Increasing the Use of Lung Bioengineering's Ex-Vivo Lung Perfusion Service

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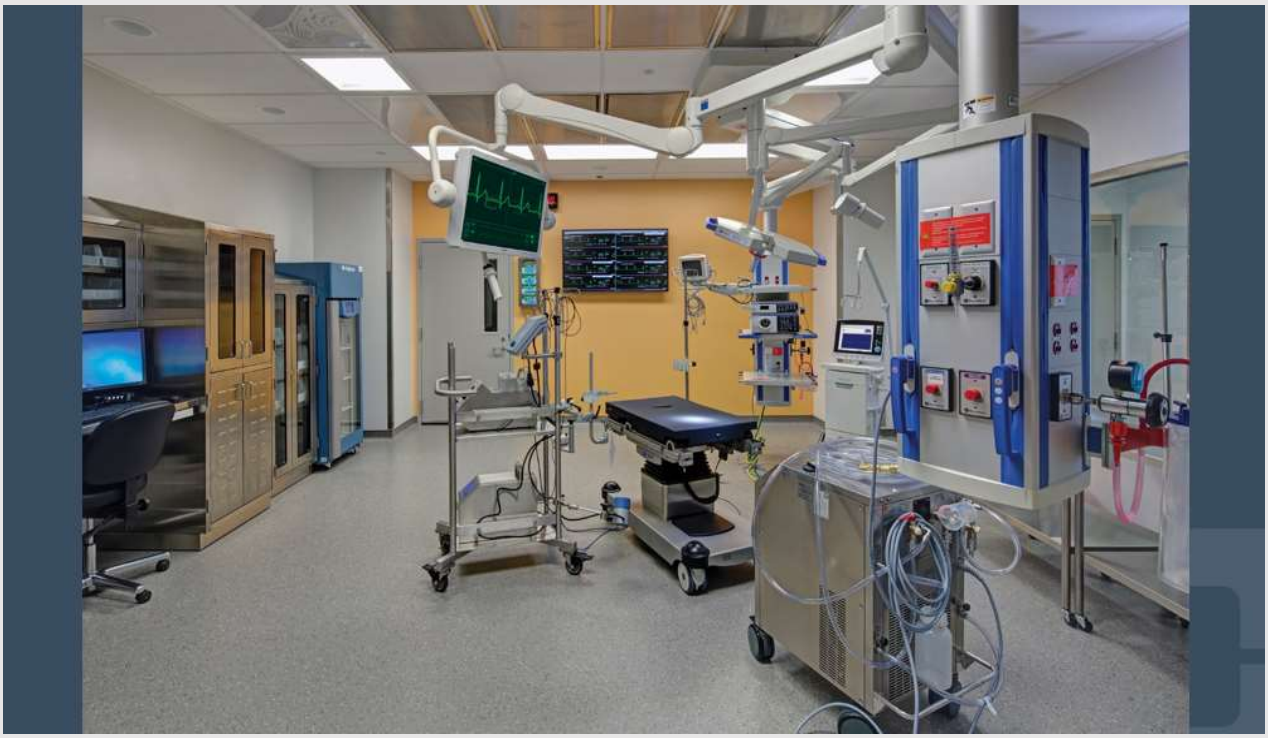

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Disclaimer

The author conducted this study as part of the program of professional education at the Frank Batten School of Leadership and Public Policy, University of Virginia. This paper is submitted in partial fulfillment of the course requirements for the Master of Public Policy degree. The judgments and conclusions are solely those of the author, and are not necessarily endorsed by the Batten School, by the University of Virginia, or by any other entity. This study was conducted for Lung Bioengineering, but does not represent an official position of either organization or any member thereof.

Honor Pledge

On my honor, I have neither given nor received help on this assignment.

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Contents

Acronyms

Ex-Vivo Lung Perfusion (EVLP)

Organ Procurement and Transplantation Network (OPTN)

Chronic Obstructive Pulmonary Disease (COPD)

United Network for Organ Sharing (UNOS)

Health Resources and Services Administration (HRSA)

Organ Procurement Organization (OPO)

Lung Allocation Score (LAS)

Centralized Lung Evaluation System (CLES)

Xvivo Perfusion System (XPS)

Food and Drug Administration (FDA)

Executive Summary

To address the lack of viable lungs for transplant in the United States, Lung Bioengineering needs a successful strategy to increase the use of their Ex-Vivo Lung Perfusion (EVLP) service. Currently, individuals in need of a lung transplant are struggling with chronic illnesses and even dying while waiting for a transplant. These individuals suffer greatly from their illnesses, and they inflict a cost on society of many millions of dollars through medical treatment costs and lost productivity. To solve this issue, Lung Bioengineering has created an EVLP service that can be used as part of the lung transplantation process. This technology, which alleviates logistical complications and can vastly improve the condition of a lung potentially being transplanted, has the potential to drastically reduce the number of individuals waiting for a lung transplant.

Despite the promise of this technology, Lung Bioengineering faces various concerns from relevant stakeholders in the lung transplantation process that have prevented Lung Bioengineering from expanding the use of their EVLP service rapidly. To address these issues, Lung Bioengineering should work with Organ Procurement Organizations (OPOs) to change their organ discarding procedure so that discarded lungs are sent to Lung Bioengineering. This alternative addresses gatekeeping barriers put up by Organ Procurement Organizations and transplant physicians by taking lungs that would otherwise be thrown away and making them potentially viable for transplant. Furthermore, this alternative does well to maximize cost-effectiveness, and scores highly in other criteria such as political feasibility and sustainability.

Problem definition

There are too few viable lungs available for transplant in the United States. As a result, around 10-20% of individuals waiting for a lung transplant die every year (OPTN, 2019). To combat this issue, hospitals and other private companies have begun using Ex-Vivo Lung Perfusion (EVLP), a methodology that greatly increases the potential viability of lungs for transplant. However, it is unclear under what circumstances this technology would be most effective in increasing the number of lungs transplanted.

This is important to my client, Lung Bioengineering, because they need an effective strategy for introducing their EVLP service as they finish their FDA trials. They need to build support for the service among transplant centers, Organ Procurement Organizations, and patients to increase the use of EVLP and increase the number of lungs successfully transplanted.

Scope and magnitude of the issue

Currently, 112,932 individuals are waiting for a lifesaving organ transplant (UNOS, 2019). Of these individuals, 1,474 are waiting for a lung transplant (UNOS, 2019). Unfortunately, many of the individuals on this waitlist never get a transplant. In 2018, 212 individuals died while waiting for a lung transplant (UNOS, 2019). While this number is low compared to the 5,196 individuals who died waiting for a kidney transplant in 2018, the number of individuals who die waiting for a lung transplant is far too high when considering the number of potentially viable lungs for transplant (UNOS, 2019).

Every year, roughly 2.8 million individuals die in the United States (CDC, 2019). Of these individuals, 54% are registered organ donors (HRSA, 2019). This creates a pool of roughly 1.5 million individuals who could potentially donate their lungs to those on the waitlist. Given the enormous number of potential donors, it does not seem logical that there are hundreds of individuals dying on the waitlist every year. However, 80% of potential lungs are unable to be transplanted for reasons such as disease, organ injury, and the lapse of too much time between organ recovery and transplantation (Pierce, 2019). Nonetheless, the discrepancy between the enormous number of potential lung donors and the fact that there are still hundreds of individuals dying every year while waiting for a lung transplant is central to the issue at hand. The scope and magnitude of this problem are relatively small when compared to other public health issues. There are only a few thousand people every year in need of a lung transplant (UNOS, 2019). However, given the current numbers of potential organ donors, it should be possible to practically eliminate this entire problem.

Defining Success

Ideally, the number of individuals who die yearly while waiting for a lung transplant would be zero. Additionally, of the individuals potentially in need of a lung transplant, they would be able to receive a lung transplant with minimal wait time and disruption of their everyday lives.

