**2021-2022 Conrad Challenge Business Plan**

**Team AstraCell**

Company Introduction

At AstraCell, we are here to ignite the revolution of biologically composed fuel cells. Our purpose is to create a cell that outlasts and outperforms the competition, while also being incredibly beneficial to the environment and cost-effective. Our concept sparked from a conversation that three of our team members, Sarvesh, Srirag, and Ishan, had during lunchtime. We were having a conversation about NASA’s plan to go to Mars, and what the factors were stopping this project. After some research out of curiosity, we found that NASA had asked for fuel cells to last 10,000 hours for future projects, and this is where our desire to solve this issue came from. We decided collectively that we would all love to become the solution to this ask. After constantly seeing tragic photos and videos on the media of miners, starting from the blood diamonds issue, we also knew our product needed to help this industry in some way- we just did not know how yet. One of our most prominent complications was the lack of information about the fuel cell industry, as it is still incredibly new. The companies that did exist often had little-to-no specific information publicly available. Through our research of alternative energy sources rather than fuel cell sources, we were able to find the glucose-oxidase enzyme and our honeycomb system that would prove to become our value proposition. Once this was in place, we were able to put together today’s innovative solution; AstraCell. The four team members, Sarvesh Prabhu, Ishan Mahajan, Srirag Tatavarti, and Varnica Basavaraj, all have equal stakes in this company. Sarvesh Prabhu presides over business operations as the CBO, Srirag Tatavarti oversees technology as the CTO, Varnica Basavaraj works on marketing and finance as our CFO, and Ishan Mahajan as CEO. Our company will remain a Limited Liability Corporation in our developing stages. Our board of advisors includes Professor Justin Rhys Mansell from Purdue University, Plamen Atanassov from the University of California, Mark Owkes from Montana State University, and Mr. Thomas Fuller from the Georgia Institute of Technology.

Business Prospectus

**Business Description**

Space travel: once a dream in the minds of millions, is closer than ever to becoming a commodity in the near term. Whether these may be scientific explorations, the rise of the neo-norm space tourism companies, or the government space agencies racing to find our second planet earth, we as the aerospace industry face a fire that has not burned so brightly since the first satellite in orbit. The demand for traditional PEMFC fuel cells is skyrocketing, which in turn is rapidly increasing platinum extraction from the earth. AstraCell is an innovative alternate fuel cell technology that alleviates traditional fuels’ safety and durability concerns while optimizing cost and efficiency. Additionally, AstraCell benefits the environment by using a new biological component system. It is a profitable yet environmentally beneficial solution.

The massive increase in demand for platinum has posed an issue of its longevity on the planet. There are currently an estimated 69,000 metric tons left on the earth for extraction. At the current platinum extraction rate, the demand coupled with the decreasing quantities is sure to spike the prices and ease of obtaining the mineral. Containing hydrogen in such a large density and quantity at cryogenic temperatures can be highly hazardous, some of the adverse effects being vessel ruptures, weld failure, and even corrosion. The modern fuel cell is composed of many different materials; two prominent ones are platinum and hydrogen. The demand for these two materials is at an all-time high- new incredibly ambitious plans for the future in space have left the aerospace industry facing a new set of goals unlike any they have tackled before in history. In 2021, NASA released a statement calling out for fuel cells to last 10,000 hours, with PEMFC fuel cells only lasting up to 5,000 hours. In the dawn of this new era, NASA has asked the industry to double the lifetime of the PEMFC cells.

