html

[74] Consert, "Cellular Networks: The Future of Smart Grid Technology," January 7, 2011, accessed September 27, 2011, http://www.consert.com/articles/cellular-networks-the-future-of-smart-grid-technology

[75] *Smart Grid News*, "Smart Grid Communications Smackdown: The Cellular Companies' 'Combine-and-Conquer' Strategy," October 19, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications/Smart-grid-communications-smackdown-the-cellular-companies-combine-and-conquer-strategy-3163.html

[76] GigaOM, Stephen Johnston, "10 Reasons Why Utilities Want to Use Public Networks for Smart

Wireless infrastructure can also be designed to work on multiple types of networks (such as 2G, 3G, or 4G). This permits backwards compatibility, redundancy, increased coverage, and asset longevity.[77] Together, these factors make wireless technology a powerful tool in building broad-reaching, high-capacity, flexible smart grids to realize transformative environmental benefits.

Fast wireless speeds are also valuable to successful management of smart grids. Particularly with point-to-point networks, wireless can facilitate near real-time communications. This is extremely valuable in assessing up-to-the-moment demand loads, initiating demand response measures, and tracking the effects of those measures.

While it was once extremely expensive to build a smart grid on wireless technology, prices have come down markedly in recent years (see Figure 10).[78] This makes realizing the environmental impacts of wireless smarts grid more financially feasible for utilities and consumers.

There are, nevertheless, challenges in implementing wireless smart grid solutions. Some homes may not be as ripe for energy efficiency improvements. For example, homes that are heated with gas instead of electricity may gain environmental and financial benefits. Additionally, despite wireless networks' broad coverage, some homes in isolated areas may still be beyond the reach of reliable connections. Regulatory hurdles and logistical complexity can also slow implementation.

Select smart grid components also require a conceptual shift for some utilities to go "behind the meter." Traditionally, utilities do not engage in what electricity use goes on in the home; rather, they measure the total at the meter. With wireless smart grids, though, utilities are gathering information from within the home to help consumers make better choices. This brings great benefits, but is a new way of doing business for many utilities.

Furthermore, these systems are still nascent, and the long-term costs are uncertain. As more utilities deploy wireless smart grids on a large scale and gather longitudinal data, it will be important to evaluate the financial implications of the systems.

Additionally, not all providers are choosing wireless as the backbone of their smart grids. These utilities perceive a number of benefits to their own build-outs, including coverage, reliability, data response times, the ability to control and prioritize transmissions and potential financial advantages.[79]

Grid," August 2, 2010, accessed September 27, 2011, http://gigaom.com/cleantech/10-reasons-why-utilities-want-to-use-public-networks/

77 Qualcomm, "The New Role of Cellular Networks in Smart Grid," (materials presented at Greentech Media webcast, "The New Role of Cellular Networks in Smart Grid," September 6, 2011).

78 SmartSynch, "More Utilities Drawn to Cell Networks for Smart Grid," July 21, 2011, accessed September 27, 2011, http://blog.smartsynch.com/?p=770; *Smart Grid News*, Jesse Berst, "Smart Grid Technology: Cellular Emerges As a Viable Communications Choice," May 5, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications_News/Smart-Grid-Technology-Cellular-Emerges-As-Viable-Communications-Choice-2300.html; Consert, "Cellular Networks: The Future of Smart Grid Technology," January 7, 2011, accessed September 27, 2011, http://www.consert.com/articles/cellular-networks-the-future-of-smart-grid-technology.

79 *Smart Grid News*, "Smart Grid Communications Smackdown: The Cellular Companies' 'Combine-and-Conquer' Strategy," October 19, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications/Smart-grid-communications-smackdown-the-cellular-companies-combine-and-conquer-strategy-3163.html;

Ultimately, there are advantages and disadvantages to both public and private networks. Depending on the particular utility and circumstances, different types of networks may be better for different customers. As demonstrated by the wireless smart grid projects currently planned or underway, however, public wireless networks will contribute great value in enabling smart grids to realize environmental, societal, and economic benefits.

REALIZE SMART GRIDS' POTENTIAL THROUGH WIRELESS

Wireless is a link in the smart grid's chain of technologies; many smart grids rely on wireless to do the smart grid's heavy lifting, even if it is only one link. Many other technologies are critical to making smart grids a reality, but wireless is what helps those technologies communicate and become viable. With the spread of smart grids, wireless can continue to play a valuable role in enabling all of the smart grids sustainability and economic benefits. As such, wireless is helping to realize the smart grid's potential to save 360 million metric tons of CO_2 by 2020, at an estimated savings of $15 billion to $35 billion dollars.[80]

Additionally, wireless smart grid technology can help incorporate renewable power sources into the grid. Smart meter data allows utilities to account for the CO_2 savings from renewable energy, which can be critical for compliance and encouraging renewable power efforts. Furthermore, the improved demand information lets utilities more seamlessly integrate fluctuating wind and solar power sources into the grid.

Despite the attention to wireless smart grids in recent years, however, the technology is just now being brought to scale. Many of the major pilots mentioned herein—those by Duke, TNMP, Wake Forest, etc.—have only recently been completed and approved for full rollouts. As a result, it is difficult to precisely quantify the current and potential impact of these programs. With rollouts underway at hundreds of thousands of homes and businesses across the United States, however, it will soon be possible to capture more clearly the effects of wireless smart grids.

CASE STUDY: CONSERT TECHNOLOGY

Consert is a Texas-based company that provides cellular smart grid solutions, which demonstrate how wireless technology contributes to these systems' environmental benefits. Its technology focuses on enabling improved load management by utilities and better choices by consumers, including energy savings.

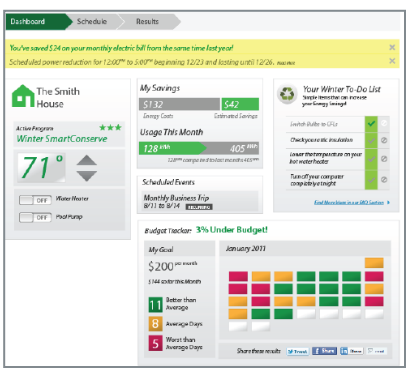

Figure 11: Consert's consumer web portal offers simple, visual electricity use information and control.
(Source: Consert)

A typical Consert installation centers on installing a new smart meter with ZigBee and cellular connectivity, along with a smart thermostat control. Monitors are installed on high-energy household appliances—HVAC units, pool pumps, and water heaters. These appliances typically account for 40 percent to 60 percent of household energy use. The monitors communicate via ZigBee with the new smart meter to provide detailed information about appliance electricity use. The monitor then takes information on appliance and total household energy use, and

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GigaOM, Katie Fehrenbacher, "Verizon Plays Catch-Up to AT&T's Smart Grid Plans," October 8, 2010, accessed September 27, 2011, http://gigaom.com/cleantech/verizon-plays-catch-up-to-atts-smart-grid-plans/; *Smart Grid News*, Jesse Berst, "Smart Grid Technology: Cellular Emerges As a Viable Communications Choice," May 5, 2010, accessed September 27, 2011, http://www.smartgridnews.com/artman/publish/Technologies_Communications_News/Smart-Grid-Technology-Cellular-Emerges-As-Viable-Communications-Choice-2300.html; GigaOM, Katie Fehrenbacher, "The Cellular Smart Grid Grows Up," May 27, 2010, http://gigaom.com/cleantech/the-cellular-smart-grid-grows-up/.

80 GeSI and Boston Consulting Group, "SMART 2020: Enabling the Low-Carbon Economy in the Information Age, United States Report Addendum," 2008, p. 18, http://www.smart2020.org/_assets/files/Smart2020UnitedStatesReportAddendum.pdf

"Through the use of Consert's technology, CPS Energy hopes to realize a savings of 250 megawatts. This tool will afford our customers the ability to directly impact the reduction of kilowatt-hours used in the San Antonio area. CPS Energy is confident that its long-term vision of reducing 771 megawatts of peak demand by 2020, and thereby by delaying the need for the construction of another power plant, is well within its reach."

– CPS Energy spokesperson, September 2011

transmits it point-to-point over existing cellular networks. Presented through a web portal, this information can be used by customers and utilities.

- **Customers' energy management portal:** Customers can access an online energy management portal that allows them to see how much energy they are using, which of the connected appliances are using it, and when they are using it. In a 10- to 15-minute setup process, customers can establish adjustable parameters and programs for their daily energy use. They can then set up a schedule for their home appliance and energy use based on their daily lives. For example, someone who goes to the office Monday through Thursday and works from home on Fridays can set up a customized schedule that powers down the air conditioning and water heater during working hours on Monday through Thursday. A separate schedule for Fridays can leave the appliances on to accommodate working from home. A user can also set a monthly energy use goal, and the portal can help customers figure out how to achieve that goal based on use history. Consert estimates that consumer-driven energy reduction measures can cut electricity use by 15 percent to 20 percent. Additionally, customers can establish parameters for what to do in the case of a high-demand period. For example, the customer can set the system so that if there is an exceptionally high electricity demand straining the grid, the utility can automatically shut off the pool pump to reduce demand.
- **Utilities' "Virtual Peak Plant":** Through a simple web app, utilities can view up-to-the-moment electricity use and projections. With this information, utilities can make better decisions about how much electricity is needed to sufficiently supply customer demand without exceeding it. In the event that peak demand exceeds capacity, the utilities can initiate demand reduction measures by using the wireless link to instruct smart meters to follow the user-set protocols in powering down appliances and changing HVAC settings. Consert estimates that for every 500 homes on a smart grid, the utility can save 1 megawatt of peak power. That is electricity that the utility does not need to supply through additional purchases or by running inefficient generators.[81]

Several successful pilots demonstrate how the wireless technology in Consert's smart grid solutions is already driving real sustainability impacts, and why such programs are in the process of expanding:

- **CPS Energy in San Antonio, Texas:** CPS Energy has piloted Consert's technology in 100 homes and is now in the process of extending the pilot to 1,000 more homes. Ultimately, the utility looks to expand this program into 140,000 homes in its service area. Based on CPS Energy estimates of individual home savings from the pilot, one can extrapolate that the program could save up to approximately 145,000 metric tons of CO_2 emissions per year—equivalent to the annual greenhouse gas emissions of nearly 29,000 cars.[82] Furthermore, CPS Energy hopes to generate 250 MW of peak electricity savings, helping to delay the need to build a new power plant.[83]
- **Wake Electric Membership Corporation in Wake Forest, North Carolina:** Consert piloted a smart grid with 100 Wake Electric members. Compared to a control group, pilot participants saw energy savings of approximately 6 percent. Wake Electric conducted a trial to measure the impact of demand

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[81] BSR conversations with Consert and CPS Energy, September 2011; Consert website, accessed September 27, 2011, http://www.consert.com

[82] CPS estimates that energy savings could be approximately 10 percent per household, with households at roughly 1600kWh energy used per month. Extrapolation based on 140,000 households and CPS Energy emissions factor. Estimate developed in contact with CPS Energy.

[83] BSR conversations with CPS Energy, September 2011.

reduction controls on two climactically comparable days. In just under two-and-a-half hours, the trial found energy reduction of almost 39 percent and savings of over 73 kWh. Consert could account for and report over 248 pounds of CO_2 saved during the trial.[84]

» **Fayetteville Public Works Commission (FPWC) in Fayetteville, North Carolina:** Consert technology was used in a 12-month pilot program with striking impacts. The FPWC realized a 50-percent reduction in peak demand among pilot participants, while participants averaged monthly energy savings of 17 percent over their previous year's bills (adjusted for weather differences). Following the pilot, in April 2011 FPWC selected Consert to provide its energy management system and commercialize the pilot.[85]

In addition to environmental benefits, Consert believes the technology pays off financially. The company puts a typical return on investment at a mere 36 to 48 months.[86]

Wireless and Smart Water Management

The United States' water distribution system loses an estimated 5 billion to 7 billion gallons of water daily through leakage[87] out of 410 billion gallons withdrawn for use each day. To cut this leakage by only 5 percent would save an estimated 270 million gallons of water a day and avoid approximately 225,000 MT of embedded CO_2 emissions.[88]

Such reductions are increasingly critical. Droughts and shortages are already problems in many areas throughout the United States. The devastating 2011 drought in Texas, for example, has highlighted the environmental and economic impacts of water scarcity. Ranchers are facing an estimated $5.2 billion in costs, and shortages have caused towns to impose severe austerity measures; some folks have taken to spray-painting their dead lawns green.[89] Climate change is expected to exacerbate this problem. By mid-century, 1,100 U.S. counties—one-third of counties in the lower 48 states—will face higher risks of water shortages, with extremely high risks for 400 counties.[90]

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84 Consert, "Uniting the Best Interests of Utilities and Consumers, Case Study: Wake Electric Membership Corporation," 2010, http://files.consert.gethifi.com/Consert_WEMC_Pilot_Brief_Case_Study-_FINAL.pdf

85 Consert, "Fayetteville Public Works Case Study," January 6, 2011, http://www.consert.com/case-studies/fayetteville-public-works-case-study ; "IBM and Consert Help North Carolinians Reduce Energy Consumption With Smart Grid Technology," September 21, 2009, http://www.prnewswire.com/news-releases/ibm-and-consert-help-north-carolinians-reduce-energy-consumption-with-smart-grid-technology-59987467.html; Consert, "Fayetteville Public Works Commission Selects Consert for its Energy Management System," April 4, 2011, http://www.consert.com/news/press-releases/fayetteville-public-works-commission-selects-consert-for-its-energy-management-system.

86 BSR conversation with Consert, September 2011.

87 "Drinking Water," Report Card for America's Infrastructure, accessed September 27, 2011, http://www.infrastructurereportcard.org/fact-sheet/drinking-water; Bevan Griffiths-Sattenspiel and Wendy Wilson, The River Network, "The Carbon Footprint of Water," May 2009, http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf; "Water Loss Control – Efficiency in the Water Utility Sector," Alliance for Water Efficiency, accessed September 27, 2011, http://www.allianceforwaterefficiency.org/Water_Loss_Control_Introduction.aspx.

88 Bevan Griffiths-Sattenspiel and Wendy Wilson, The River Network, "The Carbon Footprint of Water," May 2009, http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf

89 *New York Times*, Manny Fernandez, "Sacrifices and Restrictions as Central Texas Town Copes With Drought," September 6, 2011, http://www.nytimes.com/2011/09/07/us/07drought.html?pagewanted=all

90 Tetra Tech Consulting and the National Resource Defense Council (NRDC), "Climate Change,

Figure 12: Neptune Technology Group's R900 Gateway V2 Data Collector can use solar power to transmit water use data with a GPRS modem

(Source: Neptune Technology Group)

Achieving water reductions is a challenge, however. While energy grids are replete with data collection points and monitoring, water grids often lack the same comprehensive and timely monitoring of usage.[91] Additionally, the low cost of water in many areas creates little incentive to reduce use, unlike electricity. Increasing local and regional scarcity may change that for some areas, but that may not drive as much nationwide attention and it may be slow to come. Consequently, smart water solutions generate less buzz than smart energy solutions.

Data and cost issues are challenges in some regards, yet they also offer high-impact opportunities to enhance measurement and monitoring. By capturing that untapped data, opening machine-to-machine communications, developing smart water systems, and using information to enable action, technology can have a tremendous impact that flows through to sustainability improvements and financial benefits.

Wireless technology is already playing a role in efforts to achieve these efficiencies through improvements in metering and monitoring, as well as applications that help consumers and facilities managers develop smart irrigation systems. Together, these approaches can help increase efficiency of water use and enable reductions.

