Improving Energy and Water Efficiencies in Duke Laboratory Buildings

Client: Duke University Occupational and Environmental Safety Office

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Table of Contents

Introduction

The Duke University Occupational and Environmental Safety Office (OESO) supports the university-wide efforts to manage safety and environmental programs in education, healthcare delivery, medical teaching and research. While the organization focuses on health and safety issues, it also extends its reach to those projects that will further the institutionalization of sustainability at Duke University. Because OESO has a longstanding commitment to environmental education and stewardship, it researches and develops a variety of projects in order to drive environmental performance improvement at Duke. OESO has worked with various university partners to develop environmental projects to enhance energy and water efficiency within the Duke community.[1] This Masters project is a collaborative effort between OESO and the Nicholas School of the Environment to frame and study the challenges of reducing environmental impacts and further improving environmental performance at Duke University.

Like most of the architectural facilities in the 21st century, Duke University's academic buildings and laboratories on Campus are both water and energy intensive. Therefore, our team was charged with a task to develop feasible solutions to drive environmental performance on the Duke Campus. The team focused on two metrics: electric power generation and water conservation in scientific research laboratory buildings. This research activity was intended to: (1) investigate whether it is

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[1] Duke OESO, Environmental Programs, http://www.safety.duke.edu/EnvPrograms/, Retrieved on December 20, 2012

environmentally and financially viable to participate in a demand response program with a local utility provider; (2) strategize ways to address the problem of improper sewer disposal ; and (3) suggest potential opportunities to enhance water efficiency in laboratories. Through our research, pilot studies, interviews, and surveys, the team identified best practices and provided management strategies that would drive environmental performance improvements at Duke University. We believe that these replicable recommendations could be rolled out to other academic institutions in order to promote environmental sustainability within the higher education sector.

Improving Environmental Performance on Duke Campus through the Demand Response Program and Electric Power Generation

Demand Response Program

The need for environmental sustainability and energy security is leading to a greater focus on efficient management of energy generation. Since the university already maintains a large inventory of electricity generators to provide emergency power to essential buildings, OESO is currently interested in incorporating electric generators into Duke Energy's Demand Response (DR) Programs. Duke Energy encourages businesses and institutional customers to save energy through PowerShare®, a DR program that rewards business clients for adjusting or curtailing their energy consumption during the peak time periods.[2] In other words, the DR Program is a strategy employed to voluntarily reduce electrical consumption in response to explicit requests based upon critical conditions, time, and market prices. Duke University currently participates in this program by operating 9 of its 66 electric generators to produce its own power temporarily, thereby reducing stress on the overloaded electric grid. This mechanism was put in place to prevent electrical brown-outs and even potential power interruptions, such as black-outs. Duke University could receive additional financial incentives from Duke Energy to curtail on-site electricity demand by expanding its on-site generation capabilities.[3]

There could be a cost-effective strategy for Duke University to work with the local utility company to reduce the total environmental impacts associated with electric power generation. In fact, more than 50% of the power generated by Duke Energy comes from coal combustion, which emits higher level of pollutants than the majority of Duke University's diesel-powered electricity generators.[4] Moreover, while the DR program shifts the source of power generation from centralized coal power plants to Duke University's emergency electricity generators, it translates into a lower total amount of power consumed due to an enhancement of transmission efficiency. Cleaner feedstock and higher transmission efficiency work to reduce the overall levels of pollutants generated. Without effective DR programs, scientists have

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[2] Duke Energy, PowerShare DR Program, http://www.duke-energy.com/south-carolina-large-business/energy-efficiency/sclb-powershare.asp , Retrieved on January 29, 2013.

[3] Interviews with Randy Teasley on January 21 and 30, 2013

[4] Interviews with Jeff Koone on Febuary 1, 2013

estimated that the systems used to heat and cool homes across the United States would release "150 million tons of carbon dioxide into the environment in 2009."[5]

Since Duke University is one of the largest power consumers of Duke Energy, the research team decided to assess the feasibility of entering into an expanded agreement with Duke Energy in order to curtail the University's overall environmental footprint.

Emergency Generators Deployed at Duke

The Duke Campus and the Medical Center is a city within a city, having more than 250 buildings with diverse profiles: administrative offices, academic facilities, research laboratories, libraries, dormitories, dining rooms, conference centers, and hospitals. The Campus also has 66 emergency generators to support those buildings, and their operation is governed by EPA's specific regulatory requirements. The sizes of these electricity generators vary from the smallest 40 horsepower generator in Cameron Indoor Stadium to the largest set in the French Science Center with a capacity of 2,876 horsepower.[6] Despite having four generators that use natural gas as the feedstock, the majority of Duke University's generators are powered by diesel fuel.[7] (Table 1)

Table 1: Generators fleet at Duke

Generator (by fuel type)	Diesel-powered	Natural Gas-powered

[5] US Department of Energy, Energy Efficiency and Renewable Energy, http://www1.eere.energy.gov/consumer/tips/heating_cooling.html. Retrieved on January 11, 2013.
[6] Interviews with Randy Teasley on January 21, 2013.
[7] Interviews with Randy Teasley on January 30, 2013.

Max Capacity (hp)	<600	>=600	<600	>=600
Number of Generators	31	31	4	0

Figure 1: Diesel-powered Emergency Generators at Duke Chilled Plant #2

Figure 2: Diesel Fuel Tanks below the Generators

Duke University and the PowerShare Program

PowerShare is the DR program designed by Duke Energy to reward participating organizations for adjusting energy consumption levels during peak time periods. The PowerShare program's predecessor, Standby Generation Program, could be dated back to early 1980s when Duke Energy determined the DR program is the cheapest, fastest and cleanest way to effectively manage peak energy demand. Nine emergency generators at Duke University are currently enrolled in the **Generator Curtailment Option** under the PowerShare program; in which, during any capacity constrained period, the load from the Duke Energy power source is switched to the on-site generators.[8]

As a result, Duke University is eligible for curtailed energy credits of $0.10 per kilowatt-hour generated during the curtailment period in addition to a monthly capacity credit of $3.50 per kilowatt.[9] For example, a DR electricity generator with a testing output capacity of 1000 kilowatt would be able to received $3500 capacity credit per month to participate in the PowerShare Program. In addition if there is any curtailment request issued by Duke Energy during this time period, a curtailed energy credit of $0.10 per kilowatt-hour will be rewarded to Duke University depending on the total electricity curtailment. Our research focused on quantifying the potential additional credits from increased participation (more generators in the PowerShare program) to determine whether these incentives would encourage Duke University to register as many eligible electric generators as possible into the DR Program. This

[8] Interviews with Jeff Koone on February 12, 2013.
[9] Interviews with Jeff Koone on February 12, 2013.

expanded participation would curtail the overall energy demand and reduce the needs for Duke Energy to build new power plants in the future. Furthermore, Duke University's participation in this energy reduction effort would also provide Duke Energy with more time to develop renewable sources of energy in its power production portfolio. However, if Duke University chooses to use its existing emergency generators for more than 100 hours annual allowance in a DR program, these generators would no longer be considered emergency generators and would be subject to more stringent regulatory requirements.[10]

Regulatory Policy for Electricity Generators

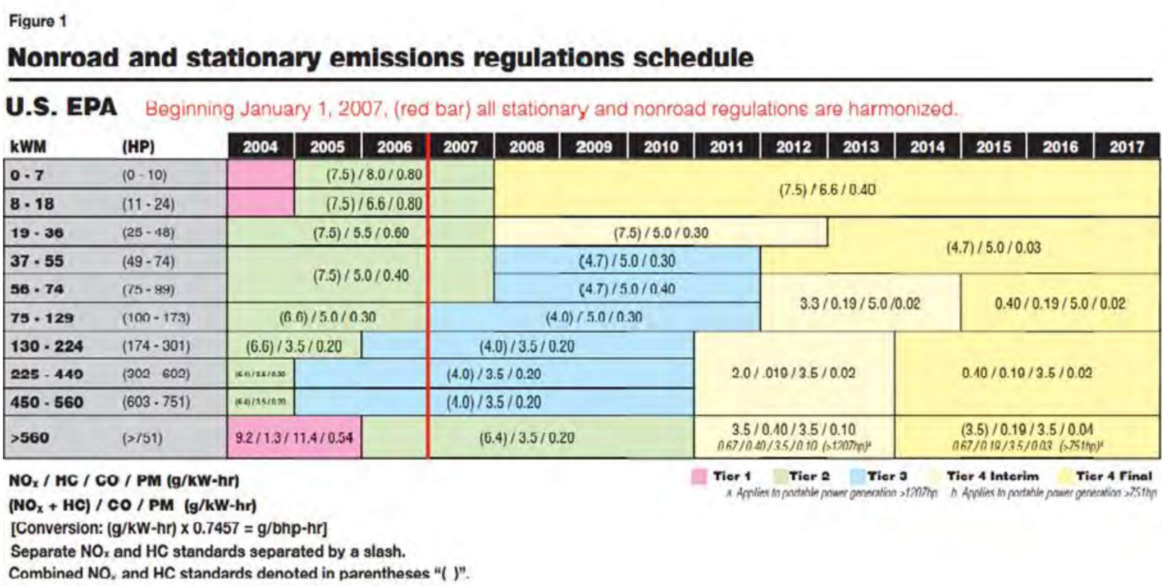
The US federal government has promulgated two separate emissions regulations for stationary diesel electricity generators: New Source Performance Standards (NSPS) and a National Emission Standards for Hazardous Air Pollutants (NESHAP) for Reciprocating Internal Combustion Engine (RICE) generators; the applicability of either depends on the year the engines was installed or reconstructed. The US Environmental Protection Agency (EPA) finalized the NSPS on July 11, 2006 in order to regulate air exhaust from newly installed stationary diesel generators.[11] These new standards "synchronized emissions requirements for stationary diesel engines with the pre-existing EPA non-road" and mobile engine emissions regulations. Stationary engines are defined as "any engine that is permanently installed and used as a power source."[12] This category includes "standby generators, on-site prime and

[10] Conversation with Charlotte Clark and Bill Brewer on September 10, 2012.

