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東京大学
統合物質・情報国際卓越大学院 (MERIT-WINGS)
統合物質科学リーダー養成プログラム (MERIT)
World-leading Innovative Graduate Study Program for Materials Research, Information, and Technology
Materials Education program for the future leaders in Research, Industry, and Technology

MERIT Corporate Internship

~Development of Lithium Extraction Technology~

PURE LITHIUM

At Pure Lithium Corporation
Period: June 5th 2023 - Dec 1st 2023 (180 days)

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Support: Michika Onoda (MERIT 4th)

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Abstract

I did a six-month internship at Pure Lithium Corporation (PL), a start-up company in the United States. The aim of this activity is to learn about the academic startups in the United States through research activities with my own research skills (experimental condensed matter physics) in a different field. It is also important to incorporate knowledge from different fields and utilize it in future research.
This activity was carried out with the full cooperation of Dr. Michika Onoda, MERIT 4th graduate.

1 Introduction

Start-up companies are in an intersectional position that allows science to return the profit to society, and are extremely important to enrich people's day lives. In recent years, the ambitious themes and research styles of startup companies have attracted attention in Japan, and various supports have been implemented. On the other hand, its scale and speed are still small compared to the United States, which is growing as the world's largest science and technology[1-3].

Through this internship, I underwent the scientific research at Pure Lithium Corporation (PL), an up-and-coming startup company in the United States. PL is a young startup whose lab was launched in January 2021 with Prof. Donald Sadoway from Massachusetts Institute of Technology (MIT) as co-founder. However, the scale of their research and business goals are especially different from those of startup companies in Japan, in terms of corporate philosophy. The goal is to learn the following things through internship activities and utilize them in the future.

- ✧ Understanding academic startup companies in the US
- ✧ Understanding research culture in the United States and its future application
- ✧ Utilizing own experience and knowledge in different fields
- ✧ Acquire new techniques and knowledge for future research activities

In particular, research in PL mainly deals with polymer chemistry, electrochemistry, and organic chemistry, so it can be expected to greatly expand my horizons and ambitiously engage in research with the goal of acquiring knowledge in new fields.

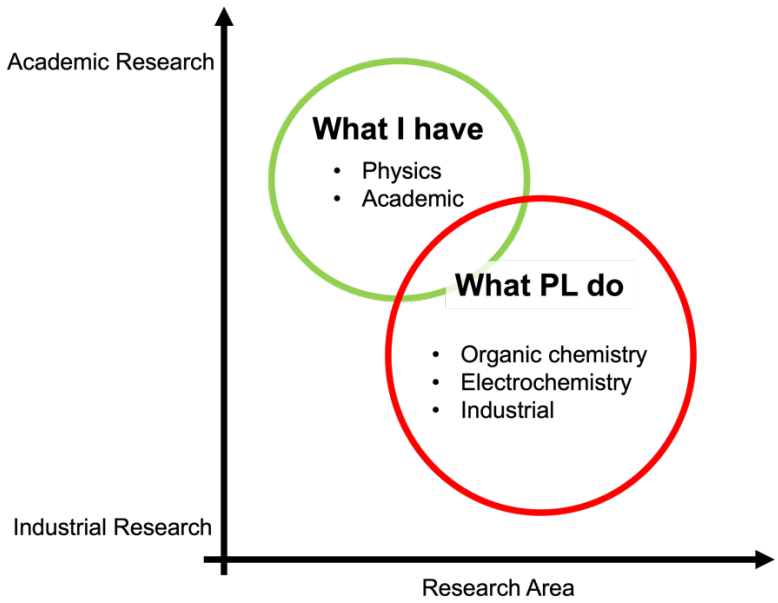

Figure 1: Schematic illustration of the aim of this internship. Research can be broadly expressed by two factors. The vertical axis represents the degree of corporate research pursuing profit and academic research dealing with science in general. The horizontal axis broadly represents research areas. Research in PL is close to an academic field, but also has aspects of corporate research. Main topics are organic chemistry and battery technology. We can expect to expand our horizons from these perspectives.

