Supplemental Materials

for

Exploring Flexible Infrastructure Opportunities

December 6, 2018

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Sponsor: The Department of Energy

These materials supplement the above named project report and are submitted to the faculty of WPI in partial fulfillment of the requirements for the Degree of Bachelor of Science

Part A - Authorship

Writing	
Introduction	Eric: Wrote initial version and edited Chris: Wrote initial version and edited
Methodology (Named differently in our report)	Eric: Filled in table data for assets and criteria, wrote about criteria, wrote about profile methods, edited 1st version, edited 2nd version Chris: Wrote about infrastructure assets, filled in table data for assets and criteria, wrote Objective 1, edited 1st version Roger: Wrote about infrastructure criteria, filled in table data for assets and criteria, wrote about profiles methods, edited 1st version Robert: Wrote about infrastructure criteria, filled in table data for assets and criteria, edited first and second version
Results/ Trends/ Patterns	Eric: Wrote about trends leading into profiles, edited Chris: Connected matrix to trends (1st paragraph), edited Roger: Wrote about profile choice
Green Roof Profile	Chris: Wrote initial version and edited first/second version Roger: Wrote initial version and edited first/second version Eric: Formatted and edited second version
Microgrid Profile	Eric: Wrote initial version and edited all revisions
Smart Traffic Systems Profile	Robert: Wrote Initial version and edited. Edited second version Roger: Wrote initial title page and edited second version Eric: Edited second version
Conclusions & Recommendations	Eric: Wrote initial version and edited Roger: Edited/wrote second version Chris: Edited/wrote second version
Supplementals	Eric: B, C, D, F, H, I Chris: D, E, H, I

	Roger: C, D, G, H, I Robert: C, D, G, H, I
Interviews	
Green Roofs	Chris: Interviewed all green roof contacts: Stack, Coard, Lane, Wood, Furbish, Farber, Swann Roger: Scribed for Stack, Coard, Lane, Wood, Furbish, and Farber
Microgrids	Eric: Interviewed all five microgrid people: Borer, Heleno, Ganion, Castellini and Carter. Scribed for Ganion also Roger: Scribed for Heleno Robert: Scribed for Borer, Castellini, and Carter
Smart Traffic Sensors and Systems	Eric: Scribed for Barlow interview Roger: The interviewer with Fellows and Barlow Robert: Scribed for Fellows, interviewer for Curtis, and interviewer/scribe for Molinaro
Research	
Matrix Criteria Categories	Eric: Researched and brainstormed criteria, wrote market criteria Robert: Researched and brainstormed criteria, wrote market criteria
Infrastructure Assets Categories	Roger: Organized 16 infrastructure types into three major categories, and found examples for initial set of infrastructure Chris: Organized 16 infrastructure types into three major categories, and found examples for initial set of infrastructure
Matrix	Eric: Researched and filled out cells for Standard Permanent Microgrid, Flexible Large Power Transformer, Dams, Flexible water treatment plant, green roofing Chris: Researched and filled out cells for Transportable Microgrids, Self-Adaptive Traffic Lights, green roofing Roger: Researched and filled out all cells for Combined Heat and Power with District Heating, Green Transit, and Public Transportation Robert: Researched and filled out all cells for Smart Pavement and Permeable Surfaces
Profiles	Eric: Created and filled out rows for the three microgrid cases

Matrix (only organizational tool)	Chris: Created and filled out rows for three green roof cases Roger: Created and filled out rows for the three smart traffic sensor cases
Design	
Slide Design (slide number after name)	Robert: 6, 11, 19, 25, 28 Chris: 4, 5, 10, 14, 15, 24, 26 Eric: 3, 5, 9, 16, 17, 18, 20, 23, 27 Roger: 7, 8, 12, 13, 21, 26, 28
Poster	Eric: Worked on initial version, edited revisions Chris: Worked on initial version, edited revisions Roger: Worked on initial version Robert: Worked on initial version
Publisher	Robert: Designed the entire thing

Part B - List of Interviewees

Interviewees are highlighted by subject interviewed about.
Green Roof Experts: 7 interviews
Microgrid Experts: 5 interviews
Smart Traffic Systems Experts: 4 interviews

