ENGINEERING

McMaster University

Final Report

McMaster Recycling Plant Project

ENGINEER 2PX3 – Integrated Engineering Design Project 2

Tutorial 14

Recycling-32

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Executive Summary

McMaster might consider an on-campus MRF (material recovery facility) to follow its sustainability initiatives and create a zero-waste campus. The problem statement that guided the design process was: Design an automated recycling plant located at McMaster that helps sustain a zero-waste campus for the local McMaster/Hamilton community.

We used the PERSEID framework (**P**erformance + **E**nvironmental + **R**egulatory + **S**ocio-cultural screening for **E**ngineering **I**ntegrated **D**esign) throughout the design process for this project in order to help select potential designs. In particular, environmental and performance constraints like waste throughput and carbon footprint were essential for the MRF.

The finalized design for the MRF has the location of lot M on the McMaster campus. The equipment in the plant uses a hybrid of custom equipment and standard equipment. The optical sorting unit inside the MRF uses a combination of FTIR sensors as well as Raman spectroscopy sensors. This design performs well when it comes to performance constraints has the best sorting accuracy thanks to the combined use of FTIR and Raman Spectroscopy sensors. Environmentally it has an optimal energy usage for its recycling processes. It also satisfies all the guidelines and laws necessary for the MRF to be able to be built and perform its duties. Additionally, it is located away from the center of McMaster campus, which means that people on campus will not have deal with smell or noise issues. In this design there are also implementations of the sorting function in the optical sorting unit as well as the overall recycling flow of the MRF.

There's also a wide variety of steps we would pursue if we were to expand on this project. One thing we would do is to improve the efficiency of the sorting function inside the optical sorting unit. This could involve using different simulation tools, like one made in MATLAB, to better understand which type of sensor is better at identifying certain types of plastic. We could also create more simulation prototypes to better understand how effective our solution would be at handling McMaster's waste. For example, we could do an analysis on how much time and energy it would take for waste collection and transportation to the MRF from McMaster. The recycling flow would also be expanded to include all types of recyclables and not just plastic (e.g., metal). In addition to this, there would be a lot more community involvement in the design process. This could be done by having shareholder surveys throughout the design process so shareholders could share their opinion on the design.

Introduction

Background

One of the major environmental issues facing the world today is the global warming caused by the increasing amounts of greenhouse gas emissions. One of the main reasons for this increase in greenhouse gas emissions is the widespread usage of plastics in our day to day lives. Plastic appears often in packaging and disposable products, which unfortunately means that it ends up in a landfill or even the ocean through microplastics. A stark visual example of this plastic pollution is the great pacific garbage patch, which spans an area twice the size of Texas [1]. Recycling is a great way to reduce the amount of plastic waste. However, Canada only ends up recycling 9% of plastic, which is well below the percentage needed to stop global warming [2]. Unfortunately, McMaster is no different with campus producing 2400 tonnes of waste with about half ending up in the garbage [3]. Fortunately, our project proposes a solution to this issue: creating a MRF (materials recovery facility) on McMaster campus to help sustain a zero-waste campus. Such a facility could also be a learning opportunity for students at McMaster in environmental sustainability.

Stakeholders

When creating a potential MRF its important to consider the impacts that it would have on potential stakeholders. As such our group listened to some of the potential concerns that some individuals in the local McMaster/Hamilton community have [4]. From these concerns our group identified the potential stakeholders them being waste collection workers, the City of Hamilton, and the students, staff, and administration at McMaster.

The primary stakeholders for a potential MRF would be McMaster staff, students, and administration. This is because they would be directly affected by an MRF because of its location on campus. There are three potential locations of the MRF on campus them being JHE, 10-acre field, and lot M which have a variety of pros and cons. JHE is located right in the middle of campus, which means lower transportation costs. However, because of its location there might be more noise and smell complaints. 10-acre field is a wide-open space that allows for a construction of a MRF sufficiently large enough to handle the amount of waste that McMaster produces. However, its proximity to Cootes Paradise may raise concerns about the environmental risks of MRF (e.g., waste being improperly disposed of). Lot M is located the farthest away from the center of campus, so it probably would have the least noise and smell complaints for people on campus. However, because of its proximity to the local Hamilton community there may be noise and smell complaints coming from them. University administration also needs to find a way to fund a potential MRF, whether that comes from government grants or university resources. Additionally, students might be worried about potential increases in tuition needed to fund a potential MRF. University administration also might be concerned about the safety protocols and laws that need to be followed for a MRF, which may increase costs further.

The secondary stakeholders for a potential MRF would be the City of Hamilton and its residents as well as waste-management workers. The City of Hamilton might be worried about the MRF following the proper regulations necessary for it to exist. Existing waste collection schedules would also need to be changed, which would affect waste-management workers. Additionally, waste-management workers might also be also concerned with increased workloads especially if there is a lot of manual steps in the MRF.

Problem Statement

The problem statement that guided the project was: Design an automated recycling plant located at McMaster that helps sustain a zero-waste campus for the local McMaster/Hamilton community.

PERSEID Constraints

Table 1

List of Design Constraints

List of Technical Constraints:	Category	What parameters of your design are affected/associated with this constraint?	Strategies/comments
Ontario Waste Management regulations	Regulatory	Storage of waste Amount of waste being processed at a time	Follow the Ontario regulations for waste disposal
Municipal By-laws	Regulatory	Location of Plant	Area/size of plant must abide by the standards given from municipal by-laws.

McMaster University Health and Safety Policy	Regulatory	Location of the plant (Noise and air pollution from plant)	-Recycling plant should be in a space where Hamilton and McMaster community will not be affected by the pollutants emitted by the plant
Cleanliness and smell of the recycling plant	Socio-cultural	Location of MRF Visual appeal of the MRF Storage of waste	Ensure waste is stored out of sight, maintain a scheduled cleaning routine that ensures the plant stays clean.
Community perception of the recycling plant	Socio-cultural	Location of the MRF Visual appeal of an MRF	Ask for suggestions from McMaster community to see where they would like to have the plant.
Safety of students and staff	Socio-cultural	Level of student participation in the recycling process Safety regulations	Ensure thorough protocols are put in place before allowing any student participation
Sorting accuracy	Performance	Operating Frequency Speed of conveyor belt Cleanliness of waste	-Setting speed in algorithm at a rate that does not dramatically affect sorting accuracy. -Ensure contamination has been removed from waste earlier in the process
Waste throughput	Performance	Operating Frequency Size of conveyor Speed of Conveyor Frequency of Sensors	-Have a high enough operating frequency to handle waste given -Ensure maximum speed is obtained without negative effects on accuracy -Design physical system with equipment large enough to have an acceptable throughput