AstraCell is the scientific breakthrough the neo-space age has been calling for. AstraCell is pioneering the fuel cell revolution by incorporating our new honeycomb and enzyme catalyst system with traditional fuel cell technologies. Because this honeycomb system with the enzyme catalyst operates at a significantly higher rate than traditional fuel cells, our fuel cell can perform optimally at temperatures as low as 50oC while still being more efficient. This makes AstraCell abundantly safer than the PEMFC cells due to the removed risk of ruptures, weld failure, and corrosion. The lowered temperatures also allow for a slower degradation process, increasing AstraCell’s lifespan to an estimated 10000+ hours. On top of the performance benefits, AstraCell reduces the sheer amount of hydrogen and oxygen needed by approximately 25% and replaces large quantities of costly platinum with frugal enzymes. This in itself produces a multi-faceted benefit. The cost decreases due to the lower quantity of rare metals involved, which can also positively impact the environment. AstraCell’s first step towards an entirely biological component system has counteracted the rapidly increasing price of platinum and the decreasing demand. The decrease in platinum extraction will significantly improve the conditions of the mining towns and the miners themselves, as they can enjoy a much lower pressure to produce and perform beyond an ethical limit of worker liberties. A hassle with procurement is that natural resources are often protected, and over the past three years, worldwide economic uncertainty has dramatically decreased harvesting- AstraCell’s solution significantly decreases the magnitude of this issue. AstraCell empowers safe, resilient, economical, and eco-friendly space travel using the all-new honeycomb-enzymatic system.

Through AstraCell’s commitment to looking out for today’s environment, employees, and through the passion for furthering space exploration and discovery as humans know it, AstraCell can create a broad leeway for some of the most powerful space agencies, government-owned or privately owned, to confidently push that envelope with the security of both safety and longevity. Through these first steps, AstraCell begins the march towards writing out the next steps in technology, from finding earth’s next cousin planet to making fuel cells a commodity product. At AstraCell, we solve today’s problems while opening the gates of tomorrow’s solutions for the world to walk through triumphantly.

**Civic Engagement**

From its inception, AstraCell was created with the intent of evolving into a fully biological solution. By cutting platinum out of the aerospace bloodstream, we not only save costs but more importantly, we can help the mining communities. This includes both the miners themselves, as well as their loved ones and hometowns. Currently, the world’s largest platinum mine, known as Mogalakwena, is located in Limpopo, South Africa. Currently, Limpopo has one of the highest rates of poverty in South Africa. Many of the miners working in this town are not able to keep up with even their local taxes, due to the incredibly small wages that companies such as Norilsk Nickel are paying. AstraCell plans to lessen the impact of this atrocity by pivoting our full marketing attention towards the removal of platinum from the space industry, through the introduction of our honeycomb system. By doing so, we at AstraCell hope to reach platinum companies and advocate for better wages or living compensation such as housing for these workers. AstraCell also has plans to have a direct impact on the mining communities as well, through our non-profit charity organization AstraHelps, which will donate 15% of all profits directly for helping Limpopian citizens improve living conditions. This will drive AstraCell to have a multi-faceted indirect and direct benefit back to those who are on the front lines of platinum extraction. Not only will this impact the miners and the families they support but as a whole mining towns like Limpopo will be able to rise and contribute a greater revenue stream to their countries than ever before.

**Competitive Analysis**

AstraCell offers a fresh new take on space fuel cells that revolutionize the industry. AstraCell combines historically successful power mechanisms such as dealloyed platinum catalyzation with new innovative discoveries such as the use of an enzymatic power production system. No other competitor on the market comes close to bringing the value that AstraCell does to the space industry. The current leading commercial competitor in regards to space fuel cells is Ballard Energy. However, not only do their products lack the dual power source mechanism that AstraCell utilizes but beyond that none of their products capture the unique features needed for space. Their products are massive, and inefficient for their size. This makes it difficult to transport their products and utilize them in small spaces such as aircraft. AstraCell upgrades the recyclability and productivity of existing AFCs and makes them efficient for space travel. With AstraCell, space exploration can make significant strides as spacecraft systems will now have a specialized fuel cell to provide high amounts of electricity economically. AFC Energy is another company that specializes in alkaline fuel cells specifically, however, their products do not meet the efficiency levels that AstraCell has to offer. The average AFC Energy alkaline cell only has a lifespan of about 3000 which is below the industry average and three times less than the lifespan goals outlined by NASA. AFC aims to compensate for this reduced life span by capitalizing on its regenerative nature, however, AstraCell can accomplish this while creating functionally zero waste. AstraCell on the other hand is also not only able to reach NASA’s outlined goals, but far surpass them increasing the scope of exploration and guaranteeing consistent access to power. Finally, the last big competitor in the energy market is Ricardo. Ricardo does not match the efficiency or price point of AstraCell.