Specifically for Lung Bioengineering, they have seen a steady increase in the number of EVLP cases per year. In 2019, they successfully made 40 lungs available for transplant, a 25% increase from 2018. At a minimum, the number of lungs successfully transplanted should continue to increase yearly by at least 25%.

Cost to Society

Lung transplants are very expensive. There are many direct costs like transplant evaluation, surgeon fees, hospital stay, and post-transplant rehabilitation (UNOS, 2019). However, these costs exist regardless of whether or not an individual receives a lung that has undergone EVLP. The main costs to society are the costs incurred by individuals who are waiting to receive a lung transplant. EVLP makes more lungs available for transplant, which reduces the amount of time an individual spends on the waitlist. If EVLP were to be perfectly implemented, no individual would ever have to wait to receive a lung transplant. Thus, the cost to society can be thought of as the costs that individuals incur while waiting for a lung transplant. While there are many indirect costs associated with waiting for a lung transplant, the cost of treatment of the disease that requires a lung transplant and the loss of productivity on behalf of the individual represent the largest costs.

Individuals require a lung transplant for four main reasons: chronic obstructive pulmonary disease (COPD), pulmonary fibrosis, pulmonary arterial hypertension, and cystic fibrosis (Thomas, 2019). Of these diseases, COPD is by far the most prevalent (Thomas, 2019). As a result, the estimated costs for treating an ailment before transplant and the loss of productivity will be estimated as if all individuals waiting for a lung transplant had COPD.

For individuals with COPD, medication costs are roughly $63 per day and visits to the doctor average out to $23 per day (Theobald, 2014). This adds up to a daily cost of $86 to treat COPD. The average wait time for a lung transplant is 185 days, which results in a total cost of $15,910 per individual to treat their COPD while they wait for a lung transplant (Rapp, 2017). There are 1,474 individuals currently on the lung transplant waitlist. This results in a total cost of treatment for those waiting for a transplant of $23,451,340.

In terms of productivity, the CDC estimates that the loss of productivity for individuals with COPD is around $8 billion per year (Ford, 2015). This loss in productivity is attributed to the resulting absenteeism from having COPD. Dividing this by the 16 million individuals with COPD, the loss of productivity per person per year is $500, or $1.36 per day. Applying this rate to the 1,474 individuals who wait 185 days for their transplant results in $373,547 in lost productivity.

Added together, the estimated cost to society incurred because there are 1,474 individuals currently waiting for a lung transplant is $23,824,887. This is certainly an underestimate. Individuals with COPD who do require a lung transplant are in much worse condition than individuals with the same ailment who do not require a lung transplant. This likely means that loss of productivity is much higher and that the need for medical care to manage the ailment while waiting for a transplant is much more intense. Furthermore, these calculations are just a

static representation of the cost to society. Individuals are constantly being added to the lung transplant waiting list, resulting in an ongoing cost to society far higher than just $23 million.

How lung transplantation works

Organ transplantation is managed by the Organ Procurement and Transplantation Network (OPTN). The OPTN was established in 1984 by the National Organ Transplant Act and is managed by the United Network for Organ Sharing (UNOS) through a public-private contract. The OPTN has a board of directors and separate sub-committees responsible for enacting new rules. The OPTN operates under the Health Resources and Services Administration (HRSA), and all policies and new rules go through the same regulatory processes as other executive agencies.

Allocation

When an individual who is a registered organ donor dies, their organs are donated to recipients in need. A single donor can save the lives of up to eight people, and their tissue donation can improve the lives of up to 50 people (UPMC, 2015). The organ donation process is both complex, and severely time-constrained. This is especially true for lung transplantation. Once an individual dies, a transplant recipient is identified and chosen for transplant based on their Lung Allocation Score (LAS). This score, which is calculated by the OPTN, is a reflection of many factors including waitlist urgency, survival probability without a transplant, survival probability post-transplant, and many more factors (OPTN, 2019). Individuals on the list are contacted in order until a suitable recipient can be found. This process is carried out by regional nonprofit organizations regulated by the OPTN called Organ Procurement Organizations.

Transportation

Once the allocation process has taken place a procurement team is sent to the donor hospital from the transplant center to take the lungs from the donor's body, and they are cooled down and flushed with a solution. The lungs are stored on ice, and they are transported by plane or ambulance depending on how far away the recipient is. After the lungs arrive at the transplant center, the recipient undergoes surgery to receive the pair of lungs. Lungs can only be outside the body for a very short amount of time. Typically, a lung can only be outside the body for 5 hours (UMTC, 2010). This puts enormous constraints on successfully coordinating a lung transplant. OPOs have to work quickly, and many lungs are not successfully transplanted because of logistical complications involving distance and contacting recipients.

Lung transplantation with EVLP

To alleviate the logistical stresses and strict criteria for acceptable lungs, Lung Bioengineering's EVLP service provides stakeholders more flexibility in the allocation process. EVLP is a medical procedure performed on the lungs once they have been removed from the donor's body. Doctors connect the lungs to a special machine that fills the lungs with a fluid that has a high concentration of a protein called albumin (Popa, 2019). The machine, as well as the special fluid, allows doctors to perform many procedures that increase the likelihood of a lung being transplanted. First, they can evaluate the function of the lung much better than if it were in the donor body. They can assess oxygenation rates, airflow, and tissue damage. Furthermore, doctors

can repair collapsed portions of the lung, and remove any fluid that is not supposed to be in the lungs. Finally, they can also treat lungs that are infected with a host of illnesses, including Hepatitis C. These treatments address many of the contributing factors previously mentioned that make lungs unsuitable for transplant. Furthermore, EVLP vastly expands the time window to coordinate transplantation logistics. Instead of a five-hour window, EVLP allows for a transplant window of over 15 hours (Popa, 2019). As a result, many more lungs are available for transplant, and surgeons can feel much more comfortable about the quality of the lungs they are transplanting.

Lung Bioengineering can perform EVLP using two different types of equipment and methods: centralized lung evaluation system (CLES) and XVIVO Perfusion System (XPS). Lung Bioengineering is currently in the process of getting FDA approval to perform EVLP using CLES. EVLP using CLES is the preferred method, although Lung Bioengineering can also perform EVLP using an XPS machine. The XPS machine, created by a company called XVIVO, is a self-contained platform designed strictly for EVLP. The XPS machine has already received FDA approval, and XVIVO sells these machines to hospitals that want to perform EVLP in-house. Because these machines have already been FDA approved, transplant centers not part of the FDA trial for the CLES method can still use Lung Bioengineering's EVLP service.

The lung transplantation process is slightly different when EVLP is used. When using Lung Bioengineering's EVLP service, lungs taken from the donor do not go directly to the transplant center. Instead, they are taken to an EVLP center where they undergo perfusion, and they are then sent to the transplant center. Currently, Lung Bioengineering operates two EVLP centers. One is in Silver Springs Maryland, and the other is in Jacksonville Florida. Lungs are sent to whichever facility is closer to the transplant center, and after the EVLP procedure, the lungs go directly to the transplant center.

Key Stakeholders

Organ Procurement and Transplantation Network (OPTN)

Organ transplantation is managed by the OPTN, which operates under HRSA. They are in charge of the transplantation "wait-list" for each organ. For lungs, this waitlist is a list of all individuals needing a lung transplant organized by their Lung Allocation Score (LAS). The OPTN is a stakeholder because they are in charge of regulating lung transplantation. While both the OPTN and Lung Bioengineering share the goal of making more lungs available for transplant, the OPTN has been hesitant to make policy changes that incorporate the new EVLP technology.