REGULAR COMMUNICATIONS FOR METERING AND INFRASTRUCTURE MONITORING

As with smart energy grids, wireless can be a crucial part of the nation's water grid infrastructure. Wireless technology is especially useful in taking aggregated local data and transmitting it via a main trunk service to form the water grid's communications.[92] Smart water solutions provider Neptune Technology Group points out that such systems allow utilities to get meter information quickly and frequently. Instead of only getting meter information every month or so when a meter is manually read, wireless gateways can transmit local meter information as often as every 15 minutes. This provides a much more granular and timely view of water usage.[93]

These wireless-enabled systems gather and convey data about household water use to promote better choices, increased efficiency, and improve water safety:

» **Household leak detection:** With more frequent meter information and more timely reads, utilities can help consumers detect household leaks. If a household never has a period with zero water use, then the utility can quickly notify the household that there may be a leak. A Neptune Technology Group study in Canada found that 9 percent of utilities' accounts had intermittent leaks, and 8 percent had continuous leaks. Household leak detection and response saves water and money.

» **Reverse flow detection:** Water systems are pressurized to deliver water in the home. When pressure shifts, it can cause water to "reverse flow" from a household back into the system. This can carry with it fertilizer, chemicals, or other contamination. Wireless smart meters can detect these events and alert utilities to work with customers in solving the problem and reducing water supply contamination.

Water, and Risk: Current Water Demands Are Not Sustainable," July 2010, accessed September 27, 2011, www.nrdc.org/globalwarming/watersustainability/files/WaterRisk.pdf

91 CleanTechies, Guy Horowitz, "It's Time for the Smart Water Grid," June 8, 2010, accessed September 27, 2011, http://blog.cleantechies.com/2010/06/09/time-for-the-smart-water-grid

92 Tropos Technology Brief, "Comparison of Licensed and Unlicensed Spectrums for Utility-Owned Wide Area Networks," November 2009

93 BSR conversation with Neptune Technology Group, September 2011.

Wireless Opportunities to Reduce Environmental Impacts: Home Energy use

Matching Supply and Demand: Wireless peak demand management enables utilities to reduce energy demand rather than increasing energy production.

Using Less: Wireless monitoring allows utilities to increase efficiency of energy delivery by monitoring for and addressing system failures.

Shifting behaviors: Wirelessly tracked information about home energy use empowers consumers to understand and change their usage patterns.

» **Meter tampering:** Smart meters can help detect when someone has tampered with a meter, ensuring that water use is properly billed to prevent excessive use.

» **Consumer information:** By providing more granular and regular information, consumers can better understand their water use and change behavior accordingly.

» **Infrastructure leak detection:** Monitoring systems throughout water delivery infrastructure can help detect leaks.

Clermont, a 28,000-person town in Florida, is currently deploying a smart water system designed by Neptune Technology Group to aid in water administration and conservation efforts. Neptune's systems can use a combination of radio frequency readers and cellular backhaul over solar-powered Gateways. The systems enable remote monitoring and meter reading, and provide much more granular data like 24-hour usage/consumption profiling (in addition to saving meter reading fleet emissions).

This data can be used to support better information for customers, including detailed graphs of water useage patterns. Furthermore, leak detection alarms help minimize loss; alarms can flag leaks down to 0.1 gallon. Reverse-flow alarms can also help detect possible sources of contamination.The town will be able to route the alarms to customers via email so they can address problems. Improved data also makes it easier to enforce water conservation efforts. For example, the utility can now understand patterns in water usage to spot when someone is violating residential lawn watering restrictions.[94]

Smart water systems can generate real results and scalability, as well. In a 2011 study of a pilot smart water program in Dubuque, Iowa, IBM found that smart water meters and consumer interfaces drove a 6.6 percent reduction in average household water consumption. Extrapolated citywide across 23,000 households, that would tally 65 million gallons of water at an aggregate savings of over $190,000.[95] These programs have the potential for scale, as well. For instance, IBM is also part of a program that is rolling out 120,000 water meters across the island of Malta.[96] Such a large-scale solution could encourage better choices and efficiency in many sizable American cities.

In addition to enabling improved smart meter reading, wireless technology enables important infrastructure monitoring applications. Wireless-enabled monitors can detect and analyze data covering a number of factors, including water quality, system pressure, leak detection, infrastructure maintenance issues, and rainfall. For example, Telog is a provider of wireless water infrastructure monitoring that uses wireless transmissions for many of their solutions. The company offers a system that monitors pressure-reducing valves (PRVs)—critical water infrastructure components that maintain appropriate pressure levels to decrease water loss and prevent pipe breaks. Telog's system monitors the valves to ensure proper operation, and transmits the data on the wireless network, where it can be sent to a central server, web browser, or cell phone alert system (see Figure 13). By improving this monitoring technology, utilities can save water and money, along with time, expense, and the environmental impact of running maintenance operations.

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94 *Water Efficiency*, Carol Brzozowski, "The Smart Water Grid," September-October, 2011, http://www.waterefficiency.net/september-october-2011/smart-water-grid-2.aspx

95 IBM Research, "Smart Water Pilot Study Report," June 6, 2011, http://www.cityofdubuque.org/DocumentView.aspx?DID=3116

96 Itron, "Itron Delivers Smart Water Meters for Nation-Wide Grid in Malta," March 22, 2011, https://www.itron.com/newsAndEvents/Pages/Itron-Delivers-Smart-Water-Meters-for-Nation-Wide-Grid-in-Malta.aspx

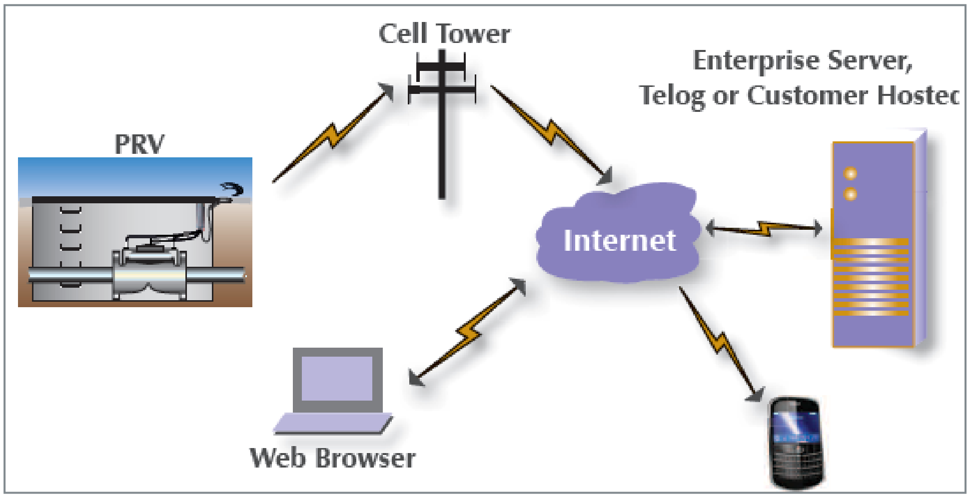

Figure 13: Telog PRV Monitoring System (Source: Telog Instruments)

Figure 14: ET Water's QUICKDRAW mobile application allows users to operate irrigation systems remotely.
(Source: ET Water)

In addition to saving water resources, smart water technology generates energy savings. Extracting, treating, pumping, recapturing, treating—the water use cycle requires tremendous amounts of electricity. In California, for instance, moving water is responsible for over 20 percent of the state's electricity use.[97] Nationally, water-related energy use is estimated at 13 percent of the nation's electricity consumption.[98] In improving the availability of information, smart water meter and infrastructure systems help utilities reduce water demand and better manage their own electricity demands. Combined with electricity management tools, water utilities can reduce electricity consumption and improve grid stability. For example, Southern California's Eastern Municipal Water District enrolled in EnerNOC's demand response system. By shutting down electricity-using equipment (such as pumps), the utility better managed electricity, and received $100,000 per year from EnerNOC for its commitment to lower energy use by 1.5 megawatts. EnerNOC also uses a demand response system that helps consumers understand the link between electricity and water costs, enabling better choices that reduce energy demand.[99]

Wireless technology can also be used to help water planners and consumers use water more efficiently. Smart, remote control of irrigation and water systems reduces consumption and efficiently manages water usage. Individuals, municipalities, corporations, and residential communities are using these systems to gather information about users, landscapes, weather forecasts, and sensor data to regulate the amount of water dispersed. To do this, the systems often rely on wireless technology to transmit data and enable user control. For example, a system might use a wireless transmission to check weather reports and, if rain is predicted, scale back watering.

ET Water is a company that builds wireless-enabled smart water management systems that reduce irrigation costs, improve landscape management, and drastically cut the amount of water that customers draw from utilities. Its systems

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97 *Water Efficiency*, Carol Brzozowski, "The Smart Water Grid," September-October, 2011, http://www.waterefficiency.net/september-october-2011/smart-water-grid-2.aspx

98 Bevan Griffiths-Sattenspiel and Wendy Wilson, The River Network, "The Carbon Footprint of Water," May 2009, http://www.rivernetwork.org/sites/default/files/The%20Carbon%20Footprint%20of%20Water-River%20Network-2009.pdf

99 *Water Efficiency*, Carol Brzozowski, "The Smart Water Grid," September-October 2011, http://www.waterefficiency.net/september-october-2011/smart-water-grid-2.aspx

include features like watering schedules that self-adjust, as well as remote monitoring and management via the internet. The application of ET Water and Numerex technology in Northern California's Rossmoor Communities, a senior adult community with approximately 7,000 residential units, covers 2,600 acres of landscaping and 700 acres of open space. Over five years, the controllers helped Rossmoor Communities cut its water bills by 53 percent.[100]

Another example is WeatherTRAK's smart irrigation solutions. The larger WeatherTRAK systems can download satellite data on weather forecasts, calculate the effect on irrigation needs, and use wireless networks to broadcast new irrigation protocols to watering systems. RNM Properties, a San Francisco-based developer, found that the WeatherTRAK technology reduced water use by 46 percent at two locations, an office building and a shopping plaza. After the successful trial, the company is rolling the technology out across its entire portfolio. WeatherTRAK's technology is deployed by water agencies, community associations, school districts, and retirement communities.[101]

Looking Ahead

These are new technologies, and many are just now being rolled out to scale. In the coming years, it will be critical to track and quantify the effectiveness of the programs as utilities continue to learn how to optimize benefits. Fortunately, one of the benefits of smart utilities is the ability to capture information that can be used to assess and refine efforts.

Wireless technology is vital to realizing the vision of a smarter, more efficient, easier to manage, and more responsive utilities infrastructure. Wireless is enabling smart energy grids across the country, forming the communications networks critical to bringing the smart grid to life. In doing so, it presents benefits ranging from ease of implementation to adaptability to new technology.

Wireless is also making smarter water management possible, through modes such as leak detection and enabling consumers to draw less on utilities' limited water resources. This vision of an improved utilities infrastructure is not just about greater infrastructure reliability or cost savings, however; it is also about dramatically reducing the environmental impact of utilities and their users. It is about more effectively and sustainably powering our daily lives and our nation's future.

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[100] ET Water Systems, "Bay Area's Largest HOA Selects ET Water," accessed September 27, 2011, http://www.etwater.com/public/case-property-manager.html

[101] *Today's Facility Manager*, "Product of the Month: WeatherTRAK from HydroPoint Data Systems," September 2007, http://www.weathertrak.com/pdfs/news2007/Todays_Facility_Mgr_0907.pdf; HydroPoint website, accessed September 27, 2011, http://weathertrak.com

Nourishing People

Section Overview

WIRELESS AGRICULTURE APPLICATIONS: POTENTIAL IMPACTS
Soil Moisture Monitoring could save up to 6 trillion gallons of water per year
Wireless Pasture Management reduces soil erosion and desertification
Wireless livestock monitoring improves herd health and reduces methane gas

Introduction: The Wireless Potential in Agriculture

When hunter-gatherers planted seeds in the ground for the first time about 10,000 years ago, they forever altered the relationship between humans and the food that nourishes us. The advent of agriculture meant that food was no longer provided according to what nature could offer, but rather according to what humans could demand.

Those first seeds had barely touched the ground before humans began to devise ways to demand more. Through the practice of agriculture—literally, "to cultivate the field"—farmers discovered ways to control the natural forces working against their pursuits to maximize production and minimize inputs. Technology has been agriculture's handmaiden since the beginning, from the invention of the plow and the cotton gin, to the steam turbine and the modern combine harvester. The ICT revolution has helped lead the way by providing field and herd tracking software, database systems to organize and analyze farm data, and even laser-guided hydraulic steering systems in those big combine harvesters.

The introduction of wireless applications in agriculture is the next step along this technological journey—but with a twist. Instead of using cutting-edge technology to control and harness nature's power to maximize productivity, wireless applications help farmers understand natural forces, with the aim of adopting more resourceful, thoughtful, and conservationist approaches to agriculture.

But we have a lot of ground to make up, as our collective demand on the earth's resources has been severe:

» One-third of all greenhouse gases produced by human activity are attributable to agriculture.[102]

» Livestock-related emissions of CO_2 and methane gas account for more greenhouse gas emissions than the entire global transportation industry.[103]

» 80 percent of the fresh surface water used in this country goes to irrigate crops and fields.[104]

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[102] Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 198.

[103] United Nations, Food and Agricultural Organization, "Livestock's Long Shadow," Rome, 2006, accessed September 27, 2011, http://www.fao.org/docrep/010/a0701e/a0701e00.HTM

[104] U.S. Dept. of Agriculture, Economic Research Service, Briefing Rooms, "Irrigation and Water

The challenge for smart technologies is to balance the ever-increasing demand on agricultural resources with increasingly fewer resources. Although wireless applications in agriculture are still relatively new, several applications have achieved widespread adoption, and several more are on the cusp of a breakthrough.

The applications featured in this section discuss both the plant and animal worlds.

- **Wireless in Precision Agriculture.** Applications include wireless soil moisture monitoring—one of the most important single pieces of information needed to properly irrigate crops—and microclimate monitoring to detect weather conditions around the plant.
- **Wireless in Livestock Management.** Wireless sensor networks are used in herd and animal tracking, and help inform important rotational grazing strategies. This section also discusses methane monitoring, one of the more experimental—yet enormously beneficial—applications of wireless technology.

As wireless in agriculture is poised to become the next big technological breakthrough, its power will hopefully usher in a different relationship between humans, nature, and food—one that is healthier and more sustainable, both for us and the planet.

ENVIRONMENTAL IMPACT OF AGRICULTURE

Smarter agriculture practices enabled by wireless technology have the potential to reduce the large environmental footprint of the agriculture industry.

In the United States, agriculture is sited on approximately 922 million acres of land, or nearly 40 percent of all land in this country.[105] Agriculture land is home to 2.2 million farms, each an average size of 418 acres. Approximately 55 million acres are irrigated fields, an increase of 4.5 percent since 2003, and require 91.2 million acre-feet of water per year (about 30 trillion gallons).[106] Agriculture now accounts for 80 percent of ground and surface water consumption in the United States, and over 90 percent in many Western states.[107] Not surprisingly, energy expenses required to power irrigation pumps increased 73 percent from 2003 to 2008, costing growers $2.6 billion in 2008.[108]

While demands from agriculture are growing, the land devoted to agriculture practices is shrinking. Since 1982, over 41.3 million acres of rural land used for crops, pasture, rangeland, and forests—about the size of Illinois and New Jersey combined—have been converted to non-agricultural developed uses.[109] Now, more than ever before, farmers must adopt innovative ways to produce more food with less land, less water, and less energy.