Beyond fuel cell development in the private sector, NASA has been specifically developing new alkaline fuel cells for aerospace, and companies such as AlkaMem and Hydro-X Cell have been working relentlessly to break the industry. Unfortunately, the public sector is nowhere closer than commercialized companies. All of these companies fight to remain profitable and efficient hydrogen fuel intent as they are forced to carry the cost of precious metal extraction and platinum implementation into their fuel cells and produce large amounts of purified hydrogen fuel for their cells. AstraCell can sidestep these significant profit barriers with its enzymatic system. Not only are enzymes easily produced in a lab environment, but in addition, platinum’s limited supply makes it even more economical to utilize enzymes. For the platinum that AstraCell does utilize, the purity is making the cost of a platinum alloy far lower without sacrificing efficiency.

Overall, no competitor on the market has incorporated the technological innovations that AstraCell has. AstraCell is the first alkaline fuel cell to utilize a honeycomb structure for its enzymatic reaction making it more efficient than any previous exploration into enzymatic-based cells. Previous attempts to create a hybrid cell have not even made it past the academic research phase due to lapses in power. AstraCell is not only backed by numerous universities in its methodology but also provides empirical backing for all of its benefits. AstraCell is the best fuel cell on the market designed for space exploration.

**Market Analysis**

Overall, the space industry is booming. From major new strides in space exploration to the discovery of natural resources and ice on Mars, companies are unlocking all the space has to offer. A market analysis completed by Morgan Stanley estimates that by 2040, the overall revenue of the space industry is expected to top a trillion dollars. Exploration-oriented companies are looking to commercialize space travel, while communications companies are looking to make headway with satellite broadband. Even the United States government is expanding its reach into the space industry with the establishment of the Space Force in 2019. Countries like Russia and China are only accelerating their programs in coordination overall setting the world racing on a path towards space. The one common factor that is necessary for any of this development is access to high energy and efficient fuel

AstraCell’s target market encompasses the entirety of the space industry. Due to its efficient yet more frugal nature, it can be utilized for everything from space exploration to space shuttle upkeep. Because of its versatile nature, we look to government organizations such as NASA, that fund space explorations, as a significant clientele base. Especially with the introduction of the Space Force, market analysts project that the government will increase subsidization of the space industry by nearly 5-fold in the coming decades creating a larger market for AstraCell to capitalize on in the public sector. We also hope to entice commercial companies such as SpaceX, Blue Origin, and Boeing. Given our market-topping efficiency and cost incentives, we believe this will maximize profit for clients making it an attractive option. The environmental benefits of our project will also improve the ESG or Environmental Social Governmental ratings of company stock as it shows that our clients are environmentally cautious which is another incentive for using our product. Especially with increasing legislation that incentives the use of low emission technologies, Astra’s environmentally friendly system would yield tax breaks for our clients as well. Overall, with more and more organizations racing towards space exploration, our target market is only expanding and AstraCell’s unique benefits capture this market effectively. Beyond its economic benefits, as a product, AstraCell is uniquely designed for space use as it is zero waste. The output produced is water which can then be filtered making AstraCell dual use. The fact that it has no emission reduces the cost of use because there is no need to dispose of waste making it ideal for crafts of all sizes. Its hybrid nature utilizes both platinum and enzymatic activity as catalysts allowing it to reach output levels that top charts while being small enough for space travel. As opposed to typical alkaline fuel cells that are designed with the general industrial application in mind, AstraCell opts for materials that are friendly for space travel and safer. Overall, its size, efficiency, and waste management system make it perfect for space.