Name	Title	Date
Rebecca Stack	Principal of Design Green LLC	11/16
Miguel Heleno	Senior Scientific Engineer Associate at Berkeley National Lab	11/19
Ted Borer	Energy Plant Manager at Princeton University	11/19
Jana Ganion	Energy Director for Blue Lake Rancheria	11/20
Anonymous	Anonymous	11/27
Greg Barlow	CTO of Rapid Flow Technologies	11/27
Cecilia Lane	Environmental Protection Specialist at Department of Energy and	11/28

	Environment for Washington, DC	
Sandy Farber Bandier	Green Roof Coordinator at University of the District of Columbia	11/28
David Carter	Senior Research Engineer at Schatz Energy Research Center	11/28
Chase Coard	CEO of Ecospaces DC	11/29
Robert Wood	Director of Engineering and Analysis Division in the Office of Science and Technology at Environmental Protection Agency	11/29
Michael Furbish	President of Furbish Co.	11/30
Laura Castellini	Sustainability Coordinator for Golden Gate National Recreation Area for National Park Service	11/30
Keith Swann	Special Assistant to the Executive Vice President at the American Society of Landscape Architects	12/3
Eddie Curtis	Traffic Management Specialist at Federal Highway Administration	12/3
Joe Molinaro	Traffic Management Systems Manager at Albeck Gerken Inc.	12/4

Part C - Interview Preamble

Thank you for giving us your time for this interview. We are students from Worcester Polytechnic Institute (WPI) working with the Department of Energy (DOE) to explore opportunities where implementing flexible infrastructure would enable communities to prosper in face of dynamic needs. Your participation in this interview is completely voluntary and you may stop it at any time. Are we allowed to quote you on the information given during this interview or would you prefer to remain anonymous? Are we allowed to record this interview? We give you the right to review materials we use from this interview and will send you our report to allow you to review or modify what we used prior to submission. If you have any questions about our research feel free to ask or contact us at gr-DC18DOE@wpi.edu. You may also contact our WPI advisors, Dominic Golding at golding@wpi.edu and Lorraine Higgins at ldh@wpi.edu.

Part D - General Interview Questions

Questions are presented in groups of two, the first question is for individuals who have worked with, own, or install this infrastructure directly. The second question is for individuals who are experts in the field and have general knowledge but not case specific knowledge. The questions gather the same information but are worded slightly different.

1. Can you elaborate on your experience (or connection) with this infrastructure?
Can you elaborate on your expertise with respect to this infrastructure?
2. What benefits were monetized (valued) when deciding to have this infrastructure installed?
What are the most common benefits people monetize (value) when installing this infrastructure?
3. How was this infrastructure financed? What incentives or financial support was received to install this infrastructure?
How do people finance this infrastructure? Are there incentives or financial support that people contemplating installation can receive?
4. What are the benefits this infrastructure has provided since installation? Are these different than the ones you expected prior to installation? What benefits does it provide to parties outside your immediate organization (company, etc.)?
What benefits does this infrastructure provide to the owners? Do actual benefits differ from ones owners expect prior to installation? What benefits does it provide externally, to people outside the owner?
5. What maintenance is required to keep this infrastructure running optimally?
6. What issues or downsides have you had with this infrastructure since installation?
What issues or downsides are common with this infrastructure? Do they appear after installation or after continued operation?
7. In what ways do you see this infrastructure adapting to the future?
How will this infrastructure adapt to the uncertain changing needs of the future?
8. Where do you see the market for this infrastructure over the next few years?

Part E - Green Roof Interview Questions

1. How prevalent have leaks been since infrastructure?
How prevalent are leaks with green roofs?
2. Would you have installed this green roof if you didn't receive incentives or financial support?
Would this infrastructure have widespread development and installation without the many incentives provided by local governments?
3. Do you own this building? If not who decided to have this green roof installed and for what purposes?

How do green roofs get installed on communal buildings such as apartment buildings? What benefits do the owners of these buildings see if they don't live within the building? Does having a green roof increase the property value of such a building/apartment?

4. Is there a technical standard that defines the difference between extensive and intensive green roofs?

- **a.** Which is more popular?
- **b.** Do incentives vary?

Part F - Microgrid Interview Questions

1. Which benefit was valued more in the installation: the variety of benefits this microgrid provides or its ability to adapt to changing demands over time?

Which benefit is generally valued more by microgrid owners: the wide array of benefits or the ability to adapt to changing demands over time?

2. What resources did you use to install this microgrid? Was it hard to find information on practices with microgrids?

How does the lack of a certified institution providing resources on standard best practices affect the rate of installation of microgrids?

