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Lessons Learned Developing and Running a Virtual, Faculty-Led, International Program on Sustainable Energy in Brazil

Dr. Courtney Pfluger, Northeastern University

Dr. Courtney Pfluger an Associate Teaching Professor at Northeastern University in the College of Engineering. In 2011, she joined Northeastern as a teaching professor in the First Year Engineering program. As part of the First Year Engineering faculty she focusing on curriculum innovations and implementing educational lessons and engineering design projects on sustainability. In 2017, she moved full time into the Chemical Engineering department where she currently teaches Unit Operations Laboratory, Capstone Design, and Conservation Principles. She also developed and has run, for 8 years, a month long faculty led international summer program to Brazil which focuses on Sustainable Energy Technologies.

Lessons Learned Developing and Running a Virtual, Faculty-Led, International Program on Sustainable Energy in Brazil

Globalization in engineering education has become increasingly important, especially when discussing innovating sustainable designs and technologies to help relieve the climate crisis [1]. However, in 2020 the COVID-19 pandemic has ravished the international education community, as travel became close to impossible. Many international faculty-led programs had to re-imagine the benefits of global learning in a virtual space. This paper discusses how a faculty member at Northeastern University developed and executed a virtual, one-month, faculty-led, international program focused on sustainable energy in Brazil. Specifically, for this program we wanted the students to gain knowledge on sustainable energy systems for resilient and climate aware future and understand socio-cultural, economic and environmental impacts drive innovation.

Previous on-ground program

The on-ground program in Brazil ran 7 consecutive years in a row, starting in 2013. The faculty-led program was 5 weeks long, with class sizes that range from 18-24 undergraduate Northeastern University students. The students took two second-year courses, an introduction to chemical engineering course called *Conservation Principles*, and a sustainable energy systems course. The program was enhanced by working with an in-country provider who helped with logistics and collaborations with companies and universities in Brazil. The program spent 2 weeks in Sao Paulo, Brazil and then traveled to experience other cities in Brazil and how they implemented sustainable energies. While on this program, students visited and engages in discussions with sustainable companies and universities. They engaged in interactive cultural activities, such as capoeira and samba lessons, take Portuguese language classes and collaborate with University students in Brazil on a sustainable energy design project.

Specifically, this international, faculty-led program focused on global sustainability issues and how to produce innovate engineering solutions to these problems. Additional added benefits to students who participate in these international experiences are that they become more globally aware and global citizens, more personally and socially aware, and strengthening their career and academic choices [2,3,4]. The desired student learning outcomes of this program are:

1. Understand and solve problems related to scientific engineering principles that govern sustainable energy technologies.
2. Understand engineering, socio-cultural, environmental, and economic issues related to implementation of sustainable energy technologies.
3. Demonstrate outcomes 1 and 2 through collaborating, designing, and presenting on innovative engineering ideas to solve issues related to the Global Grand Challenges as they relate to sustainable energy.

The program met these desired student learning outcomes in three ways: 1. course lectures and discussions on technical, environmental, socio-cultural, and economic issues technologies; 2. site visits to companies, discussing operation, economic, environmental and political impacts, and 3. performing a project with Brazilian Students and Local Government Liaisons or Companies to deeper understanding of the cultural context with implementing sustainable energies.

When the pandemic began in March 2020, it was clear that the traditional program would not be able to run in-country. We developed an online, virtual program with the research question, *"Can we develop and deliver an international virtual program that meets similar global learning outcomes as the previous in-country international program?"*. Next, the details on how that program was developed, executed and learning outcomes assessed will be discussed.

Development of virtual program

A creative virtual program was developed in which students were able to experience similar learning objectives and outcomes about sustainability on a global scale and discussed innovations to these international issues to become globally aware. The program had 18 second year engineering students participate in the virtual international program from our large R-1 private university. Zoom was used to present synchronous lectures and presentations and were also recorded for all students to view outside of class time as well. In addition, a Slack virtual workspace was utilized to have a common space for all those participating in the program to discuss lecture and project topics, ask questions and offer ideas, and to post articles about current events and topics relevant to the program. The Slack channel allowed for spontaneous communication, which has shown to improve intercultural learning in geographically distributed groups of people [5].