**Cost**

One overall fuel cell will require 55 bipolar plates combined with 54 MEAs and an outer protective casing. Each bipolar plate will be 50cm x 50cm x 3.75mm, will weigh roughly 25 grams, and cost around $11. Using current material costs without regard to production-scale price discounts, each MEA will be 1020 microns (1.02 millimeters) thick and cost roughly $850. However, by using existing factories that already produce these materials at a large scale, the cost of MEAs is expected to drop to approximately $475 per cell. Finally, the endplates, gaskets, current collectors, casing, and other miscellaneous parts cost roughly $225. Overall, this means the final 54-cell, 50cm x 50cm x 30cm fuel cell stack should cost around $26000 and weigh roughly 60 kg. Most importantly, this is the cost of producing a single fuel cell. Previous trends in fuel cell production have shown that a 30 times increase in units produced corresponded with a 5 times decrease in cost, as production becomes more efficient, unique materials become cheaper in bulk, and individual materials become cheaper as profits and R&D funding increase. In our case, the first 100 to 1000 cells produced may be very costly to produce. However, like space tourism, exploration, and research increase in the coming decade, we expect to soon produce 3000 to 30000 cells, which would drop individual fuel cell costs to a mere $5200.

NASA’s previously mentioned fuel cell system is 35.56cm x 38.1cm x 114.3cm and 118 kg, which is almost 80,000 cm2 larger and 58 kilograms heavier than AstraCell. A typical space shuttle uses 3 fuel cell stacks since 2 systems are used as backups in the case of malfunctions or breakdowns. This means AstraCell’s miniaturization can free up 240000 cm2 of space and lighten the overall weight of the shuttle by 174 kilograms, which has profound consequences. NASA currently spends $54,500 per kilogram to launch a payload into space, and recent innovations by private companies like SpaceX have managed to decrease launch costs to $2,720/kg. AstraCell’s fuel cell size reduction can save space launches a minimum of $473,280 per launch and up to $9,483,000/launch for less efficient launches. Because AstraCell utilizes an innovative platinum-enzyme complex immobilized in a novel graphite honeycomb matrix as well as quality, efficient materials like carbon cloth GDLs and Nafion membranes, our product can generate the needed energy with fewer materials, weight, and volume, which leads to enormous savings for the space industry when they manufacture, install, and launch our cells.

With competitors sustaining heavy losses over the past few years, AstraCell needed a solution to remain profitable in a newborn industry while price-matching to space fuel cell companies, notably Infinity Fuel Cells. For the time being, AstraCell plans to match the exact price as Infinity Cells, which will offer higher performance and reliability for the same cost output from the customer’s perspective. To make up for the losses other companies have, AstraCell plans to capitalize on the many uses of the material graphene. Since AstraCell will become a producer of graphene for fuel cell use, we can sell this material to companies that may also incorporate graphene with their products, including tennis racquets, smartphones, and more. As time and economy begin to take off with space missions finally graduating from mere development, AstraCell will move out of this temporary revenue stream and begin to scale the company by increasing its output capability to match the demand of the current market at that time. This includes increasing marketing, more capital goods such as factories, and more research and development teams to find new, pragmatic product lines. This outreach to other industries not only protects tumultuous profit margins but increases AstraCell’s mark on the world as a whole.

**Funding Sources**

Our business strategy is reliant on small business grants and angel investors as our two initial capital inflows. The grant money will be used to build the foundational technology while private venture capital will be used for marketing and product launch. First, we will apply for the NASA Space Research Grant which allows small businesses partnered with universities to access as much as $550,000 in the capital. Our team reached out to over 45 professors in the space fuel and energy industry to gain insight into the viability of our product. Given the positive responses we have had from a variety of academic professors from Purdue to Georgia Tech, we see this as a stellar opportunity. Additionally, the reduced environmental impact AstraCell has, it is also eligible for the Air Force Office of Scientific Research’s Environmental Fuel Development Grant which also is over $500,000. AstraCell not only reduces mining and Finally, but we will also look towards NASA's Small Business Innovation Research Grant that sponsors fleshed out and viable prototypes and helps them enter the market. Over the past 5 years, this program has given out over $45 million in grant money. Because AstraCell is more efficient than its competitors and cheaper, investors will be drawn in due to profit potential. And the market is booming. In fact, according to data from the McKinsey Institute of Research, space industry investment is at an all-time high of 8.9 billion dollars as of this year demonstrating the interest of venture capital firms. Additionally, AstraCell uniquely appears to investors due to its market research division. Due to the constantly changing needs of the space industry catalyzed by its quick rate of discovery, AstraCell recognizes the need for a product that is willing to keep up with those changes. For this reason, our market research division will keep up with what the newest needs are and adapt our products to fit the needs of our clients. This willingness to keep pace with the market is inciting investors as they can rely on the profit margins of our company over time. Thus overall, due to the quality of AstraCell as both a product and business our company can reliably benefit from both grants and angel investors.

