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BIOFUELS

Creating a social platform and upscaling a photobioreactor for the growth of a phototrophic microbial community at extreme alkaline conditions

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Preface

For the present research, I had the opportunity to be part of the Energy Bioengineering Group (EBG) at the University of Calgary – Canada. This could not have been possible without the support of my supervisor prof. Siegfried Vlaeminck of the Universiteit Antwerpen who generously offered his contact with prof. Marc Strous from the University of Calgary. It's because of his open mind and personal network that an international research could take place.

The present research was part of the Solar Biocells project, where prof. Marc Strous trusted me to be part of his team. Even though my study background was not a direct match with the subject, Marc Strous acknowledged my personal skillset as valuable to the team. I can't be more thankful for the trust and support that he and his team gave me. The people of EBG guided me throughout my research whilst still being able to own my work and allowing me to develop an individual perspective on the project. Because it was team work from the very first moment, I was able to conduct an interdisciplinary and valuable research in the bioenergy field.

I would also like to thank the experts who were involved in this research, on topics where I lacked knowledge. Prof. Bonnie Lee Shapiro from the University of Calgary warmly welcomed me several times at her office to provide me background information on educational and social research. Her knowledge and experience was part of the base of this research.

Also, I would like to acknowledge Myrsini Sakarika, PhD student at the University of Antwerp and Prof. Christine Sharp, Post-Doctoral fellow at the University of Calgary, as the second readers of this thesis. I am gratefully indebted to their valuable comments on this research.

Finally, I must express my very profound gratitude to my family and partner for providing me with unfailing support and continuous encouragement. Not only during the time of my stay in Canada, but throughout my years of study and the process of researching and writing this thesis. This accomplishment would not have been possible without them.

Thank you.
Daisy Rycquart

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Abstract

The present research focusses on algal technology within bioenergy and how an interdisciplinary approach could improve implementation in society. Questions that arise are: Is there a social platform for biogas and algae to be created with an educational perspective? Do children learn more from hands-on techniques while researchers educate about biofuels in general? And how does a photobioreactor (PBR) need to be designed in order to be user friendly for children but still functional as the laboratory technology?

All these answers are provided in the present research that is conducted at the University of Calgary. First, an educational PBR is designed and manufactured based on the specifications of the already existing laboratory PBR. The biomass production of the educational PBR was compared with the known biomass production rates of the laboratory PBR. Although the educational PBR was designed to be more user friendly, it also yielded 42,44% more biomass production compared to the laboratory PBR. Future research could reveal if the new design and additional features were responsible for this.

Second, the educational PBR is implemented in an elementary school as a pilot project called ‘Fixing the Atmosphere’, where observations on the amount of awareness and knowledge were made on children ranging 10-12 years. The pilot project took place during 3 weeks in which the class was visited twice a week in order to explain and teach about the Solar Biocells technology. As part of the teaching, the children were able to actively grow and harvest the algae to give them a scientific experience. This awareness and knowledge is where the present research is focused on as it has the possibility to become a platform and potentially implement biofuels in general.

From the observed data, it appeared that the most valued aspect of the pilot project was clearly the appearance of scientists in the classrooms. Second, the videos, microscopes and information about algae was highly appreciated to make the project to a success. The research also revealed that there is lack of knowledge and awareness with children from this age on biofuels and the impact of fossil fuels. In summary, the pilot project ‘Fixing the Atmosphere’ was a success as it added value in the classroom and children had the opportunity to learn and gain knowledge on sustainable alternatives that make part of their future.

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List of abbreviations

BECCS	Bioenergy with carbon capture and storage
BECCU	Bioenergy with carbon capture and utilization
GHG	Greenhouse gases
LOI	Loss of ignition
PBR	Photobioreactor
RPi	Raspberry Pi
SAIT	Southern Alberta institution of technology

1 Introduction

1.1 The anthropocene

For the first time in geological history, humanity has been able to observe and be part of the processes that potentially may signal a change from a preceding to succeeding epoch (Waters et al., 2014). Pointing out examples of direct and indirect anthropogenic influences as agriculture, energy industry, transport, human overpopulation… it became clear that human impact over the last decades is undeniable and consequences are unavoidable. Therefore, it is no surprise that the '*Anthropocene*' was first proposed by Crutzen & Stoermer (2000) as a stratigraphical unit. Although it hasn't been officially stated as an official term to emphasise a new epoch, there are different aspects to support this consideration, at least according to (Waters et al. (2014).

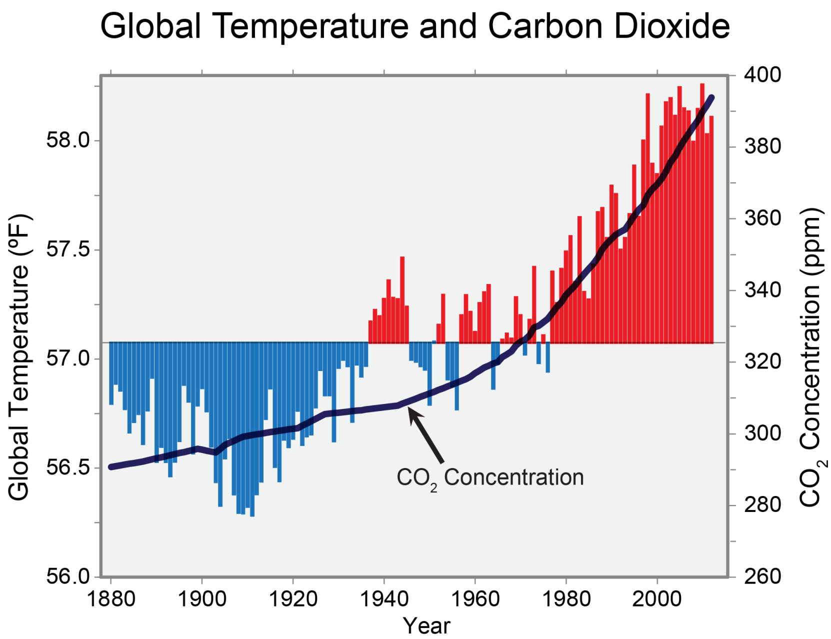

Figure 1 Global annual average temperature (as measured over both land and oceans) has increased by more than 0,8°C (1,5°F) since 1880 (Karl et al., 2009)

There's increasing realization that anthropogenic impacts such as resource consumption, will have long-standing consequences at global level. Strain on ecological systems and natural biogeochemical cycles that support human life, are already occurring (Zaimes et al., 2015). The impact is clear, looking at the second half of the 20th century for example, where anthropogenic resource degradation and overconsumption of natural capital have changed ecosystems more rapidly and extensively than in any comparable period in human history (Sarukhan et al., 2005). Depleting resources such as fossil fuels, comes with the emission of greenhouse gases (GHG) and changes in climate on the global scale. The atmospheric CO_2 levels for example, shown in Figure 1, are exponentially rising which results in an increased global average temperature. The energy sector is by far the largest anthropogenic source of

GHG emissions coming primarily from the combustion of fossil fuels (WEO, 2016). As seen in Figure 2, the energy generation from fossil fuels is responsible for about 68% of the total worldwide anthropogenic greenhouse gas emissions in 2016 (IEA, 2017).

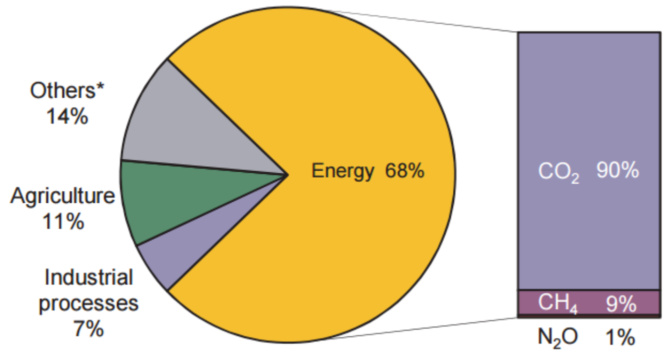

Figure 2 Estimated shares of global anthropogenic GHG (IEA 2016)

This climate change is predicted to cause widespread damage unless our carbon dioxide emissions are reduced well below current levels (Solomon et al., 2007). Vulnerable areas are facing the adversely effects from climate change by rising temperature and sea levels (Day & Day, 2017). Another example of the consequences is Australia, who faces severe impacts to agricultural production, natural-resource based tourism and water supply because of resource depletion (Garnaut, 2011).

Knowing energy production and use is the most important source of air pollution, coming from human activity, several transitions are currently in progress. Research and development has been made the past decades, which resulted in a range of different renewable technologies. Alternative and clean sources of energy are currently available, for instance: solar, hydroelectric, wind and bio-fuels such as bio-diesel and bio-ethanol from energy crops, agricultural waste or microalgae. However, it can not be overseen that none of these alternatives have so far been able to produce sufficient energy to provide a complete substitute for fossil fuels (Chisti, 2007; Schenk et al., 2008). As Dale & Ong (2014) describe, it could be essential to implement large-scale bioenergy systems with near zero or negative GHG emissions to ensure a sustainable energy supply in the future.

There is a need for further research within the current available technologies, to offer a complete and sustainable substitute for fossil fuels. Therefore, the present research is focussing on an application of one of the most promising carbon mitigation strategies, which is bioenergy with carbon capture and storage (BECCS) (Chase et al., 2003). Current BECCS strategies focus on plants and their use of photosynthesis to capture and convert CO_2. The organic matter is thereafter burned in power plants, stripping the resultant CO_2 from the waste gas and storage via CO_2 injection into geological formations (Gough C, 2011). However, only relying on BECCS at the required scale would have vast ecological consequences, risk inflating food prices and create a carbon debt (Newbold et al., 2015). But there are different approaches on BECCS, such as the use of algal cultures which use the same photosynthetic mechanism as plants. The idea is the same, capturing CO_2 and converting it into biomass and O_2, but there are interesting aspects to consider compared to the implementations of BECCS.

A fresh perspective on the use of microalgae developed by the University of Calgary, which uses microalgae to mitigate CO_2 emissions and transfer them in affordable climate neutral fuels, is used in the present research. The difference with BECCS is the aim for carbon capture and utilization (BECCU), instead of carbon capture and storage. The main benefits of this specific technology are the competitiveness due to the low costs and the high conversion rate of CO_2 and H_2O to biomass and O_2. Currently there is an ongoing project called Solar Biocells within the university where this technology is proven at lab scale. The present research will focus on the first steps towards upscaling, by designing and manufacturing an educational photobioreactor (PBR) on one hand. On the other hand, a method is created towards implementation of the technology in society by creating a social platform with an educational approach.

1.2 Research overview

The following chapters will take the reader into the topic of microalgae and their benefits, as well as their downsides. The existing technologies and ongoing trends are explained in the chapter 'Theoretical Framework'. It is at this stage where the innovative perspective of the University of Calgary comes in, and how this new technology may overcome the challenges of algal technologies.
After the Theoretical Framework, the 'Interdisciplinary and Social Framework' will explain how this research contributes to society. The impact of environmental problems will be framed in the educational approach, where reversed intergenerational education is the base towards finding a long-term sustainable solution.
The 'Problem Statements and Identification' is the fourth chapter in this research, where two main research questions are presented. These will be approached with the tools described in the fifth chapter 'Methods'. The outcome will be discussed in 'Results and Discussion'. An overview of all the results and the answer on the research question will be the final part of this research and are presented in the chapter 'Conclusion'. Any supporting materials can be found in the chapter 11 Appendix. An overview of the overall structure that is presented in this research can be found in Table 1.

Table 1 Research overview

1. Introduction
2. Theoretical Framework
3. Interdisciplinary and Social Framework

4. Problem statement and identification

5. Methods

5. Results and Discussion

6. Conclusion

7. Recommendations

2 Theoretical framework

This chapter provides the essential theoretical background of microalgal technology for the present research. It consists of three main sections, first: a broad introduction to microalgae and the existing technology. Second: an in-depth analysis of the new perspective on the innovative microalgal use in high alkaline and high pH conditions. Third: an introduction towards the Solar Biocells project that is currently under development at the University of Calgary.

2.1 Existing microalgal technology

Continuing into BECCU, an innovative perspective can generate biomass using phototrophic microorganisms (Sharp et al., 2017). Among several advanced biofuel options, unicellular microalgae are considered as a promising feedstock to generate biomass. Microalgae are eukaryotic single-cell algae (5-50 µm) and oxygenic photosynthetic bacteria, such as cyanobacteria, which grow in salt or fresh water (Richmond, 2004; Zamalloa et al., 2011). Even though cyanobacteria are formally not microalgae, they are commonly included under this category. In terms of massive production, microalgae can also be seen as photosynthetic cell factories who are able to convert sunlight, carbon dioxide and organic compounds into biomass like any other plant. Biomass can thereafter be converted into biofuels, such as biogas for example (Chisti, 2007; Zamalloa et al., 2011).

Microalgal biomass has several advantages over conventional energy crops. The first major benefit of microalgae species is that they have projected biomass per area production rates that are relatively higher than conventional biofuel feedstock (Mata et al., 2010). This is a result of the increased photosynthetic efficiency that microalgae possess compared to terrestrial energy crops (Chisti, 2007). The second benefit is that the land area needed to cultivate microalgae can be degraded or unproductive, which decreases the competition of land for human food crops (Acién et al., 2012). Furthermore, the algae do not require herbicides or pesticides like terrestrial crops. Lastly, microalgae use less water than terrestrial crops and freshwater use can be reduced even more by using brackish or waste water for some species (Handler et al., 2012; Rodolfi et al., 2009).
However, there are several downsides as well of using microalgal technologies: low CO_2 absorption rates, low volumetric productivities, and inefficient downstream processing. These downsides currently cause microalgal biotechnology to be highly energy intensive, expensive, and not economically competitive for energy production compared with fossil fuels (Acién et al., 2012). The main reasons for these downsides are:

1 To provide a continue carbon source for autotrophic algae, CO_2 must be added to the aquatic media where the algae grow. Operational costs are high due to the energy requirements of bubbling gas containing carbon dioxide through the media which makes the growth process expensive (Sharp et al., 2017).

2 Apart from high costs, algal biotechnology also struggles with a lack of robustness. Current algal systems usually focus on the axenic cultivation of a single strain, such as *Spirulina*, *Nannochloropsis*, *Chlorella* or *Dunaliella*. However, at large scale, aseptic conditions are difficult or expensive to maintain and avoid natural processes such as contamination by other algae species, decimation by grazers, fungi and/or viral infection. These ecological processes cause instability within the algal system and make developments on large scale inefficient (Quinn et al., 2012; Oswald, 1980; Cauchie et al., 1995).

2.2 A new perspective on microalgae and biofuels

2.2.1 Solar Biocells

To become an affordable and sustainable technology, competitive within the current energy sector, the University of Calgary has done further research towards the applications of microalgae. As part of the research group within the geoscience department, the Solar Biocells project was set up. This project focuses on the use of microalgal cultivation at highly alkaline and high pH conditions. Daelman, et al. (2016) state the base of this research: "*Both growth of algae and anaerobic digestion of organic matter are known to occur in nature at high pH and high salinity*". It is also known that soda lakes are saline lakes, due to the high concentration of sodium carbonates, and that these natural ecosystems are among the most productive in the world (Melack, 1981). Since several studies of alkaline soda lakes have clearly shown that both microalgae and cyanobacteria are highly active, the Solar Biocells project focuses on the application of it on a large scale. So far, research and development has improved this technology, taking care of the two main downsides mentioned before. The solutions to eliminate the downsides and improve the overall technology are:

1. Using high pH and high alkaline conditions, the CO_2 solubility in the aquatic medium improves and uncouples CO_2 absorption and biological uptake. This directly leads to lower energy requirements and costs compared to the current algae systems (Daelman et al., 2016; Chi et al., 2014; Canon-Rubio et al., 2016). Since haloalkaliphillic eukaryotic algae and cyanobacteria can use bicarbonate instead of CO_2 as a carbon source, the use of these alkaline and high pH conditions match with the growth requirements (Kupriyanova et al., 2015).
2. Using a mixed microbial community instead of axenic strains, there is no need for aseptic conditions. This is because of the same ecological reasons as mentioned before, where a mixed

community collaborates and improves the robustness. In this mixed community, the predominant cyanobacteria (>60%) are represented by *Phormidium Kuetzingianum*, shown in Figure 3 (Sharp et al., 2017).

Figure 3 Fluorescent microscopy image of predominant cyanobacteria *Phormidium Kuetzingianum* (100µm)

So far, the Solar Biocells project has been able to live up to these expectations. As these improvements have a strong effect on the costs, this technology may become competitive with fossil fuels in general. An overview of these cost-effects can be found in Figure 4, where the economic improvements can be observed and compared with other existing algae-systems. The 'Alkaline System 2015' is the one used in the present research, and the 'Open Pond', 'Tubular BR' and 'Flat Panel PBR' are the main systems currently used in existing algal biotechnology. These main algal systems are cultivated with axenic strains and at low alkalinity and near neutral pH (Canon-Rubio et al., 2016).

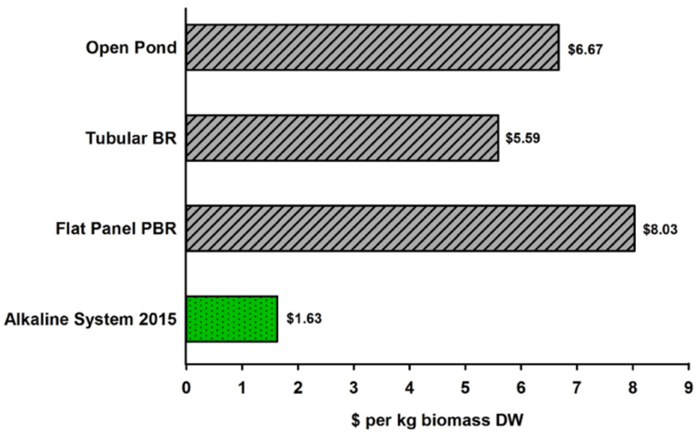

Figure 4 Use of highly alkaline conditions to improve cost effectiveness of algal biotechnology (Canon-Rubio et al., 2016)

2.2.2 Laboratory PBR

Since the design of the educational PBR is based on the laboratory PBR, all the main specifications from Sharp (2017) are listed in this section. The laboratory PBR is based on a flat panel PBR, with acrylic vessels and an illuminated surface area of 197.5 cm^2 and an inner volume of 69.1 cm^3. The geometry of these flat panel bioreactors was designed to provide a more even distribution of the medium flow. The walls of the PBR contain thin grooves, which enables part of the microalgae to evade harvesting, leading to effective regrowth after each harvest. A schematic representation of the laboratory PBR can be found in Figure 5

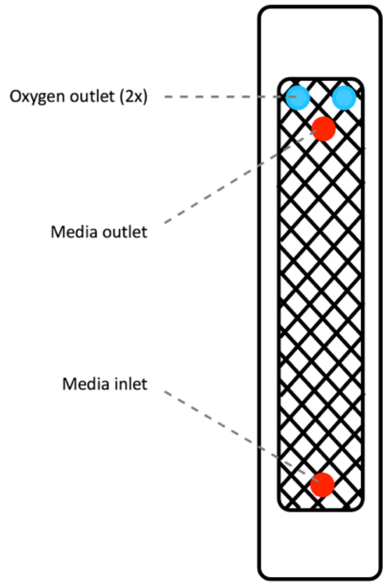

Figure 5 Schematic presentation of the laboratory PBR unit with descriptions

Each PBR is fed with a high pH, high alkalinity medium (pH 9; 0.5 mol L^{-1} dissolved carbonate) and inoculated individually with microbial mats from four soda lakes located in Canada. The soda lakes where the mats were collected are located in British Columbia: Last Chance Lake, Probe Lake, Deer Lake, Goodenough Lake.

2.2.3 Educational project 'Fixing the Atmosphere'

In extend of the Solar Biocells developments, a side project called '*Fixing the Atmosphere*' was introduced in February 2017 as part of the present research. This educational approach on the application of microalgae as a sustainable alternative energy source was introduced to provide social support besides the technical developments. It also contributes to the improvement of education about climate change in general, which Dr. Bonnie Lee Shapiro states to be something that educational institutions and governments worldwide are striving to.

The Fixing the Atmosphere project presents the design of a collaboration between university scientists and elementary school classrooms to gain more knowledge and awareness about the algal technology. As described, research and development have led to a new, cost-effective process for algal growth involving a growing procedure which can be readily performed by elementary school children. To gain a better understandings of climate change and biofuels, children will work with materials like those in the university research project, but specifically designed for use in elementary classrooms. Children will contribute in capturing atmospheric CO_2 from the air using the microalgae in high alkaline and high pH conditions, collected from soda lakes. They will convert the captured CO_2 into algal biomass, as mentioned before. One of the goals of the Solar Biocells project is to convert biomass into biogas. Children will not convert biomass into biogas but engage in another important aspect of the research, the process of capturing CO_2 from the air and growing biomass. Using the same unique algae as in the laboratory, children are part of the research and place in onto an accessible and hands-on educational PBR. Children will be able to control different variables using a raspberry pi (RPi), and test which conditions improve the growth rate of the algae. They will send the data to the website called www.fixingtheatmosphere.com to show how the experiment is proceeding and ultimately, share it with other classrooms participating from all over the world.

The present research focuses on the design and development of an educational PBR, based on the laboratory PBR specifications. It also contributes in the results of the first pilot project of Fixing the Atmosphere in an elementary school. The pilot project lasted for 3 weeks, where social observations were made while children and scientists were working and interacting with the PBR.

2.2.4 Downstream processing

After growing and harvesting the microalgae, the downstream processing is the next step in carbon capture and utilization. There are several options to use microalgal biomass, where one option could be conservation, referring to carbon capture and storage. But other, more useful, applications are possible as shown in Figure 6. The downstream process used in the Solar Biocells project is anaerobic digestion, marked in red in Figure 6. Microalgae share with terrestrial crops the quality that their conversion to biogas by anaerobic digestion can be performed without net production of greenhouse gas due to the capture of CO_2 with photosynthesis. When biogas is burned, the CO_2 during combustion is taken from the atmosphere again (Zamalloa et al., 2011). But, the downstream product created with the Solar Biocells project differs since the application of anaerobic digestion produces nearly pure methane (CH_4) instead of biogas. This is a result of the fixed carbon in the alkaline medium as sodium bicarbonate, and therefore stays in solution of the aquatic medium.