2 Research activity at start-up company in the U.S.

This section briefly explains the outline of the research conducted at Pure Lithium. A pillar of Pure Lithium is building an innovative supply chain for lithium metal batteries. Lithium metal batteries are the ultimate batteries with high energy density and can be described as the ultimate energy storage system. However, widespread commercialization remains impractical due to the extremely high cost of lithium metal electrodes, which is essential for battery production. Therefore, the company aims to provide lithium metal batteries safely, inexpensively, and quickly by applying a lithium anode manufacturing technology, Brine to Battery™. This method makes it possible to electrochemically extract lithium metal in one step from wide-range of lithium brines around the world, including oil field brine, which is a currently unused lithium resource. It ultimately differs from Direct Lithium Extraction (DLE) in that Brine to Battery™ is the direct extraction of lithium metal, whereas DLE is the extraction of lithium. Furthermore, since the company is able to manufacture high-performance lithium metal electrodes in-house, the resulting lithium metal batteries are also extremely high-performance. PL has already developed a battery that can maintain 97% capacity after 500 cycles.

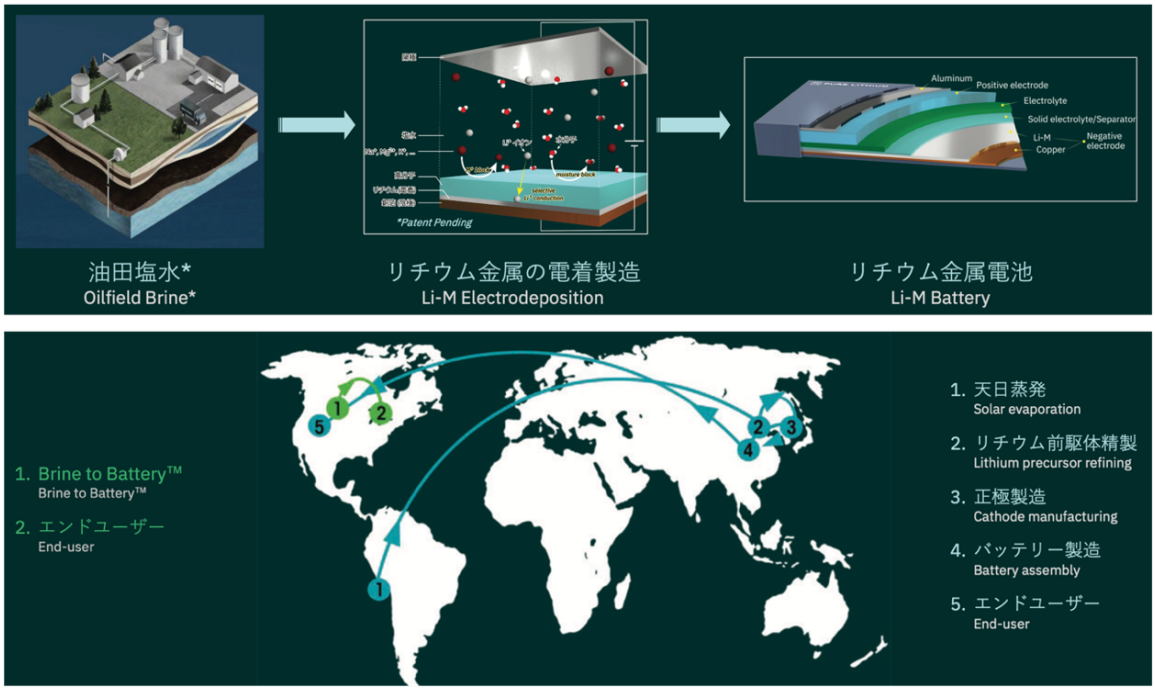

Figure 2: Strategy for building a lithium metal battery supply chain using lithium ion extraction technology. Top: Overview of the Brine to Battery process. Lithium anodes for use in lithium metal batteries are created directly from Oilfield Brine, and lithium metal batteries are manufactured. (*PL has demonstrated technology using lithium brine collected by E3 Lithium corporation) Bottom: Comparison of lithium metal battery manufacturing using the Brine to Battery concept and the conventional battery making process. Brine to Battery technology enables the creation of lithium anodes in one step, significantly shortening the manufacturing process. By minimizing transportation costs, PL is able to complete the production only within the United States / local areas.