For AstraCell to attend the Innovation Summit this April for the final round our team will fundraise money through a three-step approach: talking to small startups, sponsorships from larger companies, and local fundraising. Small startups struggle with recognition of their company in their initial phases so AstraCell plans to help these startups with this issue while also earning funding to attend the Innovation Summit. As AstraCell presents and talks to big-name investors at the Investor Pitch we can promote these startups in return for some funding. Additionally, we plan to pitch our idea in the following months to potential sponsors such as Amazon Web Services, American Express, and Dell Center for entrepreneurs. These companies are well-known for sponsoring small businesses so we are confident that with our idea and the right pitch we can receive sponsorships from these companies. Finally, we plan to raise money through tutoring for aerospace engineering students 6th-9th through using AstraCell as an example for real-life implementation.

Technical Concept Report

**Technical Summary**

AstraCell is an innovative hydrogen fuel cell that serves as an improved power source for spacecraft as we know it. Traditional fuel cells function through the input of hydrogen in the anode side and the input of oxygen to the cathode side. At the anode, there are catalysts present that take the hydrogen gas, H2, and break it down into electrons and protons. The electrons move through an external circuit that is attached to the fuel cell to produce electricity. The protons on the other hand move through the electrolyte membrane to combine with the oxygen gas present, O2, to form water (H2O). Currently, spacecraft favor the use of proton-exchange membrane fuel cells (PEMFCs) to power their flight through space. AstraCell has many similarities to PEMFCs as it shares similarities in the fact that both fuel cells use platinum as a catalyst, both fuel cells use Nafion as an electrolyte membrane, and both fuel cells are surrounded by gas diffusion layers. AstraCell’s distinctiveness from PEMFCs and other fuel cells used in space lies in the fact that AstraCell uses dealloyed platinum in conjunction with immobilized enzymes in a graphite honeycomb structure as the catalyst for our fuel cell. Though AstraCell uses platinum, similar to PEMFCs and other fuel cells, Astracell uses a type of platinum that is altered in such a way that refines the catalytic properties of platinum to make it the most efficient catalyst possible. As the catalyst is more efficient this allows AstraCell to contain less platinum in its fuel cell which reduces the overall manufacturing cost as platinum is extremely expensive to manufacture. With these catalysts, we will be using immobilized enzymes known as glucose oxidase and laccase to create a nano biohybrid catalyst. These immobilized enzymes will be glucose oxidase at the anode and laccase at the cathode. Using enzymes is advantageous because they are much cheaper than platinum, can be produced in mass, and in the right conditions can even produce more energy.

A honeycomb structure, an energy-efficient system, will be made out of three-dimensional graphite. Graphite is a two-dimensional carbon-based nanomaterial, and it is proposed for an enzyme immobilization platform due to its large specific surface area, high electronic conductivity, biocompatibility, and high chemical stability. The structure eliminates many of the issues that come with using an enzyme as a catalyst and overall maximizes the reactions in the fuel cell to the fullest. However, a modification will have to be made to this graphite honeycomb structure since the cathode, where more platinum will be needed, is prone to leaching of core transition metal atoms to the surface of the nanoparticles into the electrolyte membrane as the catalyst is cycled. Therefore, the honeycomb structure must be modified in a way that the core metals will remain in the catalyst layer.