To ensure students met the global learning outcomes in the virtual international program, the program was designed with three main strategies that mirrored the in-country activities but in a virtual format. The first was to provide a wide range of guest lectures from multiple companies and experts in Brazil on sustainability and energy. Second was the development of virtual cultural lectures and workshops on Brazilian culture. Lastly, the students performed a project with Brazilian university students and a company to design and innovate sustainability into the company's operations.

Guest Lectures

Previous in-country international partnerships were harnessed to provide guest lectures from global companies, to discuss their sustainable energy technologies and how they make an impact on the environment, society, and economy both before and during the pandemic. Guest lectures were tied to topics discussed in the two courses to supplement and give context to the engineering concepts discussed in the courses. Examples of the technical guest lectures are listed below:

- Lecture on Solar Energy in Brazil by a Professor from Maua Institute of Technology (IMT)
- Lecture on sustainable fuels development and needs by CTC Ethanol Technology Center
- Guest lecture by the Operations Manager of the Itaipu Binational discussing Operations of the Itaipu Hydroelectric Dam and by the Manager of the Environmental Conservation Protections of Itaipu
- Lectures by industry leaders at Comerc Energia and MegaWhat to discuss energy data management and the sustainable energy market
- Suzano Paper Pulp Company on operations of their plant and sustainable technologies they have implemented in the company

Cultural Workshops

Secondly, the students took part in weekly culture workshops and discussions to learn about Brazilian culture. The topics included history, music, cuisine, and language. The students performed research and discussed these aspects of Brazilian culture and how they influence sustainable practices and policies. Each week a new topic was introduced with a lecture from a Brazilian culture teacher hired by our international provider. Each lecture included an activity where students researched a specific person or topic of their interest from lecture, posted a written reflection, and commented on other students' reflections using the asynchronous online discussion board, Slack. The following class virtual gathering would include group discussions in break out rooms on Zoom and having a discussion on what they picked from that lecture topic that interested them and why. In that group break out session, they would pick the best researched topic and use it make a video about at end of course with all the best-chosen ideas for each lecture topic. The topics each week were: 1. Influential Brazilians Personalities, 2. Brazilian Music and Festivals, and 3. Biomes of Brazil.

The program also offered interactive cultural engagement activities such as a synchronous Capoeira tutorial and a cooking class to make famous Brazilian dishes, such as pão de queijo and brigadeiros. Both these events included discussions on their history and how they are culturally relevant today in Brazil. These events were both fun and educational for the students to understand some of the culture of Brazil.

Inter-cultural Project

Lastly and most importantly, the students worked with Brazilian engineering students from Maua University to perform a project in collaboration with Suzano, a sustainable paper pulp company located in Brazil. Suzano provided five areas the company would like to improve their sustainable practices. The students are split into five teams, each focused on a certain sector of their business. Specifically, the five sectors were:

1. Inlet raw material transportation
2. Outlet product Pulp transportation
3. Energy consumption and efficiency of mill
4. Alternative fuel sources for lime kiln process
5. Heat energy and water efficiency pulp plant

The teams performed research, developed, and designed a proposed plan in which Suzano can become more sustainable in the designated sector. This project required the students to gain technical knowledge on their sector's processes and the impact their sector has on the sustainability of the company and its goals. The teams then collaborated to innovate new solutions and develop a plan for the company to be more sustainable, looking at its resources and needs. They applied engineering concepts and discussed international policies that impact the company's sustainable goals. Teamwork was particularly important for the success of this project, especially given the online format of the program. Team charters were used to ensure an agreement was established within the group on how they planned to work together.

Virtual Team Dynamics

To ensure the geographically distributed teams worked together effectively, the groups had a team discussion and developed a team charter that discussed how they were going to work together and ensure equitable and inclusive team performance [6, 7]. They discussed goals for collaboration,

including when and how they plan to work together. They discussed how they plan on working together to meet the timeline of deliverables, expectations about said deliverables and how they plan to ensure each team members ideas and contributions are acknowledged and valued. These team discussions allowed for discussions on conflict resolution and intercultural differences in teamwork which allows for shared context to improve team dynamics [8]. This was an important piece of working on an inter-cultural, online team project to ensure team cohesion and distribution of work [5]. These discussions lead to conversations about how teamwork is done in Brazil and the USA and the differences in work cultures.