3. Is your microgrid fully autonomous in daily operation? How often is human required to step in? Does islanding happen automatically or require human intervention?

How autonomous are microgrids in general? How often are humans required to intervene, especially in terms of islanding?

4. What role did your utility play in developing this microgrid?

Are utilities for or against the widespread development of microgrids and why?

Part G - Smart Traffic Systems Interview Questions

1. What are the barriers to implementing traffic sensors?

What prevents adaptive traffic lights from being widely implemented across the country using these Microloop sensors? Are there issues with privacy or policing?

2. Are the people affected or funding this realizing the benefits and effects of this technology?

Is this technology having trouble emerging because of indirect ownership of the technology?

3. What are some other ways traffic sensors can be used or adapted to future needs?

4. Are traffic sensors consistent in easing traffic congestion in different population densities?

How are they adaptive to specific times and locations?

5. How are you choosing the areas of implementation and how many sensors need to be implemented?
6. How long has the market for adaptive traffic systems been around for? And are there different markets for sensors and adaptive traffic systems?
7. Does a community's value of smart traffic systems prohibit implementation?

Part H - Interview Concluding Remarks

Thank you for taking the time to answer our questions. When we are done with our paper we will send you a copy to approve.
1. Who else should we interview?
2. Do you mind if we get back to you later with any follow up questions or clarifications?
3. Are there any reports or other documents we should pursue?
4. Are there other questions we should ask?

Part I - Annotated Bibliography For Matrix

ABB Inc. (2018, March 30). Novel Concept for Flexible and Resilient Large Power Transformers (Tech.). Retrieved November 29, 2018, from Department of Energy Office of Scientific and Technical Information website: https://www.osti.gov/servlets/purl/1435970
"ABB is a private company that is currently leading research in large power transformers with financial aid from the Department of Energy (DOE). ABB won $350,000 USD in order to conduct the research necessary to publish his report and create this infrastructure. This report is their final deliverable to the DOE on their novel concept of a flexible large power transformer. The report provides context on the current issues plaguing large power transformers and therefore the need, purposes, and benefits of flexible large power transformers. This report provides information about all criteria, and this source provides information on the current market of large power transformers since the flexible ones are still in development. Therefore this was the only source used to fill out the flexible large power transformers row."

Ahlgren, E. (2013). *Energy Technology Systems Analysis Programme*(Issue brief No. E16). International Energy Association.

"This technology brief on district heating systems showed the process, performance, costs, potential, and barriers of the system. District heating systems have limitations in location, but

can be compounded with combined heat and power systems to use recycled heat energy to heat residences and commercial areas. District heating delivers this heat through underground infrastructure from energy generation sites (combined heat and power), which can raise the efficiency of the energy expended during generation."

Berkeley National Lab. (2018). About Microgrids. Retrieved November 28, 2018, from https://building-microgrid.lbl.gov/about-microgrids

"Researchers at Berkeley National Lab (BNL) update and maintain this repository of microgrid information. BNL researchers are world experts on microgrids and have been involved in implementing and operating microgrids. This site contains varying definitions of what a microgrid is, general information such as what a microgrid does, and barriers currently opposing widespread development. This site also has many examples of microgrids installed and operating along with case studies for a majority of them. These were used to fill out all the criteria for Standard Permanent Microgrids excluding market information."

Cronkleton, R. A. (2018, May 22). Smart Pavement Startup Announces Contract with Colorado Department of Transportation. Retrieved November 10, 2018, from http://www.govtech.com/fs/infrastructure/Wi-Fi-in-the-Road-Kansas-City-Tech-Start-Up-is-WiringPavement-for-Safety--And-Fun.html

"Government Technology, a division of e.Republic, is a magazine that discusses the importance and role of IT in state and local governments. The article they published is by Robert Conkleton, a reporter for The Kansas City Star, who wrote this article that elaborates on the benefits, design, implementation, and construction of Smart Pavement. We used this article to fill in all Smart Pavement criteria with the exception of market uncertainty criteria."

Wood, E. (2018, August 30). What's Driving Microgrids toward a $30.9B Market? Retrieved November 29, 2018, from https://microgridknowledge.com/microgrid-market-navigant/

"Elisa Wood is a renowned energy journalist who has written for a variety of high profile publications and currently is chief editor of Microgrid Knowledge. The articles on this site, specifically the one in the citation, contain a wealth of information about the market of microgrids. They disseminate information from private market research firms which charge thousands of dollars to access a report. Therefore we are unable to view the primary source and have to use these articles. The website also has information about microgrid development and economic models. This source was used to fill out the market criteria for Standard Permanent Microgrids."