AstraCell does not plan to stop its journey of using a biological enzyme system in fuel cells in space as in the future AstraCell plans to develop technology to create a fully enzymatic, non-platinum fuel cell. Additionally, we plan to make our fuel cell into a fully regenerative fuel cell so that we can reduce the input of hydrogen and oxygen into our fuel cells over time.

Overall, these current and future features from the honeycomb system to the fully-enzymatic system create an innovative, highly-efficient fuel cell that will revolutionize spacecraft travel as we know it today.

**Need Statement**

Interest in the space industry is currently growing at an unprecedented rate with both public and private groups looking to capitalize on what it has to offer. Unfortunately, the limitations on the current distance we can travel along with how long a craft can remain in space have hindered numerous major developments. One such notable development is the expansion of broadband satellites. Currently, according to data from the United Nations, over 47 percent of the world lacks access to the internet. The issue is even present in the most developed nations with as many as 163 million people in America not having access to high-speed broadband internet. This is catastrophic as the internet is crucial for not only the education of people but also provides an avenue for services such as eCommerce and telehealth that can revolutionize the developing world. NASA has recognized this potential and collaborated with corporations like Amazon to establish projects like Kuiper. However such projects are limited in the impact they can have due to the high costs of power generation. Another area where power generation has served as a major downfall is commercial space exploration. Companies like SpaceX have been pushing for the expansion of commercial space trips, however, the massive cost burden that exists and lack of a reliable energy source is one of the top 10 reasons this has not been made possible according to a review from the New York Times. Allowing for space tourism could open up a whole new economic industry that revitalizes what space means to us today. Increasing access to space would additionally serve as a new way to acquire much-needed natural resources without the environmental strain that mining and drilling place on Earth today. Revelations like coal and iron on Mars have brought about a significant uproar in numerous sectors. However, because mining in a region without gravity is more power-intensive than ever, it has not been successfully executed. Reducing the prices of such materials can be greatly beneficial to the industrialization of developing countries by reducing the cost of materials. Additionally, outsourcing mining efforts to space would greatly reduce the environmental impact of localized mining on Earth, helping avert pollution that disrupts thousands of communities. Overall, it is very evident that there is a strong need for a powerful fuel cell that can help our space industry accomplish these revolutionary tasks today.

**Background Technology**

Fuel cells have been developed and utilized for over a hundred years. Therefore, there are several fundamental designs, structures, and inventions that we utilized while creating our fuel cells. While the catalyst electrodes and bipolar plates will be uniquely designed by us, the electrodes and gas diffusion layers will be identical to existing technologies.

Nafion is the ideal choice for the electrolyte in AstraCell, as it is already commonly used in most proton-exchange membrane fuel cells (PEMFCs). Electrolytes are how hydrogen ions from the glucose-oxidase mediated anode can move to the laccase mediated cathode. In the past, potassium hydroxide was typically used as the electrolyte in alkaline fuel cells, an older form of hydrogen fuel cells, but this substance is often prone to degradation if there are contaminants in the input gases. However, recently developed fuel cells are increasingly utilizing alternative electrolytes like Nafion in order to compensate for the downsides of potassium hydroxide. Nafion is a solid, flexible plastic known for its chemical stability, thermostability, and durability, which allows it to be used for several years in high-stress environments like fuel cells. Furthermore, Nafion is known to move hydrogen ions through the cell more quickly, allowing the platinum-enzyme complex to generate energy more quickly, and they are resistant to electron conduction, which is important since electrons must generate electricity by leaving the cell rather than travel through the electrolyte. More importantly, Nafion is not harmed by potential contaminants like carbon dioxide in the oxygen and hydrogen inputs, which poses a problem in other electrolytes like potassium hydroxide. Finally, Nafion operates optimally at relatively low temperatures of 80°C. However, our fuel cell will still be able to produce energy effectively at higher or lower temperatures since Nafion is exceptionally thermostable. While Nafion currently costs $500 per square meter at a thickness of 100 microns, it has the potential to drop to $50 per square meter with future innovations and increased production scales.