Project Details and Outcomes

The project was split into three deliverables: 1. Background research on a Google Site, 2. Group presentation and question and answer (Q&A) session, and 3. Group report. The project assignment with detailed explanation of deliverables can be found in **Appendix A**. The first deliverable was to have the students build a Google Site with their background research on their given sector. Google site allows synchronous online collaboration which enabled students to work together from multiple locations at the same time. The deliverables for this part of the project were to do extensive research on their sector topic, such as what is currently done, what background science or technologies govern this sector, and what inefficiencies can they determine to innovate new solutions for. This was due week 3, which was halfway through the program, as benchmark for the project. These background sites were assessed by the professor and by a sector engineering expert from Suzano to ensure accuracy and project trajectory.

The second deliverable, which was due in week 5, was a 12-minute group presentation on Zoom with a Q&A session. This was attended by all students in the program and Suzano engineers helping with the project. The Q&A session was used to ask questions and offer improvements on the innovative sustainable designs the student teams developed. The teams then had a week to make improvements to their designs and write a final report, which was deliverable three.

The third and final deliverable was a group report with proposed ideas to improve sustainable practices in their given sector for Suzano. They had to apply calculations and perform data analysis learned in the courses they were taking during the program. Specifically, they were assessed three main sections:1. Introduction and Background, 2. Detailed Proposal, and 3. Quality of Written Proposal.

First, the introduction and background which was worth 35% of the report grade. The introduction and background for their sector included: a description with background, usages of energy and/or materials, the need for sustainable energy and/or materials, problem statement, and project objectives. Next, they had to provide a detailed sustainable proposal worth 50% of the report grade. The proposal needed to include a detailed action plan on how they would innovate the sustainability of their sector with detailed ideas, designs, and calculations using materials and energy balances proving sustainable practices would lead to a more sustainable manufacturing plant for Suzano. They had to demonstrate efficiency and saving techniques that reduce consumption of energy and/or materials with designs that took safety of the plant into consideration. Their proposal had to include a feasible economic assessment of proposed ideas and discuss environmental, societal, and economic impacts of their designs. Lastly, they were evaluated for the quality of the written report worth 15%, specifically looking at the clarity and

quality of communication, organization, technical voice, and having a minimum three scholarly journals referenced. Examples of student project outcomes from reports can be found in **Appendix B**.

The project ended with a one page write up on individual contributions and reflection on the experience. Specifically, students were asked to discuss how the program connected with their future goals such as major, coop, career aspirations, environmental impacts, their experience working on the global aspects of the project and working with international students, and what they learned from the overall experience. As seen in some of the student comments from the reflection assignments below, they found the experience valuable to understanding cultural differences and how that pertains to sustainability and engineering design.

"Working with the Brazilian students as well as being able to partake in discussions/ lectures with people from various Brazilian companies was really great as I was introduced to issues and approaches that I may not have come across through my more traditional American education."

"The experiences I gained from completing this project will be very relevant for my goals in the future as my major of Chemical Engineering and minor of Environmental Studies. I have learned when choosing to design a system to make a structure more energy efficient while minimizing environmental damage through the sourcing of the materials."

"The global aspects of the project and working with Brazilian students has truly been a valuable cultural experience for me. This experience has shown me nuances within the United States' and Brazilian cultures, and others' perspectives and knowledge as a result of their environment. walk away from this program with newfound knowledge and cultural understanding."

"This experience gave me much more insight into how companies work to meet sustainability goals and how engineers can tailor solutions specific to the company needs to make those accomplishments possible."

"I think that it is important to retain a global mindset and open perspective relating to many things in life, but I feel that this is especially important when talking about sustainability. Climate change is something that has been caused by many different nations and it will continue to affect us on a global scale if drastic preventative measures are not taken worldwide. This is why I thought it was so interesting to hear about the contrast between the USA and Brazil in terms of renewable energy goals and progress."

"I enjoyed overall interaction with Brazilian students (and our university's students) in this class. It was very nice to be able to interact with other students in this capacity while we are still in quarantine and learn about their lives and cultures along the way."

Student Evaluation Results

In addition to the personal reflections, the students also completed a program evaluation survey after the program. Figure 1 demonstrates the results of this survey when the students were asked about overall virtual program satisfaction. The survey had three choices: exceed expectations, met expectations, or failed to meet expectations. It found that 50% of the students (N:10) said program exceeded their expectations and the other 50% said that it met their expectations.

