SP0149 Final Report

Please answer the following questions and return the completed form to the SPF Staff via e-mail.

Project Title: Green Light Microscopy

Final Report prepared by: Claire Brown

E-mail: claire.brown@mcgill.ca

Actual Project Start Date: 9/1/2015 Actual Project End Date: 8/31/2016

1. Please summarize the project and its key accomplishments in 1-2 sentences.

(400 characters maximum)

The project involved replacing mercury containing microscope light sources with LED based models. The main benefits being the elimination of mercury from the waste stream and the lower power consumption of LEDs. We continue to increase awareness of green microscopy light sources and we completed an indepth LCA analysis.

2. Did your team achieve your project's goal? In your answer, please describe the impact your project had on McGill's structures, processes, and/or systems. Also, please specify how this positively transformed people's behaviors/perspectives/habits on McGill campus(es).

(Unlimited characters, suggested minimum ½ page or approximately 250 words)

Yes. We replaced 5 mercury containing light sources in the Advanced BioImaging Facility (ABIF) of the Life Sciences Complex (LSC) with solid state sources and removed ~1.25 g of mercury from the McGill waste stream. The reduced power consumption of the new units will result in savings of 11.250 kWh. Three undergraduate students worked on the project; Firas Mubaid tested many different solid state light sources for stability on multiple time scales. He is currently working on custom modifications to the sytsem for live cell imaging. These modificaitons will reduce photo-toxicity to living samples. Cecile Raya is a marketing student who re-designed our Green Light Microscopy (GLM) poster, posted it throughout the LSC, and developed a wonderful promotional video. She is continuing to work on an incentive plan to encourage researchers to replace their mercury based light sources with new green solid state ones. We applied for a Honda Grant to contribute to the incentive plan but we were unsuccessful. She is investigating other grants that we will apply for. Maria Anghelopoulou is an engineering student and she performed a detailed LCA (see attached report) comparing the metal-halide mercury containing light source with a solid state light source from the same company. The solid state source was 3-5 times superior in all metrics she studied. She willl present her work as a poster on Thursday, October 20th at the University Wide Undergraduate Research Day.

3. Please describe the key successes and challenges of your project. (Minimum of two examples for each)

(Unlimited characters, suggested minimum ½ page or approximately 250 words)

The ABIF was able to go mercury free. LCA demonstrates how much better green light sources are for the environment. The main difficulty is finding funding towards an incentive program to try and make the LCS microscopes mercury free. There is also difficulty in getting software, acccurate database information and product information for an accurate LCA analysis. In the end a lot of assumptions had to be made.

4. What key points of advice or *lessons learned* would you give to other SPF teams either regarding your experience managing your project or the project itself?

(Unlimited characters, suggested minimum ½ page or approximately 250 words)

If you are asked to do a LCA there are no resources at McGill to do this. My student spent about two months researching options and with no budget for this we ended up using a student version of a free software. This software did work but it is now expired, therefore if we want to work further on this, delve deeper, or get a more Canadian data base of information we will need to start over. I am constantly amazed at the excitement, commitment and dedication of the students who worked on this project. They love working in their area - fluorescence, marketing, and engineering on a highly relevant sustainability problem. It was a pleasure managing this project.

5. **What recommendations do you have for the future of this project to be continued and are there any opportunities for complementary projects? Who will take responsibility for the project's future and how can interested persons be in touch? The SPF team will also be in touch with this contact for updates on the project's progress in coming years, if ongoing.**
(Unlimited characters, suggested minimum 1 paragraph)

My goal for several years now has been to phase out mercury based light sources in the LSC and eventually campus-wide at McGill. We will continue to develop an incentive program, a database of mercury based systems in use and try to get funding for this part of the project from outside sources. I will continue to push on this project but things will slow down now that the SPF funding is finished. I would highly recommend the SPF purchases at least one full license for LCA software with a high level Canadian database. The LCA analysis was a requirement for our project but we did not have the resources we required to do the analysis. In fact, it would be beneficial to repeat the analysis with my current student using a full software license and a Canadian database. Otherwise, researchers should be encourgaged to put $3-10k into their project budgets to get a copy of the appropriate software.

6. **In your application, you listed the following sources of funding:** Close Focus Consulting ($10,000); Carl Zeiss Canada In-Kind ($4,928); ABIF/CIAN/MNI ($5,000); Corporate Support - Outreach Events ($5,000)

Please confirm if you received this funding in the space below. In your response, please list the actual amount (in dollars) that you received. Note: If you received funding from a McGill Department, Unit, or Funding Source, please attach a letter or other formal documentation in an appendix confirming the actual amount of support.
(1,800 characters maximum)

We received $2000 from the MNI Imaging Facility, $1000 from the CIAN Biology Facility. The $2000 from the ABIF which was used to supplement intern salaries as more hours were worked than we budgeted for. The interaction with the Close Focus Consulting group was not as significant as proposed due to career changes. The estimate was $1,000 worth of free consulting rather than $10,000 from Close Focus Consulting. We did not end up doing an outreach event so we did not receive $5,000 of corporate support for that initiative. This initiative could still be planned. We received a discount of $9,821.75 (not $4,928) from Carl Zeiss Canada as in-kind support for the 5 light sources.

7. **Did you purchase equipment or make an installation on campus?** ☒ **Yes** ☐ **No**
If yes, please briefly describe how these items will be maintained and used in the future.
(1,800 characters maximum)

Five X-Cite 120 LED light sources were installed in the ABIF. The systems are routinely maintained by the ABIF staff and are part of our service contract support from Carl Zeiss on the microscopes. The ABIF plans to maintain any service contracts or repair costs with our institutional IOF funding for the ABIF infrastructure.

8. **At the beginning of your project, you submitted a work plan or impact metric that included target measurables or indicators of your project's success (e.g. # of tons of GHG emissions reduced). Please pick 3 indicators that best showcase the success of your project and complete the table below. To share updates on other indicators that you set, please attach an appendix to this report.**

Selected Key Success Indicators	Target #	Actual #
Replaced 5 light sources - removed mercury from the waste stream	1.25 g	1.25 g
Power consumption reduced with the new light sources	11250 kWh	11250 kWh
First LCA report in the field.	Completed	Completed

If there is a significant difference in the target numbers and the actual numbers achieved, please explain. If you have any additional information to share about these success indicators, please also include it below.
(1,800 characters maximum)

9. **Please complete the table below for the Standard SPF Key Success Indicators, if the data is available.**

Standard SPF Key Success Indicators	Actual #
# of volunteers directly or indirectly engaged in the project	9
# of people (student, staff, or other) trained in the context of the project	3
$ raised for project activities subsequent to SPF funding	$29,821
# of partnerships or collaborations developed between the project team and other McGill administrative units, student groups, community groups, other universities, and/or other groups/organizations.	2

Regarding the last Key Success Indicator, please list the groups and/or organizations that you counted.
(Unlimited characters; point form acceptable.)

Procurement, Hazardous Waste (also collaborative with Faculty of Management, Faculty of Engineering, Faculty of Medicine, Faculty of Science and the MNI at the MUHC

If you have any additional information to share about the Standard SPF Key Success Indicators, please include it below. (1,800 characters maximum)

10. **Please rate your project team's overall satisfaction with the support provided by the SPF Staff. Choose only one response.**

☐ Very Dissatisfied ☐ Dissatisfied ☐ Neither Satisfied Nor Dissatisfied ☒ Satisfied ☐ Very Satisfied

11. **Please provide any feedback or recommendations regarding your team's experience with the SPF.**
(Unlimited characters, suggested minimum 1 paragraph)

The main issue was the lack of resources or information on how to complete the LCA analysis. The SPF should purchase at least one copy of high end LCA software with a detailed Canadian Database.

12. **If there is additional information you would like to share about your project, please use the field below.**
(Unlimited characters)

Maria Anghelopoulou will present her work at the Faculty of Science Undergraduate Research Day

13. **Has involvement in this SPF project positively impacted your team in the area of <u>professional growth</u>? Please choose one. If you would like to elaborate, please use the field below.** (800 characters maximum)

☒ Yes ☐ No ☐ Prefer Not to Share

Great cross discipline project with science, medicine, management and engineering.

14. **Has involvement in this SPF project positively impacted your team in the area of <u>personal growth</u>? Please choose one. If you would like to elaborate, please use the field below.** (800 characters maximum)

☒ Yes ☐ No ☐ Prefer Not to Share

15. Which of the following skills or attributes has your team improved through involvement in your SPF project? Choose all that apply.

- ☐ Budgeting
- ☒ Communications
- ☐ Conflict Resolution
- ☒ Leadership
- ☐ Listening
- ☒ Mentoring
- ☐ Negotiating
- ☐ Networking
- ☒ Planning
- ☐ Problem Solving
- ☒ Project Management
- ☐ Public Speaking
- ☐ Stakeholder Engagement
- ☒ Stakeholder Identification
- ☐ Systems Thinking
- ☒ Teamwork
- ☐ Technology
- ☐ Time Management
- ☒ Writing
- ☐ Other (Please specify in the field below)

Other:

16. Since starting your SPF project, has your team improved its knowledge of sustainability? Please choose one. If you would like to elaborate, please use the field below. (800 characters maximum)

☒ Yes ☐ No ☐ Prefer Not to Share

I really understand what goes into the LCA analysis now and the importance of collecting as much information as possible, having a solid software program as well as an accurate database.