Next, gas diffusion layers (GDLs) will provide the mechanism by which hydrogen and oxygen gas can efficiently be transported to the electrode catalyst layers, wastewater can quickly be removed, and heat can be safely diffused out of the cell. The GDLs will be made from a thin layer of carbon cloth, which is a porous material composed of a dense carbon fiber array. Furthermore, the GDLs will be wet proofed to improve water transport, reduce water retention, and maintain hydrophobicity, while a thin microporous layer between the GDL and electrode catalyst layer will enhance water management and prevent the catalyst from leaching into the GDL. Overall, the GDL can passively wick water out of the catalyst layer while simultaneously carrying gas inputs to the catalyst layers. Wet-proofed carbon cloth with microporous layers and a thickness of 410 μm costs approximately $700-$900 per square meter with further price cuts when mass-produced from to, allowing the GDL to be frugally constructed for our fuel cell. With enough connections, some suppliers are willing to sell fuel-cell grade carbon cloth at $150 per square meter.

Finally, our fuel cells will use the same hydrogen and oxygen fuel as prior fuel cells. NASA often carries hundreds of kilograms of these gases to power energy generation systems and other technologies. Furthermore, space shuttles already need to carry oxygen since astronauts need to breathe in the capsule. Since AstraCell also utilizes these gases for energy production, we will depend on existing gas refineries and packaging pipelines for our product.

**Concept Details**

AstraCell is a novel biological proton-exchange fuel cell that can be utilized in space shuttles and other astronomical applications. The battery will be composed of 5 main parts: an electrolyte membrane, gas diffusion layers, a glucose oxidase-catalyzed anode, a laccase-catalyzed cathode, and bipolar plates. In addition, both electrodes will utilize a carbon nanotube-inspired honeycomb structure to increase enzyme reaction surface area, which would make the rate of energy production more efficient with less degradation. As mentioned previously, a 100 micron Nafion electrolyte membrane will be utilized at the center of an individual cell to mediate hydrogen ion movement from the anode to the cathode. Furthermore, a 410-micron wet-proofed carbon cloth will be used as the gas diffusion layer to help carry gases to the electrodes and remove wastewater. While the membrane and GDLs are modeled after commonly existing technologies, the design and structure of the catalyst layers and bipolar plates will be unique to AstraCell.

The catalyst in fuel cells powers the reactions that allow for the inputted hydrogen and oxygen to create the final products of electricity and water. Catalysts are found at the anode and cathode of fuel cells, and at these locations, different types of reactions occur. At the anode side of the fuel cell, a catalyst facilitates a reduction reaction where the inputted hydrogen gas (H2) is reduced to protons and electrons. The electrons then flow through the external circuit to produce electricity while the protons flow through the aforementioned Nafion electrolyte to the cathode. At the cathode side of the fuel cell, a catalyst facilitates an oxidation reaction where the inputted oxygen gas (O2) is oxidized in combination with the protons and electrons to create water molecules (H2O), which will be managed by the gas diffusion layers and bipolar plates. Platinum is the main catalyst that is used in fuel cells for space as it is the most efficient metal catalyst for speeding up chemical reactions. Additionally, platinum is the only metal catalyst that can withstand the varying temperature and acidic conditions of fuel cells in space. Though platinum is an effective catalyst, it is extremely expensive to mine, purify, and use. For these reasons, platinum contributes greatly to the enormous costs of current fuel cells, since platinum catalysts account for almost 20% of the cost of the total cell. Reducing the cost of the catalyst is important for future fuel cells as the high cost of fuel restricts the amount of money that can be put into other technology in space. AstraCell reduces the cost of the catalyst by using immobilized enzymes such as glucose oxidase and laccase in conjunction with dealloyed platinum to create a platinum-enzyme complex that is both a cost-effective and energy-efficient catalyst. When platinum is dealloyed, the catalytic properties of platinum are magnified to generate the best possible catalyst. These enzymes will have the same function as platinum as glucose oxidase will be present at the anode and conduct reduction reactions while laccase will be present at the cathode and conduct oxidation reactions. Using enzymes as catalysts proves to be effective in reducing costs since enzymes can be easily mass replicated within a lab making them inexpensive to create. Moreover, because enzymes can be as efficient as platinum catalysts, this allows AstraCell to decrease the amount of platinum used within our fuel cell.