Level of automation	Performance	Operating Frequency Sensors used Sensor frequency	Optimizing the operating and sensor speed, ensuring both are able to keep up with one another.
Carbon footprint	Environmental	Location of the Plant Choice of process units Waste Disposal	Keep emissions limited Try to keep transportation to a minimum Dispose of wastes in an eco-friendly manner
Energy consumption	Environmental	Choice of Process Units Size of Plant Waste throughput Hours of Operation	Buy energy efficient units Reduce size of plant while maintaining technical constraints (sorting accuracy, waste throughput, etc.)
Any direct local environmental concern/hazard	Environmental	Location and Size of plant Waste disposal	Dispose of wastes in an eco-friendly manner Try to not disturb local species

Table I describes the list of design constraints that our group considered in the PERSEID framework (**P**erformance + **E**nvironmental + **R**egulatory + **S**ocio-cultural screening for **E**ngineering **I**ntegrated **D**esign). This framework involves filtering potential design alternatives through the constraints to select a final potential design that is possible to implement [5]. The constraints for the performance aspects include constraints like sorting accuracy, automation, and waste throughput. These constraints make sure that the MRF performs to the standards necessary for the MRF to be effective. Environment constraints are especially important for this project since the whole purpose of having the MRF is to be sustainable. These constraints include carbon footprint, energy consumption, as well as any direct local environmental concern. Regulatory constraints are necessary to ensure that the MRF is legally possible to build and use. The regulatory constraints considered include following McMaster safety and health guidelines as well as government laws and guidelines. Sociocultural constraints are important to make sure the community is satisfied in using the MRF. The sociocultural constraints for this project are mainly determined by our stakeholder concerns and include concerns like community perception and cleanliness and smell. The table also describes the parameters affected by these constraints (e.g., sorting accuracy is affected by the sensors used in the optical sorting unit). These parameters help describe the choices that our group has made in our design alternatives. Additionally, the table includes the strategies our group brainstormed in order to help fulfill these PERSEID constraints in our designs.

Scope of the Report

The scope of this project was mainly determined by the project module [6]. The main deliverables for the project were a flowchart of the recycling plant, design recommendations for the optical sorting unit, as well as the computer program used in optical sorting. In this design report plastic is the main recyclable focused on with there being 9 main types (HDPE, LDPE, PP, PVC, PS, PU, PC, PET, Polyester) in the simulation. Additionally, details about the actual waste collection process (e.g., transportation of waste to the MRF) were not discussed in full detail.

Conceptual Design

Design Alternatives

Design 1:

The first design for a potential recycling plant has the location of lot M. The equipment in the plant uses a hybrid of custom equipment and standard equipment. The optical sorting unit uses a combination of FTIR sensors as well as Raman spectroscopy sensors.

Design 2:

The second design for a potential recycling plant has the location of 10-acre field. The equipment in the plant uses only standard equipment. The optical sorting unit in this design uses only Raman spectroscopy sensors.

Design 3:

The third design for a potential recycling plant has the location of JHE. The equipment in the plant uses only custom equipment. The optical sorting unit in this design uses only FTIR sensors.

Decision Matrices

Table 2

Decision Matrix

Evaluation	Weight	Design 1	Design 2	Design 3
Environmental	3	2	1	3
Regulatory	2	3	2	1
Performance	3	3	2	1
Socio-cultural	2	3	1	2
Weighted Total		27	15	18

To select our final design for this project from the three above designs, our group used a decision matrix. The decision matrix had the criteria of the PERSEID constraints coming from earlier on in this design report. When deciding the weights, our group decided that performance and environmental were more important than regulatory and socio-cultural constraints. Good performance in the environmental constraints was considered necessary since the main goal of the whole project is to have an MRF that is sustainable for the environment. The performance constraints are also of the highest priority. This is because adequate performance is also necessary for the MRF to be able to handle the waste that McMaster produces on a daily basis. Socio-cultural constraints are still important so that the local community is satisfied by the MRF. However, they are not quite as important to the overall MRF as environmental and performance constraints. The same goes for the regulatory constraints, which are obviously necessary so the MRF can legally perform its duties. In short, the goal of this design matrix was to select a final design that goes above and beyond in satisfies the performance and environmental constraints while still satisfying the socio-cultural and regulatory constraints. The overall scores for each category will be expanded upon in the next section.

Design Evaluation

Design 1

Performance

This design performs quite well when it comes to performance constraints. The main constraint this design performs well in is in sorting accuracy. This design has the best sorting accuracy thanks to the combined use of FTIR and Raman Spectroscopy sensors. The use of a combination of standard and custom equipment allows for a good price to performance ratio in terms of equipment. This design also has a high enough waste throughput for McMaster's waste output thanks to its location in Lot M. However, the recycling process for this design would take a longer time to develop than competing designs thanks to the need to interface standard and custom equipment.

Environmental

This design performs adequately when it comes to the environmental constraints. The main environmental consequence of this design is the distance the MRF is from campus. This is because the MRF is the farther east away from the center of campus, which means that transportation is required to transfer waste to the MRF. This means that the carbon footprint for this design is the highest of all designs. The energy consumption is in the middle of all the designs.

Regulatory

This design performs well in the regulatory constraints. This design satisfies all the guidelines and laws necessary for the MRF to be able to be built and perform its duties. The location of this design (that it is far enough away from the center of campus) means that it easily fulfills McMaster's health and safety policy. As such, it would be easier to convince McMaster administration that the MRF is safe for students and staff on campus. Development costs are also in the middle of all the designs.

Socio-cultural

This design performs well when it comes to fulfilling socio-cultural constraints. The design is located away from the center of McMaster campus, which means that people on campus will not have deal with smell or noise issues. However, Hamiltonians might complain about the closer proximity that lot M has to their residential areas. Parking in lot M needs to be removed for the construction of the recycling facility, which may be unpopular. However, there are many parking lots at McMaster with most being way closer than Lot M so we predicate that there would not be much backlash.

Design 2

Performance

This design also performs quite well when it comes to sorting accuracy. The biggest boon to this design is the potential size of MRF allowed by its construction at 10-acre field. A larger MRF means a higher waste throughput, which means that this design will easily be able to handle the waste produced by the McMaster campus. The sorting accuracy of this design is adequate thanks to the use of Raman Spectroscopy sensors. Using standard equipment reduces the cost of maintenance and building the MRF in turn for less optimal performance.

Environmental

The main way this design suffers is in the environmental constraints, which it performs the worst at of all the designs. The 10-acre field location is far away from the center of campus. This in turn results in an increase in carbon footprint caused by the transportation required to transfer wastes to the MRF. Additionally, the location of the MRF on 10-acre field occupies some of the limited green space on campus. The proximity to Cootes Paradise also poses an environmental risk to the endangered animals that live there.

Regulatory

This design also poses a lot of regulatory concerns. This design satisfies all the guidelines and laws necessary for the MRF to be able to be built and perform its duties. The location of this design (that it is far enough away from the center of campus) means that it easily fulfills McMaster's health and safety policy. As such, it would be easier to convince McMaster administration that the MRF is safe for students and staff on campus. However, the main concern of this design would be any extra environmental regulations that need to be followed as a result of the proximity of 10-acre field to Cootes Paradise. These regulations could limit the size of the MRF, which in turn, would hurt the waste throughput of the design. Development costs are also cheaper than the other designs because of the use of standard equipment vs. custom equipment.