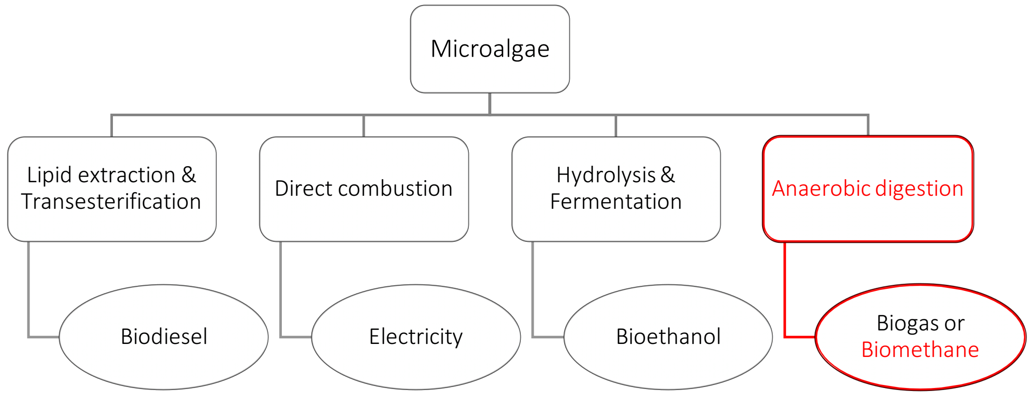

Figure 6 Downstream processing options for microalgal biomass (Figure modified from Solar Biocells presentation by Christine Sharp)

As the present research is only focussing on the first stage of the microalgae-biofuel technology, marked in red in Figure 7, there will be no further research towards the applications of anaerobic digestion. This first stage is the stage of growing the algae in a PBR and harvesting the biomass. At this moment, the Solar Biocells project has a fully functional lab-scale unit that produces algal biomass 24/7. The present research continues on how the PBR is designed and introduced in the classrooms.

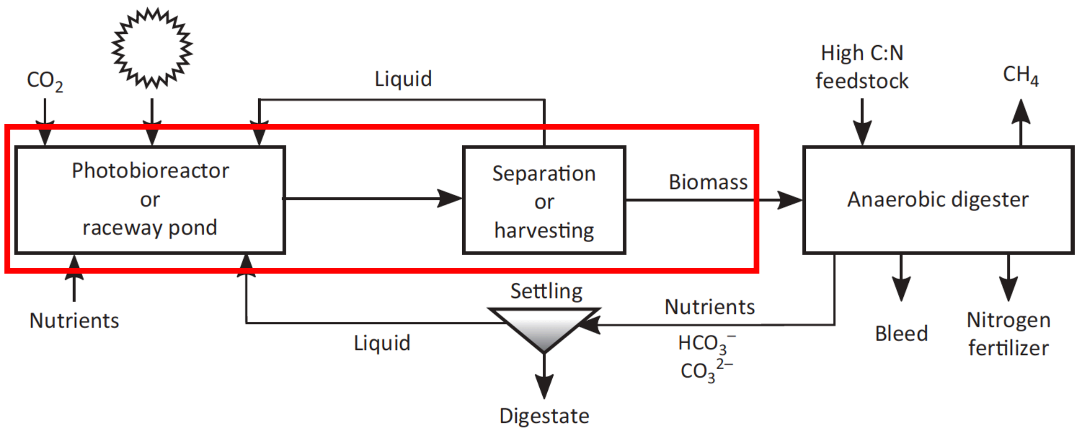

Figure 7 Scheme of the total algal biofuel process (Daelman et al., 2016)

3 Interdisciplinary and social framework

Environmental problems are multifaceted as is the concept of sustainability, based on the three known pillars shown in Figure 8. In this perspective, biofuels could offer a sustainable alternative for fossil fuels, yet the growth of terrestrial energy crops still has adverse effects with environmental and socioeconomic consequences (Daelman et al., 2016). Sustainability is based on three pillars where sustainable development is: “meeting the needs of the present without compromising the ability of future generations to meet their own needs” to quote the Brundtland Report (UN, 1987).

Looking at the development of biofuels as a potentially sustainable and cleaner replacement for conventional fuels, there is a unique challenge for the chemical industry that requires simultaneous consideration of economic, social and ecological aspects and therefore serves as an excellent example of multifaceted environmental problems (Zaimes et al., 2015). Zaimes, et al. (2015) also mentions the importance of joint consideration of economic, environmental, and social factors for designing sustainable biofuels that span multiple scales intra- and intergenerational. Solar Biocells is an example of a project that aims to solve environmental problems while interacting with the social and economic aspects.

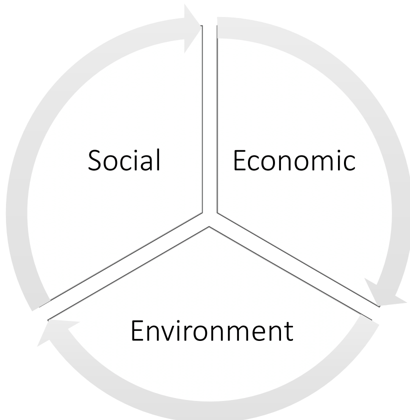

Figure 8 Schematic view on sustainability based on three pillars by the Brundtland report (UN,1987)

In order to not end up in the same situation we are currently facing with fossil energy, it is important to develop bioenergy systems that are sustainable, which are systems that can reasonably expect to operate indefinitely. This definition inherently includes the need to maintain the conditions of the surrounding ecosystem and human society in such way, the system persists. It also assumes that production facilities will be able to be upgraded or replaced as they depreciate. However, this definition is in marked contrast to current fossil energy systems, which because of excessive outputs, certainly cannot be expected to operate indefinitely (Dale & Ong, 2014). One approach to substitute the current energy system is the use of bioenergy. To do so, sustainable bioenergy systems will need to focus on key design objectives related to economic, social and environmental performances over the very long term to satisfy. This indicates the need for an interdisciplinary research approximation.

A first approach on interdisciplinary research is to include technical improvements next to social developments. In the present research, those two aspects were woven together by focussing on upscaling the current technology developed by the University of Calgary and on the implementation of this technology in society with the educational project.
Murphy & Hall (2011) mention that the economic growth and social development of human societies is completely depended on energy use. As our entire society is based on polluting energy sources, a potential solution might be biofuels as a substitute of fossil fuels (Dale & Ong, 2014). Developing a technology to become sustainable is one step, but integrating this technology into society is equally important. Therefore, the present research provides a new perspective on integration, by using reverse intergenerational education to create a social platform for biofuels in general.

Traditional intergenerational education is known to have the younger inexperienced individual learning from the older more experienced one (Cozzi, 1998). This is recognisable all the way through the social practices of humans from the family, to schools, through social activities of clubs and societies and into the workplace (Tempest, 2003). But, reverse intergenerational education is a process where a young person is using their knowledge of technology to teach or learn a more senior individual in its uses (Pyle, 2005), which is the base of the educational project in the present research. As Baily (2009) states: "*There is a growing realisation that technology can be used to bridge the gap between young and old using reverse mentoring*". Approaching the bioenergy technology by educating the younger generation about it, therefore might be a major step towards integration.

By providing an educational package, containing a unique designed PBR, the kids have a hands-on project to work with in classrooms. It is important at this point to acknowledge the "*fundamental difference between training and learning*" as Craig (2001) mentions. Training tends to focus on skills acquisition, where learning has a wider connection and link into the development of knowledge. Therefore, creating an environment where children get to work with this innovative project and learn about it at the same time could generate awareness and knowledge among younger generations. This might support the integration of the microalgal technology in society. It is also said that the younger generation is the future, but in today's rapidly changing world, youth is the present (Pyle, 2005). Triggering the youth at this stage of innovation might therefore be essential to make a difference in social developments and existing infrastructures.

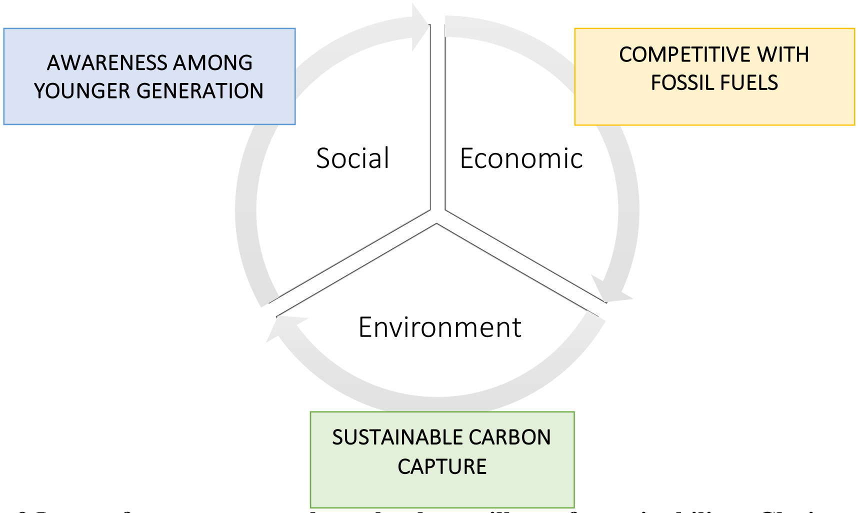

Figure 9 Input of present research on the three pillars of sustainability - Closing the loop

With this educational approach, the present research is providing an interdisciplinary perspective to close the loop of sustainability, shown in Figure 9. The base of the first pillar, **environment**, is provided by the developments of sustainable biofuels, creating room for environmentally friendly energy use in the future. This is done by the capture and conversion of excessive carbon dioxide in the atmosphere by microalgae, while the biomass could again be converted into biofuels. The second pillar, **economic,** is provided with the use of highly alkaline and high pH conditions, which creates high productivity and growth rates. It makes the technology economically feasible whereby this biofuel could become competitive within the current fossil fuel-based market. And lastly, the third pillar, **social**, is included in this research by focussing on the younger generation with an educational project called: Fixing the Atmosphere. Children will be working the easy and innovative technology, and learn about its benefits. The gained awareness and knowledge could subsequently be transferred to the older generation called: reversed intergenerational education. Developing a social platform that supports the use of this sustainable technology, and other sustainable applications in general, is the first step towards integration.

4 Problem statement and identification

As described before, the production of biofuels is not a new topic. To determine whether the use of these microalgae as a biofuel could become profitable, there are more aspects to consider beside the technical developments. To create a social platform where sustainable biofuels can increase its market share in society, a window of opportunity is essential. The present research is developing an educational PBR for the high alkalinity and pH microalgal system in the first phase. The second phase is the pilot project Fixing the Atmosphere, where the introduction of the educational PBR in an elementary school takes place. As the present research will review how this educational approach might become useful in implementing the technology in society, observations are made. The knowledge of scientists will be merged with the output that the children give during the pilot project. This is where the interdisciplinary influence of the present research is given. The main research question in this paper therefore is:

"How can an interdisciplinary approach be beneficiary for the implementation of biofuels in society by introducing the photobioreactor in elementary schools?"

To answer this research question, a sub question is used:

1. *Is there improved awareness and knowledge on climate change and the positive impact of biofuels among the children who worked with the educational package?*

The educational project Fixing the Atmosphere is currently a side project of the Solar Biocells project, where the focus is commercializing the biofuels into the market. Introducing the PBR in elementary schools contains more potency than just reviewing the social aspects since designing and building the educational PBR is also a step towards upscaling. As the process is now fully functional at lab scale, it is interesting to see how the biomass production will be influenced by the growth in the redesigned PBR. Therefore, there is a second research question that will be answered in this paper:

"What are the results of upscaling the photobioreactor on the productivity-rate of the algae compared to the lab-scale unit?"

The method to form an answer to these research questions will be an overview of the developing process during 4 months of research. In this period, the design and manufacturing of the educational PBR took place, as well as the practical developments and introduction of the educational project Fixing the Atmosphere itself. The research objective for each research question can be found in chapter 5 Methods, where the outcome of the project is presented in chapter 6 Results. The final answers on the research questions above are described in chapter 8 Conclusion.

5 Methodology

This chapter addresses the methods towards finding an answer on the research questions from chapter 4. The methodology follows a chronologic structure on how the research was done. The first phase is the upscaling of the PBR since the designing and fabrication of this PBR was done before it was introduced in classrooms. The second phase is an overview of developing the educational package and how observation were made with Fixing the Atmosphere during the pilot project in classrooms for three weeks. All calculations made in this chapter can be found in chapter 11.1.

5.1 Educational PBR

5.1.1 Research objective

To provide an answer on the following research question: *"What are the results of upscaling the photobioreactor on the productivity-rate of the algae compared to the lab-scale unit"*, the productivity results of the lab-scale PBR are compared with the educational PBR. The scope of this research is not to improve the productivity by upscaling the PBR, but to deliver a child friendly and complete educational package for elementary schools. But, comparing the productivity of the lab-scale PBR and the upscaled PBR will provide useful information about the conditions the algae prefer and if adjustments could be made in the future.

5.1.2 Educational PBR

Developing a complete educational package, where children capture CO_2 and convert it into biomass and O_2 and biomass, creating an educational PBR was the first phase of the present research. A new design was made where the focus was to create an inexpensive, child-friendly and interactive project. The timeline of the manufacturing process can be seen in Figure 10.

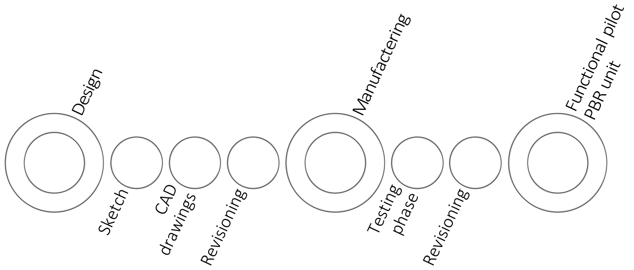

Figure 10 Timeline of the manufacturing process of the educational PBR

Specific sensors where bought or designed to provide a tool of measurement for the variables mentioned before. Besides collecting the required information, an addition to the laboratory PBR was to make the data available for everyone to see. Therefore, a website was designed where the data could be streamed to called: www.fixingtheatmosphere.com. Using a RPi, it was programmed to collect the data from the connected sensors and transfer it wireless to the website.

5.1.2.1 Design of the educational PBR

The sketch and design was created by Karen Canon-Rubio and myself. Since the educational PBR was based on the laboratory PBR, as much of the specifications as possible were adopted. Therefore, the educational PBR was designed in the same acrylic material, the grooves were applied and the inlet and outlet ports were copied from the laboratory PBR specifications. This educational PBR is not designed to receive the highest productivity, but to gain the most experience with children while still having an independent functional algal producing reactor. For that reason, not all specifications of the laboratory PBR were adopted and adjustments have been made:

The first change is **the size** of the PBR, chosen with the '*golden ratio*' 1:1,61 in mind. Being 40 cm wide, 65 cm high and 1,3 cm depth it has an eye-pleasing effect. The biomass chamber has an illuminated surface of 1.700 cm^2 and an inner volume of 595 cm^3. As the laboratory PBR was air tight using a rubber band and screws, this was not a feasible option for children to harvest the algal biomass. The laboratory PBR had to be completely unscrewed each time to harvest the biomass.

To provide a hands-on and easy process in classrooms, the second adjustment was a **lid on top of the PBR** where paper clamps and a rubber band were used to close the PBR. To make inoculating and harvesting easy, a thin plastic **mesh** was used in the biomass chamber. The microalgae could easily attach on the grid and removed afterwards by the children.

Also, an **extra outlet port** was provided next to the media inlet port, so any remaining algae and media could be removed easily if necessaire. Finally, the biomass chamber of the PBR was designed in a **corner of 15° at the bottom** of the chamber. This choice was made to ensure that the microalgae would not stay in the corners but slide down after with gravity towards the extra outlet port in the lower corner of the chamber.

A sketch of the design is presented in Figure 11 (note: grooves are not visible on this sketch). After finishing the sketch, a final CAD-design was made by the Southern Alberta Institute of Technology (SAIT) for manufacturing and can be found in chapter 11.2.

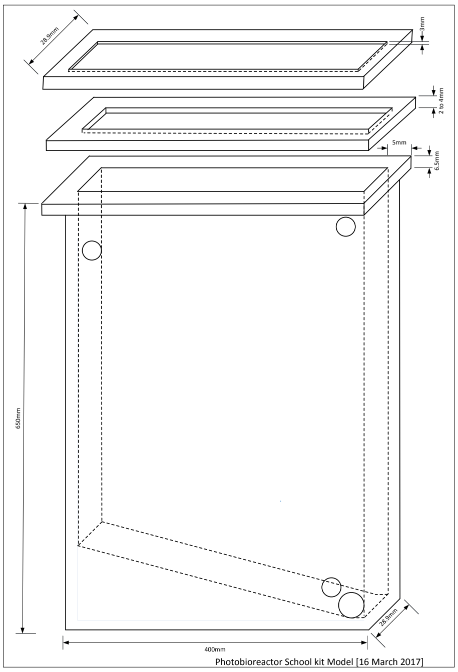

Figure 11 Sketch of the educational PBR

5.1.2.2 Specifications and variables

The following variables are selected as they provide information about the growth rate of the algal biomass:

1. Temperature (°C)
2. Light intensity (µmol photon m^{-2} day^{-1})
3. pH

Temperature may range between 15°C and 35°C for optimal growth. Temperatures below 15°C may reduce microbial activity, while above 35°C can be lethal for culture survival under phototrophic conditions (Sharp et al., 2017).

Since the **light conditions** have an effect of the growth conditions, shown in Figure 12 expressed by the O_2 production, the light intensity is controlled. Photobioreactors were grown under ambient red light conditions with a 16:8 h light:dark photoperiod. The red light is selected because of previous laboratory experiments where biofilms grown under red light (590-656 nm) showed highest productivity rates. This is measured by the amount of oxygen production and can be seen in Figure 13, where the experiment was done with three different light spectrums (Sharp et al., 2017).

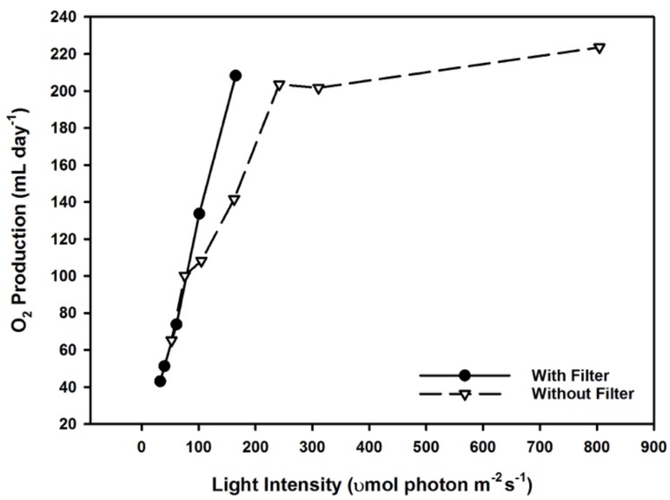

Figure 12 Light intensity experiment on the effects of growth conditions (Sharp, 2016; unpublished)

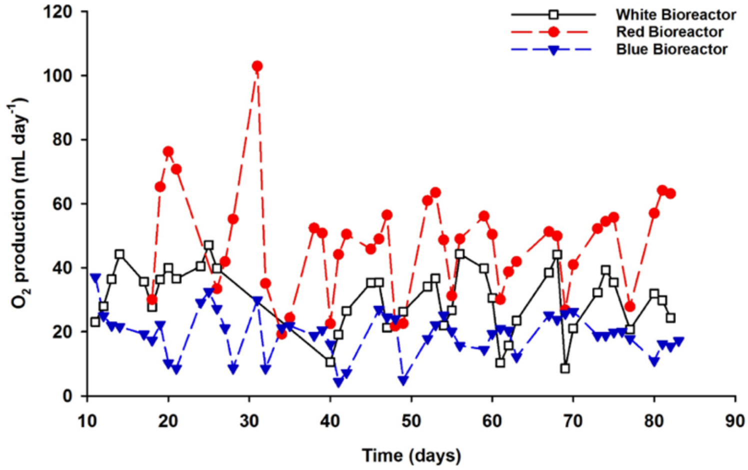

Figure 13 Comparison of different light spectrums on the effect of the algal growth rate (Sharp et al., 2017)

The **pH** of the media flowing through the PBR provides information about the amount of dissolved inorganic carbon, where the alkalinity represents the buffer capacity of the medium. As mentioned before, alkalinity has a significant effect in the equilibrium concentration of CO_2 in the gas. As the carbon dioxide gas present in the gas is absorbed into the aqueous medium, CO_2 reacts with water or hydroxide ions to form carbonate and bicarbonate ions. The reason for this improvement is because of the HCO_3^- the algae can consume and convert it into CO_2 on their own. The effect that carbonate alkalinity has on the equilibrium of the CO_2/carbonate-bicarbonate system is shown in Figure 14. The further to the right the equilibrium line is in the graph, the higher the driving force or chemical potential will be to allow the transfer of CO_2 from the gas phase into the liquid phase (Canon-Rubio et al., 2016)

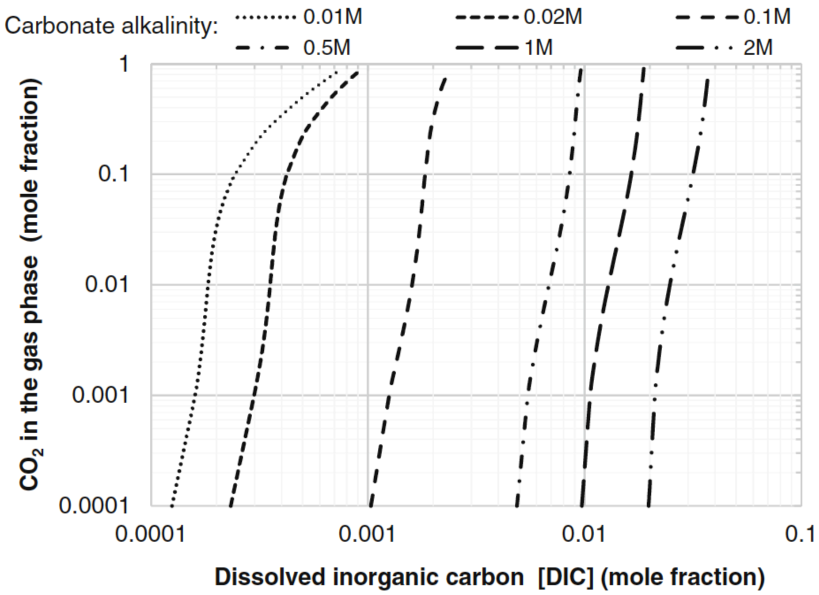

Figure 14 The effect of alkalinity on the equilibrium of CO2 / carbonate-bicarbonate systems at 25°C (Canon-Rubio, 2016)

The alkaline media provides the same carbon source but in a different form. The equations of the equilibrium reaction are presented below:

$$CO_2(g) \rightarrow CO_2(l) + H_2O \leftrightarrow H_2CO_3$$
$$H_2CO_3 \leftrightarrow HCO_3^{\;-}$$
$$HCO_3^{\;-} \leftrightarrow CO_3^{\;2-}$$

As these forms are represented in the media depending on the pH which, the right pH range must be chosen to make sure the correct carbon source is available for the microalgae. Since the microalgae consume HCO_3^-, the media needs to be at pH 9-10,5 to answer these demands, and therefore needs to be analysed.