[11] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/. Retrieved on January 11, 2013.

[12] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/. Retrieved on

distributed emergency power systems, and a wide variety of industrial engines mounted on permanent bases or foundations."[13] The inventory of emergency generators at Duke University is considered to be stationary because they are installed at a single location for more than 12 months. More specifically, in February 2013, the EPA NSPS also defined interim emissions requirements to help transition the new stationary engine regulations. The diagram below summarizes the EPA NSPS exhaust regulatory schedule out to 2017 and defines how emissions requirements vary in tier requirements by engine horsepower (hp) and transitional phases.[14]



Concurrently, the federal government also promulgated regulations for stationary internal combustion engines named the RICE NESHAP. The RICE NESHAP is the acronym for the US EPA's regulatory mandate for "reciprocating internal combustion engines national emissions standards for hazardous air pollutants". The RICE NESHAP

January 11, 2013.

[13] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/. Retrieved on January 11, 2013.

[14] Cummins Technologies, EPA NSPA regulations, http://www.cumminsgdrive.com/as_regulations. Retrieved on January 12, 2013.

rule requires implementation of new emissions reporting practices for existing and newly implemented stationary engines. This ruling affects existing stationary diesel engines in the following categories: "(1) Engines defined as "area sources" of hazardous air pollutants (HAPs) and constructed or reconstructed before June 12, 2006; (2) engines defined as "major sources" of HAPs, have a site rating of less than or equal to 500 hp, and constructed or reconstructed before June 12, 2006; and (3) engines defined as "major sources" of HAPs for non-emergency purposes, have a site rating of greater than 500 hp and constructed or reconstructed before December 19, 2002."[15] The abovementioned area sources are defined as those electricity generators that "emit or have the potential to emit less than 10 tons per year of a single HAP or 25 tons (total) per year of multiple HAPs".[16] A major source is a generator whose HAPs emissions exceeds, or could exceed the EPA's mandated limits above and, thus, is subjected to more stringent regulatory requirements. All emergency generators at Duke University belong to the "area source category" due to the small amount of air pollutants emitted.

However, when the EPA finalized the RICE NESHAP rule on March 3, 2010, the agency decided not to include existing emergency generators which were constructed or reconstructed before June 12, 2006 in the rule of applicability.[17] Therefore, pre-existing emergency generators installed prior to 2006 at Duke University and

[15] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/. Retrieved on January 11, 2013.
[16] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/. Retrieved on January 11, 2013.
[17] Duke OESO, Clean Air, http://www.safety.duke.edu/EnvPrograms/CleanAir.htm. Retrieved on December 6, 2012.

Medical Center are exempt from the RICE NESHAP and all of its requirements. Despite this, the stationary emergency generators which were installed after 2006 must comply with NSPS Tier 3 requirements, but are exempt from Tier 4 Interim and Tier 4 Final regulations.[18]

Prior to January 2013, the EPA allowed existing emergency generators to run up to 15 hours per year for the DR financial arrangement with utility providers and still be classified as "emergency generators." However, this annual time ceiling for DR purpose was later extended to 100 hours annually on January 14, 2013.[19] If Duke University decides to operate an electric generator under the DR program for more than the 100 hours annual quota, this particular generator will then be categorized as a non-emergency generator and subject to the specific RICE NESHAP and NSPS Tier 4 emissions requirements.

Objective

Our Masters project was intended to analyze the feasibility of converting emergency generators into non-emergency DR application generators and to provide recommendations on the feasibility and the economic and/or environmental benefits of participating in the DR Program. Data was analyzed to determine whether retrofitting and operating emergency generators under the DR scheme would be a cost effective method to reduce Duke University's overall environmental impacts. We

[18] US EPA, Reciprocating Internal Combustion Engines RICE , http://www.epa.gov/region1/rice/, Retrieved on January 28, 2013.
[19] US EPA, Federal Register, January 30, 2013.

believed that the project would provide valuable insights for the university administration in making more informed decisions about improving environmental performance on campus.

Methodology

Pilot Study: MSRB and MSRB-II

1. **Criteria selection for identifying target generators**

We conducted a pilot study which focuses on one generator set and then applied the research patterns and conclusions to other generators at Duke University. We selected large capacity generators because large capacity generators are more cost effective for retrofitting. Meanwhile, as discussed in regulatory policies for electricity generators, generators installed before June 12, 2006 (existing generators) and generators installed after June 12, 2006 (new generators) are subjected to different emission limits: NSPS and RICE NESHAP respectively. Therefore, we selected one existing generator and one new generator as our pilot studies in order to comprehensively assess the feasibility of our scenarios.

The existing generator is the emergency generator at the Medical Science Research Building (MSRB) that was installed in 1994 with a capacity of 1879 hp, while the new generator is the emergency generator at the Medical Science Research Building-II (MSRB-II) that was installed in 2008 with a capacity of 1676 hp.[20] The MSRB generator is enrolled in the PowerShare program with Duke Energy, meaning that it is required to provide a minimum of 200 kilowatts of

[20] Interviews with Bensinger & Garrison Environmental, Inc. on January 22, 2013.

curtailable load during curtailment periods when Duke Energy experiences capacity constraints. Duke University can receive a Capacity Credit of $3.50 per kilowatt each month even if there are no curtailment periods, and a Curtailed Energy Credit of $0.10 per kWh produced during Curtailment Periods for each generator. The Capacity Credit is calculated by multiplying $3.50 per kilowatt with the maximum capacity during the running time of the generator including the testing time. The Curtailed Energy Credit is calculated by multiplying $0.10 per kWh with the total amount of electricity produced only during the curtailment period.

2. Scenario profile

In order to determine the most feasible and cost-effective way of incorporating emergency generators into the DR program, three scenarios for each generator were evaluated to compare their feasibility: (1) Test Only scenario in which emergency generators are run under load one hour per month, (2) Emergency Max scenario in which emergency generators can be run for 100 hours per year under the new RCIE MACT rules, and (3) Non-emergency Generator scenario in which emergency generators would be converted to non-emergency generators. Therefore, six scenarios in total were determined, shown in Table 1.

Table 2: Scenario Profiles Introduction

Scenario #	Generator	Running hrs/yr for DR Program	Interpretation
1	MSRB	12 T* + 0 MC**	Test Only scenario; Only 1 hour for testing purpose per month in DR program.
2	MSRB	12 T + 88 MC	Emergency Max scenario; All 100 running hours allowance has been used in DR

			program.
3	MSRB	> 100	Non-emergency Generator scenario; Converted into non-emergency generators without DR program.
4	MSRB-II	12 T + 0 MC	Test Only scenario; Only 1 hour for testing purpose per month in DR program.
5	MSRB-II	12 T + 88 MC	Emergency Max scenario; All 100 running hours allowance has been used in DR program.
6	MSRB-II	> 100	Non-emergency Generator scenario; Converted into non-emergency generators without DR program.

**: T represents running hours for generator testing.*

***: MC represents running hours for mandatory curtailment in PowerShare program when Duke Energy experiences capacity constraints.*

- The Test Only scenario refers to no mandatory curtailment hours situation of the emergency generators in MSRB and MSRB-II. According to the National Fire Protection Association, facilities must "exercise and test their emergency generators under load at least monthly for a minimum of 30 minutes" [NFPA 110(99), Sec. 6-4.1; NFPA 110(02), Sec. 8.4.1]. Therefore, the emergency generators at Duke would still run about one hour per month for testing purpose when no emergency events occur. This hour can earn the Capacity Credit of $3.50 per kW.[21]
- The Emergency Max scenario incorporates 100 hours into the DR program without changing its emergency generator status. According to the finalized RICE MACT Amendments published by EPA on January 14, 2013, [22] "The EPA proposed to limit operation of emergency stationary RICE as part of an

[21] Interviews with Large Business of Duke Energy. Retrieved on February 12, 2013.
[22] The amendments will be effective on April 1st 2013.

emergency demand response program to within the 100 hours per year that is already permitted for maintenance and testing of the engines."[23] Given that the maintenance and testing of the engines would take 12 hours annually, we set the running time for elective mandatory curtailment quota of 88 hours per year in this scenario. Therefore, this scenario can earn both the Capacity Credit and the 88 hours' Mandatory Curtailed Credit.

- Non-emergency Generator scenario refers to converting emergency generators to non-emergency generators with a running time of more than 100 hours so that the generator must conform to the EPA's emissions standards for non-emergency generators. The running time of the generator in this scenario was set to be a regular generator's running time that is 24 hours per day and 365 days per year. Under this circumstance the generator cannot participate in the DR program, and therefore cannot earn any credits from Duke Energy.

3. Compliance analysis and abatement technology overview

Currently all emergency generators at Duke conform to the emissions standards of EPA. However, they must adhere to more stringent rules once they are converted into non-emergency generators. Figure 3 below summarizes the EPA's applicability flows for different kinds of generators.