Use," 2004, accessed September 27, 2011, http://www.ers.usda.gov/Briefing/WaterUse/

105 U.S. Dept. of Agriculture, Economic Research Service, Data Sets, "State Fact Sheets: United States," 2011, accessed September 27, 2011, http://www.ers.usda.gov/statefacts/us.htm

106 U.S. Dept. of Agriculture, National Agriculture Statistics Service, 2007 Census of Agriculture: 2008 Farm and Ranch Irrigation Survey, "Survey Highlights," accessed September 27, 2011, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Fact_Sheets/fris.pdf

107 U.S. Dept. of Agriculture, Economic Research Service, Briefing Rooms, "Irrigation and Water Use," 2004, accessed September 27, 2011, http://www.ers.usda.gov/Briefing/WaterUse/

108 U.S. Dept. of Agriculture, National Agriculture Statistics Service, 2007 Census of Agriculture: 2008 Farm and Ranch Irrigation Survey, "Survey Highlights," accessed September 27, 2011, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Fact_Sheets/fris.pdf

109 American Farmland Trust, "What's Happening to Our Farmland," accessed September 27, 2011, http://www.farmland.org/resources/fote/default.asp

HOW WIRELESS TECHNOLOGY CAN HELP

Wireless applications are poised to provide new opportunities for farmers to develop better farming techniques that allow them to do more with less in several overlapping ways:

» **Providing data that informs resourcefulness**. The more farmers know about their fields, the better they can allocate resources efficiently and resourcefully. Wireless monitoring systems provide access to real-time data from sources that farmers have never had before—such as soil moisture readings in real-time every 10 seconds, the sap flow rate from a leaf in a grape vineyard, or the timing of methane production inside cows. This information is now uniquely available with wireless technology.

» **Improved scalability**. The level at which wireless applications can scale to provide data about the field and animal conditions has never been possible before. Soil-based temperature and humidity sensors, for example, have been around for a long time, but the cost and destruction of digging up a field to lay wired sensors underground makes them cost prohibitive. Wireless sensors do not have these same installation costs, and are easily installed throughout hundreds of acres of fields. This means that entirely new sets of data can be generated from places that have never been monitored before.

» **Remote, nomadic, and mobile**. Wireless applications are particularly useful in agricultural applications because of their ability to be remote, nomadic, and mobile.

  - *Remote:* Wireless applications are "remote" in the sense that they can be installed not only in remote areas of a country, but also in remote and difficult-to-reach areas of a field, without requiring wires or connection to a grid-based power source.
  - *Nomadic:* Wireless applications are "nomadic" in the sense that they can be transferred to myriad locations when seasons or field conditions change.
  - *Mobile:* Wireless applications are "mobile" in the sense that they are able to collect and analyze data "on the move"—attached to grazing animals, mounted on half-mile-wide irrigation pivots, or tossed inside a harvesting basket.

Whether reducing water inputs through remote soil moisture monitoring systems or integrating wireless applications into livestock management practices, each of the applications featured in this section are powering innovations to reduce the environmental impacts of agriculture. They are helping to lower greenhouse gas levels in the atmosphere, prevent soil and land erosion, improve the quality of drinking water, and, ultimately, grow healthier and more sustainable plants and animals.

Wireless in Precision Agriculture

Precision agriculture techniques utilize various technologies, including wireless applications, to provide farmers with information about real-time farming conditions and form the basis for more resourceful farming techniques. If done correctly, precision agriculture techniques help farmers avoid applying the same farming techniques across widely varying field conditions.

Innovations in remote sensing technology have led to the present ability to monitor environmental conditions, such as soil and landscape characteristics, locations and health of livestock, grazing patterns, and weather conditions.[110] This information provides highly localized data under real-time conditions that farmers and ranchers use to make better decisions about agricultural practices.

Soil moisture monitoring and microclimate monitoring are two of the most widely adopted wireless applications in precision agriculture. Both applications allow farmers to make smarter decisions based on real-time data about soil quality, water, and weather conditions from the fields, rather than on hypothetical conditions or inaccurate generalizations. The data collected through remote, nomadic, and mobile wireless devices provides information needed to make better decisions about efficient resource management.

One of the biggest challenges facing modern farmers is getting the right amount of water to the right crops at the right time. Farmers have wrestled with this problem for thousands of years, and yet it's still largely educated guesswork. In a 2007 survey on watering techniques, most U.S. farmers responded that they irrigate their fields based only on a visual assessment of the crop's condition and the "feel" of the soil.[111] About eight percent of farmers said they irrigate their fields based on new monitoring technology that can detect when the soil is ready to take on more water—about the same number of farmers who said they irrigate their field based on when their neighbors decide to do so.[112] While this local knowledge is accurate up to a certain point, it can easily lead to inefficient farming, excessive and wasteful irrigation, soil and land erosion, and lower crop yield.

Until now, farmers have not been able to truly understand all of the complex factors involved in getting the right amount of water in the right place at the right time. Lacking accurate data leads to one-size-fits-all watering strategies that do not account for the vast amount of variance in soil conditions over an average-sized farm. As one report from the U.S. Department of Agriculture pointed out, because of "factors like soil type, subsurface conditions, topography, drainage issues, and disease problems, a piece of farmland that looks uniform on the surface is, in reality, a complicated, irregular patchwork of smaller plots, each defined by its own set of problems."[113]

The relationship between soil, water, and plants is complicated, but is critical to achieving optimal crop health. Obtaining accurate information about the condition of the soil is one of the most important ingredients in deciding when to irrigate fields.[114]

At its most fundamental level, soil acts as a holding tank for water between irrigation intervals—like a sponge—from which plants slowly extract water and nutrients from the soil into its roots.[115] Dense soils tend to hold water for longer periods of time, while loose and sandy soils let water pass through more quickly.

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110 University of Minnesota, Precision Agriculture Center, "What is Precision Agriculture?" http://www.precision.agri.umn.edu/education.shtml

111 Organization for Economic Co-operation and Development (OECD), Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

112 U.S. Dept. of Agriculture, National Agriculture Statistics Service, 2007 Census of Agriculture: 2008 Farm and Ranch Irrigation Survey, "Methods Used in Deciding When to Irrigate: 2003 and 2008," Table 36, http://www.agcensus.usda.gov/Publications/2002/FRIS/tables/fris03_36.pdf

113 U.S. Dept. of Agriculture, Agricultural Research Service (ARS), Erin Peabody, "Wireless Watering: New Irrigation Technologies From ARS Can Help Conserve a Vital Resource," July 2007, accessed September 27, 2011, http://www.ars.usda.gov/is/AR/archive/jul07/wireless0707.pdf

114 OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

115 Texas Water Development Board, "Agriculture Water Conservation Practices," 2001,

To achieve optimal health and production from crops, the precise amount of water required by each plant varies as soil conditions and other environmental

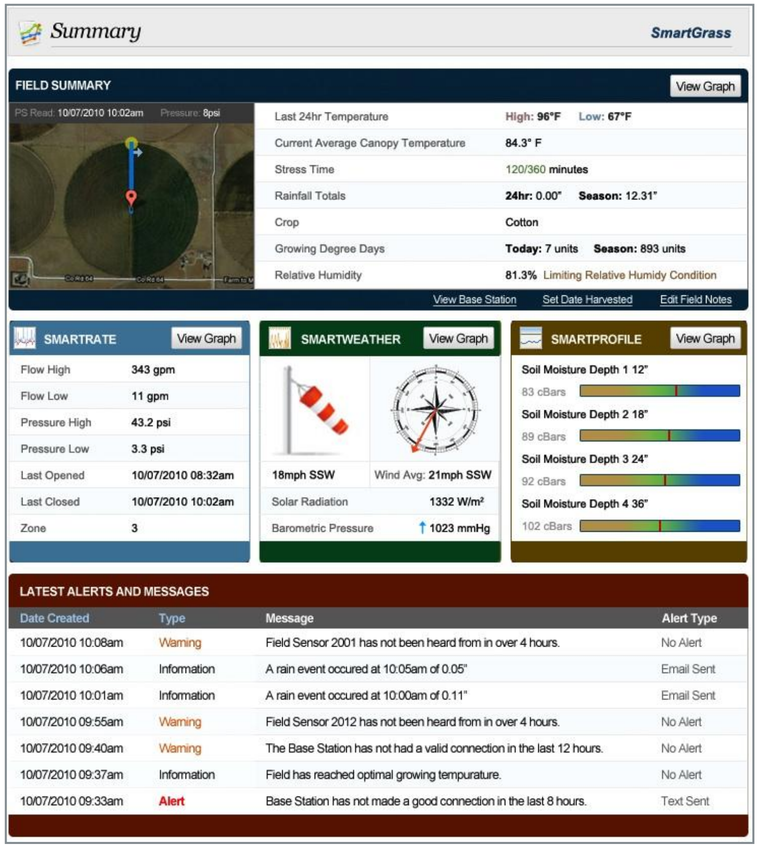

Figure 15: Interactive dashboards with information provided wirelessly about field conditions, including plant temperature, crop water stress levels, ambient temperature, relative humidity, and rainfall. (Source: Smartfield, Inc.)

factors constantly change.[116] Providing too much water (over-irrigation) or not enough water (under-irrigation) can harm the plant. Once the soil's water-holding capacity has been reached, excess water percolates through the soil beneath the roots and cannot be utilized by most plants.[117]

Knowing the type of soil, and the precise rate at which water is held or lost through that soil, is crucial to preventing over-irrigation and under-irrigation of crops.[118] Wireless monitoring devices positioned within the soil accurately provide this much-needed data about real-time soil moisture. Monitoring real-time conditions in the soil provides a wealth of information to farmers about the optimal time to irrigate and amount of irrigation that crops need. Wireless monitoring sensors buried around crops are able to provide information to the farmer about soil moisture, fertility, compaction, salinity, humidity, and soil-water tension as often as every ten seconds.[119]

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http://www.twdb.state.tx.us/assistance/conservation/conservationpublications/agbrochure.pdf

116 *International Journal of Engineering Science and Technology*, Kshitij Shinghal, et al, "Wireless Sensor Networks in Agriculture: For Potato Farming," Vol. 2(8), 2010, 3955-3963, http://www.ijest.info/docs/IJEST10-02-08-104.pdf

117 Texas Water Development Board, "Agriculture Water Conservation Practices," 2001, http://www.twdb.state.tx.us/assistance/conservation/conservationpublications/agbrochure.pdf

118 *International Journal of Engineering Science and Technology*, Kshitij Shinghal, et al, "Wireless Sensor Networks in Agriculture: For Potato Farming," Vol. 2(8), 2010, 3955-3963, http://www.ijest.info/docs/IJEST10-02-08-104.pdf

119 U.S. Dept. of Agriculture, ARS, Erin Peabody, "Wireless Watering: New Irrigation Technologies From ARS Can Help Conserve a Vital Resource," July 2007, accessed September 27, 2011,

Wireless soil moisture monitors could reduce watering on farms by up to 6 trillion gallons per year, the equivalent of about 240 billion showers.

(Source: U.S. EPA Greenhouse Gas Equivalencies Calculator)

One of the most useful measurements about soil moisture is the soil-water tension. The soil-water tension measures how much energy a plant must exert to extract water from the soil.[120] When the amount of water in the soil decreases, the amount of energy required by the plant to extract the water from the soil increases. Likewise, as the amount of water in the soil increases, the energy required by the plant to extract it decreases.

WIRELESS SOIL MOISTURE MONITORING

Farmers have been measuring soil-water tension for decades through the use of gypsum blocks and other mechanical sensors. But these methods require individual calibration and are inaccurate when exposed to other environmental conditions, such as temperature changes or the presence of fertilizers, and require frequent re-installation.[121]

Wireless sensor monitors have been shown to provide more accurate data about the soil-water tension, and are longer-lasting, less labor intensive, and easier to deploy throughout thousands of acres of fields—previously impractical with wired

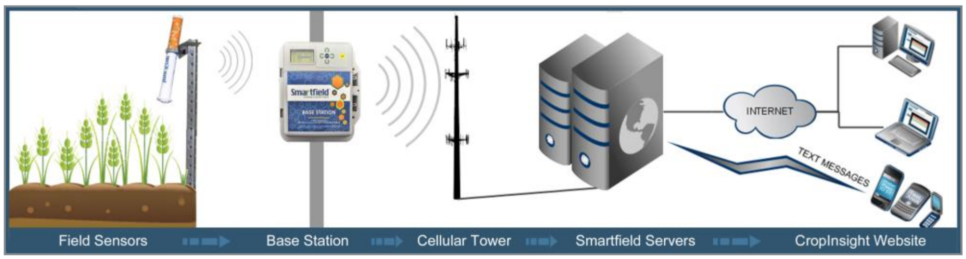

Figure 16: Graphic representation of soil moisture monitoring system. (Source: Smartfield, Inc.)

or mechanical sensors.[122] Wireless sensors can also be easily transported to other parts of the field depending on changing seasons or weather conditions, which would have been cost-prohibitive with wired sensors.[123]

Multiple sensors communicating with each other from the field to the farmer requires lots of complex technical coordination:

» Multiple smart wireless soil sensors are placed throughout a field to collect and transmit information about the soil as frequently as every ten seconds.

» The sensors send this information to a base station signal at the edge of the field via radio frequency (RF) signal.

» The base station communicates with a local cellular network, which then uploads information to servers. The data is accessible via the internet or the farmer's computer workstation.

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http://www.agclassroom.org/teen/ars_pdf/tech/2007/07wireless.pdf

120 The National Center for Appropriate Technology, "Water and Energy Conservation with the AM400 Soil Moisture Monitor," prepared for the Montana Dept. of Environmental Quality, June 2004, accessed September 27, 2011, http://www.ncat.org/pdf/FinalReport.pdf

121 Texas Water Development Board, "Agriculture Water Conservation Practices," 2001, http://www.twdb.state.tx.us/assistance/conservation/conservationpublications/agbrochure.pdf

122 *InformationWeek*, Chris Murphy, "Farmers Try Smart Tech to Save Water," Nov. 13, 2009, accessed September 27, 2011, http://www.informationweek.com/news/mobility/221601558?pgno=1

123 U.S. Dept. of Agriculture, ARS, Erin Peabody, "Wireless Watering: New Irrigation Technologies From ARS Can Help Conserve a Vital Resource," July 2007, accessed September 27, 2011, http://www.agclassroom.org/teen/ars_pdf/tech/2007/07wireless.pdf

With an internet connection, farmers can monitor real-time environmental conditions from any location. One company recently released a mobile application for Android phones that allows for real-time remote monitoring of field conditions, updated every 15 minutes. Irrigation scheduling can be performed remotely, as well as programming alarms to monitor occurrence of certain in-field conditions, such as unexpected draught or heavy rain. Alarms can then be updated throughout the growing season to reflect seasonal changes.

Other systems currently in development link the information obtained from the sensor networks in the field directly to the irrigation hardware. Special software has been designed to manage the M2M communications to enable automatic updating and adjustment of auto-irrigation systems based on real-time data coming directly from the field.[124]

ENVIRONMENTAL IMPACT OF SOIL MONITORING

Currently, the limited number of farmers adopting wireless sensing technology has made it difficult for researchers to measure the precise impact of soil sensing technology on water reduction. Nonetheless, a 2008 study on wireless soil sensor monitors showed that the use of field sensors reduced water use by 20 percent.[125] Another influential study by the Pacific Institute found that a combination of precision irrigation technologies, including wireless soil sensors, could reduce agricultural water consumption by 17 percent per year in California.[126] Other studies measuring the impact of precision irrigation systems using weather data integrated from automated weather stations and meteorological soil-monitoring data found water reductions ranging from 11 percent to 50 percent.[127]

If adopted by all farmers irrigating fields in the United States, wireless soil sensing technologies could reduce water use by as much as 18.2 million acre-feet of water, or 6 trillion gallons per year, assuming an average 20-percent reduction in water use.[128] While the research is probably not robust enough at this point to confirm these estimates, it at least provides a plausible directional figure of how much impact wireless sensors can have on the environment. Even a five percent reduction in water use—less than the results achieved in current research—translates to approximately 1.5 trillion gallons saved per year, which is still a significant impact.