Organ Procurement Organizations (OPOs)

OPOs are responsible for coordinating the logistics of organ transplantation. They coordinate transportation and communication between the donor hospitals and transplant centers. There are 58 OPOs across the country, each responsible for managing organ donations in a defined region they serve. OPO attitudes about EVLP vary widely across the country. Some OPOs have been very willing to work with Lung Bioengineering to use EVLP, while others have been vocal in their opposition to the technology.

Lung transplant centers

Transplant centers are hospitals where individuals can receive a lung transplant. Similar to OPOs, there are very mixed attitudes towards the use of EVLP. The physicians at a transplant center are responsible for deciding whether or not they want to use EVLP for a particular set of lungs. Given that EVLP is a relatively new technology, some doctors have been hesitant to adopt the new technology while others have fully embraced it. Transplant centers that were part of Lung Bioengineering's EVLP FDA trial have been the biggest supporter of the technology. Of these transplant centers, the Cleveland Clinic uses the EVLP service the most. Most transplant physicians recognize the promise of EVLP, but the hesitancy to adopt the technology presents one of the biggest barriers for Lung Bioengineering.

Individuals in need of a lung transplant

Approximately 200 individuals die every year waiting for a lung transplant (Pietroski, 2020). Currently, 1,474 individuals are waiting for a lung transplant (OPTN, 2020). These individuals are all critically ill, and expanding the number of transplantable lungs through EVLP is sure to be supported by these individuals. Patient groups have the power to influence the decisions of physicians and hospitals, and mobilizing these groups to advocate for EVLP represents a strong advocacy tool for Lung Bioengineering.

Legislative and regulatory stakeholders

The OPTN oversees nearly all of the organ transplantation process. Both Organ Procurement Organizations and transplant centers are members of the OPTN, and they are subject to the OPTN's policies. Lung Bioengineering is not a member of the OPTN, but they are still subject to most of their policies. Additionally, Lung Bioengineering's EVLP service is also regulated by the FDA. The machines required to perform EVLP are classified as medical devices which means they have to go through FDA approval.

In terms of legislative stakeholders, there are committees in both the House of Representatives and the Senate that would likely be in charge of organ transplantation legislation. These committees are the Energy and Commerce Subcommittee on Health and Environment; the Ways and Means Subcommittee on Health; and the Committee on Health, Educations, Labor, and Pensions. These committees originally considered the National Organ Transplant Act, likely meaning that they would also consider future organ transplant legislation.

Major obstacles

Lung Bioengineering's EVLP service alleviates some of the most serious challenges of lung transplantation. However, adoption of the technology has been slow. Many transplant centers are hesitant to change their practices resulting in limited use of the EVLP service. This begs the question as to why this service has not been widely adopted.

In a study conducted over the summer of nearly all of the transplant centers across the country, I found that transplant physicians were overwhelmingly worried about two things: cost and effectiveness of EVLP. Physicians are concerned that the procedure will not be appropriately reimbursed, and they are also concerned as to whether or not EVLP can take lungs unsuitable for transplant and make them viable.

Effectiveness

In terms of effectiveness, there is overwhelming evidence from studies in other countries that EVLP can successfully increase the supply of transplantable lungs. The most relevant of these studies comes from the Toronto General Hospital in 2009. This study showed that EVLP could greatly increase the amount of time a lung could be out of the body before being transplanted, and also showed that poorly functioning lungs can be effectively treated and transplanted (Cypel, Rubacha, et. al, 2009). More importantly, the study also led to the creation of the Toronto Protocol, a particular method of doing EVLP that has since been adopted by Lung Bioengineering (Cypel, Rubacha, et. al, 2009). The Toronto Protocol has consistently been shown to be effective in increasing the number of lungs available for transplant. Moreover, its effectiveness has been shown in trials with both animals and humans (Pan, Yang, 2018). In a 2018 application study of EVLP, lungs that had undergone the Toronto Protocol showed no significant difference compared to normal lungs for several lung quality metrics including primary graft failure, length of postoperative mechanical ventilation, ICU days, hospital days, or 30-day mortality (Pan, Yang, 2018). These outcomes are the most important for evaluating patient stability, and they all suggest that marginal lungs that go through EVLP can perform just as well as normal lungs that have not undergone EVLP.

Cost

Given the demonstrated effectiveness of EVLP, transplant physicians are also concerned about cost. There are high costs associated with EVLP and lung transplantation in general. UVA lists their average price for a lung transplant at $808,897. EVLP only adds to that cost. Just the disposable items for an EVLP procedure cost $14,000. This does not include transportation costs or payment of the surgeon and support staff. As a result, there is concern about whether or not the EVLP procedure will be fully reimbursed by Medicare, Medicaid, or a private insurer. Despite these concerns, there is strong evidence that EVLP will be reimbursed by public and private payers. In 2016, CMS announced that they would be fully reimbursing costs associated with EVLP as part of a transplant center's organ acquisition costs. Nonetheless, some transplant physicians are either unaware of this announcement or have concerns about private payers.

Disrupting traditional transplantation practices

Put simply, Lung Bioengineering represents a significant disruption to the lung transplantation process. Transplant centers, OPOs, and the OPTN have operated in a closed system to manage lung transplantation for decades. The OPTN's rules and regulations have been built around certain assumptions about how lung transplantation works, especially with regards to transportation and the allocation process. Many of these assumptions need to be reconsidered, especially with regards to how EVLP can give more time to find a suitable recipient and make lungs that would be discarded based on traditional guidelines potentially viable. If the OPTN is unwilling to change its regulations to accommodate EVLP, the technology will not be used to its full potential.

Best Practices from Other Countries

Many other countries use EVLP. One of the most famous examples is the Toronto Lung Transplant Program, which has been instrumental in developing and introducing EVLP to

transplant programs across the world (Cypel, 2019). However, the EVLP procedure in the Toronto Lung Transplant Program is done at the transplant center, rather than a third-party facility like Lung Bioengineering's EVLP centers. Lung Bioengineering has worked closely with the Toronto Lung Transplant Program to train staff, and develop best practices for the EVLP procedure itself. As a result, Lung Bioengineering has surgeons and support staff that are uniquely qualified to perform the EVLP procedure. In terms of running a third-party EVLP center, however, Lung Bioengineering is the first to adopt such a model. As such, there is little guidance from other countries on how best to run a standalone EVLP service center.

Criteria

Cost-effectiveness

This criterion is a measure of how many more lungs are transplanted every year. For this criterion, I will first estimate Lung Bioengineering's current operating costs by estimating capital costs, depreciation, maintenance, salaries, and overhead. I will then estimate the additional costs of each intervention, and divide those costs by the expected increase in the number of lungs successfully transplanted. A full explanation of this process will appear in the analysis portion. Cost-effectiveness is arguably the most important criterion. Lung Bioengineering wants to maximize the number of lungs successfully transplanted while minimizing the amount of money spent. However, this criterion has the potential to be completely inaccurate. There are likely to be many unforeseen costs not calculated in the cost-effectiveness analysis, and estimating how many more lungs are transplanted is somewhat arbitrary. As a result, this criterion is weighted at 20%.