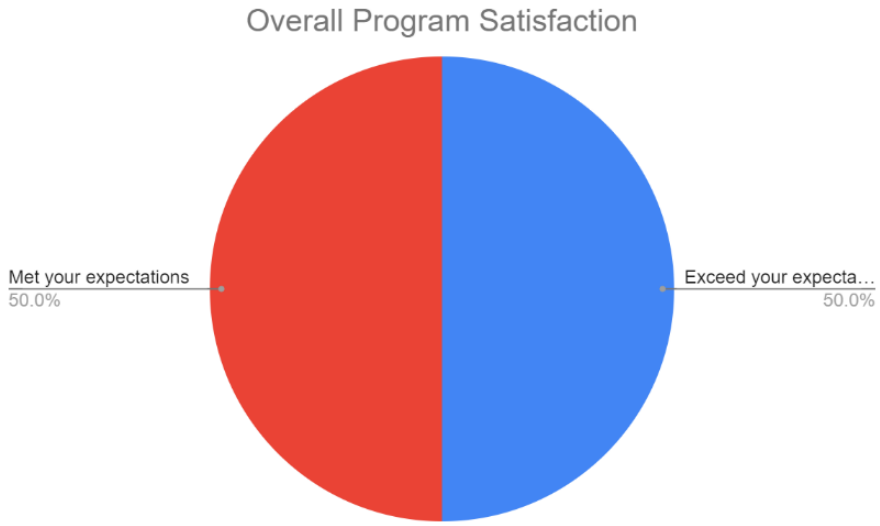

Figure 1: Results from Survey on overall student satisfaction of the virtual program

The students were asked how they would evaluate the company project with Suzano. They could choose from excellent, good, average, or poor. The students' responses indicated that 60% of the students said good and 40% responded excellent, as shown in Figure 2.

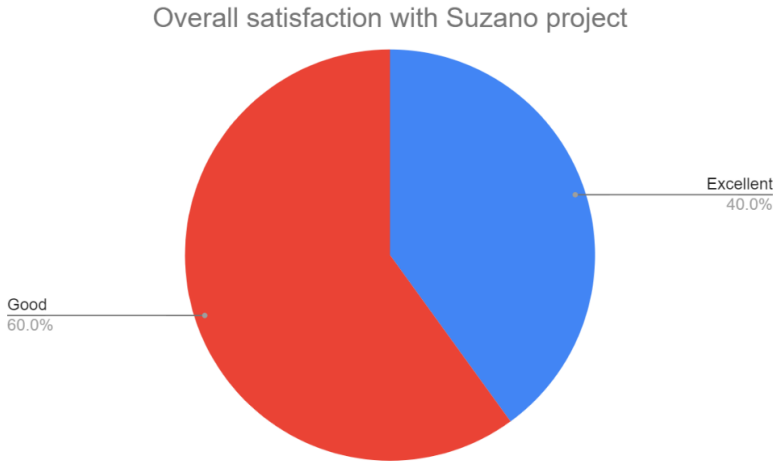

Figure 2: Results from students responses to evaluation survey asked their satisfaction with project where they collaborated with a Brazilian company, Suzano, and Brazilian University students.

The survey also asked the students to identify the skill they felt they developed the most during the program. The students were able to choose from: intercultural competence, intellectual growth, personal growth, global citizenship, professional development, interpersonal skills, or a write in answer. The results shown in Figure 3 found that 30% of the students found intercultural competence as their most developed goal. While another 30% indicated professional development and 30% intellectual growth, and 10% global citizenship. These results indicate that their virtual programs can have many intellectual, professional, and global learning outcomes for the students.