[23] Environmental Protection Agency. National Emission Standards for Hazardous Air Pollutants for Reciprocating Internal Combustion Engines; New Source Performance Standards for Stationary Internal Combustion Engines 2013. http://www.epa.gov/ttn/atw/rice/20130114amendments.pdf. Retrieved on January 29, 2013.

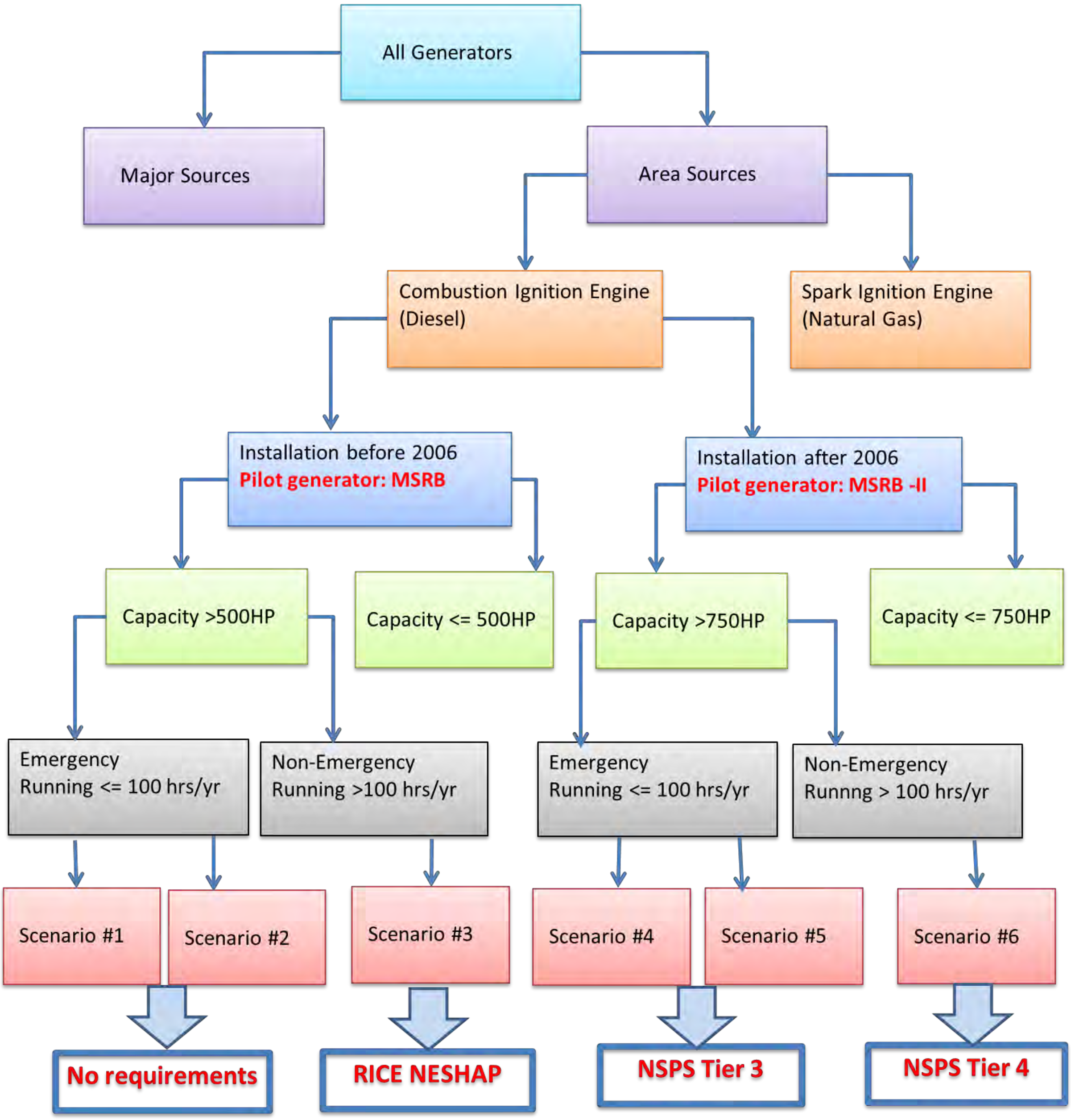


Figure 3: Flow Chart for Compliance Analysis

It can be seen from Figure 3 that the source type, engine type, installation date, capacity, and emergency or non-emergency status need to be determined in order to identify the applicable emissions requirements. First, all generators at Duke belong to area sources which "emit less than 10 tons annually of a single hazardous air pollutant or less than 25 tons or more annually of a combination of the 188 identified hazardous air pollutants".[24] Second, all generators are combustion ignition (CI) engines powered by diesel except for four natural gas powered generators on the campus. Third, the installation date and capacity need to be determined. MSRB was selected to be the pilot generator installed before June 12, 2006 with a capacity of more than 500 hp. By contrast MSRB-II was selected to be the pilot generator installed after that date with a capacity of more than 750 hp. Finally, the designation as emergency status or non-emergency status results in additional, different requirements. Therefore, the emissions requirements for all six scenarios can be summarized in Table 2. It can be seen that once the generator in MSRB is converted into non-emergency generator, it has to conform to the RICE NESHAP, which requires the reduction of CO. Similarly, once the emergency generator in MSRB-II is converted into a non-emergency generator, it must conform to the more stringent Tier 4 emission limits instead of Tier 3 emission limits, which would require emissions of particulate matter (PM) and mono-nitrogen oxides (NOx) to be reduced by about 90%.[25]

Table 3: EPA Rules for All Scenarios

Scenario	EPA Rules	Criteria Pollutants	Applicability
1,2	None	None	Existing*, emergency
3	RICE NESHAP	CO	Existing, non-emergency
4,5	NSPS Tier 3	NOx, PM, HC, CO	New**, emergency
6	NSPS Tier 4	NOx, PM, HC, CO	New, non-emergency

[24] EPA Website. 2012. http://www.epa.gov/ttn/atw/pollsour.html Retrieved on February 3, 2013
[25] DieselNet website. Stationary Diesel Engines (NSPS). 2010. http://www.dieselnet.com/standards/us/nonroad.php#tier4. Retrieved on February 3, 2013.

**: Existing refers to generators installed before June 12, 2006.*

***: New refers to generators installed after June 12, 2006.*

Emissions factors data for the MSRB and MSRB-II generators were provided by Duke OESO. In order to determine whether the converted non-emergency generators need to install additional emissions control devices, emissions factors of MSRB were compared with the RICE NESHAP emission limits and the emissions factors of MSRB-II were compared with the NSPS Tier 4 Standards, shown in Table 3 and Table 4 respectively. Table 3 shows that CO emissions control device needs to be installed to reduce the CO emissions by 70% for the MSRB non-emergency generator scenario. As Table 4 shows, emissions of NOx significantly exceed the EPA regulations, while emissions of PM, CO and HC (hydrocarbon) do not. Therefore, retrofitting technology is needed to reduce PM emissions by 50% and reduce the NOx emissions by 89% for the MSRB-II non-emergency generator scenario.

Table 4: Emissions Factor Comparisons for MSRB and EPA Regulations

Pollutants	Emissions Factor of CO (ppm)	RICE NESHAP for Engines > 500 hp (g/kwh)	Compliance
CO	155	Either reduce CO by 70% or the current emission is 23 ppm	No

Table 5: Emissions Factor Comparisons for MSRB–II and EPA Regulations

Pollutants	Emissions Factor of the	EPA Tier 4 Standards for	Compliance

	Generator (g/kwh)	Engines > 900kW (g/kwh)	
PM	0.20	0.1	No
NOx	6.208	0.67	No
CO	3.5	3.5	Yes
HC	0.192	0.4	Yes

Retrofitting Technology Overview

The most difficult challenge in designing today's diesel engines often involves a trade-off between NOx and PM emissions. Most engine modifications that decrease NOx have a tendency to increase PM emissions. Conversely, techniques to reduce PM tend to increase the production of NOx. This inverse relationship is caused by the engine's combustion temperatures: when combustion temperatures increase in the cylinder, the amount of PM decreases but NOx increases, and as temperatures decrease, NOx decreases but PM increases.

For larger non-emergency generators, the achievement of "Tier 3 stationary NOx and PM emission limits are about the maximum limit for diesel engine in-cylinder control strategies."[26] In order to comply with Tier 4 levels of NOx and PM, generators must be retrofitted with controls to further reduce exhaust gases. Today, viable emissions control technologies can reduce diesel exhaust from electricity generator operation.

The following technologies have already achieved a practical level of commercialization in a variety of applications. The most common devices used to

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[26] DieselNet website. Stationary Diesel Engines (NSPS). 2010. http://www.dieselnet.com/standards/us/nonroad.php#tier4. Retrieved on February 3, 2013.

control PM are Diesel Oxidation Catalyst (DOC) and Closed Crankcase Ventilation (CCV). On the other hand, the Selective Catalytic Reduction (SCR) technology is best known for successful removal of majority of NOx emissions.