17. (Optional) If applicable, please list the total number of team members voluntarily self-identifying as members of marginalized communities:

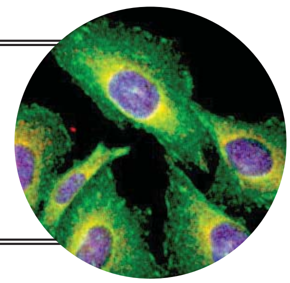
Please identify the represented communities below. (e.g. women, Indigenous people, people of colour, LGBTTQI, student parents, members of ethnic minorities, immigrants, people with disabilities)
(1,800 characters maximum)

Thank you for completing your Final Report!

Please e-mail your report to the SPF Staff attaching any additional information that you would like to share about your project (e.g. other reports, research, documents, photos, etc.). Please note that this Final Report will be shared publicly on your SPF project's webpage.

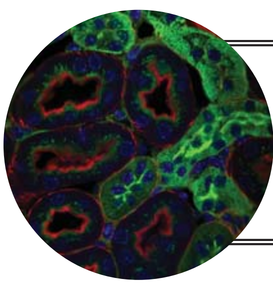
GREEN LIGHT MICROSCOPY

WHY SHOULD THE LIFE SCIENCES COMPLEX ADOPT MERCURY FREE LIGHT SOURCES?



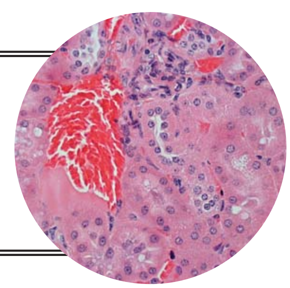
RELIABILITY

STABLE POWER OUTPUTS • RAPID SWITCH ON/OFF



DURABILITY

LED LIGHT SOURCES LAST AT LEAST 20,000 HOURS



SUSTAINABILITY

SAVES ENERGY • REDUCES HEALTH HAZARDS

FOR MORE INFORMATION ON THE EFFORTS BEING MADE TO SWITCH TO LED-BASED MICROSCOPES AT MCGILL, CHECK OUT:

WWW.MCGILL.CA/GLM

ABIF ADVANCED BIOIMAGING FACILITY

the Sustainability Projects Fund

CIAN

neuro

Sustainability Projects Fund
McGill Office of Sustainability (MOOS)
1010 Sherbrooke St West, Suite 1200
Montréal, Québec H3A 2R7

Fonds des projets durables
Bureau de développement durable
1010, rue Sherbrooke Ouest, Suite 1200
Montréal (Québec) H3A 2R7

Project Title:	SP0149 - Green Light Microscopy, Phase 2		
Activity Code:	SP0149		
Project Leader:	Claire Brown		
Email Address:	claire.brown@mcgill.ca	Phone Number:	514-398-4400 ext 00795
Project start date:	July 6, 2015	Project end date:	

Deliverables

Type	Start Date	Updating Date	Completion Date
Workplan	Aug-15		Aug-15
Budget $39,482	Aug-15		Aug-15
Video	Jan-16	n.a.	Mar-16
Photos	Aug-15	n.a.	Sep-16
Progress report	Feb-16	n.a.	Feb-16
Final report	Aug-16	n.a.	Sep-16
Monitoring Impact Metrics*	Aug-15		Sep-16

** For selecting you Impact Metrics, you can inspire from the list 'SPF Sample Impact Metrics' that was provided to you with the Award Letter, in the SPF Project Package attached to the email.*

*** Examples of what your own planned communication and engagement deliverables could include: posters, launching event, workshops, consultations, online surveys, etc. This will allow MOOS to help with promotion of your project activities through our networks and social media (Facebook, Twitter, MOOS newsletter, etc.). Please do not forget to recognize the support of the SPF on all materials by including our logo (in the SPF Project Package sent to you), with the text "This project is proudly supported by the McGill Sustainability Projects Fund."*

Project Workplan

Task	Start Date	End Date	Status	Costs	Purchase Date	Purchase method	Details	Impact Metrics*	
Milestones, including the above deliverables and your own communication and engagement commitments**	Estimate mm/dd/yy	Estimate mm/dd/yy	Choose from dropdown menu	If Applicable	If Costs Applicable	e.g. P-Card; McGill Marketplace; Work Order; Expense Report	Anything relevant: i.e. support required, etc.	Indicate how you will gauge success	
								TARGET	ACTUAL
1. Purchase and install 5 light sources for the ABIF	Sep-15	Oct-15	Complete	$ 31,739.82		MMP	$31,739.82 covered by SPF, $9,821.25 In Kind from Carl Zeiss Canada, See attached Quote	# purchased; kg Hg removed; power saving	1.25 g of mercury removed from the McGill Wastestream, saved 11,250 kWh of power
2. Identify corporations and test GLM based light sources	Sep-15	Sep-16	Complete	$ -					This work was done as part of a PHGY396 Course so there was no cost. We are working on a paper.
3. Perform an inventory of mercury containing light sources in the Life Sciences Complex, Conduct LCA for light sources	Sep-15	Sep-16	In Progress	$ 12,000.00		Time Sheets/Stipend	This stipend was covered by the SPF for Cecile Raya. We are continuing the work with the funding from the ABIF, CIAN, MNI and McGill Work Study. Maria Anghelopoulou completed a full LCA analysis of a metal halide and an LED based light source. The report is attached. Her stipend was covered by the SPF and the ABIF.	First LCA in the field, 1 paper	Continuing to work on inventory. LCA paper is attached.
4. Update and expand GLM information brochures	Jan-16	Sep-16	In Progress	$ 2,000.00		MMP, P-Card	We redesigned the GLM poster and had it printed and distributed throughout the LSC. We generated a new GLM promotional video at no cost. We are still working on the brochure.	Inform McGill community of GLM - likes on social media	Posters around campus. New Video. Can look up number of times the video has been viewed.

5. Determine incentives to encourage researchers to upgrade to GLM compatible light sources	Jan-16	Sep-16	In Progress				Tried to get funding from Honda. Were not successful with the grant. Working on other options. Working on inventory of units. Expoloring other stakeholders who may invest. LCA analysis gives clear rational and benefits of switching.	# of GLM compaible purchased, survey of potential labs who would upgrade	Survey ongoing, Data from LCA readily available - see attached.
6. Calculate the energy, monetary, and mercury benefit of a campus-wide conversion	Jan-16	Sep-16	In Progress					Calculate true savings for ABIF systems	We need to have the inventory to do this properly. For the ABIF we will use 4x less energy with the 5 new light sources.
7. Develop a new funding model for mercury light source conversions	Sep-15	Sep-16	In Progress					Number of labs considering conversion	Honda Grant was not successful. Will continue to apply for grants.

Project Workplan

Task	Start Date	End Date	Status	Costs			Details	Impact Metrics*	
Milestones, including communication commitments	Estimate mm/dd/yy	Estimate mm/dd/yy	Choose from dropdown menu	If Applicable	If Costs Applicable	e.g. P-Card; McGill Marketplace; Work Order; Expense Report	Anything relevant: i.e. support required, etc.	Indicate how you will gauge success	
								TARGET	ACTUAL
8. Continue the awareness campaign, community and scientific talks	Sep-15	Dec-16	Not started	$ 5,000		MMP, P-Card	scientific conference (corporate support), student presentations, corporate exhibits	# researchers attending, # companies attending, $ corporate support	This event was not planned. The LCA and inventory took much more time than expected. It could still happen in the future.
9. Create and run PHGY396 independent study courses and summer internships	Sep-15	Apr-16	Complete				one in the fall term and one in the winter term	2 students-3 credit course	Only one student did this course. Firas Mubaid. He got an A in the class and measured the stabitliy of the 120 LED to be less than 1% on all time scales tested.
10. Present results to external stakeholders for contributions for a light source conversion fund, e.g. Quebec, Hydro Quebec, Environment Canada	Mar-16	Dec-16	Not started					# stakeholders reached, $ stakeholder contributions	This was not done but could be done in the future.
11. Develop a system to flag PS purchases or OSR submitted grants that might involve mercury based lamps	Jan-16	Jun-16	Complete					# of GLM compatible purchases, amount of mercury avoided, power saved	A document was sent to procruement. We need to follow up to see if they are flaging potential purchases.
12. Prepare for Phase 3 implementation of campus wide fiscal incentives. Implement the model to fund replacements to phase out mercury light sources	Sep-16	Dec-16	In progress					Feedback from SPF on Phase 3 proposal, researchers interested in upgrades	Actively working on grant funding from third parties. Spreading word to stakeholders.
13. Estimate how many mercury bulbs are replaced on campus (with EHS and Waste Management)	Sep-15	Dec-15	In progress				Intern 1 will work on this.	mercury waste reduction, power saved	We require the inventory for this. We have all the information in the LCA to do the calcualtions.