5.1.2.3 Manufacturing

Using the final CAD-design, the PBR could be manufactured by the SAIT. To provide a complete educational package for the Fixing the Atmosphere pilot project, other systems had to relate to the educational PBR. These systems are the sensors connected to the RPi and the feeding stock of the algae. A complete overview of the process scheme can be found in Figure 15. The RPi coding was done externally by the SAIT in contribution with Karen Canon-Rubio and myself.

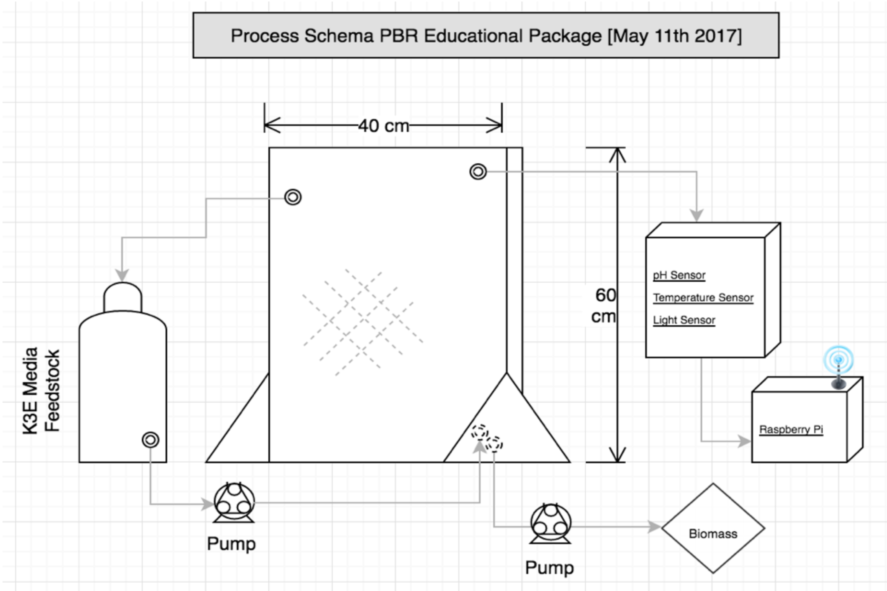

Figure 15 Process overview educational PBR –Fixing the Atmosphere hardware

All the detailed materials used to manufacture the PBR can are listed in Table 2. The materials are divided in three main sections: the PBR unit itself, the continuous external media feeding loop and the external RPi for measurements. Detailed specifications per section are listed after Table 2.

Table 2 Educational PBR detailed materials list

1. PBR (manufactured by the SAIT)	2. ALGAL FEEDSTOCK	3. RASPBERRY PI
Acrylic sheet ½-inch	Flexible Propene Tubing 1/8-inch	RPi 3th edition
Fittings	Clamps	Oxygen Sensor – Gas Flow Meter
Red Spectrum Filter (cellophane)	K3E Media (recipe can be found in Table 3)	Temperature Sensor
Algal Inoculum	Pump 12V (1-100mL/min range) with Speed Control and Power Switch	Light Intensity Sensor
LED Growing Lights	Plastic Box (Christine)	RPi case
Acrylic glue	Plug Timer	Wifi connector
Binder clips		pH Sensor
Rubber Sealing Ring		
Plastic mesh		

1. PBR

The PBR was made of ½-inch acrylic sheets. The sheets were cut with a waterjet machine and the grooves were bound with a laser with a depth of 1mm. After cutting and lasering, the sheets were glued together with acrylic glue and left to dry for 48 hours. The inlet and outlet ports were drilled and provided with a fitting for rubber 1/8-inch tubing. The lid of the PBR, manufactured of the same acrylic material, was clamped with binder clips and a rubber ring in between. This way the biomass chamber was air tight and still easy to access for the children. This was all done by the SAIT.

To make sure the algae had a second attaching point in the growing chamber, there was a removable plastic mesh presented in the PBR, as mentioned before. This ensured that the algal biomass could re-colonize the PBR after harvesting. An extra function that the mesh provided is the removable aspect. Harvesting the algal biomass was done by removing the entire mesh from the PBR and gently scraping the algae from the mesh into a container.

Making sure the algae grow in the most favourable light conditions, a red filter was provided in front of the PBR. This red cellophane sheet is used to filter the incoming light so the algae show better growth rates, as mentioned before (Sharp et al., 2017). The sheet was applied with Velcro straps, external on the PBR, so the media doesn't encounter the cellophane. Children could easily remove the sheet from the PBR and view the algal growth over time.

2. Algal feedstock

As the microalgae use carbon as a feedstock, and the growing conditions occur in high alkalinity and high pH, a specific media was prepared. This media provided all the carbon in the form of HCO_3^- and is produced to (over)flow through the PBR, using the media inlet at the bottom and media outlet port on top. The composition of the K3e Media can be found in Table 3.

Table 3 Composition of the algal feedstock: K3e Media for 1L

K3e MEDIA (pH 9 - 0,5 mol L^{-1} dissolved bicarbonate)	
$NaHCO_3$	42,5 g
K_2HPO_4	1 g
$MgSO_4.7H_2O$ (or $MgCl_2.6H_2O$)	246 mg
NH_4Cl	218 mg
Trace element solution (see chapter 11.3)	1 mL

To transport the feedstock from the media bottles to the biomass chamber in the PBR, ¼-inch rubber tubing was used and a 12V pump with speed control. The flow rate of the media used at laboratory-scale was 4 times the volume of the biomass chamber per 24 hours. For the educational PBR a flow rate of 2,4 L day^{-1} was required because of the internal volume (0,6 L). To maintain equal conditions, a flow rate of 1,7 mL min^{-1} was set. Since the minimum flow rate of the pump was 14,8 mL min^{-1}, a plug timer was set on connecting the pump for 7 minutes per hour, maintaining the hydraulic retention time of the process.

3. Raspberry-Pi

Besides a working PBR unit, there were variables that needed to be monitored during the growth process of the algae as mentioned before:

1. Temperature (°C) – outside the PBR
2. Light (µmol photon m^{-2} day^{-1}) – outside the PBR
3. pH - in the media

To monitor these variables, the required sensors were attached to the PBR and connected with the RPi. This RPi was programmed by the SAIT to receive the measurements of the sensors and transfers them to the www.fixingtheatmosphere.com website, all coding scripts can be found in chapter 11.4. By giving public access of the data, the children in the classrooms had a live view on what's happening in the PBR during the project. At the same time, it provided the researchers to follow up the growth of the algae, and making sure harvesting was done at the right moment as mentioned before.

5.1.3 Biomass production

To compare the biomass production of the laboratory PBR and the educational PBR, the amount of biomass produced by the educational PBR is determined. The method used for the present research is the direct estimation of organic matter by loss of ignition (LOI). LOI is used to determine the organic matter content (%OM) of a sample, in this case the algal biomass from the educational PBR. Calculating the %OM of the harvested biomass is done by the difference in weight before and after ignition of the sample, see equation below. The complete procedure can be found in chapter 11.5.

$$\%OM = \frac{\text{pre ignition weight (g)} - post\ ignition\ weight\ (g)}{pre\ ignition\ weight\ (g)} . 100$$

5.2 Fixing the atmosphere

Next to the design and manufacturing of the educational PBR, the Fixing the Atmosphere project required ethical approval and educational supporting materials which are explained in this chapter. After this preparation phase, the pilot project was introduced into an elementary school which was part of a school system in a large western Canadian city. The children working with the Fixing the Atmosphere project were part of a mixed grade 5-6 classroom and aged 10-12 years. During the project, the children got a practical experience of being a researcher and working with algae. At the same time the researchers collected information to analyse and integrate in future projects. A timeline of the developments for Fixing the Atmosphere (parallel with the manufacturing of the educational PBR is presented in Figure 16 below.

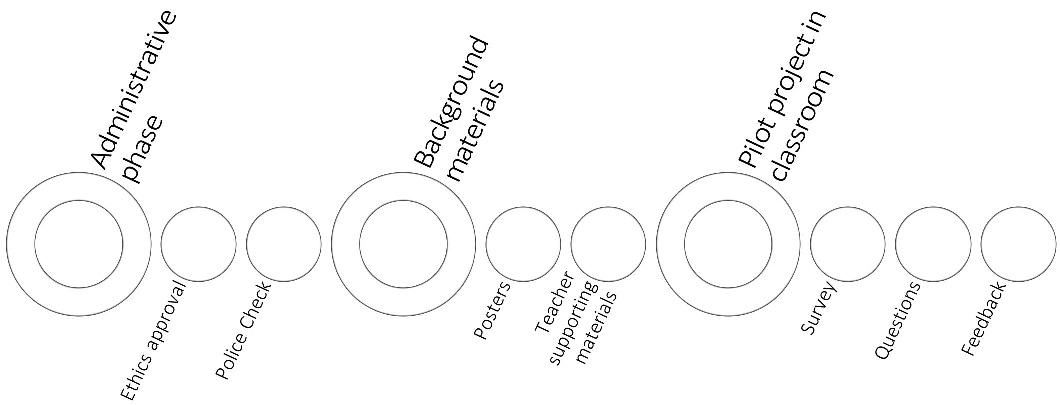

Figure 16 Timeline of the developments for the Fixing the Atmosphere pilot project

5.2.1 Research objective

To provide an answer on the research question: *"How can an interdisciplinary approach be beneficiary for the implementation of biofuels in society by introducing the photobioreactor in elementary schools?"*, the children in this pilot project were observed and a multi angled approach was used to give a substantiated conclusion.

The research objective for the supporting research question: "*Is there improved awareness and knowledge on climate change and the positive impact of biofuels among the children who worked with the educational package"*, contains an approach from three different angles. The three angles provided pillars to review and find an answer to this supporting research question.

The first pillar was a **survey**, developed by Dr. Bonnie Lee Shapiro, where the children were asked to answer questions to determine the conceptions that children had who were coming in to the project. It provided information about their ideas on algal systems and how they relate to topics such as: climate change, fossil fuels and biofuels. Since the raw survey data could not be used for the present research due to ethical conflicts, preliminary data of the survey was used instead. An example of the given survey can be found in chapter 11.6. Together with the insights from the survey, observation of the **questions the children ask** during the entire project was done. Depending on how much the children learn from working with 'Fixing the Atmosphere', the amount and characteristics of the questions might change over time, which contributes to the outcome of the survey. The final pillar used to form a substantiated conclusion with the other two pillars is oral and written **feedback**. The oral feedback consists of the answers to the question '*What did you like most of the pilot project Fixing the Atmosphere?*', while the written feedback is gained from post-its on supporting educational posters (paragraph 5.2.1.2). An overview of the research objective with the three pillars can be seen in Figure 15.

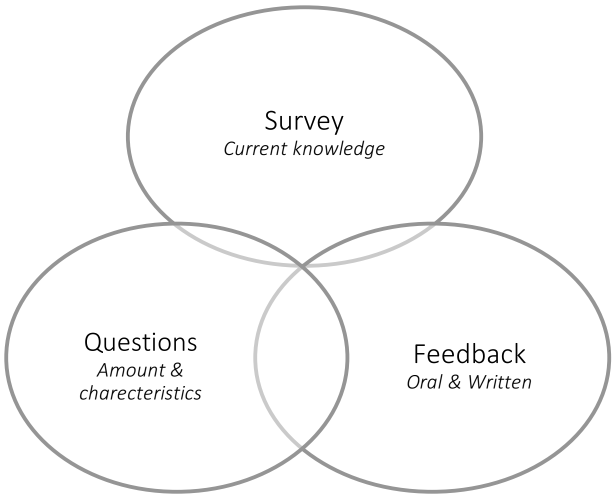

Figure 15 Research objective educational package 'Fixing the Atmosphere'

5.2.1.1 Administrative phase

Starting a scientific and educational project which is not part of the school's curriculum and involves research with living human participants, requires an approval by the governmental board of education and the university board itself. For this reason, the ethics application was prepared and submitted by Dr. Marc Strous and Dr. Bonnie Shapiro. Since this was a critical phase in the developing process of the educational package and effecting the present research in collecting and analyzing data, some examples from the ethics are given below:

1. "Research methods for this study involve: interviews, survey and questionnaires, observational research, materials created by participants."

2. “Collected data will not be transferred or made available to persons or agencies outside of the research team.”

It is because of this sensitive audience; raw data could not be used for the present research without violating with the ethics approval. Therefore, only observations and preliminary data is used to determine answers on the above-mentioned research questions. The complete ethics application and approval documents can be found in chapter **Fout! Verwijzingsbron niet gevonden.**.

Besides the ethics approval, a **police check** was required for all university staff and students working in the school where the pilot project was introduced. Working with children means working with a vulnerable community and therefore people who are not official school employee, but want to work with children, need a **police check**. An example of a police check is enclosed in chapter 11.7.

5.2.1.2 Background materials

Since the teachers received clear information about the project, there was also need for appropriate information for the children who worked with the PBR. Therefore, an **introductory presentation** and a set of **4 interactive and educative posters** were developed to support the Fixing the Atmosphere project. The presentation gives the children and teachers insight on the environmental problems that occur and how they could be part of the solution. This can be reviewed in chapter 11.8. The posters contained all the information about the PBR and accessories with background information on how the algae contribute in ‘fixing’ the atmosphere. The core of the posters was for them to be interactive and informative. This was realised by having a query each poster which did not refer to the information that was presented on that specific poster. To find the answer on the multiple-choice questions, the children had to search for another poster where the information could be found. Again, this new poster contained a query and the process repeats. This way the children were not just receiving information from a poster, but were part of a rotating and interactive quest. Finally, to learn from the children as well, a blank space was available on the bottom of each poster where children could leave their feedback/questions/comments on small post-its. The researchers received insight on how the children were thinking and what possibly could become better in future projects. A resize of the designed posters can be found in chapter 11.9.

5.2.1.3 Pilot project in classroom

After completing all the preparations, the Fixing the Atmosphere pilot project was introduced in the first classroom at the beginning of May 2017. Before the project could officially start, a first meeting with the classroom was required to share the letters of consent. This is where the researchers inform the children with the fact that a project started the next week and all children could participate. Since the Fixing the Atmosphere project was not part of the curriculum, children were not obligated to participate as mentioned before. Therefore, a letter of consent is given to the children for them and their parents, an example can be seen in chapter 11.10. After the researchers received ‘*green light*’, the project was officially started.

Since the pilot project was done over a total of three weeks, an overview of the practical class meetings and research topics are presented in Table 4. Detailed information about the real-time experience by the reseachers can be found in chapter 11.11.

Table 4 Fixing the Atmosphere pilot project timeline

Week 1 Introduction	Week 2 Follow up	Week 3 End of project
Survey (given by Dr. Bonnie Lee Shapiro)	Observing the questions	Interviews (lead by Dr. Bonnie Lee Shapiro)
Observing the questions	Microscopic view on the algae	Observing the questions
Introduction to 'Fixing the Atmosphere' with introductory presentation	Reviewing posters and video + Receiving feedback from posters on post-its	Final feedback from the children
Start of the PBR: first harvest of PBR and inoculating the PBR for regrowth	Chat talk with Dr. Marc Strous to provide background information about the developments of the project	Informative presentation about the anaerobic digestion of the algae and converting them into biofuels
	Harvest the algae from the PBR with the children	End of the PBR: clean up the PBR with the children and conclusion

6 Results and discussion

6.1 The photobioreactor

6.1.1 Comparison of laboratory PBR and educational PBR

As mentioned before, the goal of the educational PBR is not to become more productive than the laboratory PBR. Although the focus is to deliver a hands-on and independent functional unit which is pleasing for the eye and attractive for children to use, it is interesting to compare results of biomass productivity and see where differences are occurring with the laboratory PBR. An overview of the productivity results of both the laboratory PBR and the educational PBR can be found in Table 5.

Table 5 Comparison laboratory PBR biomass production (Sharp, 2017) with educational PBR biomass production from the present research

	LABORATORY PBR (SHARP, 2017)	EDUCATIONAL PBR: EXPERIMENTAL DATA
Inner volume PBR chamber (cm^3)	138,3	750,0
Illuminated surface area (cm^2)	197,5	1700,4
CO_2 consumption (mg day^{-1})	75,6	78,3
O_2 production (mL day^{-1})	55,0	107,7
Average biomass production (g m^{-3} day^{-1})	862,9	1229,1

The data retrieved from the educational PBR is corrected with the difference in light intensity, due to the use of a mesh in the educational PBR. All calculations of Table 5 can be found in the chapter 11.1.

The difference in average biomass production is clearly revealed by the 1229,1 g m^{-3} day^{-1} biomass from the educational PBR and the 862,9 g m^{-3} day^{-1} from the laboratory PBR (Sharp, 2017). The educational PBR produces 142,4% biomass of the laboratory PBR. Therefore, it consumes 78,3 mL day^{-1} CO_2 per day and produces 107,7 mL day^{-1} O_2 per day.

6.1.2 Discussion

One can discuss that although the educational PBR was not designed for maximum productivity, it is more productive than the laboratory PBR by 42,4% measured by the average biomass production. Since Sharp (2017) mentions that the robustness is improved by using a mixed community, it is no surprise that the growing conditions of the educational PBR are similar to those of the laboratory PBR. The

42,4% more biomass gained from the educational PBR could mean a step forward towards cost reductions since Socher et al. (2016) mentions that large-scale processes require a high cell density to become economically attractive. The other aspect that the flat panel format of the educational PBR has, compared to the laboratory scale, is the larger light surface area. One can discuss that the larger and even light path is an advantage towards biomass growth, causing 142,4% production (Skjanes et al., 2016). Addressing that Socher et al. (2016) mentions that there is no optimum photobioreactor for all applications and that the design and operation depend on the requirements of the system and applications. Future research will therefore have to reveal if the design of the educational PBR could be potentially useful towards upscaling applications.

6.2 Fixing the Atmosphere

In this chapter, the observed and received data from the pilot project Fixing the Atmosphere, May 2017, is presented and discussed. First, the preliminary data obtained from the survey at the start of the project; second, the questions the children asked during the project. At last, the feedback given by the children written on the posters and orally at the end by answering 'What did you like most about the pilot project Fixing the Atmosphere?'.

6.2.1 Survey

The survey was done in the first week by Dr. Bonnie Lee Shapiro, before any additional information about the pilot project was given to the children. This way it provided information about the knowledge and position the children had about the topics discussed in the project. In total, 44 children took part in the survey where the male-female distribution was around 50/50. For the present research, preliminary data is provided to analyse part of the outcome of the survey. This preliminary data consists of 9 questions where 2 questions ask about the knowledge of algae and biofuels seen in Figure 17, and the remaining questions ask about the children's opinion towards climate change seen in Figure 18.