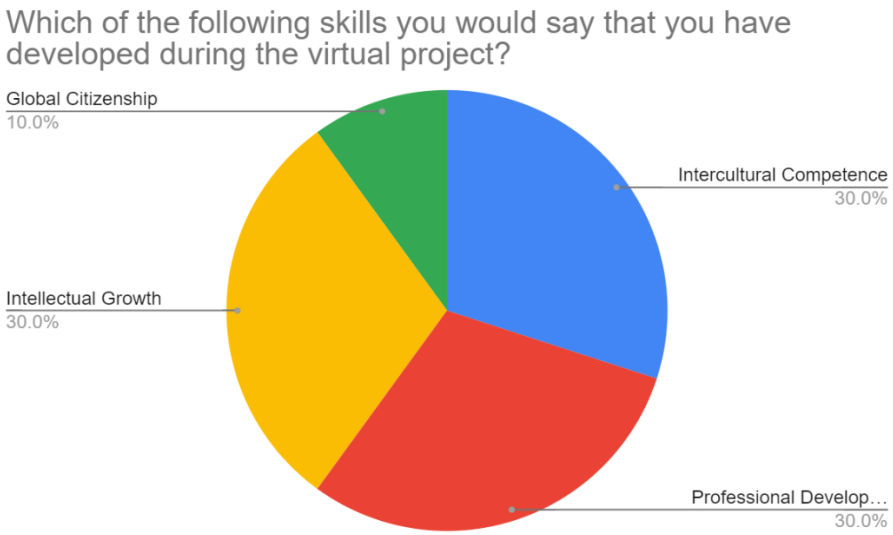

Figure 3: Students' responses from program evaluation survey on global competencies

The students also gave written feedback on the program as part of the survey. The students' responses when asked "what was the highlight of the course? What was your favorite assignment or activity?" are below:

- *"I enjoyed the interactive experiences, the cooking class and capoeira workshop. Not only were they fun, but they added a bit more depth to some aspects of Brazilian culture that we learned about in the culture lectures."*
- *"My favorite assignment was the cultural challenges because they gave us the opportunity to do research and learn more about Brazilian culture as well as interact with the Brazilians."*
- *"My favorite aspect was the Suzano project. I feel that I actually got to know some of the students better and learned about Brazilian culture from the Brazilian student, which is difficult to achieve through online learning. I also enjoyed having a real-world application of class concepts with room for creativity and further research."*
- *"The Suzano project was my favorite assignment for the course. It was really cool to be able to apply what we had learned to a real-life scenario."*
- *"I was really happy with how the program went, especially having been moved online with such short notice. It was a really great opportunity."*

Through the students' responses and project outcomes, it was discovered that the students gained valuable global knowledge through discussions with Brazilian students and company leaders to apply engineering practices to sustainable needs for the company. The positive responses from the students demonstrate the success of student learning and global understanding from the program. Their participation in this interactive learning experience to apply course content to a sustainable, global challenge indicates that the learning outcomes of global engineering education can be done in a virtual environment to enhance global competencies and learning.

From the faculty leader prospective, it was found that the students were able to meet the same engineering learning outcomes from the virtual global engineering program as they would have from the in-country program. The students were able to interact with Brazilian companies and

students and foster community through spontaneous communication and apply engineering knowledge to a real-world project. However, the virtual program cannot fully meet the international, in-country learning experience from a personal growth perspective. Global experimental learning is strengthened when students are interacting in another culture with all their senses. Cultural competence is achieved when students are immersed in another culture which takes them out of their own culture comfort [9]. This immersive cultural competence is hard to achieve in the virtual global programs. In conclusion, virtual global experience programs work well for cross-cultural engineering education project-based learning but may not achieve the same cultural competencies that an in-country program would achieve.

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Appendix A: Project Description and Overview

Improve Sustainable Practices in Suzano Paper Manufacturing Plant

Goal: You will help design and suggest improvements for Suzano Pulp Manufacturing Plant to be more sustainable. They have identified 5 sectors/processes that need to be addressed and improved to reduce the company's energy and material usage. These 5 sectors/processes are:

- ✓ **Raw material transportation (inbound):**
- Based on the information provided in the presentation, how to reduce the fossil fuel consumption (diesel) of the trucks that carry the wood to the wood handling patio?
- What are the fuel alternatives that we can replace them in an economically viable way?

- ✓ **Product Pulp transportation (outbound):**
- How to reduce the consumption of fossil fuel of the fleet that transport pulp to ports?
- What are the fuel alternatives that we can replace them in an economically viable way?

- ✓ **Energy consumption and efficiency of mill:**
- Based on the information provided in the presentation, which would be the most viable to reduce energy consumption among the various equipment available at a pulp mill?
- If we compare an old pulp factory with a modern one, as shown in the presentation, what would be the actions to reduce energy losses in one or the other?

- ✓ **Alternative fuel sources for lime kiln process:**
- What are the viable alternatives to further reduce the usage of Natural Gas in the lime kiln?
- Could hydrogen from the chemical plant or methanol (from evaporation) be viable alternatives to replace NG?
- Is there another viable alternative to replace NG in the lime kiln?

