New York State Energy Research and Development Authority

Road-Based Energy Harvesting for Distributed Generation

Final Report

December 2014

Report Number 14-35

nyserda
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Road-Based Energy Harvesting for Distributed Generation

Final Report

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Notice

Abstract

Energy Intelligence conducted a feasibility study for a demonstration project at the Eastman Business Park (EBP) in Rochester, NY. The proposed technology is an innovative road-mounted energy-harvesting system that converts waste energy from braking vehicles into available electricity onsite. EBP is a very large industrial complex that features two security gates to the facility (one on the eastern boundary of the property and one on the western boundary) through which all vehicular traffic must pass to enter or exit. Furthermore, all vehicles must stop to swipe a security badge or be checked in by security personnel, therefore wasting energy as heat loss and friction while braking. Capturing this waste energy is a suitable application for the proposed technology and could bring substantial economic benefits to EBP. The study involved measuring traffic and other conditions onsite and simulating those conditions on a prototype system to estimate energy harvesting potential and improve the design.

The key tasks of the study centered on a thorough site assessment and technical analysis to adapt and improve the technology based on site requirements. The site assessment focused on traffic flows and energy infrastructure onsite and consisted both of manual observation and automated data collection by commercial devices. Technical analysis was primarily conducted remotely from the study site, simulating site conditions in a test environment to iteratively modify design and evaluate the impact on performance. Furthermore, the study evaluated environmental and economic factors that were relevant to a potential demonstration. Ultimately, the study concluded that one of the two security gates at EBP would be a suitable site for a demonstration project. A demonstration at EBP would mainly validate implementation and performance of an end-to-end system, rather than maximizing output and returns.

Keywords

Energy harvesting, energy recovery, distributed generation, onsite generation, kinetic energy, waste, vehicles.

Acknowledgments

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Acronyms and Abbreviations

EBP	Eastman Business Park
ESA	Energy Savings Agreements
ft	feet
GWh	gigawatt-hour
hr	hours
In	inches
kW	kilowatts
kWh	kilowatt hours
LCOE	Levelized Cost of Electricity
m/s	meters per second
min	minutes
mph	miles per hour
MW	megawatt
MWh	megawatt-hour
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
PAG	Project Advisory Group
s	seconds
W	watts
Wh	watt hours

Executive Summary

This feasibility study considered the physical, operational, and economical feasibility of deploying road-based energy harvesting systems at the Eastman Business Park (EBP) in Rochester, NY. The technology in development proposes to convert wasted kinetic energy from braking vehicles into renewable electricity that can power equipment onsite, thereby reducing electricity expenses.

The study focused on two particular locations at EBP where concentrated vehicular traffic entering the complex must stop at one of two security gates, thereby dissipating kinetic energy through heat loss and friction. The road-based energy harvesting systems could be installed at each of the two security gates and generate electricity with each passing vehicle to power equipment nearby. For example, the systems could supply electricity to a series of streetlights or to administrative offices in close proximity, thereby offsetting commercial purchases of energy and reducing operating expenses. Furthermore, if alternative sources of energy produce harmful emissions, then introducing the proposed form of renewable generation would have a positive environmental impact.

The study consisted of several work streams aimed at collecting measurements and data at or about the study site and using that data to simulate conditions on a test prototype to evaluate technical and economic feasibility of a demonstration project. Through manual efforts and automated measurement devices, the team collected granular data about traffic flows onsite and was able to gain a much clearer, quantified understanding of energy available to the road-based systems. Alongside site assessment activities, the study enabled an iterative testing, evaluation, and modification cycle to improve the overall system design in light of study site conditions. As part of this cycle, the study uncovered unmet market needs where certain parts and components did not exist within certain ranges of functionality and specification relevant to the target applications.

Ultimately, this study conducted important research and analysis in tuning and optimizing critical components and system architecture to match local site requirements and conditions and uncovered the complexity of designing and optimizing the coupled power conversion unit that is tasked with transforming pulses of hydraulic flow into conditioned electrical power. The results of the study are the completion of a thorough site assessment, modification of the device design, simulation and iterative testing to validate projected performance metrics, and a decision as to whether or not the studied gates are a good fit for a full-scale demonstration project.

The study found that one of the two studied security gates would be physically and operationally practicable. Both gates presented appropriate spacing and dynamics with slowing vehicles; however the lesser volume of vehicles and number of hours of operation of the smaller gate was determined not to be feasible for a demonstration project. In contrast, the larger of the two gates makes for a very compelling demonstration site, in terms of potential energy generation, site layout, and interconnection with local equipment.

1 Introduction

Road-based energy-harvesting solutions create a unique opportunity to make use of existing real estate (roads) and a significant, free, and currently untapped energy source (vehicles' waste energy). Vehicles waste much of their translational kinetic energy through heat, friction, and pressure on internal mechanics, particularly when they slow down. In fact, between 74% and 86% of energy consumed by vehicles is lost, and a combined 10% is dissipated while braking as waste heat and friction. All of this waste could be put to better use if harnessed and used to power facilities in place of more expensive alternatives. Many of the commercial and industrial facilities that would be good candidates for the technology, such as parking garages, distribution centers, port terminals, and toll plazas, spend millions of dollars per year on electricity and stand to benefit in substantial cost savings. Furthermore, many distributed generation solutions for remote and off-grid facilities, like diesel generators, are powerful, but expensive and produce harmful emissions. Therefore, savings could be reflected both in cost and sustainability improvements.

The global opportunity for road-based energy harvesting is tremendous, but the market is still nascent because currently no solution exists to cost-efficiently harvest this waste energy at scale. The few known research attempts at road-based generation solutions have applied different core technologies, and all failed to achieve competitive economics because of high upfront cost and very low output, among other issues. For example, using piezoelectric materials to harvest energy from vibration created in roads is compelling because it is minimally intrusive to vehicles, but is not economically feasible because it produces microwatts of power and requires expansive installation to achieve scale. Conversely, more mechanical designs that have been proposed require substantial excavation and roadwork for installation and present upfront costs that site owners are not willing to take on. Other generation alternatives at road sites with reduced speed zones are limited because of space, climate, or energy requirements. For example, many sites do not have sufficient space for renewable alternatives, such as large solar installations or wind turbines. Research and development efforts to date have demonstrated that the potential energy that could be harvested on roads is significant, and the challenge and opportunity lies in developing a system that is simple to install and maintain, minimally obstructive to facility operations, and economical enough to build and operate so that it is compelling to site operators and competitive with alternative generation solutions.

This study evaluated the technical and operational feasibility of deploying an innovative road-mounted energy harvesting system at the Eastman Business Park in Rochester, NY. The proposed technology is a flat, compact, hydraulic based system that is mounted right on top of the road surface and generates electricity as vehicles drive over, presenting the economic efficiency, compact form factor, and durability required for competitive positioning in the commercial distributed generation market. The system is intended for use on stretches of road where vehicles are required to slow down or stop, such as entry/exit gates, off- and down-ramps, and a variety of checkpoints. Vehicles passing over the systems will transfer kinetic energy otherwise dissipated as heat loss and friction while braking through the system to generate electricity. More specifically, passing vehicles will drive over a compact mat or pad and push pressurized hydraulic fluid contained within, building pressure to run a hydraulic motor and ultimately generate electricity. In full form, these systems may self adjust in real-time to optimize performance and maximize efficiency in response to dynamic traffic and vehicle conditions, requiring sophisticated control mechanisms and computer operated commands.

If successful, the proposed technology would revolutionize distributed renewable energy capabilities at a wide range of commercial and industrial facilities. At scale, the technology will significantly reduce onsite energy generation costs, offset commercial purchases and the associated harmful emissions of conventional generation sources, and bring economic benefit to the local economy through job creation. A scale installation is projected to have a levelized cost of electricity (LCOE) of $0.07/kWh, 1-2 year payback period, annual generation over 1 GWh, and 750 ton CO_2 equivalent emission reduction, where a single installation will be composed of many individual systems strung together. In fact, an installation can easily be scaled up or down to effectively match site conditions and onsite energy requirements with system specifications. Globally, the value of potential energy that could be generated by this technology is well over $10 billion annually. In New York State, there are estimated to be over 150 facilities where this technology could be deployed in the near-term, making the potential economic value of associated electricity sales and other benefits achieved reach tens of millions of dollars annually.

1.1 Energy Intelligence

Energy Intelligence is an innovative cleantech company and an emerging leader in the energy harvesting space that is developing ultra-compact, road-mounted technology that converts wasted kinetic energy from braking vehicles into renewable electricity. The company was incorporated in 2010 and has made significant progress in development of intellectual property and technical models and prototypes over the past few years. In fact, the company has been issued two patents, has several more applications pending, built numerous bench-top models and test rigs, and has gained significant traction in the market with potential customers and operating partners.

The company's founders, Daniel Shani and Nissim Shani, together with several other staff members and contractors jointly represent the operational, technical, and business skills necessary to commercialize this technology and they successfully executed the project plan for this study. The core team members bring experience in entrepreneurship (several successful ventures from founding through exit), engineering, systems development, quantitative analysis, manufacturing, procurement, operations, and business development. Daniel Shani coordinated all efforts across the various project stakeholders, and he performed much of the analysis and reporting as well. Nissim Shani was present at all projects site visits as well as visits to Aslan Controls, a subcontractor, in Beacon, NY. His contributions centered on his involvement with deployment considerations and implementation plans. Energy Intelligence personnel contributed time to data collection and analysis, testing, technical design modification, research, and other data management.

1.2 Technology

Energy Intelligence is developing ultra-compact, road-mounted generator systems that turn the motion of vehicles into electricity and represent a global opportunity in the road-based energy harvesting space. The system will be deployed at designated slowdown areas, for example entry gates, weigh stations, or toll plazas, and will supply power locally to site operators. The solution is competitive with other generation technologies and aims to substantially lower onsite electrical expenses. Key objectives for ongoing development include trying to make the system as compact (and easy to install) as possible, adaptable to varying vehicle types and road conditions, and economical (lowering production and maintenance costs and increasing output). Though several versions of the system have been built and tested, its modification to specific site conditions and requirements was a focal point of the study to optimize performance and future economic potential.

1.3 Eastman Business Park

Eastman Business Park is a 1,200-acre technology center and industrial complex located near Lake Ontario in Rochester, NY, and is currently home to more than 35 companies and on-site suppliers. With more than 1.5 million square feet of available manufacturing, laboratory, office and warehouse space, and over 300 acres of prime industrial developable land, EBP is an ideal site and partner to help startups, like Energy Intelligence, carry out R&D, manufacturing, testing, and demonstration of their innovative technologies. Of particular relevance to Energy Intelligence, EBP operates an independent electrical grid and can easily and efficiently facilitate interconnection and integration between Energy Intelligence’s road-based energy-harvesting system and the local grid. Functional demonstration of power generation technology is critical in early stages of development, and EBP was excited to help Energy Intelligence overcome this hurdle by serving as site partner and host to a demonstration of the company’s unique solution.

During the course of the project, EBP was an engaged and excited partner and provided resources and support to help facilitate the completion of project activities. Broadly, EBP staff provided facility access, onsite know-how, and administrative assistance, coordinated on-site personnel and protocols, and participated in key project meetings. Furthermore, EBP staff contributed time to assist in data gathering and analysis, specification of requirements for a potential demonstration project, preparation of documentation and materials (e.g., site maps, traffic data), providing overviews of facilities and on-site equipment, and participation in working sessions.

1.3.1 Energy On-site

Recycled Energy Development (RED-Rochester) acquired all of Kodak's utility infrastructure at EBP in December 2012 and finalized transition terms in September 2013. The utility business today provides electricity, steam, chilled water, compressed air, industrial water, sewer services, nitrogen, natural gas, and potable water to EBP's more than 40 owners and tenants. RED-Rochester plans to make significant investments over the next five years in a variety of energy efficiency projects and to convert the plant from coal to natural gas. The power plant on-site has an electric generating capacity of 125 megawatts and also can deliver a similar amount of thermal energy to EBP in the form of steam and chilled water.

Bernie Nee, general manager of RED-Rochester, was the point person for the study and participated in key meetings, provided information about onsite equipment and operations, and toured facilities with Energy Intelligence personnel.

1.3.2 Targeted Demonstration Sites

The study focused on two potential installation sites at EBP: Gate 24 and Gate 340. The two access points are the only way to enter and exit the facility. These two locations, the East and West entrances to EBP, have been selected not only because all vehicles that enter or exit the facility must pass through one of these two gates, but also because their layout is appropriate with clearly defined traffic lanes, every vehicle must stop to swipe a security badge or check in with security offices, and they are within the edge of the fenced security perimeter. These elements together create an opportunity to capture energy wasted by vehicles entering the facility under controlled conditions as well as a suitable layout to install the proposed energy harvesting systems along with digital displays to exhibit real-time statistics about the energy generated and vehicular traffic activity on-site.

1.4 Project Participants

Participants in the study included management and staff of Energy Intelligence, engineering subcontractors, including Aslan Controls, Eastman Business Park personnel including Michael Alt, Sarabeth Litt, Robin Chontosh, and Jack Sherwood, Kodak Security Personnel, including Regina Helfer, RED-Rochester personnel including Bernie Nee, and NYBEST personnel including Jim DeJager. Project Advisory Group members are identified in the next section.

2 Project Initiation

Energy Intelligence conducted a 6-month feasibility study to evaluate the potential demonstration of its road-mounted energy harvesting technology at the Eastman Business Park in Rochester, NY. To prepare this technology for a potential (not currently funded) demonstration at the study site, Energy Intelligence measured and analyzed site characteristics and requirements (including environmental factors), made adjustments to the initial system design for the specified site, and evaluated the impact of those adjustments on a potential demonstration at the study site. Early project tasks focused on site assessment to validate vehicular traffic counts and characteristics and identify interconnection requirements with local equipment. The project followed with an assessment of the technical feasibility and economic analysis of deployment to the site given the validated site details. Finally, preliminary notes about deployment considerations such as installation requirements, data acquisition and management, and maintenance plans were drafted for the specific site.

The project work was conducted in several locations, including the study site in Rochester, NY, Aslan Control's workshop in Beacon, NY, and Energy Intelligence's office and facilities in Greentown Labs, a co-working and prototyping space for energy and cleantech companies in Somerville, MA.

2.1 Kickoff Meeting

In the first phase of the project, the team dedicated a significant amount of time to preparing documentation and materials to help setup and manage the project, gathering preliminary site information about the Eastman Business Park, and beginning work with the project subcontractors relating to technical analysis. However, before any of that work began, Energy Intelligence coordinated all involved parties for a kickoff meeting at NYSERDA's offices to facilitate introductions, provide an overview of the technology and its applications, describe overall project objectives, and review project plans. Throughout the meeting participants raised questions regarding methodology, technical limitations, deployment considerations, and economics, which were discussed and recorded for further review during the project. The kickoff meeting represented the official start of the project and the first of two touch points with all project stakeholders with the second being the final wrap-up meeting.

2.2 Project Advisory Group

The Project Advisory Group (PAG) was assembled to review progress, help guide project activities, and provide a varied, objective perspective on the work being conducted throughout the course of the project. A number of people and organizations were solicited to support the project by serving on the PAG. The final list of individuals on the PAG was:

- Joseph Tario, Senior Project Manager – NYSERDA
- Daniel Shani, CEO – Energy Intelligence
- Jack Sherwood, Program Manager, Facilities – Eastman Business Park
- Sarabeth Litt, Marketing Manager – Eastman Business Park
- Bernie Nee, General Manager – RED-Rochester
- Gary Tatro, Research Engineer – NYS Thruway Authority
- Gary Frederick, R&D Director – NYS Department of Transportation

The PAG for this project included facilities and marketing managers from the study site, the General Manager from the local (recently privatized) utility operator, and, in support of potential widespread transportation deployment, representatives from the NY Thruway Authority and the NY Department of Transportation. Gary Tatro and Gary Frederick were unable to join meetings due to travel schedules and other commitments, but were kept abreast of project updates and communications. Throughout the study, the PAG received several communications, participated in the kickoff and wrap-up meetings, and individual members were reached out to as needed for involvement in particular areas of expertise.

2.3 Research Method

The project plan consisted of five primary work streams:

- Project management.
- Site assessment.
- Analysis of technical feasibility.
- Analysis of economic viability.
- Deployment plans.

At a high level, all project tasks followed an iterative process to collect information about the potential demonstration sites and analyze it in technical and economic terms to evaluate system performance and demonstration feasibility. The research method put in practice entailed observing and measuring site conditions and simulating those on physical test setups to measure, modify, and optimize system prototypes. Many tasks were completed in parallel, with some results dependent across tasks and some completely independent. For example, measurements and data were collected at the study site independently of other tasks, whereas incorporating that data into system design and testing was an iterative and interdependent process. Most work throughout the course of the project was concentrated on Tasks 2 and 3, given that there was substantial data collection and analysis and rigorous experimentation with the test prototype based on simulated study site conditions.

The project stakeholders raised many questions – ranging from technical details to project timing and logistics – that helped spark productive discussions and shape research objectives. Examples of questions and topics raised include:

- System versatility: How will the system adapt to varying vehicle types on public roadways (e.g., motorcycles vs. passenger vehicles vs. trucks)?
- System durability: How will materials/components stand up to snow/rain/salt/cold?
- System capacity/performance: What can the system power? At what scale? With what economic payback?
- System design/application: What alternative designs have been considered? How can the system be more compact? Can the design be adapted for railways/trains?
- Legal questions: How do installations on public thruways differ from private sites? What issues will there be with titles, liability, and other factors?

3 Discussion of Key Activities

The project activities that commanded the most effort and resources related to the study site assessment and technical analysis of the test prototype. The site assessment entailed gathering information about site conditions and requirements from multiple sources and processing the data to make it usable for technical and economic evaluation. The technical analysis interpreted site conditions and translated them into design requirements that were iteratively tested and incorporated into system design. The following sections outline some of the specific tasks completed and highlight selections from the resulting data, analysis, and learning.

3.1 Site Assessment

The activities completed throughout the project aimed at assessing the study site ranged from direct data collection on-site to better understanding facility operations and management. The primary area of interest, as far as data collection is concerned, was quantifying and mapping the vehicular activity on-site. This data collection was carried out in three ways – deployment of accurate, commercial grade traffic counters and classifiers on facility roads, manual classification and identification of vehicles entering the facility through security logs, and qualitative assessment of vehicular activity and movement throughout the facility. Secondary to collecting and understanding this data, it was necessary to understand energy-related operations, capabilities, and policy currently used on-site. This was achieved through direct conversation and discussion with facility personnel, touring and direct observation of and within facilities, and general qualitative observation externally. The objective of this latter series of tasks was to determine the best use of additional energy generated on-site and to identify the means by which to connect the system and distribute the energy.

Early discussions and interactions at EBP included Michael Alt, executive director of EBP, and the project liaisons: Sarabeth Litt, EBP marketing manager; Jack Sherwood, EBP facilities manager; and Robin Chontosh, facility management. All required EBP paperwork, security registration, identification badges, office/facility setup, and other administrative requirements were successfully completed during the first visit. The individuals named above contributed significant work effort in anticipation of the site visit to prepare and complete each of the tasks previously listed, as well as those relating to data collection and measurement onsite.

Study site visits included overview presentations and tours of different facilities within EBP and numerous discussions of relevant application points for the energy harvesting system and potential installations. The most likely candidates for installations onsite and the focal points of the site assessment were the two main entrances to the facility, one on the east side and one on the west. These both host permanent security booths where all traffic has to pass and swipe credentials in order to enter. From these, the critical variables and site factors to be measured were defined for further assessment and evaluation. Each gate is described in more detail in the following paragraphs.

Gate 24 is the eastern entrance to the facility and features a two-lane pass (1 in, 1 out) right next to a large security office and a pedestrian turnstile entrance. This entrance sees almost exclusively passenger vehicles, with few exceptions for delivery trucks or service workers. This is a highly visible gate, close to nearby EBP administrative and fully occupied office buildings, though it processes relatively less of the traffic that enters the facility. There is ample space on either side of the security badge/check in stations, both inside and outside the facility, for installation of additional hardware and local displays. This gate is closed at night, with the secure perimeter fence locked and the security office unoccupied.