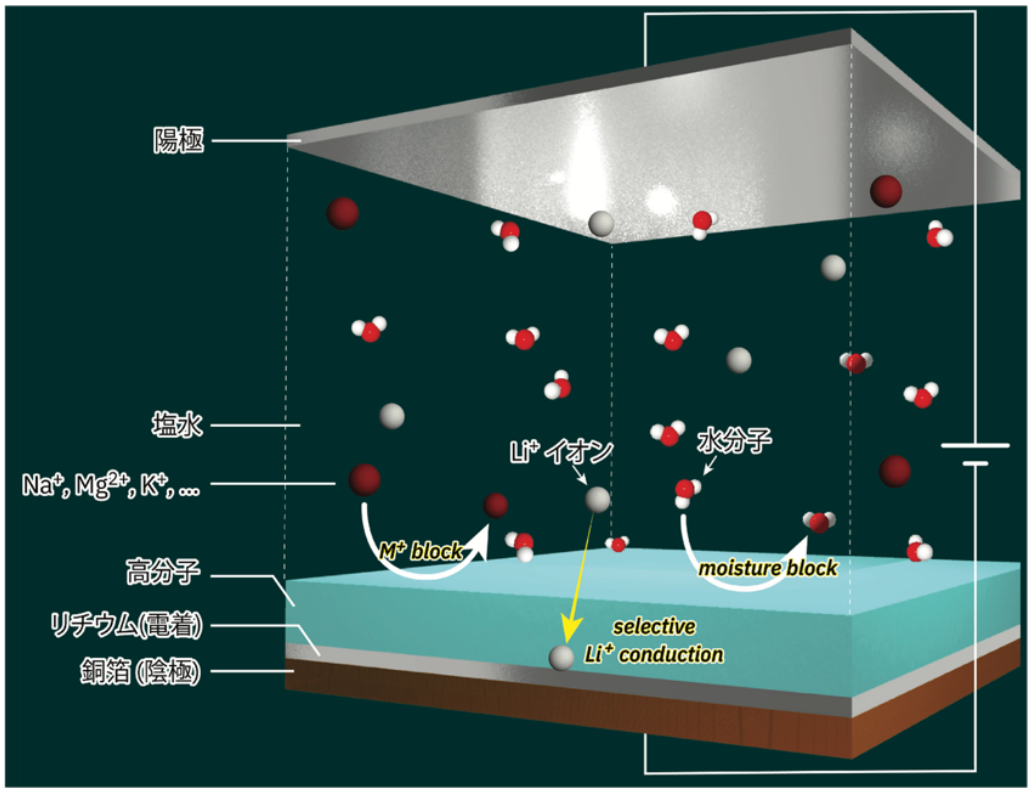

Figure 3: Schematic illustration of lithium extraction technology from Brine. By using a polymer membrane, only lithium ions from Brine are selectively delivered, creating a high-quality lithium metal layer directly on copper foil.