Administrative feasibility

Lung Bioengineering is a subsidiary of United Therapeutics, a large pharmaceutical and biotechnology company. Lung Bioengineering has to work within the constraints of the larger company. Resources spent on policy alternatives for Lung Bioengineering could also be spent on United Therapeutics' other subsidiaries and projects. The resources and decisions of Lung Bioengineering exist in the larger context of the company, so policy options should reflect that reality. As such, effective policy options need to account for what is likely to be approved by Lung Bioengineering leadership. Policy options that take away resources that could be better used by other subsidiaries or policy options that go against the values and strategic direction of the company will score poorly for this criterion. Additionally, policy options must be able to be put into place quickly if they want to be adopted by the company. This is especially true given the current state of Lung Bioengineering' FDA trial of their CLES protocol. Virtually all lungs that are sent to Lung Bioengineering are part of the CLES FDA trial. This means that once the trial has been concluded, there is the potential for a steep drop off of lungs sent to Lung Bioengineering. To address this potential drop off, Lung Bioengineering needs to implement policy options that can generate meaningful results in a time frame of only 1-2 years. Policy options that take years to produce results will score poorly for this criterion. This criterion is the most important because policy options that do not have approval from the company have no chance of being implemented. This criterion is weighted at 40%

Political feasibility

Some of the potential policy options involve regulatory changes and the mobilization of some relevant legislative stakeholders. As a result, policy options must take into account the political dynamics and interests in the lung transplantation field. By its nature, Lung Bioengineering's EVLP service is a disruption to how lung transplantation has traditionally operated. Stakeholders like OPOs, transplant centers, and the OPTN have exhibited varying levels of support for how Lung Bioengineering is changing the lung transplantation process. Policy options must take into account how relevant stakeholders are likely to react. Lung Bioengineering's EVLP service can only exist if transplant centers want to send lungs for EVLP, and the OPTN does not enact rules that make it impossible for Lung Bioengineering to operate. Policy options that overly upset these stakeholders will score low for this criterion. However, most of the alternatives have minimal political considerations when analyzing their viability. As a result, this criterion is only weighted at 15%.

Sustainability

For the implementation criterion, the importance of quickly implementing a suggested alternative was an important consideration given the timing of the FDA trial completion. However, alternatives must also be sustainable. While EVLP might eventually be phased out as 3-D lung technology progresses, effective policy options should create a path for Lung Bioengineering to operate in the lung transplantation field for at least the next 10-15 years. For some of the policy options that involve regulatory changes, it will be important to analyze whether that regulatory change is likely to stay in place for an extended amount of time. Moreover, policy options must be able to continue to as Lung Bioengineering evolves. Employee turnover is a constant at any company, and policy options must be able to survive independently from those responsible for the initial implementation process. This criterion is weighted at 25%.

Alternatives

Option 1: *Status quo*
The status quo requires Lung Bioengineering to take no additional actions. As it stands, Lung Bioengineering is running a very successful FDA trial, and the transplant centers in the trial have demonstrated continued interest in using the EVLP service. Furthermore, Lung Bioengineering is continuing its contracting process with transplant centers, and increased use of the EVLP service is expected as these contracts are finalized. This alternative is appealing also because of the generally positive movement towards the increased use of EVLP in general. While the adoption of the technology is slow, it is becoming increasingly evident that EVLP is both cost-effective, and can improve health outcomes for lung transplant recipients.

Option 2: *Cultivating patient demand for EVLP through targeted efforts of lung transplant communities*
For most commercially available drugs and medical devices, companies spend considerable time and resources cultivating patient demand and support for their products. While the use of

medical devices and the prescription of drugs is ultimately decided by a physician, patients have considerable sway in what products are used in treating their particular condition. This policy option would recommend a similar strategy for Lung Bioengineering. Lung Bioengineering should make efforts to cultivate patient support by modeling their outreach strategies similar to other successful outreach strategies by other medical device companies. Some of these actions could include partnering with lung transplant communities like The Living Bank, Second Wind Lung Transplant Association, and many more. The members of these communities are those in need of a lung transplant, and these individuals can have conversations with their transplant physician about how EVLP could help them get a lung transplant more quickly. Lung Bioengineering should make sure to meet with these organizations and provide relevant training information and should provide steps and talking points for patients to initiate conversations about EVLP.

Lung Bioengineering should also make clear to these organizations which transplant facilities are currently contracting with Lung Bioengineering to use their EVLP service. For some patients, they can choose where they would like to receive their transplant. If outreach works effectively, these patients might be more likely to choose transplant centers that have contracted with Lung Bioengineering to use their EVLP service over other transplant centers. Furthermore, Lung Bioengineering should consider direct advertisement and outreach to patients outside of the lung transplant community organizations. This outreach can manifest itself in a variety of ways and has the potential to be very effective in increasing patient demand for EVLP.

To be certain, cultivating patient demand for EVLP is slightly more nuanced than cultivating demand for a regular drug or medical device. It is not up to the sole discretion of the transplant physician to use EVLP for a lung transplant. Nonetheless, consistent patient support for EVLP is likely to increase the use of Lung Bioengineering's EVLP service

Option 3: *Working with OPOs to adopt new lung discard procedures*
In 2018, 10,721 individuals were identified as potential candidates to have their lungs donated (OPTN, 2019). Of these individuals, only 2,407 had their lungs successfully recovered and transplanted. This leaves a discrepancy of 8,314 lungs. Of those 8,314 lungs, 6,767 were never recovered. This means that even though a set of lungs might have had the potential to be transplanted, a transplant physician team did not get to the donor hospital to take out the lungs from a donor. This leaves a further discrepancy of 1,547 lungs that were successfully recovered from the donor but were not then transplanted. Both of these discrepancies have the potential to be addressed by Lung Bioengineering's EVLP service.

The largest category of lungs that could potentially be sent for EVLP are those lungs that are never recovered. Potentially transplantable lungs are not recovered mostly because of the logistical difficulties previously discussed associated with the tight time window to transplant a set of lungs. It can be difficult to contact potential recipients, and sending a lung recovery team from the transplant center to the donor hospital can be difficult if the two locations are particularly far apart. As a result, transplant physicians who initially thought that a lung could potentially be transplanted decide to not attempt a recovery and transplant. Lung Bioengineering's EVLP service is designed precisely to address situations like these. Ideally, all

of the 6,767 lungs that were previously not recovered would be sent to lung Bioengineering's EVLP service to be further evaluated and potentially sent to a transplant center. However, this ideal scenario runs into one of the biggest obstacles to increasing the use of EVLP: transplant physicians as gatekeepers. In the transplantation process, it is largely up to the particular transplant physician to decide on whether or not to recover a lung and attempt a transplant. Transplant physician attitudes towards EVLP vary widely. Concerns about cost-effectiveness as well as hesitancy to change their established lung transplantation process results in transplant physicians not electing to use EVLP even when the use of EVLP would likely result in a successful transplant. Changing transplant physician attitudes will take a significant amount of time, and Lung Bioengineering has already implemented several strategies to educate physicians about the benefits of EVLP. Nonetheless, this process will take place over the next few years and Lung Bioengineering needs policy options that can be more quickly implemented.

Given that Lung Bioengineering is already taking steps to change physician attitudes about EVLP, and that Lung Bioengineering needs a successful strategy to increase the use of EVLP in the short term, it makes sense to consider strategies that work with the 1,547 lungs that are recovered but not eventually transplanted. Of these 1,547 lungs, 1,181 lungs were recovered for research and 95 lungs were discarded.[1] This subset represents an enormous opportunity for Lung Bioengineering to increase the use of their EVLP service without having to overcome the same transplant physician barriers.

Once a transplant physician decides that they do not want to use a lung for transplant, it is up to the OPO to decide what they should do with the lung. Most OPOs have relationships with research hospitals and organizations that receive the lungs once it is determined that they will not be transplanted. Similarly to these research hospitals and organizations, this alternative would involve Lung Bioengineering establishing close relationships and agreements with OPOs so that lungs that have been turned down by a transplant physician are sent to Lung Bioengineering. These lungs, having been sent to Lung Bioengineering, would undergo EVLP and the allocation process would occur a second time provided that the EVLP process made the lung viable for transplant.

This process partially circumvents the hesitancy of transplant physicians to send a lung for EVLP. Instead of the transplant physician deciding whether a poorly performing lung will be able to improve with EVLP, they only have to have to assess whether or not the lung is suitable for transplant after the lung has undergone the EVLP process.