Although water savings is the main environmental impact achieved by soil sensors, additional environmental benefits accrue as well. Wireless sensors can help detect the conditions under which disease or infestation is likely to occur,

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[124] U.S. Dept. of Agriculture, ARS, Erin Peabody, "Wireless Watering: New Irrigation Technologies From ARS Can Help Conserve a Vital Resource," July 2007, accessed September 27, 2011, http://www.agclassroom.org/teen/ars_pdf/tech/2007/07wireless.pdf; SmartField, Inc., "Products," accessed September 27, 2011, http://www.smartfield.com/smartfield-products; PureSense, Inc., "Product Spotlight: Droid App Available for PureSense Irrigation Manager," September 20, 2010, accessed September 27, 2011, http://growingproduce.com/news/?storyid=4355

[125] Gary Marks, "Precision Irrigation: A Method to Save Water and Energy While Increasing Crop Yield, A Targeted Approach for California Agriculture," March 2010, accessed September 27, 2011, http://www.irisconnectioninc.com/images/documents/2010%20Precision%20Irrigation.pdf

[126] Pacific Institute, Heather Cooley, et al, "Sustaining Agriculture in an Uncertain Future," July 2009, accessed September 27, 2011, http://www.pacinst.org/reports/california_agriculture/

[127] Gary Marks, "Precision Irrigation: A Method to Save Water and Energy While Increasing Crop Yield, A Targeted Approach for California Agriculture," March 2010, accessed September 27, 2011, http://www.irisconnectioninc.com/images/documents/2010%20Precision%20Irrigation.pdf

[128] BSR analysis based on 91.2 million acre-feet (about 30 trillion gallons) of water used for all irrigation in 2008. One acre-foot of water (the amount of water required to cover an acre with a depth of one foot) is approximately 325,853 gallons. Source: U.S. Dept. of Agriculture, National Agriculture Statistics Service, 2007 Census of Agriculture: 2008 Farm and Ranch Irrigation Survey, "Survey Highlights," accessed September 27, 2011, http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Fact_Sheets/fris.pdf

which directly affects crop output and land utilization rates.[129] This helps farmers plan better crop rotation and field allocation strategies. Well-managed land allocation and rotational use of fields helps prevent excessive soil compaction, erosion, and suboptimal salinity levels.[130] Soil monitoring also helps inform more resourceful fertilizer and pesticide management, which ultimately affects soil quality and the quality of crops.[131] Another advantage is that more accurate data can be collected over a longer period of time, which allows for more robust longitudinal data that could reveal more water and fertilizer reduction opportunities after five, ten, or even 20 years of monitoring.

MICROCLIMATE MONITORING

In addition to soil monitoring, wireless sensor networks can be used to monitor incremental changes in the environmental weather conditions around plants. Wireless sensors monitor for temperature, relative humidity levels, precipitation, leaf wetness, solar radiation, and wind speed. These sensors produce data that can help predict harmful weather-related events, including early frost warnings by alerting farmers when temperatures drop to dew point.[132] Other microclimate monitoring systems monitor rain levels and water flow levels to predict flooding.[133] When combined with historical data about the plants and fields, more robust predictive models can be created.[134]

Figure 17: Onset HOBO U30 Frost Alarm System
(Source: Onset)

Weather station supplier Onset has developed a web-based, wireless sensing system to monitor for frost with automated triggering of the irrigation system to prevent freezing. Onset's wireless monitoring station is equipped with temperature sensors and configured to activate autostart controllers on irrigation systems when frost conditions occur, and deactivate them once the conditions pass.

Controlling the autostart on the irrigation pumps gives them time to prime during frost conditions protecting them from damage. For example, the system can be configured to turn on irrigation when the temperature drops below 34 degrees Fahrenheit, and turn off irrigation at 39 degrees Fahrenheit. Notifications can also be sent to a grower's mobile phone to provide notification of when the irrigation system is turned on or off, so growers can know immediately when a frost event occurs.

Other wireless sensor systems provide data about weather conditions under which known diseases are more likely to occur. This means that farmers can deploy fertilizers more accurately and resourcefully to prevent the onset of disease. In one study of a potato field, researchers set up a wireless sensing network to monitor microclimates around the potatoes to help fight phytophthora, a fungal disease.[135] The disease is known to attack crops more frequently under certain climate conditions, including humidity levels, temperature, and wetness of

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[129] OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf.

[130] OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

[131] OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

[132] Cooper Industries, "Vineyard/Environmental Monitoring," Case Study, http://www.cooperindustries.com/content/public/en/bussmann/wireless/resources/library/industrial_applications/agriculture.html

[133] *Sensors*, Luis Ruiz-Garcia, et al, "A Review of Wireless Sensor Technologies and Applications in Agriculture and Food Industry: State of the Art and Current Trends," June 5, 2009, accessed September 27, 2011, http://www.mdpi.com/1424-8220/9/6/4728

[134] *Sensors*, Joao Valente, "An Air-Ground Wireless Sensor Network for Crop Monitoring," June 7, 2011, accessed September 27, 2011, http://www.mdpi.com/1424-8220/11/6/6088/pdf

[135] Delft University of Technology - The Netherlands, Aline Baggio, "Wireless Sensor Networks in Precision Agriculture," http://www.sics.se/realwsn05/papers/baggio05wireless.pdf

leaf. Monitoring these critical weather conditions reveals when the crop is at highest risk of attack, thus allowing farmers to treat the crops with fungicide only when absolutely needed.

CASE STUDY: WIRELESS WINE

The viticulture sector was one of the first adopters of wireless monitoring technology in agriculture settings. One of the first companies to provide the technology was Grape Networks. In 2004, Grape Networks began offering wireless climate monitoring systems to vineyards around the world. Wireless sensors embedded in fields monitor soil, moisture, temperature, humidity, luminosity, methane, and hydrogen sulfide. The data is sent over the internet and can be accessed anywhere at any time. Highlighting the unique benefits of wireless technology, the sensors are small enough to fit under plants, but powerful enough to transmit data across valleys, rivers, mountains, fields, and other geographic features that present barriers to wired sensing technology.

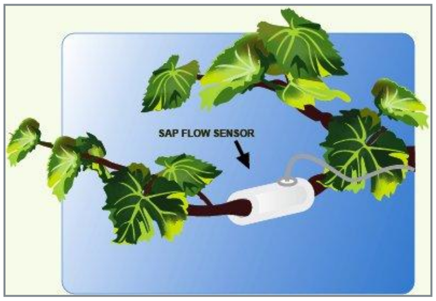

Figure 18: Real-time wireless sensors attached to vines send reading of the vine's transpiration rate, measuring how much water is moving through the vine and providing an indication of the vine's water needs.
(Source: Fruition Sciences, Inc.)

With proven results, wireless monitoring systems have been adopted throughout vineyards in California. At Hoot Owl Creek/Alexander Valley Vineyards in Sonoma County, growers installed wireless soil monitors across 300 acres to conduct weekly monitoring of soil conditions. The growers realized water savings of over 60 percent when compared to standard growing practices.[136] Victor Hugo Vineyards in Templeton, California, also adopted a wireless monitoring system, and realized water savings of approximately 50 percent to 60 percent.[137] With wireless sensors, "we may start sooner and irrigate more often, but we're not using as much water," explains Victor Hugo Roberts, owner of Victor Hugo Vineyards. "Instead of one long irrigation cycle during the week in the warmest part of the season, we might go with two lighter irrigation cycles, and still use less water."[138]

One study in the Russian River Valley in Sonoma County measured the impacts of wireless soil monitoring on water reduction, and estimated that between 12,524 acre-feet and 16,713 acre-feet of water could be saved per year across all vineyards in the valley.[139] Water savings also translates to cost savings for growers. The study estimated that energy savings could add up to as much as

[136] *Northbay Biz*, Barry Dugan "Water Into Wine," August 2010, accessed September 27, 2011, http://www.northbaybiz.com/General_Articles/General_Articles/Water_Into_Wine.php

[137] *Western Farm Press*, Brenda Carol, "Soil Moisture Monitoring Saves Water, improves Wine Grape Quality," August 29, 2008, accessed September 27, 2011, http://westernfarmpress.com/soil-moisture-monitoring-saves-water-improves-wine-grape-quality-0

[138] *Western Farm Press*, Brenda Carol, "Soil Moisture Monitoring Saves Water, improves Wine Grape Quality," Western Farm Press, August 29, 2008, accessed September 27, 2011, http://westernfarmpress.com/soil-moisture-monitoring-saves-water-improves-wine-grape-quality-0

[139] *Northbay Biz*, Barry Dugan "Water Into Wine," August 2010, accessed September 27, 2011, http://www.northbaybiz.com/General_Articles/General_Articles/Water_Into_Wine.php.

"The animals come and go, but the grasses, which directly or indirectly feed all the animals, abide, and the well-being of the farm depends more than anything else on the well-being of its grass."

– *Michael Pollan,* Omnivore's Dilemma

$1.8 million, and greenhouse gas emissions could be reduced by as much as 7,411 MT CO_2 per year throughout the valley.[140]

Whether monitoring the soil-water tension in a field of crops, or the amount of water moving through grapevines, wireless applications in precision agriculture are providing the information needed to adopt smarter and more sustainable farming techniques.

Wireless in Livestock Management

By any measure, the practice of raising livestock has had a devastating impact on the environment. Livestock-related emissions of CO_2 and methane account for 18 percent of world's total greenhouse gas emissions—more than all of the transport industry combined.[141] The agriculture industry produces 65 percent of human-induced nitrous oxide (which has 296 times the global warming potential of CO_2), and 37 percent of all human-induced methane (which has 25 times the warming potential of CO_2). Livestock production occupies 70 percent of all land used for agriculture, or 30 percent of the land surface of the planet.

Changes in the way that livestock are bred, raised, and managed are slowly contributing to incremental reductions in these environmental impacts. Wireless technology helps farmers gain access to better data about how healthy animals live, how changing their environments can help the environment, and how to monitor their impacts so as to develop even more innovative solutions.

This section features wireless applications in two areas of livestock management: herd and pasture management that helps improve rotational grazing practices; and methane tracking and reduction in cows. Although some of the technology is still in its experimental phase, other technology is on the cusp of widespread adoption within the next three to five years, and could generate significant positive environmental impacts.

HERD AND PASTURE MANAGEMENT

The environmental impacts of wireless animal tracking are not simply in knowing the location of the animal, but knowing when and where they've been eating their meals. Since the 1950s, research into pasture management has demonstrated that so-called "rotational grazing," in which cows are rotated through various sections of the pasture to prevent over- and under-grazing, helps keep the pastures healthy and diverse.[142] Overgrazing pastures means the grass stays too short, preventing it from sinking deep roots into the soil, creating a dry, brittle environment, and eventually leading to desertification and land erosion.[143] Excessive grazing also decreases the plant species variety, creating weedy fields that do not have dense root systems.[144]

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140 *Northbay Biz*, Barry Dugan "Water Into Wine," August 2010, accessed September 27, 2011, http://www.northbaybiz.com/General_Articles/General_Articles/Water_Into_Wine.php.

141 United Nations, Food and Agricultural Organization, "Livestock's Long Shadow," Rome, 2006, accessed September 27, 2011, http://www.fao.org/docrep/010/a0701e/a0701e00.HTM

142 U.S. Dept. of Agriculture, ARS, "Rangelands, Pasture, and Forages," National Program 205, Accomplishments Report (2001-2005), accessed September 27, 2011, http://www.ars.usda.gov/SP2UserFiles/Program/215/205Accomplishmentcombined920%5B1%5D.pdf; Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 190.

143 *Pervasive Computing*, Tim Wark, et al, "Transforming Agriculture through Pervasive Wireless Sensor Networks," April-June, 2007, http://eprints.qut.edu.au/33794/1/33794.pdf; Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 190.

144 Tyrchniewicz Consulting, "The Science of Greenhouse Gas Emissions and Grazing Management Strategies: An Investigative/Awareness Report," March 31, 2006, http://www.ipcs.on.ca/biodiversity/ghg/pdf/discussion_paper.pdf; U.S. Dept. of Agriculture, ARS, "Rangelands, Pasture, and Forages," National Program 205, Accomplishments Report (2001-

Under-grazing pastures is just as damaging, leading to excessive growth of weak and aging grasses, preventing growth of grasses that are healthier and favored by grazing cattle.[145] However, getting it right—"grazing the optimal number of cattle at the optimal moment to exploit the blaze of growth" in a pasture—creates a healthy mix of grasses to sustain the soil and keep animals at optimal health and productivity.[146]

Getting it right carries significant benefits for the environment as well. Well-managed pastures allow grasses to form deep root systems from a variety of grasses, which contributes to the CO_2 sequestration process (green pastures draw CO_2 out of the atmosphere and store it in the soil, where it increases soil fertility).[147] Well-managed pastures also increase forage utilization, improve manure distribution, and protect the soil surface from erosion, which improves ground and surface water quality.[148] Research shows that cattle grazing in well-managed pastures with high-quality forage reduces methane gas production by as much as 20 percent.[149] When multiplied across the 408 million acres of pastureland and 93 million cows in the United States, this creates opportunities for significant improvement of environmental impacts.[150]

HOW WIRELESS IMPROVES PASTURE MANAGEMENT

The two key challenges to achieving optimal pasture management through traditional rotational grazing are: knowing when to rotate the cows from one pasture to the next, and being able to actually move the cows to the new section of pastureland. The amount of time it take a certain paddock to recover depends on several variables, including temperature, rainfall, exposure to the sun, and time of year, as well as the requirements of the particular types of cows grazing in that section.[151] Currently, understanding this complicated mix of factors is largely based on the farmers' observations and nuanced historical knowledge.[152]

Wireless technology helps to overcome these barriers and provide more accurate and reliable data. Myriad applications using a variety of technologies are available, from GPS animal tracking and virtual fencing using local networks, to RFID animal health monitors.[153] This data can then be aggregated and carried on wireless networks to point of use, such as a farmer's computer or wireless smart

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2005), accessed September 27, 2011, http://www.ars.usda.gov/SP2UserFiles/Program/215/205Accomplishmentcombined920%5B1%5D.pdf.

145 Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 191.

146 Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 191.

147 Tyrchniewicz Consulting, "The Science of Greenhouse Gas Emissions and Grazing Management Strategies: An Investigative/Awareness Report," March 31, 2006, http://www.jpcs.on.ca/biodiversity/ghg/pdf/discussion_paper.pdf

148 U.S. Dept. of Agriculture, National Resources Conservation Service, "Plant Enhancement Activity PLT10: Intensive Management of Rotational Grazing Enhancement," May 2010, http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs143_007708.pdf

149 Tyrchniewicz Consulting, "The Science of Greenhouse Gas Emissions and Grazing Management Strategies: An Investigative/Awareness Report," March 31, 2006, http://www.jpcs.on.ca/biodiversity/ghg/pdf/discussion_paper.pdf

150 U.S. Dept. of Agriculture, Economic Research Service, Data Sets 2011, "State Fact Sheets: United States," accessed September 27, 2011, http://www.ers.usda.gov/statefacts/us.htm

151 Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, p. 191.

152 Michael Pollan, *Omnivore's Dilemma: A Natural History of Four Meals*, Penguin Press, 2006, pp. 190-91.

153 *Computers and Electronics in Agriculture*, 61, E.S. Nadimi, et al, "ZigBee-based wireless sensor networks for monitoring animal presence and pasture time in a strip of new grass," 2008, http://www.ing.unlp.edu.ar/electrotecnia/procesos/papers/Zavala.pdf

device. This data will allow farmers to create optimal conditions that could decrease the amount of energy used in built environments and the amount of energy required to nurse sick animals to health.[154]

Researchers have used wireless sensor networks and "smart collars" to track animals in smaller pastures, and have set up virtual fences that emit warning sounds and low-level stimuli when cows approach sensors buried in the ground.[155] Cattle quickly learn the boundaries of the virtual fences, allowing a farmer to easily change the placement of the fence when animals need to be rotated. These networks are also equipped with sensor nodes that monitor environmental conditions in the pasture, including temperature, soil moisture, and real-time imaging of the pasture, equipping farmers with real-time data about the state of the pasture in which the cows are currently grazing.