Table 6: Overview on Applicable Abatement Technologies

Abatement Technologies		Diesel Oxidation Catalyst (DOS)	Closed Crankcase Ventilation (CCV)	Selective Catalytic Reduction (SCR)
Emissions Reduction (%)	NOx			75-90
	PM	25-50	Capture PM	30-50
	HC	70		50-90
	CO	90		

Table 7: Costs of Applicable Retrofitting Technologies

Retrofitting Technologies		Diesel Oxidation Catalyst (DOS)	Closed Crankcase Ventilation (CCV)	Selective Catalytic Reduction (SCR)	Continuous Emission Monitoring System (CEMS)
Cap. Costs	$	50,000	2,000	184,142 (MSRB) 117,110 (MSRB-II)	5,000
Calibration Cost	$	N/A	N/A	N/A	1,500/year
Scenario Applied		#3 and #6	#3 and #6	#6	#3 and #6

(Lifetime: Assume 20 years)

A Diesel Oxidation Catalyst (DOC) is a device which "utilizes a chemical process in order to break down pollutants from diesel engines in the exhaust stream, turning them into less harmful components." DOC is typically able to reduce total PM typically by as much as 30-50% by mass. DOC can also reduce up to 90% CO, and 70% of the toxic HC emissions in diesel exhaust. The capital cost of DOC is $5,000 per installation.

Selective Catalytic Reduction (SCR) systems are widely used on stationary diesel engines; SCR systems "incorporate aqueous urea injection into the exhaust stream passing over a suitable catalyst to reduce NOx up to 90%. Because the systems consist of an SCR catalyst, urea injection system, urea tank, pump and a control system", SCR has been shown to be the most effective control technology for reducing NOx emissions. Moreover, SCR systems are also capable of removing 30-50% of PM and 50-90% of HC emissions. SCR systems are priced at $98 per hp according to the size of generation capacity.

Closed Crankcase Ventilation (CCV) is installed on diesel generators to eliminate crankcase emissions. CCV systems are able to capture PM generated in the crankcase and return them to the lubricating system of the engine. The capital cost of CCV is approximately $2,000 per installation.

A Continuous Emission Monitoring System (CEMS) is an instrument that continuously measures actual emissions levels from a stationary source. The CEMS directly "measures the pollutant of concern or measures a surrogate pollutant for the pollutant of concern." The exhaust pollutants CEMS typically monitored include CO, NOx, SOx, and HC. The capital cost of installing CEMS is about $5,000 with an annual calibration cost of $1,500.

4. Cost benefit analysis

In order to discover the most cost effective scenario, the cost benefit analysis for all six scenarios was conducted. Table 6 below summaries all data and assumptions provided by Duke OESO and Medical Center Maintenance Office for cost benefit calculations for both generators.

Table 8: Assumptions and Data for Cost Benefit Calculations

Variable	Value
Diesel Price ($/gallon)	3.2
Electricity Price of Duke Energy ($/kWh)	0.064
Load Utilization Ratio	75%
Expected Lifetime of Abatement Devices (years)	20
Capacity Credit ($/kW)	3.5
Mandatory Curtailment Credit ($/kWh)	0.10
Capacity of MSRB (hp)	1879
Capacity of MSRB-II (hp)	1676
Diesel Consumption at 75% Load for MSRB (gal/hr)	91.2
Diesel Consumption at 75% Load for MSRB-II (gal/hr)	68.5

Table 9 and Table 10 below contain cost benefit results for MSRB and MSRB-II. The Test Only scenario has the largest net benefit because of the high testing revenue, and as the running hours for mandatory curtailment increase, the net benefit decreases. By contrast, the non-emergency scenario costs the most due to the large consumption for diesel, additional emissions abatement retrofitting cost and the lack of the incentive credits from Duke Energy.

Table 9: Cost Benefit Summarization of Three Scenarios for MSRB

Scenario	1: Test Only	2: Emergency Max.	3: Non-emergency Generator
Running Hours of MSRB for Curtailment(hr/year)	0	88	8760
Running Hours of MSRB for Testing(hr/year)	12	12	0
Annual Benefits			
Curtailment revenue	0	9248	0
Testing revenue*	45398	45398	0
Total Electricity revenue ($)	45398	54646	589164
Annual Costs			
Diesel cost ($)	3502	29184	2556518
Maintenance and Operations	6976	6976	6976

(Labor) Costs ($)			
Retrofitting Cost for Emissions Abatement ($)	0	0	2850
Annual Net Benefits			
Net benefit before retrofitting	34920	18486	-1974330
Net benefit after retrofitting	34920	18486	-1977180

*Testing Revenue refers to the capacity credits from 12 hours/yr of testing time.

Table 10: Cost Benefit Summarization of Three Scenarios for MSRB-II

Scenario	**1: Test Only**	**2: Emergency Max.**	**3: Non-emergency Generator**
Running Hours of MSRB for Curtailment(hr/year)	0	88	8760
Running Hours of MSRB for Testing(hr/year)	12	12	0
Annual Benefits			
Curtailment revenue	0	8249	0
Testing revenue	40493	40493	0
Total Electricity revenue ($)	40493	48742	525513
Annual Costs			
Diesel cost ($)	2358	19648	1920192
Maintenance and Operations (Labor) Costs ($)	6450	6450	6450
Retrofitting Cost for Emissions Abatement ($)	0	0	126036
Annual Net Benefits			
Net benefit before retrofitting	31413	20372	-1401129
Net benefit after retrofitting	31413	20372	-1403979

The net benefit of running without the DR program scenario was then calculated to compare the cost effectiveness of participating in the DR program with not participating. In this scenario the costs include diesel consumption for 12 hours of testing and maintenance and operations cost, while the only benefit is the avoided electricity demand from Duke Energy. The pilot study indicates that the net benefit for MSRB without the DR program is $-9,671 /year while the net benefit for MSRB-II without the DR program is $-8,361 /year, which are both more negative than the Test

Only Scenario and the Emergency Maximum Scenario. Therefore, participating in the DR program for the emergency generators would be better off than not participating. Figure 4 and Figure 5 below show the net benefit curves in regard to the length of running hours under different scenarios. Similarly with the Table 9 and Table 10, the figures show the trend that as the running hours increase the net benefit decreases, and participating in the DR program would be more cost effective than not participating.