Life Cycle Analysis of a Mercury-Based Microscopy Light Source and a Solid State Mercury-Free Light Source

Submitted: September 22nd, 2016

Prepared by:

Maria Anghelopoulou

Contents

Executive Summary

The Advanced Bio-Imaging Facility (ABIF) of the McGill University Life Sciences Complex is transitioning away from mercury-based microscopy light sources to solid state (LED) mercury-free light sources and is interested in evaluating the environmental impact of producing, using and disposing of these two light sources.

This Life Cycle Assessment (LCA) aims to analyze the contribution of each life cycle stage to the overall environmental load. The two different light sources, the mercury based light source and the solid state (LED) light source are compared in their footprints on the environment in terms of production, energy consumption during useful life as well as end of life disposal.

The functional unit for this study is "providing light for 8 hours/day, 5 days a week, 52 weeks a year, for 12 years". The reference flows were therefore chosen to be the number of light sources required (i.e. metal halide bulbs used in the mercury based light source and solid state LED light sources). The metal halide bulb was assumed to have a lifetime of 2000 hours, while the LED light source was assumed to have a lifetime of 25,000 hours.

The bulk of electricity consumed over the life of the light sources is in their use phases with relatively little electricity being consumed in their manufacturing phases. The environmental impact of the light sources in all indicators considered (Global Warming Potential, Acidification, Human Toxicity and Soil and Water Ecotoxicity) is largely due to the assumption that they are manufactured in China.

Conclusions

The LED light source versus the metal halide has (over the functional unit of 12 years under normal use):

a) Four times less energy consumption during the use phase.
b) Three times less energy consumption during the manufacturing phase.
c) Avoids 250 mg of mercury entering the McGill waste stream.
d) Reduces the acidification potential by 3 times.
e) Three times less global climate change effect.
f) Three times less water toxicity.
g) Three times less soil toxicity.
h) Three times less effect on human health (e.g. respiratory problems).

1. Goal of the Study

This study aims to:

- Evaluate the environmental impact of a mercury-based microscopy light source as well as an LED light source in different phases: production from raw materials, waste disposal and power consumption during its lifetime.
- Evaluate what energy savings can be achieved by using a solid state light source instead of a mercury based one.
- Evaluate how much mercury can be avoided from entering the McGill waste stream by switching to the solid state light source

This will be achieved by:

- Creating a Life Cycle Inventory of inputs and outputs to the life cycle
- Calculating the environmental impacts using LCA (Life Cycle Assessment) of the mercury-based light source and comparing it with the results of the life cycle of the solid-state (LED) mercury-free light source.
- Interpreting the results to see the amount of mercury eliminated from the waste stream as well as any relevant energy savings from switching to a solid-state light source.

The primary audience for this study is the general McGill body of students and staff, the Sustainability Project Fund as well as the Advanced Bioimaging Facility users.

2. Scope of Study

The scope of the study outlines what will be included within the LCA of the microscope light sources.

2.1. System Boundaries

The figure below illustrates the system boundaries of this LCA. This cradle-to-grave life cycle considers the following steps of the life cycles of the two light sources:

- Raw material production
- Material processing phase
- Bulb assembly phase
- Use phase
- End of life

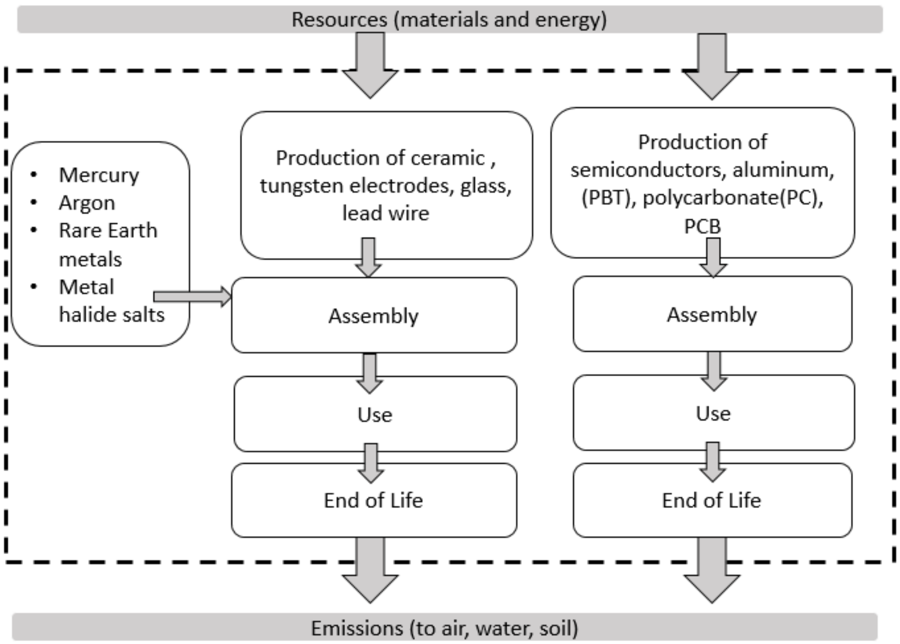


Figure 1: Life cycle of the metal halide (left) and LED (right) light sources.

The transportation of the two microscope light sources from the production facility to McGill will not be considered in this analysis as both light sources are produced by the same manufacturer, and have similar weights so the transportation costs and environmental impacts are assumed to be the same. Additionally, the casing of the microscope light sources will not be considered in the system boundaries as both casings are very similar in components in that they are both made of steel, of approximately the same size and contain printed circuit boards. Therefore, only the variable impact of the light sources themselves will be compared in this study.

2.2. Software and Database

This LCA study was modelled using a software called Gabi for life cycle engineering, developed by PE INTERNATIONAL (http://www.gabi-software.com/international/index/). Several of the raw and process materials are modelled using life cycle inventory data from the GaBi LCI database.

2.3. Time/Technology/Geographical Coverage

The background data that related to raw materials, energy, some production processes, etc. were obtained from the Gabi 6.0 Education Version Database 2016. The manufacturing was assumed to take place in China using electricity mostly produced from coal, and the use and disposal is in Quebec. However, some data from the Gabi database were from European processes, and Canadian specific ones were not available. For example, the electricity use phase of the microscopes in Quebec was modelled as taking place in Norway, where the majority of the electricity produced also comes from hydropower.

2.4. Functional Unit

The functional unit for this study is:

"Providing light for 8 hours/day, 5 days a week, 52 weeks a year, for 12 years" for a total of 24,960 hours ≈ **25,000 hours**.

This functional unit was chosen so that it would cover the lifetime of one LED light source and so that the number of metal halide bulbs required in that time span could be directly compared.

The reference flows for the functional unit mentioned above are:

12.5 metal halide light bulbs
1 LED light source

In order to compare the two light sources, the varying lifetimes of each one needs to be taken into account.

The metal halide bulb has been assumed to have a lifetime of 2000 hours. Any impacts from manufacturing, and end of life disposal for this light source have to be accounted for 12.5 times.

The solid state LED light source has been assumed to have a lifetime of 25,000 hours. The manufacturing and end of life disposal have been accounted for only once.

The metal halide bulb has 12.5 production phases as well as 12.5 end of life phases. For the same functional unit, the solid state LED light source has only one production and end of life phase. The use phase for both reference flows will be discussed later in the report.

2.5. Selection of Life Cycle Impact Assessment (LCIA) Methodology and Types of Impacts

The calculation methodology selected for this study was TRACI (Tool for Reduction and Assessment Chemicals and other environmental Impacts) which was developed by the US Environmental Protection Agency. The TRACI impact categories were selected because they are specific to the US. This is a closer approximation to Canada than other European impact categories like CML, developed at the Institute of Environmental Sciences at the University of Leiden in the Netherlands. CML is the most widely used methodology and it derives its impact factors from primarily European data, unlike TRACI which uses mostly North American data. [2]

The impact assessment categories chosen for this study were [1,2]:

1) Global warming potential
2) Acidification potential
3) Ecotoxicity soil
4) Ecotoxicity water
5) Human health criteria

2.6. Sources of Data

Sources of data include primary data from the supplier (Excelitas Technologies, Mississauga, ON, http://www.excelitas.com/Pages/Index.aspx) as well as data from the Gabi database. Additional sources of data used include a product data sheet for a comparable metal halide bulb product from Osram (http://www.osram.com/osram_com/products/lamps/specialty-lamps/index.jsp). As specific data regarding the production and manufacturing of the mercury metal halide light source was unavailable, several data points were assumed as the “industry standard” from Zeiss Microscopy, where typical components and manufacturing procedures were outlined. [3]

2.7. Cut-off Criteria

When modelling the light sources, certain cut-off criteria were created for excluding certain materials. If a component represented less than 1% of the total mass of the light source, it was excluded from the study. However, the exception to this is when the component might have a significant environmental impact such as the mercury content in which case it is still considered.