Equipped with real-time data about the location of grazing animals, the health of the pastures, and the health of the animals, farmers can more accurately rotate cows through pastures, and better plan development of new grazing areas to prevent under- and over-grazing and land erosion.[156] Healthier pastures mean greater reduction of greenhouse gas emissions, reduced methane gas produced from cattle, and ultimately healthier environments in which animals live.

METHANE GAS REDUCTION

In 2010, the U.S. dairy industry produced over 193 billion pounds of milk, with each cow contributing about 21,000 pounds.[157] The production process has several substantial impacts on the environment, the largest being methane gas production and emission.

Estimates place total methane gas emissions from livestock in the United States at 139 MT CO_2 equivalents per year.[158] Within the dairy value chain, methane from livestock is the largest contributor to greenhouse gases, followed by methane emissions from manure, and then emissions from fossil fuel consumption.[159]

Methane gas reduction has two positive impacts. First, it is a particularly harmful emission, about 25 times more powerful than the global warming potential of CO_2, so efforts focused on reducing methane gas can have significant effect on reducing overall greenhouse gas emissions. Second, methane gas can be captured and used as a renewable energy source that can be used to power farm operations.

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154 BSR conversations with DVM Systems, September 2011.

155 Commonwealth Scientific and Industrial Research Organisation (CSIRO), ICT Centre, "Sensor Networks in Agriculture," accessed September 27, 2011, http://research.ict.csiro.au/research/labs/autonomous-systems/sensor-networks/agriculture

156 OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

157 Innovation Center for U.S. Dairy, J.R. Knapp, et al, "Cow of the Future Research Priorities for Mitigating Enteric Methane Emissions from Dairy," Working Draft, July 2011, http://www.usdairy.com/Sustainability/Documents/Cow%20of%20the%20Future%20Research%20Priorities%20White%20Paper.pdf

158 Innovation Center for U.S. Dairy, J.R. Knapp, et al, "Cow of the Future Research Priorities for Mitigating Enteric Methane Emissions from Dairy," Working Draft, July 2011, http://www.usdairy.com/Sustainability/Documents/Cow%20of%20the%20Future%20Research%20Priorities%20White%20Paper.pdf

159 Innovation Center for U.S. Dairy, J.R. Knapp, et al, "Cow of the Future Research Priorities for Mitigating Enteric Methane Emissions from Dairy," Working Draft, July 2011, http://www.usdairy.com/Sustainability/Documents/Cow%20of%20the%20Future%20Research%20Priorities%20White%20Paper.pdf

Wireless Opportunities to Reduce Environmental Impacts: Food Production

Matching Supply and Demand: Wireless monitoring of crops may enable farmers to know the ideal harvest time, thus reducing waste through spoilage.

Using Less: Wireless sensor networks enable efficient application of fertilizers, pesticides, and water, reducing overall use and resulting environmental impacts.

Shifting Behaviors: Using wireless monitoring to understand how animal behavior is associated with methane production enables farmers to adjust their practices accordingly.

Given the dual benefits of capturing and reducing methane gas, policy makers have begun expanding efforts to reduce methane emissions. Former President Bill Clinton recently stressed the need and relative cost-benefit to focusing on methane gas reduction.[160] One key barrier to methane reduction has been a lack of financing. "The financing has not been available for these things because they have been looked at as eyesores, not goldmines," Clinton said.

In order to make advances in reducing methane emissions from livestock, the gases need to be measured and captured—two areas in which wireless technology can help. Wireless sensors can collect data about methane production and release in real-time environments what was previously unobtainable, leading to smarter and more effective methods to reduce methane gas before it is created.

Currently, methane gas emissions are measured through respiration chambers that capture cattle breath air, or by using a sulfur hexafluoride tracer gas technique. However, the respiration chamber is expensive, labor-intensive, and cannot be deployed at scale. The tracer gas method monitors methane levels while cattle are roaming freely but has wide variance in its results.[161]

However, researchers are currently experimenting with a wireless sensor that can be placed into the rumen of animals (the second stomach that allows cows to digest grasses and produces methane) to monitor methane gas production. These wireless sensors may be able to provide continuous monitoring within the stomach environment with low labor input, accurate data, and under real-time grazing conditions.[162] Preliminary research has shown that more methane gas may be produced at different times of the day depending on feeding schedules. Specifically, the wireless sensors were able to demonstrate that the level of methane gas in rumen fluid dropped to its lowest point 30 minutes before feedings, and steadily increased to reach a highest point 1.5 hours after feeding. The implication is that treatments to reduce methane gas in cattle may be more effectively and accurately deployed depending on when animal feeding occurs.[163]

Looking Ahead

Wireless applications are on the cusp of achieving widespread adoption in both the plant and animal worlds of agriculture. While it may seem daunting to think about wireless devices monitoring so much of the food that nourishes us, the trend to deploy wireless networks to help us understand the natural world is likely to increase.

Cisco Systems is in the process of developing the "Planetary Skin," which consists of various wireless sensor networks spread throughout the world to act as "skin" sensors for the planet. In development are "skins" covering myriad aspects of the natural world—land skin, water skin, energy skin, and an agri-food skin. As Cisco describes it, "Agri-Food Skin will support improvements in areas of

160 *Bloomberg*, Alexander Ragir and Joao Oliveira, "Clinton Sees 'Goldmine' in Capturing Methane to Fix Climate," June 1, 2011, http://www.businessweek.com/news/2011-06-01/clinton-sees-goldmine-in-capturing-methane-to-fix-climate.html

161 Innovation Center for U.S. Dairy, J.R. Knapp, et al, "Cow of the Future Research Priorities for Mitigating Enteric Methane Emissions from Dairy," Working Draft, July 2011, http://www.usdairy.com/Sustainability/Documents/Cow%20of%20the%20Future%20Research%20Priorities%20White%20Paper.pdf

162 Innovation Center for U.S. Dairy, J.R. Knapp, et al, "Cow of the Future Research Priorities for Mitigating Enteric Methane Emissions from Dairy," Working Draft, July 2011, http://www.usdairy.com/Sustainability/Documents/Cow%20of%20the%20Future%20Research%20Priorities%20White%20Paper.pdf

163 *New Zealand Dairy Exporter*, "Study Offers Hope of Methane Control," http://www.dairyexporter.co.nz/article/35107.html

agricultural productivity, agricultural risk management, and famine prevention by piloting new uses for remote sensing and participatory sensor networks." These include weather monitoring networks that will provide the basis for agricultural risk management insurance for small farmers around the world, and a "virtual agricultural extension service" to support operational decisions of small farmers.[164]

[164] Planetary Skin Institute, accessed September 27, 2011, http://www.planetaryskin.org/home

Providing Public Services

Section Overview

WIRELESS GOVERNMENT APPLICATIONS: POTENTIAL IMPACTS
Smart Traffic Applications could reduce CO_2 emissions by 20 percent
Smart Bus and Parking applications could remove 1.2 million MT CO_2 per year
Wireless enhances environmental monitoring and citizen/government exchange

Introduction: Improving Public Services through Wireless

A typical Friday night in San Francisco…and every parking spot in the city seems to be taken. Hundreds of anxious drivers circle the neighborhoods, trying to reach popular destinations, clogging the narrow roads. In reality, about 30 percent of these drivers are not going anywhere at all—they're looking for parking, but there's no space to be found. (At least that what's they think.)

This familiar scene, frequent throughout most U.S. cities, could be chalked-up as a frustrating part of modern urban life. It is also a particularly wasteful one. Americans consume about 19 million gallons of gas per year—spending $68.4 million—simply looking for places to park.

Urban drivers will be both disappointed and encouraged to learn that the problem is not a lack of parking spaces, after all. The problem is a lack of knowledge about where the available parking spaces are when they are needed. The current solution of driving around to look for them is inefficient, expensive, and environmentally harmful.

Now, cities can use wireless technology to find better solutions. Cities can install wireless sensor systems to identify and map open parking spaces to provide mobile information that helps drivers find a free spot. Such systems can decrease congestion, reduce CO_2 emissions, save money for drivers, and improve citizens' daily lives.

From a parking space in San Francisco to a remote monitoring buoy bobbing in the Chesapeake Bay, government plays a variety of roles in the United States. Public Sector programs generate and influence an incalculable effect on the environment—sometimes positive, sometimes negative. Government activities manage cities, burn fossil fuels, tend natural resources and habitats, use and manage water supplies, and carry out myriad other activities with direct environmental impacts.

These activities also frequently intersect with activities previously discussed in this report—from managing public sector vehicle fleets to regulating utilities and providing important weather information to farmers. Consequently, wireless technology is well positioned to help improve the environmental impact of public services. It does this both by helping government activities run more sustainably themselves, as well as by providing tools to better drive sustainability in society.

Ultimately, these advances improve the daily lives of citizens and the sustainability of society in several areas. First, government can use wireless technology to better coordinate and operate urban transportation systems to decrease environmental harms. Second, wireless can help the government monitor environmental conditions and hazards to improve environmental knowledge, management, and protection. Third, through increased citizen engagement and communication, government can better detect, respond to, and inform the public about environmental hazards. In these areas, the data gathered and communicated across wireless connections help foster sustainability by increasing the efficiency of government and citizen activities, enabling better allocation of resources, and detecting outliers—from unexpected traffic jams to spikes in pollution levels.

Wireless and Urban Transportation Systems

In a recent survey conducted by Siemens in 25 of the world's largest cities, traffic management issues were considered the most pressing infrastructure problem.[165] This issue is only compounded by estimates that one-third of the world's population is expected to migrate to urban areas by 2030, and once they arrive they will likely be moving around extensively, in private vehicles or through public transportation systems.[166] Individual vehicle ownership in the United States has increased 156 percent since 1950, from approximately 323 vehicles owned per 1,000 people to 828 in 2010.[167] People are also driving their cars more: between 1982 and 2007, vehicle miles traveled per person increased by 47 percent from an average of 6,800 miles per year to almost 10,000.[168]

This means that more people will be on the roads, causing more congestion and competition for more scarce resources—from traffic lanes to parking spaces. Indeed, U.S. drivers wasted 4.2 billion hours, 2.8 billion gallons of fuel, and $87.2 billion due to traffic congestion in 2007.[169]

Wireless technology is poised to help alleviate traffic congestion problems, improve public transportation on buses, and reduce the amount time spent looking for parking spaces. These technologies will make urban transportation systems run more efficiently and effectively, leading to significant reductions in CO_2 emissions as well as other air pollution, and improving the sustainability of citizens' daily lives.

SMART TRAFFIC MANAGEMENT SYSTEMS KEEP CITIES RUNNING EFFICIENTLY

Wireless traffic management systems enable real-time monitoring and wireless control of traffic systems to help reduce congestion and improve traffic flow. Two of the most common traffic management systems are adaptive signal-control systems, and wireless sensor networks embedded beneath roads to help monitor traffic flow.

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165 Siemens, "Intelligent Traffic Solutions," accessed September 26, 2011, http://www.siemens.com/sustainability/en/environmental-portfolio/products-solutions/mobility/intelligent-traffic-management.htm

166 Siemens, "Intelligent Traffic Solutions," accessed September 26, 2011, http://www.siemens.com/sustainability/en/environmental-portfolio/products-solutions/mobility/intelligent-traffic-management.htm

167 U.S. Department of Energy, *Transportation Energy Data Book*, 30th Ed., (June 2011), Table 3.5, http://cta.ornl.gov/data/tedb30/Edition30_Chapter05.pdf

168 U.S. Department of Transportation, Federal Highway Administration (FHWA), "Traffic Volume Trends," August 2007, http://www.fhwa.dot.gov/ohim/tvtw/07augtvt/index.htm

169 IBM, "The Case for Smarter Transportation," September 2010, http://www-07.ibm.com/innovation/my/exhibit/documents/pdf/2_The_Case_For_Smarter_Transportation.pdf

Adaptive traffic management systems enable traffic managers to actively manage, coordinate, and optimize traffic signals using wireless sensor technology that monitors congestion and unexpected traffic events. This improves the flow of traffic, leading to lower fuel waste and lower CO_2 emissions.[170] Intelligent switches and controllers communicate with traffic management control centers to allow managers to update traffic signals in real-time based on real road conditions using wireless sensors in the roads on traffic lights.[171]

Adaptive signal control systems tested in cities in California, Florida, Delaware, Michigan, and Minnesota have shown reduced driver delays between 19 percent and 44 percent.[172] Other studies have shown that intelligent traffic management systems could reduce fuel consumption by as much as 20 percent, and reduce nitrogen oxide and CO_2 emissions by up to 50 percent and 33 percent, respectively.[173]

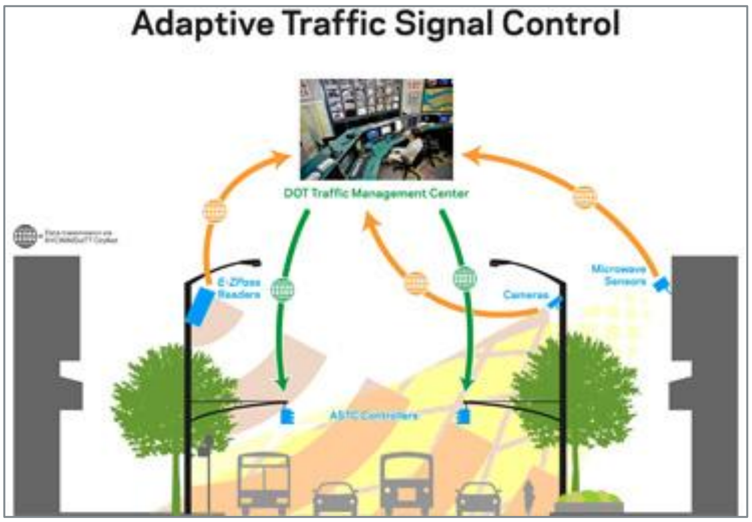

Figure 19: Intelligent Traffic Management system in New York City utilizes wireless technology to relieve congestion and route traffic around unexpected events in real time. (Source: New York City Department of Transportation)

In July 2011, New York City Mayor Michael Bloomberg announced that New York would be adopting an intelligent traffic management system to monitor and improve traffic flow in Manhattan.[174] The proposed system will deploy wireless sensors, video cameras, and other traffic management technology to reduce

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[170] Tropos Networks, "Building Communications for Intelligent Transportation Systems," June 2009, http://www.tropos.com/pdf/whitepapers/ITS-WP-061809.pdf

[171] Motorola, Inc., "Keep Traffic Moving with High-Speed Wireless Connectivity," http://www.motorola.com/web/Business/_Documents/Specifications/Static%20Flies/WNS_Transportation-Traffic%20Monitoring_Data%20Sheet_Web%20Version.pdf

[172] Tropos Networks, "Building Communications for Intelligent Transportation Systems," June 2009, http://www.tropos.com/pdf/whitepapers/ITS-WP-061809.pdf

[173] Siemens, "Intelligent Traffic Solutions," accessed September 26, 2011, http://www.siemens.com/sustainability/en/environmental-portfolio/products-solutions/mobility/intelligent-traffic-management.htm

[174] The City of New York press release, "Mayor Bloomberg Announces New, Real-Time Traffic Management System to Reduce Congestion in Midtown Manhattan," July 18, 2011, http://www.nyc.gov/html/om/html/2011b/pr257-11.html

congestion and improve traffic flow. The state-of-the-art technology will allow traffic engineers to identify congestion choke points in real-time, and wirelessly control traffic signals at intersections to adjust traffic patterns and clear traffic jams. The total cost for installation of the system was approximately $1.6 million.[175]

The real-time data is transmitted over the New York City Wireless Network (NYCWiN), a proprietary broadband cellular network managed by the Department of Information and Technology and Telecommunications. Real-time traffic information will be available to motorists and app developers for use on mobile phones and PDAs.