- ✓ **Heat energy and water efficiency pulp plant**
- Considering the energy cycle inside a pulp plant, can you describe how to use less heat to produce pulp?
- Is there a way to reduce the amount of water use in the plant?

Overview of outcomes: Three parts:

1. Background Google Site due May 26

2. Final 12 minute Video Presentation DUE June 12 at 12pm EST posted on Slack #general

3. Live Q&A on Zoom on June 12 at 1:30pm EST

3. Final Proposal Report (5-7 pages) Due June 18

Role: You are a college student working in collaboration with university students in Sao Paulo to help devise a plan to lead the company to a more sustainable production plan.

Audience: Your primary audience is the supervisors and heads of Suzano Paper Company.

Product: Presentation to supervisors and heads at Suzano on your proposed implementation of sustainable practices and energies for your sector. You will build background research and proposal guidelines on a google site as a group. The final product is a 5-7 page written proposal and a one page executive summary to the supervisor summarizing the plan your group has outlined.

Due Dates per Stage of Project:

3 Stages:

1. Project Part 1 DUE May 26 - Background research on sector (25% Grade)
2. Final Project Video Presentation DUE June 12th – 12 minute Video presentation for proposed sustainable improvements (25% grade)
3. Final Report DUE June 18th Proposal report (50% grade)

Suzano Project Part 1

DUE May 26

Background research on the sector you were assigned

Each team sector will collaborate to make a **Google Sites page** fulfilling the requirements of Stage 1 of project answering the prompts below:

4) Briefly describe your sector with background that has been done already and the challenges it may face. What are the usages of energy and/or materials in this sector for the company?
5) Explain the need for sustainable energy and/or materials for your sector and how they can be implemented in the company.
6) Research current practices of your sector are, including their usages and needs. Use this research to recommend certain sustainable technologies or practices to meet the Low Emission or Material Strategy goals, detailing the pro and cons of the technologies and/or practices, and explaining and calculate how the new technologies and/or practices would decrease emissions.
7) Describe how your sector impacts the environment, society & culture, and economics, both positives and negatives. Research data and statistics comparing with other companies in US and Brazil (OR Sao Paulo and Boston).
8) Research and detail what sustainable technologies and/or practices are available for this sector. Established and new, impacts on environment, society, and economics.
9) Are there policies for this sector that can help reduce their impact on global climate change, better our future environment, and energy consumption. (i.e. Energy efficiencies, clean water or air regulations, waste removal, raw materials, transportation of waste, raw, and/or products). How might the policies in the Brazil differ from ones in the US?
10) What are the needs for the company in your sector? (i.e. save money, reduce waste, reduce by-products, manufacturing safety)

Suzano Project Final

12 minute Video Presentation DUE June 12 at 12pm EST

5-7 page Final Proposal Report DUE June 18th at 11:59pm EST

As a team, you will write a proposal to the supervisor detailing how the company can be more sustainable with the plan you have outlined for the sector you are assigned to. The final video presentation and report should **summarize what you found in the background section in Part 1 AND** should detail:

- Detailed action plan on how you would innovate the prompt(given) for your sector
- Describe the ideas and designs to make your sector more sustainable.
- Prove your proposed plan/design will be more sustainable by:
    - Including **calculations** that detail and explain how the implementation of these technologies and/or practices will lead to a more sustainable manufacturing plant for Suzano (i.e. calculate reduction in fossil fuel use, reduction in GHG emissions, reduction in raw material usage by recycling materials, reduction in waste products). **This should be done by implementing material and energy balances.**
- Include efficiency and saving techniques that should be implemented to reduce consumption of energy and/or materials.
- Provide images/ drawings/ sketches on how these technologies/designs/plan would be implemented for your sector.

You need to have all references in IEEE format. You need to use and reference at least three scholarly journals.

Individual Assignment DUE June 19 at 12pm EST

Final Project Reflection and Contribution Write Up

Write a one page INDIVIDUAL write up on your individual contributions for the project. Reflection on the experience, such as the topic and how it can be relevant for your goals in the future (major, coop, career aspirations, environmental impacts). Also discuss the global aspects of the project and working with the Brazilian students. How did you learn from this overall experience?