3. Life Cycle Inventory

The microscope light sources that are being compared in this life cycle analysis are two light sources made by Excelitas, the X-Cite 120 PC Q (Figure 2) and the X-Cite 120LED (Figure 3).

X-Cite® 120PC Q

Figure 2: Mercury based metal halide microscope light source [4].

X-Cite® 120LED

Figure 3: Solid State (LED), mercury-free light source. [6]

The X-Cite 120 PC Q is a fluorescence microscope illumination unit that uses a 120W mercury vapour short arc lamp or metal halide bulb as the light source. The 120W metal halide lamp is replaced once it has reached the end of its life. The lamp is guaranteed for a lifetime of 2000 hours, but typically lasts around 2500 hours. It requires a warm up phase of 20 minutes as well as cool down phases between uses, meaning that the bulb often stays on for extended periods of time and cannot be turned on and off repeatedly for practical reasons. Each bulb contains 20 mg of mercury which can be harmful and toxic to the environment. [4] The metal halide lamp is shown in Figure 4 when inserted into the light source housing and just the metal halide bulb is shown in Figure 5.

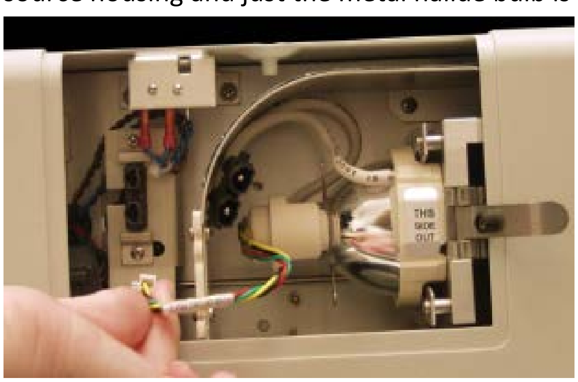


Figure 4: Excelitas Metal Halide Lamp containing mercury [4]

Figure 5: Excelitas metal halide replacement lamp [5]

The X-Cite 120 LED is a fluorescence microscope LED illumination unit. The components of the X-Cite 120LED microscope light source are the black PowerCUBE on the left and the LED head attachment on the right (Figure 3). The 230 W LED Head attachment is connected directly to the microscope and is used as the light source. [6] The lifetime of the LED lamp is 25,000 hours with no lamp replacements required. It can be turned on and off instantly, and therefore requires no warm up/cool down phases. It can also be set-up to automatically turn on during microscope image acquisition and then turn off when done, resulting in lower power consumption. Some advantages of the LED light source over the metal halide one are that it contains no mercury, it has greater power stability over time and the ability to turn it on and off instantly results in much lower electricity consumption. [7]

Some assumptions had to be made regarding the LED light source due to limited information provided in User Guides and WEEE instructions from Excelitas Technologies. For the whole LED microscope light source the masses of some general components (Table 1) was estimated.

Table 1: Component materials and masses for X-Cite 120 PC Q [6].

ELECTRICAL COMPONENT LIST (Total Weight ≈ 0.7 lbs)

Quantity	Component Description	Material Content
1	PCB BOARD 1	Electronics
1	PCB BOARD 2	Electronics
5	CABLE ASSY	Nylon, Brass, Tin, PVC, Copper

OTHER COMPONENTS: Metals (Total Weight ≈ 9.4 lbs) and Miscellaneous (Total Weight ≈ 0.5 lbs)

For the electrical components of the microscope light source, the total mass of the PCB boards (1 & 2) and the cable assemblies are 0.318 kg. The LED head contains one printed circuit board (PCB Board 2) while the POWERCube contains the other (PCB Board 1). It is assumed that half the mass of the electrical components and circuit assembly of the microscope light source are in the LED head.

$$\frac{0.318\ kg}{2} = 0.16\ kg$$

A top open view of the LED head shows the LED light source (Figure 6). The miscellaneous components discussed in Table 1 have a mass of ~0.23 kg and are assumed to be components within the LED light source. Additionally, it is assumed that some of the metal is in the LED's aluminium heat sink.

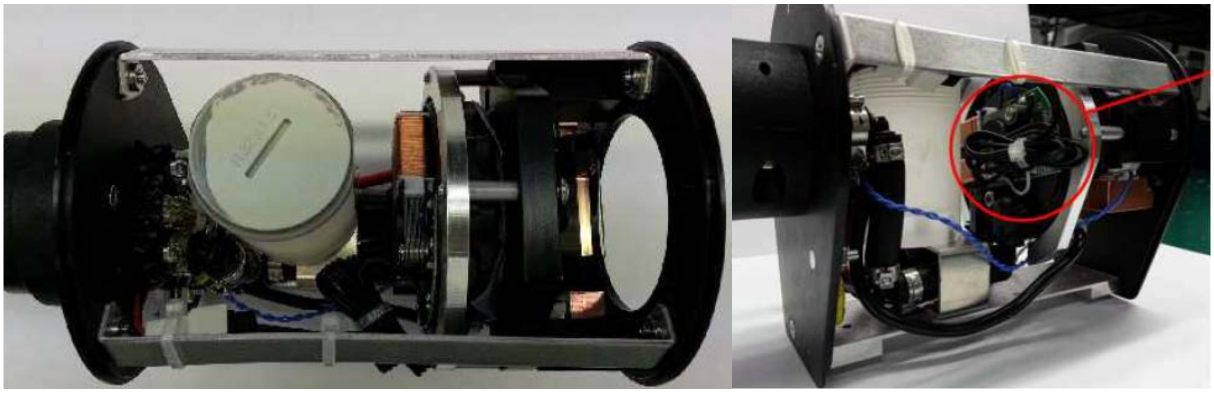


Figure 6: Top open view of the LED head

The total mass of the LED head is 0.9 kg, therefore the balance once the electrical (0.16 kg) and miscellaneous (0.23 kg) components have been subtracted is 0.51 kg of metal. It is assumed that a large part of the metal goes to the steel for the hardware structure [8], and some of the metal is the aluminum required for the LED heat sink. Therefore, it is assumed that approximately 50% of the weight of the LED head is from the steel hardware structure and the remaining mass (0.45 kg) is from the LED light source. A summary of the data for the two light sources is shown in Table 2.

Table 2: Summary of Data from Excelitas Technologies, supplier for the two microscope light sources:

	Metal Halide Light Source	**LED Light Source**
Wattage	120 W	230 W
Lifetime	2000 hours	25,000 hours
Mercury Content	20 mg	0 mg

4. Life Cycle Modelling

This section discusses the model made for each light source as well as all the assumptions made in modelling with the Gabi software.

4.1. Metal Halide Bulb

Insufficient information was known about the Excelitas Technologies metal halide bulb, therefore several assumptions had to be made. Firstly, regarding the total mass of the bulb, it was assumed that the mass of the bulb is 215 g, from a similar 150W metal halide bulb, the POWERSTAR HQI- R by Osram, (Figure 7). [9]

Figure 7: Osram lamp similar to one used [9].

Regarding the production of the metal halide bulbs, assumptions on the manufacturing processes were made from Zeiss Microscopy documentation [3], which describes the industry standard manufacturing of metal halide bulbs. Knowing the total mass of the bulb, assumptions were made regarding the different material components with a larger weight for the body, and with trace masses of the metal halide salts and mercury.

The system boundaries and different stages of the life cycle of the metal halide bulb were considered (Figure 8) and modelled in the Gabi software.

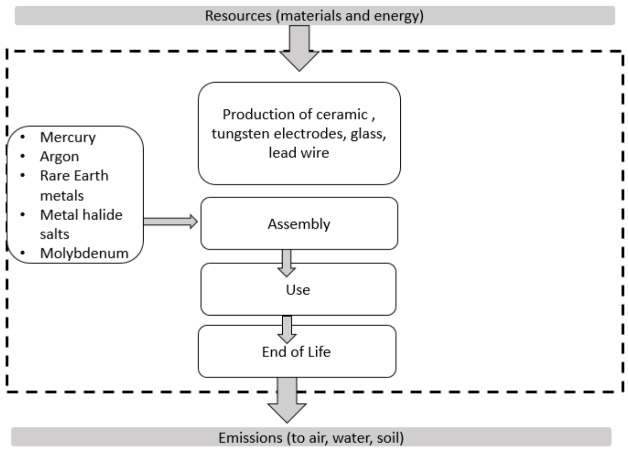
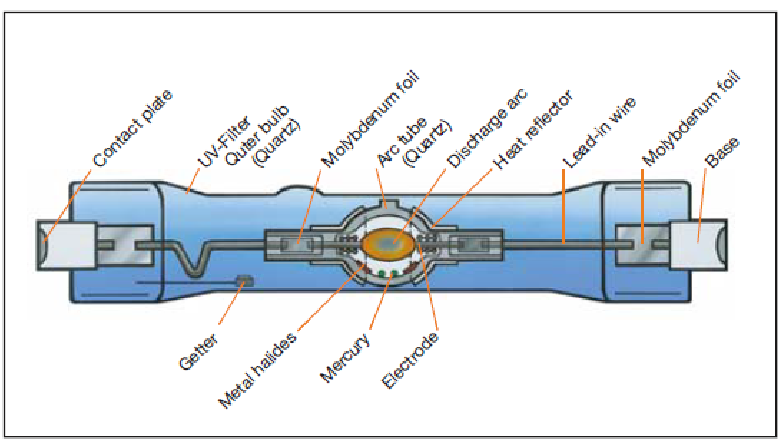


Figure 8: Main life cycle stages of the metal halide light source.