Socio-cultural

This design also performs poorly when it comes to the socio-cultural constraints. The design is located away from the center of McMaster campus, which means that people on campus will not have deal with smell or noise issues. However, people might disapprove of the MRF based on the proximity to Cootes Paradise and the environmental damage it could potentially cause. Additionally, extracurricular teams like the McMaster Rugby team will not approve of the removal of the space used for their extracurricular activities.

Design 3

Performance

This design performs adequately in the performance constraints; however, it is outperformed by the other designs. The main boon for this design is that it has optimal connectivity due to the fact it uses an entirely custom-made system. However, this will add a considerable amount of time to the development process as developing and interfacing the custom equipment will undoubtedly take a lot of time. The main performance downside for this design is the limited size of an MRF that could fit in the JHE. This means that the waste throughput of the design might not be high enough to handle the amount of waste that McMaster produces. Additionally, the sorting is accuracy is adequate thanks to the use of the FTIR sensors.

Environmental

This design has the best performance of all the designs in the environmental constraints. Transportation of wastes to the MRF is easy due to the central location of the MRF on campus. This means that this design has the lowest carbon footprint of all the designs. Additionally, the smaller MRF size has the advantage of lower energy usage than competing options.

Regulatory

This design also poses a lot of regulatory concerns. This design satisfies all the guidelines and laws necessary for the MRF to be able to be built and perform its duties. However, there might be more regulations to follow and consider due to the MRF being located directly in the heart of McMaster campus. There might be questions about how safe it is for the MRF being in JHE where there will be students and staff. Additionally, due to the use of custom equipment, the cost and development time for this design will be much greater than the other designs.

Socio-cultural

This design performs adequately in socio-cultural constraints. There is a high likelihood of noise and smell complaints due to the location of the MRF in JHE. Additionally, JHE might have to be closed for an extended period to allow for the construction of an MRF inside it. However, as a benefit this design allows the greatest interaction between students and the MRF. A design like this is also the best for creating learning opportunities for future engineers at McMaster as there can be more student interaction with the design.

Final Proposed Design

Description

Using the design matrix from the previous section, our group selected design 1 to be the final design for the project. To reiterate design 1 was the design located at lot M and used a combination of FTIR and Raman Spectroscopy sensors for sorting as well as a combination a combination of standard and custom equipment. This design performs the best in the performance constraints as the combination of Raman Spectroscopy and FTIR sensors yields the highest sorting accuracy of all the designs considered. Additionally, the potential size of the MRF is large enough to handle the amount of waste that McMaster produces on a daily basis. In terms of regulatory constraints this design also performs better than the competing designs as there is not any overarching regulatory concerns. Socio-culturally this design also performs well as the distance from the center of campus reduces noise and smell complaints. Additionally, there should not be many complaints about the MRF replacing some parking in lot M. The main way this design suffers is in the environmental constraints due to the distance of the MRF from central campus. However, the design performs adequately enough in the environmental constraints to ensure that it is sustainable environmentally. Taking all of this into account design 1 has the best overall performance in the PERSEID constraints, which is why our group selected it to be our final design for this project.

Model

Simulation

To evaluate our final design, mainly in the performance aspects, a python simulation was used that was provided in the project module. The simulation simulated the optical sorting unit inside the MRF. Inside the simulation containers with an unknown plastic type are passed through an optical sorting unit and identified using a sorting function. The simulation outputs the overall sorting accuracy, time, and number of containers processed after completion. In addition to the sorting function, our group also had control over parameters like, the conveyor speed, conveyor width, number of containers to process, and sampling frequency. Sensor data in the optical sorting unit is stored in a pandas (python module) series. Specifically, the two types of sensors we had access to were FTIR and Raman Spectroscopy sensors. Using the sensor data for each type of sensor our group used matplotlib to create a graph of the spectrums, which can be seen in figure 1 and 2 below. A specific thing to note about the simulation is the trade-off between waste throughput and sorting accuracy in the simulation. Increasing conveyor speed results in a decrease in sorting accuracy as more containers are missed. The number of containers missed can be mitigated by increasing the sampling frequency. However, this results in more noise in the sensor data, which decreases sorting accuracy as more containers are misidentified [7]. As noted earlier both waste throughput and sorting accuracy are key performance constraints, so it is important to find a good balance between them.