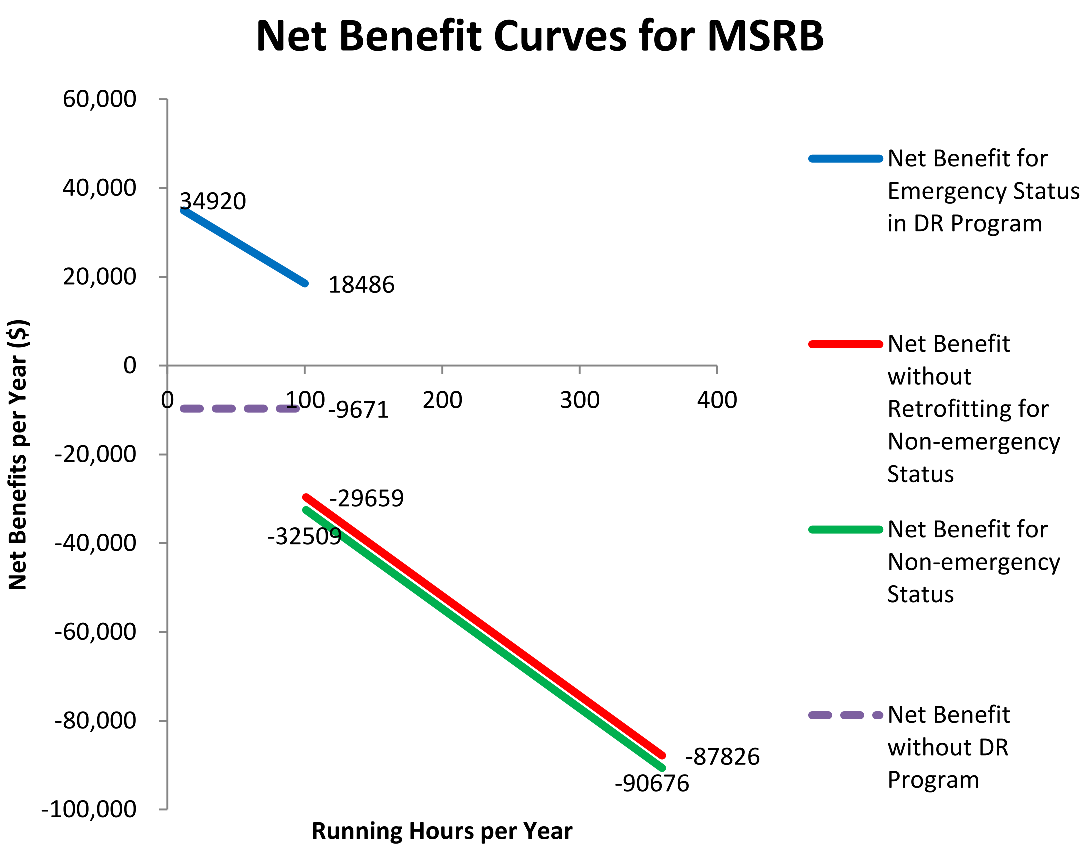

Figure 4: Net Benefit Curves in regard to Running Hours for MSRB

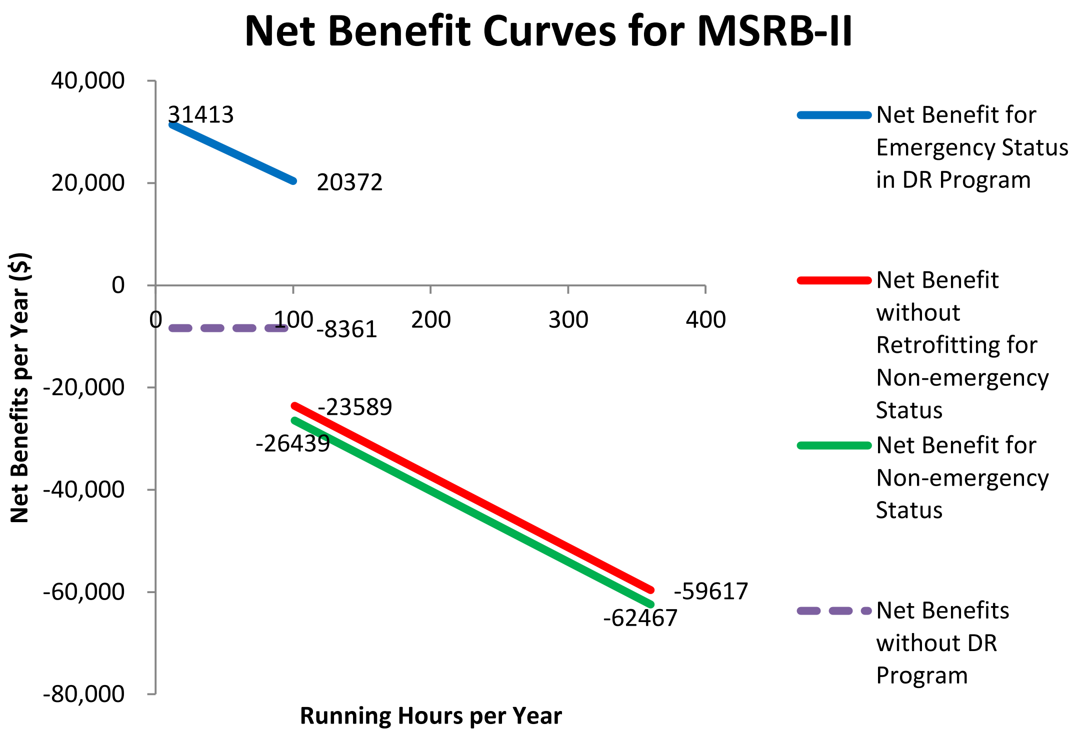

Figure 5: Net Benefit Curves in regard to Running Hours for MSRB-II

5. Environmental impact analysis

The environmental impacts of producing electricity have been recognized by Duke University and its administrators. Registering the on-campus electric generators with Duke Energy's PowerShare Program presents an excellent opportunity for potential reduction in emissions as the result of implementing the recommended demand response scheme. Although Duke Energy has a diverse mix of generation resources in its portfolio, including nuclear, coal-powered, oil- and natural gas powered, and hydroelectric power plants, more than half of the company's electricity generation is a byproduct from fossil fuel combustion. Thus, the emissions discharged, including SO_2, NOx, PM, CO_2 and other greenhouse gases, should be carefully reviewed and examined.

The data on these air pollutants and greenhouse gas emissions (GHG) are important because there are many models and considerable scientific literature that permit detailed analysis of the dispersion and the adverse impacts of these pollutants. As discussed previously, the compliance analysis indicates that the criteria pollutants emitted from Duke University's diesel generators have higher factors than Duke Energy. Despite retrofitting with abatement technologies that would significantly reduce unwanted pollution, the emissions control equipment is not recommended because of its cost ineffectiveness. The scientific literature on CO_2 reflects considerable uncertainty about the magnitude of the impacts from global warming and climate change. The electricity generated by Duke's generators in the DR program would displace a certain amount of electricity generated by the local power provider, Duke Energy. This research intended to determine whether operating electricity generators under the DR program would be more environmental-friendly than environmental impacts from Duke Energy's power plants.

The research team compared the difference of emissions inventory factors among the MSRB, the MSRB-II generator, and Duke Energy Carolinas overall portfolio, shown in Table 11. The results show that the emissions factors of NOx in both MSRB and MSRB-II are more than 90% larger than average emission factors in Duke Energy Carolinas. However, the CO_2 emissions in Duke Energy generation portfolio in North and South Carolina areas is 0.376 kg/kWh while the emissions factor of MSRB and MSRB-II generators are only 0.189 kg/kWh. Therefore, although most of the criteria pollutants emitted from the Duke University generators (NOx in particular) are greater than Duke Energy average inventories, the GHG emissions are much smaller.

This advantage implies an opportunity to collaborate the ongoing carbon reduction efforts with carbon offset programs at Duke University. Developed by Duke's Campus Sustainability Committee in 2007, the Climate Action Plan (CAP) entails the University's steadfast commitment to achieve climate neutrality before 2024. The Duke Carbon Offsets Initiative (DCOI) is a flagship program to discover and investigate emerging offset opportunities. According to Duke's 2012 GHG inventory, energy comprises 70 percent of the University's GHG emissions. Since energy use at Duke Campus has a significant impact on the environmental footprint of the University, the full participation in the DR program would be a promising endeavor to further reduce the University's carbon footprint.

Table 11: Emission Factors Comparison between MSRB, MSRB-II and Duke Energy Carolina

Criteria Pollutants	**MSRB-II (g/kwh)**	**MSRB (g/kwh)**	**Duke Energy Carolina (g/kWh)**
PM	0.20	0.536	N/A
NOx	6.208	9.246	0.272
CO	3.5	11.436	N/A
HC	0.192	1.338	N/A
GHG Emissions	**MSRB-II (g/kwh)**	**MSRB (g/kwh)**	**Duke Energy Carolina (g/kWh)**
CO_2	189	189	376

Results and Discussions

According to our cost-benefit analysis for MSRB and MSRB-II generators, participating in the DR program for the emergency generators would be better off than not participating. Therefore, we suggest that the eligible emergency generators with a capacity of more than 200 kW participate in the DR program as much as possible. Since the diesel cost accounts for the largest part of total cost, the generators with higher diesel consumption efficiency are more encouraged to participate. According to Duke Energy[27], 28 curltailment events occurred in the last thirty years with a total mandatory curtailment period of 124 hours. Assuming the annual mandatory curtailment period is 4.4 hours/year, equal to the average level in the past thirty years, participating in the DR program can save $43769 per year for MSRB generator and save $39221 per year for MSRB-II without converting any generators to non-emergency generators.

According to our environmental impact analysis, participating in the DR program will not reduce the overall emissions of criteria pollutants since most of the criteria pollutant emission factors from Duke University generators (PM and NOx in particular) exceed Duke Energy average factors. However, the DR program can avoid constructing additional power plants which would cause large environmental impacts. Moreover, the GHG emissions from the generators at Duke University are be much lower than the average emissions level per unit of energy of Duke Energy, which suggests an opportunity to collaborate the ongoing carbon reduction efforts with carbon offset programs at Duke University.

[27] Interviews with the Large Business of Duke Energy. Retrieved on February 12, 2013.

Improving Environmental Performance on Duke Campus through Water Conservation and Sink Disposal Initiative

Introduction

The Masters project also evaluated ways of improving environmental performance on the academic campus through water conservation and a sinks disposal initiative. The research questions were (1) how could the researchers improve their sink disposal practices and (2) how could they improve water use efficiency in their laboratories.

First, according to the Duke Occupational and Environmental Safety Office (OESO), chemical waste from research, teaching and other operations at Duke University need to be disposed fully complying with Federal, State, and local regulation. Some chemical substances can be safely disposed through the sinks to the sanitary sewer system. However, other chemical substances are prohibited from sink disposal.[28] The reasons for the prohibition, based on the "National Pretreatment Program," are that certain pollutants will "interfere with the operation of the publicly owned treatment works, may pass through the treatment processes without being appropriately treated, or may undermine the opportunities to recycle and reclaim municipal and industrial sludge".[29] Therefore, OESO has developed guidelines for limited sink

[28] OESO Environmental Program, Guideline for sink disposal of chemical substances, 2010, http://www.safety.duke.edu/envprograms/Docs/drain_disposal_practice.pdf. Retrieved on January 2013.
[29] EPA, Introduction to national pretreatment program, 2011, http://www.epa.gov/npdes/pubs/pretreatment_program_intro_2011.pdf, Retrieved on January 2013.

disposal of chemical substances, which all laboratories on Duke Campus should follow. A school-wide audit by OESO indicated that most labs follow the guideline; however, some labs still dispose of the hazardous chemical wastes directly into the sewer system. Issues in our laboratories sink disposal include: Ethidium Bromide Solutions, Buffer solutions, Ethanol/Methanol in glass washing, Biological waste, and acid and basic cleaning solutions. [30]

Second, based on the typical laboratory water use data from EPA, [31] most laboratories consume much more water than commercial buildings because of enormous cooling and process loads. For example, cooling tower make-up water accounts for 42% of water use in laboratory buildings, and process equipment use accounts for another 25% of the total water use. However, initiating a few changes in the cooling system and process equipment, developing best practices and identifying opportunities for water reuse can, to a large degree, reduce the water usage in the laboratories. Our focus for improving water efficiency was on the process equipment; exploring best practices as well as other potential water reuse opportunities.

Methodology

Literature review

In order to better understand the current standard of care regarding sink disposal

[30] Data from OESO office
[31] EPA, Lab water usage & office water usage, 2012, http://www.epa.gov/oaintrnt/water/lab_vs_office.htm. Retrieved on January 2013.

and water efficiency in labs, a wide range of literature was reviewed. Examples include National Pretreatment Program by US EPA, Durham Sewer Use Ordinance, Occupational and Environmental Safety Office Guidelines for Sink Disposal of Chemical Substances, and Green Labs for 21st century by EPA and US Department of Energy.

Interviews

Interviews were conducted with several researchers to better understand the current sink disposal practices and water usage in laboratories on Duke Campus; Interviews were conducted in several types of laboratories including immunology labs and chemistry labs. Participants were asked questions based on the interview proposal developed by our team. Samples questions include:

1. Since your last laboratory safety audit, have you made any improvements with respect to the sink disposal of chemical substances?
2. Have you encountered any difficulty collecting chemical substances that cannot be disposed of directly into sewer systems?
3. What is your current glassware rinsing practice? Have you heard about counter-current rinsing?
4. Do you think there is any possibility to use other water sources, such as rainwater harvesting, condensate recovery or reclaimed used water?