4.1.1. Production of a Metal Halide Bulb

Metal halide lamps belong to the group of discharge lamps. The light is generated by a gas discharge of the particles between the two electrodes inside the discharge tube. There is an external layer to the discharge tube, which consists of an outer bulb in order to isolate the hot quartz arc tube (Figure 9). [10]



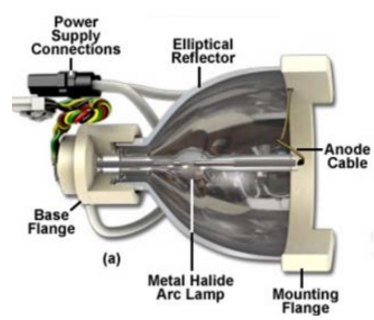


Figure 9: Components that make up the metal halide lamp. [10]

Figure 10: Metal Halide Bulb. [3]

The discharge tube is made from quartz, and includes inside it the system of electrodes as well as the metal halide salts, fill gases and the mercury. Quartz is used to make the tube so it can withstand the large mechanical and thermal stresses on the light source. The outer bulb is made from silica glass, and is pinched and capped at both ends. [11] The discharge tube is held inside the outer bulb, by the supply leads made of molybdenum foil. The electrodes inside the metal halide bulb are made from doped tungsten alloys. During the manufacturing process, they are hermetically sealed inside the lamp shaft and electrically bridged to the bases using molybdenum foil. This thin foil is welded to lead wires which are connected to both the power supply as well as to the tungsten electrodes. [3] Within the larger bulb unit one side of the lamp is attached to the base for support and the other is connected to the external power supply (Figure 10).

The lamp is filled with an inert starter gas like argon as it has desirable properties for ignition and doesn't react with the other fill components. [3] Regarding the metal halide salts, the most widely used halogens are iodine and bromine that react with rare earth metals. The rare earth metals in the metal halide lamps are usually dysprosium, thulium and holmium. Other fill components include 20 mg of liquid mercury. The metal halide salts and the mercury contained inside the arc tube are excited by the current flow through the bulb giving rise to emitted full spectrum white light (Figure 11).

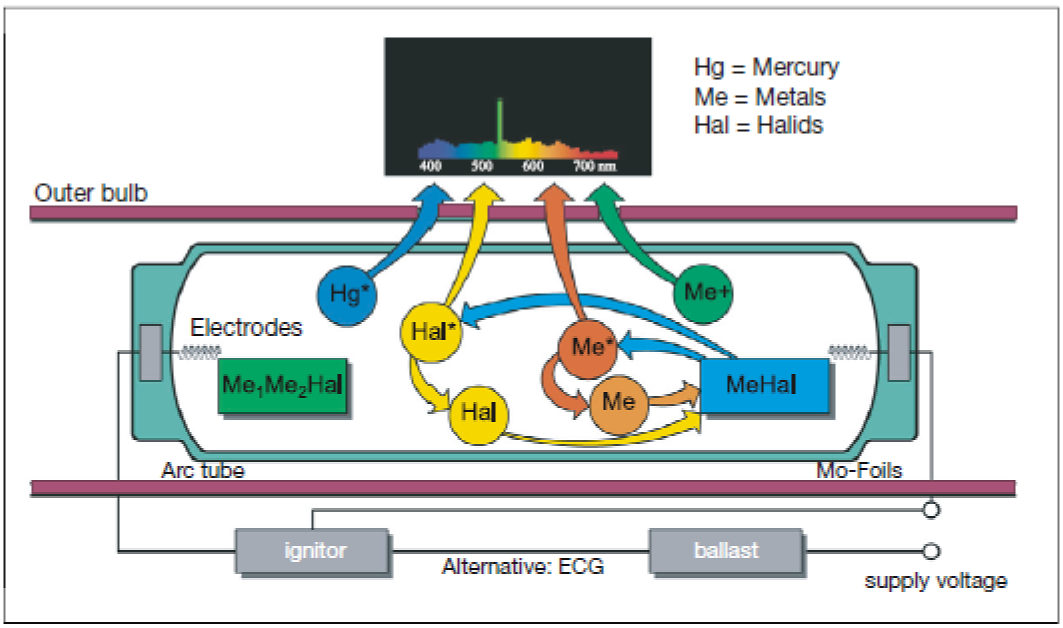


Figure 11: Excitation of the metal halide salts and mercury. [10]

The vaporized metal halide salts are dissociated by the arc and excited into higher energy states. As they diffuse closer to the cold walls of the lamp, the rare earth metals recombine with halogen to repeat the excitation cycle. Iodide salts are commonly used in metal halide lamps because they dissociate more easily than other halogens. [10]

4.1.2. Use Phase of Metal Halide Bulb

The following assumptions have been made for the use phase:

The impact of the use phase is from operating the microscope at 100% power for the length of our functional unit: "Providing light for 8 hours/day, 5 days/week, 52 weeks/year, for 12 years."

The wattage of the mercury light source is 120 W. Therefore, for the length of the functional unit, this microscope would be using 2995.2 kWh.

$$energy = \frac{8\ hours}{day} \times \frac{5\ days}{week} \times \frac{52\ weeks}{1\ year} \times 12\ years \times \frac{120\ W}{1000}$$

4.1.3. End of Life

As the specific end of life scenario was not known, for this study, it was assumed that at the end of life it went to landfill. The landfill scenario from the Gabi inventory was used, however as there was no data specific to Canada, the landfill scenario for the following EU countries was used: (Austria, Germany, Italy, Luxembourg, Netherlands, Switzerland and Sweden).

4.2. LED Bulb Life

In order to model the manufacturing process for an Excelitas LED light source, data on an Osram 8W LED bulb was used and scaled in order to make reasonable assumptions regarding the LED light source. Osram, a lighting manufacturer, completed an LCA on their 8W LED bulb outlining their manufacturing process as well as providing a detailed data sheet with all the components and their masses, that was used as the basis for several assumptions. [12]

The main stages in the life cycle of the LED light source (Figure 12) will be discussed further in the production, use phase and end of life sections. The 8W Parathom LED lamp that was taken as the basis for several assumptions (Figure 13). This LED bulb contains 6 Golden Dragon LEDs.

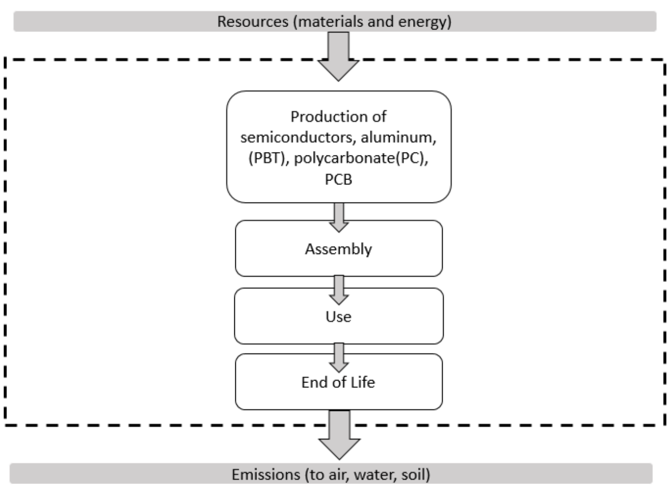


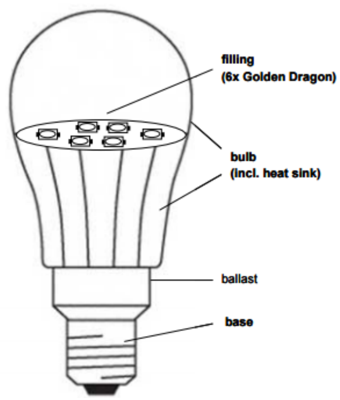
Figure 12: Main life cycle stages of the LED light source.

Figure 13: 8W Osram LED lamp that is used as the basis of assumptions. [12]

In order to make an assumption regarding the number of LEDs in the Excelitas 230W solid state light source used for microscopy, the number of LEDs was scaled relative to the wattage given 173 LEDs.

$$\frac{230\ W}{8\ W} \times 6\ LEDs = 173\ LEDs$$

The other components of the LED light source are also based on the components that make up the Osram 8W Parathom LED lamp (Figure 14).