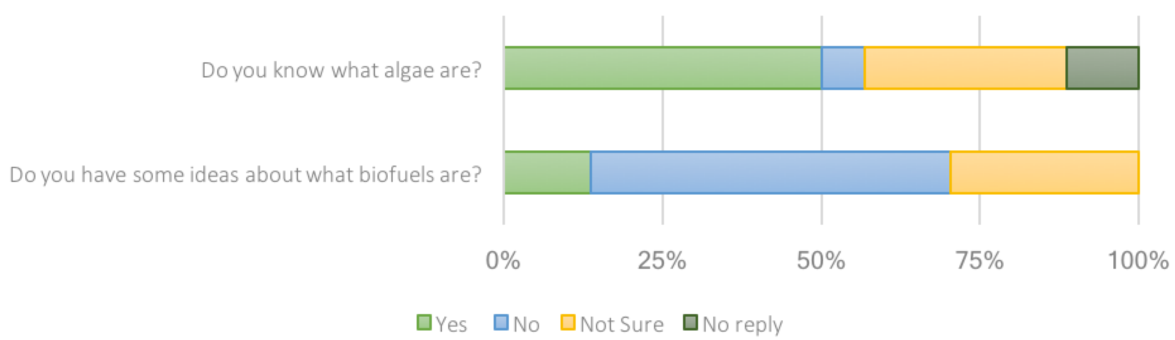

Figure 17 Survey pilot project Fixing the Atmosphere May 2017 - Preliminary data received from Dr. Bonnie Lee Shapiro

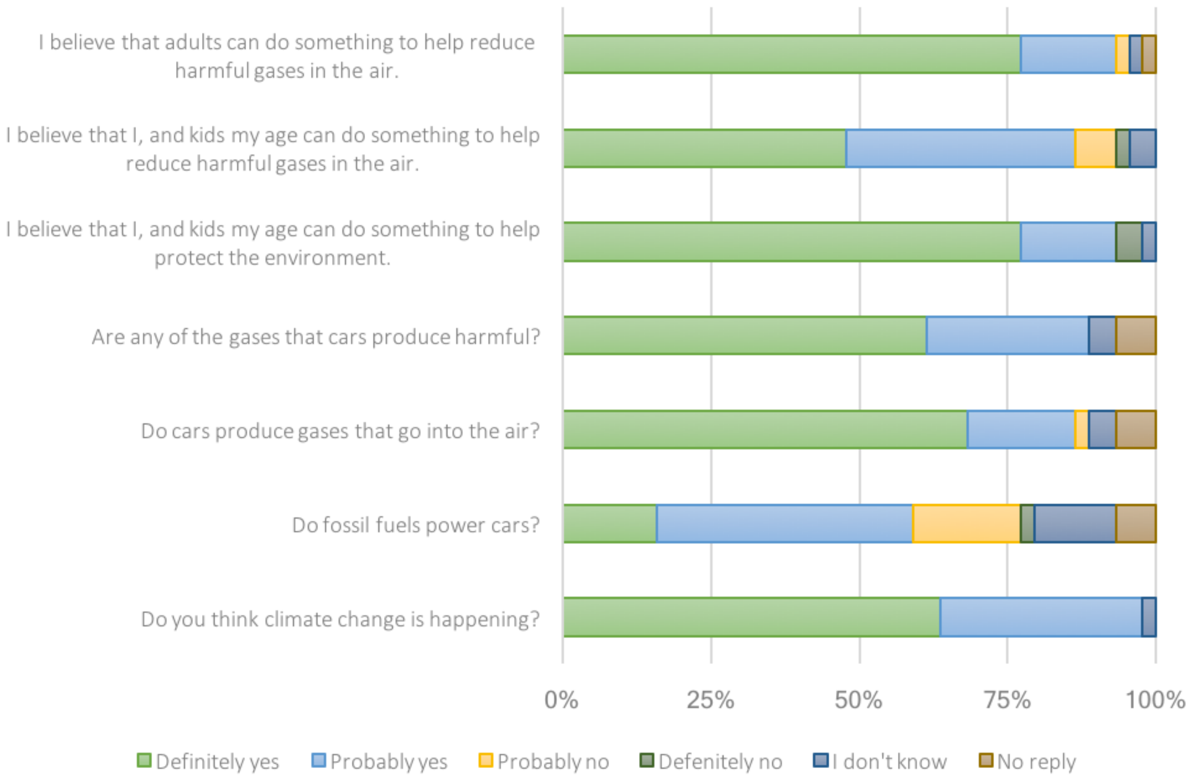

Figure 18 Survey pilot project Fixing the Atmosphere May 2017 - Preliminary data received from Dr. Bonnie Lee Shapiro

6.2.1.1 Results

The first question of Figure 17: *"Do you know what algae are?"* is showing that **50% of the children replied they know** where 38% of the children replied they didn't. Half of the classroom therefore has been in contact with algae before in their life where the other half had to learn about it.

The second question of Figure 17: *"Do you have some ideas about what biofuels are?"* is showing a strong lean towards not knowing what it is. Over **85% of the children replied they did not know** what a biofuel is or were not sure where only 13,6% replied they had an idea about what a biofuel is.

The second graph, seen in Figure 18, asked more about their opinion in the first 3 questions. These are: *"I believe that adults can do something to help reduce harmful gases in the air."*, *"I believe that I, and kids my age can do something to help reduce harmful gases in the air."* and *"I believe that I, and kids my age can do something to help protect the environment."*. The children shared a similar opinion since **86-93% of the answers were 'definitely yes' or 'probably yes'**.

Looking at the other questions in Figure 18, it is convincing that almost **98% of the children replied: 'definitely yes' or 'probably yes'** to the question: *"Do you think climate change is happening?"* and 0% replied 'definitely no' or 'probably no'.

Going further with the questions regarding fossil fuels and cars, over **85% of the children replied: 'definitely yes' or 'probably yes'** to the question: "*Do cars produce gases that go into the air*?" and almost **90% of the children believe** that: "*Any of these gases produced by cars can be harmful*.". It is therefore in contrast that **20,5% of the children answered: 'probably no' or 'definitely no'** to the question: "Do fossil fuels power cars?".

6.2.2 Questions

During the 3 weeks, when the pilot project was carried out in the elementary school, researchers observed the children and the questions they asked. The questions have been categorized into the following four main characteristics: global warming, fossil fuels, bio fuels, and the PBR. The amount of questions and the distribution of characteristics of the questions the children asked are shown in Figure 19. Since the ethics did not include the research of the questions asked by the children, the data used in the present research is only received by observations. It provides a brief overview on how the children's thoughts might or might not change during the overall project.

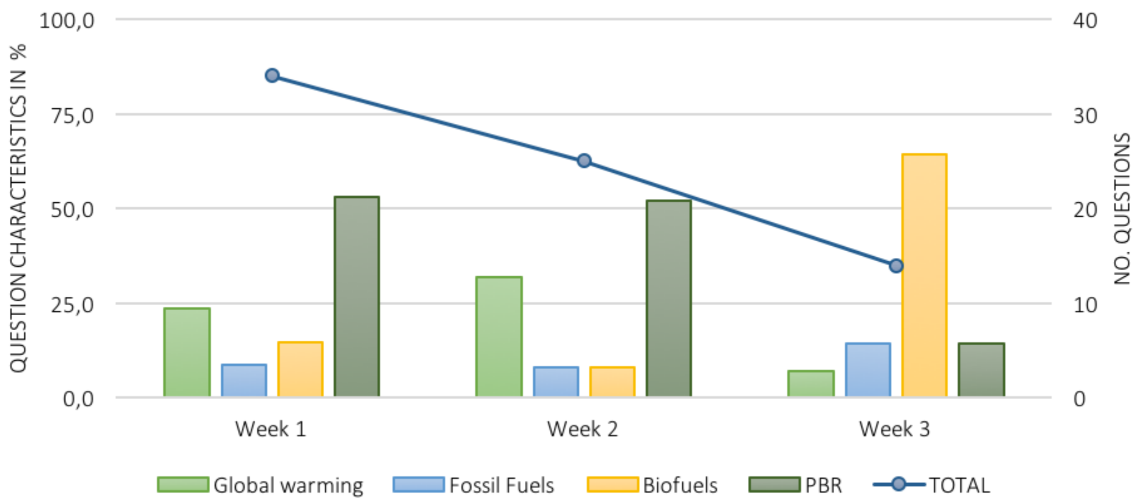

Figure 19 Observation of questions asked by the children in the Fixing the Atmosphere pilot project May 2017, with the relative distribution of the question characteristics (left vertical axis) and the total amount of questions (right vertical axis)

6.2.2.1 Results

Figure 19 clearly shows a **decline in the total amount of questions** by the children each week as the project evolves. Besides that, the figure shows that during the first two weeks of the project, most questions were related to the PBR and global warming. Regarding the first week, one could argue that this is due to the introduction of the PBR itself and its impact on global warming. For the second week, the relatively high amount could be related to the repeated harvesting moment with the children. Since there was no hands-on interaction with the PBR in week 3, this could clarify the decrease of PBR and global warming related questions. The relative increase of questions about biofuels in week 3 supports this, as this week focused more on the results and down-stream possibilities of the algal technology. The questions related to fossil fuels show a relatively low distribution over the 3 weeks, which could be linked to the focus on biofuels in the overall project.

6.2.3 Feedback

Since the ethics approval did not give permission to share raw data with anybody outside the research group, no actual quotes and exact percentages are used for the present research. Therefore, the feedback from the pilot project has been analyzed by observations of the classroom during the 3 weeks.

On one hand, the children were asked what they liked most about the pilot project Fixing the Atmosphere. The answers given by the children appear in a roughly distributed radar diagram in Figure 20, showing popularity of different topics. Figure 21 presents a different perspective in a pie chart, where this oral feedback is divided in three themes regarding the topic: educational support, hands-on and content. An overview of the subdivision of the oral feedback is shown in Table 6.

On the other hand, the written feedback from the post-its on the posters is used in a moodle, seen in Figure 22. The moodle represents the gained data and gives greater prominence to words that appeared more frequently in the written feedback.

Figure 20 Radar diagram representing oral feedback on the question 'What did you like most of the pilotproject Fixing the Atmosphere?' May 2017

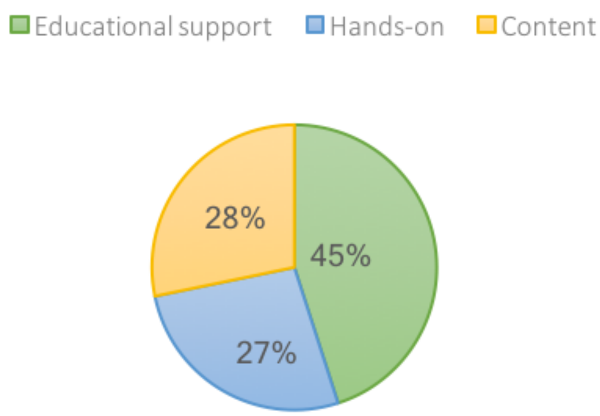

Figure 21 Distribution of feedback on question 'What did you like most of the pilot project Fixing the Atmosphere?' May 2017

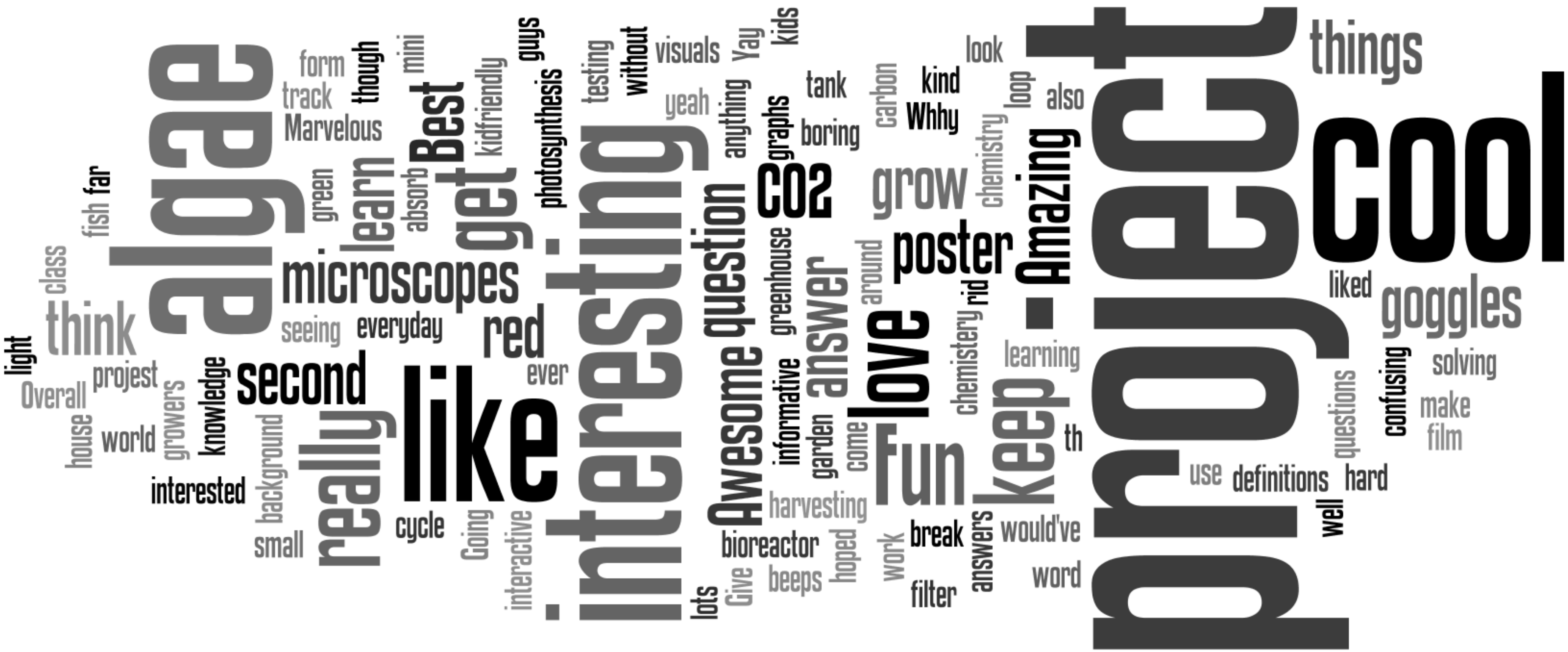

Figure 22 Moodle representing written feedback from posters during pilot project Fixing the Atmosphere, May 2017

Table 6 Overview subdivision oral feedback regarding the question: '*What did you like most of the pilot project Fixing the Atmosphere?*'

Educational Support	Hands-On	Content
Seeing real scientists	Harvesting	Learning about methane
Videos	Microscopes	Learning about a carbon sink
Posters		Info about the algae

6.2.3.1 Results

Answering the question '*What did you like most of the pilot project Fixing the Atmosphere*', Figure 20 shows clearly that the **appearance of real scientist** in the classroom has made a big contribution. One could state that the interaction and discussion with scientist, gave the children a realistic and positive impact on the project. It is likely that it also explains the popularity of the subdivision 'Educational support' in Figure 21. Other educational support, coming from the **videos**, was also of significant importance. The **posters** did not seem to be most liked by all the children, but still provided meaningful written feedback for the researchers. Besides that, the pie chart in Figure 21 reveals the subdivisions 'Hands-on' and 'Content' in an evenly distribution. This could mean that the interactive aspects of the project are as important and supportive as the informative aspects of Fixing the Atmosphere. One could argue that the educational approach of the project was welcomed by the children, supported with the hands-on experience.

Looking at the moodle in Figure 22, a selection of the greater prominent words are: '**project**', '**algae**', '**cool**', '**interesting**', '**like**', '**microscopes**' and '**fun**'. Although most feedback is positive, the moodle also contains the small words '**confusing**', '**though**', and '**boring**'. However, since most of the written feedback contained positive and rewarding words, one could argue that the majority of the children enjoyed the project. The small words on the moodle can be considered for adjustments in future projects, focussing on the feedback.

6.2.4 Discussion

Since education has been recognized to be a driving force for sustainable development, one can argue that the Fixing the Atmosphere project is a first major step for the Solar Biocells project (ILO, 2011). The results also show that the children had a lack of information on climate change and biofuels in specific. Working with the Fixing the Atmosphere project shows that the children's knowledge increases, based on the decline of total questions asked by the children. This is in line with Van Dael et al. (2017) who states that providing cognitive information by a lecture approach increases the knowledge about bioenergy.

The method used to transfer information via presentations can be considered beneficial since there is support in the development of acceptance of bioenergy products with standard classroom teaching methods (Shephard, 2008). Notice that Perlaviciute et al. (2014) and Simlock et al. (2014) mention that providing more information about the bioenergy topic is not by definition equivalent to an increased knowledge level and increased acceptance. Therefore, it should be stressed that the lecture approach is not enough to influence future behavioral change into sustainable alternatives. The Fixing the Atmosphere project aims to combine lecturing with practical and hands-on applications. Since Van Dael et al. (2017) mentions: "*Ideally, learners should not only be involved cognitively by a message that is relevant to them, but also actively and emotionally engaged during the process*", one can argue that the Fixing the Atmosphere project is a direct contribution into a wider strategy of learning and communication. The approach of having scientists in front of the classroom was received positive, based on the written and oral feedback of the children. This is in line with Van Dael et al. (2017) where it's stated that the messenger should be a trustworthy expert to have a better chance of being effective.

Not all aspects of the pilot project were received positive by the children, meaning that future projects will need adjustments. This is based on the feedback given by the children. One can also argue that there is a difference between what children learn and what children value (Shephard, 2008). It does not necessarily mean that if the children mostly liked to work with the photobioreactor, that they will automatically value the message behind it. It should be emphasized that preliminary data only reveals a small part of the outcome. But, since the Fixing the Atmosphere project does not only focus on cognitive learning but also on practical and affective learning goals as well, one can state that the overall approach can be used as an applicable base in future bioenergy educational projects.

Finally, the application of reverse intergenerational learning is made by the approach of children instead of adults to transfer a message of sustainability. Since generational diversity can generate new opportunities, the Fixing the Atmosphere project contributes in creating knowledge among a younger generation (Legault, 2003). Future outcomes will have to reveal if the knowledge of the children did or did not influence the awareness of other generations. But, since the approach of scientists was one with openness and positive attitude to change and learning, reverse intergenerational learning can begin to take place on all levels (Gerstner, 1999).

7 Conclusion

Fixing the Atmosphere

The sub research question on the first research question created for the present research was: *Is there improved awareness and knowledge of climate change and the positive impact biofuels can have on reducing climate change among the children who worked with the educational package*?

To answer this question, three pillars were used and analyzed to form a substantiated conclusion. The first pillar, the survey, emphasizes the importance of knowledge about algae and biofuels. This is based on the lack of knowledge from over 50% of the children, who did not know or were not sure about what algae or biofuels are. Besides that, the children did have an idea about climate change and did believe that adults or children their age could do something about it. Therefore, the Fixing the Atmosphere project is of added value and applicable in the chosen age range.

For the second pillar, the weekly amount of questions asked by the children clearly show a decline during the three weeks of the pilot project. One can conclude that the children learned more about the presented topics and gained more knowledge and awareness. This is also based on the amount of question about biofuels and the PBR, which were relatively higher than the questions about fossil fuels. It supports the overall focus of the project: algal technology and biofuels.

The last pillar, oral and written feedback, represents the experience from the children's point of view. The oral feedback reflects what the children liked most about the pilot project. The most valued aspect of the project was clearly the appearance of scientists in the classrooms. Second, the videos, microscopes and information about algae was highly appreciated to make the project to a success. The written feedback shows that the children had an overall positive experience with the pilot project. However, not all the information seemed to be evenly clear, which is an aspect to consider in future educational applications.

Answering the main research question: *How can an interdisciplinary approach by introducing the photobioreactor in high-schools be beneficiary for the implementation of biofuels in society?*

One can conclude that the educational approach of the algal technology and biofuels can possibly support the implementation in society. Since the children gained knowledge and awareness about the technology, one could state that this will be used in future discussions with adults or friends while growing up. Since the children and teachers asked for the PBR again for the fall term in September 2017, one can conclude that the Fixing the Atmosphere pilot project had an overall successful and positive impact. Since this was a pilot project, future developed projects and experience will have to reveal a significant effect in the long-term.

The educational photobioreactor

Answering the second research question: "*What are the results of upscaling the photobioreactor on the productivity-rate of the algae compared to the lab-scale unit*"

A summary of the results show that the educational PBR is responsible of 142,4% biomass production of the laboratory PBR. Therefore, one can conclude that the educational PBR is 42,4% more productive than the laboratory PBR. Although the educational PBR was not designed to be more productive than the laboratory PBR, the present research reveals that the adaptations on the design made the educational PBR more productive.

8 Recommendations

For the educational project Fixing the Atmosphere, the following improvements could be done:

- As discussed in paragraph 6.2.2.1, the information about down-stream processing was given in the third and final week of the project. The children could benefit more from the purpose of the harvested biomass, if this information is given at the start of the project instead.
- Since the impact of real scientists in the classrooms seemed to support the success of the pilot project, it is likely to continue this trend. However, there is a limit regarding the availability of real scientists for multiple projects. Especially if the Fixing the Atmosphere project would be enrolled on national scale. Therefore, future research is needed to reveal the actual impact of scientists in the classrooms and how this could be substituted.

Besides improvements for the project, future research on the interdisciplinary approach is recommended:

- To gain more knowledge from the children and analyse it for research, this must be mentioned in the ethics application. For future research, additional analysing by students or other individuals from the research group could be included in the application. This way, more substantiated conclusions can be formed.
- More in depth research about the change of knowledge and awareness. For example: creating a survey to test the children's knowledge and awareness about algae, biofuels, fossil fuels and global warming. The gained knowledge and/or awareness can then be compared by taking surveys at the start and at the end of the project.
- To investigate the effects of reversed intergenerational education, research on the interaction between child and parent may be of interest. Interviews with the parents or a small survey could gain important results on the effects of the interdisciplinary approach and the implementation of biofuels in society.

For the manufacturing of the educational PBR, small improvements can be considered from the experience of the present research:

1. Exploring the effects of the pump's speed control (flow rate) on the algae growth. Research on diverse flow rates could be interesting for future developments in the alkaline algal technology.
2. Exploring the effects of the use of a mesh in the biomass chamber of the PBR, which could be one of the reasons why the educational PBR is 42,4% more productive than the laboratory PBR.