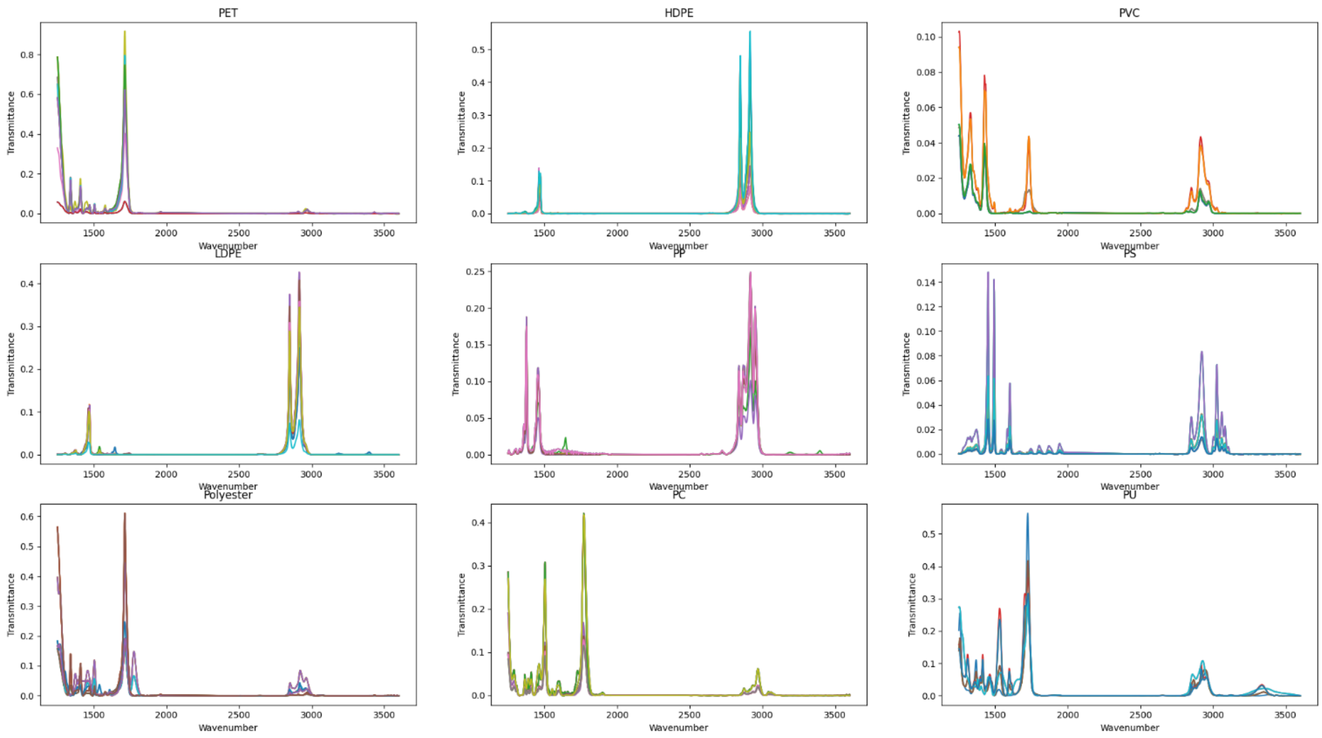


Fig. 1. FTIR Spectrum

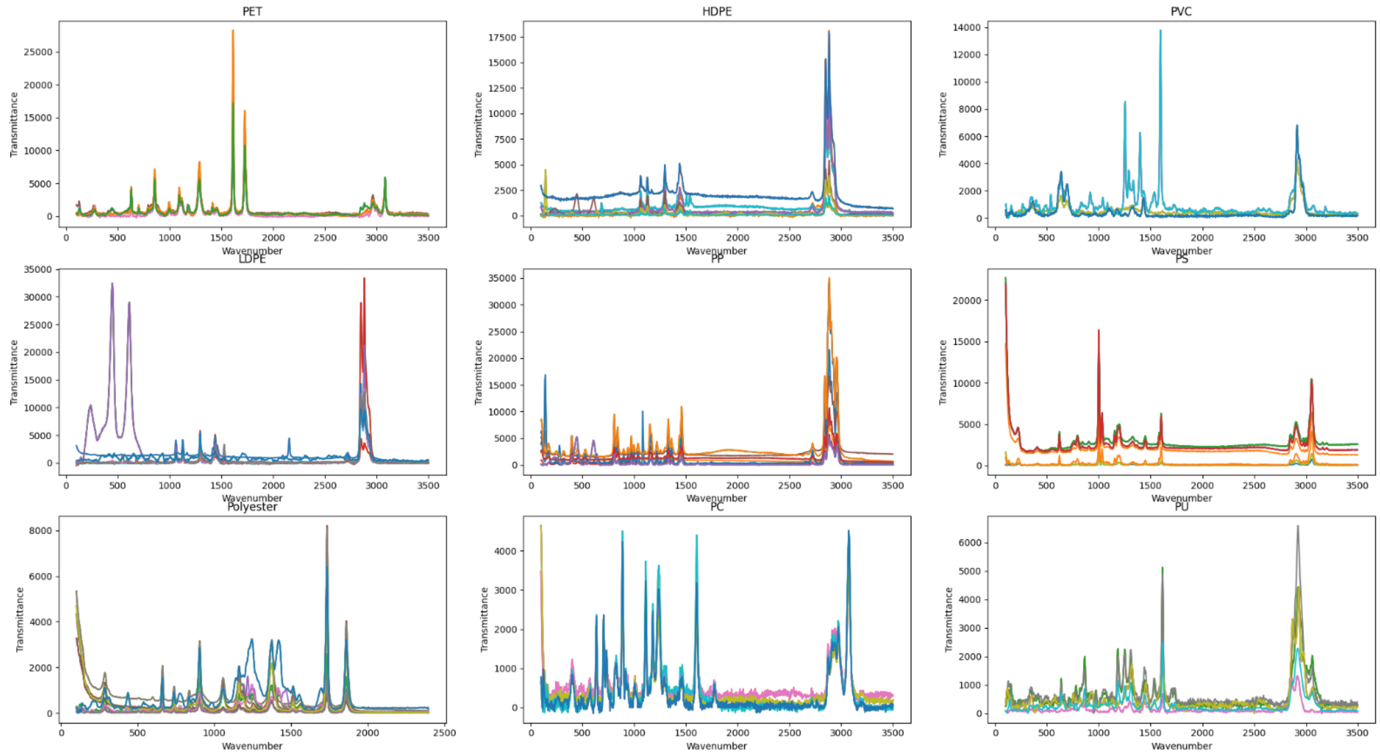


Fig. 2. Raman Spectroscopy Spectrum

The way the sorting function for the optical sorting unit works was to split the plastics into two categories based on their chemical composition. This is primarily based on whether the maximum sensor value lied in the first or last half of the FTIR spectrum. One of these groups consisted of HDPE, LDPE, and PP plastic. The other group consisted of PET, PVC, PS, Polyester, PC, and PU plastic. The similarity in these groups can be seen on how similar their spectrums look in figure 1 and 2 above. From there the individual plastic type could be identified using local maxima related to the spectrum of each type. This was the most difficult part of the sorting function and was the most prone to errors due to noise. An example of this difficulty can be seen in trying to differentiate between LDPE and HDPE because their spectrums are very similar due to them having a similar chemical composition. The sorting function checks if there is a local maximum in the 1300-1400 wavelength range in the IR spectrum to see if the plastic is LDPE. It's worth noting that misidentification at this stage due to noise is not as bad since a plastic is only likely to be misidentified as a similar plastic (e.g., HDPE being confused for LDPE). Plastics misidentified at this stage can be resorted manually by workers. The code for the sorting function can be found in the appendix.

In terms of performance the simulation processed 100 containers at a waste throughput of about 0.35 containers/second with a sorting accuracy of 80%. This is sufficient for the amount of waste McMaster produces on a daily basis. This is considering that we could use multiple optical sorting units in parallel to help improve the waste throughput in the whole process. The main way we balanced the trade-off between sorting accuracy and waste throughput was to put a hard constraint on the sorting accuracy (80%). From there the sorting function used the other parameters (like conveyor speed, sampling frequency, etc.) to maximize the waste throughput based on that constraint. The reason for that hard constraint on sorting accuracy was to minimize the amount of manual work needed. This is because if a plastic is misidentified in sorting it needs to manually be put into the correct category by workers. In conclusion, the simulation shows that our final design can handle the performance constraints of waste throughput, sorting accuracy and automation.