Pilot study

Pilot studies were conducted in those laboratories participating in the interview. Based on the information collected in the interview, opportunities were identified for improving the drain disposal practice and water efficiencies. Pilot studies were conducted in multiple research buildings including the Jones Building, the Clinical and Research Laboratory Building, the French Family Science Center and the Bryan Research Building.

Feasibility and cost analysis

After the opportunities were identified, feasibility and cost analyses were conducted to determine whether any retrofits could be made or if new best practice could be promoted in laboratories to improve both drain disposal practices and water efficiency.

Best practice development

Based on the results from the pilot study, further research was done to assess whether retrofits and best practice could be shared and broadcast to other laboratories at Duke University and other academic campuses. Therefore, the research results of this project could be used to improve the environmental performance on academic campuses.

Pilot study

Pilot study 1: Laboratories in the Immunology Department

The goal of the immunology department at Duke University is to understand immunologic principles and mechanisms through research and to educate tomorrow's academic leaders.[32] The department researches the functioning of the

[32] Duke Immunology Department, 2011,http://immunology.mc.duke.edu/home. Retrieved on January 2013.

immune system such as infectious disease and cancer. [33] There are more than ten laboratories in this department conducting research in immunology.

Current Performance

The Immunology Department outperforms on chemical disposal practices. According to the interviews with laboratories staff, they follow the sink disposal guideline from OESO. For example, Ethanol/Methanol cannot be disposed in the sink if the concentration is greater than 30%. For buffer solutions, only those with neutral PH can be drain discharged. There are special containers to collect chemical wastes and labels are attached to the containers so that they can easily be distinguished from other materials. Lab staff can request a pick-up from OESO to have those hazardous waste collected. [34]

Figure 6: waste liquid collector

Figure 7: Ethidium Bromide container

With regard to the water efficiency, overall the water usage in immunology laboratories is not large. Dishwashers and autoclaves are the two biggest water

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[33] Duke Immunology Department, Introduction, 2011, http://immunology.mc.duke.edu/home/introduction-department. Retrieved on January 2013.
[34] Interview with lab staff from immunology department, Duke University, February 2013.

consumers and they are located in a separate room. The dishwasher is AMSCO Hoplab 1021 and the autoclave is AMSCO 3023 Vacamatic. All glassware and other containers that need washing from the various laboratories are collected and sent to that central dishwasher/autoclave facility. In addition, several laboratories share one filtration/water purification system, which produces deionized water for experimental purposes. There are also vacuum systems in the lab, which produce culture medium, but this process does not consume much water. The medical film developer is another big water consumer since the process of washing films needs a large amount of water.


Figure 8: Filtration system


Figure 9: Film processor

Potential Opportunities to Minimize Environmental Impact:

Replace hazardous chemicals with safer chemicals

According to the interviews, the immunology labs have already started using EZVISION, which has the same function of staining DNA with Ethidium Bromide (EB)

Solutions[35] in a safer process. The traditional EB is carcinogenic that can be detrimental to human health. The replacement will not only protect human health, but also alleviate the burden of collecting hazardous waste.

Reduce the use of dishwashers

Lab staff can use the laboratory equipment or other containers with a conservative approach so that fewer items are sent for washing. For example, according to the discussion with the laboratory staff, if they can reuse glassware without compromising their work, a lesser number of items will be sent for washing, which saves water. However, it would vary from person to person and operation to operation depending upon their work plan and approach. Therefore, it may not be feasible for all work[36]. An additional note is that the dishwashing equipment should be operated only when they are fully loaded; and newer and cleaner dish detergents should be used along with reduced rinse cycles when possible. [37]

Activate the water conservation function in the film developer system

Traditionally, a film developer consumes a large amount of water in the washing process. However, according to our discussion with the laboratory staff that manages the film processing, the film processing has already been converted to an automatic system, the Konica Minolta SRX-101. The fixer and developer used in the process are stored in two separate tanks. After the system stops working, the waste fixer and developer are collected in a dedicated container instead of being disposed of into

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[35] Interview with lab staff from immunology department, Duke University, February 2013.
[36] Interview with lab staff from immunology department, Duke University, February 2013.
[37] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

the sewer system directly. The washing process still consumes a large amount of water; however, it is controlled entirely by the machine in an automated process.[38] The original concern here was that the system needed to be manually turned off after the work is finished. It is unclear whether there is water flowing in the time period between when the film process stops and the system is turned off. If there is unnecessary water consumption, then a timer can be installed. Therefore the system can be shut off and the water will stop flowing after the preset time. However, based on the information of SRX-101A Tabletop Processor manual, there is a built-in control for the water conservation. Therefore, it is unnecessary to add a timer to control the water flow. However, this water conservation function needs to be activated, which need someone who has the instruction manual, or technician from Minolta service organization.

Although the film processor in the Immunology Department does not necessarily need a timer to control the water flowing, other film processors, which do not have a built-in water conservation tool, or other equipment in which water flows all the time can still implement this concept to control their water usage.

Develop other mechanisms to cool proteins/cells

One problem that the lab staff encounters is that there is no efficient way to cool down proteins/cells in order to maintain their temperature between 0-4 centigrade. Currently they use ice as the cooling mechanism. Therefore, one question facing the team was whether we could utilize used water to provide a cooling system for

[38] Interview with facility manager from immunology department, Duke University, February 2013.

proteins/cells. One potential solution would be to connect the pipeline from the sterilizer/dishwashers to a tub, which could collect the used water from that system. Then that used water could be used to feed the ice machine, which would achieve the goal of non-potable water reuse. Other suggestion, provided by Duke University Medical Center (DUMC) engineering staff, included using a mechanical refrigeration unit, or using dry ice/liquid nitrogen, which is very cold and can cool water down. [39]


Figure 10: current cooling mechanism

Install rainwater harvesting

Based on "Labs for the 21st Century"[40], rainwater is an excellent source of non-potable water, which contains few impurities. After checking water regulations in North Carolina, rainwater harvesting is legal in North Carolina.[41] However, one of the concerns would be the cost to install the equipment, which is used to collect and store the water. Rainwater systems usually consist of "roof, gutters, downspouts, leaf

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[39] Information source: emails with DUMC engineering staff, Feb 2013

[40] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

[41] WRAL.com, NC to allow rainwater harvesting, 2011, http://www.wral.com/news/local/story/5543632/. Retrieved on January 2013.

screens, roof washers, storage tanks, a conveyance and treatment system"[42], with storage tank as the most costly part. In order to know the amount of rainwater that can be collected on site[43], one needs to know the collection area, collection efficiency, average rainfall, as well as conversion factor. The collection efficiency is determined by various factors such as roof material, design retention etc. If the roof surface is more impervious and much cleaner, more high quality rainwater can be collected. Based on 21st Green Labs, generally the collection efficiency is between 75% and 90%. The conversion factor is interpreted as "the rainwater collected from one inch of precipitation on one square foot of collection area" and is supposed to be 0.6233gal/in.[44]

The picture below is a non-potable water collection and reuse system that a laboratory building could probably use to collect and reuse rainwater. Also, the system works for other potential local water reuse opportunities, such as reusing condensate from air-conditional system to irrigate landscape etc.

[42] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

[43] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

[44] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

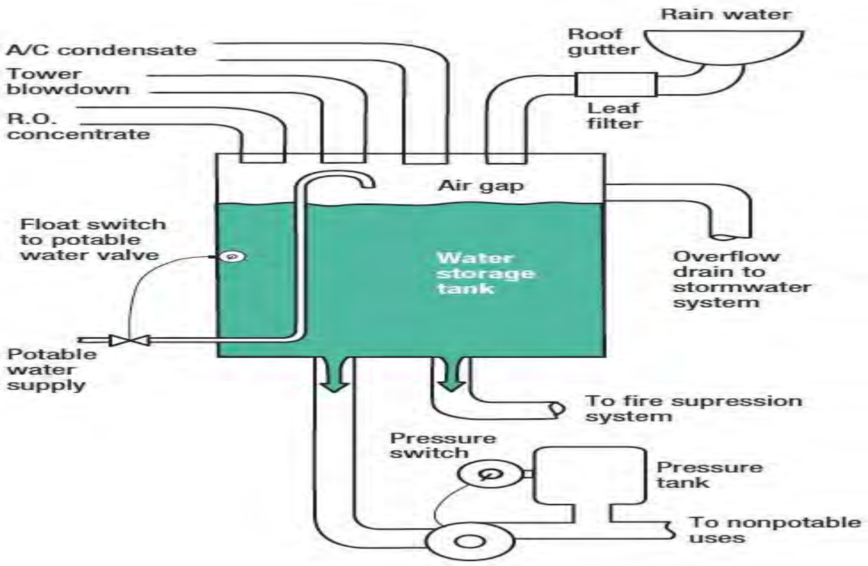

Figure 11: non-potable water collection and reuse[45]

Utilize used water to feed the Reverse Osmosis System

Potential opportunities include using used water from dishwashers, or autoclaves to feed the RO system. This can be done through a small retrofit. The pipeline from dishwashers, or autoclaves can be reconnected to a tub, which is also connected to the reverse osmosis system. Therefore, the condensate from the sterilizer can be used to feed the purification system. This method can achieve the goal of local water reuse.