In order to better stabilize our platinum-enzyme catalysts in the electrodes and further increase energy production rates, we will utilize an innovative honeycomb energy structure to which the catalysts will bind. As seen in our CAD models, the honeycomb structure is simply a hexagonal lattice that will be made from three-dimensional graphite. By immobilizing the platinum and enzymes, the oxidation and reduction reactions will be more stabilized, which will allow energy to be produced more easily with less long-term deterioration. Furthermore, compared to a free-floating enzymatic solution in the electrodes, the honeycomb fuel cell will increase the reaction surface area, raising the likelihood for effective collisions between the catalysts and their substrates. This honeycomb structure will also be modified slightly in the cathode layer so platinum, which exists in higher concentrations in the cathode, will remain immobilized and not contaminate the Nafion electrolyte layer. Previous research on graphite-based matrices in fuel cells has shown that a honeycomb structure, similar to the one we designed, truly has the ability to boost energy production. This novel invention ultimately sets AstraCell apart from its competitors since our design allows our fuel cell to be highly energy-efficient. Overall, this means our cell can be smaller with fewer catalysts since the honeycomb will multiply the rate at which catalysts can create electricity without harming their lifespan.

The electrolyte membrane, catalyst electrode layers, and gas diffusion layers make up a single cell, or membrane electrode assembly (MEA). To connect multiple MEAs in a stack, bipolar plates are needed. Bipolar plates connect individual fuel cells in a stack with the needed voltage by connecting the anode of one cell to the cathode of the next. Furthermore, ingrained flow field patterns within the bipolar plates will help input hydrogen and oxygen gas, distribute the gases uniformly across the surface area of the GDLs in the MEAs, and aid in temperature management. We will most likely use a serpentine flow field pattern since past literature has shown that this design can effectively distribute gases throughout the cell and automated robots can easily etch this design into the plates at our manufacturing plants. In addition, the bipolar plates facilitate water removal from the overall fuel stack and they are often attached to the outer fuel cell shell to clamp the cells together into one cohesive stack. The bipolar plates allow the fuel cell stack to remove the pure water from the system, and the water can be used for consumption by individuals on the shuttle or in other applications. Finally, due to its multiple functions, bipolar plates must be chemically inert, resistant to corrosion, impervious to gases, and electrically and thermally conductive, and they are often the thickest, heaviest, and most voluminous parts of the fuel cell stack. Many metals, like aluminum, steel, and titanium, can be used for the bipolar plate, but graphite plates are most optimal since they are durable, corrosion-resistant, and highly conductive. We will use graphite plates for our fuel cell, which are typical $45 per square meter at 3.75 millimeters thick. The plate will be etched using a machine or electrochemically in a parallel or serpentine pattern to create an efficient flow field for the fuel cell.

Our novel fuel cell incorporates various technologies to present the most efficient and cost-effective fuel cell for space applications. By using past research on the energy production of the individual components in our cell, we estimate and predict that each fuel cell will generate roughly 90 mW/cm2 at .34 V. The use of platinum-enzyme complexes immobilized on graphite honeycomb structure as well as efficient materials like Nafion electrolyte and carbon-based GDL and bipolar plates lead to highly efficient and productive power output. Each MEA is roughly 50cm x 50cm, so each cell will provide approximately 225 watts at .34 V. 54 MEAs will be layered with bipolar plates into a single fuel cell stack that produces roughly 12.15 kW of energy continuously. For comparison, NASA’s fuel cell system can produce 12 kW constantly and up to 16 kW for short periods.