Recycling Process

For the recycling flow of the MRF, we decided to focus mainly on the plastic stream as our optical sorter only deals with plastic. The process for the recycling flow was adapted from the Waterloo MRC process flow from the project background information [8]. The first stage in the process after loading waste on the conveyor is the manual pre-sort. In this stage workers will manually get rid of anything that obviously does not belong in the recycling or is hazardous (e.g., large pieces of scrap metal). The next stage first involves the tearing up bags of waste using a bag opener. Then, constant and even flow of recyclable material is provided to the rest of the system using a metering drum. The next stage involves filtering out any non-plastic recyclables like fiber, glass, and metal. OCC, ONP, ballistic and fine screens are used to filter fiber and glass out of the main recycling stream [8]. These screens are earlier in the process since fiber is easier to recover the earlier it is removed from the main recycling stream. The next step in the recycling process is to filter out any metals using a magnetic separator as well as an eddy current separator. The magnetic separator removes any ferrous metals while the non-ferrous metals are removed using the eddy current separator. The final step before the actual sorting plastics is to break them down using the perforator and air classifier. It's important that all metals are filtered out at this stage as metal can have unpredictable effects on future processes [8]. Then in the next stage the plastics are sorting using an optical sorter unit using the sorting function described in the previous section. From there a manual quality control check is done on the plastics to make sure they're identified as the right type. This is important because as noted earlier the sorting function in the optical sorting unit does not have a 100% sorting accuracy. The full process can be seen in figure 3 below. This process fulfills the performance constraint of a high-level of automation since there are very few manual steps. Those being the manual pre-sorting at the beginning and the manual quality control check at the end.

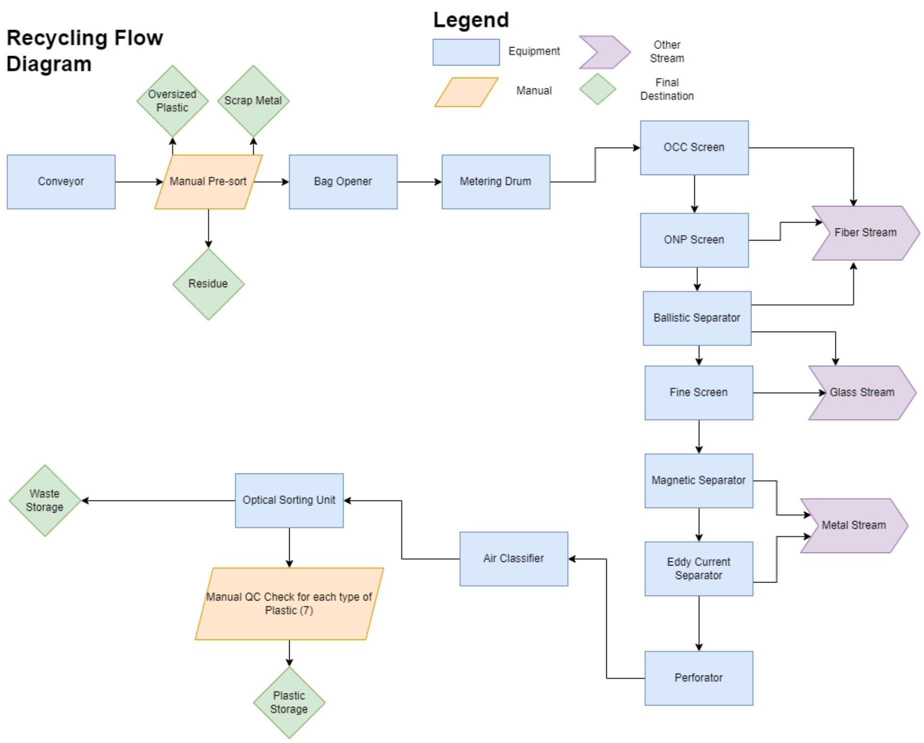


Fig. 3. Recycling Flowchart

Conclusion

Next Steps

Looking ahead, if we were given more time towards this project much more could have been done to further our progress with the MRF. During our design process of the performance aspect, we were given the option of using either the Raman Spectroscopy sensor or the FTIR sensor, or both. We had decided to use both sensors in our final design to handle any inconsistencies with different plastics being sorted. One suggestion that was given to us was to use a separate program like MATLAB to help determine which sensor should be used for a specific type of plastic. If time was not a limitation, we could have implemented this suggestion and overall improved our sorting accuracy in that aspect. However, we decided to stick with both sensors and if an inconsistency was shown between both sensors the plastic would be placed in the unsorted bin. Another way we could have gone further with this project was to fully prototype a simulated recycling facility using different software available to us online. However, we had the limitation of time and the capabilities of designing a full working recycling facility by just using the free software given to us. An advanced simulation would provide us useful information like, how will it look on campus the maximum possible size of an MRF in Lot M. This would help further analyze the MRF and the next steps our group would take. One final step we could have taken was diving into the socio-cultural aspects and surveying stakeholders and those living on campus near the recycling facility. This would have given us a better understanding of how stakeholders would react to a recycling facility built with the design specification decided upon. It would also better prepare both the stakeholders and our design team when deciding on design specifics in stakeholder meetings.

Reflections

Throughout the project we explored the PERSEID method and how that can apply to any engineering design we may encounter. It allowed us to explore different aspects of our design that we would not have previously thought of in more depth. For example, when considering the sociocultural aspect of our design we learned how even the location and cleanliness of the recycling facility may influence residents living on campus and helped give us direction when deciding on this factor. The PERSEID method came in handy, and we learned that it can be very important during the design process. Another key factor to this project was our team dynamics. It was crucial for efficiency purposes to have excellent communication and organizational skills amongst our team members and assigning roles and splitting up the work also contributed to this efficiency. We learned as a team that scheduling to finish tasks early on gave us enough time to review and improve any tasks at hand. However, this required time management skills which we made a habit of early in the project. The one change that could be made to our design process involves taking our skills to the next level, and possibly taking the time to prototype our design. We would have to take extra steps along the way to do this. However, this process may make the decision process easier when it comes to physical and performance aspects of our design. If we were to work together again on a project we would definitely try to work beyond the worksheets and go the extra mile to perfect our design, as we found we had organized our time well enough that we could have achieved this with a few tweaks. Another improvement could be made when assigning tasks to team members, as we could split up the work more evenly to get farther in the design process. Overall, we learned a lot about team dynamics and the design process by working on the McMaster Recycling Plant.

References

[1] M. Clayton, “Congress acts to clean up the Ocean,” The Christian Science Monitor, 11-Oct-2006. [Online]. Available: https://www.csmonitor.com/2006/1011/p02s01-usgn.html. [Accessed: 02-Apr-2022].

[2] “Canada recycles just 9 per cent of its plastics,” *Recycling Council of Ontario*, 06-Dec-2019. [Online]. Available: https://rco.on.ca/canada-recycles-just-9-per-cent-of-its plastics/#:~:text=Canada%20recycles%20just%209%20per%20cent%20of%20its%20plastics%20with,litter%2C%20a%20new%20report%20shows. [Accessed: 03-Mar-2022].