United States Geological Survey. (2018, June 27). Hydroelectric power water use. Retrieved December 5, 2018, from https://water.usgs.gov/edu/wuhy.html

“This source is published by two U.S. government agencies, the United States Geological Survey and the Department of the Interior, to bring awareness to pros and cons of hydroelectric dams. The site has links to further articles we used that explain how these dams work, along with sources for their claims. Therefore this source was used to gain a unbiased understanding and fill out the general criteria for hydroelectric dams, most notably this source provides detailed benefits and risks along with stakeholders for each. This site briefly mentions market criteria but doesn’t provide enough information to use in our matrix.”

Department of Energy. (2018, April). 2017 Hydropower Market Report. Retrieved December 5, 2018, from https://www.energy.gov/eere/water/downloads/2017-hydropower-market-report

“This report written and published by the DOE provides an extremely detailed view of the hydropower dam market. The market growth, and size is examined deeply along with barriers to implementation. Therefore this source was used to fill out the market criteria for hydroelectric dams as this is a definitive look into the market of them. A majority of the information gathered was from reports and forms required by the federal government to maintain operation of these dams and a long list of references is provided at the end if more analysis is desired.”

Verdygo Inc. (n.d.). Technical facts and figures. Retrieved December 5, 2018, from https://www.verdygo.com/verdygo-for-you/technical-facts-and-figures/

“This site is published by Verdyo a leading flexible water treatment developer. The exact URL leads to a page discussing the flexibility of such a plant but there are links on the site that redirect to individual implementations and case studies. Therefore this source was used to fill out all criteria for flexible water treatment plants except some of the market criteria

M. B. (2017, September 29). Restoring Power After Natural Disasters - From A Shipping Container. Retrieved from https://kjzz.org/content/543639/restoring-power-after-natural-disasters---shipping-container

“Mark Brodie interviewed Dr. Nathan Johnson, the creator of transportable microgrids, on the radio and asked him about what inspired him to create this flexible infrastructure asset. They discuss the effects of Hurricane Maria in Puerto Rico and some of the other potential implementations of transportable microgrids. This was used to fill out the general criteria about transportable microgrids such as purposes and benefits “

Kullman, J. (2018, February 23). The large impact of microgrids. Retrieved from https://asunow.asu.edu/20180222-solutions-large-impact-microgrids

"An article on an ASU website profiling Dr. Nathan Johnson. It features some quotes from Johnson about transportable microgrids and what they are working on to improve them. This source was used to fill out the criteria relevant to the issues (risks) of transportable microgrids."

Anzilotti, E. (2018, January 10). Imagining The Adaptable, Sensor-Filled Street Of The Future. Retrieved from https://www.fastcompany.com/40514146/imagining-the-adaptable-sensor-filled-street-of-the-future

"This article talked about the future of Smart Cities and several advances in technology that are being developed to make cities 'smarter'. It mentions self-adaptive traffic lights and one case of implementation in Seattle, WA. We used this source to fill out the non-market criteria relevant to adaptive traffic lights such as benefits, purposes, and stakeholders. This article also mentions investors and some barriers as to why these haven't been implemented everywhere which boils down to a lack of understanding of technological capabilities by urban planners."

Gutman, D. (2017, April 24). New, high-tech traffic signals make the Mercer Street trek less messy. Retrieved from https://www.seattletimes.com/seattle-news/transportation/new-high-tech-traffic-signals-make-the-mercer-street-trek-less-messy/

"This article from the Seattle Times elaborates on the installation of a self-adaptive traffic light at a Mercer Street intersection in Seattle. We used this article to examine specific benefits that adaptive traffic lights may provide to an urban area that would not be valued in a rural one. This informed and was used to fill out general criteria combined with the source prior that contrasted individual benefits provided in specific areas."