Gate 340 is the western entrance to the facility and also features a two-lane pass (1 in, 1 out) with a smaller security booth stationed in the middle of the road. This gate processes the relative majority of traffic that enters the facility, including a large portion of trucks and service vehicle that enter nearer to the facilities, industrial plants, and loading docks on that side of EBP. The types of vehicles processed at this gate range from lightweight passenger vehicles, to midsized SUVs, to service vans, to mid-weight freight trucks, to fully loaded long-haul trucks. This is a 24/7 entrance and sees traffic at all hours of the day and night. The lanes are more constrained than at Gate 24, in the sense that there is a small barrier wall along one side of the road and a narrow pass through a security fence just inside the facility.

3.1.1 Traffic Counting and Classification

EBP staff supported ongoing project coordination and communications, as well as on-site security-related protocol and authorizations, which were especially important in relation to installing and using traffic counting equipment onsite. Furthermore, EBP assisted in manually collecting information about site activity and classifying vehicular traffic. This information was very useful in estimating energy potential onsite in addition to understanding on-site electrical requirements, power generation capabilities, and site layout.

3.1.1.1 Manual Data Collection

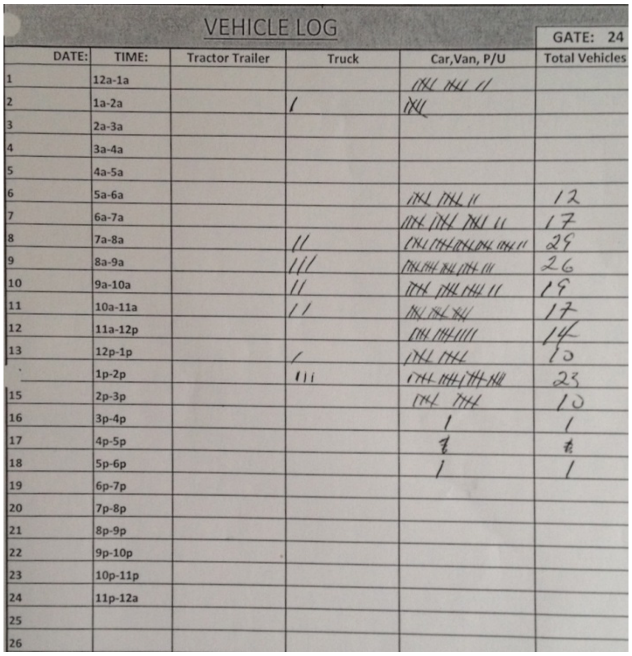
Energy Intelligence and EBP staff collected traffic data about vehicular activity onsite through security gate records and access badge swipes. Eastman Kodak Worldwide Corporate Security was instrumental in the process – monitoring and recording vehicular activity manually on a daily basis. This support provided important information about site activity and traffic logs, as well as simple aggregations across different categories of vehicle classification. The information later served to validate and cross-check data collected at both gates with traffic classifiers installed. The manually collected data was transcribed into spreadsheets, sorted, processed, analyzed, and further manipulated to create useful graphs and to draw meaningful conclusions.

Figures 1 through 5 illustrate the types of analyses conducted on the raw traffic data collected manually at both gates. Trend lines from daily reports or averages calculated for the entire period clearly reflect traffic activity over the course of the day and enable forecasting of expected flow.

Figure 1. Sample Vehicle Log Recorded by Eastman Kodak Security

Single, daily vehicle log for Gate 24 reflecting the hourly tallies of different vehicle types (e.g., cars, trucks, tractor trailers) passing by the security booth.

Source: Energy Intelligence



VEHICLE LOG — GATE: 24

DATE:	TIME:	Tractor Trailer	Truck	Car,Van, P/U	Total Vehicles
1	12a-1a				
2	1a-2a				
3	2a-3a				
4	3a-4a				
5	4a-5a				
6	5a-6a				12
7	6a-7a				17
8	7a-8a				29
9	8a-9a				26
10	9a-10a				19
11	10a-11a				17
12	11a-12p				14
13	12p-1p				10
	1p-2p				23
15	2p-3p				10
16	3p-4p				1
17	4p-5p				1
18	5p-6p				1
19	6p-7p				
20	7p-8p				
21	8p-9p				
22	9p-10p				
23	10p-11p				
24	11p-12a				
25					
26					

Figure 2. Sample Resultant Calculations from Manually Collected Vehicle Logs, Gate 340

Sample spreadsheet mapping out daily vehicular activity, by hour, at Gate 340 and calculating hourly averages and cumulative totals to analyze traffic patterns on-site.

Source: Energy Intelligence

	5/24/13	5/25/13	5/26/13	5/27/13	5/28/13	5/29/13	5/30/13	5/31/13	6/1/13	6/2/13	6/3/13	6/4/13	6/5/13	6/6/13	6/7/13	Hourly	Cumulative
0:00		2	1	2	2	4	4	5	2	0	0	0	8	4	4	4	4
1:00		3	2	1	2	3	2	4	1	1	1	4	1	2	2	3	6
2:00		3	0	0	4	2	3	1	9	0	2	5	2	5	2	3	9
3:00		3	2	0	2	1	2	2	8	0	0	6	5	3	12	4	14
4:00		10	0	2	9	4	13	6	6	0	0	13	6	13	55	15	28
5:00		26	5	6	60	59	52	56	14	7	5	52	52	51	52	54	83
6:00		9	2	4	86	63	97	90	9	4	5	89	94	97	85	88	170
7:00		4	4	3	112	115	134	114	5	0	5	69	109	104	115	109	279
8:00		13	10	3	98	103	81	83	6	4	5	89	64	87	73	85	364
9:00		2	7	10	83	102	89	83	8	7	5	91	88	60	64	83	447
10:00		7	4	8	97	104	85	81	8	7	5	55	68	82	60	79	526
11:00		13	2	5	120	110	112	84	6	5	5	93	91	83	82	97	622
12:00		7	0	6	114	107	135	89	7	2	5	84	98	83	81	99	721
13:00		9	7	4	85	93	70	68	2	2	5	59	78	57	88	75	796
14:00	90	5	4	8	119	96	126	108	5	9	5	113	84	87	90	103	899
15:00	56	1	5	2	116	86	100	82	6	10	5	75	62	82	59	83	982
16:00	53	10	4	11	56	77	61	68	5	5	5	41	72	57	48	60	1042
17:00	35	25	16	16	52	60	60	35	12	12	5	54	48	57	39	51	1092
18:00	10	2	1	2	24	19	17	6	0	3	14	19	20	18	13	17	1109
19:00	12	2	7	3	2	7	27	9	3	1	10	8	8	10	3	9	1119
20:00	3	4	1	1	8	8	5	4	2	2	3	5	4	9	6	6	1125
21:00	1	5	3	5	2	9	10	8	0	6	4	4	8	8	3	7	1131
22:00	14	12	8	14	17	18	29	15	6	16	13	14	12	13	14	17	1148
23:00	2	4	3	3	19	12	9	1	5	3	14	13	13	4	7	10	1157
24 hr total	276	181	98	119	1289	1262	1323	1102	135	106	126	1055	1095	1076	1057	1157.375	
	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday		

Figure 3. Sample Chart Created from Vehicle Log Data, Average Daily Vehicular Activity

Visual representation of average daily activity for vehicular traffic at Gate 340, reflecting hourly totals and cumulative total over the course of the day.

Source: Energy Intelligence

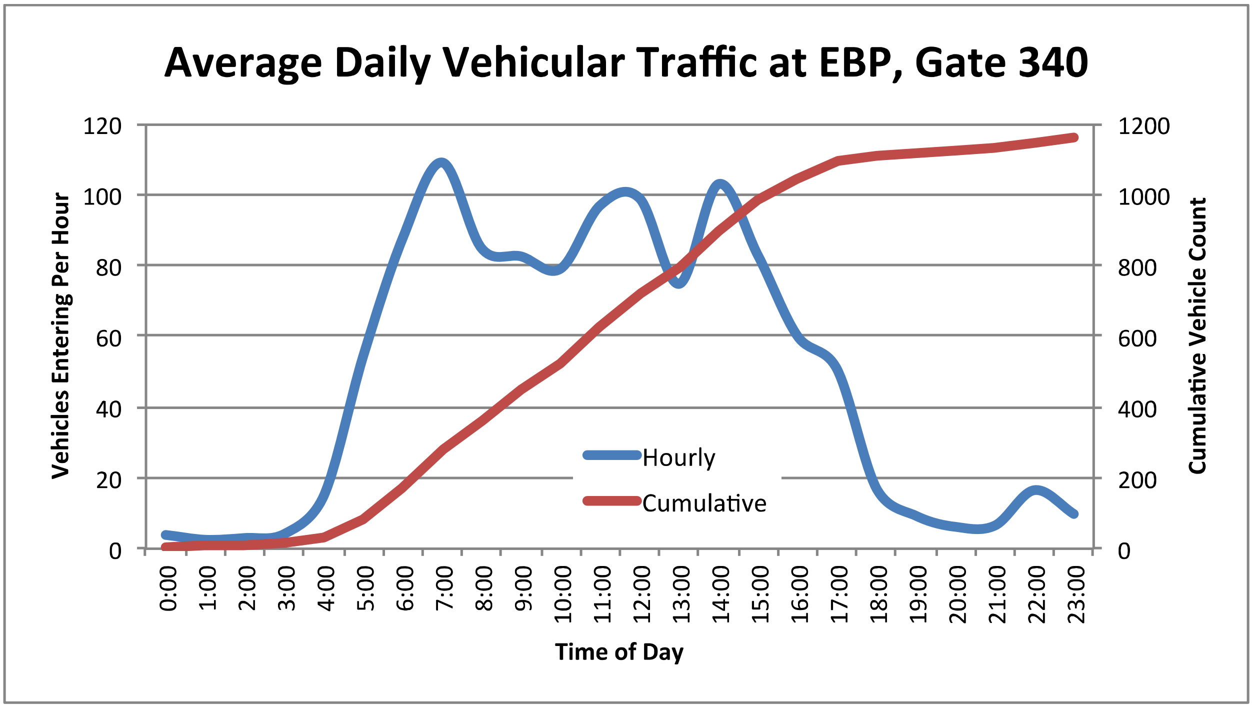


Figure 4. Chart Created from Vehicle Log Data, Average Daily Totals by Vehicle Type, Gate 340

Visual representation of average weekday activity for vehicular traffic at Gate 340, broken down by hourly totals for each vehicle type (i.e., car, truck, tractor trailer).

Source: Energy Intelligence

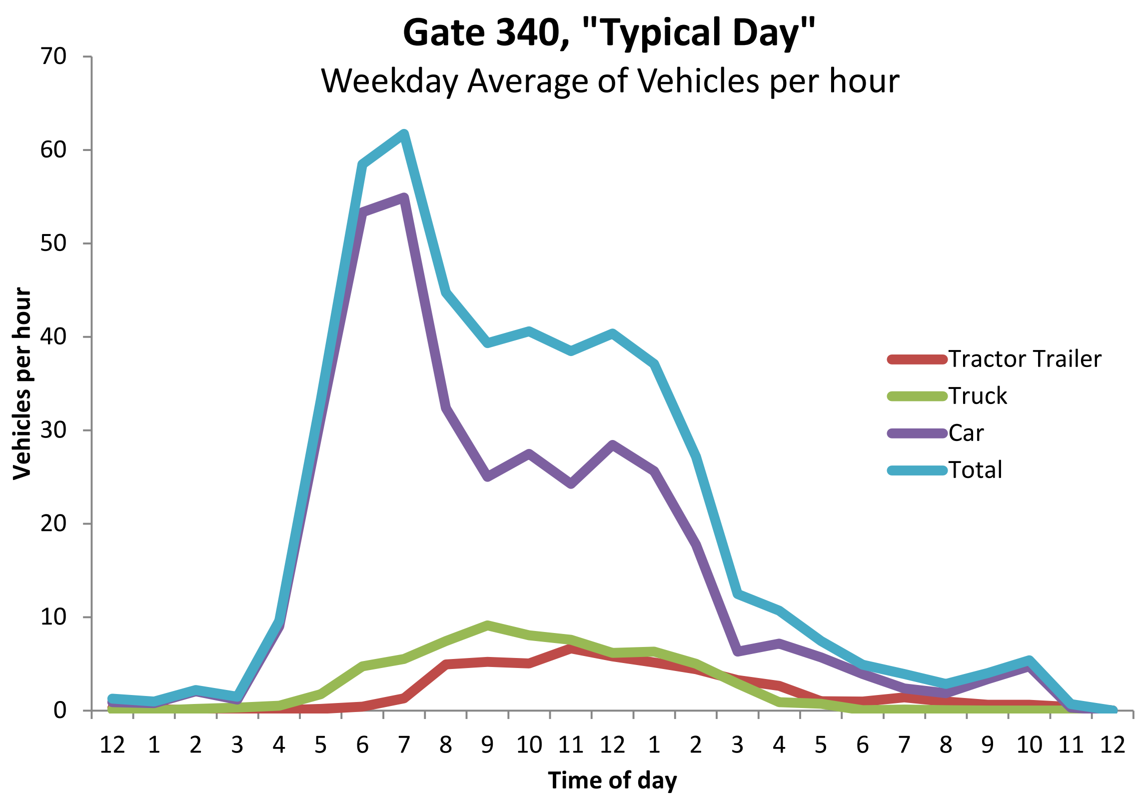


Figure 5. Single Day Report, Gate 340

July 9, 2014 data displays hourly totals for vehicle traffic broken down by vehicle type (car, truck, tractor trailer) in table and chart form. Traffic trends over the course of the day and peak activity hours are clearly visible in chart and are detailed in accompanying table form.

Source: Energy Intelligence

Date	Time	Tractor Trailer	Truck	Car	Total
7/9/14	12	0	0	1	1
Gate: 340	1	0	0	1	1
	2	0	0	2	2
	3	0	0	1	1
	4	0	2	7	9
	5	0	3	37	40
	6	2	12	64	78
	7	2	9	69	80
	8	3	4	39	46
	9	6	5	31	42
	10	3	6	32	41
	11	8	5	25	38
PM	12	5	7	40	52
	1	6	10	37	53
	2	3	3	22	28
	3	7	4	6	17
	4	4	1	7	12
	5	1	1	6	8
	6	0	0	1	1
	7	0	0	1	1
	8	2	0	1	3
	9	2	0	3	5
	10	1	0	7	8
	11	1	0	1	2
	12	0	0	0	0
				Total	569

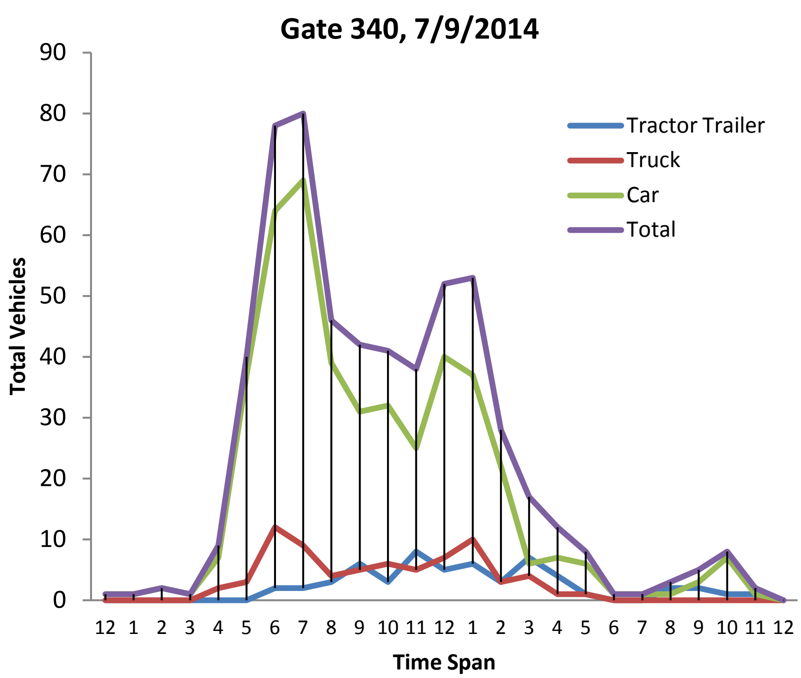


Figure 6. Chart Created from Vehicle Log Data, Average Daily Totals by Vehicle Type, Gate 24

Visual representation of average weekday activity for vehicular traffic at Gate 24, broken down by hourly totals for each vehicle type (i.e., car, truck, tractor trailer).

Source: Energy Intelligence

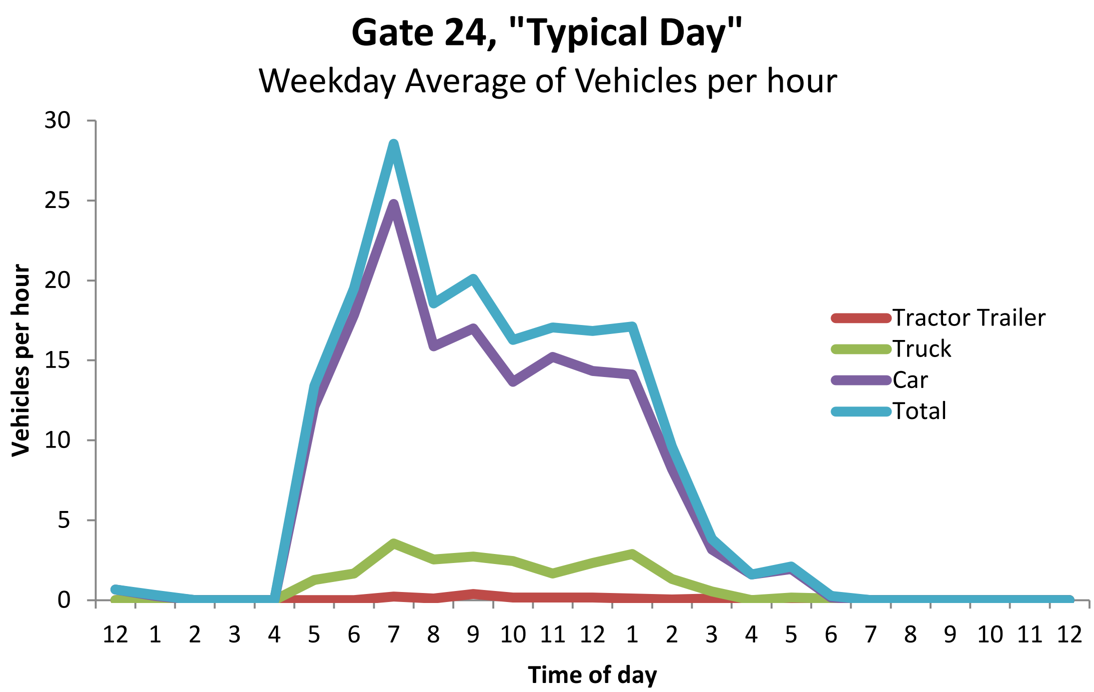
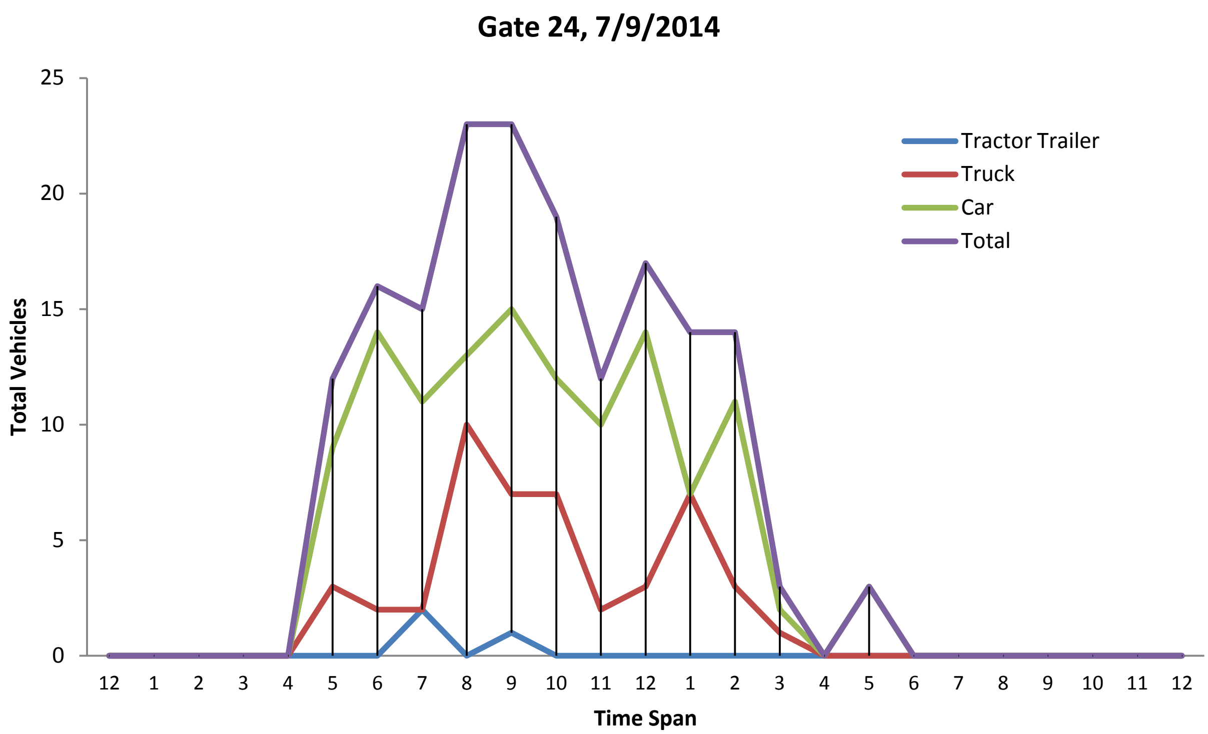


Figure 7. Single Day Report, Gate 24

July 9, 2014 report displays hourly totals for vehicle traffic broken down by vehicle type (car, truck, tractor trailer) in chart form. Traffic trends over the course of the day and peak activity hours are clearly visible in chart.