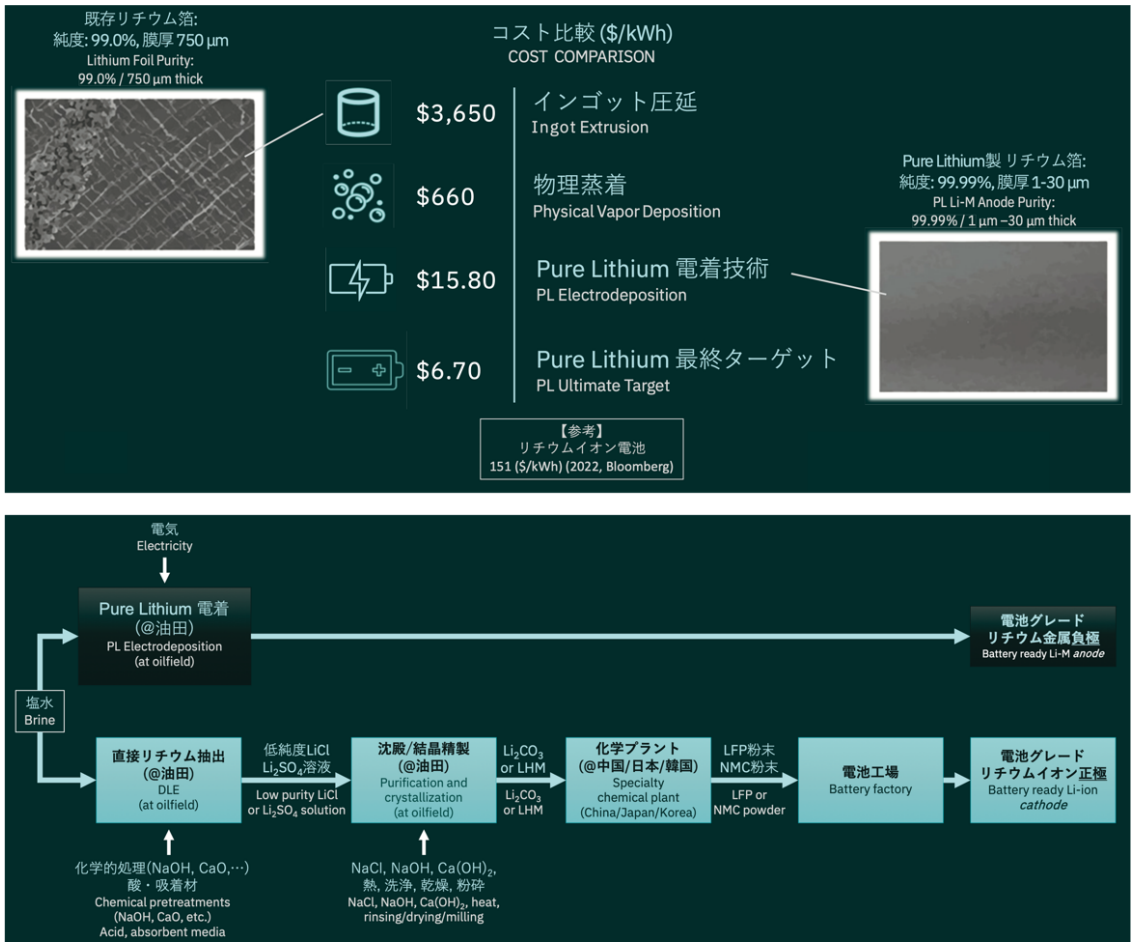

Figure 4: Differences in the cost of lithium metal anode production (top) and the processing of natural lithium brine resources by PL and current technologies. PL can produce lithium metal anode from brine in a single step at a cost more than 100 times lower cost than current technologies (top). In addition, current technologies mostly produce cathode materials for lithium-ion batteries through multiple chemical processes in different locations around the world, starting from the natural brine (bottom). The basic technology of PL, which allows for the extremely simple production of the lithium metal negative electrode itself rather than the positive electrode material while significantly simplifying the process, is an innovative technology that is completely different from current technology.