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11 Appendix

11.1 Calculations

Laboratory PBR (Sharp, 2017)		
Specification	**Value**	**Unit of measure**
Illuminated surface	197,5	cm^2
Ground area	18	cm^2
Inner volume	69,1	cm^3
	0,07	L

Growth conditions	Value	Unit of measure
RedLight	80	micromol photon/m^2day
pH	9	
Dissolved NaHCO3	0,5	M

Productivity	Value	Unit of measure
Biomass	862,91	g/m^2day
O2 production	55	mL/day
CO2 consumption	75,625	mg/day

Educational PBR		
Specification	**Value**	**Unit of measure**
Illuminated surface rectangle	1857,06	cm^2
Illuminated surface triangle	156,636	cm^2
Total illuminated surface area	1700,424	cm^2
Ground area	/	cm^2
Inner volume PBR	750	cm^3
	0,75	L
	0,00075	m^3

Growth conditions	Value	Unit of measure
RedLight	41	micromol photon/m^2day

pH	9	
Dissolved $NaHCO_3$	0,5	M

Productivity	Value	Unit of measure
Biomass	1229,11	g/m^3day
O_2 production	78,342	mL/day
CO_2 consumption	107,72025	mg/day

Calculations		
Illuminated surface area		
PBR specifications		
Rectangle	**Value**	**Unit**
Height	54,3	cm
Width	34,2	cm
Triangle	**Value**	**Unit**
Height	9,16	cm
Width	34,2	cm
Angle	15	°
Depth	**Value**	**Unit**
	0,35	cm
Calculated value	**Value**	**Unit**
Rectangle area PBR	1857,1	cm^2
Triangle area PBR	156,6	cm^2
Total illuminated area PBR	1700,4	cm^2

%OM		
Laboratory measurements		
	Value	**Unit**
Total weight	55,57	g/week
Sample of total weight combusted		
Wet weight	1,55	g
Dry weight	0,121	g
Anorganic matter	0,049	g
Organic matter	0,072	g
%OM	**59,5**	**%**

Calculations		
Media flow rate PBR		
Flow rate = 4 x Inner Volume PBR per 24 hours		
Laboratory PBR	**Value**	**Unit**
Inner volume	69,1	cm^3
Flow rate	276,4	cm^3/day

	276,4	mL/day
Educational PBR	**Value**	**Unit**
Inner volume	750	cm^3
Flow rate	3000	cm^3/day
	3000	mL/day
Educational PBR	**Value**	**Unit**
Desired flow rate	2,1	mL/min
Min. pump flow rate	14,8	mL/min
Correction	7,1	times to fast
Timer pump	**8,4**	**s/min**

Pump specifications		
Specification	**Value**	**Unit of measure**
Voltage (max)	12	V
Voltage (min)	4	V

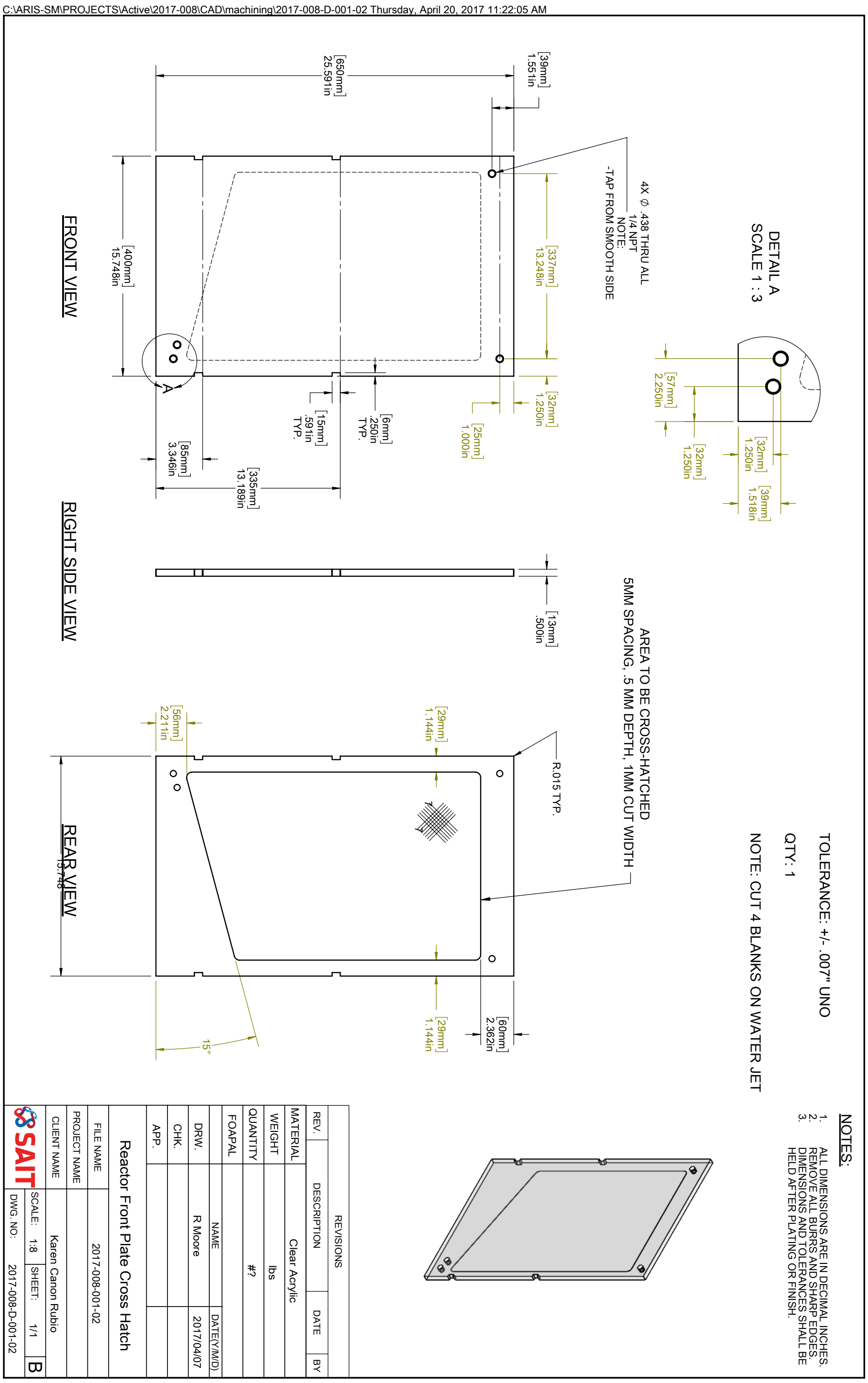
Minimum flow rate experiment		
Time (min)	**Volume (mL)**	**D volume (mL)**
0	0	14
1	14	15
2	29	15
3	44	15
4	59	15
5	74	
Volume	**Value**	**Unit of measure**
Mean Volume	**14,8**	mL/min
	0,0148	L/min
	0,888	L/h

Maximum flow rate experiment		
Time (min)	**Volume (mL)**	**D volume (mL)**
0,5	31	33
1	64	32
1,5	96	32
2	128	31
2,5	159	32

3	191	

Volume	Value	Unit of measure
Mean Volume	32	mL/0,5min
	64	mL/min
	0,064	L/min
	3,84	L/h

11.2 Final CAD-design of the bench-scale PBR unit



11.3 Trace element solution composition for K3E Media

Trace element solution (per 1000ml):		
Titriplex III (EDTA)	500 mg	
$FeSO_4 \bullet 7H_2O$	200 mg	(*Iron (II) Sulfate Heptahydrate*)
$ZnSO_4 \bullet 7H_2O$	10 mg	(*Zinc Sulfate Heptahydrate*)
$MnCl_2 \bullet 4H_2O$	3 mg	(*Manganese (II) Chloride Tetrahydrate*)
H_3BO_3	30 mg	(*Boric Acid*)
$CoCl_2 \bullet 6H_2O$	20 mg	(*Cobalt (II) Chloride Hexahydrate)*
$CuCl_2 \bullet 2H_2O$	1 mg	(*Copper (II) Chloride Dihydrate*)
$NiCl_2 \bullet 6H_2O$	2 mg	(*Nickel (II) Chloride Hexahydrate*)
$Na_2MoO_4 \bullet 2H_2O$	3 mg	(*Sodium Molybdate Dihydrate*)

11.4 Raspberry-Pi coding by SAIT

Solar Biocell Software/Pi Documentation

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May 5, 2017

Contents

1 Introduction

This document provides information required to install the sensor software onto a Raspberry Pi, and configuration of the Pi WiFi so that an Ethernet connection can be avoided. Wiring diagrams are not provided, as most wiring was completed before SAIT's involvement in the project. To duplicate the setup for a second Pi, a new full wiring diagram will have to be created.

2 File Descriptions

The archive SolarBiocellFiles.zip that accompanies this document contains the following files:

genericsensor.py Defines a generic sensor in Python. Supports sensors that need to be run periodically to collect sensor readings, or those that need to record sensor readings based on a monitored condition changing. This also defines how readings are sent to the server, so that it does not have to be rewritten for each sensor.

sensor_light.py Implementation for light sensor.

sensor_temperature.py Implementation for temperature sensor.

sensor_gas.py Implementation for oxygen sensor.

sensor_ph.py Implementation for pH sensor.

crontab.txt Schedule definitions that run the above files so that sensor readings can be recorded.

send_json_to_server.sh A script that when run will send recorded sensor readings to the server, and move the reading files to a "sent" subdirectory.

old_files directory A copy has been provided of the files that existed previously on the Pi for sensor readings but that are no longer used. These include: `bh1750.py`, `make3jsonposts.sh`, `master_datavalue.json`, `thermometer.py`, and `Adafruit\_I2C.py`

Unfortunately, because every sensor could have a different method for connecting to the Pi, or provide its data in an unexpected format or scaling there are still parts that will have to be added to the code by hand. New sensors will have to define either `get_value()` or `monitor_value()` depending on sensor type. The light and gas sensors respectively are good examples for this.

3 Installing Sensor Programs on the Pi

We will require python and a library for the ADC device that the pH sensor routes through. All of which can be installed with the following commands:

```
sudo apt-get update
sudo apt-get install python python3 python-pip python3-pip
sudo pip install adafruit-ads1x15
```

Following the old Pi configuration, the above files (not including old files) should be copied to the Pi, in the directory `/usr/local/bin/BioReactor/`. You can use a different directory, but this will require modifying line 33 in `send_json_to_server.sh` and line 12 in `genericsensor.py` to match the new path.

To change the server that pH values are sent to, modify line 25 in the file `send_json_to_server.sh`. Currently this is set to `2Connect2Biz.com`, and so the url's used for sending sensor readings are as follows:

- `http://2Connect2Biz.com/pitemp`
- `http://2Connect2Biz.com/pigasflow`
- `http://2Connect2Biz.com/pilight`
- `http://2Connect2Biz.com/piph`

> "Currently the `piph` URL is not supported by the server, and so it is not accepting the pH readings created by the Pi. This will have to be corrected by the person responsible for the server. It also appears that the server is doing extra processing on the oxygen values, as it was observed that a value of "1.0" being sent from the Pi was being displayed as "10.0" on the server. This unnecessary processing should be disabled."

3.1 Sampling Automatically

By default, the 4 sensor program files will only run manually. We will use a scheduling service called crontab on the Pi to run them. If you are using the Pi desktop you can find the scheduler under the main menu, otherwise if you are interacting with the Pi via command-line, you can execute the command "`crontab -e`".

Regardless of method, you will enter the lines found in the crontab.txt that came with this document into the scheduler. This will set the system to collect temperature, light and pH values every 5 minutes, to run the oxygen sensor continually (monitoring for oxygen cycles) and finally to upload all collected sensor readings to the server every 5 minutes.

Because the server does not yet support receiving pH sample values, the schedule entry for the file `sensor_ph.py` has been disabled by adding a '#' symbol to the beginning of the line. Remove this symbol once server support is added.

4 WiFi Setup

Not all versions of the Raspberry Pi operating system come with a WiFi GUI tool. To configure a USB dongle, or if you are using a Raspberry Pi 3 that has built-in WiFi, we can add a GUI tool that will make it much easier to configure the Pi.

To install the tool, run the following commands:

```
sudo apt-get update
sudo apt-get install wpagui
```

As this is a visual tool, you will have to be connected to the Pi via a monitor, keyboard and mouse for the rest of these instructions.

1. Open the main Menu and select "Run...", type in `wpa_gui` and press enter. This should start the tool.
2. To add a new network, click "Scan", then in the scan results that display, double-click the network you wish to connect to, which will open a new "NetworkConfig" window for that specific network.
3. In the "NetworkConfig" window, fill out the fields for the WiFi network, and finally press Add at the bottom of the window.
4. In the main window on the "Manage Networks" tab, click the network you added and ensure the "enable" radio button is highlighted.
5. In the main window on the "Current Status" tab, select the network you configured in the drop-down box, and then click the connect button.
6. When you successfully connect, you should see a status of "Completed (station)", a value listed for the IP address of the Pi, and you should see a WiFi signal strength indicator in the top right corner of the Pi desktop.

Repeat #2 and #3 above as needed for additional networks.

As an example, the SAIT website has a page that defines the properties of the sait-secure network at `https://wireless.sait.ca/secure_wireless.html` at the bottom of the page. In the "NetworkConfig" window of the `wpa_gui` tool, we fill out the fields accordingly (fields not mentioned were left on default/blank values):

Field	**Value to Enter/Select**
SSID	sait-secure
Authentication	WPA2-Enterprise (EAP)
Encryption	CCMP
EAP method	PEAP
identity	username provided by SAIT
password	password for your username
Inner Auth	EAP-MSCHAPV2

5 Sensor Notes

There are several locations in the program files that may need adjustments for the current sensors.

5.1 Oxygen Sensor

Because the oxygen sensor is not directly sensing oxygen flow, but rather triggering when the sensor periodically cycles, you may need to change the volume value reported per cycle.

The location for this can be found in the file `sensor_gas.py` on line 27. Currently this has a default value or 7.4, but the line can be changed to any other value as long as it is a decimal value.

5.2 PH Sensor

The pH sensor[1] reports its sensor reading by outputting a specific voltage over one of its cables. This has been connected to the ADS1115 analog to digital converter (ADC) that was paired with the Pi.

While it is stated[2] that the voltage should be in the range -412.12mV to 412.12mV (a change of 59.16 per pH level from 0-14), upon installing the pH sensor this was not the case. Instead, the pH sensor is currently reporting a value of 2V, and after some online investigation it appears likely that the pH sensor is instead being read through the ADS1115 in the range of 0mV to 4096mV. The code has been changed accordingly, but additional testing is required to verify if this is correct.

Once you are able to test the pH sensor with several different liquids at known pH levels, the file `sensor_ph.py` can be modified accordingly. In particular, it is line 25 that will have to be changed, which currently converts a voltage in the range of 0mV-4096mV to a pH value with the equation $\frac{voltage}{4096} * 14$. For faster testing, you can run this file manually instead of waiting for the automatic 5 second trigger by opening a terminal window, navigating to the `/usr/local/bin/BioReactor` directory, and then running the pH sensor with the command “`python sensor_ph.py`”.

[1] `https://www.dfrobot.com/product-1110.html`
[2] `https://www.dfrobot.com/wiki/index.php/PH_meter(SKU:_SEN0161)`

11.4.1 Light sensor

```
#!/usr/bin/python3
# ------------------------------------------------------------
# Based off of bh1750.py from http://www.raspberrypi-spy.co.uk/
# ------------------------------------------------------------
from genericsensor import Sensor
import smbus
import time


class LightSensor(Sensor):
    """Collects temperature sensor values and outputs them to a json file for transfer to server."""
    DEVICE = 0x23  # Default device I2C address
    # Start measurement at 0.5lx resolution. Time typically 120ms
    # Device is automatically set to Power Down after measurement.
    ONE_TIME_HIGH_RES_MODE_2 = 0x21

    def __init__(self):
        super().__init__()
        # self.bus = smbus.SMBus(0) # Rev 1 Pi uses 0
        self.bus = smbus.SMBus(1)  # Rev 2 Pi uses 1

    def get_value(self):
        data = self.bus.read_i2c_block_data(LightSensor.DEVICE,
LightSensor.ONE_TIME_HIGH_RES_MODE_2)
        return ((data[0] << 8) | data[1]) / 1.2

    def _monitor_value(self, callback):
        raise NotImplementedError("Light sensor does not support monitoring.")

if __name__ == '__main__':
    sensor = LightSensor()
    value = sensor.get_value()
    print(value)
    sensor.generate_file('lux', "{:7.1f}".format(value), 'bio_light', time.localtime())
```

11.4.2 Temperature sensor

```
#!/usr/bin/python3
from genericsensor import Sensor
import time


class TemperatureSensor(Sensor):
    """Collects temperature sensor values and outputs them to a json file for transfer to server."""
    def __init__(self):
        super().__init__()
        self.device = '/sys/bus/w1/devices/28-0000075d2009/w1_slave'

    def get_value(self):
        with open(self.device, 'r') as f:
            data = f.readlines()
```

```
        deg_c = ''
        if data[0].strip()[-3:] == 'YES':
            temp = data[1][data[1].find('t=') + 2:]
            try:
                if float(temp) == 0:
                    deg_c = 0
                else:
                    deg_c = (float(temp) / 1000)
            except:
                print("Error with t=", temp)
                pass
        return deg_c

    def _monitor_value(self, callback):
        raise NotImplementedError("Temperature sensor does not support monitoring.")

if __name__ == '__main__':
    sensor = TemperatureSensor()
    value = sensor.get_value()
    print(value)
    sensor.generate_file('temperature', "{:4.1f}".format(value), 'bio_temp', time.localtime())
```

11.4.3 Gas flow meter

```
#!/usr/bin/python3
from genericsensor import Sensor
import RPi.GPIO as GPIO
import time


class GasSensor(Sensor):
    """Collects oxygen cycle values and outputs them to a json file for transfer to server."""
    def __init__(self):
        super().__init__()
        self.gpiopin = 16
        GPIO.setmode(GPIO.BCM)  # With BCM mode, the pin matches the label on the board. 16
above is GPIO16.
        GPIO.setup(self.gpiopin, GPIO.IN, pull_up_down=GPIO.PUD_DOWN)  # We want to monitor
the pin as input to detect the water cycling through.

    def get_value(self):
        raise NotImplementedError("Gas sensor can not return instant values, must monitor for activity.")

    def _monitor_value(self, callback):
        GPIO.add_event_detect(self.gpiopin, GPIO.FALLING, callback=callback, bouncetime=10000)
        while self.continue_monitor:
            time.sleep(5)  # The max potential delay before the monitor shuts down after stop_monitor is
called.
        GPIO.remove_event_detect(self.gpiopin)

    def gas_callback(self, channel):
        print("Callback on channel: ", channel)
        # We detected a gas cycle! Push it out to a new file.
```

```
        value = 7.4  # Every pulse always indicates the same volume of oxygen passing through the
sensor.
        print("Value: ", value)
        sensor.generate_file('flow', "{:4.1f}".format(value), 'bio_gas', time.localtime())

if __name__ == '__main__':
    sensor = GasSensor()
    sensor.start_monitor(sensor.gas_callback)
    sensor.wait_monitor()
```

11.4.4 pH sensor

```
#!/usr/bin/python
from genericsensor import Sensor
import time
from Adafruit_ADS1x15 import ADS1x15


ADS1115 = 0x01


class PHSensor(Sensor):
    """Collects oxygen cycle values and outputs them to a json file for transfer to server."""
    def __init__(self):
        super(PHSensor, self).__init__()
        self.adc = ADS1x15(ic=ADS1115)

    def get_value(self):
        # Get voltage in the range of 414.12 (pH 0) to -414.12 (pH 14)
        # Each drop in 59.16mV from 414.12mV is an increase of pH by one.
        voltage = self.get_voltage()
        print("Voltage: ", voltage)

        # Convert voltage to ph and return.
        # return (414.12 - voltage) / 59.16
        # Value appears to be getting scaled to 0-4V instead of expected, calculation modified
accordingly.
        return (voltage / 4096) * 14.0

    def get_voltage(self):
        # Read voltage from ADS1115 pin A0
        return self.adc.readADCSingleEnded(0)

    def _monitor_value(self, callback):
        raise NotImplementedError("pH sensor does not support monitoring.")

if __name__ == '__main__':
    sensor = PHSensor()
    value = sensor.get_value()
    print("Value: ", value)
    sensor.generate_file('ph', "{:4.1f}".format(value), 'bio_ph', time.localtime())
```

11.5 Procedure: Direct Estimation of Organic Matter by Loss of Ignition (LOI)

Weigh all samples to 3 decimal places…	
Pre-preparation Work:	
1	Heat porcelain crucibles for 1 hour at 550°C in a muffle furnace. Place in a desiccator and cool to RT. Take out of desiccator and weigh on the analytical scale.
	1.1 This will be the crucible weight.
2	Put crucibles back in the desiccator until ready to use.
Sample Preparation:	
3	Spin down mats in falcon tubes and pour off supernatant.
4	Take crucibles out of desiccator and add samples. Weigh sample + crucible.
	1.2 Wet sample weight = (weight sample + crucible) – (crucible weight).
5	Dry at 105°C for 24 hours. Cool to RT in a desiccator. Weigh sample + crucible.
	1.3 Dry sample weight = (weight dry sample + crucible) – (crucible weight).
6	Place dry mat samples + crucibles back in the desiccator after weighing.
Pre-ignition Work:	
7	Place the crucibles + samples in the furnace.
8	Turn on the muffle furnace by flipping the switch on the front.
	1.4 The LOI process requires a slow temperature increase of 5°C/min. The current protocol is set to ramp at that rate up to 550°C and hold there for 4 hours.
9	Allow the furnace to run for 4 hours at 550°C.
Post-ignition Work:	
10	When sufficient time has passed remove the samples from the oven and place in a desiccator using tongs.
11	Wait until the samples are cooled than remove the samples from the desiccator and weigh the samples for their post-ignition weight. Subtract the initial crucible weight.
12	Put remaining ash into a sterile falcon tube (or centrifuge tube) and store at RT.
13	Calculate %OM

11.6 Survey – Developed by Dr. Bonnie Lee Shapiro (2017)

Page 1 of 3

Solar Biocells Pilot Project - Student Survey

Your name ______________________________

Your date of birth: Year ____ Month __________ Day ____

1	Have you heard about climate change? Circle your response:	Yes	No	
2	Do you have some ideas about what climate change is? Circle your response:	Yes	No	Not Sure
3	If you have some ideas about what climate change is, please list them here:			
4	Do you have some ideas about what photosynthesis is? Circle your response:	Yes	No	Not Sure
5	If you have some ideas about what photosynthesis is, please list them here:			
6	Do you have some ideas about what biofuels are? Circle your response:	Yes	No	Not Sure
7	If you have some ideas about what biofuels are, please list them here:			

		Definitely yes	Probably yes	Probably no	Definitely no	I don't know
8	Do you think that climate change is happening?	☐	☐	☐	☐	☐
9	If you think climate change is happening do you think it is caused by:	☐	☐	☐	☐	☐
10	• Burning fuel used in cars, buses, airplanes	☐	☐	☐	☐	☐
11	• Volcanic eruptions	☐	☐	☐	☐	☐
12	• Cows	☐	☐	☐	☐	☐
13	• Cutting down trees	☐	☐	☐	☐	☐
14	• The ozone layer	☐	☐	☐	☐	☐
15	• Natural patterns in the weather on Earth	☐	☐	☐	☐	☐
16	• Forest fires	☐	☐	☐	☐	☐
17	None of the above because climate change is not happening	☐	☐	☐	☐	☐

1

Page 2 of 3

18	Do you have some ideas about what fossil fuels are? Please list them here:					
	Which of the items below do you think are fossil fuels?	Definitely yes	Probably yes	Probably no	Definitely no	I don't know
19	• Oil	☐	☐	☐	☐	☐
20	• Wood	☐	☐	☐	☐	☐
21	• Solar energy	☐	☐	☐	☐	☐
22	• Water	☐	☐	☐	☐	☐
23	• Kerosene	☐	☐	☐	☐	☐
26	• Natural gas	☐	☐	☐	☐	☐
27	• Carbon dioxide	☐	☐	☐	☐	☐
28	• Coal	☐	☐	☐	☐	☐
29	What do you think happens when fossil fuels are burned? Please describe:					
	Where do you think the energy in fossil fuels comes from?	Definitely yes	Probably yes	Probably no	Definitely no	I don't know
30	• The sun	☐	☐	☐	☐	☐
31	• Rocks	☐	☐	☐	☐	☐
32	• Plants that grew millions of years ago	☐	☐	☐	☐	☐
33	• Dinosaur fossil remains	☐	☐	☐	☐	☐
34	Do fossil fuels power cars?	☐	☐	☐	☐	☐
35	Do cars produce gases that go into the air?	☐	☐	☐	☐	☐
36	Are any of the gases that cars produce harmful?	☐	☐	☐	☐	☐

2

Page 3 of 3

	When gasoline, natural gas or diesel fuels are burned which of the following are produced?	Definitely yes	Probably yes	Probably no	Definitely no	I don't know
37	• Water	☐	☐	☐	☐	☐
38	• Oxygen	☐	☐	☐	☐	☐
39	• Carbon dioxide	☐	☐	☐	☐	☐
40	• Hydrocarbons	☐	☐	☐	☐	☐
41	• Hydrogen	☐	☐	☐	☐	☐
42	• Helium	☐	☐	☐	☐	☐
43	• Carbon monoxide	☐	☐	☐	☐	☐
44	• Nitrogen oxides	☐	☐	☐	☐	☐
45	Do you know what algae are? Circle your response:	Yes	No	Not sure		

46 If you have some ideas about what algae are, please list them here:

____

____

47 When you plant an apple seed in the soil, it grows into a tree. Where does the material that makes up the apple tree trunk and branches come from?