Feasibility and cost analysis

Feasibility and cost analysis were conducted to assess those opportunities identified in immunology laboratories, beginning with rainwater harvesting which is the most complex and expensive option, followed by some simpler solutions like feeding reverse osmosis system with used water.

[45] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

First, the rainwater harvesting results in huge savings in water cost. Currently, the average yearly rainfall in Durham is 48.04 inches, which is nearly evenly distributed throughout the year.[46] The potential benefit of capturing this water can be envisioned through the following example. Suppose the roof area of the building is 50,000 ft^2, with a collection efficiency of 75%, the facility could capture approximately 1,128,874 gallon of rainwater per year. According to the water fees (FY13) in Durham, the potential money saved is around $14320. The Tier 5 rate and monthly service charge are used in the calculation.

Monthly Water Rates	FY 11 Rates	FY 12 Rates	FY 13 Rates
Service Charge	$5.35	$5.56	$5.77
Volume Charge – Tiered Rates (per 100 cubic foot – ccf)			
Tier 1 (0 – 2 ccf)	$1.72	$1.73	$1.74
Tier 2 (> 2 – 5 ccf)	$2.59	$2.60	$2.62
Tier 3 (> 5 – 8 ccf)	$2.84	$2.85	$2.87
Tier 4 (> 8 – 15 ccf)	$3.71	$3.72	$3.75
Tier 5 (> 15 ccf)	$5.56	$5.57	$5.62

Figure 12: water rates in Durham[47]

However, the rainwater recovery system can be expensive to install. A storage system is particularly expensive. It is hard to estimate the cost since it largely depends on the complexity of the system. For example, a rainwater harvesting system for a single-family home could be between $3,000 and $10,000, with the storage tank as the most expensive part. A sophisticated system for large industrial facility may cost over $100,000 to construct.[48] Calculating an accurate cost estimation for such a

46 Durham, NC weather, 2013, http://www.idcide.com/weather/nc/durham.htm. Retrieved on January 2013.
47 City of Durham, Department of Water Management, Water and Sewer rates, http://durhamnc.gov/ich/op/dwm/Pages/Water-and-Sewer-Rates.aspx. Retrieved on January 2013.
48 Wholly H2O, rainwater harvesting cost, 2013, http://www.whollyh2o.org/rainwater-stormwater/item/59-costs.html. Retrieved on January 2013.

system requires an accurate breakdown of the total costs for tanks, pumps, piping, etc., which was beyond the scope of our project. Nonetheless, one can estimate the return on investment using the following example: Assume the cost of the system is $100,000 for a single building on Duke Campus, the payback time would be seven years, which is not very cost-effective, even though a large amount of water would be saved. However, since the calculation is a rough estimation based on existing data, this water conservation strategy provides an opportunity for future research into the cost/benefit of future rainwater harvesting.

Another water conservation opportunity that we evaluated was the reuse of used water locally, which means reusing the used water from the laboratories in different operations within the same or adjacent laboratories. One way to achieve this goal is to "feed" the reverse osmosis system or laboratory ice-maker or, even the condenser on a distillation apparatus with the used water from dishwashers/sterilizers by a tub to collect this water by simply connecting the piping that runs to the sanitary sewer to the collection tub instead. Such a retrofit would not be expensive since it only involves reconnecting the pipeline and installing a tub. Therefore, the retrofit to reusing targeted used water is both feasible and cost-beneficial.

Pilot study 2 Chemistry Laboratories in French Science Building

Duke University's Chemistry Department is famous for outstanding facilities, dynamic faculty, strong graduate students, novel foci, internationally respected research and balance between research, teaching and service.[49]

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[49] Duke University, Department of Chemistry, http://www.chem.duke.edu/about/. Retrieved on January

Current performance

In evaluating the sink disposal performance, we interviewed the laboratory staff, and found that overall they did very well in preventing hazardous chemical waste disposal into the sewer system. They routinely collect their hazardous wastes in one big container to avoid discharging it to the drain. However, there may still be incidental discharges such as improper ethanol/methanol or weak acid solution disposal.

With respect to the water efficiency in labs, we evaluated two major water consumers, namely the condenser on a distillation apparatus and the dishwashers for cleaning laboratory glassware. The condenser is used to cool and condense the solvent that is being purified. It operates with water flowing through the condenser and then flowing directly into the drain without being recirculated. This single-pass operation wastes a large amount of water. Another big water consumer is dish/glassware washing. Currently the chemistry department does not have centralized dishwashers. Usually laboratory staff put dishes or other equipment into tanks and let the tap water flow for one hour, which consumes a large amount of water.

2013.

Figure 13: condenser

Figure 14: dishwashing process

Potential Opportunities

Education materials for sink disposal

Since there is still evidence of occasional sink disposal, simplified education materials/ signs were developed and posted in the laboratories. An educational flyer has already been developed by the Masters project team, which summarizes both the chemical substances that cannot be disposed of in the sanitary sewer system, and the reason why those substances cannot be discharged. Also, since ethanol/methanol and acid solutions are incidentally disposed into sewer system, a sign defining best practices for managing those wastes can be put on the wall to serve as a reminder for lab staff.

Recirculating water in the condensers and feed it with used water

Condensers are used in laboratories to cool hot vapors or liquids.[50] Specifically in chemical labs, the condenser is used to conserve the volume of solvent in reaction flasks as well as maintaining the concentration and temperature of the solution being

[50] Wikipedia, Condenser, 2013,http://en.wikipedia.org/wiki/Condenser_(laboratory). Retrieved on January 2013.

heated. Broadly, the condenser's purpose is to cool the vapors or whatever solution is being heated. In this way, they condense back into liquid and return to the reaction flask. Condensers are also used for distillation to selectively evaporate away a certain component from a mixture, and then condense it back into a receiving flask to be collected.

Currently, most condensers consist of two-glass column, with the inner tube containing the vapors and the outer tube flushed with air or water to take the heat away, in this way the vapor can cool and condense into liquid. In the laboratory, tap water is being used since it is a constant source of cold temperature compared to air. However, the tap water does not recirculate in this process and is dumped into the sewer system directly.

Therefore, the potential opportunity would be installing a tub and connecting it to the discharge end of the condenser system. The water going through the system could then be pumped back from the tub to "feed" the cooling condenser. In addition, the water that used to feed the tub for the condenser could actually be recovered as used water from dishwashing process.

Counter-current rinsing for glassware washing

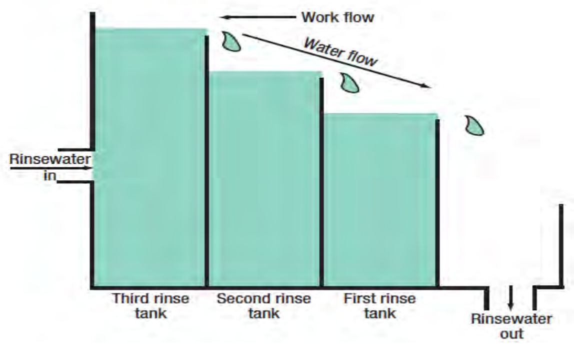

Figure 15: counter-current rinsing system[51]

The figure above shows the principle of counter-current rinsing system. In considering that regular equipment washing consumes a lot of water, especially when the water flows constantly in tanks for an hour for the washing purpose, a counter-current rinsing system can be taken into consideration. The principle is to "use the cleanest water only in the last stage of a rinse operation; water for early rinsing tasks is obtained later in this process when the quality is not as important".[52]

Feasibility and Cost Analysis

The retrofit of the condensers system is cost-effective, and is highly recommended. It achieves the used water reuse and water recirculation. The retrofits include installing a tub that connects the system, and reconnecting the pipeline that originally connected to the sewer system to the condenser system in order to feed the tub.

The counter-current rinsing system consumes much less water than regular rinsing

[51] Picture from EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

[52] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.

system. Counter rinsing system can cut typical water usage by 40 to 50%. In an electroplating industry, for example, a two-stage counter rinsing system has the possibility of reducing water consumption by 90-97%.[53] In addition, this system can reduce the sewage disposal, which will reduce the reduction in sewage cost. From the water-saving perspective, it is a great solution. However, it is more suitable for industrial process rather than the laboratories. Counter current rinsing tanks can be retrofitted to an existing tank by dividing a large existing tank into several compartments or can be purchased new. [54] Due to the limited space of the laboratories, it may not feasible to install such system in each laboratory. The possible solution to this is to have a central equipment washing station in each floor and install a counter rinsing system or an automatic dishwasher. A person is in charge of collecting dishes that need washing everyday. The tank in each laboratory can still be kept for occasional use.

Pilot study 3 Biomedical Lab in Carl Building

Duke Biomedical research is engaged in improving human health through research. It utilizes interdisciplinary approach to improve diagnosis and treatment of disease.[55]

Current performance

The current sink disposal is not always handled appropriately in the laboratories that were interviewed. There are currently no special containers for chemical substance

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[53] Department of Environmental affairs and development planning, Counter current rinsing fact sheet, http://www.westerncape.gov.za/text/2006/1/6_counter_current_rinsing.pdf. Retrieved on January 2013.
[54] EPA, Laboratories for the 21st century: Best Practice, water efficiency guide for laboratories, http://www.i2sl.org/documents/toolkit/bp_water_508.pdf. Retrieved on January 2013.
[55] Duke University, Department of Biomedical Science, http://www.bme.duke.edu/research. Retrieved on January 2013.

that cannot be disposed into the sewer systems. The staff do not have clear understanding about what chemicals cannot be disposed of in the sanitary sewer system. For example, substance like buffer solutions is dumped directly into the sewer once a while.