Source: Energy Intelligence



3.1.1.2 Use of Traffic Classifiers for Data Collection

In addition to the manual collection of traffic data that was carried out throughout the project, Energy Intelligence installed sophisticated traffic monitoring and classifying equipment onsite to collect and analyze more granular data about traffic patterns and conditions.

First, the Contractor conducted substantial research to evaluate and source the best equipment for this site assessment and ultimately selected DiamondTraffic as its preferred vendor. Online research was conducted and calls were made to numerous vendors, including DiamondTraffic, TimeMark, JAMAR Technologies, Metro Count, TRAFx, CityLab, and Sensource. Energy Intelligence evaluated vendors and their products based on capabilities, limitations, price, ease of deployment, lead-time, and other key metrics. Two products from DiamondTraffic were selected as the best fit: The Apollo and The RoadRunner 3. Both products are portable traffic counters that offered the capabilities and flexibility necessary for proper assessment of traffic activity at EBP. They can be setup for different lane configurations and keep track of vehicle count, speed, classification, axle spacing, and other data points that enabled robust analysis and reports. Each device came with a software package that enabled the creation of specific test programs tailored to each gate.

Once purchased, the equipment was tested by Energy Intelligence at its private facilities as well as with the project Subcontractors. The equipment can be set up many different ways and programmed to track and record different parameters and types of data given, for example, different lane and road setups. Through this pre-deployment testing, the Energy Intelligence identified and programmed the best data acquisition setup for EBP. For example, the layout decided on for Gate 24 consisted of four road tubes, two pairs of alternating length, laid out across two lanes of opposite direction, to classify the vehicles passing in both directions. Exact spacing between tubes and pairs of tubes was necessary for the equipment to record data accurately. This layout enabled the collection, for example, of vehicle speed, length, classification, frequency, axle spacing, and other relevant parameters.

EBP project liaisons introduced Energy Intelligence to security personnel at the Eastman Business Park, operating as part of Kodak Worldwide Security and responsible for all on-site security protocol and management at EBP. The Contractor Energy Intelligence had a series of discussions with key security personnel regarding protocol and requirements for equipment installations of this kind and coordinating necessary approvals, accompaniment on installation day, and other issues. Regina Helfer, Head of Eastman Kodak Corporate Security for the Americas, was the point person on the project. Energy Intelligence described to her the context of the project and involvement with EBP and informed them of the objectives in site assessment tasks. The priorities and objectives were noted for deploying equipment and the broader team discussed possible solutions, including specific locations, arrangement, security questions, and timing considerations (when there would be the least activity onsite) for installation. Energy Intelligence was authorized to install equipment on a specific day and time with an onsite security team helping to coordinate traffic and provide extra safety measures. Given strict onsite security protocol, even taking photographs of the study site needed to be cleared with EBP security personnel.

With the help of EBP staff and security personnel, the equipment was successfully deployed, monitored, and removed, producing a rich set of data. To install the equipment onsite, the proper Eastman Kodak security protocol had to be followed. Regina Helfer supported the project in terms of security protocol and authorizations. On the day of installation, two security personnel escorted Contractor staff members to each of the two gates/equipment installation locations to oversee the process and control traffic. At both gates, all vehicles must stop to either swipe their pre-registered security badges or be checked in by a security officer. Therefore, these checkpoints offered the right slow down requirement to install the proposed energy harvesting systems, given that vehicles waste energy while braking. Figure 8 and Figure 9 show the equipment installed at each of the two gates at EBP.

Figure 8. Two-lane Traffic Classifier Installed at EBP Gate 340

RoadRunner III traffic classifier from DiamondTraffic was installed at Gate 340, EBP's western gate. Top row photos exhibit road tubes stretched across two lanes of traffic to collect data for incoming and outgoing traffic, with the traffic classifier secured to perimeter fence infrastructure off to the side of the road. Bottom row photos show a tractor-trailer in motion driving over the road tubes.

Source: Energy Intelligence

Figure 9. Two-lane Traffic Classifier Installed at EBP Gate 24

Apollo traffic classifier from DiamondTraffic were installed at Gate 24, EBP's eastern gate. Top row photos exhibit four road tubes stretched across two lanes, set up with pairs of alternating length tubes to classify vehicles on the incoming and outgoing lanes. The traffic classifier is secured to a security storage structure off to the side of the road. Bottom row photos shows a vehicle entering the facility and driving over the road tubes.

Source: Energy Intelligence

The equipment actively monitored and recorded traffic activity for a period of roughly 6 weeks, and then Energy Intelligence sorted, cleaned, processed, and analyzed the data in order to prepare reports for further review and forecasting. Figure 10 through 14 are sample reports from the data. At the completion of the data collection period, Energy Intelligence went through a similar process for removal of the equipment as with installation of the equipment. Security protocol and authorization was required, and security personnel accompanied Contractor staff and controlled traffic while removing equipment on the roads.

Figure 10. Weekly Traffic Report, Gate 340

Report produced for a week's worth of data collected at Gate 340, from July 7 to July 13. The data is broken down by day and by hour and aggregated across both columns and rows. Additional analysis is provided in the bottom third of the chart, highlighting peak activity hours during the morning, midday, and afternoon hours. These peak figures and weekday versus weekend averages represent much more granular data than was collected manually in the earlier stages of the project.

Source: Energy Intelligence

Station: EBP Gate 340 *Lane #1 (West) Data From 13:15 - 06/25/2014 To: 02:29 - 07/29/2014*

Lane #1 (West) Weekly Data 07/07/2014 to 07/13/2014

Time	07/07 MON	07/08 TUE	07/09 WED	07/10 THU	07/11 FRI	Weekday Average	07/12 SAT	07/13 SUN	Weekend Average	Week Average
- AM -										
12 - 1	0	0	3	1	2	1	1	0	1	1
1 - 2	1	2	1	2	3	2	3	2	3	2
2 - 3	1	4	2	1	4	2	2	0	1	2
3 - 4	0	0	1	1	2	1	2	0	1	1
4 - 5	3	12	11	9	11	9	10	6	8	9
5 - 6	15	42	38	50	43	38	35	11	23	33
6 - 7	14	65	79	89	91	68	64	14	39	59
7 - 8	1	88	82	101	92	73	74	7	41	64
8 - 9	1	48	58	67	54	46	51	4	28	40
9 - 10	2	39	67	57	64	46	52	8	30	41
10 - 11	1	49	59	49	74	46	55	5	30	42
11 - 12	5	44	50	60	58	43	61	9	35	41
- PM -										
12 - 1	0	44	53	64	76	47	47	8	28	42
1 - 2	6	69	63	77	68	57	47	4	26	48
2 - 3	4	48	56	50	48	41	49	7	28	37
3 - 4	2	17	21	34	23	19	19	2	11	17
4 - 5	4	10	12	18	26	14	10	8	9	13
5 - 6	7	12	18	22	12	14	16	3	10	13
6 - 7	5	10	11	5	6	7	6	6	6	7
7 - 8	7	5	3	3	5	5	3	2	3	4
8 - 9	1	7	2	4	2	3	2	1	2	3
9 - 10	4	5	11	5	5	6	4	2	3	5
10 - 11	9	12	7	9	5	8	9	4	7	8
11 - 12	0	0	0	4	2	1	2	2	2	1
TOTALS :	93	632	708	782	776	597	624	115	375	**533**
% Avg Day :	17%	119%	133%	147%	146%	112%	117%	22%	70%	
AM (12am-10am) Peak Volumes										
15 Minute :	7	30	30	32	31	25	29	7	15	22
One Hour :	16	96	93	112	102	82	85	14	49	72
P.H.F. :	0.67	0.80	0.78	0.88	0.82	0.82	0.73	0.50	0.82	0.82
PH Begins :	4:45am	6:30am	6:15am	6:30am	6:15am	6:30am	6:30am	6:00am	6:15am	6:30am
Mid (10am-2pm) Peak Volumes										
15 Minute :	5	23	20	38	23	17	21	4	12	15
One Hour :	6	69	65	91	76	57	62	11	36	49
P.H.F. :	0.30	0.75	0.86	0.60	0.86	0.84	0.74	0.69	0.82	0.82
PH Begins :	1:00pm	1:00pm	12:45pm	12:30pm	12:00pm	1:00pm	10:15am	11:15am	11:00am	12:30pm
PM (2pm-12am) Peak Volumes										
15 Minute :	4	16	19	15	17	13	16	4	9	12
One Hour :	11	48	56	50	48	41	49	8	29	38
P.H.F. :	0.69	0.75	0.74	0.83	0.71	0.79	0.77	0.50	0.81	0.79
PH Begins :	9:45pm	2:00pm	2:00pm	2:00pm	2:00pm	2:00pm	2:00pm	4:00pm	2:00pm	2:00pm

Figure 11. Weekday Average Report, Gate 340

Report summarizes average weekday traffic activity at Gate 340, over the entire data collection period. The hourly data is broken down by lane, eastbound and westbound, and total. Additional analysis is provided in the bottom third of the chart, highlighting peak activity hours by lane during the morning, mid-day, and afternoon hours. 15-minute and 1-hour peak intervals represent much more granular data than was collected manually in the earlier stages of the project.

Source: Energy Intelligence

Station: EBP Gate 340 — Weekday Average Summary (by Direction)

Weekday Average Summary (by Direction)

Time	EB	WB	EB+WB	TOTAL
- AM -				
12 - 1	1	2	3	3
1 - 2	1	1	2	2
2 - 3	2	2	4	4
3 - 4	1	1	2	2
4 - 5	3	10	13	13
5 - 6	9	34	43	43
6 - 7	15	63	78	78
7 - 8	25	70	95	95
8 - 9	35	49	84	84
9 - 10	37	44	81	81
10 - 11	38	46	84	84
11 - 12	51	42	93	93
- PM -				
12 - 1	44	49	93	93
1 - 2	40	49	89	89
2 - 3	52	39	91	91
3 - 4	53	19	72	72
4 - 5	34	14	48	48
5 - 6	31	13	44	44
6 - 7	9	5	14	14
7 - 8	5	5	10	10
8 - 9	5	4	9	9
9 - 10	4	4	8	8
10 - 11	4	7	11	11
11 - 12	6	1	7	7
TOTALS :	505	573	1078	**1078**
% Total :	46.8%	53.2%	100.0%	
AM (12am-10am) Peak Volumes				
15 Minute :	11	23	16	16
One Hour :	38	74	50	50
P.H.F. :	0.86	0.80	0.78	0.78
PH Begins :	8:30am	6:30am	6:45am	6:45am
Mid (10am-2pm) Peak Volumes				
15 Minute :	14	16	13	13
One Hour :	52	54	48	48
P.H.F. :	0.93	0.84	1.00	1.00
PH Begins :	11:15am	12:30pm	11:15am	11:15am
PM (2pm-12am) Peak Volumes				
15 Minute :	18	12	12	12
One Hour :	59	40	45	45
P.H.F. :	0.82	0.83	0.94	0.94
PH Begins :	2:30pm	2:00pm	2:00pm	2:00pm

Figure 12. Total Volume Report, Gate 24

Report aggregated total traffic counts by hour, by lane, and by day of the week for the entire data collection period. Percentages are calculated to reflect the relative distribution of traffic by hour, day, and lane. These calculations provide insight on relative flows of traffic by different measures and highlight peak activity within those categories.

Source: Energy Intelligence

Basic Volume Summary: EBP GATE 24

Grand Total For Data From: 15:00 - 06/24/2014 To: 09:59 - 07/29/2014

Total Count	*0000*	*0100*	*0200*	*0300*	*0400*	*0500*	*0600*	*0700*	*0800*	*0900*	*1000*	*1100*	*1200*	*1300*	*1400*	*1500*	*1600*	*1700*	*1800*	*1900*	*2000*	*2100*	*2200*	*2300*	*Total*
Lane #1	0	1	0	9	14	93	172	582	475	458	481	551	467	442	386	401	344	259	50	5	1	3	9	6	5209
Lane #2	23	24	12	65	45	315	666	992	627	649	571	586	568	530	360	245	226	153	62	72	26	24	76	69	6986
TOTAL	23	25	12	74	59	408	838	1574	1102	1107	1052	1137	1035	972	746	646	570	412	112	77	27	27	85	75	12195

Percents:	*0000*	*0100*	*0200*	*0300*	*0400*	*0500*	*0600*	*0700*	*0800*	*0900*	*1000*	*1100*	*1200*	*1300*	*1400*	*1500*	*1600*	*1700*	*1800*	*1900*	*2000*	*2100*	*2200*	*2300*
Lane #1	0%	0%	0%	0%	0%	2%	3%	11%	9%	9%	9%	11%	9%	8%	7%	8%	7%	5%	1%	0%	0%	0%	0%	0%
Lane #2	0%	0%	0%	1%	1%	5%	10%	14%	9%	9%	8%	8%	8%	8%	5%	4%	3%	2%	1%	1%	0%	0%	1%	1%
TOTAL	0%	0%	0%	1%	0%	3%	7%	13%	9%	9%	9%	9%	8%	8%	6%	5%	5%	3%	1%	1%	0%	0%	1%	1%

ADT:	*0000*	*0100*	*0200*	*0300*	*0400*	*0500*	*0600*	*0700*	*0800*	*0900*	*1000*	*1100*	*1200*	*1300*	*1400*	*1500*	*1600*	*1700*	*1800*	*1900*	*2000*	*2100*	*2200*	*2300*	*Total*
Lane #1	0	0	0	0	0	3	5	17	14	13	14	16	14	13	11	11	10	7	1	0	0	0	0	0	149
Lane #2	1	1	0	2	1	9	19	28	18	19	17	17	17	16	11	7	6	4	2	2	1	1	2	2	203
TOTAL	1	1	0	2	1	12	24	45	32	32	31	33	31	29	22	18	16	11	3	2	1	1	2	2	352

LANE #1

	Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*		*Total*	*Percent*
DW Totals :	38	1113	1049	1107	1021	853	28	Weekday (Mon-Fri) :	5143	99%
# Days :	5.0	5.0	4.8	5.0	5.0	5.0	5.0	ADT :	207	
ADT :	8	223	219	221	204	171	6	Weekend (Sat-Sun) :	66	1%
Percent :	1%	21%	20%	21%	20%	16%	1%	ADT :	7	

LANE #2

	Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*		*Total*	*Percent*
DW Totals :	186	1413	1338	1442	1301	1145	161	Weekday (Mon-Fri) :	6639	95%
# Days :	5.0	5.0	4.8	5.0	5.0	5.0	5.0	ADT :	268	
ADT :	37	283	279	288	260	229	32	Weekend (Sat-Sun) :	347	5%
Percent :	3%	20%	19%	21%	19%	16%	2%	ADT :	35	

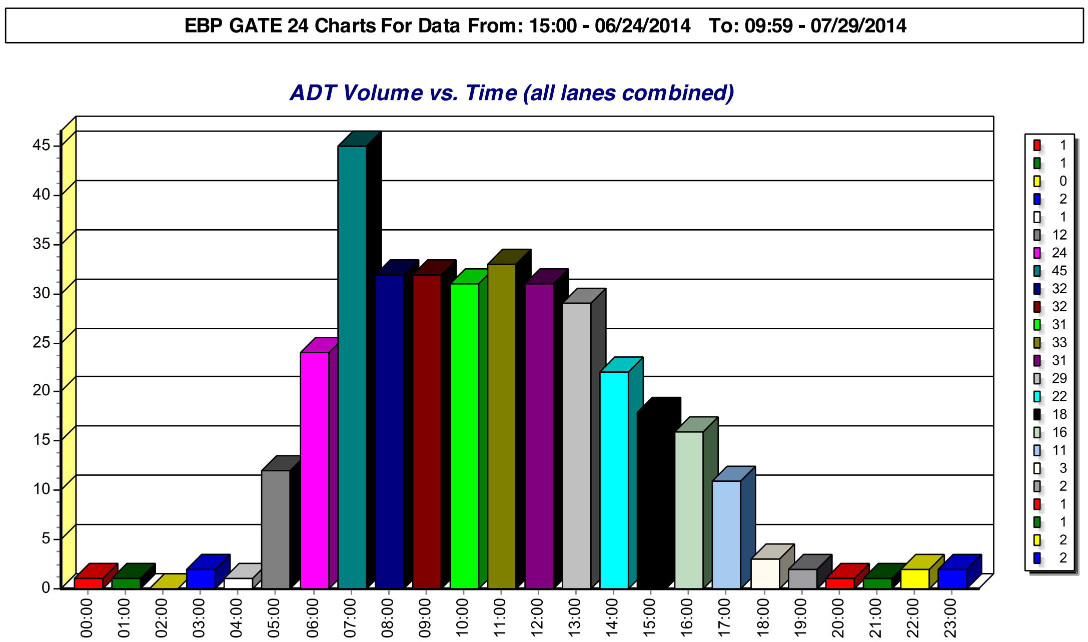
ALL LANES

	Sun	*Mon*	*Tue*	*Wed*	*Thu*	*Fri*	*Sat*		*Total*	*Percent*
DW Totals :	224	2526	2387	2549	2322	1998	189	Weekday (Mon-Fri) :	11782	97%
# Days :	5.0	5.0	4.8	5.0	5.0	5.0	5.0	ADT :	475	
ADT :	45	505	498	510	464	400	38	Weekend (Sat-Sun) :	413	3%
Percent :	2%	21%	20%	21%	19%	16%	2%	ADT :	41	

Figure 13. Total Volume by Hour, Gate 24

Report that aggregates total traffic counts by hour and lane for the entire data collection period. The visual representation clearly illustrates the flows of traffic over the course of the day and peak times. The second chart highlights one anomaly in the data, as an example, where inbound traffic exceeds outbound traffic.