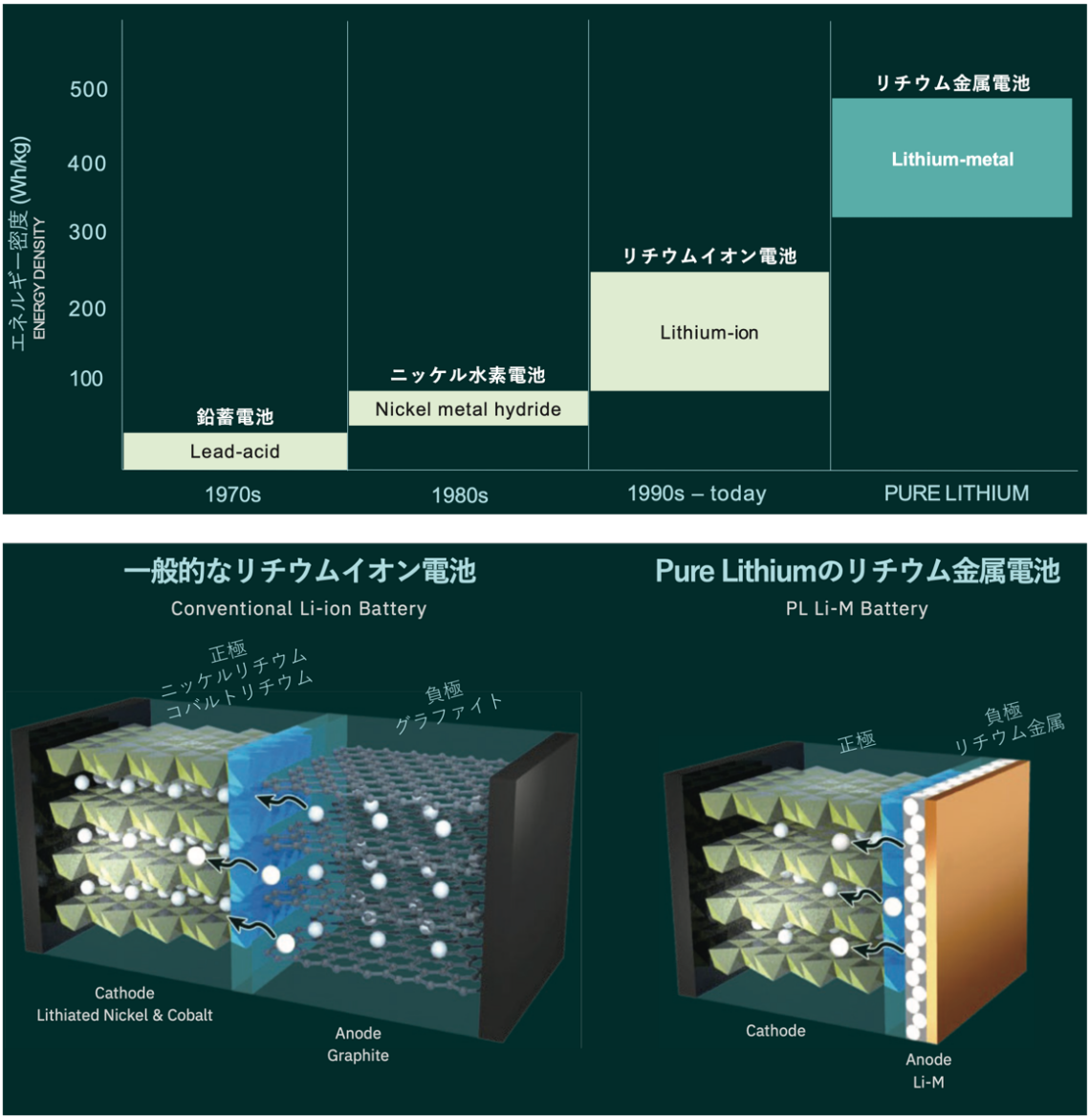

Figure 5: Top: Energy density in lithium metal batteries. Lithium metal batteries made by PL have an energy density that is about 2 to 4 times larger than lithium ion batteries. Bottom: Schematic illustration comparing the structure of a lithium ion battery and a lithium metal battery. Since PL does not use lithiated cathode materials in batteries, PL can dramatically reduce the cost of cathode materials. In addition, graphite is not used for anode material, but an inexpensive and high-performance lithium metal manufactured in-house is used. This makes it possible to reduce costs while significantly increasing energy density.