When a poorly performing lung is sent for EVLP, there is a chance that the lung cannot be transplanted even after having gone through the EVLP process. Usually, about 75% of lungs are successfully transplanted after having undergone EVLP (Pietroski, 2020). This policy option would require Lung Bioengineering to assume the risk that a lung that undergoes EVLP is not successfully transplanted. If a lung is not successfully transplanted, Lung Bioengineering would pay for the transportation charges, and would not charge their normal EVLP service fee. However, in the case that a lung is successfully transplanted, Lung Bioengineering would be

[1] There are 271 lungs that are unaccounted for in the data available

reimbursed by the transplant center for the transportation costs and would also be able to charge their EVLP service fee.[2]

Option 4: *Building support for EVLP with XPS through a traditional medical device launch*
Currently, Lung Bioengineering possesses multiple XPS EVLP devices. These devices are FDA approved and are available for use at any time by a transplant facility. Unfortunately, a majority of Lung Bioengineering's EVLP cases are part of their FDA trial and are not on the XPS device. Given the untapped potential to use these devices for EVLP cases for any transplant regardless of enrollment in the FDA trial, Lung Bioengineering needs to increase the demand for their EVLP service through these XPS devices. One strategy to increase the use of the XPS devices would be through a comprehensive rollout aimed at transplant centers. This option would involve hiring individuals to make up a sales team, medical science liaisons, doctor key opinion leaders, and project managers. These individuals would go to transplant centers to create relationships and encourage transplant centers to begin a contracting process with Lung Bioengineering. Furthermore, doctor key opinion leaders and project managers would provide ongoing support after the contracting process, answering any questions and concerns that a transplant center has about using the EVLP service. Given that transplant centers' opinions of Lung Bioengineering's EVLP service greatly increase after their first use, project managers are especially helpful because of the guidance they can provide as a transplant center goes through their first use of the EVLP service.

Option 5: *Lobbying the OPTN and other regulatory bodies to ensure positive rule changes*
Currently, two proposed rules have the potential to negatively impact the use of the EVLP service: composite travel score changes, and organ research exclusions for OPO outcome scores.

Composite Travel Score

The OPTN has published a new concept paper to optimize LAS score calculation though an algorithmic method that takes into account several relevant medical and logistical considerations in an attempt to make transplantation more efficient. Of these considerations, ease of transportation is one of the biggest factors. As previously explained, EVLP significantly eases transportation difficulty by allowing for a much broader time window to allocate the lungs. However, the proposed algorithmic model does not take this into account. If this goes into effect, transportation difficulty will be calculated based on a five-hour time window regardless of whether the lung will go through EVLP. One of the biggest advantages of EVLP is the added time to transplant a lung, and this concept paper will eliminate that advantage. As a result, Lung Bioengineering' EVLP service will be used far less frequently. However, if the use of EVLP is appropriately factored into the algorithmic method, Lung Bioengineering's EVLP service will likely be used much more frequently. If the model were to be built around the assumption that all lungs can be sent for EVLP, presumably meaning that all lungs had the extended time window

[2] Transplant hospitals would pay a certain percentage to Lung Bioengineering from the reimbursement they receive from paying the standard acquisition costs to OPOs

for allocation, then it is likely that the use of Lung Bioengineering's EVLP service would increase greatly.

Research organ exclusions for OPO performance metrics

The OPTN has also proposed new changes to the performance metrics used to evaluate OPO effectiveness. One of these changes involves eliminating the measurement of how many lungs an OPO makes available for research because this metric does directly relate to actual lung transplants. Often lungs are initially recovered for transplant but are then ultimately deemed unsuitable by the transplant center for many reasons. These lungs are often then made available for research purposes. Once a lung is designated for research, Lung Bioengineering can ask for the lung to perform EVLP as discussed in option three. If they can successfully make the lung viable for transplant and convince the transplant center to accept the lung, they can charge for their service. This rule change would eliminate the OPO performance metric relating to the number of lungs recovered for research. As a result, OPOs would have little incentive to recover lungs that are just going to be used for research. This would dramatically decrease the number of research lungs, and would further limit the use of Lung Bioengineering' EVLP service.

How to address these issues

If these rules go into effect, lungs are much less likely to be sent to Lung Bioengineering for EVLP. Lung Bioengineering must ensure that this does not happen. Currently, Lung Bioengineering has engaged in the comment process for these proposed rules. However, this alternative would require Lung Bioengineering to pursue a much more serious lobbying strategy. Lung Bioengineering should look to engage the OPTN with continued comments, informal communications, and the lobbying of OPTN members to explain the potential impact of the suggested rule changes on Lung Bioengineering's EVLP service. Lung Bioengineering should also consider a top-down approach to their advocacy efforts. This alternative might include the direct lobbying of HRSA, as well as the targeting of legislators on key subcommittees of health and healthcare in Congress. Given Lung Bioengineering's lack of lobbying infrastructure, it might also be advantageous to establish a broader lobbying coalition. This coalition might include organ transplantation communities, transplant centers, and even some competitors in the EVLP industry. Currently, several perfusion societies exist across the United States. These perfusion societies are largely concerned with perfusing other organs such as the liver, kidney, and even the heart. However, Lung Bioengineering should look to get involved with these societies to focus them on lung perfusion to expand Lung Bioengineering's advocacy power. In terms of competitors, Lung Bioengineering competes in the lung perfusion market with two companies: XVIVO and TransMedics. Both of these companies make EVLP machines that differ from the comprehensive service offered by Lung Bioengineering. Despite these differences, it is likely that the regulatory changes described above have the potential to hurt and help these competitors in a similar way to Lung Bioengineering.

Cost-Effectiveness Methodology

Cost-effectiveness will be calculated as the operating costs plus the cost of each intervention divided by the number of lungs that undergo EVLP and are successfully transplanted. Costs will

be projected out 10 years accounting for inflation and will be converted into net present value. This net present value will be divided by the expected number of successfully transplanted lungs to estimate a cost per lung. Operating costs have been calculated as follows:

Capital

The two main capital costs are the costs of the facilities and the costs of the equipment needed to perform EVLP. I calculated the costs of the facilities by first finding the square footage of the Silver Springs and Jacksonville facilities. The square footage of the two buildings is 28,000 and 50,000 square feet respectively (Pietroski, 2019). The Jacksonville facility is technically 75,000 square feet, but one of the three floors is shared with the Mayo clinic. I then multiplied the total square footage by the average cost per square foot to build a hospital in the U.S. This estimate is $500 per square foot (Hoppszallern, 2016).

To calculate the cost of the equipment, I found the cost of an XPS machine. While Lung Bioengineering has both CLES operating rooms and XPS machines, I assumed that all 9 of the currently owned machines were all XPS devices. The cost of a single XPS device is $300,000 (Nilsson, 2014). Adding this cost to the building costs results in a total capital cost of $41,700,000.

Depreciation

To calculate the depreciation of the machines and the building, I assumed a nine-year lifespan for each XPS machine and a 25-year lifespan for both of the facilities. I assumed that depreciation was linear and that there were no salvage costs. The total cost of the XPS machines was $2.7 million, which results in $300,000 in depreciation per year. The total cost of the buildings was $39 million. This results in a yearly depreciation of $1.56 million per year. Total depreciation costs are $1.86 million per year.

Maintenance

Maintenance costs were assumed to be 3% of depreciation per year. This results in a yearly depreciation of $55,800 per year.

Expenses

The main expenses are the disposable materials used in each EVLP case. Relying on the same assumption that all EVLP machines used by Lung Bioengineering are XPS machines, the disposables cost $14,000 per EVLP case (Nilsson, 2014). In 2019, Lung Bioengineering did 55 total EVLP cases for a total cost of $770,000 (Pietroski, 2019). Status quo will assume that Lung Bioengineering continues to only do 55 cases per year. Policy options that increase EVLP use will have increased expenses that will be factored in accordingly.