	LED Lamp
Base	• Insulator • Contact Plate • Plastic Sleeve • Aluminum Board • Electronic Ballast
Bulb	• Bulb Material • Aluminum Heat Sink
Filling	• 6 Golden Dragon LEDs

Figure 14: Osram 8W LED Lamp Components. [12]

4.2.1. Production of LED Bulb

The production of the LED light source involves the production of many individual LEDs as well as the integration of these LEDs with the other components of the lamp structure. The basic structure of a typical LED consists of the semiconductor material (the chip), a frame where the chip is mounted, and the encapsulation material that surrounds the assembly. [13] For the scope of this project, it was assumed that the light source was made in China, so all calculations by the Gabi software account for electricity made from coal. The production of each individual LED requires two stages: the frontend and the backend processes. In the frontend processes, the semiconductor chip is manufactured. Different steps in the frontend processes such as epitaxial growth via Metal Organic Vapour Phase Epitaxy (MOVPE) onto the substrate, metallisation, lithography and substrate replacement involve adding layers to the semiconductor chip (Figure 15). [12]

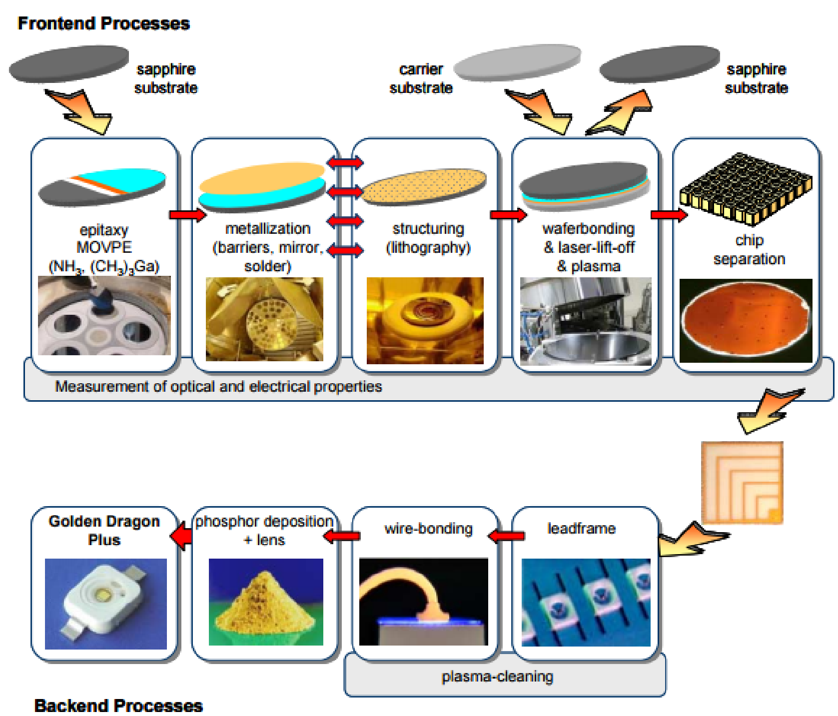


Figure 15: Front and Backend Processes to make a Golden Dragon LED. [12]

In the backend processes, the semiconductor chip manufactured in the frontend stage is packaged into the individual LED. These processes involve integrating the semiconductor chip into a lead frame, bonding the wires, depositing the phosphor and the lens, to create the final LED (Figure 15, 16). [12]

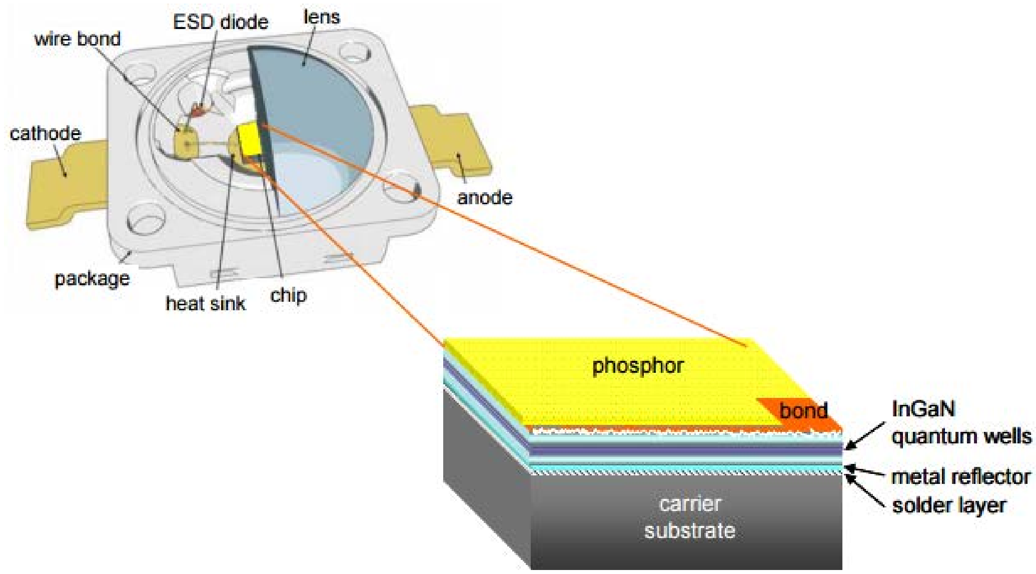


Figure 16: A semiconductor chip and how it integrates into a single LED. [12]

In order to make an assumption on the amount of electricity required to manufacture the LED light source, the manufacturing of the LED 8W Osram lamp was scaled relative to wattage (173x).

The total energy demand required for both the frontend and the backend processes for a single Golden Dragon LED is 0.41 kWh (Figure 17). Scaling to 173 LED equivalents for the Excelitas 230 W LED light source would require a total of 70.7 kWh.

$$0.41\ kWh\ \times 173\ LEDs = 70.7\ kWh$$

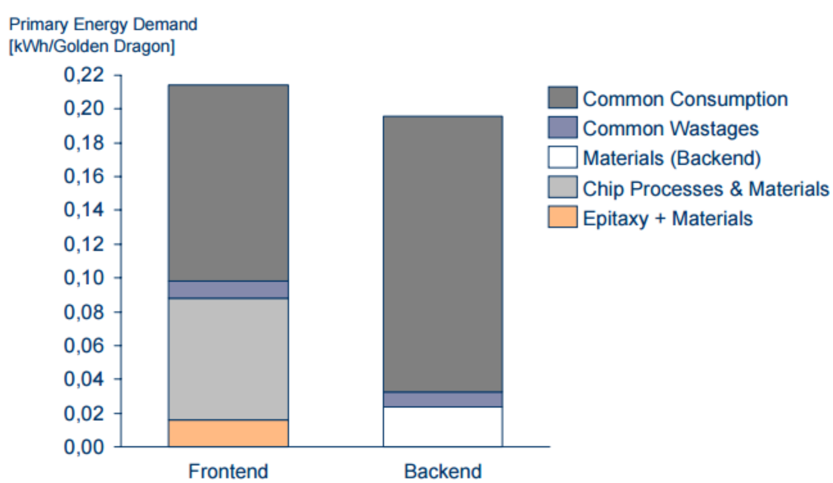


Figure 17: Energy demand of the frontend and backend processes to manufacture a single LED [12].

In order to manufacture the other components of the 8W lamp an additional 7.44 kWh is required for a total additional energy demand of 9.9 kWh per 8W LED lamp (Figure 18).

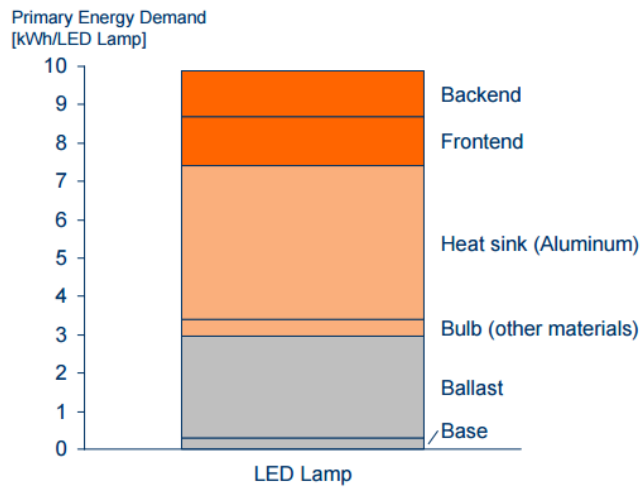


Figure 18: Energy Demand of Manufacturing for 8W LED lamp components. [12]

The Osram 8W LED lamp has a mass of 180 g [14], with each LED having a mass of 0.3 g. For the light engine with 173 equivalent LEDs, it is assumed to have a total mass of LEDs of 52 g. For the scope of this project, it was assumed that the components (excluding the LEDs) could be scaled by doubling the mass for each component in accordance with the assumption of the total mass of the light source. The energy demand for manufacturing each component was also doubled from 7.44 to 14.88 kWh. Doubling the masses of the other components results in an assumption of a total mass of 390.9 g for the LED light source. This is quite close to the general approximation discussed in the inventory where approximately half of the LED head was thought to be the LED light source (≈ 450g).