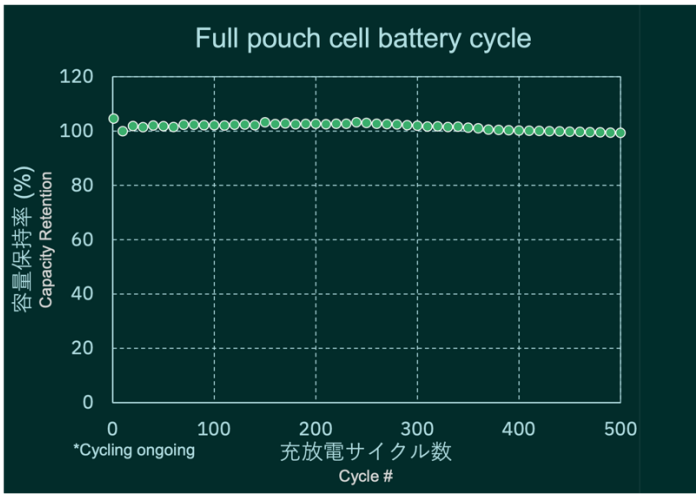

Figure 6: Battery cycle test data. It maintains high capacity even after more than 500 charge/discharge cycles.

2.1 Research topic

As a research topic during my internship period, I worked on the development of the core technology related to Brine to Battery™. Brine to Battery™ is a technology that electrochemically extracts lithium metal from brine in one step. Due to the high reactivity of lithium metal with water, it is required to eliminate any potential risk of water contamination. To avoid this, I conducted experiments combining the perspectives of electrochemistry, polymer chemistry, and organic chemistry.[i]

2.2 Acquisition skills

I learned a lot from three main points of view.

✧ **Electrochemistry, organic chemistry research methods and knowledge**

Six months was too short to master the experiment techniques perfectly, but I think I was able to understand a wide range of knowledge. In particular, research knowledge about the phenomenon of lithium ion transport from electrochemistry view, and the properties of polymer compounds can be utilized in the future research activity. In particular, I believe that I was able to learn about the differences in material design in inorganic and organic, and methods of functional design through discussions with Dr. Onoda, who is a professional of polymer design.

✧ **Team research**

Start-up companies have ambitious challenges, and all members are conducting research to realize company's goals. Even if they belong to different teams, the experimental process is divided up on a daily basis, and the company as a whole has the flexibility to change the resources depending on the research results that need to be focused on. Research in such an environment requires communication skills and a comprehensive understanding of the research. Smooth communication is expected to improve team productivity and accelerate research. In addition, understanding the research content of the company as a whole will make it clear how your own skills and experimental techniques can contribute to other teams.

✧ **Communication in the U.S.**

When conducting research in English-speaking regions, the way in which discussions should proceed is very different from that in Japan. Coupled with linguistic backgrounds, they often communicate in a very positive manner, and learning how to communicate in this way was a very important experience for me, who uses English as a second language.

3 Culture difference from my experience

In addition to specialized knowledge and research methods, through working at a start-up company in the United States for six months, I learned a lot about the pros and cons aspects of U.S. research culture and the differences between company and academic research. These experiences are that I would like to utilize in the future in the research environment in Japan creating a better research environment.

3.1 Research culture especially in the U.S.

I felt that research scale and research speed are the most important aspect in the United States. The fact that startup companies are able to conduct research very close to academic fields is a symbol of the scale of research in the United States. What supports the scale of research is also related to the amount of money invested in scientific research. University research also has close collaboration with large companies, and there are many investors who invest in startup companies. These investments are very different from the investment style in Japan, and aim not only to quickly recover funds, but also to develop technology that will be a game changer. It can be said that faith and hope in ambitious scientific research are part of the culture of the scientific and technological power house, United States.

On the other hand, research speed is required because the research is close collaboration

with industry. There are a lot of competition within the country due to a variety of funding sources, including investments from venture capital, companies, and public research grants that support a wide range of research, and there is a need to be the first to realize new technology. In order to achieve this speed of research, there is an environment that fosters innovation by researchers engaged in science. The Boston area is perhaps one of the most diverse area in terms of researchers (in terms of race, field of expertise, etc.), where new ideas and perspectives intersect every day. I experienced how research can be accelerated by the collaboration of different perspectives and by having many people involved in a single research project.

3.2 Academic and Industrial difference

Research at start-up companies has qualitatively different aspects from research at universities.