[3] Waste Reduction Group Inc, “McMaster University 2019 Solid Non-Hazardous Waste Audit”, McMaster University, Oct. 2019. Accessed on: Mar. 10, 2022. [Online]. Available: https://facilities.mcmaster.ca/app/uploads/2020/09/P1012-McMaster-University-2019-Waste-Audit-FINAL.pdf

[4] “Wk-3 - Stakeholder video – Recycling Plant”, class notes for 2PX3, Department of Engineering, McMaster University, Winter, 2022

[5] “2PX3 Design Lecture Wk-1 - Course Overview”, class notes for 2PX3, Department of Engineering, McMaster University, Winter, 2022

[6] “Project Module – McMaster Recycling Plant Design”, class notes for 2PX3, Department of Engineering, McMaster University, Winter, 2022

[7] “Optical Sorter Simulator Guide”, class notes for 2PX3, Department of Engineering, McMaster University, Winter, 2022

[8] “McMaster Recycling Plant Background Information”, class notes for 2PX3, Department of Engineering, McMaster University, Winter, 2022

Appendix:

Team Charter

Stage 1: Team Charter

As you are getting started to work on your project, one of the very first steps is to create a team charter. A team charter is a document that outlines the purpose of your team (i.e. your end goal), as well as detailed information about the team members.

Please list all the team members' information below.

Member	Full name	Preferred name	Email
Team Member 1	Marcus Cohoon	Marcus	cohoom1@mcmaster.ca
Team Member 2	Justin Dang	Justin	dangj15@mcmaster.ca
Team Member 3	Olorunloluwa Oguntunde	Lolu	ogunto1@mcmaster.ca
Team Member 4	Rayan Mokdad	Rayan	Mokdadr@mcmaster.ca

Take a picture of your team. Be creative! Paste your team portrait below.

In a few sentences, please describe your team's goal for ENGINEER 2PX3 and what you are aiming to achieve.

As a team we hope to work together to submit the milestones on time or complete before the due date to give us extra time to review or improve our ideas. By the end of 2PX3 we also hope to have a tangible deliverable to showcase our new design and show our progress throughout the course. By working together as a team, we hope to further develop our teamwork and interpersonal skill throughout this process. And overall, we want to complete all these goals and our project while having fun.

Please outline 3 strengths for **team member 1** with one example or specific experience for each.

Strength	Example

Communication	I have extensive experience communicating in high stress team environments, which I gained through captaining many rugby teams throughout my career.
Problem Solving	While on placement this summer at a civil engineering firm, I was required to constantly be problem solving to quickly learn and adapt to new concepts and software.
Time Management	I believe my ability to complete my course load in computer engineering while also being a member of the McMaster Men's Rugby team speaks to my ability to manage time.

Please outline one area of improvement for **team member 1**.

I believe one area that I most need to improve on is my tendency to become overanxious about deadlines and deliverables. I thin k I need to have more faith in myself and my teammates to know we will do what is needed to complete the tasks at hand.

Please outline 3 strengths for **team member 2** with one example or specific experience for each.

Strength	Example
Programming	Programing java, python, C, etc.
Finishing stuff on time	I have not handed in anything late **yet**
Being organized	Having and maintaining a schedule

Please outline one area of improvement for **team member 2**.

I think one area I could improve in is communication. Sometimes, I do not participate enough in a group setting.

Please outline 3 strengths for **team member 3** with one example or specific experience for each.

Strength	Example
Time Management	I have the ability to work based on my schedule and finish tasks on or before deadlines.
Creativity	I have the ability to think outside the box and bring my creative side to play with any kind of assigned tasks or projects. I can bring creative solutions and innovative ideas to the table whilst paying attention to details (understanding slightest errors, malfunctions or software bugs)
Programming	I have some knowledge in C, C++, Java, and Python

Please outline one area of improvement for **team member 3**.

A major area of improvement is communication.

Please outline 3 strengths for **team member 4** with one example or specific experience for each.

Strength	Example
Outgoing	I participate in any setting that require public speaking or group work, like in 1P13 I was willing to communicate and interact with others while still completing tasks at hand.
AutoCad Inventor	Completed an engineering Co-op that required using Inventor throughout the entirety of the term. I have experience remaking and redesigning parts for a machine.
Organized	I maintain an organized folder dedicated to each of my classes with folders dedicated to each week when new materials are handed out.

Please outline one area of improvement for **team member 4**.

I believe I need to improve on stressing less about certain projects/areas that do not need to be focused on.

Lastly, please outline the order of student presentations of your team.

Week	Member(s)
Weeks 3 and 7 *	Justin Dang
Weeks 4 and 8	Marcus Cohoon
Weeks 5 and 9	Rayan Mokdad
Weeks 6 and 10	Olorunloluwa Oguntunde
Which Group are you paired with? Group 5	

*For teams of 5, 2 members can present on their chosen weeks other than weeks 3 and 7

Chart of Constraints

List of Technical Constraints:	Category	What parameters of your design are affected/associated with this constraint?	Strategies/comments
Ontario Waste Management regulations	Regulatory	Storage of waste Amount of waste being processed at a time	Follow the Ontario regulations for waste disposal
Municipal By-laws	Regulatory	Location of Plant	Area/size of plant must abide by the standards given from municipal by-laws.

McMaster University Health and Safety Policy	Regulatory	Location of the plant (Noise and air pollution from plant)	-Recycling plant should be in a space where Hamilton and McMaster community will not be affected by the pollutants emitted by the plant
Cleanliness and smell of the recycling plant	Socio-cultural	Location of MRF Visual appeal of the MRF Storage of waste	Ensure waste is stored out of sight, maintain a scheduled cleaning routine that ensures the plant stays clean.
Community perception of the recycling plant	Socio-cultural	Location of the MRF Visual appeal of an MRF	Ask for suggestions from McMaster community to see where they would like to have the plant.
Safety of students and staff	Socio-cultural	Level of student participation in the recycling process Safety regulations	Ensure thorough protocols are put in place before allowing any student participation
Sorting accuracy	Performance	Operating Frequency Speed of conveyor belt Cleanliness of waste	-Setting speed in algorithm at a rate that does not dramatically affect sorting accuracy. -Ensure contamination has been removed from waste earlier in the process
Waste throughput	Performance	Operating Frequency Size of conveyor Speed of Conveyor Frequency of Sensors	-Have a high enough operating frequency to handle waste given -Ensure maximum speed is obtained without negative effects on accuracy -Design physical system with equipment large enough to have an acceptable throughput
Level of automation	Performance	Operating Frequency Sensors used Sensor frequency	Optimizing the operating and sensor speed, ensuring both are able to keep up with one another.