4.2.2. Use Phase of LED Bulb

The recommended usage level for the LED lamp is between 5-10% of the maximum lamp wattage. This assumption comes from a discussion with a frequent user of the LED light source. There is a linear relationship between the percentage of maximum wattage of the LED light source and the power consumption (Figure 19). Therefore, it was assumed that although the light source is a 230W LED, the average power consumption is at the 10% setting or 30W. [15]

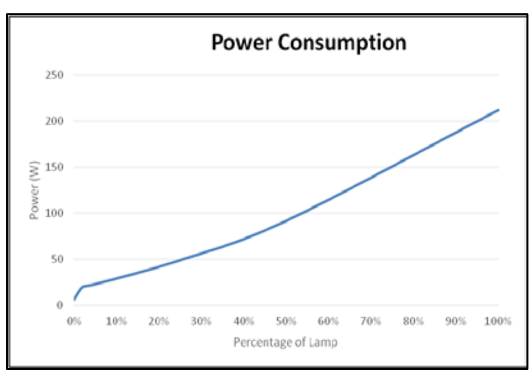


Figure 19: Power consumption as a % of Lamp. [15]

Thus, the total energy consumption for the length of the use phase of the functional unit is 750 kWh.

$$total\ energy\ = \frac{8\ hours}{day} \times \frac{5\ days}{week} \times \frac{52\ weeks}{1\ year} \times 12\ years \times \frac{30\ W}{1000} = 750\ kWh$$

4.2.3. End of Life of LED Bulb

Similar to the metal halide light source, as the specific end of life scenario was not known for this study, it was assumed that at the end of life it went to landfill. The landfill scenario from the Gabi inventory for Austria, Germany, Italy, Luxembourg, Netherlands, Switzerland, and Sweden was used.

5. Environmental Impact Assessment

Electricity Consumption: The both cases use phase is the major energy consumption phase compared to the energy used during the manufacturing stage for the length of the functional unit (Figure 20). The energy consumption of the manufacturing phase for the metal halide is larger than that for the LED. This is due to the fact that 12.5 metal halide light sources have to be manufactured. In fact, the power consumption for the manufacture of a single metal halide bulb is lower than that for the LED light source but because it has a shorter lifetime the overall manufacturing energy consumption for the use phase is higher. If fact, the metal halide light source has a **four times greater energy consumption during the use phase**, and **almost 3 times greater energy consumption in the manufacturing phase.** Thus, the LED light source will use **2,250 kWh less of electricity** over the length of the functional unit. Similarly, with regards to the mercury saved, the manufacture of 12.5 metal halide bulbs would be avoided. With each metal halide bulb containing 20 mg of mercury, **250 mg of mercury per microscope would be prevented from entering the McGill waste stream** over the length of the functional unit.

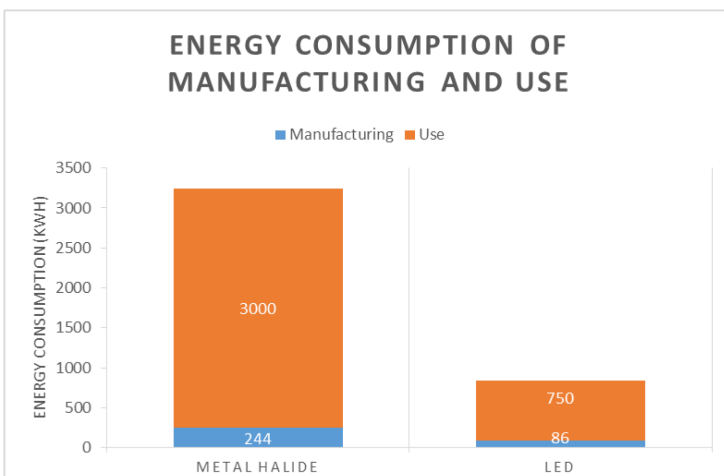


Figure 20: Manufacturing and use energy consumption of metal halide and LED light sources.

Environmental Impacts: The TRACI methodology was used in this study as it is considered the best available practice for life cycle assessments in the United States. This methodology was developed by the US EPA (Environmental Protection Agency) and was assumed to be closer to the Canadian scenario than European models.

The potential effects that were considered in this study and compared between metal halide and LED light sources were acidification, human health, global warming, and water and soil ecotoxicity. Generally, the bulk of the environmental impact comes from the manufacturing phases as it was assumed that this takes place in China where electricity is produced from coal. Therefore, even though the use phase consumed more electricity, the fact that this electricity comes from hydropower in Quebec made the environmental impact much smaller.

Acidification

Acidification is the increasing concentration of the hydrogen ion (H^+) within an environment, either from addition of acid or other substances that through chemical reactions increase the acidity of the environment. [2] The largest contributors to acidification are sulphur dioxide and nitrogen oxide, both the result of the combustion of fossil fuels. The high sulphur content in coal from the electricity manufacturing in China contributes highly to acidification. The **metal halide bulb has approximately 3 times greater acidification potential** as it requires more manufacturing phases (12.5 vs 1), and therefore more coal is combusted to manufacturer them (Figure 21).

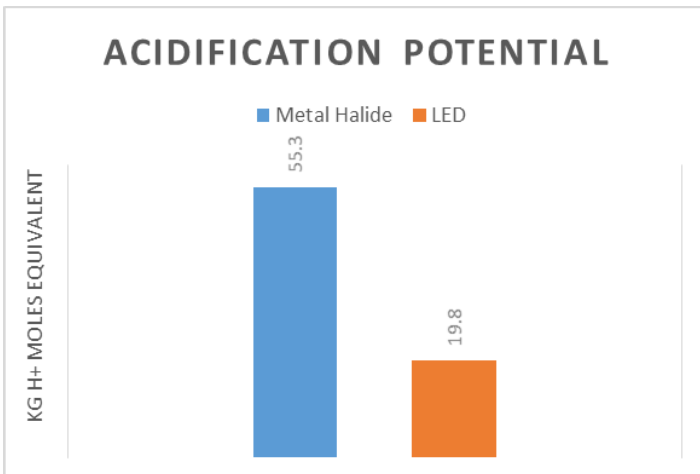


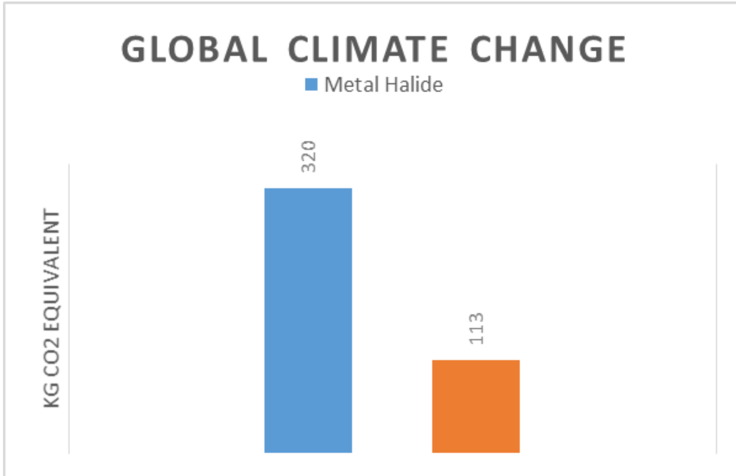
Figure 21: Acidification Potential of Metal Halide vs LED.

Global Climate Change

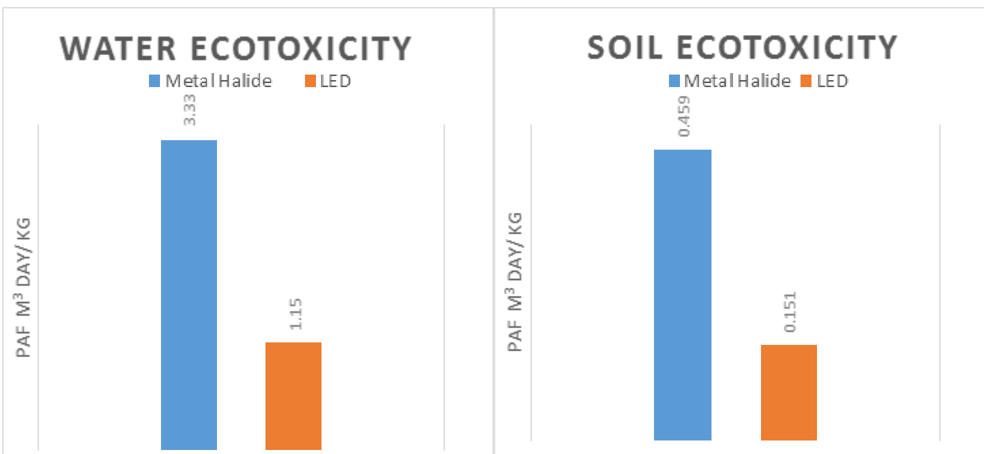
A measure of greenhouse gas emissions, such as CO_2 and methane. These emissions cause an increase in the absorption of radiation emitted by the earth and magnify the natural greenhouse effect. [2] Similar to acidification, this is mostly caused by the combustion of fossil fuels, and therefore for similar reasons as explained above, metal halide has also **approximately 3 times greater global climate change effect** greater impact than the LED light source due to the multiple manufacturing phases required (Figure 22).