Overhead

To calculate overhead, I looked for a hospital in the U.S. with a similar number of employees as Lung Bioengineering. I estimated that Lung Bioengineering has about 23 employees that strictly work for Lung Bioengineering. While other individuals work for United Therapeutics who do

some work for Lung Bioengineering, I decided to exclude those individuals from this cost-effectiveness analysis. After finding a comparable hospital with 23 employees, I looked at the Medicare cost report data to find the hospital's overhead costs. For the comparable hospital I found, the overhead was $1,922,260 (CMS, 2019).

Salaries

I found the average salaries for surgeons, surgical assistants, and IT technicians. I assumed that there were 6 surgeons, 12 surgical technicians, and 5 IT technicians between the two facilities. The salaries were as follows: $544,087 for a surgeon, $68,363 for an assistant, and $68,473 for an IT technician (Kane, 2019). The total salaries added up to $4,427,243.

Inflation and net present value

I assumed the U.S healthcare inflation rate to be 4.6%. I also used the OMB discount rate of 7% to calculate the net present value.

Number of lungs successfully transplanted

In 2019, Lung Bioengineering performed 55 cases, with 40 lungs being successfully transplanted. This suggests a roughly 75% conversion rate for each EVLP case. This conversion rate will be used as the reference rate for all of the alternatives.

Final Calculations

For 2020, the yearly operating costs are calculated to be $50,735,303. If Lung Bioengineering mirrors its 2019 performance and does 55 cases, with 40 lungs successfully going to transplant, the cost per lung is calculated to be roughly $1.26 million. This, however, is not likely to happen in reality. Based on previous trends in the use of Lung Bioengineering's EVLP service, I expect the number of cases to grow by 25% every year without any policy interventions. This will be further explained in the cost-effectiveness section of the status quo option.

The projected costs and increased number of lungs for the next 10 years are shown below. Each alternative's cost per lung will be explained in the cost-effectiveness section of the analysis. Additionally, a full breakdown of the cost-effectiveness calculations can be found in Appendix 1.

Policy Option	Total # of lungs for 10 years	Cost per lung
Status quo	1372	$324,994.37
Patient demand	4675	$107,907.50
Discard plan	10472	$64,669.10
XPS rollout	14761	$46,024.60
Advocacy	3674	$132,609.78

It is worth noting that none of these cost-effectiveness calculations results in a cost per lung lower than the rate of $35,000 charged by Lung Bioengineering for their EVLP service. This

indicates two things. First, this indicates that there are some significant inaccuracies in my estimates. Second, even if these inaccuracies could be corrected, this cost-effectiveness analysis demonstrates the need for Lung Bioengineering to aggressively seek economies of scale. Only the most disruptive alternatives resulted in costs per lung even remotely close to the $35,000 mark. Hypothetically, Lung Bioengineering can operate at a max capacity of 3400 lung cases per year. This cost-effectiveness analysis suggests that Lung Bioengineering needs to operate somewhat close to that hypothetical maximum to be profitable.

Outcomes Matrix

	Criteria			
Policy Alternative:	Cost-Effectiveness (20%)	Administrative feasibility (40%)	Political Feasibility (15%)	Sustainability (25%)
Status quo	$324,994	Low	High	Low
Cultivating patient demand for EVLP through targeted efforts of lung transplant communities	$107,907	High	High	Low
Working with OPOs to adopt new lung discard procedures	$64,669	High	Medium	High
Building support for EVLP with XPS through a traditional medical device launch	$46,024	Low	High	Medium
Lobbying the OPTN and other regulatory bodies to ensure positive rule changes	$132,609	Medium	Medium	High

Analysis

Option 1: *Status Quo*

Cost-effectiveness

For the status quo, there are no policy interventions. The $16 million intervention cost over the next 10 years reflects the increase in expenses from consumables used for every EVLP case assuming a constant growth rate of 25%. This results in a total of 1372 total lungs sent for transplant over the next 10 years with a cost per lung of $324,994.

Administrative feasibility

Lung Bioengineering has been consistently searching for options to increase the use of their EVLP service. As shown in the cost-effectiveness section, Lung Bioengineering currently faces incredibly high operating costs with relatively low utilization of their EVLP service. Without serious efforts to increase the use of their EVLP service, their strain on United Therapeutics' resources could become overwhelming. This alternative has very low administrative feasibility.

Political feasibility

This alternative has no political feasibility considerations. As a result, this option has high political feasibility.

Sustainability

If Lung Bioengineering wishes to keep operating, barring any changes from other alternatives implemented by Lung Bioengineering outside of this report, this option is not sustainable. As a result, this alternative has low sustainability.

Option 2: *Cultivating patient demand for EVLP through targeted efforts of lung transplant communities*
Cost-effectiveness

This policy option requires the hiring of a Customer Relationship Manager. This individual is responsible for creating and maintaining relationships with lung transplant communities. Through these relationships, the community relations manager will educate individuals in need of a lung transplant about the benefits of EVLP. Through these efforts, increased patient demand for EVLP will result in a yearly increase in the use of Lung Bioengineering's EVLP service by 50%, a 25 percentage point increase from the status quo. The cost of this intervention and the accompanying increase in growth over the next 10 years is calculated to be $75,397,437. This results in a cost per lung of $107,907.

Administrative feasibility

Option two scores highly in administrative feasibility. The intervention requires hiring limited additional personnel which is likely to be favored by United Therapeutics. Additionally, this alternative requires little involvement from the larger company because Lung Bioengineering can spearhead the targeted efforts without having to receive further guidance from United Therapeutics. Existing employees at Lung Bioengineering have substantial experience creating and maintaining relationships in the organ transplantation space which likely means that forging new relationships with these support communities would be relatively easy. This policy option can also be implemented in a very short amount of time, which is another advantage concerning administrative feasibility. This option is rated as having high administrative feasibility.

Political feasibility

There is no reason to think that political feasibility would play a role in the option. As a result, this option has high political feasibility

Sustainability

Option two struggles the most with sustainability. This policy option requires both the building and maintaining of close relationships with lung transplant support groups. If the individual hired by Lung Bioengineering to create these relationships leaves the company, it is unclear if a new individual would be able to sustain the same level of support from the lung transplant community. This policy option is also weak with regards to sustainability because the option does not have a defined time period for the intervention to take place. Potentially, support group attitudes towards EVLP could change, and the demand for EVLP could vary widely. This option is rated as having low sustainability

Option 3: *Working with OPOs to adopt new lung discard procedures*
Cost-effectiveness

This option would require the creation of relationships and contracts with OPOs so that they would send lungs that have been recovered to Lung Bioengineering for EVLP. This would require the hiring of a lobbyist with existing contacts to OPOs to begin this process, and it would also require a Customer Relationship Manager to sustain these relationships and act as a liaison between OPOs and Lung Bioengineering. The salaries of these two individuals take up a significant portion of the cost of the intervention. However, transportation fees are also an important cost. As explained in the alternative section, Lung Bioengineering would take on the risk that a lung goes through EVLP and is not successfully transplanted. Based on the conversion rate, I would expect this to happen 25% of the time. When these cases occur, Lung Bioengineering is responsible for paying the OPO their normal Standard Acquisition Cost (SAC). This charge is usually paid by transplant centers to OPOs for costs associated with organ procurement and transportation. It would be the responsibility of the two individuals hired to negotiate these fees with the OPOs. From my research, I have been unable to find an average SAC. To factor this cost into my analysis, I have added $3,000 to the expenses so that the consumables are $17,000 per case instead of $14,000.