Source: Energy Intelligence



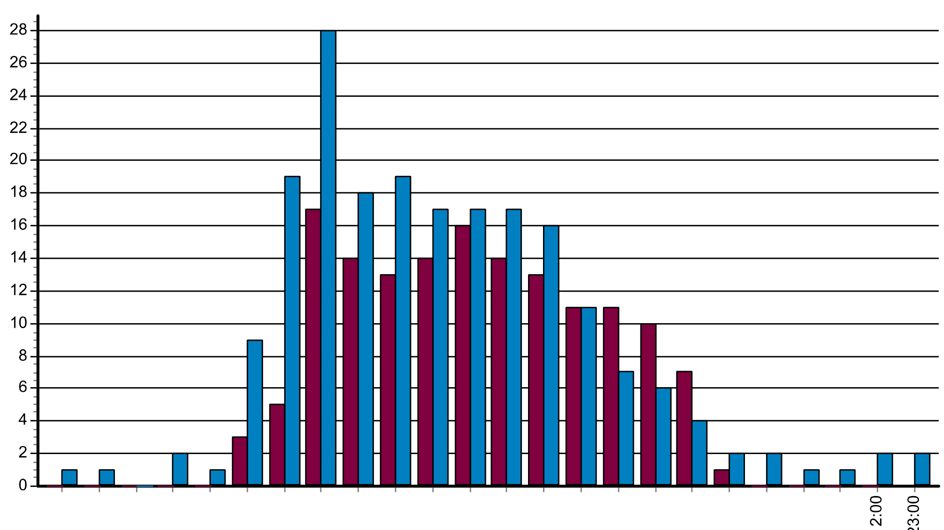
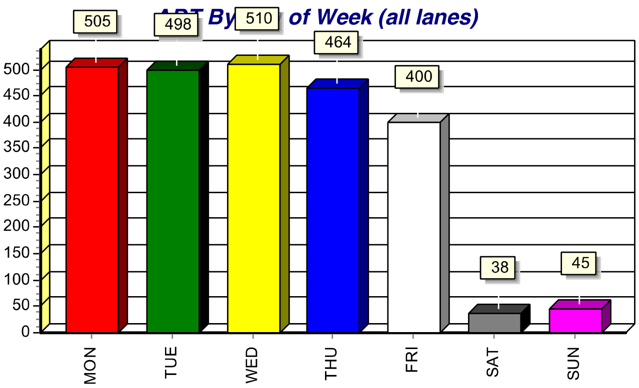


Figure 14. Total Volume by Day of Week, Gate 24

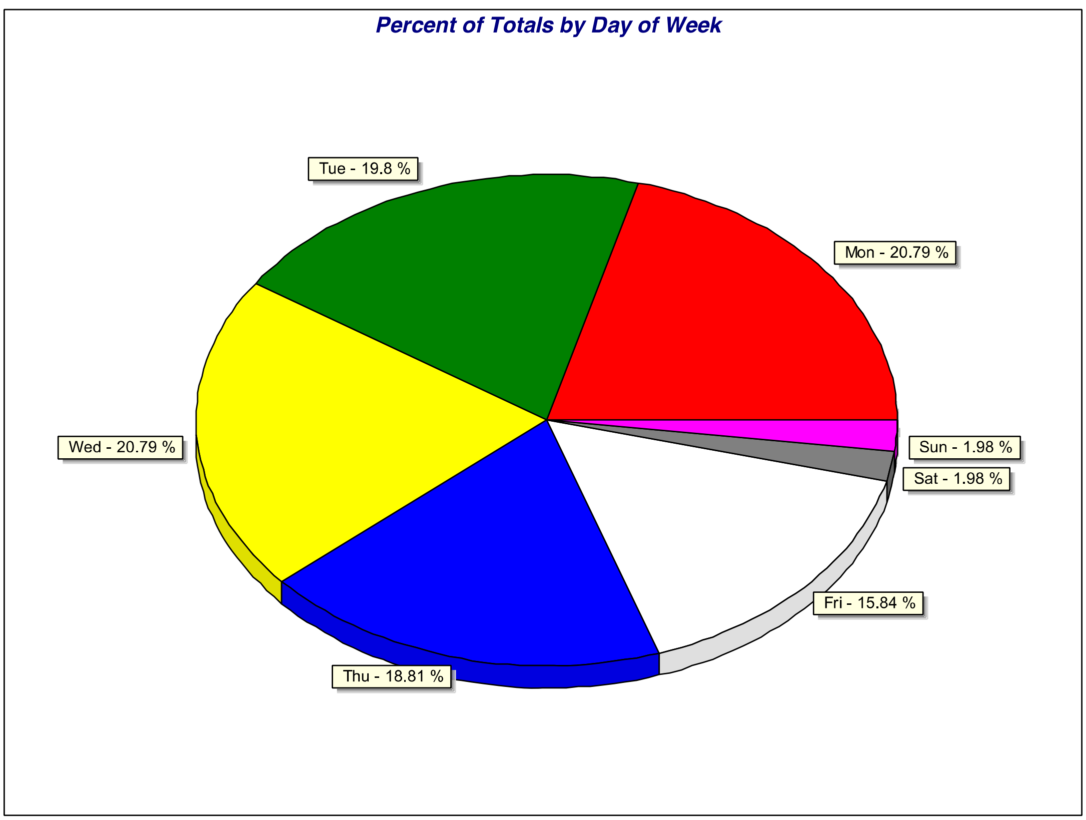
Report that aggregates total traffic counts by day of the week for the entire data collection period. The visual representations clearly illustrate the consistency through the first half of the workweek and the slight drop off toward the end of the week.

Source: Energy Intelligence

EBP GATE 24 Charts For Data From: 15:00 - 06/24/2014 To: 09:59 - 07/29/2014



DAY	ADT	TOTAL	# DAYS
Mon	505	2526	5.0
Tue	498	2387	4.8
Wed	510	2549	5.0
Thu	464	2322	5.0
Fri	400	1998	5.0
Sat	38	189	5.0
Sun	45	224	5.0



Both the manual and equipment-enabled traffic data collection carried out over the site study period were critical in quantifying and better understanding vehicular traffic on-site. Building a rich data set for traffic activity onsite was necessary to adapt the energy harvesting system design and to more accurately forecast potential energy generation and savings on-site. A number of traffic metrics were tracked over the course of the study, including:

- Total traffic count.
- Traffic count and other metrics reported by hour, by day, etc.
- Average vehicle speed.
- Average vehicle classification (including number of axles, axle spacing, and distribution).
- Estimated average vehicle weight.

The results uncovered by the reports in Figures 10 through 14 and others clearly highlight the concentration of traffic on-site to weekdays over weekends, and generally to morning hours over afternoon or evening hours. At both gates, vehicular activity generally picked up between 5:00 a.m. and 6:00 a.m. and continued relatively consistently until between 5:00pm or 6:00pm, with greatest activity generally in the first half of the day. Some trends were opposite between the two gates. For example, at Gate 340, outbound traffic was greater in the morning and inbound traffic in the afternoon, whereas the opposite was true at Gate 24. Also, Gate 340 experienced substantially more traffic overall and longer hours of operations. These facts, along with the complete analysis conducted on the data collected, lead to the conclusion that Gate 340 would be an attractive site for a demonstration of the energy harvesting system, whereas Gate 24 does not have sufficient traffic. These conclusions are described further in the final sections of this report.

3.1.2 On-Site Facility Evaluation

Another important part of the study site assessment was understanding EBP's site operations and energy infrastructure and touring relevant facilities. EBP is unique in that it had long operated its own energy generation assets and distribution infrastructure, like a private, independent utility. In recent years, all energy assets were sold to RED as a result of the Kodak Chapter 11 Bankruptcy filing. Now, RED-Rochester operates the energy assets and has a plan in place to modernize and "green" the equipment and infrastructure.

EBP staff helped coordinate specific site visits within the business park to get a better sense and closer look at on-site energy equipment, capabilities, and plans. Most notably, Energy Intelligence staff spent time onsite with Bernard Nee, general manager of RED-Rochester, on several occasions. Bernie hosted Energy Intelligence at RED's corporate offices to review and discuss facility wide information about ongoing energy services. EBP is a very large facility, covering an expansive geographic area, and in its prime, years ago, drew a very large electrical load. With specialized equipment and energy-intensive manufacturing processes on-site, EBP was able to justify private energy infrastructure onsite and fully utilized the 100^{+}-MW, high-voltage capacity. Interestingly, energy was, and still today is, primarily distributed in the form of steam, rather than electricity, mainly for efficiency gains given that much of the big equipment and refrigeration technology onsite uses steam directly. Currently, the facility as a whole is running at significantly lower utilization and not all energy related assets are in use. In practical terms, that means one or two of the four large steam generators is shut down at any given time, though RED is often, but not always, able to sell surplus electricity into the grid. Bernie also gave Energy Intelligence a tour of and firsthand look at the on-site power plant and energy related assets. RED staff gave overviews of the generating assets, interconnection points, distribution protocol, control station, monitoring equipment, and safety mechanisms. The power plant is currently still coal-powered; a long-term plan to modernize the equipment and improve sustainability metrics is already in action. While EBP does not have a shortage of cheap energy available on-site, there is a clear push toward modernization and sustainability. From these objectives, stems the interest in the proposed energy harvesting technology, in addition to a general interest in supporting and helping to advance innovative technologies.

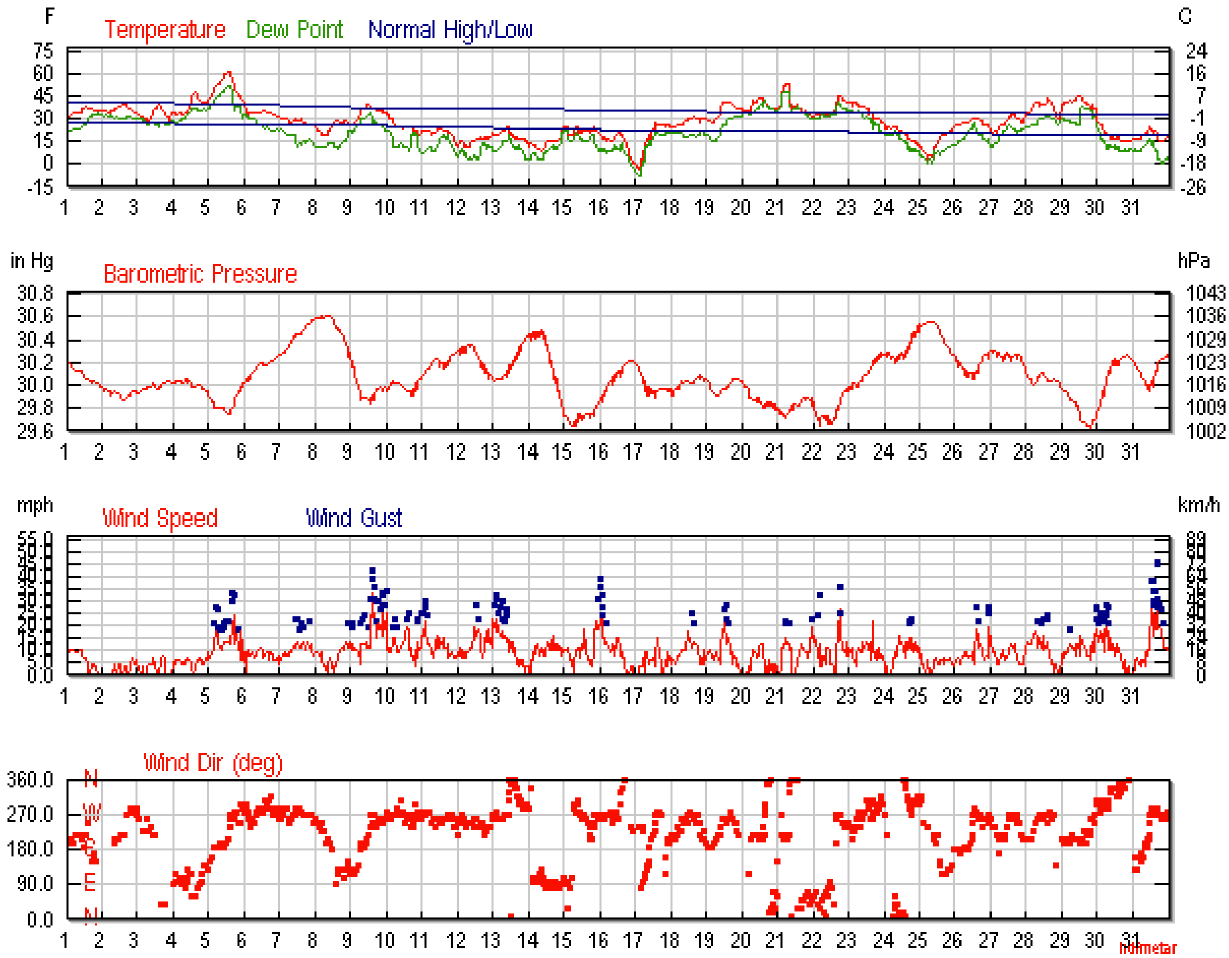
Similarly, Jim DeJager, director of the New York Battery and Energy Storage Testing Facility (NYBEST), located at EBP, gave Energy Intelligence staff a tour of the newly installed equipment and machinery at the facility. While Energy Intelligence is not developing battery or energy storage technology directly, storage is certainly an important part of the proposed technology. The combined group discussed the proposed technology and potential storage needs, and Jim recommended continuing the conversation if and when a demonstration is pursued on-site. He certainly believed there would be room to collaborate and value from doing so. Involving NYBEST, along with other relevant stakeholders located within or associated with EBP was an important part of the study and reflected a healthy level of collaboration locally to the study site and within the region to develop new relationships and strengthen the relevant ecosystem, which NYSERDA is an important part of.

Additionally, environmental factors that impact requirements for material selection, durability, and other design considerations were measured and studied. One such metric was weather patterns (e.g., temperature ranges, rainfall, and seasonal changes). Figure 13 includes a sample weather data report. The conditions researched and data collected suggest the study site would not be significantly different from the Contractors test grounds in the greater Boston area and would not substantially change system requirements. Initial installations and demonstration sites will likely be under some type of canopy, covering, or roof structure to eliminate concerns around direct contact with snow, salt, ice, and snow plows. These circumstances will certainly be taken into account and planned for in the final stages of design engineering, but enabling early demonstrations to focus primarily on system performance and general durability, without external factors as distractions, will be useful.

Figure 15. Sample Weather and Environmental Data Collected for Project Site

Selection of weather data for the month of December for study site in Rochester, NY. The variables with the most direct impact on system materials and performance are temperature and barometric pressure. Even in December, with extreme temperatures and wintry conditions, the study site was determined to be reasonably comparable to conditions previously tested by Energy Intelligence at company facilities.

Source: Weather Underground, History for Rochester, NY, December 2013



3.2 Technical Analysis

The technical analysis portions of the study consisted of three primary areas of work. First, Energy Intelligence, with the support of Aslan Controls, continued work in mechanical analysis and design optimization of the system. Second, Energy Intelligence staff designed and developed a prototype of the sensor data management system, tying together system hardware and firmware with backend database management to collect, monitor, and manage data produced by the energy harvesting systems. Third, Energy Intelligence staff developed detailed designs and schematics for the power electronics system that would connect the energy harvesting systems with existing infrastructure and equipment at project sites.

Analyzing the technical feasibility of the proposed system at the study site entailed an iterative process to evolve system design in line with measured site requirements and repeatedly test the prototype system remotely against simulated study site conditions. From initial assessments of vehicular activity on-site and average vehicle characteristics, the team proposed various design changes to better accommodate study site conditions and maximize system performance. For example, given low average vehicle weight onsite, it was determined that the system may more effectively activate the hydraulic generation components with linear peristaltic elements rather than vertically oriented hydraulic cylinders. This type of adjustment enables a more compact, “mat”-like design that can be mounted right on top of the road surface without any excavation or road work. To this end, the study team designed and assembled an initial test rig that was used throughout the study to evaluate system performance given simulated study site conditions. The work leading up to creating the test rig included research on low-pressure hydraulic flow systems, developing a system of equations to isolate the limiting factors of a linear peristaltic pump for this application, and iterative experimentation with the hydraulic and structural components to determine an appropriate system layout. Over the course of the study, additional design experiments were conducted to further improve the expected performance of the system at the study site.

In parallel, the project team did quite a bit of work on the electronics and data elements of the system. Both the data acquisition and management subsystem and the power electronics subsystem are important and necessary parts of a potential demonstration; therefore, initial development of each system was carried out as part of this study in line with plans for a demonstration project (not currently funded) at the study site. The data-related needs include measuring electrical outputs from the energy harvesting system, collecting the data and storing it remotely in a Web server, and managing the data in such a way that it can be accessed for local displays at installation sites or for customer dashboards showing real-time system performance. The power electronics system deals with converting, controlling, storing, and distributing the electricity generated by the system and connecting with local infrastructure.

The following sections describe and discuss some of the key technical issues and design considerations raised over the course of the study and include sample materials to highlight key points.

3.2.1 Background and Technical Considerations

The technology evaluated as part of this study is the result of an iterative research, design, and prototyping process. The company has built several early prototypes and evolved the design quite a bit over time. The inclusion of hydraulics as the main energy capture mechanism in the system has been consistent through several designs in order to maximize power density and compactness. However, other features of the system like materials, component orientation, and system layout have been modified over time. The current setup involves a peristaltic hydraulic design wherein passing vehicles depress the top surface of the system and pinch hydraulic channels (simulated by fire hoses in early tests) to push pressurized fluid forward through the channels and into energy conversion mechanisms. These energy conversion mechanisms convert the hydraulic flow into rotational force, effectively flowing liquid spinning various components, and the central rotating axle is connected to generator components, which produce electricity.

The important limitations on the power potential of the energy harvesting system can be described as follows:

Essentially, maximizing the electricity generated by the energy harvesting system means moving as large a volume of fluid as possible with the wheels of each passing vehicle. The system under investigation as a potential better match for the project site was a linear peristaltic pump, using 1-3 hoses of various diameters. Equation 1 describes the model:

Power (kW) = H*F*eff/11.8 (1)

Where

- H is available head in feet.
- F is flow in cubic feet per second.
- and eff is the efficiency of energy conversion.

Equation 1 shows that increasing the pressure drop or increasing the flow will increase the power. In the linear peristaltic pump design, the flow, and the pressure drop are inversely correlated – as you increase one, you decrease the other. Two things are happening in this relationship:

1. As the backpressure in the hose is increased, the uplift force on the bottom of the tire increases, and works to lift the tire and allow leakage in the hose below the tire. Increased speed of the vehicle tends to increase the backpressure in the hose, and increasing the number of hoses under the tire increases the area that the uplifting backpressure is working against - both of these forces decrease the flow through the hose.
2. At higher backpressures, the tire is tending to form around the hose, rather than flatten it, like a low-pressure balloon rolled over a high-pressure hose. The balloon will deflect around the hose, rather than flattening the hose, or rather than lifting up.

Both behaviors mean that there is an upper limit to the pressure drop the system can absorb (or head, in Equation 1), which is essentially about equal to the tire pressure for any vehicle. The flow is limited by the amount of fluid under the tire, without lifting the tire, or without creating enough backpressure to deflect the tire around the hose. Therefore, the larger the area of fluid under the tire, the larger the up-force is for any given backpressure.

Two models were studied as examples. The first model had round hoses, similar to the test rig designed and built for the study (Figure 16). This model includes a single 1-inch hose for each side of the car that is 5 ft long, and assumes a maximum pressure drop of 30 pounds per square inch (psi). The second model is an extrapolation to a conceptual model with rectangular channels, rather than round hoses, and the assumption is that the full width of the tire would create the push. This too has limitations, but is useful as an upper bound model. The increase in fluid volume (and thus power) comes from this assumption. The pressure drop has not changed, because as previously explained, this input is limited. The financial numbers look better for this model, but again this is meant to represent more of an upper theoretical limit, rather than a practical model. Of course, the other way to increase power is to target sites with greater numbers of cars passing through and to place many multiples of the energy harvesting systems in series.

3.2.2 Testing and Findings

The testing conducted over the duration of the study aimed to test the limits and operating thresholds of the system as a whole given project site conditions and individual system components. The testing method and process was iterative and rigorous, running dozens of experiments under different operating conditions and analyzing results. If a demonstration project were to proceed, the system would undergo an additional and different set of tests, for example, replicating external weather and other factors with salt spray tests for durability, temperature chambers for performance, and impact testing with a cyclical load simulator for materials resiliency. In this round of testing, experiments were simulating different scenarios expected at the study site, primarily focused on traffic flows, and measuring changes in energy transferred through individual parts and through the system as a whole. For example, operating vehicles at different speeds over the system, operating different class vehicles over the system (for example, light passenger vehicles versus loaded delivery vans), or rigging up the test system differently to induce failure modes and monitor the system. The testing conducted for this study was instrumental in evaluating the impact of design changes on system performance, identifying the limiting components of a given design, and quantifying the real performance limits on tested parts.

Figure 16 shows a test prototype that was designed and built specifically to simulate the study site conditions against, and numerous modifications were made to that system to accommodate different experiments. For the construction and assembly of this model system, the study team had to weld metal materials and parts, build wooden support structures, assemble various pipes and fittings, identify and connect the appropriate sensors and gauges (e.g., pressure, flow, and electronic readings), and rebuild subassemblies of the system for each experiment and design variation. Through the experimentation, the team focused on determining the limiting factors of the system, for example, the upper and lower pressure limits for hydraulic components, sources of system backpressure, measuring impact of vehicle weight distribution and speed, and understanding tradeoffs in each system component between pressure and flow. Table 1 and Figure 17 lists one complete set of experiments (along with a sample of the resulting data) and illustrates the iterative nature of the testing conducted by describing the parameters modified for each test.

Figure 16. Constructed Test Rig

Study team designed and built a test rig to measure various energy conversion and hydraulic components and generally to test design concepts and modifications.