Department of Energy and Environment. (n.d.). Green Roofs in the District of Columbia. Retrieved December 5, 2018, from https://doee.dc.gov/greenroofs

"This source was used to obtain general information about green roofs. This site is maintained by the local DC government which is one of the largest green roof cities in America and therefore has a lot of data to backup claims. This site details the benefits and risks of green roofs along with all general, non-market criteria such as purposes and stakeholders. This site also provides information on incentives when building a green roof in DC, and contains links to other pages with detailed examination on large showcased DC green roof projects they have worked on. "

Green Roofs for Healthy Cities. (2017, July). *2016 Annual Green Roof Industry Survey Executive Summary* (Rep.). Retrieved December 6, 2018, from Greenroofs.org website: https://static1.squarespace.com/static/58e3eecf2994ca997dd56381/t/5967869229687ff1cfbb6ada/1499956889472/GreenRoofIndustrySurvey2016ExecutiveSummary.pdf

"Green Roofs for Healthy Cities conducts a yearly industry survey to analyze market trends in green roofs. This source is compiled from surveys of green roofs all across North America and therefore has a wealth of data about the market of green roofs. This source was used to fill out the market criteria for green roofs as it details the exact information required, unfortunately the whole report costs money so all we could use is this executive summary but it has all the information we required."

Virginia DEQ Stormwater Design Specification No.7: Permeable Pavement: Version 1.8. (2011, March 1). Retrieved November 5, 2018, from https://www.vwrrc.vt.edu/swc/NonPBMPSpecsMarch11/VASWMBMPSpec7PERMEABLEPAVEMENT.html

"The Virginia Department of Environmental Quality, a state level government department, has created this document to inform the community about permeable surfaces. The Virginia Department of Environmental Quality's mission is to provide Virginia with solutions for cleaner water, improved air quality, and better uses of contaminated land. This document provides an in-depth look into performance, design, construction, maintenance, and risks of permeable surfaces. With this information we were able to fill out matrix criteria for purposes, degree of flexibility, risk streams, installation and maintenance, life expectancy, and the costs of standard and permeable surfaces."

MarketsandMarkets. (n.d.). Pervious Pavement Market. Retrieved November 6, 2018, from https://www.marketsandmarkets.com/Market-Reports/pervious-pavement-market-154481916.html

"MarketsandMarkets is a market research firm that aims to produce research on upcoming opportunities or risks and is serving over 7,500 customers located around the world. Their customers include 80% of Global Fortune 1000 companies. MarketsandMarkets wrote this report to bring awareness to pervious/permeable pavement market size and future. Therefore we used this article to fill out most of the market uncertainty criteria for permeable surfaces."

Aguilar, J. (2018, May 30). Colorado Set to Be First State to Test 'Smart Pavement'. Retrieved November 6, 2018, from https://www.ttnews.com/articles/colorado-set-be-first-state-test-smart-pavement

"Transport Topics is an online source of news that covers news regarding freight transportation. The article they published was written by John Aguilar, a reporter for The Denver Post, who wrote the article to inform readers about general information and areas of implementation on Smart Pavement including the market for smart highway technology. The market information was provided by a research firm names Research and Markets, and their information helped us fill out market uncertainty criteria for Smart Pavement."

Transbay Joint Powers Authority. (2013, December 6). Transit Center. Retrieved December 5, 2018, from http://tjpa.org/project/transit-center

"This site included a large amount of information of the San Francisco Transbay Transit Center. The company which put this green transit hub in place included information on many of the benefits, risks and financial costs of the project. This source displayed that the Salesforce Transit Center included green infrastructure, and and is a hub of multiple transportation options such as long and short distance rail, as well as providing for multiple bus company options. Within this infrastructure, multiple forms of commerce, recreation, and living space is provided."

Department of Energy. (2017). *Overview of CHP Technologies* [Fact Sheet].

"The Department of Energy created an overview of multiple combined heat and power technologies which displayed each process within the powerplant. These processes showed the production of power, as well as costs for each mechanism in the power plant. The fact sheet showed the user benefits as well as national/local benefits for a CHP plant.

Lako, P. (2010). *Energy Technology Systems Analysis Programme*(Issue brief No. E04). International Energy Association.

"This technology brief on combined heat and power plants revealed data on costs, the potential of the system, and the barriers, and information on how combined heat and power plants function. The document had tables on district heating technologies and markets, and the types of fuel used to power this generation system. At the end of the document, a data table showed projections of energy efficiency and net production costs in the years 2020 and 2030."

Trelstad, B. (2011, January 6). OSU Energy Center first Platinum LEED-certified power facility in nation. Retrieved December 6, 2018.

“This online news article displayed a Platinum LEED certified green combined heat and power plant in Oregon State University. This power plant combines cogeneration with green infrastructure which recycles stormwater into the steam systems within the power plant. The cogeneration plant also recycles the water to raise efficiency, and provides educational purposes for environmental studies at the University.”