To quantify the growth in the number of cases, I estimated two growth measures. First, I estimated that OPOs would send an additional 773 lungs per year to Lung Bioengineering through the lung discard program. In 2018, 1,547 lungs were recovered for transplant but were not transplanted. While it might be tempting to assume that all of these lungs could be sent to Lung Bioengineering, that does not account for research needs. Lungs that are recovered but are not transplanted are most commonly sent to hospitals for training or research for new treatments. It would be up to the individuals hired for this policy alternative to negotiate what percentage of lungs would be sent for research versus what percentage of lungs would be sent to Lung Bioengineering. I have estimated a rate of 50% which would mean an additional 773 lungs would be sent to Lung Bioengineering yearly, but this rate could vary widely across OPOs.

On top of the 773 lungs per year, I also estimated a continual growth rate in cases of 50%. This reflects the likelihood that transplant physicians will want to send more lungs to Lung Bioengineering for EVLP once they have witnessed the success of EVLP in turning previously discarded lungs into viably transplantable lungs. If Lung Bioengineering pursues this alternative they should expect to see 13,963 lung cases over the next ten years.

The cost of this intervention and accompanying growth over the next 10 years is calculated to be $222,076,275. This results in a cost per lung of $62,176. Despite only requiring the hiring of two additional employees, this alternative is far more expensive than all of the alternatives except for alternative three. This demonstrates the significant burden of paying for transportation and logistical costs for lungs that are not successfully transplanted. This alternative creates a very high incentive to raise the conversion rate for successful lung transplants. If the conversion rate suffers, this option could inflict serious financial consequences.

Administrative feasibility

Given that this policy option is already being partially pursued by Lung Bioengineering, it is very likely that this option would have high administrative feasibility. This option also requires the hiring of a very small number of additional employees which is also likely to be favored by United Therapeutics. Finally, this option can be implemented quickly. Lung Bioengineering works with OPOs regularly to help facilitate the use of their EVLP service, so there are existing connections for Lung Bioengineering to use to implement this policy option. However, it is important to keep in mind that creating new agreements with OPOs to begin sending discarded lungs to Lung Bioengineering could take considerable time. OPOs might be hesitant, and figuring out the logistics of sending discarded lungs could take serious additional work. Nonetheless, because Lung Bioengineering has made some efforts with OPOs to create agreements that are somewhat similar to this alternative, Lung Bioengineering could likely use their experience to make the contracting process move more quickly. As a result, this option has high administrative feasibility.

Political feasibility

It is conceivable that individuals at research institutions could take issue with the fact that they are being sent fewer research lungs. Conceivably, they could express their concerns to the OPTN which could, in turn, initiate new regulations that prevent the sort of agreements between OPOs and Lung Bioengineering from occurring. While this is unlikely to happen, and Lung Bioengineering could work with research organizations to send more lungs to them, it is nonetheless a valid concern. As a result, this option has medium political feasibility.

Sustainability

The sustainability of this policy option is largely contingent on the types of agreements that are made between Lung Bioengineering and the OPOs. If Lung Bioengineering can enter into contractual agreements that last for several years, this policy option will likely be very durable. Most of the important work to ensure the sustainability of this policy option will happen through the initial contracting process with OPOs where it will be crucial to make sure that OPOs are comfortable with the new transportation logistics and secondary allocation process. Provided that OPOs feel comfortable with the practice and that Lung Bioengineering provides adequate support as OPOs begin sending discarded lungs for EVLP, it is likely that this policy option will be thoroughly cemented. As a result, this option is rated as having high sustainability.

Option 4: *Building support for EVLP with XPS through a traditional medical device launch*
Cost-effectiveness

Option four requires the hiring of six additional full-time employees: a salesperson, two project managers, a medical science liaison, a doctor key opinion leader, and an IT support staff. Collectively, these individuals make up a substantial team able to increase the use of Lung Bioengineering's EVLP service using XPS. The salesperson would be required for initial outreach to transplant centers, and the project managers would be responsible for helping transplant centers through the EVLP process. The doctor key opinion leader and medical science liaison would be responsible for ongoing communication and support with transplant physicians and other hospital administrators. This policy option is meant to mirror how a medical device is traditionally launched. As a result, I would expect the most dramatic rate of growth for the use of Lung Bioengineering's EVLP service. I estimated this rate to be 75%, a 50 percentage point increase from the status quo option. The cost of this intervention and the accompanying increase in growth over the next 10 years is calculated to be $250,332,659. This results in a cost per lung of $46,024. This option is the most expensive, but also has the lowest cost per lung. This continues to show the importance of pursuing economies of scale if Lung Bioengineering wants to make a profit.

Administrative feasibility

This policy option has the lowest administrative feasibility. Hiring several new employees, and pursuing a new strategy that does not use the EVLP technology favored by Lung Bioengineering, is likely to face opposition from both United Therapeutics decision-makers as well as those within Lung Bioengineering. The option requires an enormous investment on behalf of United Therapeutics that would most likely have some repercussions with regards to United Therapeutics' other business interests. Additionally, this option might indirectly help XVIVO, the company that makes the XPS devices. While not a direct competitor to Lung Bioengineering because they only produce the machine and do not offer a comprehensive EVLP service, the added visibility of the product to transplant physicians might push the transplant center to buy the machine instead of using the service.

Despite the very likely opposition to such a dramatic intervention, such action might be necessary depending on the conclusion of the FDA trial of the CLES EVLP protocol. While it is almost certain that the CLES EVLP protocol will receive FDA approval, it is unclear how transplant centers will act once the trial is completed. Currently, there has been virtually no use of Lung Bioengineering's EVLP service by transplant centers not enrolled in the CLES trial. This is most troubling because these transplant centers not in the trial could still have potentially been using Lung Bioengineering's EVLP service using the XPS machines. Given that no transplant centers have used the EVLP service with XPS, this could be an indication that intense efforts need to be made to increase the use of EVLP with XPS. Additionally, it is unknown how transplant centers that were enrolled in the CLES EVLP trial will act once the trial has ended. With there being an expected waiting period of 6 months to a year between the end of the FDA

trial and approval, Lung Bioengineering could potentially see a steep drop in the use of their EVLP service. These factors suggest that this policy alternative is necessary for ensuring Lung Bioengineering's success in the coming years. Nonetheless, this intervention is by far the most taxing on the company, and as a result, has low administrative feasibility.

Political feasibility

There is little reason to believe that there would be any external political considerations for this option. As a result, this option has high political feasibility.

Sustainability

The sustainability of this policy option is partially interwoven with administrative feasibility. If United Therapeutics fully commits to the policy option and hires a significant team to ensure an effective rollout, this option is likely to have sustainable results if the rollout successfully increases the demand for Lung Bioengineering's EVLP service. However, if the rollout is understaffed, or it does not generate any initial interest in using EVLP with XPS, it is very unlikely that this option will any impact that lasts over time. As a result, this policy option is weighted as having medium sustainability to reflect how variable initial success would affect the sustainability of the alternative.

Option 5: *Lobbying the OPTN and other regulatory bodies to ensure positive rule changes*
Cost-effectiveness

This alternative would require the hiring of a skilled lobbyist to work with the OPTN and other relevant stakeholders to ensure that the two proposed rules previously mentioned do not go into effect. Provided that this lobbyist can work effectively to shape the potential rules so that they do not hurt Lung Bioengineering, I would expect the yearly growth rate in EVLP cases to be around 35%. This is a 10 percentage point increase from the status quo. While the impact of the policy alternative is low, the costs are also contained strictly to the hiring of one additional individual. This option could be the most attractive if Lung Bioengineering wants to pursue a less disruptive strategy. The cost of this intervention and the accompanying increase in growth over the next 10 years is calculated to be $58,209,724. This results in a cost per lung of $132,609.