____

____

		Definitely yes	Probably yes	Probably no	Definitely no	I don't know
48	I believe that I, and kids my age can do something to help protect the environment.	☐	☐	☐	☐	☐
49	I believe that I, and kids my age can do something to help reduce harmful gases in the air.	☐	☐	☐	☐	☐
50	I believe that adults can do something to help reduce harmful gases in the air.	☐	☐	☐	☐	☐
51	I believe that only scientists can do something to help reduce harmful gases in the air.	☐	☐	☐	☐	☐
52	I believe that politicians can do something to help reduce harmful gases in the air.	☐	☐	☐	☐	☐

53 How do you think cars, buses and airplanes will be powered in the future?

____

____

3

11.6.1 Ethics approval

Calgary Board of Education

www.cbe.ab.ca

1221 – 8 Street S.W., Calgary, AB T2R OL4

May 8, 2017

Dr. Bonnie Shapiro and Dr. Marc Strous
2500 University Drive NW
Calgary, Alberta T2N 1N4

Dear Dr. Shapiro and Dr. Strous,

I am pleased to confirm that the Calgary Board of Education has granted permission for you to conduct the study *Climate change and biofuels: Experiential learning in Alberta classrooms – pilot project.*

The study for which this approval is granted involves grades 5/6 students and their teachers engaging in scientific processes. Specifically, they will place algae on bioreactors and measure and report on the amount of oxygen produced. They will also report on their questions and experiences. Participants are grades 5/6 students and their teachers. Should you need to make changes either to methodology or participants, please send a request for amendment to Research Applications.

The anticipated date for completion of data collection is June 12, 2017. Within a month of this date, you are requested to e-mail Research Applications either to confirm that data collection has been completed or to send a request for extension.

The granting of this approval indicates that as a school jurisdiction we have no ethical concerns with your study. **The final decision to participate rests with the school administration, teachers, students and parents involved. This letter does not obligate participation by anyone associated with the Calgary Board of Education.**

Please note that this approval applies only to the person to whom this letter is addressed and is valid only until the date specified above as anticipated for the completion of data collection.

Please present this letter to Calgary Board of Education personnel when requesting access to teachers and students. This approval does not include access to student, staff or school records.

We wish you success in your study. We would appreciate your sharing your findings and a copy of any material that you subsequently publish.

Yours truly,

Pat Kover
System Assistant Principal, Learning
t | 403-817 7514
f | 403-777 6159
pakover@cbe.ab.ca

learning | as unique | as every student

11.7 Police check: example for research student Daisy Rycquart (2017)

CALGARY
POLICE
SERVICE

Vigilance
Courage
Pride

April 25, 2017

TO: RYCQUART, DAISY MARIA A

NEE/ALIASES: NONE

SEX: FEMALE **DOB: DECEMBER 24, 1992**

A search based on the above **name(s) and birthdate** has **not** disclosed a record of criminal convictions in Canada's National Repository for criminal records. Calgary Police Service local indices and the Alberta Court indices have **not** disclosed other relevant information. This search was conducted from identification and information provided by the applicant and not through the submission of fingerprints.

This is to confirm that a Vulnerable Sector Search (Pardon Sex Offenders Records) has been completed and there is no information to disclose.

Note: Vulnerable people are individuals who are at greater risk of being harmed than the general population, because of age, disability, handicap or circumstances, whether temporary or permanent, by persons in a position of authority or trust relative to them as is authorized under the Criminal Records Act.

By providing this information, the Calgary Police Service offers no opinions, representations or statements regarding the suitability of the applicant for the position applied for. The Calgary Police Service assumes no risk or liability whatsoever associated with the placement of this individual in the position applied for and therefore it is solely the employer's or agency's responsibility to conduct its own assessment with respect to the suitability of the applicant for the position.

Yours truly,

PLEASE NOTE: THE CPS POLICE INFORMATION CHECK UNIT RECOMMENDS A LOCAL POLICE CHECK BE CONDUCTED WHERE THIS APPLICANT PREVIOUSLY RESIDED.

Sherri Faucher, Supervisor
Police Information Check Unit
Police Business Operations Section
/CM

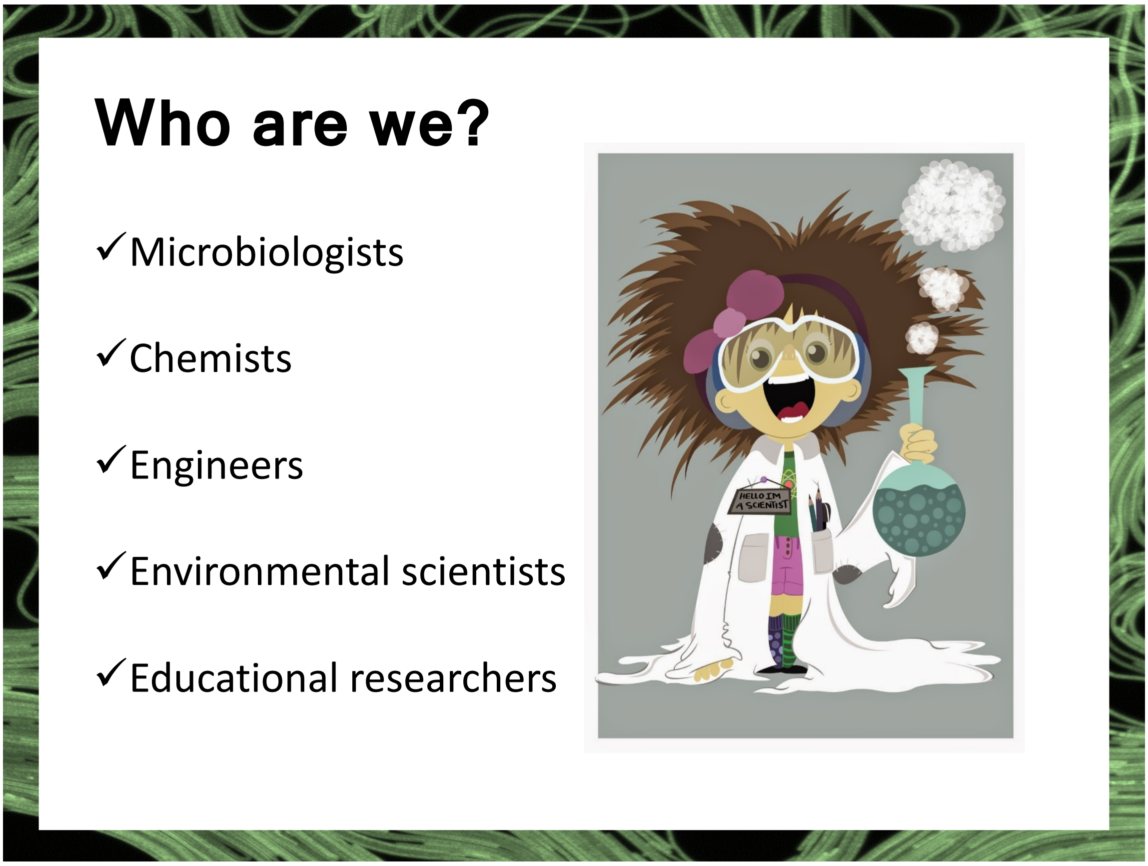
Initial PIC completed for EMPLOYMENT with UNIVERSITY OF CALGARY

5111 - 47 Street N.E., Calgary, AB
Canada T3J 3R2 (403) 266-1234
www.calgarypolice.ca

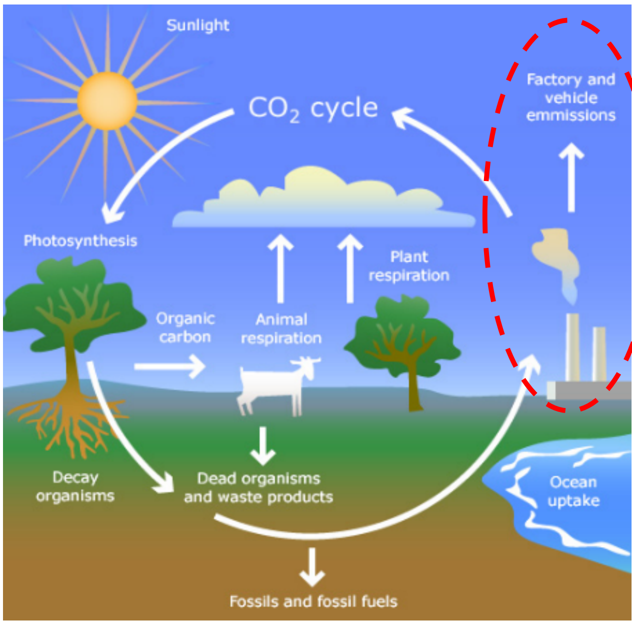
- This certificate letter is not valid unless embossed with the Calgary Police Service crest pressed into bottom left side of the paper, and must have a watermarked Calgary Police Service crest on bottom right side of paper.
- This certificate letter reports factual information. It is provided as a service only. By issuance of this certificate letter, the issuer is not making any statement regarding the applicant's suitability for the position for which they are requested to provide this certificate letter.
- On the reverse side of the certificate letter are the Calgary Police Service Search and Disclosure guidelines.

PD 17E (R2013-10)

11.8 Introductory presentation developed by Daisy Rycquart (2017)

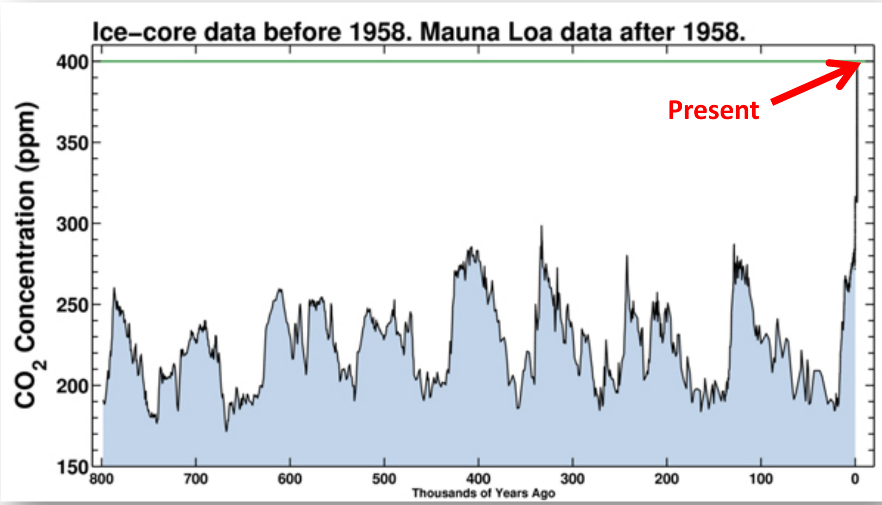


What is the problem?



- Electricity
- Transportation
- Industry
- Agriculture
- Commercial
- Residential

But is this really happening?



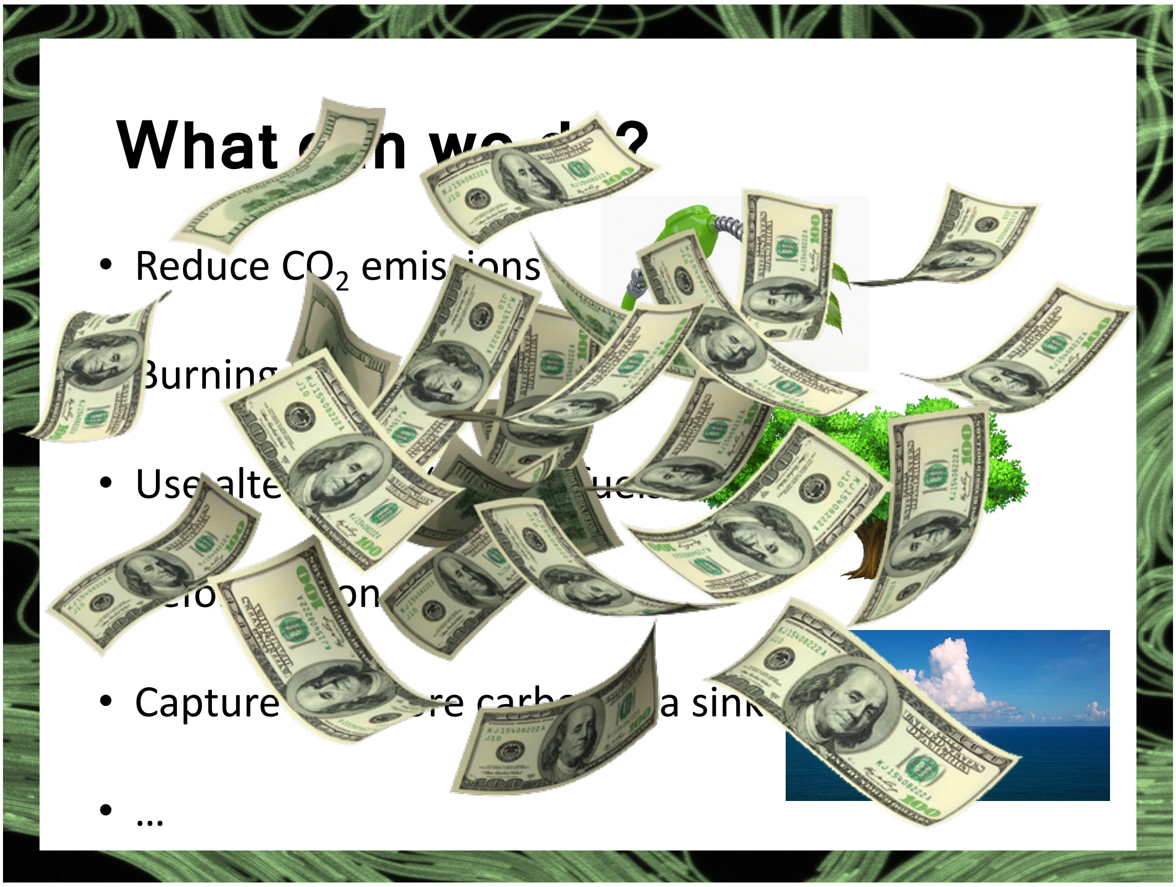
Courtesy of Scripps Institution of Oceanography – Source: https://blogs.scientificamerican.com/observations/400-ppm-carbon-dioxide-in-the-atmosphere-reaches-prehistoric-levels/

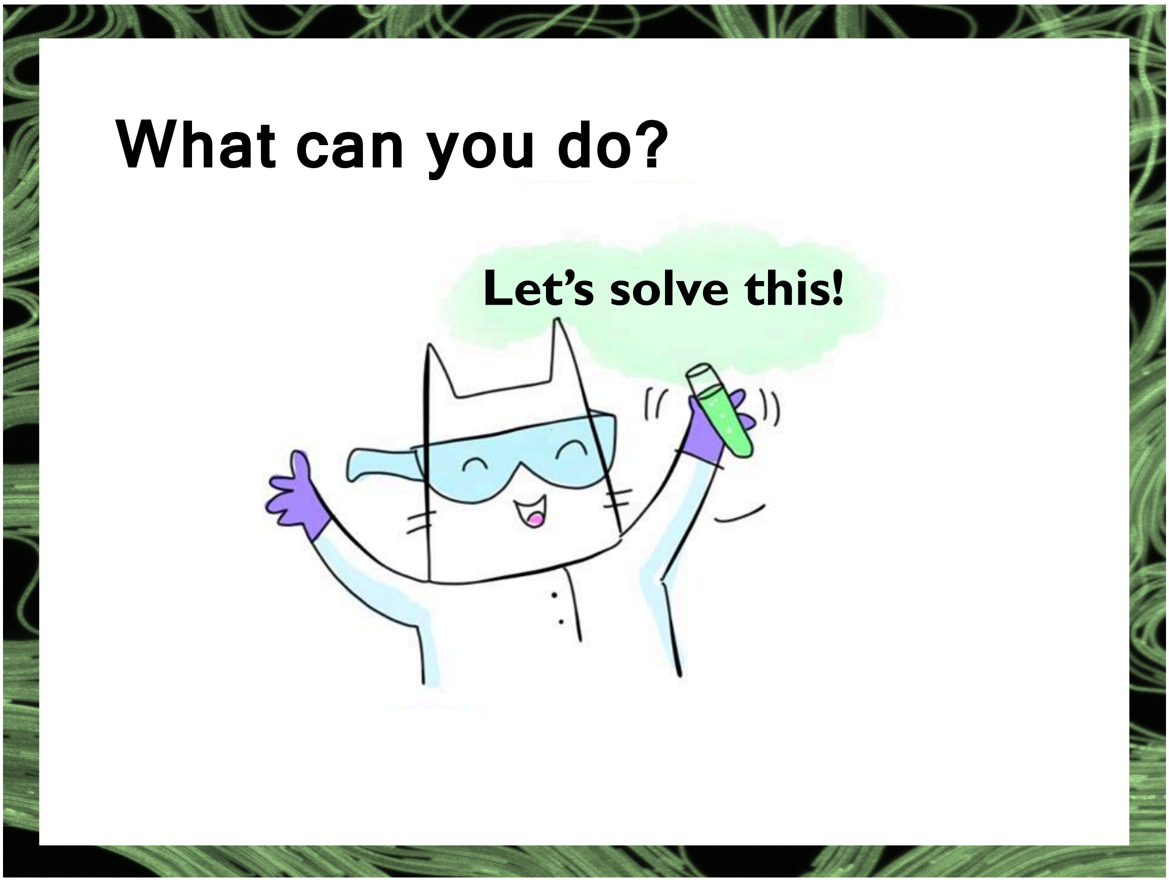
What can we do?