Several other intelligent traffic management systems also incorporate wireless video feeds, empowering managers to see unexpected traffic conditions in real-time.[176] A traffic controller, for instance, may use traffic signaling to re-route traffic around the scene of an accident, an unexpected influx of traffic, or planned events, such as the end of a sporting event when thousands of drivers will suddenly flood the roadways. Dynamic traffic signaling systems can also be used by emergency responders to help control traffic lights when emergency vehicles are approaching.[177]

Cities are also using wireless sensors embedded in roads to help monitor the intensity and fluidity of traffic patterns, and then automatically communicate with traffic lights to adjust flow rates during peak usage.[178] Embedded road sensors can also send real-time data to road signs, alerting drivers to hazardous conditions, and suggest alternative routes to help alleviate congestion.

Embedded road sensors can monitor the condition of the roads and provide more accurate data for predictive road maintenance. This data can provide more accurate planning data to state and federal transportation bureaus to better allocate funding for maintenance and repairs in areas that need it most.

SMART BUS SYSTEMS REDUCE IDLING AND DELAYS

As more people around the world move to urban areas, demand for public transportation will increase. Public transportation ultimately reduces our individual carbon footprints, but it is still one of the largest polluters in urban traffic areas. While buses comprise only 5 percent of vehicles on the road, they emit about 20 percent of the nitrogen oxide in the air, and can be a significant source of other pollutants.[179]

This problem is exacerbated when buses needlessly idle their engines during routine traffic stops, maintenance stops, or turnarounds, pumping more pollutants into the air without actually going anywhere. Buses must make several stops to

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175 The City of New York press release, "Mayor Bloomberg Announces New, Real-Time Traffic Management System to Reduce Congestion in Midtown Manhattan," July 18, 2011, http://www.nyc.gov/html/om/html/2011b/pr257-11.html

176 Motorola, Inc., "Keep Traffic Moving with High-Speed Wireless Connectivity," accessed on September 27, 20011, http://www.motorola.com/web/Business/_Documents/Specifications/Static%20Flies/WNS_Transportation-Traffic%20Monitoring_Data%20Sheet_Web%20Version.pdf

177 Motorola, Inc., "Keep Traffic Moving with High-Speed Wireless Connectivity," accessed on September 27, 20011, http://www.motorola.com/web/Business/_Documents/Specifications/Static%20Flies/WNS_Transportation-Traffic%20Monitoring_Data%20Sheet_Web%20Version.pdf.

178 OECD, Verena Weber, "Smart Sensor Networks: Technologies and Applications for Green Growth," October 2009, http://www.oecd.org/dataoecd/39/62/44379113.pdf

179 Emily Ziring, "Impacts of Idling Reduction Devices on Transit Buses: A Preliminary Analysis," Master's Thesis, Urban Planning and Policy, University of Illinois at Chicago, May 31, 2008, http://www.transportchicago.org/uploads/5/7/2/0/5720074/betterbus-ziring.pdf

load and unload passengers throughout a route, but research shows that they spend approximately 4 hours per week on stops that unnecessarily idle their engines, including stops at traffic lights.[180] Multiplied throughout the United States, this adds up to 252,000 hours of idling per week, the equivalent of about 13.1 million gallons of fuel per year and 129,727 MT CO_2 emissions.[181]

To combat this problem, several cities have adopted Transit Signal Priority (TSP) systems using wireless technology to keep buses moving during their routes and prevent unnecessary idling. Wireless sensors are mounted on buses and traffic lights so that the traffic lights can automatically detect approaching buses and adjust signal lights, allowing buses to pass through intersections without stopping.[182] By providing buses with “priority” access to green signals, TSP systems improve the scheduling and speed of routes, and prevent buses from making needless stops at traffic lights while idling their engines.

The environmental benefits of TSP systems have been shown to reduce fuel consumption by 19 percent.[183] This translates to potential fuel savings of approximately 128 million gallons of fuel per year (about $486 million in fuel costs), and a savings of 1.2 million MT CO_2 emissions per year.[184] Besides reducing idling time, staying in motion reduces the amount of time required to accelerate from a stop, which is a significant source of fuel burn.[185]

In addition to the environmental impacts, buses in TSP systems attract more riders because they are able to adhere closer to their schedule. TSP systems in 13 cities have showed a 1.5 percent to 15 percent improvement in bus travel time.[186] Transit signal priority implemented as part of the Metro Rapid BRT service in Los Angeles yielded travel time improvements of 7.5 percent.[187] In Chicago, buses realized an average of 15 percent reduction in running time.

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[180] Emily Ziring, “Impacts of Idling Reduction Devices on Transit Buses: A Preliminary Analysis,” Master's Thesis, Urban Planning and Policy, University of Illinois at Chicago, May 31, 2008, http://www.transportchicago.org/uploads/5/7/2/0/5720074/betterbus-ziring.pdf.

[181] Based on input of 64,832 public transportation buses in the United States (Source: American Transportation Association, *Public Transportation Fact Book*, 62nd Ed., April 2011, Table 9, http://www.apta.com/resources/statistics/Documents/FactBook/APTA_2011_Fact_Book.pdf), and estimated 1 gallon of fuel consumed per hour of idling (Source: Emily Ziring, "Impacts of Idling Reduction Devices on Transit Buses: A Preliminary Analysis," Master's Thesis, Urban Planning and Policy, University of Illinois at Chicago, May 31, 2008, http://www.transportchicago.org/uploads/5/7/2/0/5720074/betterbus-ziring.pdf).

[182] U.S. Department of Transportation, Research and Innovation Technology Administration, “Investment Opportunities for Managing Transportation Performance through Technology,” January 16, 2009, http://www.its.dot.gov/press/2009/transportation_tech.htm; Tropos Networks, “Building Communications for Intelligent Transportation Systems,” June 2009, http://www.tropos.com/pdf/whitepapers/ITS-WP-061809.pdf.

[183] U.S. Department of Transportation, Research and Innovation Technology Administration, “Investment Opportunities for Managing Transportation Performance through Technology,” January 16, 2009, http://www.its.dot.gov/press/2009/transportation_tech.htm

[184] Based on inputs of 19 percent savings in fuel consumption from total of 674 million gallons of fuel consumed by public buses in 2009. (Source: American Transportation Association, *Public Transportation Fact Book*, 62nd Ed., April 2011, Table 9, http://www.apta.com/resources/statistics/Documents/FactBook/APTA_2011_Fact_Book.pdf). Carbon reduction figures calculated using U.S. Environmental Protection Agency Greenhouse Gas Equivalencies Calculator, at http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results.

[185] Matthew Bernath, Jonathan Counihan, and Rex Van Olst, “An Intelligent Transport System For Controlling Traffic Lights on Bus-Rapid-Transit (BRT) Routes in Johannesburg,” http://www.gtkp.com/assets/uploads/20091129-180315-7664-Bernath.pdf

[186] U.S. Department of Transportation, Research and Innovation Technology Administration, “Investment Opportunities for Managing Transportation Performance through Technology,” January 16, 2009, http://www.its.dot.gov/press/2009/transportation_tech.htm

[187] U.S. Department of Transportation, Research and Innovation Technology Administration, “Investment Opportunities for Managing Transportation Performance through Technology,” January 16, 2009, http://www.its.dot.gov/press/2009/transportation_tech.htm

Furthermore, cities have found that when buses run on time, they can reduce the total number of buses in the fleet, leading to fewer emissions of harmful toxins. Portland, Oregon, for example, avoided adding one bus to its transit system by adopting a TSP system and generating a 10 percent improvement in travel time.[188] If the 50 largest U.S. cities removed one bus for every 500,000 people (approximately the population of Portland), that would reduce greenhouse gas emissions by an additional 936 MT CO_2 per year.[189]

The cost of installing a TPS system will vary by city based on the city size and the type of existing infrastructure. Key costs are in upgrading or replacing traffic signal software and controllers, which can range from $5,000 to $20,000 per intersection. The Los Angeles County Metropolitan Transportation Authority feasibility project was deployed at approximately 211 intersections and cost $4.2 million.[190]

SMART PARKING SYSTEMS CUT DOWN ON UNNECESSARY DRIVING

Road congestion is a significant problem in urban transportation systems. The problem is magnified by motorists who, ironically, have already arrived at their destinations and are merely looking for spaces to park their cars. This may not seem like a large problem, but research from the UCLA, Department of Urban Planning showed that almost 30 percent of the vehicles on the road in a business district in Los Angeles were looking for parking spaces.[191]

Over a year, this adds up to 950,000 vehicle miles travelled, equivalent to 38 trips around the earth, wasting 95,000 hours of drivers' time, 47,000 gallons of fuel, and emitting 418 MT CO_2 per year. If multiplied throughout U.S. urban centers, the impact jumps to 117,650 MT CO_2 per year.[192]

Wireless sensing networks have been developed to "dust" a city's parking spaces with wireless sensors providing real-time updates about available parking spaces to drivers. The sensors are either buried in the ground or attached above pavement near each parking space on the street and transmit data whenever a vehicle arrives and exits the parking space.

Several of the current systems rely on ZigBee-based wireless networks to collect the initial data consisting of arrivals and departures from parking spaces, then link to traditional wireless infrastructure to deliver real-time information to drivers

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188 Tropos Networks, "Building Communications for Intelligent Transportation Systems," June 2009, http://www.tropos.com/pdf/whitepapers/ITS-WP-061809.pdf

189 Findings based on the average number of gallons of fuel consumed by buses per year (1,300) (Source: U.S. Department of Transportation, Research and Innovation Technology Administration, "Table 4-15: Bus Fuel Consumption and Travel," *National Transportation Statistics*, July 2010, http://www.bts.gov/publications/national_transportation_statistics/html/table_04_15.html); 13 CO_2 per year, assuming CO_2 emissions from a gallon of diesel is 22 pounds/gallon; assumed reduction of 72 buses per year based on U.S. population data.

190 U.S. Department of Transportation, Research and Innovation Technology Administration, "Investment Opportunities for Managing Transportation Performance through Technology," January 16, 2009, http://www.its.dot.gov/press/2009/transportation_tech.htm

191 *Access*, Donald Shoup, "Cruising for Parking," No. 30, Spring 2007, http://www.uctc.net/access/30/Access%2030%20-%2004%20-%20Crusing%20for%20Parking.pdf

192 Methodology: Assume 1 "equivalent district" (as measured in the Shoup study) per 100,000 people in cities with a population of >400,000. The "equivalent district" calculation is based on the pilot study in San Francisco, which set up 7 wireless parking areas in a city with approximately 800,000 residents. This resulted in 425 equivalent districts in the United States. This methodology likely represents a conservative estimate. (Population data source: Infoplease, "Top 50 Cities in the U.S. by Population and Rank," accessed September 26, 2010, http://www.infoplease.com/ipa/A0763098.html)

via mobile handsets. Drivers spend less time circling neighborhoods looking for parking spaces, reduce wasted fuel and CO_2 emissions, and, perhaps most importantly, lower driver anxiety and cholesterol levels. One secondary effect is that by reducing congestion and smoothing the flow of traffic, idling time in other vehicles is also reduced.[193]

CASE STUDY: SMART PARKING IN SAN FRANCISCO

In 2010, San Francisco launched a pilot program to deploy wireless parking sensors in seven of the most high-trafficked areas in the city. The wireless sensors are developed by Streetline, a small company that pioneered the technology at the University of California at Berkeley. The wireless sensors are embedded in white plastic casings that have been attached with industrial-strength glue to the pavement near parking spaces. The devices are intended to last five to 10 years without services, and form a wireless mesh network known as “smart dust” throughout the city.

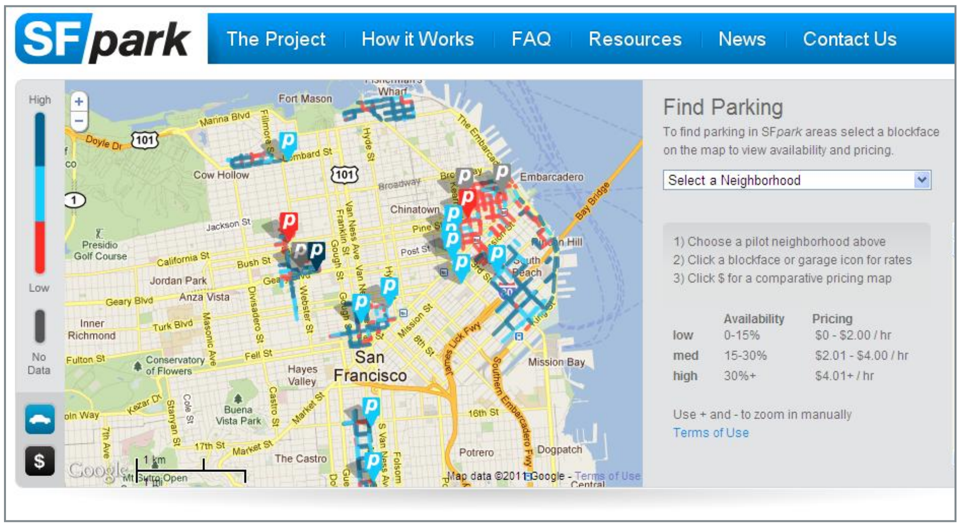

Figure 20: San Francisco drivers can now access real-time information about available parking spaces through a wireless sensor network deployed throughout the city. (Source: www.SFPark.com)

The sensors transmit information about when cars leave and occupy spaces, sending real-time data about when spaces are free. This data is transmitted to a central server that compiles the information and sends it to mobile phones and a centralized website (http://sfpark.org) for users to receive real-time updates about the number of available spaces along the street. The parking map color-codes the streets based on parking availability, and provides an estimate of how many spaces are currently available, so that drivers can avoid circling neighborhoods in search of parking.

The pilot program is scheduled to last through the summer of 2012, and will be ready for city-wide rollout shortly thereafter.

Environmental Monitoring with Wireless

A spike in a city’s air pollution levels, an emissions release from a landfill, chemical dumping in a critical fishery—all are examples of environmental conditions that the government monitors. In its role protecting public safety and

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[193] Libelium, Alicia Asín and David Gascón, “Smart Parking Sensor Platform Enables City Motorists [to] Save Time and Fuel,” May 27, 2011, http://www.libelium.com/smart_parking

health, government tracks many elements that affect environmental and personal health.

Wireless technology is helping government agencies to build networks of devices that detect and transmit crucial information to monitor environmental conditions. These systems may involve several wireless standards working in concert, including satellite technology, radio frequencies, and cellular transmissions. Even in cases where these systems primarily rely on non-cellular spectrum, however, cellular transmission is often a key component in obtaining information and enabling quick response.

These systems help governments understand the environment and more efficiently and effectively manage its health, protect it, and look after the citizens and economies it affects. Such efforts are evident in disaster detection and response monitoring, pollution monitoring, and ecosystem monitoring.