Source: Energy Intelligence

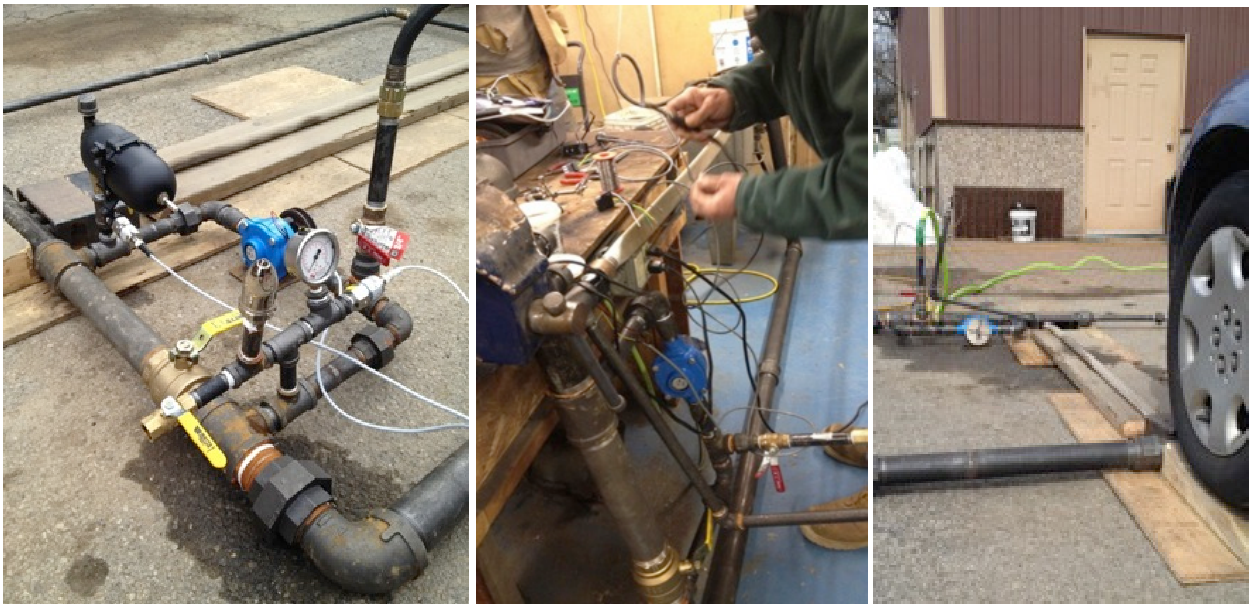


Table 1. Sample Testing Cycle – Set of Experiments

The iterative process of testing the energy harvesting system against different simulated conditions required changing 1 or 2 parameters per test to measure relative change in performance. In this example, baseline test uses a particular energy-conversion component (roller pump), with particular gearing ratios, magnets, coils, electrical resistance, and vehicles moving at certain speeds. Each distinct experiment, as noted in the table rows, describes a change in the baseline test.

Source: Energy Intelligence

Exp. #	Parameters tested	Notes
14-1	Roller Pump, 72-15 gearing, 6 shaped magnets, 3 x 20ga coils, open circuit, Cruiser, slow speed	Baseline setup, roller pump design, gearing setup, wire selection for coils, vehicle type, speed category
14-2	Repeated conditions	Same test for accuracy of measurement
14-3	Sedan (PT Cruiser), faster	Same vehicle class, higher speed
14-4	100 ohm load, slow speed	Same vehicle, high resistance, low speed
14-5	Remove one-way clutch, slow speed	Same vehicle, resistance, speed, no clutch
14-6	Increase speed	Same vehicle, resistance, increased speed
14-7	Van, slow speed	Heavier vehicle, low speed, same resistance
14-8	Repeated conditions	Same test for accuracy of measurement
14-9	Van, medium speed	Same vehicle, increased speed
14-10	1-to-1 gearing on generator	Same vehicle, speed, resistance, lower gearing
14-11	Van, high speed	Same vehicle, resistance, gearing, higher speed
14-12	Isolate 2-tubes, Van, slow speed	Isolated contact point, same vehicle, low speed
14-13	Isolate, Van, medium speed	Same vehicle and setup, increased speed
14-14	Cruiser, slow speed	Lighter vehicle, same setup, low speed
14-15	Repeated conditions	Same test for accuracy of measurement
14-16	1000 ohm load	Same test with increased resistance
14-17	10,000 ohm load	Same test with greatest resistance
14-18	1 ohm load	Same test with lowest resistance
14-19	10 ohm load	Same test with moderate resistance

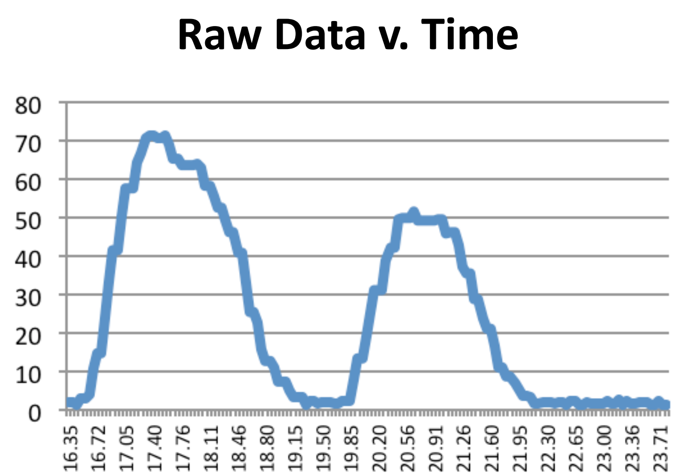
Figure 17. Sample Data Collected from Set of Experiments

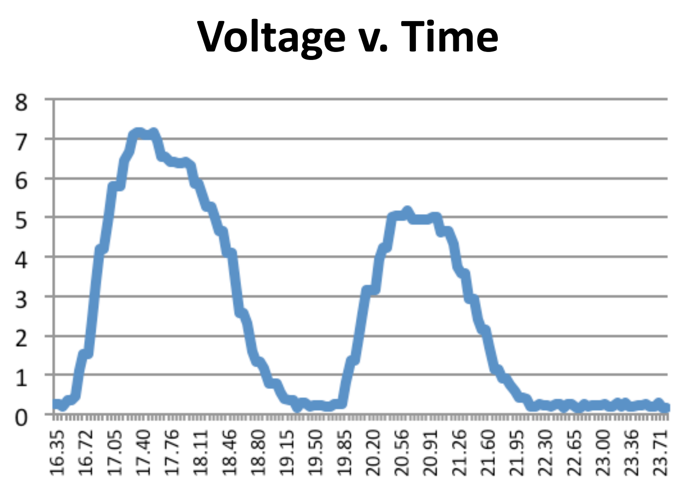
Table includes time-stamped data collected from one test out of a larger series, in this case noting voltage readings with the passage of one vehicle over the test prototype. Graphs plot the raw data readings and voltage calculations against time.

Source: Energy Intelligence

Raw Data

Time	Delta T	Raw	Voltage
16.35	0.05	2.45	0.245
16.40	0.05	2.45	0.245
16.46	0.06	1.77	0.177
16.51	0.05	3.44	0.344
16.56	0.05	3.44	0.344
16.60	0.04	4.49	0.449
16.65	0.05	11.13	1.113
16.72	0.07	15.2	1.52
16.76	0.04	15.2	1.52
16.80	0.04	23.97	2.397
16.85	0.05	33.3	3.33
16.93	0.08	41.9	4.19
16.96	0.03	41.9	4.19
17.01	0.05	50.43	5.043
17.05	0.04	57.85	5.785
17.10	0.05	57.85	5.785
17.15	0.05	57.85	5.785
17.20	0.05	64.33	6.433
17.25	0.05	66.65	6.665
17.31	0.06	70.76	7.076
17.36	0.05	71.47	7.147
17.40	0.04	71.47	7.147
17.47	0.07	70.91	7.091
17.52	0.05	70.91	7.091
17.55	0.03	71.43	7.143
17.60	0.05	69.22	6.922
17.68	0.08	65.34	6.534
17.71	0.03	65.34	6.534
17.76	0.05	63.95	6.395
17.81	0.05	63.95	6.395
17.85	0.04	63.67	6.367
17.90	0.05	63.67	6.367
17.95	0.05	64.01	6.401
18.00	0.05	63.09	6.309
18.05	0.05	58.33	5.833
18.11	0.06	58.33	5.833
18.16	0.05	55.69	5.569
18.22	0.06	52.71	5.271
18.25	0.03	52.71	5.271
18.30	0.05	49.55	4.955
18.35	0.05	46.36	4.636
18.40	0.05	46.36	4.636





3.2.3 Test Protocol and Objectives

The high-level objective of testing and the resulting analysis was to identify design modifications that would maximize hydraulic flow created by each vehicle and maximize the pressure differential absorbed by the system. Table 1 describes a single set of experiments and highlights the types of modifications made from one experiment to another – for example, modifying vehicle type, vehicle speed, and electric load resistance. Figure 17 represents data from a single experiment within one set of experiments. All of the testing performed over the course of the project consisted of many sets of experiments.

Each experiment and set of experiments aimed to find the upper bounds and limits of key variables being tested. In some cases, for example relating to the hydraulic components of the system, the upper limit was determined to occur when vehicles "hydroplane" over the hoses, meaning they cannot compress them. To quantify these limits, instrumentation was used to measure the performance of each component and of the system as a whole. The measurement devices that were used included flow sensors, pressure gauges, torque sensors, tachometers and other rotation measurement devices, and electronic data loggers. As part of the objective to determine performance limits, it was important to isolate each component of the system to get accurate measurements, for example to bypass the pump to measure unconstrained operating pressures of the hydraulic loop.

Figure 18. Data Logging Equipment

Data electronics were an important part of the study, and equipment like the chips and shown here enabled the study team to accurately collect measurements and store and analyze digital files. The data logger was connected directly to pressure gauges and flow sensors in the road-mounted energy harvesting test prototype for early experiments. The study team programmed the specific metrics and measurements to be recorded by the device. Later, various arduino processors were used to develop the data acquisition systems.

Source: Energy Intelligence

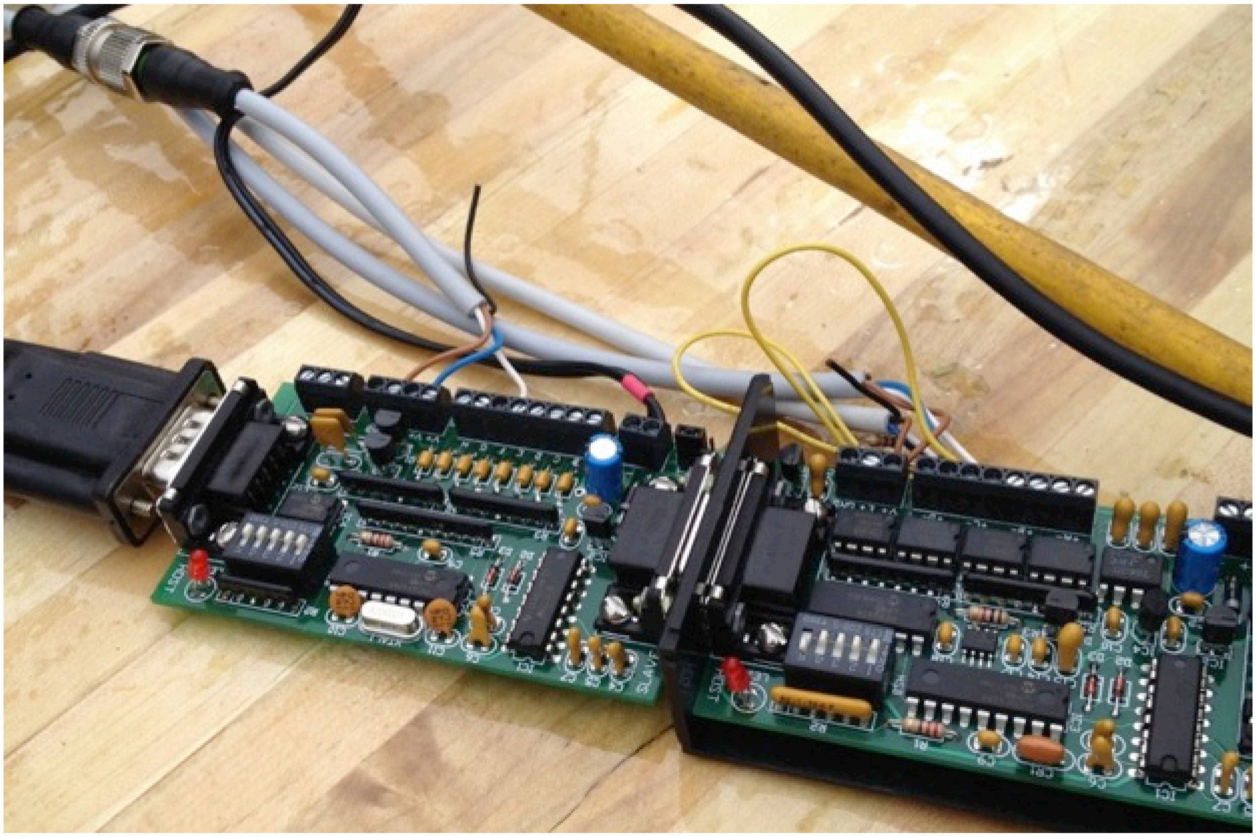
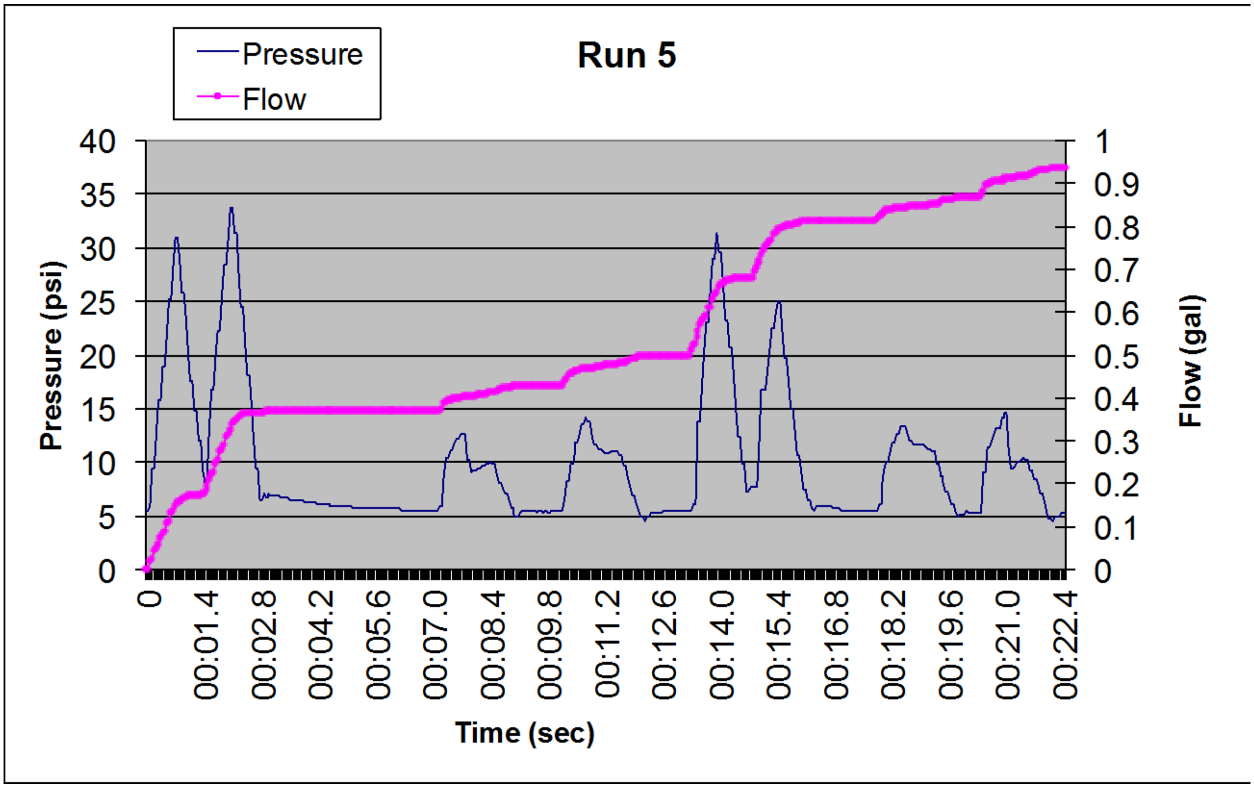


Figure 19. Sample Output from Data Logger

Cumulative hydraulic flow from a single vehicle pass and continual hydraulic pressure readings resulted from experiments run on the energy harvesting testing prototype. This chart was created with time-stamped data produced by the data logger shown in Figure 18.

Source: Energy Intelligence



The rest of this section gives more detail about the test protocol followed and the steps taken to determine and measure the operating limits of system designs, components, and materials. The following points outline the more precise methodology followed, beginning early in the study, to modify the test rig and conduct iterative experiments:

1. Assembled single-tube setup to set a baseline for each operating variable,. Then, in sequence, adjusted each variable across parameters noted in parentheses and test each combination of the varied experiments (for example, single 1-inch hose at 25 psi and single 1-inch hose at 30 psi, then two 1-inch hoses at 25 psi and two 1-inch hoses at 30 psi). Variables modified and tested included:
    - Number of hoses (1, 2, 3)
    - Type/size of hoses (e.g., diameter)
    - Operating pressures (e.g., 25–60psi)
    - Varying vehicles types and weights

2. Second set of experiments involved using a greater number of smaller hoses (3 or more 5/8-inch diameter hoses), then incorporating vent valves and autovents to more accurately and consistently remove air pockets from the hydraulic loop, and attach fittings for pressure gauge and pressure sensor. The performance of the system was significantly worse after incorporating these changes, primarily because the smaller hoses were too stiff and not easily compressed by passing vehicles, even under lower pressure.
3. Third set of experiments focused on using fewer, larger hoses (e.g., single 2-inch diameter), while modifying the architecture of the test rig. For example, modification included positioning the flow sensor after the motor in the motor loop, as opposed to in front of the motor and repositioning the vent/pressure tube after the motor. While a reinforced discharge hose was required, the larger diameter hose produced a much larger push a fluid than the first sets of tests. However, even at very low operating pressures, there was still some "hydroplaning." Ultimately, this issue reasoned to include an accumulator in the hydraulic loop to provide additional flex and alleviate spikes in pressure that prevent full compression of the hoses.

A number of conclusions were drawn as a result of the experiments described above. In some cases, the conclusions may seem simple or straightforward, when in fact they are important for prioritizing development objectives and confirming hypotheses. For example, there are practical reasons to deploy a more compact road-mounted system, but confirming that the physics work as expected is critical in determining the best overall design for a demonstration at the study site. Conclusions drawn from the early testing completed were:

- The basic idea of the linear peristaltic pump worked as expected and is worth pursuing for the study site.
- The heavier the vehicle, the greater the flow generated in the system. Lighter vehicles run the risk of not fully compressing the hydraulic lines and not pushing all the fluid through the system.
- The difference in weight distribution between the front and back axles on a vehicle comes into play and is evident in volume of fluid pushed through the system.
- System performance is better with fewer hoses – with the single hose working best. More hoses seem to provide greater fluid surface area under the tires to create more uplift for a given operating pressure, causing "hydroplaning" (not compressing hydraulic lines).

The study activities and resulting discussions continuously raised questions about design and deployment. Some questions were directly related to system design, implementation, and ongoing use; some questions evaluated big picture concerns and business strategy. All of these questions relate to the activities of the study and considerations relevant to a potential demonstration at the study site, though some of them represent near term challenges and some of them would influence longer-term goals. The following questions were raised throughout the study, starting with granular design questions and continuing to demonstration application details, to highlight the types of topics addressed and questions raised:

- Is the linear peristaltic pump design practical on a physical level? What implications will there be on durability and long-term performance?
- What happens to system performance at different vehicle speeds? What happens if a tire hits only one or two of the tubes or if drivers approach the system at an angle and tires make contact at different times?
- What is the driver experience of running over this system?
- How broad a range of conditions (vehicle weight, vehicle speeds, vehicle frequency) can a single design (tube size, number of tubes, liquid specs) span? What happens when an out of spec condition occurs?