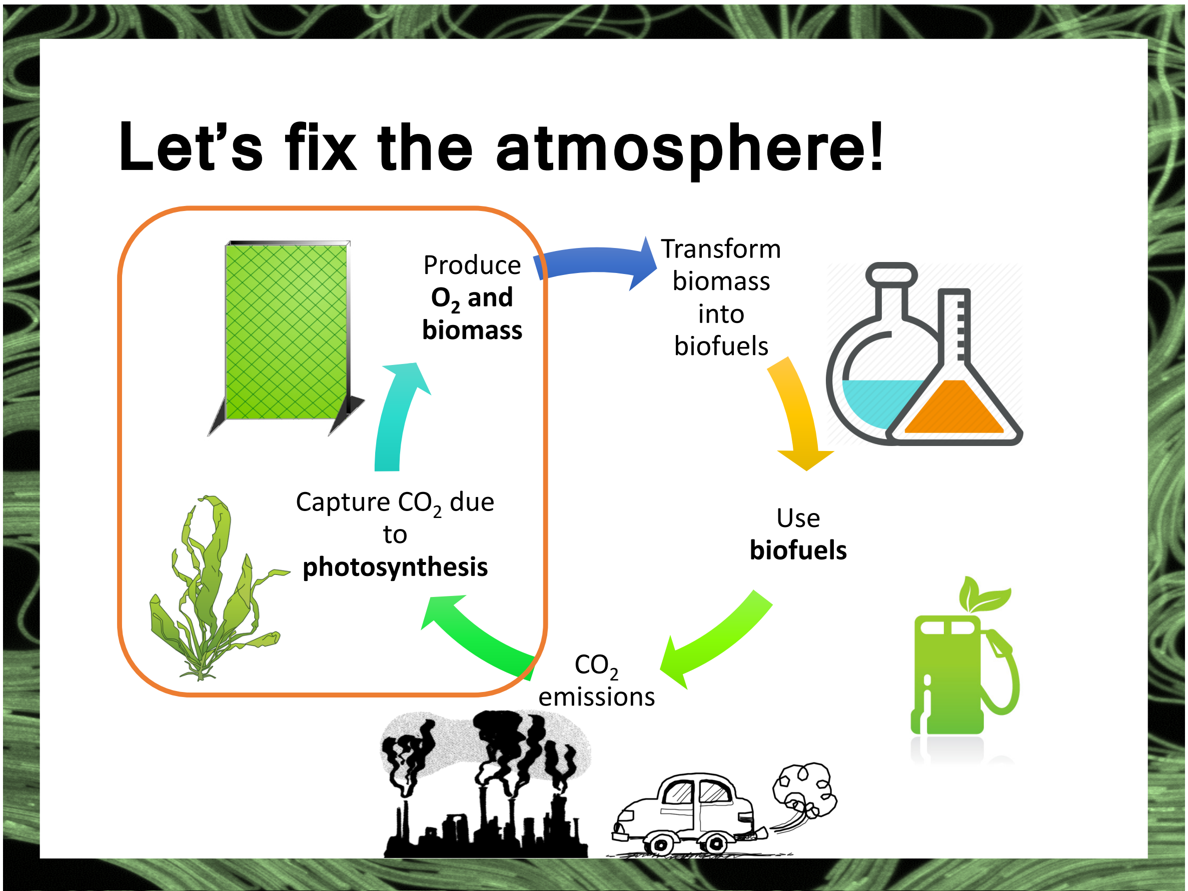
- Reduce CO_2 emissions
- Burning less fuels

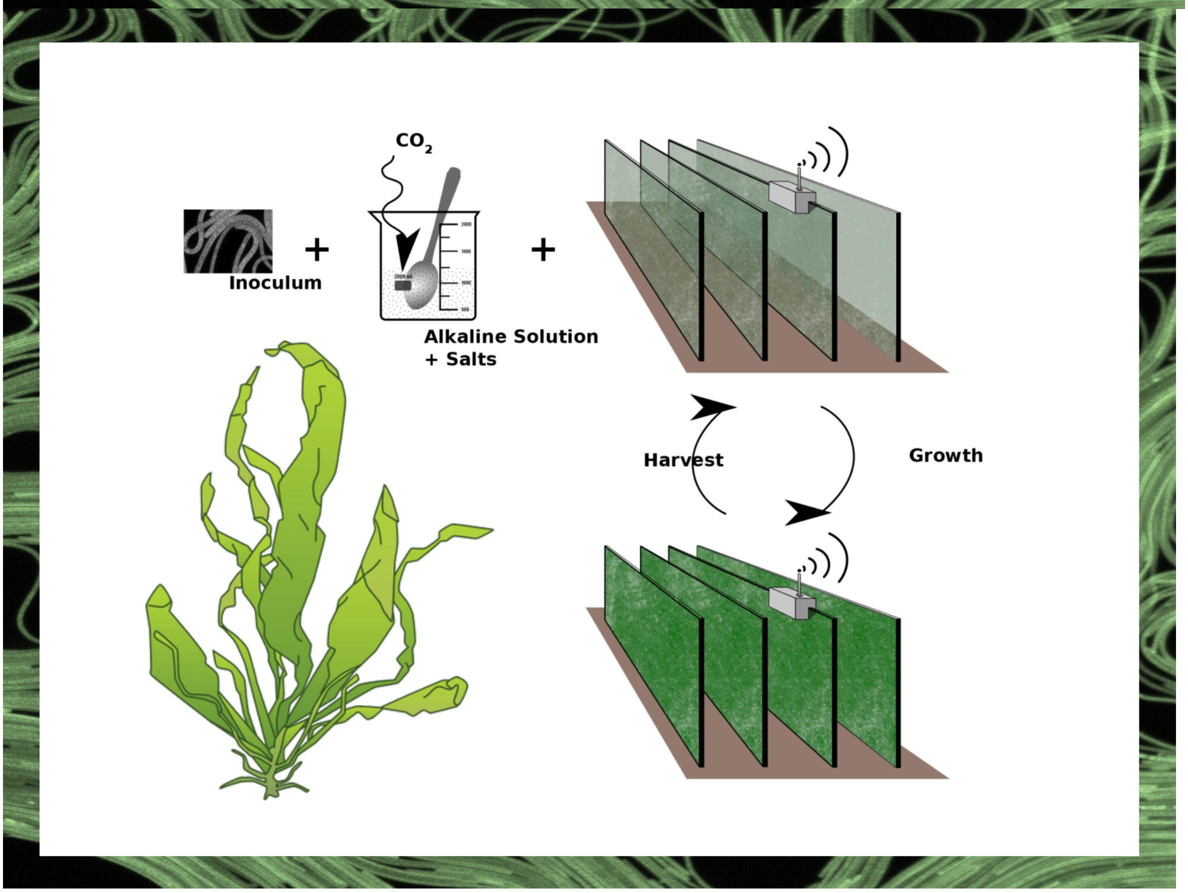
- Use alternative “green” fuels
- Reforestation

- Capture and store carbon in a sink
- …


What
• Reduce CO_2 emis
• Use
• Capture
a sin
• …


What can you do?
Let's solve this!

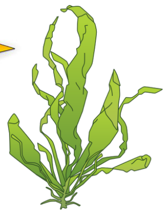

Let's fix the atmosphere!
Produce
O2 and
biomass
Transform
biomass
into
biofuels
Capture CO2 due
to
photosynthesis
Use
biofuels
CO2
emissions


CO2
Inoculum
+
+
Alkaline Solution
+ Salts
Harvest
Growth

We will work together

1. Start growing algae in the PHOTOBIOREACTOR...

2. Keep track of the algae online and LIVE!

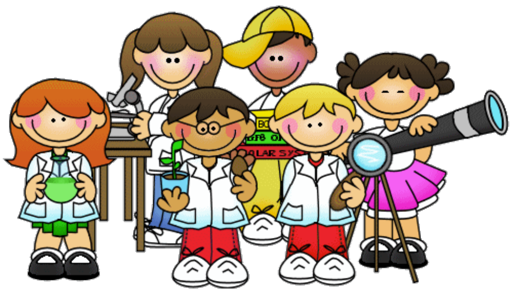


3. Harvest the algal biomass and regrow it...

4. Growing biomass = Capturing CO_2

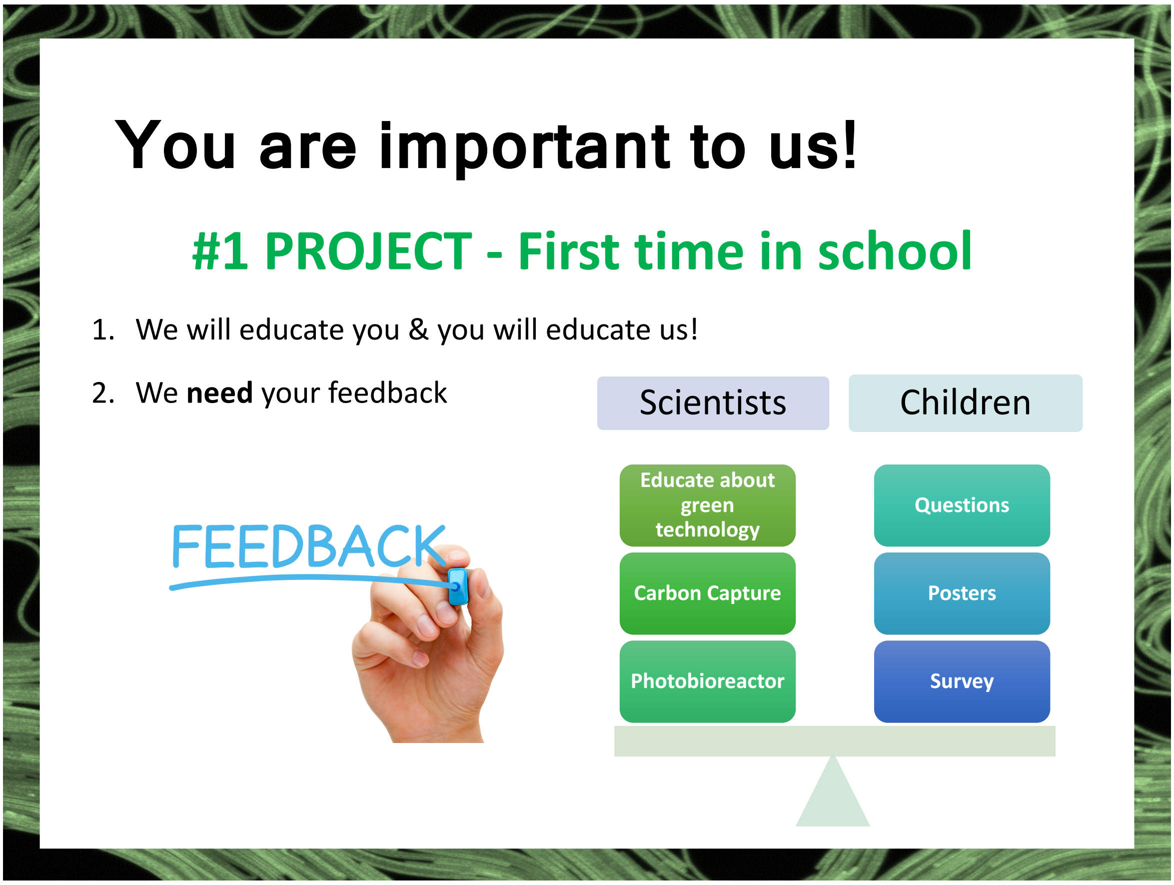
Extra interaction!

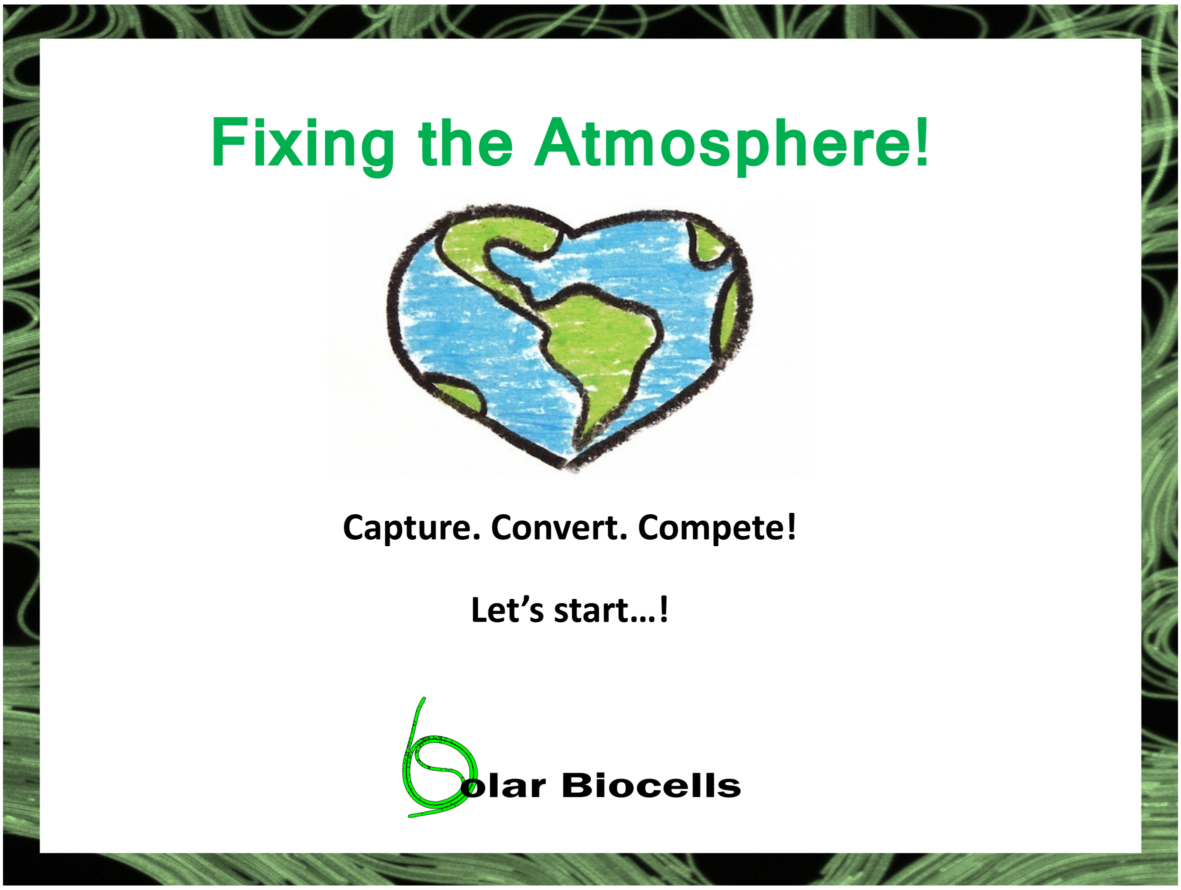
Are you a real scientist yet?



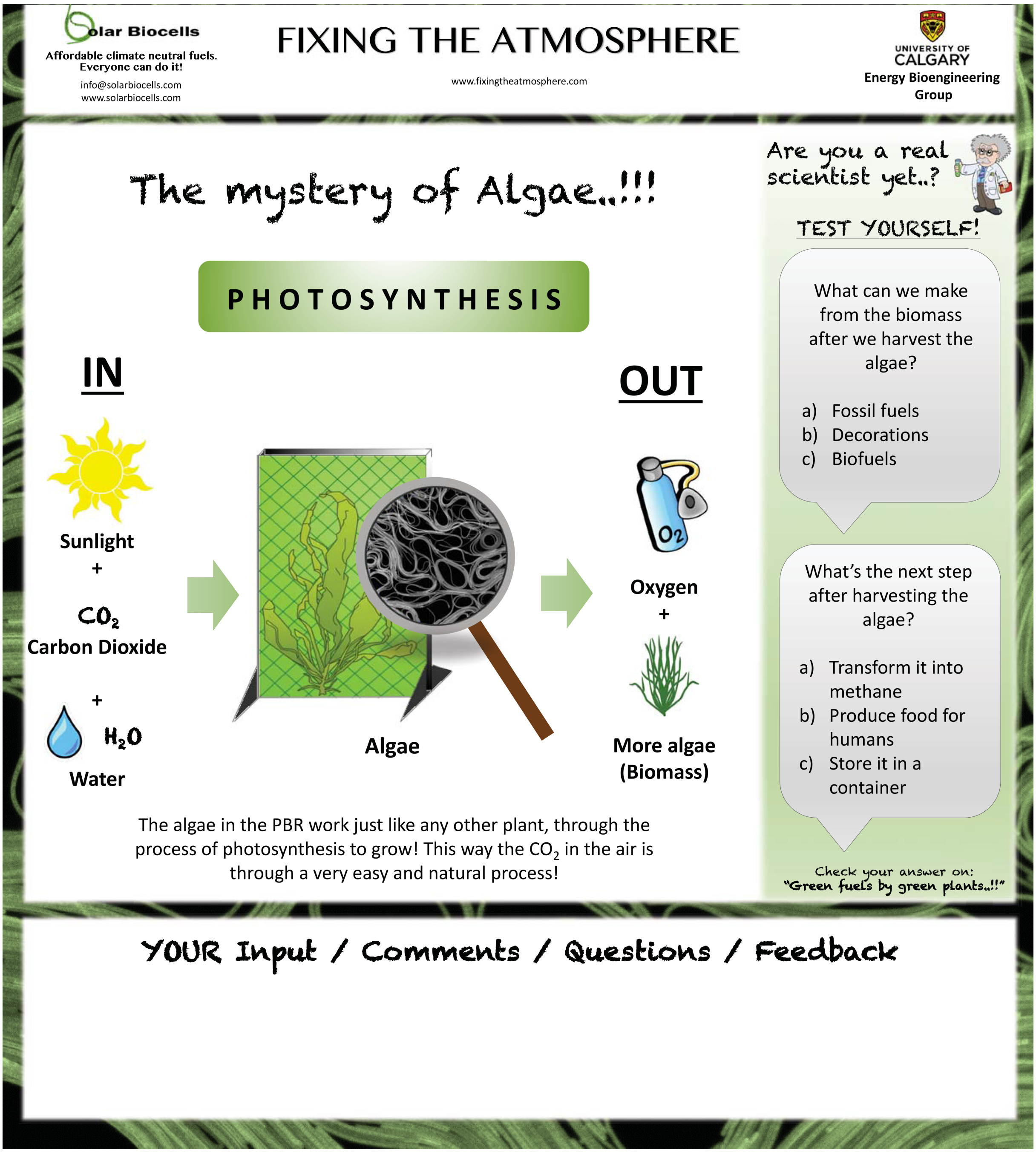
1. **POSTERS**
Can you solve all the questions?

2. **LAB WORK**
Observe and ask all your questions on the next Fresh Air Fridays


You are important to us!
#1 PROJECT - First time in school
1. We will educate you & you will educate us!
2. We **need** your feedback
FEEDBACK
Scientists
Children
Educate about green technology
Carbon Capture
Photobioreactor
Questions
Posters
Survey


Fixing the Atmosphere!
Capture. Convert. Compete!
Let's start…!
olar Biocells

11.9 Interactive posters developed by Daisy Rycquart and Karen Canon-Rubio (2017)



Solar Biocells
Affordable climate neutral fuels. Everyone can do it!
info@solarbiocells.com
www.solarbiocells.com

FIXING THE ATMOSPHERE

www.fixingtheatmosphere.com

UNIVERSITY OF CALGARY
Energy Bioengineering Group

Livestreaming the Algae..!!

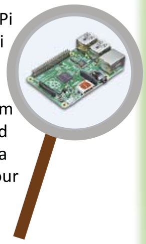
From growing algae to digital information

1. The Sensors

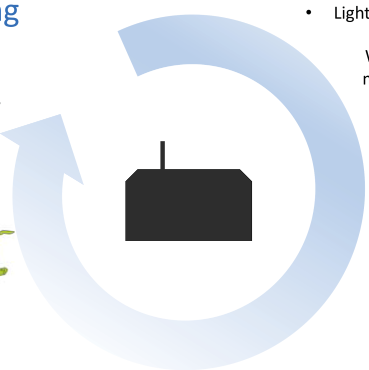
- Temperature
- Oxygen (O_2)
- Light

We measure these 3 things to make sure the process is going well.

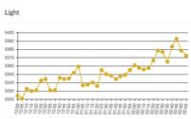
2. The Raspberry Pi



This Raspberry Pi is a useful mini computer. It receives information from the sensors and transports it via the internet to our website!



3. The Website

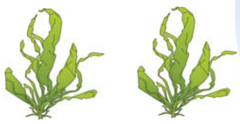


When the sensors collect information, and the Rasberry Pi transfers it to the website. Now we have a live view of what's happening in the PBR..!!

CHECK IT OUT: http://www.2connect2biz.com/mybio

4. The Harvesting

We harvest the algae from the PBR when we see a peak in the oxygen (O_2) level..! This way we prevent toxicity and the algae are ready to produce biofuels a lab..!



Are you a real scientist yet..?

TEST YOURSELF!

What does PBR stand for?

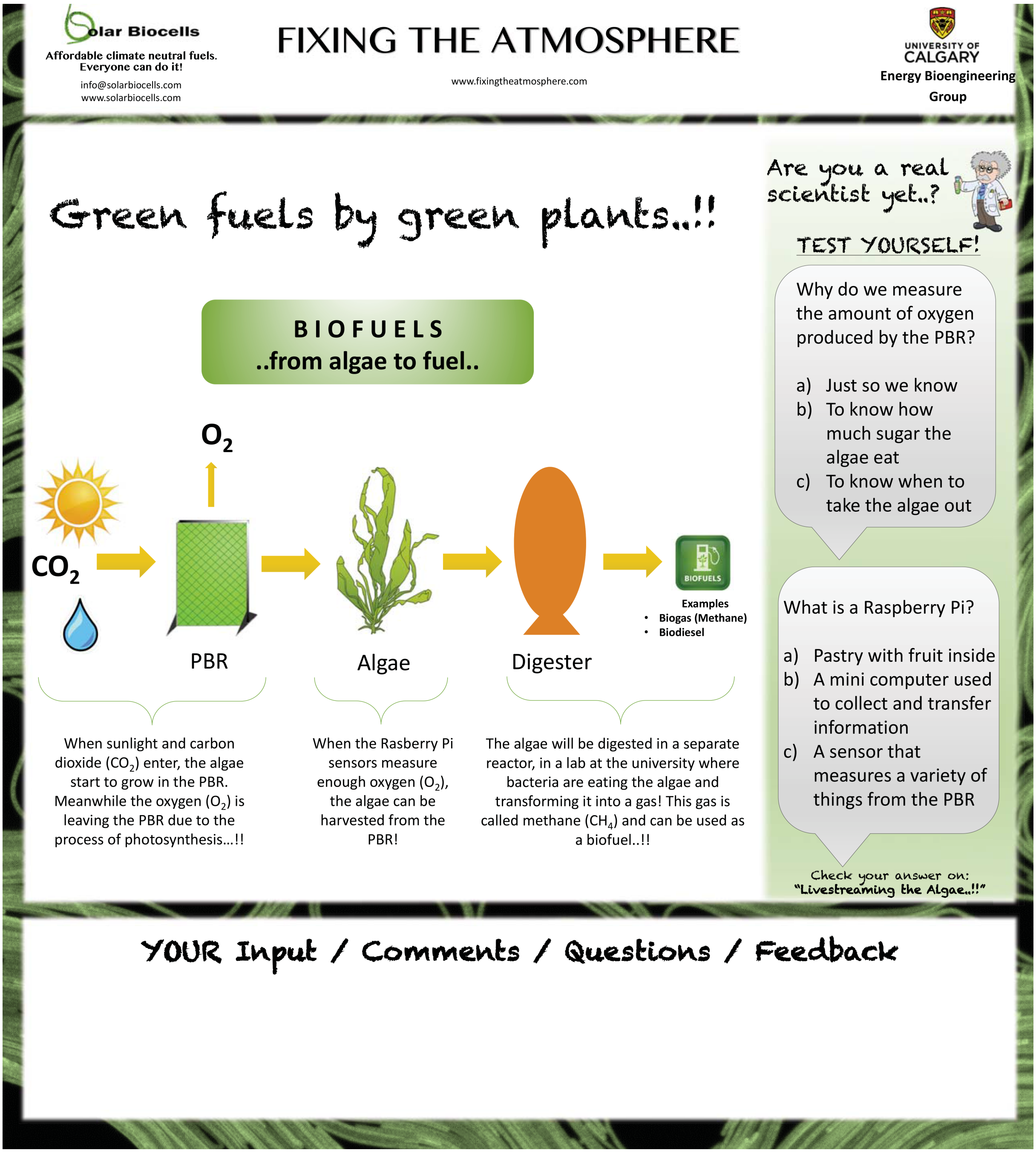
a) Photon bio reactor
b) Picture biological reasons
c) Photo bio reactor

Why do we use a red plastic film over the PBR?

a) Because red is a beautiful colour
b) To create a warmer surface on the PBR
c) To filter the sunlight so the algae will grow better

Check your answer on: "What is this PBR..??"