WIRELESS FACILITATES URBAN POLLUTION MONITORING

Real-time wireless air pollution monitoring is a powerful way to assess environmental conditions to better inform environmental management and healthcare decisions. Traditionally it can be difficult to gather useful pollution data, especially because many older systems only provide data with a time delay.[194] New systems that utilize wireless technology help scientists to better understand what conditions in a given municipality cause harmful pollution levels. Day-to-day monitoring allows scientists to "see how pollutants interact with each other and how they relate to factors like traffic levels or industrial activity." Ultimately, this helps scientists predict which mixes of conditions and meteorology will lead to spikes in pollution.[195]

For example, Libelium is a company that designs and builds technology to create wireless sensor systems, including devices for urban pollution monitoring. Libelium sensors can monitor for environmentally deleterious particulate matter (dust) and gasses (e.g. nitrogen dioxide, CO_2, and methane), among other elements. Combined with location and time data, Libelium monitors can be used to help paint a picture of urban pollution patterns. The systems can use a range of wireless standards, including GPRS, ZigBee, Wifi, and Bluetooth, and can be solar-powered. As a result, the wireless sensors are able to capture and transmit critical data on harmful urban environment factors.[196]

194 *International Journal of Wireless and Mobile Networks*, Vol. 2, No. 2, Kavi K. Khedo, Rajiv Perseedoss, and Avinash Mungur, "A Wireless Sensor Network Air Pollution Monitoring System," May 2010, accessed September 27, 2011, http://arxiv.org/ftp/arxiv/papers/1005/1005.1737.pdf

195 *International Journal of Wireless and Mobile Networks*, Vol. 2, No. 2, Kavi K. Khedo, Rajiv Perseedoss, and Avinash Mungur, "A Wireless Sensor Network Air Pollution Monitoring System," May 2010, accessed September 27, 2011, http://arxiv.org/ftp/arxiv/papers/1005/1005.1737.pdf

196 Libelium, Alicia Asín, "Smart Cities Platform From Libelium Allows System Integrators to Monitor Noise, Pollution, Structural Health and Waste Management," June 20, 2011, accessed September 26, 2011, http://www.libelium.com/smart_cities; Libelium, "Environment," accessed September 26, 2011, http://www.libelium.com/applications/Environment; Libelium, "Models," accessed September 26, 2011, http://www.libelium.com/products/meshlium/models; Alicia Asín, "Sensor networks to monitor air pollution in cities," accessed September 26, 2011, http://www.libelium.com/smart_cities_wsn_air_pollution.

Figure 21: Libelium's Smart Cities platform includes wireless pollution monitoring sensors (Source: Libelium)

Armed with valuable pollution information, scientists and officials can marshal appropriate responses to reduce urban pollution and mitigate its effects on people and the environment. Those efforts might include short-term programs like incentives to change commuting patterns, or long-term policy solutions to minimize pollution. Having real data also helps the public to better understand pollution issues to raise awareness and spur action. Furthermore, this pollution monitoring allows governments to provide information to citizens who are at a high risk of pollution-induced health issues.

Another area in which cities can use wireless monitoring to track environmental hazards is at landfills. By placing wireless sensors around a landfill, operators can get real-time alerts about operational issues, for example pressure readings and flare temperatures. One such system was installed at a landfill operated by DeKalb County, Georgia's sanitation department. The system enabled better monitoring, quicker responses, and improved environmental management, all while lowering manpower costs by obviating the need for round-the-clock on-site personnel. In describing the positive sustainability outcomes, system developer Weston Solutions noted benefits in "reducing the potential for surface emissions releases, off-site migration of methane, and groundwater contamination. Using the remote wireless monitoring system drastically reduces the flare station's operation and maintenance costs, while increasing environmental regulatory compliance."[197] This approach further illustrates how municipalities can use wireless technology to monitor environmental conditions.

ECOSYSTEM MONITORING INFORMS ENVIRONMENTAL UNDERSTANDING AND PROTECTION

Wireless technology is also useful in ecosystem and habitat monitoring to understand environmental health. In government efforts to ensure the stability, sustainability, and health of society, it is sometimes critical to monitor environmental conditions. Wireless networks can gather a wealth of information

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[197] Weston Solutions, Inc., "Wireless Remote Monitoring System Improves Landfill Operations," accessed September 26, 2011, http://www.westonsolutions.com/pdf_docs/PP-63-SeminoleRoad-GA.pdf

on everything from soil moisture to water quality in order to detect issues and understand patterns of ecosystem change.

A U.S. EPA-funded Baylor University program that uses wireless remote monitors to track water quality and ecosystem health in the Lake Waco Wetlands,[198] and a National Oceanic and Atmospheric Association remote monitoring system for the Chesapeake Bay (see case study) are just two examples of this. In another case in Australia, a wireless monitoring system for the Great Barrier Reef was significantly less expensive than the old system of in-person field research and took less time to set up while enabling the collection of real-time data.[199]

In addition to habitat monitoring, wireless technology can be used for wildlife protection and preservation. Wildlife officials can establish "geofences"—virtual perimeters around natural habitats.[200] By deploying GPS-enabled collars and tags on fauna, officials can receive SMS alerts whenever wildlife cross particular boundaries. These programs help protect wildlife by keeping them out of farmers' crops or urban areas, tracking movement patterns, and increasing awareness of other threats. Such a system is used by the Kenya Wildlife Service to protect elephants, and could also be used in the United States to monitor select species.[201] By better monitoring wildlife and interactions with humans, officials can work to protect animals and their ecosystems.

CASE STUDY: CHESAPEAKE BAY INTERPRETIVE BUOY SYSTEM
The Chesapeake Bay is many things—a beautiful body of water, a natural habitat, a tourism and recreation center, an economic engine, and a fragile ecosystem. To improve monitoring of environmental conditions, the U.S. Department of Commerce's National Oceanic and Atmospheric Association launched the Chesapeake Bay Interpretive Buoy (CBIBS) system in 2007. The program uses ten wireless-enabled, solar-powered "smart buoys" to provide real-time monitoring of weather, water quality, and water conditions throughout the bay (Figure 22). Transmitted over a wireless network, the data can be read by anyone who visits the CBIBS website or uses its mobile Android and iPhone apps.

CBIBS is designed to help a variety of groups. "Scientists," the program notes, "use data to further protect, restore, and manage the Chesapeake Bay." Education is also a major focus of the program, and NOAA advocates for the program as a powerful environmental education tool for students and teachers. Boaters might also use the system to understand environmental and weather conditions in the Bay.[202]

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198 Onset Computer Corporation, "Baylor University Studies Wetlands Water Level With Remote Weather Station," accessed September 26, 2011, http://www.onsetcomp.com/solutions/case-study/wetlands

199 Telstra, "Australian Institute of Marine Sciences,"accessed September 26, 2011, http://www.telstraenterprise.com/SiteCollectionDocuments/Case%20Studies/PDF/AIMS_FINAL.pdf

200 Lotek Wireless Inc., "Small WildCell," accessed September 26, 2011, http://www.lotek.com/small-wildcell.htm

201 CBS News, "Kenya Uses Text Messages to Track Elephant," February 11, 2009, accessed September 27, 2011, http://www.cbsnews.com/stories/2008/10/11/tech/main4515365.shtml

202 National Oceanographic and Atmospheric Association, Chesapeake Bay Interpretive Buoy System, "About the System," accessed September 26, 2011, http://buoybay.noaa.gov/about/about-the-system.html

This monitoring approach is poised to be even more valuable in coming years. Especially in places like the Chesapeake Bay—with miles of coastline and many access points—traditional methods of monitoring pollution at specific coastal effluent points are inadequate for evaluating the full health of a watershed and ecosystem. Wireless-equipped buoys, however, can be placed throughout the water to provide more comprehensive and actionable data on pollution levels and

Figure 22. (Source: Screen capture from NOAA, www.buoybay.noaa.gov)

water quality, enabling much better environmental monitoring, pollution prevention and response, and ecosystem management.

Enhanced Citizen Engagement with Wireless

When a massive blizzard hit Newark, New Jersey, on December 31, 2009, residents faced an overwhelming shoveling job. Directing a twitter message at the city's Mayor, Cory Booker, one person indicated that her 65-year old father needed help digging out his driveway. Within minutes, Mayor Booker replied: "I will do it myself where does he live." Sure enough, the mayor arrived 20 minutes later ready to dig.[203] A year later, in the midst of another snowstorm, Mayor

[203] CNN.com, Eric Kuhn, "Mayor Digs in After Twitter Appeal," January 3, 2010, accessed September 27, 2011, http://politicalticker.blogs.cnn.com/2010/01/03/mayor-digs-in-after-twitter-appeal/

Booker, staff members, and volunteers grabbed shovels and rode around the city, responding to tweets and swooping into action to lend a hand.[204]

Mayor Booker's shoveling efforts may be a small-scale, high-profile gesture, but it illustrates how technology is opening new avenues of communications among citizens and governments. On the move, from cell phones and smart phones, citizens are now able to communicate directly with government, and vice versa. This two-way communication is driving sustainability benefits by enabling more awareness and action on environmental issues as people go about their daily lives.

WIRELESS HELPS CITIZENS PROVIDE GOVERNMENTS INFORMATION ABOUT ENVIRONMENTAL HAZARDS

Through wireless and mobile internet applications, it is now easier than ever for citizens to highlight environmental and safety issues that require government attention. In doing so, citizens help government run more efficiently—for instance, by flagging pressing issues—and help government better identify and administer sustainability solutions.

Applications can benefit the environment by enabling citizens to report on environmental hazards, waste, and opportunities for improvement. Applications like Spigit and SeeClickFix create a path for citizens to report and resolve a host of civic issues, including crime, safety problems, and infrastructure maintenance needs.[205] For example, a recent report on the New York City SeeClickFix site flagged the presence of toxic chemicals and medical waste that had been left on a sidewalk. The user was able to take and upload pictures of the materials. From there, authorities were notified to deal with the issue to avert environmental or health consequences.[206] This example illustrates how mobile-enabled platforms can protect the environment and citizens through simple and immediate communications.

Wireless applications also facilitate citizen reporting beyond city sidewalks. The National Marine Fisheries Service offers an Android application called Release Mako. The application focuses on the shortfin mako shark, a species vulnerable to overfishing. In addition to providing general information about the sharks, as well as safe handling and release guidelines, the application allows fishermen on the water to use their cell phones to report shortfin mako catches. Rolling up to an interactive map, the reports help people track shortfin mako catches and conservation efforts in order to preserve wildlife and protect ecosystems.[207]

WIRELESS HELPS GOVERNMENTS PROVIDE CITIZENS WITH SUSTAINABILITY INFORMATION

Governments can also use mobile technology to push information out to citizens about environmental issues. Severe pollution conditions, water resource availability, environmental programs—all are ripe for government communications to improve sustainability. For example, in the case of a drought, a municipality could alert citizens through text message and inform them of water reduction measures. In New York City, the Notify NYC program issues text message and Twitter alerts to citizens about a range of city issues, including air

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[204] Time.com, Sean Gregory, "Cory Booker: The Mayor of Twitter and Blizzard Superhero," December 29, 2010, accessed September 27, 2011, http://www.time.com/time/nation/article/0,8599,2039945,00.html

[205] SeeClickFix, "New York," accessed September 26, 2011, http://www.seeclickfix.com/new-york; Spigit, accessed September 26, 2011, http://www.spigit.com

[206] SeeClickFix, "#84988 Toxic Chemicals and Pharma Waste on Street," accessed September 26, 2011, http://www.seeclickfix.com/issues/84988-toxic-chemicals-and-pharma-waste-on-street

[207] U.S. Government, National Marine Fisheries Service, "Release Mako," accessed September 26, 2011, http://apps.usa.gov/release-mako

and water quality.[208] Through such systems, government can better notify citizens of environmental issues and provide information to mitigate impacts.

Table 1: US Government Mobile Sustainability Applications and Websites

App/Mobile Site Name	Agency	Description	Environmental Impact
Alternative Fuel Locator	US Department of Energy - Clean Cities	Helps users find and get information about alternative fuel stations	Makes it easier for people to own and operate alternative fuel vehicles
Fuel Economy.gov	US Department of Energy - Clean Cities	Makes it possible to calculate gas mileage, fuel costs, petroleum use, and the carbon footprint of a user's car or truck	Enables better decisions about driving habits and vehicle purchasing
UV Index	Environmental Protection Agency	Lets users check UV indices and air quality ratings	Informs citizens about environmental and health risks
EPA Mobile	Protection Agency	Provides mobile access to the EPA website, including news and resources	Affords easy access to EPA information

In the United States, government agencies provide mobile websites and applications to directly engage citizens on environmental issues.[209] Some of these are shown in Table 1. The sites and applications provide information and facilitate better environmental choices.

Information services can also be valuable in the case of disasters or crises. In Japan, for instance, some phones offer an early warning service in the event of earthquakes. It appears that efforts are underway to expand such services to other disasters as well.[210] These services give people crucial time to prepare for disasters to avert environmental harms and prevent human catastrophe. In California, a collection of government agencies and universities is currently developing a similar early warning system to deliver earthquake alerts in that temblor-prone region. As in Japan, the system would utilize networked technology and personal gadgets to send alerts. *Scientific American* explains, "Individuals would get an alert on their mobile phone indicating predicted shaking intensity, a countdown until the shaking starts, and perhaps a simple instruction such as 'get under a table' or 'move to your safe zone.'"[211] In addition to helping individuals, the system would be able to alert managers to take measures to slow or stop factory lines, transportation systems, power plants, and other functions.[212]

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208 The City of New York, "Notify NYC," accessed September 27, 2011, https://a858-nycnotify.nyc.gov/notifynyc/Home.aspx?AspxAutoDetectCookieSupport=1

209 "Mobile Apps," U.S. Government, accessed September 26, 2011, http://apps.usa.gov/?v=all

210 CNNMoney, Philip Elmer-DeWitt, "Earthquake Coming? There's an App for That," August 22, 2011, accessed September 27, 2011, http://tech.fortune.cnn.com/2011/08/22/earthquake-coming-theres-an-app-for-that

211 *Scientific American*, Richard Allen, "Seconds Before the Big One: Progress in Earthquake Alarms," March 11, 2009, http://www.scientificamerican.com/article.cfm?id=tsunami-seconds-before-the-big-one&print=true

212 *Scientific American*, Richard Allen, "Seconds Before the Big One: Progress in Earthquake

Wireless Opportunities to Reduce Environmental Impacts: Smart Parking

Matching Supply and Demand: Smart parking systems give drivers a clear idea of the supply of parking spaces.

Using Less: Smart parking applications enable drivers to go directly to open spaces, reducing fuel needed to get to their destinations.

Shifting Behaviors: If potential drivers know that parking at their destination is difficult to find, they may take alternate transportation.

In doing so, the system could help avert environmental damage through hazardous material spills, crashes, fires, and other damage.

Looking Ahead

Wireless technology is already playing valuable roles in improving the sustainability of public services that touch the lives of every American. These changes impact both how government functions and what government affects. Wireless helps governments execute public services more sustainably, such as through efficient fleet management. It also makes it possible for government to coordinate and operate urban transportation systems more sustainably. Wireless enables government agencies to monitor environmental conditions to facilitate better protection, management, and safety. Additionally, wireless increases engagement and collaboration among citizens and government to identify and address environmental issues. While many wireless projects are currently in place, though, there is much more that governments can do.

Many opportunities are already identified, but governments should consider scaling those solutions for greater impact. It should not just be a select set of municipalities that develop improved traffic management systems; any sizable city should look to such systems to improve sustainability, living conditions, and citizen health. Many public bus systems could benefit dramatically from wireless applications. The environmental monitoring solutions in the Chesapeake could easily be applied in several critical areas across the country. These programs offer short-term and long-term benefits to governments, citizens, and the environment.

Alarms," March 11, 2011, accessed September 27, 2011, http://www.scientificamerican.com/article.cfm?id=tsunami-seconds-before-the-big-one&print=true

Environmental Costs of Wireless Technology

The expanding use of wireless technology in the United States clearly presents significant opportunities to improve environmental and other impacts in various ways. At the same time, the manufacture, use, and disposal of this technology has an environmental cost in terms of resource use and pollution. Other factors may also limit benefits, such as the possibility that use of wireless is simply shifting environmental costs from one area to another. Many of these concerns cut across virtually all applications, and effects can often be difficult to analyze, but should be considered when evaluating the overall effects of implementing wireless technology.

This section will review the life-cycle environmental impacts of wireless electronic devices, followed by a review of other impacts and factors that may reduce the net benefits from implementing wireless technology. The goal of this section is not to detail all of the environmental costs of wireless technology, particularly when these can vary considerably, and there is some debate about how to best measure them. Additionally, the section does not attempt to discuss social issues, such as supply chain labor and human rights. Instead, the objective is to highlight some of the significant costs and impacts, particularly those that are likely to increase with the expansion of wireless infrastructure or significantly affect the overall benefits of this infrastructure, and to identify opportunities to address these impacts.