- What are the flow and pressure characteristics of the system? Given that the flow will come in pulses, what specific data is necessary from larger arrays of systems to begin to design the prime energy recovery pieces?
- Given traffic profiles onsite, is a hydraulic turbine the most effective way to transform the energy into rotational force? Would other methods of converting hydraulic flow into electricity be more suitable?
- Would installing and powering new streetlights where the study site is dimly lit be a good use of power from a demonstration system? What other applications of energy, short of redistribution to the grid, would be valuable to EBP and to other relevant sites for a demonstration project?
- Given demonstration project conditions, as opposed to full-scale installation, what amount of storage will be required onsite to operate connected equipment smoothly?

3.2.4 System Modifications

The study team carried out significant work on refining the system design and architecture to make deployment and operation simpler on a practical level and to improve overall system efficiency. The analysis, testing, and redesign was focused primarily on two key components of the system. Although the broader issues that were considered include site conditions, safety requirements, layout and lane configuration, dimensions of available road surface, system performance, physical dimensions of individual modules relative to multi-unit system (modules in series), and installation and maintenance. All of these points directly impact requirements and components for final design, including system layout and architecture, component design, materials, plans for deployment (for example, mounting system on top of road surface versus milling top surface versus more involved excavation), and interconnection with local equipment. Still, the overarching design objective beyond performance was to make installation of the system as easy (i.e., quick and cheap) as possible, which can be carried out best with a modular system that is fully assembled off-site and can be installed on top of road surfaces without excavation. The system modifications made reflect practical changes incorporated as a result of theoretical evaluation and redesign.

3.2.4.1 Mechanical Design Considerations

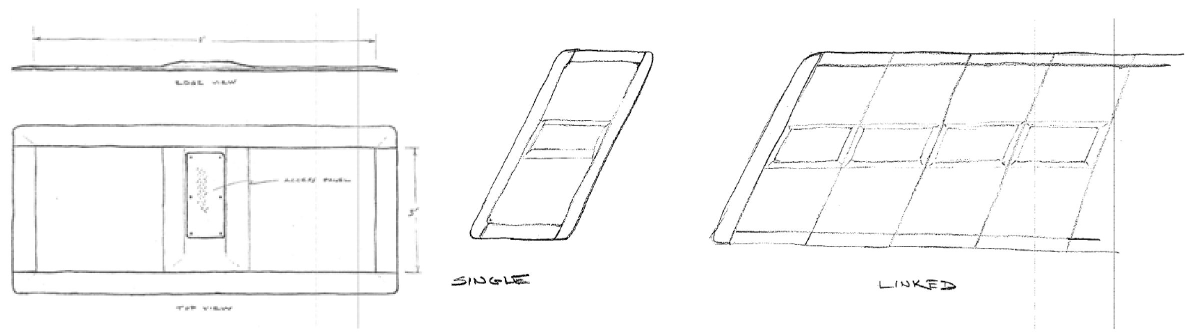
With a focus on optimizing the compact, flat, hydraulics-based system that was determined to be best fit for the project site, the study team carried out substantial analysis and experimentation to adjust the design of internal components. Namely, the hydraulic turbine (Figure 21) – which converts fluid flow into rotation – and the generator (Figure 22) – which converts rotation into electricity – are the two components most sensitive to changes in traffic and roadway conditions and that have the biggest impact on system performance. The hydraulic turbine sits in a housing in the central section of the energy harvesting system and connects the hydraulic channels that vehicles drive over to the electrical components of the system. The generator is mechanically connected to the hydraulic turbine and also sits within the central section of the energy harvesting system. More broadly, these two components make up the power conversion unit that transforms hydraulic flow into electrical energy and both need to fit very specific requirements to perform well in the targeted applications. Other primary elements of the system, like the layout of the hydraulic system, the baseline operating pressures, and the pressure management components, such as the accumulator, are well researched and understood but need to be adapted for the target application.

The test prototype designed and built during the study enabled the study team to further evolve, analyze, and optimize the concept of a surface-mounted, modular system (Figure 20). The technical work involved redesigning specific components for improved performance and restructuring system layout to make the height profile lower (more compact). Furthermore, by incorporating rubber materials as the top surface and structural components of the system, rather than steel, the system cost, weight, and portability, improves dramatically.

Figure 20. Concept Drawings of Modified Design for Study Site

Drawings reflect a few key objectives of the modified design: compactness and modularity. The left drawing shows a side view of the system laying flat on what would be the road. The right and left tires of vehicles are expected to drive over either side of a raised central manifold that houses the power conversion components. The center drawing illustrates the easy of deploying a single, standalone system versus a larger installation shown on the right of many installations connected in series.

Source: Energy Intelligence

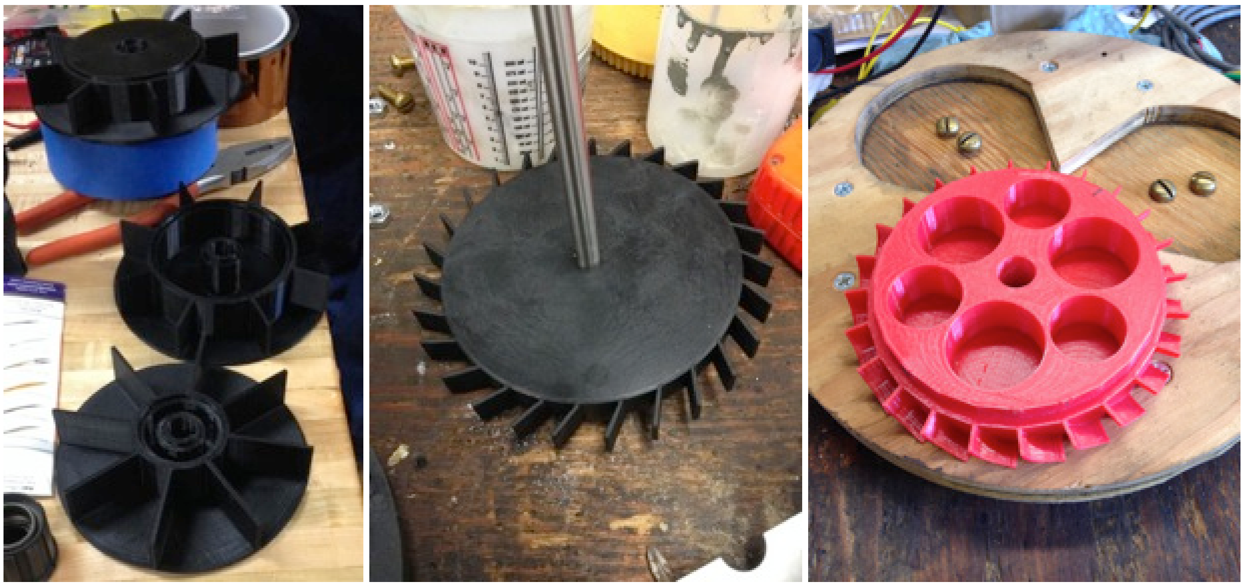


The hydraulic turbine is, in itself, an area relatively well understood, having been manufactured for many years for different applications; however, the unique circumstances of this application require adjustments in design and control that are still being explored. Furthermore, no standalone turbine or coupled hydraulic generator exists or is available commercially within the energy regime targeted for these energy-harvesting devices. Water turbines used in continuous-use applications, from water pipes to natural streams, are categorized either as low head or high head, low flow or high flow, and are known to reach efficiency levels between 20 – 50%. Given the powerful bursts of force generated by passing vehicles on the proposed system for this project, and the otherwise low pressure at rest, the system has elements of both turbine categories and therefore requires hybrid-designs. The hydraulic turbine for the study site needs to be lightweight, minimizing inertia of hydraulic fluid for each vehicle pass, but designed to build momentum and maximize the transfer of force from flow to rotational velocity. Meeting these goals called into question turbine design and dimensions, material selection and composition, and component housing. The study team designed many variations of these components and used 3D printers to prototype models of each design for testing and further analysis. Additionally, off-the-shelf hydraulic pumps were purchased and tested for comparison. Aslan Controls was able to adjust several off-the-shelf designs, for example a roller pump design, to reduce inertia, find the optimal balance between tightness of seals and resistance, and better fit the proposed application.

Figure 21. Hydraulic Turbine 3D-Printed Models

Based on research and analysis of existing turbine designs, study team developed new designs and printed 3D models that were tested with the prototype system. Many versions of each design were created, for example modifying blade dimensions and orientation, and all designs were continuously and iteratively evaluated to uncover further opportunities for improvement.

Source: Energy Intelligence



For the generator design, the challenge in optimizing performance lies in handling variable inputs and maximizing output. Not unlike variable-speed wind turbines handling changes in wind speed, the energy-harvesting system will receive pulses of strong force from each passing vehicle. In fact, the team studied multiple analogous designs from other technologies or applications and adapted design elements that were most relevant and useful. The further challenge was designing a generator compact enough to fit within the flat profile of the energy-harvesting system.

During the study, the study team designed and built several generator models that would fit within the height profile desired for the proposed demonstration. All models were built with key baseline parameters that were determined to be effective for the targeted application, such as 3 poles of wound coil on a base circular plate and 6 evenly spaced magnets on a top, rotating circular plate. The interaction of the rotating magnets over the wound coils is the biggest determinant of electricity generation. Other variables that were altered to evaluate changes in performance included wire gauge, wire length, number of coils, shape and size of coils, type of magnets, method of wrapping coils, and method of separating rotating plates. These variables represent only a subset of the possible modifications to the design that could be pursued, though they are the most critical. Therefore, the groundwork was laid for substantially more rigorous generator design optimization, given the large number of parameters that can be adjusted, but during the study the generator was brought to a point where it was no longer the limiting factor on output.

Figure 22. Flat, Axial-Generator Construction and Testing

The key design parameters of the generator were constructed and tested for use at a potential demonstration at the study site. The top row of photographs highlights the materials used and construction method. Three poles with wound copper coil on the base plate and evenly spaced magnets set in place with epoxy on the top plate are clearly visible. The bottom row of photographs captures test setups, complete with electrical and mechanical connections, measuring and evaluating the performance of each generator model built.

Source: Energy Intelligence

Key questions raised through the iterative development cycle:

- Can the system be made compact enough with a low enough height profile to sit on top of the road without requiring any excavation or milling?
- Can a back-and-forth hydraulic design, as opposed to a closed circuit design, be responsive enough given the speed and frequency of vehicles traveling onsite?
- What are the manufacturing considerations for a rubber-based system with the required specifications rather than a steel-based system? Can the intricacy of the embedded elements be achieved cost-effectively and will they be durable enough for long-term use?
- What controls can be practically implemented to adjust parameters in real time in response to varying roadway and vehicle conditions?

Ultimately, the study uncovered the complexity of designing and optimizing the coupled power conversion unit that is tasked with transforming pulses of hydraulic flow into conditioned electrical power. Where possible, the team looked elsewhere for existing technology from other applications that could be adapted to the proposed system. For example, quad-rotor drone motors are compact, lightweight, and cheap, but ultimately have capacity limitations too low for the proposed applications. Similarly, commercially available hydraulic turbines are either too small or too large for the targeted applications. Because a coupled hydraulic pump and generator fit, let alone optimized, for the targeted application and energy regime does not exist, the project team carried out substantial research and design experimentation to develop the best solution given study site requirements. Bringing completely novel optimized designs for this application to manufacturability requires substantial research and development and represents a scope of work beyond this study. The critical early tasks were initiated as part of this study and serve as a worthwhile topic for more advanced product development themselves. The team plans to propose a full product development effort on the merit of continuing this work and bringing the overall system to commercial viability.

3.2.4.2 Electrical Design Considerations

Another critical part of a potential demonstration at the study site is planning for the interconnection onsite between the energy harvesting system and local energy infrastructure. Substantial effort was put into the study to better understand onsite energy requirements and capabilities, observe site operations, identify unmet needs, and formulate a total plan to deploy a demonstration system onsite in the most useful way possible.

The electrical design work carried out during the study relates both to the data acquisition components within the system itself and to the power electronics. The data acquisition components enable performance monitoring and real-time data collection that is critical for a number of reasons. Ultimately, ensuring seamless movement of data between the road-mounted system and the cloud enables remote performance monitoring and control and local digital displays or web accessible customer dashboards providing real-time updates and statistics. The power electronics essentially represent everything between the system generator and the study site’s local switch board, and the work involved targets issues like what quality and type of power is generated by the system, how the inverter and other transmission devices are arranged, and to what connection point onsite the system ties in. The series of components researched, tested, and further evaluated include sensors and gauges, arduinos and other electronics or processors, rectifiers, PCUs, inverters, storage components, and transistors.

The sensor data management system is the main control behind collecting performance data from the energy harvesting system, storing and managing it, and processing it for display. The system will consist of hardware embedded within the energy harvesting system and wired to the generator. The hardware itself is a small stack of computer boards and chips that enable the data processing and delivery to remote servers. Once data are collected and stored, it will be delivered to various forms of displays, including real-time performance monitors setup locally at installation sites or as Web-based customer dashboards. This functionality will also be critical for Energy Intelligence in operating and maintaining system by accessing data for remote performance monitoring.

Based on the layout and local setup at the project site, it was determined what arrangement would be best for the data management of a demonstration project. One way to implement the system is to have data processing conducted on-site and directly delivered to local monitoring equipment and display monitors. Instead, for the proposed project, data will be collected locally, delivered to a remote server for processing and storage, and pulled by Web-enabled monitors as HTML files. The benefits of this system architecture are lower processing capability requirements onsite and html-based dashboard/report rendering that is compatible with all Web-connected devices.

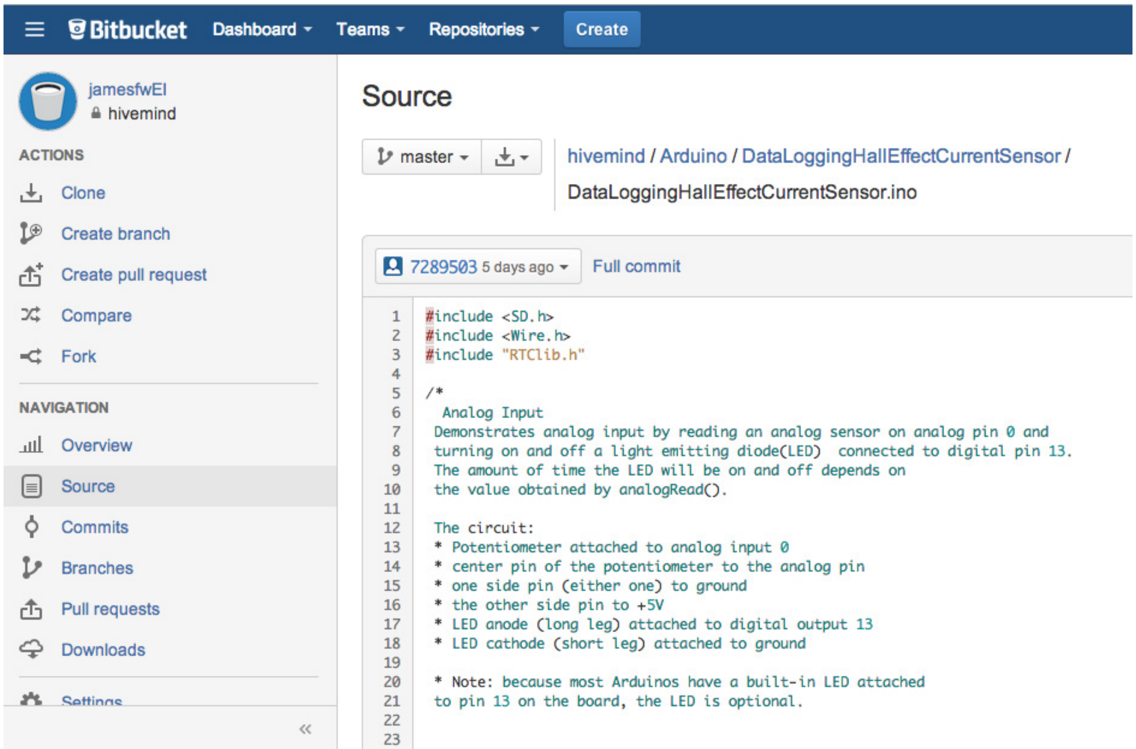
Developing this system for the project took a substantial work effort. Energy Intelligence had to spec the right sensors and gauges, define the parameters to be measured and recorded, develop the code to operate the boards and chips embedded in the system (CPUs) and initiate computer programs to collect and manage data as desired, set up a remote Web server to accept and store the data, define the operating and interconnection parameters between the CPU and the remote server, and enable remote access to the server data. Each of these objectives entailed a number of subtasks and required quite a bit of time to complete. For example, once it was determined that current was the most important parameter to measure, from which other performance metrics can be calculated, the best current sensor for this application had to be identified, purchased, and integrated with wiring, soldering, and coding.

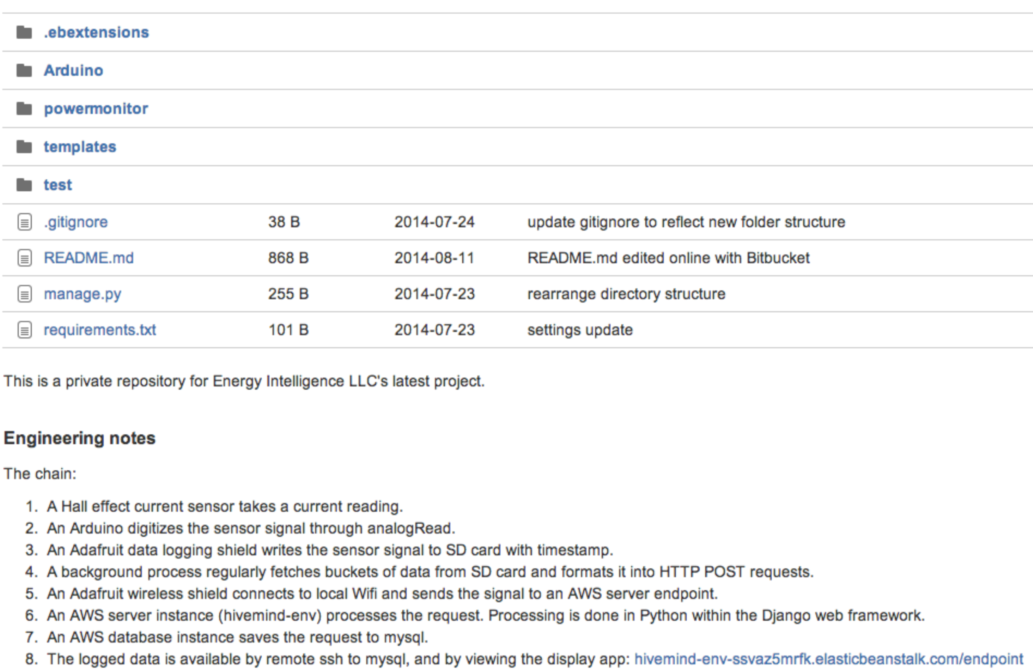
Development setup, even for something seemingly simple such as ensuring an accurate and consistent timestamp on each data measurement, required research, understanding of various options, and a fair amount of new code. For example, after evaluating several alternative methods, the project team determined that the most appropriate way to source accurate time stamps for each data point was by connecting to Universal Network Time Protocol (NTP) servers at predetermined intervals. In total, these tasks required a substantial effort and are highlighted in this document with a brief memo (Appendix A) and screenshot (Figure 23).

Figure 23. Screenshots of Code Repository for Data Acquisition and Management System

Development of the data acquisition and management system consisted of a substantial amount of new code. Bitbucket was used to manage this process and archive code developed. The screenshots below capture some of the formatting, hierarchy, and content developed.

Source: Energy Intelligence





.ebextensions			
Arduino			
powermonitor			
templates			
test			
.gitignore	38 B	2014-07-24	update gitignore to reflect new folder structure
README.md	868 B	2014-08-11	README.md edited online with Bitbucket
manage.py	255 B	2014-07-23	rearrange directory structure
requirements.txt	101 B	2014-07-23	settings update

This is a private repository for Energy Intelligence LLC's latest project.

Engineering notes

The chain:

1. A Hall effect current sensor takes a current reading.
2. An Arduino digitizes the sensor signal through analogRead.
3. An Adafruit data logging shield writes the sensor signal to SD card with timestamp.
4. A background process regularly fetches buckets of data from SD card and formats it into HTTP POST requests.
5. An Adafruit wireless shield connects to local Wifi and sends the signal to an AWS server endpoint.
6. An AWS server instance (hivemind-env) processes the request. Processing is done in Python within the Django web framework.
7. An AWS database instance saves the request to mysql.
8. The logged data is available by remote ssh to mysql, and by viewing the display app: hivemind-env-ssvaz5mrfk.elasticbeanstalk.com/endpoint

The power electronics system plays an important role in the overall deployment of the proposed technology, managing the energy generated by the system and enabling safe and reliable operation onsite. Especially with the intention to directly power equipment onsite, for example streetlights or payment collection equipment rather than send electricity back into the grid, it is imperative to have components with the right specs and to maintain the overall system within appropriate operating boundaries. Contractor personnel spent substantial time evaluating and working on electrical requirements and connection points between the proposed system and local loads, addressing questions such as:

- What quality and type of power is generated by the system?
- How should the inverter and other transmission devices be arranged?
- To what connection point onsite should the system tie in?