Appendix B: Examples of Student Work from Project

Appendix B.1: Group 5 - Implementation of Solar- Biomass Boilers to improve heat energy and water efficiency pulp plant explanation and images

Solar-Biomass Boilers

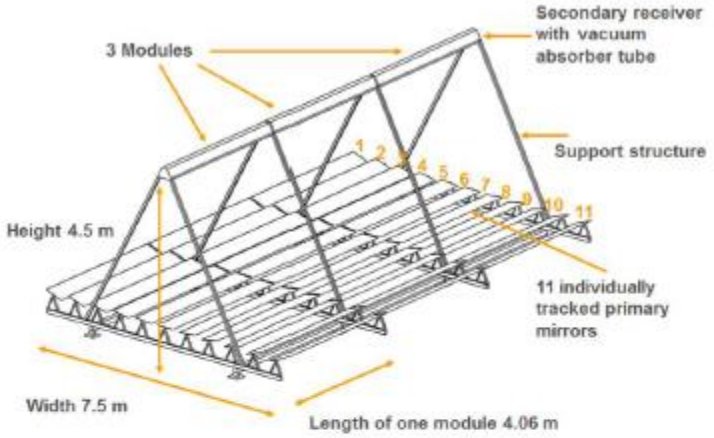
Suzano currently utilizes a biomass boiler in order to generate steam to power the turbines. Solar-biomass systems utilize the cogeneration of solar thermal technology and biomass technology. If Suzano was to install solar thermal energy to cogenerate steam alongside the biomass boiler, this would increase the steam generation of the plant, as well as reduce the consumption of resources.

Converting from a biomass-only system to a solar-biomass system would allow Suzano to cut down on their resource consumption. For example, hybrid solar-biomass systems, when compared with biomass only systems, would save 29% of biomass and land usage, as well as up to $24.8/GJ/a in land savings [10]. As with most solar technology, heat is collected from solar thermal systems and burning biomass during the day. However, at night when solar thermal energy is unavailable, the biomass boiler system will run at full capacity [12].

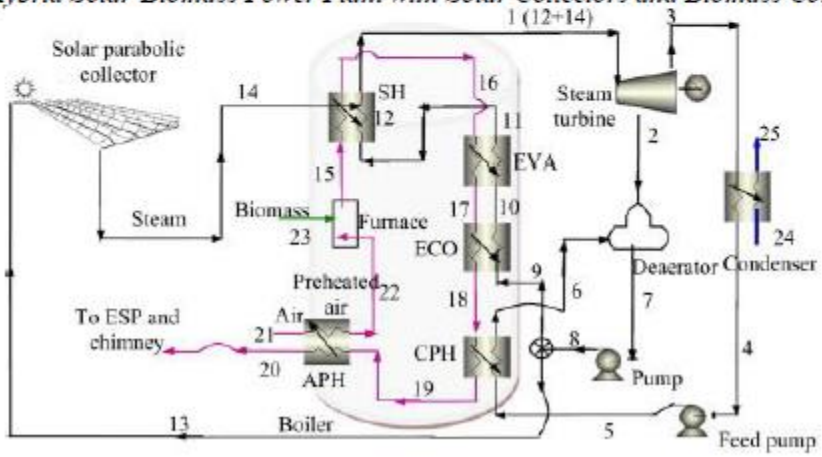
Fresnel Collectors are an efficient way of collecting solar thermal energy, as seen in Fig. D1. Fresnel Collectors are linear concentrating, solar thermal collectors that are optimal for the industrial scale, such as Suzano's paper and pulp plant. For example, the Fresnel Collector LF-11 can provide heat up to 400ºC and 120 bars. Fresnel Collectors operate by collecting direct solar radiation from several rows of single-axis tracking mirrors onto a stationary receiver. This receiver contains a vacuum tube that collects the heat in order to transfer it directly to the application. Fresnel Collectors are beneficial due to their simple direct steam generation, low operating costs, simple integration, long lifespan, ground or roof installations, and low wind load. Furthermore, Fresnel-biomass systems require the lowest specific investment of solar thermal options. When compared with other solar thermal options, such as the solar tower that is the most efficient (39.2%), the Fresnel option is the best commercially because the low cost of the Fresnel Collectors outweighs the benefit of more electricity generation from the solar towers [13].

Some specific data metrics about the Fresnel Collector LF-11 is that each standard module's thermal output is 13.82 kW. The total installation surface area is 454 W/m2. The maximum operating temperature is 400ºC and has a power range of up to 30MW. The maximum efficiency of the collectors, when the sun is at 5ºC transversal zenith angle, is 71%. The levelized cost of additional electricity output of linear Fresnel Collectors is about $628/MWh [11]. Fresnel Collectors cost roughly $168/m2, which would be about $76,272 total cost for implementing the Fresnel Collectors [14].