Carbon footprint	Environmental	Location of the Plant Choice of process units Waste Disposal	Keep emissions limited Try to keep transportation to a minimum Dispose of wastes in an eco-friendly manner
Energy consumption	Environmental	Choice of Process Units Size of Plant Waste throughput Hours of Operation	Buy energy efficient units Reduce size of plant while maintaining technical constraints (sorting accuracy, waste throughput, etc.)
Any direct local environmental concern/hazard	Environmental	Location and Size of plant Waste disposal	Dispose of wastes in an eco-friendly manner Try to not disturb local species

Decision Matrix

Evaluation	**Weight**	**Design 1**	**Design 2**	**Design 3**
Environmental	3	2	1	3
Regulatory	2	3	2	1
Performance	3	3	2	1
Socio-cultural	2	3	1	2
Weighted Total		27	15	18

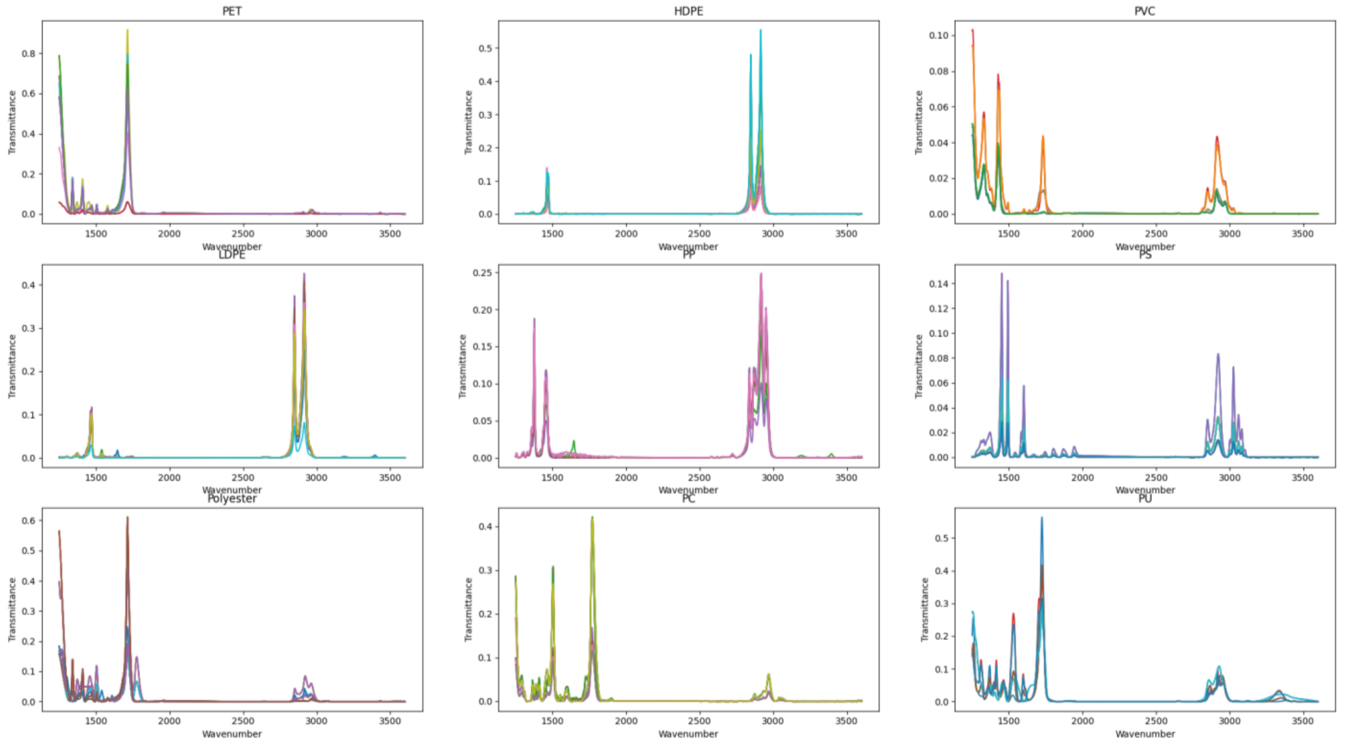
Simulation

Sorting Function

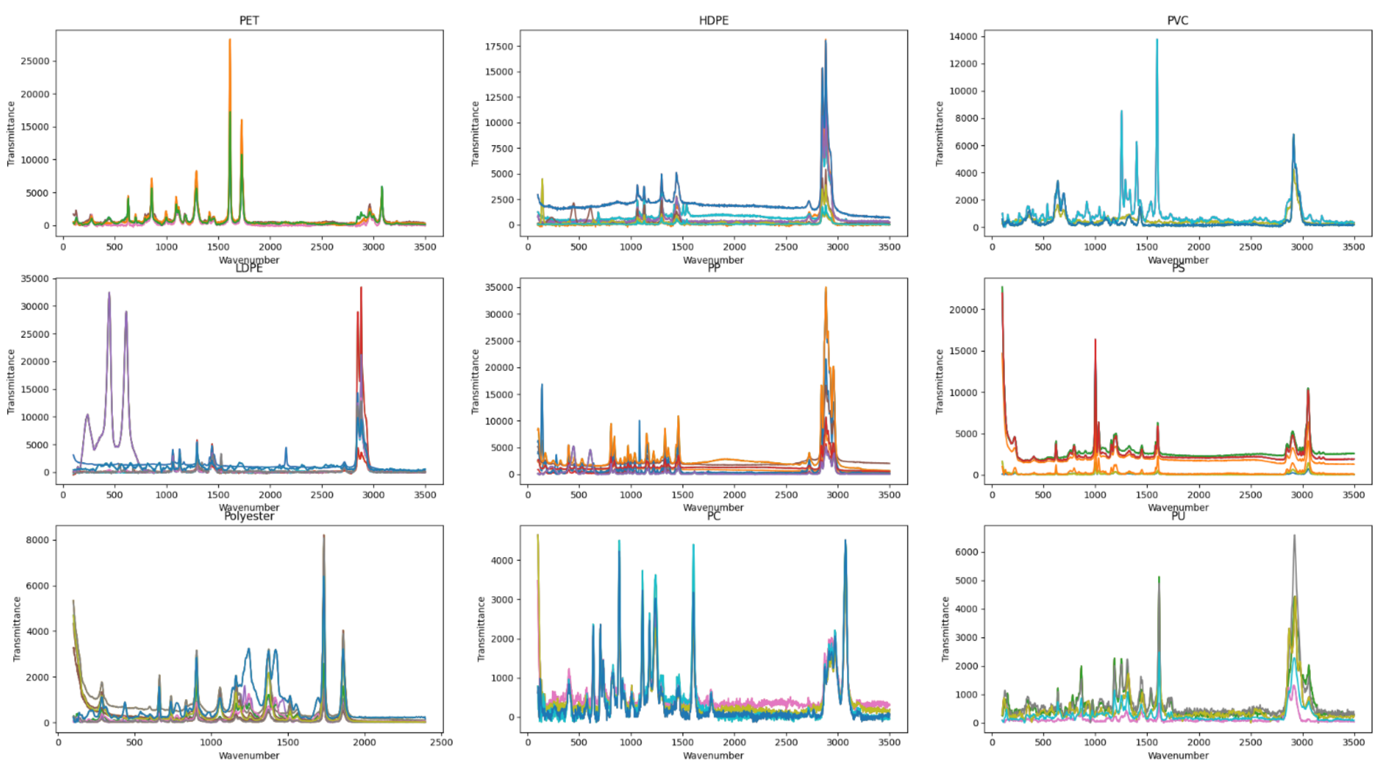
```python
def user_sorting_function(sensors_output):
    spectrum_IR = sensors_output[1]['spectrum'] # FTIR Spectrum
    spectrum_Ra = sensors_output[2]['spectrum'] # Raman spectroscopy spectrum
    id_max_i = spectrum_IR.idxmax() # Wavelength that gives max value on IR Spectrum
    ir_max = spectrum_IR.max() # Max value on IR spectrum
    ir_mean = spectrum_IR.mean() # Mean of IR spectrum
    raman_max = spectrum_Ra.max() # Max of Raman Spectroscopy Spectrum
    higher_sum_i = spectrum_IR.loc[3600:2400].sum() # Sum of first half of IR spectrum
    lower_sum_i = spectrum_IR.loc[2400:1200].sum() # Sum of second half of IR spectrum

    if (ir_max == 0): # No Object Detected
        return {1: Plastic.Blank}


    # Group 1 HDPE, LDPE, PP
    if higher_sum_i > lower_sum_i or id_max_i in range(2800, 3600):

        if 4 * lower_sum_i > higher_sum_i:
            decision = {1: Plastic.PP}
        else:
            if raman_max > 20000:
                decision = {1: Plastic.LDPE}
            else:
                if 1.5 * spectrum_IR.loc[1400:1300].max() > ir_mean:
                    decision = {1: Plastic.LDPE}
                else:
                    decision = {1: Plastic.HDPE}
```

```
    else: # Group 2 PC, PVC, PS, PU, PET, Polyester


        if id_max_i in range(1250, 1300): # Subgroup PVC, PET, PC

            if 1.1 * spectrum_IR.loc[1800:1700].max() > ir_max:
                decision = {1: Plastic.PET}
            elif 2 * spectrum_IR.loc[1800:1700].max() > ir_max:
                decision = {1: Plastic.PC}
            else:
                decision = {1: Plastic.PVC}

        elif id_max_i in range(1430, 1600): # PS
            decision = {1: Plastic.PS}
        elif id_max_i in range(1770, 1800): # PC
            decision = {1: Plastic.PC}

        else: # Subgroup Polyester, PET, PU

            if 15 * spectrum_Ra.loc[2000:2500].max() > raman_max:
                decision = {1: Plastic.PU}
            else:
                if 6 * spectrum_Ra.loc[3000:3200].max() > raman_max:
                    decision = {1: Plastic.PET}
                else:
                    decision = {1: Plastic.Polyester}

    return decision
```