With regard to the water efficiency, the overall the water usage is not extreme in the biomedical lab; the largest water usage is dishwashing. Currently there are no central dishwashers in the building. The lab staff wash their glassware manually and do not pay much attention to conserving water in this process. Autoclave, or sterilizer, is automatic system and lab staff will choose what type of objects they need to sterilize. There is no photographic system or vacuum system in the lab.

Potential opportunities

The potential opportunity with regard to the sink disposal is significant. Currently web-based material is provided to lab staff to improve their awareness. Admittedly, this method is efficient. However, it does not significantly increase the lab staff's consciousness of sink disposal issue. Therefore, a workshop should be organized by OESO to promote the importance of safe sink disposal and to educate lab staff about what chemical substance cannot be disposed directly to the sewer system. Representatives from various labs should be required to attend the workshop and they can be the point person for environmental safety in their labs. In addition, policy enforcement needs to be enhanced with regard to this issue. For example, surprise inspection instead of regular audits can be conducted to encourage staff to comply with the guideline all the time. Finally, educational material, which is mentioned before, can be attached on the wall close to the equipment.

The opportunity for saving water mainly lies in the dishwashing. On one side, best practices can be developed to encourage people use less water in dish washing. Secondly, as mentioned before, the used water from dishwashing can be reused to feed the reverse osmosis or other water-dependent systems.

Feasibility and Cost Analysis

The workshop, education materials and policy enhancement to improve the sink disposal practice need OESO's efforts; however, it is cost-effective and can, to a large degree alleviate the sink disposal issues. The local water reuse, as mentioned before, is both feasible and cost-effective.

Pilot Study 4: Neurobiology labs in Bryan Research Building

Formaldehyde is the only hazardous waste in the laboratory according to the interview. It is collected in a certain container and is not disposed into the sewer system directly. For the water use efficiency, currently the department has a centralized dishwashing and autoclave system. Deionized water is produced through the purification systems. There is no equipment in which water is flowing all the time. There is no x-ray or photographic system. For the vacuum systems, they use the vacuum from centralized vacuum line.

However, the lab staff mentioned that there were two floods recently caused by the deionized water system. The water leaked from the deionizer system and led to the floods. The cause with the leakage was the inappropriate water pressure.

Potential Opportunities

Feed the reverse osmosis system with used water from sterilizer

As mentioned, the building suffered from flooding due to the high water pressure. Therefore, one solution is to change the pressurized water system to static system. The water pressure comes from the City water system that feeds the RO system, which creates the deionized water. A tub could be installed and connected to both sterilizer system and RO system. Then the used water from the sterilizer can be stored in the tub and used to feed the RO system. In this case, the system will be a static system and would lower the flood risk. As mentioned before, such a retrofit is cost-effective.

Feasibility and Cost Analysis

Recall that from previous analysis, the local water reuse, which is to feed the RO system with used water is both cost effective and feasible.

Best Practice Development for Duke Campus and Other Academic Campuses

Reuse water locally

One big opportunity in laboratories is to reuse used water locally. For example, feeding the reverse osmosis system with used water from dishwashers or autoclaves;

or installing a tub that connects to the condenser to recirculate the water. In addition, the water used in the condenser could actually be used water from dishwashing. Also, the used water can be used to feed the ice machine, which produces ice used in experimental procedures but not for human consumptions. In such manner, water can be saved to a large degree and the philosophy of saving water can be embedded to the practice of the laboratory staff. Other options for reusing water locally include reusing the condensate from the air conditioning system to irrigate the landscaping, or using waste stream from Reverse Osmosis system, to flush the toilet. According the Yale University sustainability Office, the reuse of "gray water", which is the used water collected from washing machines, showers or other building water systems, can save 40% of that water when compared to the water required by code. [56]

Develop best practice in the behavior side

Best practice means saving water from the behavior aspect of lab staff. For example, lab staff can send less glassware or equipment for washing if they use the glassware in a conservative manner. In addition, only using the dishwasher when it is fully loaded and using high quality detergent will improve both water usage and environmental performance. Developing best practice involves no cost but requires an improvement of lab staff's awareness.

Identify other water sources

[56] Yale office of sustainability, water reuse, http://sustainability.yale.edu/gray_water. Retrieved on Feb 2013.

Through the research of rainwater harvesting, the payback time would be close to 10 years. This is not quite cost-effective currently. However, attempts at using natural water should not be given up. The cost of the technique is likely to change in the near future and further research needs to be done.

Safer chemical disposal

To ensure safer chemical disposal, firstly, safer chemicals can gradually replace hazardous chemical substances. For example, the immunology labs have already started using EZVISION, which has the same function of staining DNA with Ethidium Bromide Solutions. The traditional EB is carcinogenic that is detrimental to human health. The replacement can on the one hand protect human health; on the other hand reduce the burden of hazardous waste disposal. Also, every lab should have a point person who is responsible for the lab chemical safety and a workshop should be organized to education these representatives about safe disposal.

Conclusions and Future Recommendations

Environmental performance improvements will be increasingly important in the future because of scarcer natural resources, more stringent regulatory scrutiny, rising energy prices, and growing stakeholder demands. The findings from our Masters project can be used to stimulate strategic change and operational improvements by conducting case studies and strategizing practical solutions to further water and energy efficiency on Duke campus.

The study will enable the higher education sector to review the possibility of expanding on-campus power generation, to minimize overall environmental footprint, to reduce water consumption, and to chart best practices to enhance the quality management of water disposal. These initiatives should be implemented to reduce institutional risks, and create financial benefits through better management of water and collaborating with Duke Energy though the DR program. Given that it is financially sound for the University to participate in Duke Energy's DR program, University administrators should consider expanding the existing PowerShare contract with Duke Energy and rolling the program out to all eligible electric generators on campus. Moreover, since the magnitude of GHG emissions are significantly reduced over the curtailment periods, the active participation in the PowerShare program presents an excellent opportunity for the DCOI to obtain carbon offset credits from Duke Energy or other major GHG emitters.

One of the future considerations our team recommends be investigated is whether the existing emergency generators could be re-configured or modified to enhance mechanic efficiency and further minimize the environmental burden. For example, whether the current fleet of diesel-powered generators could be modified into natural gas powered generators. Since natural gas is a less expensive and a cleaner fuel stock than diesel, this change may be both financially beneficial and environmental friendly.

Another possible consideration is to combine several smaller electric generators in nearby buildings into a larger unit to increase its operational scale. This plan may work to achieve better environmental performance on campus because larger electric generators are known to emit less HAPs and GHG into the atmosphere. Thus, the efforts to consolidate multiple generators together could allow the university to better manage the emissions resulting from the operation of electric generators on Duke University campus.

This study also reveals several promising ways to further improve water efficiency and sink disposal. One of the most significant opportunities is harvesting rainwater as a potential way of collecting alternative water resources. Although the preliminary cost benefit analysis indicates a low return on investment, future studies could be conducted to determine the exact cost of installing the rainwater harvesting system or any related emerging techniques.

In addition, more local reuse opportunities should be researched in laboratory buildings, in addition to implementing the reverse osmosis system with wastewater from dishwashers/sterilizers and recirculating the water in distillation condensers. Using the wastestream from purification systems to flush toilets and condensate from air-conditioners to irrigate the landscape may also be of good value. In addition, identifying safer chemicals to substitute into processes requiring drain disposal could on the one hand lower the human health risks, at the other hand reduce the burden of waste collection.

Appendix

Appendix A: Interview Tool

A: The first part is about sink disposal of chemical substances. We have developed an education material about sink disposal of chemical substances, which talks about why the pretreatment is important, top violation of chemical substance disposal in last audit, and substance that are prohibited from drain disposal. The interview questions will be listed below.

- Do you think this educational material will be useful guiding people's behavior regarding drain disposal?
- Since last audit, are there any improvements with respect to the sink disposal of chemical substance?
- Have you encountered any difficulty collecting chemical substance that cannot be disposed directly into sewer systems?
- Any other suggestion on how to reduce violation of drain disposal

B: The second part is about improving water efficiency in laboratories. I have also developed an education material about the potential way of reducing water usage in laboratories (see attachment). They are focus on process equipment, best practice and other water sources respectively. The interview questions are:

Process equipment

- What is the current equipment cooling process? Do you use single-pass system for equipment cooling which consumes a lot of water? If so, will you consider change to cooling loop/ small-packaged chillers?
- What is the current glassware rinsing practice? Have you heard about counter-current rinsing?
- Is there a control valve to allow water to flow only when the equipment is being used?

Best Practice

- Do you use a filtration process to purify water? If so, do think you use the reasonable level of filtration to purify water for various purposes?
- Have you adjusted flow rate the minimum, turn off equipment that are not in use, or use high quality steam to make autoclaves and sterilizers more efficient?
- Have you tried to move to digital X-ray and photography since they consumes less water compared to traditional oil printing?
- What type of vacuum system do you use? What is the water usage of the system?
- Do you run dishwashers fully loaded? Do you use clean rinsing detergents and reduce rinse cycle whenever possible?
- Do you recirculating the water in the vivarium system?

Other water sources

- Do you think there is any possibility to use other water sources, such as rainwater harvesting, condensate recovery or reclaimed wastewater

Creative questions:

- Do you think it is possible to connect some equipment, such as dishwashers, HAV, autoclaves with Reverse Osmosis system, with the goal of reusing water?
- Do you think it is possible to install a timer on equipment, through which water flow all the time, to control the volume of water usage?