YOUR Input / Comments / Questions / Feedback


Solar Biocells
Affordable climate neutral fuels. Everyone can do it!
info@solarbiocells.com
www.solarbiocells.com
FIXING THE ATMOSPHERE
www.fixingtheatmosphere.com
UNIVERSITY OF CALGARY
Energy Bioengineering Group
Green fuels by green plants..!!
BIOFUELS
..from algae to fuel..
O2
CO2
PBR
Algae
Digester
BIOFUELS
Examples
• Biogas (Methane)
• Biodiesel
When sunlight and carbon dioxide (CO2) enter, the algae start to grow in the PBR. Meanwhile the oxygen (O2) is leaving the PBR due to the process of photosynthesis...!!
When the Rasberry Pi sensors measure enough oxygen (O2), the algae can be harvested from the PBR!
The algae will be digested in a separate reactor, in a lab at the university where bacteria are eating the algae and transforming it into a gas! This gas is called methane (CH4) and can be used as a biofuel..!!
Are you a real scientist yet..?
TEST YOURSELF!
Why do we measure the amount of oxygen produced by the PBR?
a) Just so we know
b) To know how much sugar the algae eat
c) To know when to take the algae out
What is a Raspberry Pi?
a) Pastry with fruit inside
b) A mini computer used to collect and transfer information
c) A sensor that measures a variety of things from the PBR
Check your answer on: "Livestreaming the Algae..!!"
YOUR Input / Comments / Questions / Feedback

Solar Biocells

Affordable climate neutral fuels.
Everyone can do it!

info@solarbiocells.com
www.solarbiocells.com

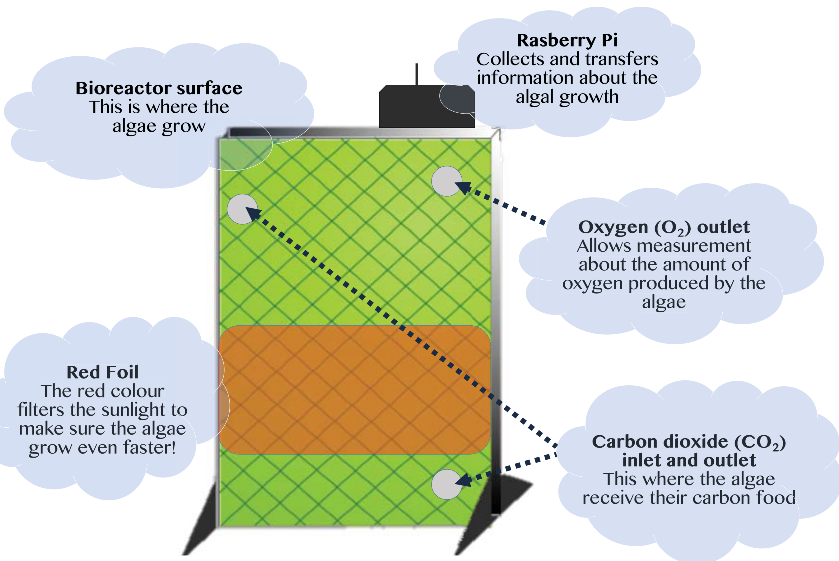
FIXING THE ATMOSPHERE

www.fixingtheatmosphere.com

UNIVERSITY OF CALGARY
Energy Bioengineering Group

What is this PBR..??

Photo Because of the Photosynthesis!
Bio Because we use living bacteria and plants!
Reactor Stands for reaction!



Are you a real scientist yet..?

TEST YOURSELF!

What do algae eat?

a) Carbon dioxide (CO_2)
b) Oxygen (O_2)
c) Sugar ($C_6H_{12}O_6$)

How does our experiment fix the atmosphere?

a) By using oil as a fossil fuel
b) By converting oxygen (O_2) to carbon dioxide (CO_2)
c) By converting carbon dioxide (CO_2) to oxygen (O_2)

Check your answer on:
"The mystery of Algae..!!!"

YOUR Input / Comments / Questions / Feedback

11.10 Letter of consent

11.10.1 Letter of consent for the parent

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:

Marc Strous, PhD
Faculty of Science
Department of Geosciences
Telephone: 403-220-6604
Email: mstrous@ucalgary.ca

Bonnie Shapiro, PhD
Werklund School of Education
Telephone: 403-220-7521
Email: bshapiro@ucalgary.ca

Title of Project:

Climate change and biofuels - Experiential learning in Alberta classrooms - pilot project

Sponsor:

VPR (Vice President, Research) University of Calgary
Seed Grant: Affordable climate neutral fuels from algae

Dear Parent,

This consent form, a copy of which has been given to you, is only part of the process of informed consent. If you want more details about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

The University of Calgary Conjoint Faculties Research Ethics Board has approved this research study.

The Calgary Board of Education has approved this research study.

Purpose of the Study

As part of its Energy Research Strategy, the University of Calgary is pursuing innovation in the fields of algal bio-fuels, with the aim of producing a cost-effective, climate-neutral biofuel. This work has led to a new process that produces fuel from algal growth. Recently, we presented demonstrations of our Project Modules that included an audience of teachers and children at Telus Spark Science Center. We discovered that these groups have great interest in, but very little knowledge about the creation and uses of bio-fuels and how they may be part of the solution to address climate change. The purpose of this pilot project is to engage elementary school students and teachers with the Project Modules to help them learn about how research related to growing simple algae is contributing to the search for new fuels that reduce harmful effects on the environment. University of Calgary scientists and Werklund School of Education science educators will work collaboratively with teachers and students to set up Project Modules in the classroom. Through engagement with the Project over a three-week period, students will learn how to set up a simple experiment to collect data and share information online with scientists and other elementary students. Students and teachers will learn first hand about climate change, the nature of biofuels, CO2 capture, and how scientific investigations proceed. Science educators will also observe and interact with students and teachers in the classroom to learn how they are developing new knowledge and skills. The purpose of the research is to consider what kinds of additional educational resources and experiences might best support learning about biofuels and climate change.

The Alberta Government, and other governments worldwide are actively striving to improve education about climate change, as a key societal challenge for future generations. We realized that our Modules and associated technology offer opportunities to provide education about climate change and participation in scientific research through experiential learning engagements. We believe that the pilot project, with its online learning and data sharing experience has the potential for students to exchange data and ideas with classrooms from all over the world.

What Will Your Child Be Asked To Do?

Students and teachers will participate in the pilot study in two ways. First they will be guided to use equipment to grow algae, capture CO2 from the air and report their findings online. Second, they will engage with the Research Team to help them learn how effective their experiences are in helping them learn about biofuels and climate change.

Prior to the start of data collection, our team will meet with teachers and students in the classroom to introduce the Modules and guide them through the data collection procedures. During additional regular visits and observations to classrooms, the Research Team will learn about student and teacher understandings and experiences with the program.

Students and teachers will be guided in work with the Modules to (1) capture CO2 from the air using algae, and (2) convert the captured CO2 into algal "biomass". The biomass produced looks like a green paste. Students will engage in a simple and safe procedure to work with Project Modules infused with the algae to capture CO2 from the air. They will use a fan to blow air through a bed of CO2-capturing beads. Next, they will mix a salt solution needed for the growth of the algae. The salt solution is poured over the capture beads to transfer the CO2 from the beads to the solution. The solution is then poured into a photo-bioreactor, which is essentially a simple, shallow aquarium. Dried algae are also added to the photo-bioreactor. Over the next several weeks, the class will monitor the light intensity, temperature and oxygen production of the aquarium with using a simple computer and connecting device called Raspberry-Pi. The data will be sent to and collected on our website at the University of Calgary and will show the class how their experiment is proceeding.

The PI and scientist developers have created a spin-off company, Solar Biocells that investigates the potential of using the technology for developing low cost fuel from gases produced during algal growth. The purpose of the classroom research is to assess the educational value of sharing the scientific process, technology and experimentation methods with teachers and students. If the educational value is confirmed, the modules provided to the schools could lead to similar experiential learning about climate change and biofuels to schools on a larger scale as students from other regions share their data. This is expected to be a not-for-profit business, but the potential of creating profit cannot be completely excluded.

The research team will engage teachers and students in short interviews to learn about their experiences with the Modules and to understand their knowledge of biofuels, climate change, C02 capture and algal growth. The purpose of the engagement is to build understanding of the kinds of educational resources and experiences that might be developed to support and facilitate work with the study modules. Some of the questions that will be asked are framed to understand how engagement with the Project modules help students learn to answer some of the following example questions: What is photosynthesis? What are algae? What is CO2 capture? What parts of the experience of working with the Project Modules in your classroom has been most useful to you in building your understanding of how scientists work on environmental problems? Has working with the project helped you to build new ideas about biofuels? Do you think that climate is changing? How do you think cars might be powered in the future?

Participation in the project is completely voluntary. You may elect to have your child refuse participation altogether, or refuse to participate in parts of the study. They may decline to answer any and all questions during interviews with the Research Team member and may withdraw from the study at any time. The classroom teacher will give students whose parents do not want them to participate in the project an alternative assignment.

What Type of Personal Information Will Be Collected?

Information about your child's gender, age and grade level will be collected. Children's names will be placed on survey and data collection sheets but only at the beginning of the research. Thereafter, all names will be changed to pseudonyms to protect individual anonymity. As individuals will not be identified in the research, no other personally identifying information will be collected or reported. In any general reporting of research findings, all references to children, teacher and school names will use pseudonyms to protect individual and school identity. No one other than the Principle Investigator and members of the Research Team will have access to any of the information collected, written classroom observations, audio records and transcripts of interviews, or photographs of children working with project materials. Photographs may be taken of children engaging in the set up of equipment and materials and engagement in work with the Modules for sharing with other teachers and students who are working with the materials. Some photographs may be selected for use in conference presentations. Individual parents will be contacted again and asked for specific permission in these instances.

There are several options for you to consider if you decide to allow your child to take part in this research. You may choose all, some, or none of them. Please review each of these options and choose Yes or No:

I grant permission for my child to participate in the pilot project:	*Yes:* ___ *No:* ___
I grant permission for my child to be interviewed and audio taped:	*Yes:* ___ *No:* ___
I grant permission for photographs to be taken of my child working in the pilot project:	*Yes:* ___ *No:* ___
I wish to have my child remain anonymous:	*Yes:* ___ *No:* ___
I wish to my child to remain anonymous, but you may refer to him/her using a pseudonym:	*Yes:* ___ *No:* ___

The pseudonym I choose for my child is: ____________________

I grant permission for my child to be photographed as they engage with project activities materials: *Yes:* ___ *No:* ___

I grant permission for my child's photograph to be used in conference presentations: *Yes:* ___ *No:* ___

Are there Risks or Benefits if my Child Participates?

Students will work with algae and salt solutions when working with the Modules. Algae are provided that have been obtained from lakes in the Rocky Mountains. They are not known to be harmful but should not be swallowed. The solution used for growth of the algae is soapy and should not be swallowed or make contact with eyes. Beads used for CO2 capture should not be swallowed. Elementary students are exposed daily to similar risks when they interact with other school project materials, for example paste and glue in art and construction projects and fish food used in school aquaria. Global climate change is a topic that can potentially cause anxiety, because of its potentially catastrophic consequences. The Research Team will work closely with the classroom teacher to assure that students handle materials carefully. Students will be supplied with safety goggles and will also use gloves when working with the Modules.

What Happens to the Information My Child Provides?

As stated above, no one other than the Principle Investigator and members of the Research Team will have access to any of the information collected, written classroom observations, audio records and transcripts of interviews, or photographs of children working with project materials.

We want to learn from work with students and teachers in the study how we might best create learning experiences that will be effective and engaging student who are learning about biofuels and alternative energy. The Principle Investigator and the Research Team plan to create curriculum materials that may be used to support a larger Citizen Science Project. The larger project will involve teachers and students collecting data using the Project Modules, who are learning about biofuels and alternative energy, and will be sharing findings online with classrooms all over the world.

If a parent or guardian elects to withdraw his or her child from the research once the study has begun, parents may also elect to have all information collected from them destroyed at that time or they may choose to have information collected to that point remain in the research project data base.

Only group information will be summarized for any presentation or publication of the results of the study. The research data will be kept on a password-protected computer and all hard copy notes or materials will be kept in a locked cabinet only accessible by the Principle Investigator and his Research Team. The research data will be stored for two years on disk, at which time, it will be permanently erased.

Signatures

Your signature on this form indicates that 1) you understand to your satisfaction the information provided to you about your child's participation in this research project, and 2) you agree or do not agree to allow your child to participate in the research project.

In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from this research project at any time. You should feel free to ask for clarification or new information throughout your participation.

I grant permission for my child to participate in the the pilot project: *Yes:* ___ *No:* ___

Child's Name: (please print) ______________________________

Parent or Guardian's Name: (please print) ______________________________

Parent or Guardian's Name Signature: ______________________ Date: __________

Researchers' Names: Marc Strous, PhD and Bonnie Shapiro, PhD

Researchers' Signatures: ______________________ Date: APRIL 5 2017

Bonnie Shapiro ______________________ Date: Apr 5, 2017

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. Marc Strous,
Faculty of Science
Department of Geosciences
Telephone: 403-220-6604
Email: mstrous@ucalgary.ca

Or

Dr. Bonnie Shapiro
Werklund School of Education
University of Calgary
Telephone: 403-220-7521
Email: bshapiro@ucalgary.ca

If you have any concerns about the way you have been treated as a participant, please contact the Research Ethics Analyst, Research Services Office, University of Calgary at (403) 210-9863; email: cfreb@ucalgary.ca.

Or

Superintendent,
Learning Innovation,
Calgary Board of Education
1221 8th Street, S.W.
Calgary, Alberta, T2R 0L4
Researchapplications@cbe.ab.ca

A copy of this consent form has been given to you to keep for your records and reference. The researcher has kept a copy of the consent form.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

11.10.2 Letter of consent for the student

UNIVERSITY OF CALGARY

Name of Researcher, Faculty, Department, Telephone & Email:

Marc Strous, PhD
Faculty of Science
Department of Geosciences
Telephone: 403-220-6604
Email: mstrous@ucalgary.ca

Bonnie Shapiro, PhD
Werklund School of Education
Telephone: 403-220-7521
Email: bshapiro@ucalgary.ca

Title of Project:

Climate change and biofuels - Experiential learning in Alberta classrooms - pilot project

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Dear Student,

We would like to invite you to participate in our research project to learn how children work with materials we have developed in order to understand more about how algae can be used to help improve the quality of our environment. We are researchers from the University of Calgary and will be reading this letter with you to be sure that you understand what is involved and so that we may answer any questions you may have.

What is a research study?

A research study is a way to find out new information about something of interest. Children are not required to be involved with a research study if they don't want to participate.

Why are you being asked to be part of this research study?

You are being invited to take part in this research study to help us learn more about how children work with materials we have developed in order to understand how algae can be used to help improve the quality of our enviro[redacted]ou to be in this study because you are a member of the grade 5/6 class[redacted]ll of your fellow class members, about 50 children, are also being invited to participate in this study.

If you join the study what will you be doing?

- We will be bringing some simple equipment to the classroom for you to work with it. We have built some equipment, two pieces of clear plastic that fit together and we will show you how to put algae on the plastic it so that they will grow when placed in a sunny spot in the classrooms. The algae are safe and the process of putting it on the plastic is also very safe. You will always work with the materials when your teacher is present.
- When we first come to visit, we will ask you to fill out a short survey to learn what ideas you have about climate change and the environment.
- We will be visiting your school and classroom primarily during Fresh Air Friday sessions over three to four weeks. We may also stop into the classroom during that time to look at the materials and speak with you if you happen to be there, before class, during class breaks or at lunchtimes or after school.
- When we visit, we would like to talk with several children about what they think of working with and observing the materials that we are leaving in the classroom. We would like to know what you believe you are learning, what interests you about working with the materials and what kinds of questions you have about the changes you see in the materials. Our conversations will usually take no more than 20 minutes per student.

Will the study help you? This study will help you to understand how scientists are working to develop ways to help protect the environment. You will learn how a simple plant, algae, naturally removes harmful gases from the air. And you will learn how to set up pieces of laboratory equipment to show how much oxygen algae contributes to the air.

Will the study help others? This is a pilot study, meaning that you are the first to be involved in working with the materials and learning experiences we provide. In this study, we want to find out how you are enjoying working with the equipment we bring to your classroom. We also want to find out what you are learning as you are involved in the project and what kinds of questions you have. This information will help us create learning experiences for children all over the world who we would like to invite to participate in the project.

Do your parents know about this study?

We are sending permission forms home with you so that your parents may decide if they want to allow you to participate in the study. You can talk this over with them before you decide.

Who will see the information collected about you?

The information collected about you during this study will be kept safely locked up. Nobody will see it except the people doing the research. The study information that you provide will not be given to your parents or teachers or to other students. You will not be given a grade for this work by the researchers or your teacher.

Do you have to be in the study?

You do not have to participate in the study. No one will be upset if you don't want to participate in this study. If you don't want to be in this study, all you need to do is to tell us.

What if you have any questions?

You can ask any questions that you may have about the study. If you have a question later that you didn't think of now, either you can call or have your parents call Dr. Marc Strous at 403-220-6644 or Dr. Bonnie Shapiro at 403-220-7521 to ask any questions that you have about the study. You can also take more time to think about being in the study and also talk some more with your parents about being in the study.

What choices do you have if you say no to this study?

If you do not want to participate in the study and since the study takes place on Fresh Air Fridays, you will have other options available to you that will be provided by your teacher.

Other information about the study.
This study has been approved by a committee at the University of Calgary that makes sure that all research is conducted in an ethical way. It is called the University of Calgary Conjoint Faculties Research Ethics Board. The study has also been approved by the Calgary Board of Education Ethics Review Board.

If you decide to be in the study, then please write your name below. You can change your mind and stop being part of it at any time. All you have to do is tell your teacher or one of the researchers who visits the class. It's okay. Your teachers, the researchers and your parents will understand and won't be at all upset if you decide not to participate.

You will be given a copy of this letter to keep for your reference.

Please check below, print your name and provide your signature and the date.

Would you like to take part in this study?

_____ Yes. I want to participate in this research study. _____ No. I don't want to participate in the study.

______________________	______________________	______________________
Your name (Printed)	Your signature	Date

Thank you very much for reviewing this letter with us about being part of the study.

Researchers' Names: Marc Strous, PhD and Bonnie Shapiro, PhD

Researchers' Signatures: Marc Strous ______ Date: April 5 2017

Bonnie Shapiro ______ Date: April 5, 2017

Questions/Concerns

If you have any further questions or want clarification regarding this research and/or your participation, please contact:

Dr. Marc Strous,
Faculty of Science
Department of Geosciences
Telephone: 403-220-6604
Email: mstrous@ucalgary.ca

Or

Dr. Bonnie Shapiro
Werklund School of Education
University of Calgary
Telephone: 403-220-7521
Email: bshapiro@ucalgary.ca

If you have any concerns about the way you have been treated as a participant, please contact the Research Ethics Analyst, Research Services Office, University of Calgary at (403) 210-9863; email: cfreb@ucalgary.ca.

Or

Superintendent,
Learning Innovation,
Calgary Board of Education
1221 8th Street, S.W.
Calgary, Alberta, T2R 0L4
Researchapplications@cbe.ab.ca

A copy of this consent form has been given to you to keep for your records and reference. The researcher has kept a copy of the consent form.

A copy of this consent form has been given to you to keep for your records and reference. The investigator has kept a copy of the consent form.

11.11 Experiencing the pilot project 'Fixing the Atmosphere'

The first week of the pilot project, researchers introduced the Fixing the Atmosphere project on Friday morning. During 3 hours, the children were first asked to fill in the survey mentioned before. This survey was done first to determine the children's knowledge and awareness on the topic at the start. After the children finished the survey, the introductory presentation was given by the researchers. During this presentation, the researchers created an accessible atmosphere where children had the opportunity to ask questions and discuss the topics. This way, the researchers and their knowledge was more approachable and not too grasped. After this presentation, the first harvesting process took place. The researchers brought a PBR filled with biomass, so they could show immediately what a filled biomass chamber look like. It also provided information about the health of the algae, which they had to maintain afterwards. Children helped with the harvesting by removing the mesh and scraping the biomass into the provided bottles. During the whole 3 hours, researchers observed the amount of questions the children asked and what characteristics these questions had.
The second week was divided in two contact moments. On Tuesday, the children had the opportunity to rotate in small groups and gain more knowledge about the microalgae they were growing. The first group project was a microscopic view on the algae. The children had to prepare their own slides and had the opportunity to see the algae on a smaller scale. The second group project was an introduction to the posters, where the children were asked to answer the questions as fast as possible. After solving the questions, they were free to write down feedback on post-its and stick them on the posters. The last group project, the children reviewed the YouTube video of the Solar Biocells sampling trip. This is where the algae were sampled from soda lakes by the researchers themselves. It provided information about the alkalinity and gave more insight on the activities of researchers. The Friday after that, there was room for a chat talk with Prof. Marc Strous, leader of the project. He told about his personal experience with the project and children had prepared their own questions for him. After his chat talk, the children were asked again to harvest the PBR. They compared the growth with the week before, and had another hands-on experience with the PBR. During the 2 days, researchers observed the amount of questions the children asked and what characteristics these questions had.
The final week was dedicated to information and debriefing. On Friday, the researchers presented how the downstream-processing was done in the laboratory. More educative support towards biofuels and methane in specific helped the children to understand what was done with the algal biomass. Questions could be asked and moments of discuss were available, to make sure the children had understanding about the presented topic. After this informative moment, the children were divided in 4 groups to have a debriefing moment with the researchers. Interview questions developed by Dr. Bonnie Lee Shapiro were presented to the children, and answers were noted by the children. It provided information about the personal experience of the children, and how the project can be improved in the future. This data is not used in the present research, due to conflicts with the ethical approval for the pilot project.