Product and Infrastructure Life-Cycle Environmental Impacts

The lifecycle of a wireless device begins with mining and other raw material extraction, and continues with various processing and manufacturing steps to turn raw materials into components and finished products. These products are then used and disposed of. Each of these stages, along with transportation between them, has distinct impacts from the use of materials and energy, and the generation of waste products.

PRODUCT MAKEUP AND OVERALL CONTEXT

The materials used in wireless products can vary depending on their applications; using mobile phones as a proxy, a typical phone may be made up of 45 percent plastic, 20 percent copper, 20 percent other metals like aluminum and gold, 10 percent ceramics, and 5 percent non-metals.[213] There are nearly 327 million mobile phones in use in the United States—a number that is large in one sense, representing more than one phone for every person in the country,[214] yet small in comparison with the total volume of the electronics market.

As demonstrated in the previous sections of this report, the potential for expansion of wireless applications and technology is immense. If current environmental costs per unit remain constant, total costs will grow with the market for these electronics. At the same time, the application of wireless technology to gather and distribute information will also increase demand for other ICT equipment, for example to process and store data.

Thus, consideration of the environmental costs of wireless should generally be considered alongside other electronics, because it will be much more cost-effective to address the entire system. And while the discussion below focuses on wireless components, the broad assessment holds true for electronics overall.

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213 Nokia, "Recycling," accessed September 27, 2011, www.nokia.com/environment/recycling

214 302.9 million wireless subscriber connections, per CTIA, "U.S. Wireless Quick Facts," accessed September 27, 2011, www.ctia.org/consumer_info/index.cfm/AID/10323

PRODUCTION

The environmental costs of equipment production are a result of the material and energy inputs and wastes generated by raw material extraction and processing, component and product manufacture, and transportation. Although modern, well-regulated mining and manufacturing systems limit the environmental risks and costs associated with wireless and other electronic equipment production, these efforts often require large-scale changes to local landscapes, use of hazardous materials, and generation of large amounts of waste. Electronics life-cycle assessment studies commonly cite energy use in manufacturing as a significant source of local air pollution and greenhouse gas emissions, in addition to the potential release of pollutants to land and water.[215] Additionally, inadvertent or deliberate noncompliance with regulations can lead to environmental costs. A recent BSR/Electronics Industry Citizenship Coalition (EICC) report on water pollution from electronics manufacturing, for example, found that about 5 percent of a sample of electronics suppliers had environmental violations, with 1 percent of the sample having multiple violations.[216]

In addition to manufacture, the transportation of raw materials, components, and finished products through global supply chains can have a surprisingly large impact, up to 18 percent to 25 percent of total environmental costs. This is largely because air transport of components and products has a much larger environmental impact than surface transport.[217]

USE AND DISPOSAL

Greenhouse gas emissions and local pollution related to energy use of wireless products and supporting infrastructure are the most significant environmental costs that occur during use of wireless technology.

The general public has probably heard the most about environmental costs related to the end-of-use (or end-of-life) of electronics, and the U.S. EPA estimates that 130 million cell phones are disposed of annually, only 10 percent of which are recycled. Although heavy metals and other potentially toxic materials contained in a phone should not be harmful if a phone is in proper working order, there are risks of environmental and human exposure to toxics if a phone is improperly disposed of, because certain materials such as copper could leach into soil and groundwater.[218] Because of these risks of exposure, concerns about the treatment of obsolete electronics—in particular, their export to developing countries with poor environmental controls—have been growing for several years. There are concerns that potentially toxic materials in the equipment may be released and damage the environment and human health. Heavy metals, PVC, and brominated flame retardants are some of the most commonly cited items of concern.

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215 "LCA Case Studies: Life-Cycle Assessment of the Mobile Communication System UMTS," 2004, accessed September 27, 2011, http://www.esu-services.ch/fileadmin/download/faist-2005-umts.pdf; "Life-Cycle Assessment of Mobile Telephone Networks," accessed September 27, 2011, http://biblion.epfl.ch/EPFL/theses/2005/3443/EPFL_TH3443.pdf

216 BSR/EICC, "Electronics Supply Networks and Water Pollution in China," November 2010, http://eicc.info/documents/EICCWWFinalReport.pdf

217 "LCA Case Studies: Life-Cycle Assessment of the Mobile Communication System UMTS," 2004, accessed September 27, 2011, http://www.esu-services.ch/fileadmin/download/faist-2005-umts.pdf

218 California Department of Toxic Substances Control, "E-waste Report: Determination of Regulated Elements in Seven Types of Discarded Consumer Electronic Products," January 2004, accessed September 27, 2011, http://www.dtsc.ca.gov/HazardousWaste/EWaste/upload/Consumer_Electronic_Products.pdf

Levers for Reducing Environmental Costs

All of the impacts outlined above are likely to expand alongside the growing use of wireless products. For the most part, however, these are well understood, and often being addressed by regulation and voluntary programs. Industry associations including the EICC and the Global e-Sustainability Initiative (GeSI) have programs to monitor and address supply chain and product-related environmental impacts. Individual companies continue to make voluntary progress on areas, including reducing toxics like PVC and BFRs, improving product energy use, finding ways to eliminate "vampire loads" from cell phone chargers, designing products to be nearly 100-percent recyclable, and strengthening product recycling programs. And governments continue to strengthen environmental regulation and enforcement.

All of these environmental costs are driven by growing use of products and infrastructure, which, if everything else remains constant, will drive increased demand for resources and energy use, and increases in waste products. It is unlikely that the number of products in use will decline, so it will be important for manufacturers and users to focus on other levers to limit environmental costs. These can include:

- **Reducing material and energy used by each product.** The miniaturization and increasing energy efficiency of electronics is an ongoing phenomenon in the ICT industry. While early cell phones were extraordinarily large by today's standards (weighing well over a pound), current models can fit in a pocket and weigh mere ounces. There are also opportunities for users to increase the efficiency of their cell phone use by adjusting backlighting, switching off applications, or limiting wireless connections when not needed.[219] In addition, a variety of pressures are driving the reduction and phase-out of potentially hazardous substances from products, such as lead, brominated flame retardants, and PVC.
- **Reducing impacts of production processes.** The electronics industry also continues to develop and adopt manufacturing processes that require lower energy and resource inputs, such as using closed-loop production processes that reuse water, chemicals, and other materials. There are also efforts to reduce or eliminate the need for toxic substances.
- **Using recycled or other lower-impact materials.** Using recycled metals or other substances can cut the need to extract virgin metals or additional petroleum products from the ground. Similarly, bio-based plastics may offer environmental benefits over petroleum-based plastics, although there are some concerns about displacing food crops and the actual environmental benefits of these alternatives.
- **Maximizing the use of existing products and systems.** In ICT datacenter environments, there is increasing emphasis on consolidating under-utilized server equipment so that individual servers do more work and spend less time idle, resulting in reducing environmental costs through both energy and equipment reductions. There may be opportunities to take similar steps in wireless infrastructure—for example, by adjusting automated wireless data transfers to occur during off-peak network usage, reducing the need to build out additional infrastructure.
- **Extending product duration of use.** On average, cell phone users replace their phones (usually while still fully functional) with a newer model about every 18 months. Encouraging continued use of products is another potential lever for environmental improvements. One study suggests that 40 percent of

[219] Nokia, "Let's Pull the Plug on Energy Waste," accessed September 27, 2011, http://www.nokia.com/environment/devices-and-services/energy-effiency

the impact of cell phones can be cut if the product lifespan is increased from one year to four, because it reduces the need to manufacture new products.[220] Both manufacturing durable products and ensuring that rapidly worn components (such as batteries) can be replaced can contribute to this. Constant technological advances are improving the usefulness of products, however, and contribute to demand for new products and a drive to retire previous models. This may be addressed by ensuring that products are upgradeable. For instance, if processing and memory chips and batteries can be designed to be replaced easily by users, then these could be upgraded without disposing of the entire product.

» **Safely reuse or recycle products.** Ensuring that products are refurbished and reused, that components get reused when possible, and that any remaining material is recycled into new electronics or other materials reduces disposal impacts of e-waste, and also provides material to reduce the environmental costs of producing new electronics or other products. Leading cellular service providers as well as retailers, community groups and others in the United States have significant and growing cell phone recycling programs, while many other ICT firms also have product take-back and recycling programs.

New Equipment, New Impacts?

Perhaps the most significant changes in the environmental costs of wireless technology are coming from the emerging “internet of things.” These are products and infrastructure that embed wireless electronics into things that did not previously have them, from clothing and buildings to remote sensors in farmers’ fields, and even cows. As these types of uses expand, producers and users will have to consider how best to collect and recycle equipment at the end of its useful life.

In particular, many of the solutions we discuss above involve casting a wide net of wireless equipment across the environment. Some of this equipment may be difficult to collect, in place for a long time, and a few are bound to be damaged, lost, or forgotten. As these equipment networks are being developed, the industry should continue to review the potential environmental costs and how to mitigate them.

Other Impacts

Bird strikes on communications towers (as well as other towers) are another commonly cited environmental cost of wireless communications. While total numbers of deaths are uncertain, estimates range from 4 million to 50 million).[221] These numbers can be reduced by addressing a range of factors, including communications tower siting (for instance, sites near bird nesting areas or in migration flyways may have higher mortality rates), tower lighting (elimination of steady lighting reduces mortality), height, and design (towers over 200 feet and those having guy wires result in more bird deaths).[222]

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220 “LCA Case Studies: Life-Cycle Assessment of the Mobile Communication System UMTS,” 2004, accessed September 27, 2011, http://www.esu-services.ch/fileadmin/download/faist-2005-umts.pdf

221 Federal Communications Commission (FCC), “Draft Programmatic Environmental Assessment of the Antenna Structure Registration Program,” August 26, 2011, http://transition.fcc.gov/Daily_Releases/Daily_Business/2011/db0826/DA-11-1455A2.pdf

222 U.S. Fish and Wildlife Service, New Jersey Field Office, “Communication Tower and Antenna Consultation in New Jersey,” March 2009, accessed September 27, 2011, http://www.fws.gov/northeast/njfieldoffice/pdf/celltower.pdf; The American Ornithologists’ Union, Commentary, “Height, Guy Wires, and Steady-Burning Lights Increase Hazard of Communication Towers to Nocturnal Migrants: A Review and Meta-Analysis,” 2008, accessed September 27,

Some also have raised concerns that use of wireless devices may be linked to human health problems. However, these concerns do not appear to be grounded in scientific fact. The World Health Organization (WHO) notes that “a large number of studies have been performed over the last two decades to assess whether mobile phones pose a potential health risk. To date, no adverse health effects have been established as being caused by mobile phone use.”[223] The U.S. Federal Communications Commission (FCC) takes a similar position, stating: “[C]urrently no scientific evidence establishes a causal link between wireless device use and cancer or other illnesses.”[224] Because of the fact that exposure rates to electromagnetic fields decrease rapidly with distance from the body (WHO notes a distance of 30 centimeters to 40 centimeters results in much lower electromagnetic frequency exposure than someone holding a mobile phone to their head), there currently seems to be no evidence suggesting that machine-to-machine or handheld applications would result in significant health impacts. The FCC notes that those who study these issues agree that longer-term studies should be done, similar to the WHO statement that the lack of longer-term data warrants further research.

Other Considerations

Wireless applications are embedded in complex systems, and their use may have unexpected results that influence overall environmental impacts. Wireless technologies may demonstrate displacement or rebound effects, in particular, which limit the overall environmental benefits.

DISPLACEMENT EFFECTS. These occur when an environmental impact is not actually reduced, but instead shifted from one location to another. A typical example of this occurs in telecommuting, where an employer may claim environmental benefits from reduced employee travel and lower energy use at the office. Some of these environmental costs are actually shifted to the employees, who may increase their own environmental impacts by heating and cooling their houses and using their own office equipment during the day while working from home.

REBOUND EFFECTS. A classic example of a rebound effect occurs when a consumer purchases a more fuel-efficient car, but then begins to drive more as a result. On a macro-scale, fuel efficiency that reduces demand for fuel across the board may cause fuel prices to decline and support some corresponding increase in demand. In the wireless arena, several types of rebound effects may occur. For example, a vehicle fleet that uses less fuel as a result of telemetrics may spend the savings in a larger fleet. Alternatively, the use of precision agriculture techniques may make it easier to farm previously marginal land, thus encouraging growth in the total amount of land under cultivation, and increasing environmental impacts from agriculture. These types of results may demonstrate a significant economic benefit and a distinct environmental benefit per unit (e.g. per mile traveled or per bushel of grain produced), but the total environmental benefit may be limited or negative.

Displacement and rebound effects are often difficult to foresee and harder to evaluate, but should be explored when developing wireless applications that are expected to provide environmental benefits.

2011, www.urbanwildlands.org/Resources/Longcore_06-253.pdf

223 World Health Organization (WHO), Fact Sheet, “Electromagnetic Fields and Public Health: Mobile Phones,” June 2011, accessed September 27, 2011, www.who.int/mediacentre/factsheets/fs193/en

224 FCC, “Wireless Devices and Health Concerns,” September 2011, accessed September 27, 2011, http://www.fcc.gov/guides/wireless-devices-and-health-concerns

Looking Ahead

Most technology advocates will admit that the application and expansion of wireless technology will not come without some direct environmental costs. These should be understood and addressed, while also keeping the wider, systemic impacts—including how the technology enables reductions in environmental costs, as well as any displacement and rebound effects—in mind.

Conclusion

Wireless technology is an important element in realizing the vision of a smarter and healthier planet. With climate change and sustainability on the minds of individuals, business and government, the wireless industry is responding. In just the last couple of years, a wide variety of applications are now available, with the potential to significantly benefit the environment.

Rapid advances in this technology coupled with widespread adoption from lower costs have made this possible. With exponential growth in the number of cell phone users—in the developed and developing world—network operators have been scrambling to keep up with infrastructure needs, with the result that much of the world's population now is "within range." A natural consequence of this is that it's never been easier to get information from Point A to Point B, from anywhere to anywhere in the world.

The primary area where wireless enables a benefit for the environment is in providing information, where previously, geographic or other barriers made this impossible. While transportation and utilities are obvious beneficiaries in areas such as route optimization and monitoring and controlling energy usage, other industries as well as the government are finding that wireless technology can play an important role in reducing environmental impact - while creating efficiencies and improving the bottom line.

Consumers are benefitting, too. As we have seen, using wireless technology to help make parking more efficient and less stressful, and tracking and modifying one's use of energy, are just two examples of how to reduce resource usage, costs, and emissions.

Government has started to play an increasing direct and indirect role. In some cases, there is room for government to do more to incentivize business and individuals to adopt some of these technologies. Government itself could be a bigger adopter of some of these technologies for the public services it provides.

Of course, adoption of this or any technology also has its negative side effects, which are not insignificant. But there are solutions in many cases, and the net benefit is still positive. Fortunately, the companies leading the march in mobility by and large recognize the negative aspects and are beginning to offer solutions. But there's a long way to go on this front.

Since many of the examples and case studies in this report are still at an experimental stage, it remains to be seen if they can be scaled cost-effectively to provide the broader impact that is envisioned. But at one time, the cell phone weighed the equivalent of a brick (and looked like it too), and cost thousands of dollars, so there's room for hope.

New applications on the horizon, such as those enabled by M2M communications, are even more exciting and could fundamentally change the way we live, work, and play. Inexpensive sensors, broadband, and a ubiquitous cellular network, coupled with humanity's embrace of wireless mobility, make the possibilities seem endless for living better and utilizing the earth's resources more efficiently. We are hopeful that the wireless industry, with the right level of government involvement, will help make this a reality.