This work stream consisted of research, sketching system layouts, parts sourcing, site visits, strategy discussions balancing performance requirements and cost, and redrafting of system design. Parts that were included in these activities include rectifiers, power control units (PCUs), inverters, storage components (e.g., batteries), transistors, DC-DC aggregators, and charge controllers. A few of the central parts were purchased and tested in conjunction with the test prototype of the generator unit to help spec the rest of the power electronics system. The system will generally have to be connected at the main switchboard of a facility or individual building/area. In this way, a PCU can monitor on-site loads and control when energy is drawn from the grid versus when it is drawn from the generating unit / battery bank. This is the safest way to tie in to local infrastructure, given pre-existing safety and shutdown mechanisms. Furthermore, it is critical to determine ahead of time what load (equipment or machinery) will be using the energy generated, because the electrical requirements can vary quite substantially from one piece of equipment to another. For example, the AC voltage requirements for streetlights are quite different than for industrial equipment, which are quite different than for basic administrative use. These parameters are set and specified with each component used for the system, with the baseline overall requirement being that the system as a whole can handle the peak / largest instantaneous draw from the connected load.

The result of these activities was a detailed schematic of the entire power electronics system that would be required for a demonstration project at the study site, connecting the road-mounted energy harvesting systems to on-site electrical connection points (Figure 24). The schematic was developed in multiple phases, first understanding the overall process flow and component types that would be required and then closely evaluating the available products and parts within each category to identify the best fits. Along with the schematics, the study team created a Bill of Materials identifying the correct parts and specifications, pricing, and other required materials for complete demonstration.

Figure 24. Power Electronics System Layout and Detailed Schematics

This schematic of power electronics system shows how to connect energy harvesting systems (generators) to on-site electrical infrastructure and connection points. The generators' AC power output is converted to DC to minimize transmission losses, and then the multiple DC signals are rectified (consolidated) to a single DC current. A charge controller then manages the energy flows to the battery bank and the inverter, passing through circuit breakers and other connection points. Full schematic view provided and followed by close-ups.)

Source: Energy Intelligence

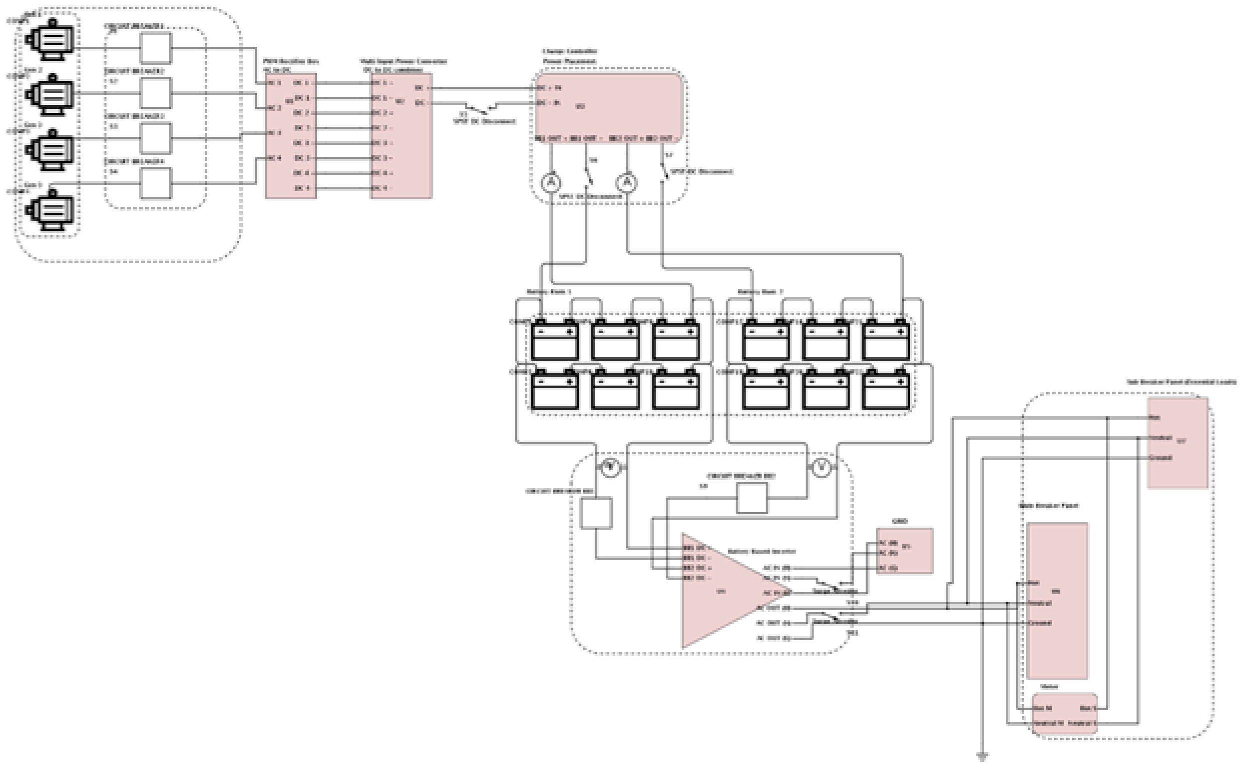
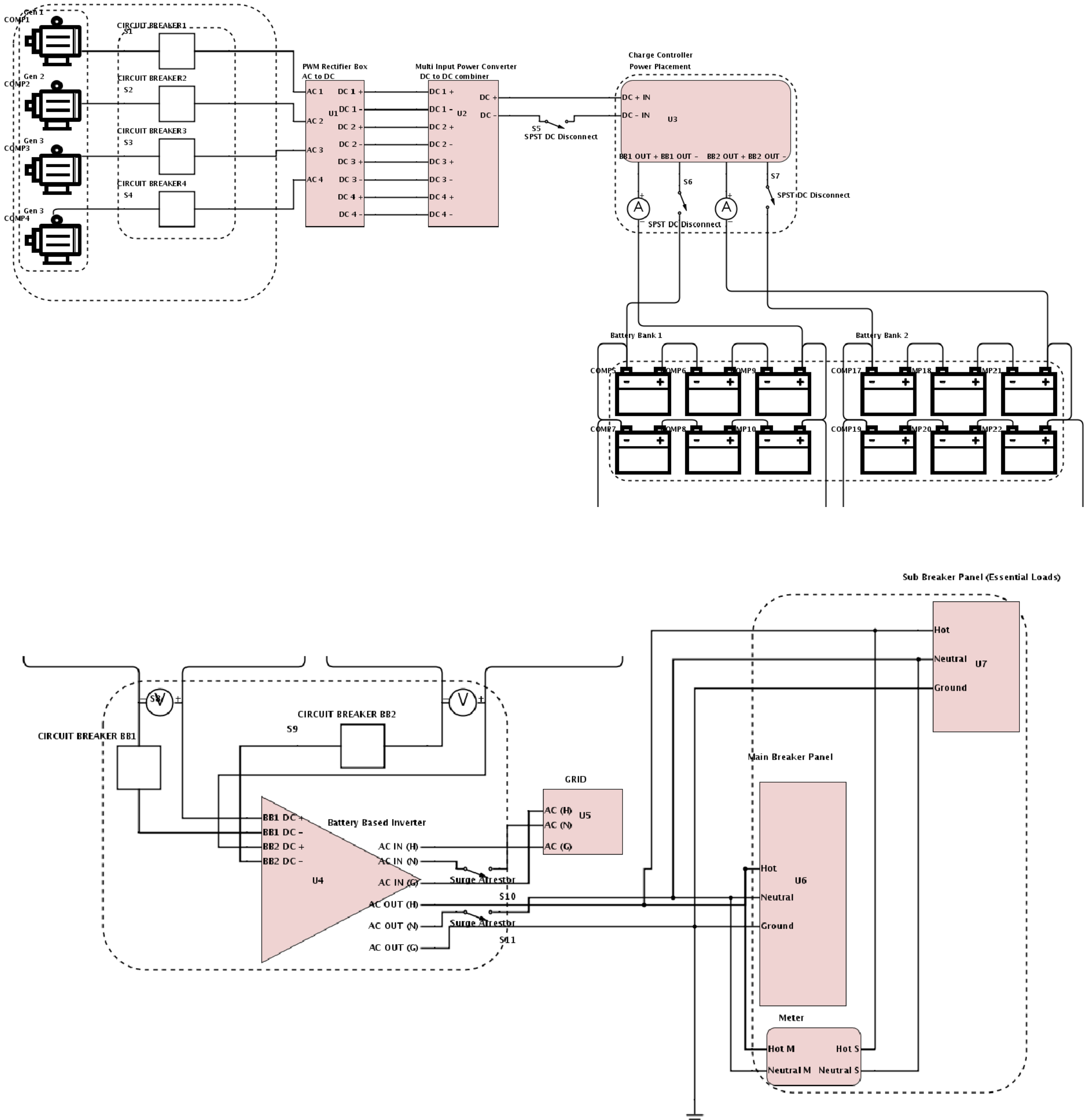


Figure 24 continued



A number of parts and materials were used for testing over the course of the study. The following list summarizes some of the key parts researched and tested and also representing a simple bill of materials necessary for a full-scale demonstration. Several detailed reports were produced from the work completed on the power electronics and related research and can be made available upon request.

- Bridge rectifier.
- Generator plans.
- Motor/generator.
- Watt meter.
- Connectors.
- Wire and magnets.
- Arduino chips and related accessories (wi-fi shield, stacking headers, jumper wire).
- Current sensor (e.g., hall effect).
- Micro Secure Digital (SD) cards.
- Bridge Rectifier.
- Charge controller.
- Inverters.
- Batteries.
- Coils, magnets, other structural parts for generator.
- Connectors, capacitors, wires.

The technical research and development successfully completed over the course of the study, both for mechanical analysis and design optimization as well as for power electronics and energy management, represents a necessary step forward in learning and preparedness for a demonstration project at the study site, but does not reflect the type of comprehensive and exhaustive work required for deployment of an actual demonstration.

3.3 Economic Evaluation

Economic research and evaluation also played an important role in the study. The main objective of activities under this task was to estimate system cost and to evaluate the economic implications of changes to design. A model was constructed to help analyze the impact of certain changes, effectively combining the estimation of energy outputs with anticipated costs in order to forecast a levelized cost of energy produced by the system over its useful life. A convenient metric for comparison is simple payback, where a design's economic merits can be measured on the number of years (or months) needed to recoup the upfront cost of a system given the value of energy produced annually. More detailed analyses can be conducted to validate part and material costs at a much more granular level, or to validate anticipated cost savings when manufacturing at scale. However, the objectives of this study were focused more on the technical and practical feasibility of pursuing a demonstration project at EBP. Ongoing economic analysis that the team is performing takes into account the energy production of an installation, the environmental benefits in avoiding generation by conventional methods (avoided emissions), and the lifetime cost-benefit analysis to forecast LCOE and compare the cost of electricity produced and delivered to host sites.

The models developed and used over the course of the study focused on estimating output and lifetime cost based on varying site conditions and traffic flows and estimated cost for a single production unit as well as at scale manufacturing. The performance models were developed to estimate available energy at the targeted site, system losses, and potential electrical output delivered to local equipment/loads, using a set of input variables than can be manually entered, a series of intermediary calculations, and final outputs estimating the energy and economic performance metrics. Building a dynamic model like this will enable accurate forecasting of expected performance and costs at the project site for a potential demonstration (Figure 25). The model will capture inputs about traffic and vehicle conditions at a specified installation site, size and capacity of the installed system, and hours of operations, and will produce output calculations for performance and cost over the system's useful life. For targeted applications and full-scale installations, the unit economics are very compelling and competitive with alternative technologies. The projected performance gives confidence to further pursuing a demonstration project.

Figure 25. Summary of Economic Model

Economic model used to estimate available energy at a site based on user-inputted values. Model takes into account traffic flows and vehicle types, energy-harvesting system layout and specifications, and market conditions to estimate the value of energy produced relative to system cost.

Source: Energy Intelligence

Design 1
Round Fire Hoses

Power (W) =195.27 p (psi) * F (cuft/s) * eff
F - Flow = volume in hose * Pushes/sec

Assume round hoses

Size of hose (in)	1.5
Number of hoses	8
Working length of hoses (in)	60
Volume (ft^3)	0.491
Volume (gal)	3.672
Number of cars/min	5
Pushes/car (number of axles)	2
Flow ft^3/sec	0.082
Flow (gal/min)	36.720
Pressure drop (psi)	32
Efficiency	0.6
Power (W)	306.729
Power (hp)	0.411
Cost per mat (development)	$500
Cost per mat (production)	$300
Electricity cost ($/kwhr)	0.14
Yearly operating hours	3650
Cost avoided/yr	$156.74
Payback (development) (yr)	3.2
Payback (production) (yr)	1.9

Design 2
Square Channels in Mat
2 side by side systems, 1 mat

Vehicle weight (lb)	3200
Front/back ratio	0.6
Tire width (in)	6
Tire pressure (psi)	34
Tire patch front (in^2)	4.706
Tire patch back (in^2)	3.137
Depth of channel (in)	1.5
Working length of channel (in)	60
Volume (ft^3)	0.625
Volume (gal)	4.675
Number of cars/min	5
Pushes/car (number of axles)	2
Flow ft^3/sec	0.104
Flow (gal/min)	46.753
Pressure drop (psi)	32
Efficiency	0.6
Power (W)	390.540
Power (hp)	0.523
Cost per mat (development)	$500
Cost per mat (production)	$120
Electricity cost ($/kwhr)	0.14
Yearly operating hours	3650
Cost avoided/yr	$199.57
Payback (development) (yr)	2.5
Payback (production) (yr)	0.6

The model outputs highlighted above suggest an opportunity to deploy low cost units in high volume to generate meaningful amounts of energy and recoup capital investments quickly. Relative to alternative onsite renewable generation sources, the estimated payback figures are very compelling. Furthermore, these calculations are based solely on the value of energy produced by the energy harvesting systems, whereas Energy Intelligence sees multiple revenues streams that will come into effect.

Economic modeling and analysis was completed alongside Technical Analysis activities in order to determine the benefits from a potential demonstration project and to extrapolate the same for large-scale installations. Generally speaking, with the design changes that have been made as a result of analyzing study site conditions and requirements, including changes to material selection and system construction to maintain a low height profile, the energy harvesting systems can cost-effectively be deployed at a wide range of sites. Material changes brought the estimated manufactured cost of a system down from $2,500 per unit by roughly 5 times, to $500 per unit at early development stags and even lower at scale. Early prototypes and small batch manufacturing will probably cost $500-$1,000 per unit, still a substantial reduction from the previous design estimates. The modified design also enables simpler connection of one unit to the next, right on top of the road surface, such that the expectation for a typical installation is that numerous units (e.g. no less than 5, as many as 50) will be connected in series.

Generation and storage capabilities can be centralized across large installations, as described, and therefore will have higher utilization and better lifetime economics. The expected lifetime of the system is 7-10 years, which may depend on the application points because the limiting factor is expected to be the material wear at the surface of the system. However, sufficient field testing has not yet been done to validate those conclusions. The lifetime of the system should depend primarily on the total number of axles that pass over the system and the average distributed weight of each axle – the more axles and the heavier they are, the more wear on the system. The expected minimum speed for operation is 5mph and the expected maximum in the near future is 25mph. Long-term the team plans to engineer the system to handle speeds up to 50mph to harvest energy from vehicles slowing down in approach to toll plazas on highway or similar high-capacity applications.

At target sites a single unit is expected to present attractive simple payback in terms of energy generated relative to the up-front cost of production. A unit installed at a site with 2,500 vehicles per day is expected to pay itself back within 12 to 18 months at scale manufacturing costs, with the energy produced valued at market rates of $0.14/kWh. Depending on the traffic conditions and volumes at any one of a wide range of facilities, a single system can generate anywhere from 300 W to 2,000 W of continuous power for up to 16 hours of operation per day. On the low end, a single system will generate roughly 1.5 MWh per year and nearly 11 MWh per year on the high end. This enables simple paybacks as low as 6 months at the most active sites and still within a few years even at moderately active sites or given current one-off production costs.

Additional work is being done to identify the best opportunities to further bring down production costs and to benefit most from scale manufacturing. Custom designs that were developed in-house during the course of the study still need to be commercialized and evaluated for most economical manufacturing method. The performance models that were developed will continue to grow more detailed over time, expanding the number of input variables that can be used to estimate available energy at the targeted site and forecast system economics. Furthermore, as individual parts are commercialized and the system is manufactured at scale, system and individual part losses will be re-evaluated to more accurately reflect the overall efficiency and performance of the system.

The study team also did research on innovative financial models for alternative renewable generation technologies and for energy efficiency projects to determine which could be implemented as part of a demonstration project at the study site (Figure 26). With the help of creative financing models, the road-mounted energy harvesting systems could become the center of broader ecosystems for energy solutions at targeted sites and bring a lot more value to site operators.

Figure 26. Illustrative Screenshots of Energy Savings Agreements (ESAs) Financial Models

Inputs and outputs of financial models were developed over the course of the study to evaluate the potential benefits to site operators of installing cost-effective energy technologies that are otherwise capital intensive at no upfront cost. For example, ESAs can help deploy energy-efficient technologies with no up-front cost to site owners that cannot cover high capital expenses and redistribute the savings over time to all parties.

Source: Energy Intelligence

ENERGY PRICES		
Current electricity price ($/kWh)	electricity_price	0.14
Expected Inflation (%)	electricity_inflation	3%
Energy Saving per LED (%)	reduced_energy_per_LED	80%
SITE ASSESSMENT		
Number of fixtures replaced	fixtures_replaced	400
Exsiting Fixture Capacity (watts)	fixture_cap	250
Hours of operation (hours/day)	hours_operation_daily	24
Historical energy usage (000's kWh per year)	baseline_energy_use	876
Days operating per year	days_per_year	365
HARDWARE SPECIFICATIONS		
LED Fixture Capacity (watts)	LED_fixture_cap	50
Total LEDs replaced	LEDs_replaced	400
Degradation Factor(% per year)	degradation_factor	1%
Expected incremental savings through controls		
Dimming Control Implemented?	use_dim_control	no
Incremental savings by using dimming (%)	incr_dim_saving	
Sensors Implemented?	use_sensors	yes
Incremental savings through sensors (%)	incr_sensor_saving	
Expected Useful life for LEDs (years)	LED_life	10
INSTALLATION COSTS		
LED Fixture Cost ($)	material_cost	$ 200.00
Other Materials ($/fixture)	other_material	$ 20.00
Tax on Material ($)	material_tax	$ 5.00
Time to install (hours)	installation_time	400.00
Labor wages ($/hr)	labor_wage	$ 12.00
O&M COSTS		
Annual maintenance costs (%)	Annual_maintenance	5%
Annual LED Premature Failure Rate	LED_failure_rate	1%
Total LEDs replaced per year	LED_replaced	4
LED cost	LED_unit_cost	$ 200.00
LED disposal cost ($/unit)	LED_disposal_cost	$ -
Time to replace a LED (hours)	LED_replace_time	
LED replacement costs	LED_replace_cost	800

KEY:
Calculated Value
User Input

FINANCIAL		
Lending Rate	lending_rate	7%
Length of the agreement	length_of_agreement	10
Depreciation Schedule	depriciation_schedule	Straight Line
OUTIRIGHT SALES		
Markup/fixture (%)	fixture_markup	20%
Financing used?	sales_finance_used	yes
% financed through debt	sales_Debt_ratio	60%
ESPC		
Guaranteed savings rate	guaranteed_savings	
Customer share	ESPC_customer_share	80%
ESCO share	ESPC_ESCO_share	20%
% financed through debt	ESPC_debt_portion	100%
ESA		
Performance Payments	performance_payments	
Customer share	ESA_customer_share	60%
ESCO share	ESA_ESCO_share	22%
Project Developer share	ESA_proj_developer_share	18%
% financed through debt	ESA_debt_portion	70%

One type of agreement, called Energy Savings Agreements, could bring capital-intensive solutions to facilities that cannot otherwise cover the up-front expenses by drawing capital from accredited third parties and redistributing the energy savings over the life of the project. These types of agreements can bring tremendous energy savings to facilities and create real financial value for all involved parties. Relating to the study, the energy harvesting systems could, for example, be connected directly to energy efficient LED lights, creating a total energy solution for EBP's facility entrances. In these scenarios, the road-mounted systems would be generating electricity that could both power lighting and other equipment nearby, while the LEDs in place of conventional lighting reduce consumption dramatically on their own. Energy savings equate to lower operating costs and improved bottom lines for facility operators. Through research, literature reviews, direct discussions with thought leaders in the field (for example, Charlotte Kim, a partner at Wilson Sonsini Goodrich & Rosati), and building financial models to evaluate scenarios, Energy Intelligence honed in on the financial models and agreements that would be best fit the proposed demonstration project and beyond. These efforts are aimed at deploying multiple technologies at a single site, joining PPA sale agreements for renewable energy generation with the equivalent of revenue sharing based on avoided costs through reductions in energy consumption on site with energy efficient technologies.