Administrative feasibility

Lung Bioengineering is already in the process of engaging with the OPTN in its rulemaking process to make sure the interests of the company are appropriately reflected in their regulatory changes. However, the extent of Lung Bioengineering's lobbying activity has been limited mainly to participating in the open comment period. Hiring lobbyists to engage in additional advocacy practices, as well as potentially lobbying other agencies above the OPTN like HRSA, is a significant change in the company's advocacy strategy. While the hiring of additional lobbyists has some administrative feasibility concerns because of the cost of new hires, the change in advocacy strategy is a bigger concern. Traditionally, United Therapeutics has adopted a position of not engaging in any significant lobbying or other advocacy work. As a result, this alternative might face strong opposition from the company. With that being said, the two rule changes in question have the potential to severely limit Lung Bioengineering's ability to increase

the use of their EVLP service. Such serious circumstances might warrant a shift in attitude towards traditional lobbying efforts. This alternative is rated as having medium administrative feasibility.

Political feasibility

This alternative has the most political feasibility considerations of any of the potential alternatives. The lobbying strategy, if properly implemented, likely has a good chance of at least ensuring the rules that go into place do not hurt Lung Bioengineering's ability to provide their EVLP service.

However, it is more unclear how receptive the OPTN will be to any lobbying efforts. In general, the OPTN has been supportive of EVLP, and it has demonstrated its willingness to potentially incorporate EVLP more seriously into the lung transplantation process in the future. Despite that support, the OPTN has been slow to recognize how Lung Bioengineering's EVLP service offers different advantages and use cases apart from a transplant center using EVLP. Speculating more on the OPTN's attitudes towards Lung Bioengineering's EVLP service is both unproductive, and their attitudes could change significantly once Lung Bioengineering completes their FDA trial. Nonetheless, there is reason for some concern about the attitudes of the OPTN towards Lung Bioengineering's EVLP service. This alternative is rated as having medium political feasibility

Sustainability

If the lobbying strategy works correctly, and the regulations that go into effect support Lung Bioengineering's EVLP service, it is very likely that this alternative will be in place for the foreseeable future. However, the OPTN has made multiple significant changes to their lung allocation process over the past few years, and there will likely be future regulatory changes that will need to be properly worded to make sure that they do not hurt Lung Bioengineering's EVLP service. Nonetheless, if the lobbying team can find a successful strategy for this round of regulatory changes, they will likely have success in the future. This alternative is rated as having high political feasibility.

Recommendation

After having considered all of the alternatives I believe that alternative two, working with OPOs to adopt new lung discard procedures, is the best course of action for Lung Bioengineering. This option finds a good balance of cost-effectiveness and has strong administrative feasibility because it does not put stress on United Therapeutics' resources. Additionally, this option has fair political feasibility with only a small chance of the OPTN getting involved. Where this option shines the most, however, is its ability to circumvent many of the barriers caused by transplant physicians. In my interviews with transplant physicians, as well as my work with Lung Bioengineering employees, I consistently witnessed the "cascading" effect of sending a lung to undergo EVLP. For Lung Bioengineering's FDA trial, the company struggled the most with getting transplant physicians to send their first lung to Lung Bioengineering for EVLP. Overwhelmingly, once a transplant physician had sent their first lung, the positive experience they had using Lung Bioengineering's EVLP service guaranteed that they would send many

more lungs in the future. While there are certainly some transplant physicians who have used the service and still only send a low volume of lungs for EVLP, most transplant physicians either use Lung Bioengineering's EVLP service with relative frequency, or not at all.

The struggle to overcome the barrier of getting a transplant physician to send their first lung is directly addressed by policy option two. Transplant physicians do not have to contend with the uncertainty of sending a lung to Lung Bioengineering. By eliminating that uncertainty, transplant physicians are much more likely to want to transplant a lung that has undergone EVLP. This is a unique feature of alternative two that sets it apart from the other alternatives.

Despite the attractiveness of alternative two, that does not mean that none of the other alternatives should be explored in conjunction with alternative two. At a minimum, Lung Bioengineering also needs to make sure they have a solid advocacy strategy in place. While the hiring of an additional lobbyist as suggested by option four might be a step too far, solely engaging in the open comment process is not enough to make sure that the OPTN does not hurt Lung Bioengineering's ability to offer their EVLP service. Furthermore, it is also worth pursuing alternative one to some extent because it poses no significant downside. While it might not be worth hiring additional employees to manage relationships with the lung transplant community, some outreach efforts could prove to be very effective. With these efforts, as well as the other existing strategies currently being implemented by Lung Bioengineering, there are sure to be more lungs viable for transplant in the U.S.

Appendix 1:

Capital			
	Machines	300000*9	2,700,000
	LB1	28,000*500	14,000,000
	LB2	50,000*500	25,000,000
			41,700,000
Depreciation			
	Machines	2,700,000/9	300,000
	buildings	39,000,000/25	1,560,000
			1,860,000
Maintenance			
	total	1,860,000*0.03	
			55,800
Expenses			
	Consumables	14,000*55	
			770,000
Overhead			
	total (cost reports)		
			$1,922,260
Salaries			
	Surgeons	544,087*6	3,264,522
	Techs	68,363*12	820,356
	IT	68,473*5	342,365
			4,427,243
		Year	Operating cost
Total		2020	$50,735,303
		2021	$53,069,126.94
		2022	$55,510,306.78
		2023	$58,063,780.89
		2024	$60,734,714.81
		2025	$63,528,511.69
		2026	$66,450,823.23
		2027	$69,507,561.10
		2028	$72,704,908.91
		2029	$76,049,334.72
		Total	$626,354,372
		NPV	$429,055,614.89

Policy Option #	Operating cost(NPV)	Intervention cost (NPV)	Total # of cases	Total # of lungs	Cost per lung
1	$429,055,615	$16,733,397	1829	1372	$324,994.37
2	$429,055,615	$75,397,437.53	6233	4675	$107,907.50
3	$429,055,615	$222,076,275.07	13963	10472	$62,176.89
4	$429,055,615	$250,332,649.42	19682	14761	$46,024.60
5	$429,055,615	$58,209,724.29	4899	3674	$132,609.78

Option 1								
	New costs	$ amount	growth rate	Total cases	Increase in cases vs Status Quo	total lungs	Increase in lungs vs Status Quo	Additional cost per lung
	Consumables per additional case	$17,904,735	25%	1829	1279	1372	959.18224812	$12,199.18
		Total NPV						
		$16,733,397.47						
Option 2								
	New costs	$ amount	growth rate	Total cases	Increase in cases vs Status Quo	total lungs	Increase in lungs vs Status Quo	Additional cost per lung
	Community Relations Manager	$90,000	50%	6233	5683	4675	4262.36572266	$16,128.26
	Consumables per additional case	$79,564,160						
		Total NPV						
		$75,397,437.53						
Option 3								
	New costs	$ amount		Total cases	Increase in cases vs Status Quo	total lungs	Increase in lungs vs Status Quo	Additional cost per lung
	Community Relations Manager	$90,000	50%+ 773 per year	13963	13413	10472	10059.75000000	$21,206.17
	Lobbyist	$113,000						
	Consumables per additional case	$237,371,000						
		Total NPV						
		$222,076,275.07						
Option 4								
	New costs	$ amount	growth rate	Total cases	Increase in cases vs Status Quo	total lungs	Increase in lungs vs Status Quo	Additional cost per lung
	Sales person	$57,000	75%	19682	19132	14761	14348.91644955	$16,958.58
	2 Project managers	$210,000						
	Medical science liason	$93,468						
	Key opinion leader	$344,090						
	IT support staff	$68,473						
	Consumables per additional case	$267,846,440						
		Total NPV						
		$250,332,649.42						
Option 5								
	New costs	$ amount	growth rate	Total cases	Increase in cases vs Status Quo	total lungs	Increase in lungs vs Status Quo	Additional cost per lung
	Lobbyist	$113,000	45%	4899	4349	3674	3261.92998560	$15,841.84
	Consumables per additional case	$60,889,360						
		Total NPV						
		$58,209,724.29						

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