D.1 - Fresnel Collector LF-11



D.2 - Hybrid Solar-Biomass Power Plant with Solar Collectors and Biomass Combustor



Appendix B.2: Group 4 - Implementation of Solar energy for alternative energy source to improve the sustainability of the lime kiln in the pulp process

Proposal of Sustainable Ideas

While Suzano has made many strides towards becoming an increasingly sustainable and renewable company, a few changes to the lime kiln process can help bring Suzano to the forefront of sustainable innovation and technological advancement. By first implementing a solar thermal heating system to indirectly heat the lime mud feed, then continuing the use of hydrogen and methane as fuel sources, and third utilizing lignin to account for any remaining energy demands, Suzano can further reduce its carbon footprint from the highly emissive causticization process.

The primary method to create a greener lime kiln is to use an alternative energy source in order to provide the necessary heat for the kiln to function. Numerous alternatives were considered while researching a solution, including hydrogen, biomass, and methanol. Ultimately, it was decided that the best solution would be solar power, with lignin as a supplemental source. Solar was chosen due to its ability to decrease emissions by using a renewable resource, and lignin was selected because it is carbon neutral, easy to implement, and readily formed at pulp mills [4]. The other alternatives also have their own issues, such as the biomass alternatives requiring heavy changes to implement in order to prevent damage to the kiln from fuel contaminants [1]. Furthermore, both hydrogen and methanol (in its carbon neutral form), despite being green alternatives, were overlooked due to both sources being costly to produce and purchase [14][15]. In addition, Suzano already uses hydrogen and methanol as supplements to natural gas in their current lime kiln production, which will remain in the new plan [Appendix A.3]. Both lignin and solar derived power fit Suzano's goal to reduce emissions and waste while remaining profitable.

Calculated reductions from proposed methods in this section are based on the material balance in Figure 1. For every 1 kg of CaO produced, another 0.786 kg of CO_2 are produced 1.786 kg of $CaCO_3$ are fed into the system [4]. This process requires 5.57 MJ of energy per kg of CaO product and consists of 0.660 MJ of heat energy lost based on the difference between operating temperature and the temperature required for the reaction [Appendix A.1.] [4].

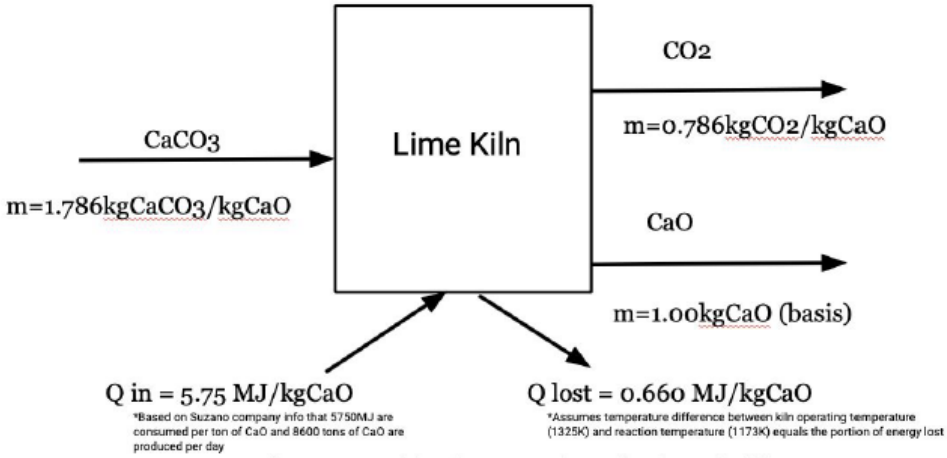


Figure 1: Material and Energy Balance for a Lime Kiln [Appendix A.1.] [4].

The following detailed analysis of the viability of solar energy and lignin fuel implements the material balance seen in Figure 1 to identify the extent to which proposed solutions can benefit suzano from an environmental and economic standpoint. While the CO_2 byproduct of the reaction cannot be reduced, focusing on cleaner and more renewable energy sources can eliminate reliance on natural gas to reduce Suzano's carbon footprint.