4 Metrics

The transportation sector and the 250 million registered vehicles in the U.S. are wasting roughly 240 billion gallons-worth of gasoline per year, equivalent to 8 million MWhs of electricity or 30% of total U.S. energy consumption. A substantial portion of energy consumed by vehicles is lost, specifically while braking, as waste heat and friction. Moreover, the Transportation sector is the second biggest producer of greenhouse gas (GHG) emissions, at 27% of total U.S. emissions, second only to the Electricity sector at 34%. Therefore, commercializing innovative technologies that can cost-effectively reduce consumption or more efficiently use existing energy sources is critical. The road-based energy harvesting technology being studied does exactly that and can bring many additional benefits to the broader energy ecosystem.

Furthermore, large commercial and industrial facilities spend much of their budgets on electricity expenses, often amounting to millions of dollars per year. Those facilities with substantial and regular traffic flows onsite are missing an incredible opportunity to convert waste energy from vehicular traffic into electricity. This essentially free source of energy can enable sites to cost-effectively generate emission-free energy onsite where available alternatives are too expensive or not suited to site conditions.

If successful, this technology would revolutionize distributed generation at a wide range of commercial sites by leveraging vehicular traffic and existing infrastructure to reduce onsite consumption, lower operating expenses, avoid harmful emissions, and create a network of smarter infrastructure. The direct benefits of the technology are based on a more efficient and productive use of existing energy, thereby reducing commercial purchases of energy and reducing strain on central loads, or avoiding the use of conventional distributed generation, like diesel generators, and the emissions they produce. The site owner benefits from reduced energy expenses and increased reliability and also creates the opportunity to play part in bringing additional benefits to the surrounding economy and community. For example, the ancillary jobs created by deploying this technology reach the services industries and manufacturing. Also, the technology is interactive by nature and creates a unique opportunity to engage and educate the public, enabling the site owner to establish itself as a steward of sustainability and innovation in its respective community. In contrast to solar panels hidden on roads, this technology will be highly visible and can increase public awareness through the use of local digital displays that provide real-time data feeds of clean energy created and messaging to encourage and thank public participation.

New York State will benefit on multiple dimensions if commercialization of this technology is successful. End users will benefit from a compelling new option for competitive electric supply that uses existing resources (roadways and traffic) and waste energy (dissipated from vehicular traffic while decelerating). Relevant facilities within the state have an opportunity to realize significant energy cost savings while also reducing their emissions. In total, the environmental benefits across all installations could help reduce the State's emissions significantly. Additionally, deployment of the proposed technology will create many new jobs, specifically for manufacturing, installation, roadwork, service contracts, and other business related functions dedicated to each installation.

4.1 Potential Energy Benefits

This energy harvesting technology aims to cost-effectively deliver clean power to industrial and commercial facilities with significant traffic volumes onsite and a need for cheaper energy. The economics of the system depend on the cost to build and operate it, and the amount of energy each system can produce. Over time the design has been improved and simplified and costs have been dramatically reduced. On the other side, output potential varies from site to site and is limited by the energy available based on traffic conditions onsite. Just like the generation capacity of a wind turbine is dependent on wind speeds and continuity, so do the energy harvesting systems depend on vehicular traffic flows. More so than wind, traffic is surprisingly predictable and aligns nicely with peak energy usage hours, meaning that traffic is heaviest, and therefore energy is generated, when energy demand is greatest. The more vehicles pass over a system, and the heavier they are, the more energy that system will produce. Output can also be increased at a site by installing more systems in series.

A single module is likely to generate 250 to 1,500 watts of continuous power while operating 12-18 hours per day, which would produce between 800 and 10,000 kWh annually. In comparison, a single solar panel occupies roughly the same square footage and produces only 200 watts on average and 400 kWh per year. A typical system is expected to be composed of 5 modules connected in series. In that case, a system would produce between 1,250 and 7,500 watts of continuous power and between 4,000 and 50,000 kWh in annual production. Similarly, typical installation sites would consist of multiple systems. For example, a multilevel urban parking garage could have one system at each of the entrance, exit, and down ramps between levels. At a port terminal for container trucks, the entrance, exit, weigh station, radiation scanner, and other checkpoints all represent relevant applications for system installations. A five-system installation site would then produce between 6 and 37.5 kilowatts of power and between 20,000 and 250,000 kWhs annually. In fact, the larger installations targeted have enough physical space to host significantly larger installations; however, the calculations are meant to reflect directional growth of output.

Given that 1 kWh of electricity equates to roughly 0.0008 tons of CO_2 equivalent,[1] this technology has the potential to offset or avoid a significant amount of harmful greenhouse gas emissions. A single unit can avoid up to 8 tons of CO_2 equivalent on its own; a 5-unit system can avoid up to 40 tons of CO_2 equivalent; and a 5-system installation can avoid up to 200 tons of CO_2 equivalent. That means a five-system installation could offset the annual emissions from electricity use at 25 homes, 422 barrels of oil consumed, or 432,000 miles driven by a passenger vehicle.

The traffic data collected at the study site enables the calculation of similar estimates for the potential energy that could be generated at EBP. Gate 340 had a weekday average of roughly 1,100 vehicles per day (500 entering, 600 exiting). Of those vehicles, roughly 10% were tractor-trailers and 15% were trucks, both of which are significantly heavier than passenger vehicles and have significantly higher potential energy. With tractor-trailers equal to roughly 15 passenger vehicles by weight and trucks equal to 3 passenger vehicles, the weekday average traffic count can be calculated as roughly 3,000 passenger vehicle equivalents. This daily vehicle count parallels the inputs used in the economic model described in Section 3.3 and suggests an annual output per energy harvesting unit of 1,120 kWh. In turn, this implies 5,600 kWh and 28,000 kWh in annual production for 5-unit systems and 5-system installations, respectively. This level of energy production equates to CO_2 emissions reductions (or avoidance) of 0.9 tons per unit, 4.5 tons per system, and 22.5 tons per installation. Gate 24 had a weekday average vehicle count of 475 per day. Adjusted to passenger vehicle equivalents, Gate 24 recorded about 570 per day. At roughly 20% the traffic flow of Gate 340, Gate 24 could generate roughly 225 kWh per unit, 1,120 kWh per system, and 5,600 kWh per installation each year. These output levels equate to 0.2 tons per unit, 0.9 tons per system, and 4.5 tons per installation of avoided CO_2 equivalent emissions.

The use of inexpensive materials and the simplicity of design result in low cost of production and compelling unit economics. At scale and at target locations, the system can pay back capital expenditures in as little as 6 months and has a levelized cost less than \$0.07/kWh. In many cases, that levelized cost reflects reductions from alternative electricity rates as high as 70%. The levelized cost calculation takes into account at a very granular level up front production costs, maintenance and other ongoing expenses, and energy generated over the useful life of the system. The energy generation projections in the paragraph above take into account mechanical losses, hydraulic line losses, and other efficiency losses throughout the system. Since modifying the system design over the course of the study, including developing entirely novel components, the team has not yet validated the end-to-end system loss estimates. Specifically, the 3D printed hydraulic turbines are known not to perform as efficiently as commercially available products. Therefore, parts developed, fabricated, and tested during the study achieved lower efficiency performance than the team expects to see with more advanced prototypes – for example with the hydraulic turbine, on the order of 10-15% efficiency where commercial products perform as well as 50% efficiency. As part of the study recommendations, the team is drafting full development plans to carry the current prototypes and designs to commercial manufacturability and to validate expected system performance at full scale.

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[1] U.S. Environmental Protection Agency Greenhouse Gas Equivalencies Calculator, www.epa.gov/cleanenergy/energy-resources/calculator.html

4.2 Potential for Replication

Any road leading to an entry/exit gate, weigh station, or other checkpoint, represents a potential installation site for this energy harvesting technology. These opportunities can be found at a wide range of facilities with regular traffic flows and a need for energy onsite, including but not limited to parking garages, transit centers, airports, stadiums, distribution centers, landfills, and port terminals. New York State is home to thousands of sites across these categories and could host an equal or greater number of installations to realize the energy and other benefits anticipated. These facilities are highly motivated to adopt cost-saving energy technologies; however, existing solutions are poorly suited for the targeted sites and no commercially viable road-based energy harvesting solution exists. In addition to quick paybacks, these customers are looking for minimal site disruption, vetted durability, and reliable performance.

In New York State, there are estimated to be more than 150 facilities, both private and public, where this technology could be readily deployed, making the potential economic value of associated electricity sales or savings and other benefits achievable in the near- to mid-term in the tens of millions of dollars annually. New York has a strong industrial, transit, and logistics presence, and as such the State presents many opportunities for successful deployment of this technology. One specific example is the Port Authority of New York, which operates one of the busiest terminals in the country and presents a tremendous opportunity to capture waste energy from freight traffic. Within a port terminal, the proposed system can be installed at numerous checkpoints and be scaled easily. Beyond port terminals, there are thousands of relevant parking facilities throughout the State. Energy Intelligence's partner, LAZ Parking, is one of the largest private garage operators in the country with nearly 2,000 garages nationwide. LAZ has over 75 large garages in the New York City and Hudson Valley areas alone, with many more concentrated around Albany. A wide range of truck applications is also attractive for potential installations, including truck stops, weigh stations, and distribution centers. Energy Intelligence is already in discussions with several potential partners, including NYSERDA grant recipients focusing on truck stop electrification. These sites and applications present interesting opportunities to deliver the energy generated from the road-based systems to specific equipment or functions, like electric charging stations or connection points to truck cab electricity supply. Finally, as an early member of this study's PAG, the New York Thruway Authority could play an important role in longer term, large scale installations throughout the State. In fact, Energy Intelligence is considering materially locating in Buffalo to establish a presence on the western side of the State, connect with local partners and potential installation sites, and take advantage of statewide opportunities.

Globally, the technology's addressable market size is greater than $10 billion annually, estimated by the potential value of energy that could be generated at target sites. With many possible applications, Energy Intelligence is currently focused on parking garages, port terminals, and toll roads and aims to create a new and significant source of onsite generation to reduce expenses, avoid emissions, and increase reliability. Energy Intelligence has validated market interest in the proposed technology and gained substantial traction with potential customers and partners and needs to carry the technology through advanced development to deliver the first field prototypes. In fact, the company has lined up four pilot sites for demonstration of the proposed technology, including an international airport and a LAZ parking garage in the Boston area, and has received several formal letters of interest from large companies, including Siemens.

5 Conclusions

To prepare this road-based energy harvesting technology for the proposed demonstration site, the project team measured and analyzed site characteristics and requirements and made adjustments to system design in order to fabricate and deploy an optimal prototype for the study site. Several work streams came together under the study and produced a robust set of data to evaluate the feasibility and potential value of conducting a full demonstration. Early project tasks focused on site assessment to validate vehicular traffic counts and characteristics and learn about interconnection requirements with local equipment. The project followed with an assessment of the technical feasibility and economic analyses of deployment to the site given design modifications and the validated site details. Finally, additional requirements for a demonstration project, including security protocol and data management, were considered and preliminary plans were drafted and prototype systems developed.

The traffic flows measured at the study site are lower than anticipated at scale target sites, but with a substantial difference between the two security gates studied. As detailed in Section 4.1, Gate 340 can achieve compelling unit economics, in line with the figures modeled in the study, though at the low end of targeted economics. Gate 24 does not have sufficient traffic flows to justify a demonstration. That said, a demonstration project, even if operating at lower than anticipated capacity, performance, and economics, could still create a lot of value in the commercialization process. Completing a field demonstration from start to finish with a fully functional system, including road-units, data acquisition and controls, backend database management, local real-time displays of performance, and connected loads, for example LED streetlights, deployed at an operational site and monitored over a specified performance period would be incredibly valuable. The ability to point to a real use case that sets baselines for performance, cost, installation timelines, reliability, durability, and other key metrics would be invaluable for ongoing development and for future projects. Furthermore, having a location at which to showcase the technology and capabilities to other potential customers would be valuable in and of itself. Operators of the many target facilities throughout New York State could easily drive to the project site to see a full demonstration and even test the system out for themselves.

Several attempts have been made at developing solutions to harvest ambient or other wasted energy on roads, yet none have succeeded at achieving competitive economics, none are commercially viable, and none have used the proposed technological approach. The concept of a fully enclosed system with no exposed moving parts and that is compact enough to lay on top of existing road surfaces is completely novel and transformative relative to the current state of the art. For this system to be economically viable and so easily deployed would fully revolutionize the still-nascent market for energy harvesting on roads. This study conducted key research and analysis in tuning and optimizing critical components of the system to match local site requirements and conditions and set the groundwork for more advanced development and, later, full scale demonstration of the system.

5.1 Future Action

Energy Intelligence suggests pursuing a demonstration project at EBP's Gate 340, but not at Gate 24. The data collected and subsequent analyses conducted over the course of the study suggest that acceptable, and even competitive, project economics can be achieved at Gate 340, given the relatively higher traffic flows recorded, greater presence of trucks and tractor trailers, and longer hours of operation. In contrast, Gate 24 simply does not have sufficient traffic flows to validate technical performances in a demonstration. Furthermore, Energy Intelligence has made the case that a demonstration of this scale and at this facility would create value and benefit broader commercialization efforts in many ways. As such, a demonstration would be worth pursuing at EBP.

The study also uncovered the complexity of adapting internal system components, especially the power conversion related parts, to site conditions like those present at the study site. The technical efforts carried out over the course of the study accomplished the objectives of the study; however to carry out a full demonstration project, more advanced product development needs to take place to finalize designs of these internal components.

Appendix A

A.1 Data Acquisition Technical Memo

Introduction

This system measures current coming out of the generator and stores it on an SD card, then pushes it all to a remote database server, the contents of which can be viewed on a static Web page (http://hivemind-env-ssvaz5mrfk.elasticbeanstalk.com/endpoint/).

The whole system is referred to as The Pipeline. It is a means to continuously monitor each installed system and site, store the readings in a central location, and extract information for various purposes. Applications include remote maintenance diagnostics, real time displays for sites, real time internal analytics, and a set of auxiliary applications with the aid of machine learning. These auxiliary applications include traffic counting, vehicle weighing, vehicle classification by energy profile, and in-depth system modeling for improved maintenance diagnostics.

Hardware:

- Circuitry to measure current in an electrically isolated and safe manner, output the current as a voltage signal, and read the voltage signal into the Arduino.
- A test system which sources from any battery pack with a female output connector an amount of current (adjustable by swapping the current-limiting resistor as needed) which is to be used for testing the performance of the current sensing circuitry. The same test system can be used for building an electrically isolated method of measuring voltages, and testing the performance of these systems in parallel.
- External input controls (buttons) to trigger various functions within the Arduino over software. These buttons can manually source current from the test system, send a signal to the Arduino which can instruct it to temporarily change the rate of sampling, and send a signal to the Arduino to tell it to pause data collection. Additional programming can cause the last button to terminate data collection, write data to SD card, and send the contents of the SD card over to the server.

Software (firmware):

- Onboard the Arduino, there is code that is capable of converting the hardware signal into a digital value, and storing the digital value into an SD card. The code is also capable of safely terminating data collection so that the Arduino can be reset using the standard reset button on the board, writing sensor data to SD as soon as the data arrives, and taking all of the contents of the SD card and transmitting them to the server.
- The software operates like a state machine: the program can be in various states (or “modes”). Currently the modes are collect data, rest temporarily, and termination, and the writing of SD card contents occurs during termination.
- Other features of the code include the ability to fetch the real world time from an NTP server, updating the system time to the real world time. This occurs on startup.

Cloud storage and display (Hivemind):

- A fully operational server endpoint which can receive data from the Arduino and log it to a remote database. This "server endpoint" runs as a cloud instance.
- A Web page which displays all of the information in the remote database in a simple table format. This Web page should be simple to modify to display the data in an appealing format for signs and monitors.
- A remote database which runs as a cloud instance separate from the server endpoint.

Sensor Electronics

- All transducers and sensors should generate a signal between 0 and 5V in order to be compatible with the Arduino's analogRead pins. These pins digitize the signal with a 10-bit ADC. Typically sampling between once per second up to several dozen Hertz, fit performance requirements and works well within the clock limits on the Arduino. These sensor readings are taken at variable rates depending on whether or not the energy conversion mechanism is being engaged by an overhead vehicle. When there is no vehicle, the sampling rate drops to once every few seconds, providing logged information, which go towards remote system diagnostics.

- Intention is to measure the following necessary values:
  - DC rectified current.
  - DC rectified voltage.
- In the future, the system would accommodate these less essential values:
  - Pressure.
  - Velocity.
  - Impelling rotation speed (or a rotation count).
- Should also consider the full power electronics system, which stores the generated energy from each mat into a battery bank. It would be nice to have (less pervasive) monitoring of the battery bank – for example, a simple voltage measurement would allow us to estimate the charge on the battery by looking up the battery-charging curve. Currently we are using a Hall effect sensor chip to measure DC.

Microcontroller (Arduino Mega)

An oncoming vehicle triggers an external input which takes the sensor system into sense mode. All data are logged to SD card. A background process runs every time the SD card reaches a predefined capacity (e.g. 1MB), posting the data to an AWS server and clearing that section of memory.

The codebase is written in C++. An annotated version of the code structure is below.

Note that the C++ is based on the standard libraries included with the Adafruit shields, but that I have modified these libraries. So do remember to use the libraries included within the Arduino folder rather than download them fresh from the Internet.

```
void setup(void)
{
 // ***** Initialise the cc3000 module *****
 // ***** Initialise the SD module *****
 // ***** Check SD file, print contents if exists *****
 // ***** Connect to local WiFi access point *****
 // ***** Obtain seconds since epoch from NTP servers *****
 // ***** Prepare for data acquisition and logging *****
}

void loop(void)
{
 // ***** State transitions *****
 //          If 21 seconds have passed, then stop collecting data
 // ***** State behaviors *****
 //          Stop routine
 //          Close logFile
 //          dumpSDcard to server
 //          Disconnect cc3000
 //      Data collection routine
 //          read value
 //          convert to miliamps
 //          calculate delay value
 //          flash LED on for delay value
 //          print sensed value to console
 //          print sensed value to SD card
 //          flush SD card buffer
 //          wait for another delay value length of time
}
```

AWS Endpoint

The data is stored in a MySQL remote database under the table titled CambridgeDevelopment2 and further processed into a normalized table where each sensor reading has its own row.

The schema is below:

```
+--------------------+ -----------------------------+
| Field              | Type                         |
+--------------------+ -----------------------------+
| ID                 |  default MySQL value         |
| event_time         | timestamp                    |
| generator_id       | int(10) unsigned             |
| reading_type       | int(3) unsigned              |
| data_blob          | varchar(64)                  |
+--------------------+ -----------------------------+
```

db name: CambridgeTest2

instance identifier: camb-dev2

port: 3306

zone: us-east-1c

username: jwu

command to log in through terminal:

mysql -h camb-dev2.cvbfnon38tsb.us-east-1.rds.amazonaws.com -P 3306 -u jwu –p

pwd is LYNXWind, and this is stored in the powermonitor app settings.py

Data_blob contains the string fetched directly from SD storage. The sensor readings are stored as space separated pairs of timestamp,value (compatible with CSV format).

Front-end

The frontend is currently implemented as a simple table view of the raw database pushed to by the Arduino. It is accessible here: http://hivemind-env-ssvaz5mrfk.elasticbeanstalk.com/endpoint/

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