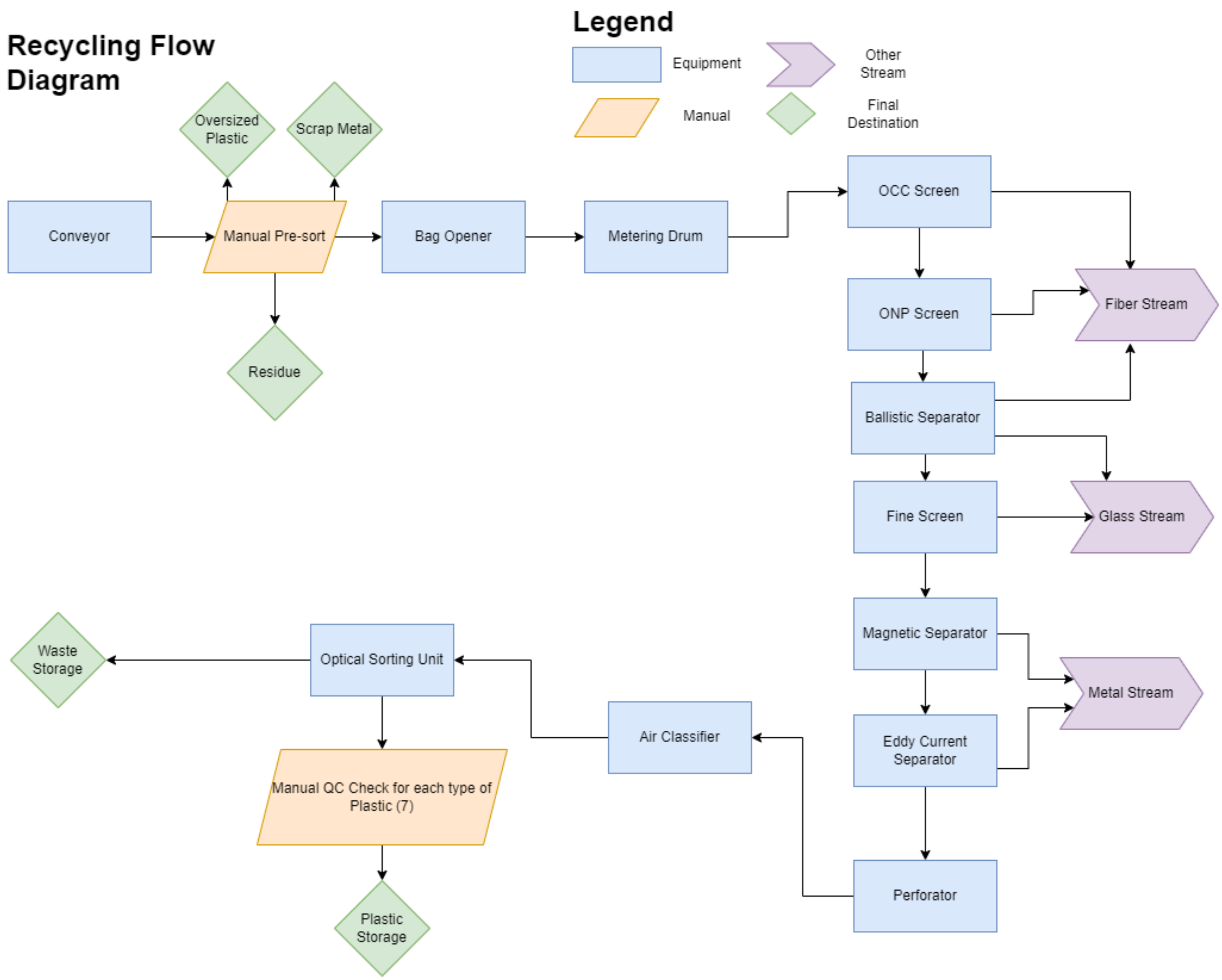
FTIR Spectrum



Raman Spectroscopy Spectrum



Recycling Flow Diagram


Recycling Flow Diagram
Legend
Equipment
Manual
Other Stream
Final Destination
Oversized Plastic
Scrap Metal
Conveyor
Manual Pre-sort
Bag Opener
Metering Drum
OCC Screen
ONP Screen
Fiber Stream
Residue
Ballistic Separator
Fine Screen
Glass Stream
Magnetic Separator
Metal Stream
Eddy Current Separator
Perforator
Air Classifier
Optical Sorting Unit
Waste Storage
Manual QC Check for each type of Plastic (7)
Plastic Storage