Ecotoxicity of water and soil

This category addresses the environmental impacts on agricultural soil, industrial soil, freshwater, and coastal marine water [2]. The majority of this impact comes from emissions of metals during the mining phases for the components of both light sources. Again, the manufacturing phase happening 12.5 times means that there are more metals that enter the soil and water. The **metal halide has approximately 3 times greater water toxicity** and **3 times greater soil toxicity** than the LED light source (Figure 23).



<u>Figure 22:</u> Global Climate Change Effects of Metal Halide vs LED



<u>Figure 23:</u> Water and Soil Ecotoxicity of Metal Halide vs LED.

Human Health

This category deals with particulate matter, small particles in the air which can cause negative effects on human health such as respiration problems. Sulphur dioxide and nitrogen oxides are common precursors to particulates and come from the combustion of fossil fuels [2]. The metal halide light source has **approximately 3 times greater effect on human health** (Figure 24).

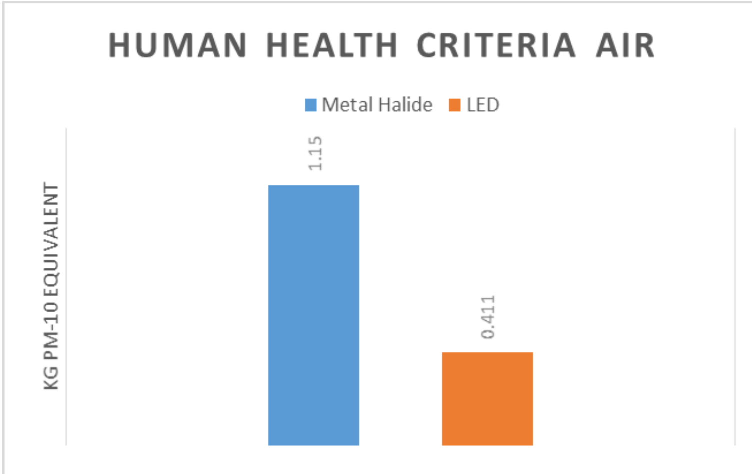


Figure 24: Human Health Criteria Air of Metal Halide vs LED.

6. Economic Impact

When considering the life cycle of the current metal halide microscopes, it is important to consider the cost of ownership of each microscope. Several assumptions are made when analysing the economic impact of transitioning to a solid state LED light source microscope:

- It costs $800 for each replacement metal halide bulb.
- It costs $20/hr for staff time. It takes ~15 minutes to change the metal halide bulb ($5).
- A new LED microscope light source costs $5,000.

Table 3: Economic analysis of changing microscope light sources from metal halide to LED.

	Metal Halide	LED
Number of Bulb changes	12	-
Cost per bulb ($)	$800	-
Cost for staff time per bulb change ($)	$5	-
Total cost for staff for total changes ($)	$60	-
Total cost of bulb changes ($)	$9,660	-
Cost of new light source ($)	-	$5,000

Therefore, assuming that each metal halide bulb has a lifespan of 2000 hours the cost of bulbs and staff time for the lifetime of the light source (12 years of normal use) is almost double the cost of a new LED light source (Table 3). In fact, after less than 7 bulb changes ($5,636) an upgrade to the LED light source would fully cover the purchase cost for a new LED light source ($5,000). Seven bulb changes amounts to 14,000 hours of time, and considering the functional unit of:

"providing light for 8 hours/day, 5 days a week, 52 weeks a year, for 12 years" , after 14,000 hours of use that would be approximately 6.7 years.

When purchasing a new light source the LED is the best option.

7. Social Impact

Another important aspect that needs to be considered with regards to the microscopes is the social impact. In evaluating the social impact, it is important to consider the countries where components of the microscope are manufactured as well as the suppliers to those plants. As it was not possible to obtain specific information about suppliers and countries of manufacture, it is hard to determine what social impacts on the communities of manufacture are. Other social impacts include potential impacts on communities where mercury is discarded or communities that are near production facilities of electricity in China.

There are many positive social impacts of a transition program from metal halide microscopes to LED microscopes. Firstly, it sets a good example to other universities as well as other centers that use microscopes. Secondly, the LED light source turns on and off when not in use taking measurements, which again sets a good example on campus on the importance of conserving electricity. All these factors are important to point out when educating students and staff on campus.

8. Limitations and Challenges

There were several limitations and challenges faced in this study. Firstly, some of the information regarding the material and mass of microscope components was considered confidential by Excelitas Technologies and their suppliers. Only information that was publically available could be used in the report. However, this information wasn't detailed enough for the purpose of this LCA, therefore many assumptions had to be made based on extrapolations from Osram and Zeiss data and literature.

Another limitation of the study was the software used. The Education version of the Gabi software was used which is limited in what data it includes. For example, some materials that were not available in the Education database had to be approximated by similar materials instead.

9. Conclusion

The solid state LED light source is a better choice than the metal halide light source for microscopes, as not only does it not contain mercury, but it also uses significantly less energy over its lifetime. They can also be set up to automatically turn on when the camera is acquiring the image. Solid state light sources can be turned on and off instantly, they last longer and reduce disposal and replacement costs as well as time lost by the staff performing bulb replacements.

The LED light source uses much less energy for manufacture and use over its life time. Although one LED light source has a higher manufacturing electricity requirement than one metal halide bulb, the fact that 12.5 metal halide bulbs are required over the lifetime of the unit means it requires more energy for manufacturing. Since the LED system only needs to be on a fraction of the time (during short 200-500 ms camera exposure times) the electrical consumption of the system is significantly lower than the values used here and much lower than the metal halide units. In principle, they could last much longer than the 25,000 hours since they are not in constant use whereas the metal halide units need to be left one for 8 hours per day and cannot be easily turned on and off.

In conclusion, the solid state light source is a better choice for reducing environmental impact as well as saving money and energy. Units should be purchased and metal halide units should be replaced.

References

1. "TRACI." GaBi Software. Web. <http://www.gabi-software.com/support/gabi/gabi-5-lcia-documentation/life-cycle-impact-assessment-lcia-methods/traci/>.
2. Bare, J.C., G.A. Norris, D.W. Pennington, and T. McKone (2003)
TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. Journal of Industrial Ecology 6(3), pp. 49-78.
<http://www.epa.gov/nrmrl/std/traci/traci.html>
3. Davidson, Michael W. "Fundamentals of Metal Halide Arc Lamps." Education in Microscopy and Digital Imaging. Web. <http://zeiss-campus.magnet.fsu.edu/articles/lightsources/metalhalide.html>.
4. Excelitas. (2016, 8 June). X-Cite® 120PC Q. Available: http://www.excelitas.com/Pages/Product/X-Cite-120PC-Q.aspx
5. "X-Cite 120 Replacement Lamp." Excelitas. Web. <http://www.excelitas.com/Pages/Product/X-Cite-120-Series-Lamp.aspx>
6. Excelitas. (2016, 8 June). X-Cite® 120LED. Available: http://www.excelitas.com/pages/product/X-Cite-120LED.aspx
7. "A Move Toward Mercury Free Microscopy." Sustainability at Harvard. 06 June 2013. Web. <http://green.harvard.edu/news/move-toward-mercury-free-microscopy>.
8. "Microscope." Encyclopedia.com. HighBeam Research, 01 Jan. 1998. Web. <http://www.encyclopedia.com/topic/Microscopes.aspx>.
9. POWERSTAR HQI-R. Osram, Web. <http://www.osram.com/osram_com/products/lamps/high-intensity-discharge-lamps/metal-halide-lamps-with-quartz-technology/powerstar-hqi-r/>.
10. Metal Halide Lamps. Osram. Web. <www.osram.gr/media/resource/HIRES/339014/3238365/metal-halide-lamps.pdf>.
11. Dietrich, Fromm. "Patent US6069456 - Metal Halide Lamp." Google Books. Web. May-June 2000. <https://www.google.com/patents/US6069456>.
12. "LCA of an LED lamp | Product Lifecycle Management | OSRAM", Osram.com, 2016. [Online]. Available: http://www.osram.com/osram_com/sustainability/environmental/product-lifecycle-management/lca-of-an-led-lamp. [Accessed: 01- Aug- 2016].
13. Davidson, Michael W. "Fundamentals of Light-Emitting Diodes." Education in Microscopy and Digital Imaging. Web. <http://zeiss-campus.magnet.fsu.edu/articles/lightsources/leds.html>
14. Material Declaration Sheet and RoHS Compliance Declaration. Osram, 27 June 2011. Web.<https://www.osram.com/media/resource/HIRES/333052/94307/osram-material-declaration-sheet_led.pdf>
15. Mubaid, Firas. Green Light Microscopy: A Sustainable Alternative in Modern Microscopy. Publication. McGill University Print. Electronic Switching and Power Consumption.