- PL is a team of around 50 people working toward ambitious goals.
- PL approaches almost all possibilities to increase competitiveness
- PL always have a business perspective

First of all, compared to university research, the number of people involved in a project is much larger. Independent experiments are of course carried out by individual researchers, but experimental results that are favorable to the company's goals are immediately shared to other teams. Therefore, the researchers involved are required to flexibly change the next process based on the experimental results obtained. Researchers who are able to bring out their own character in the shifting research are generally excellent, and through my own experience I found the fun and difficulty of research at a start-up company in this point.

One of the reasons why many people are involved is to maintain the strength of the company through an intensive study of a project. Having a large number of people allows us to have a quantitative advantage in terms of ideas and research. By comprehensively conducting related research, companies can secure a competitive advantage through patent applications. Furthermore, since ambitious research goals are based on long-term strategies, there is always the possibility of encountering difficulties. Having many people involved in research is suitable for solving difficult problems, and new ideas from diverse researchers play an important role for the ultimate goals.

Finally, a business perspective always need to be considered. Unlike academic research, even a result that could be called a failure of an experiment, such as ‘it is impossible to

achieve the goal with this method' can be a progress. We place importance on promoting research through the shortest route while investigating all possibilities to achieve our technological goals.

3.3 Industry-Academia-Government collaboration

Although it was a short internship, I had the opportunity to speak directly with CEO Emilie and Co-founder, Chief Scientific Officer Donald Sadoway. Here I will write down the new perspectives I came up with on each occasion. I feel that both are extremely important perspectives for industry-academia-government collaboration.[ii]

- **Connecting academic research with industry requires time and effort, which can be called "tough tech".**

  There is a huge gap between basic research and industrialization. Some of the recent startup companies are often related to software due to the development of artificial intelligence, and software can be brought to market relatively quickly. On the other hand, in my research on lithium metal batteries and lithium extraction technology, there are many roadblocks to build a supply chain. Research into fundamental technologies takes time and effort, and most require specialized knowledge even just interpreting the data. In addition, it is necessary to scale up the results in order to make them into products that can be sold in the market, rather than results on a laboratory scale. Scaling up takes a long time and effort to optimize basic technology and return this kind of research to the market. Therefore it should be called "tough tech" compared to other technologies.

  In order to elevate scientific research (especially basic research) to corporate research, we should use the company's technological strengths obtained through basic research as an advertisement, and always take a long-term perspective (looking ahead to scale up). It is necessary to push forward with research.

- **Start-up companies gather people based on strategy**

  Pure Lithium is one of the most successful startups, and has experts in each field who run the company. In order to carry out consistent research, specialized knowledge in various fields is required, as well as people who run the company.

  Selection of people at start-up companies is strategic. The base of the company was formed by gathering people with the necessary knowledge and skills. I learned that

having a Pure Lithium office in the Boston area and having Prof. Sadoway as a co-founder are extremely important in acquiring talent. Additionally, as social media has become so popular these days, many companies are recruiting people from all over the United States with the skills they want through job postings.

4 Other activities

Since I stayed in the U.S. for 6 months, I was able to not only do activities in the startup, but also activities that can only be done, as well as some aspects of American culture and history.

Visiting Checkelsky lab

I also visited MIT laboratories related to the research fields being conducted at the university, and had a wide-ranging discussion about the state of academic research in the United States. Prof. Checkelsky, who runs the laboratory, is a researcher who has research experience at RIKEN, and the style of the laboratory has a RIKEN style that is familiar to me.

Thanksgiving day

I spent Thanksgiving day at Alexa's home, whom I met through Pure Lithium's activities. This was first experience of actually spending Thanksgiving in America, and I enjoyed to talk with her family about the culture of spending Thanksgiving, and have traditional meals such as turkey.

Boston Symphony Orchestra

Symphony Hall, where the Boston Symphony Orchestra works, is a concert hall that retains the ideal shoebox format of the 19th century. BSO has been performing in Boston since October, and I was able to listen their first performance. I had a great time, not only enjoying the concert in a hall with excellent acoustics, but also enjoying the sights of existing historical buildings.

Haymarket

Every weekend, I used Haymarket, an open market with a long history in Boston. Haymarket is run by volunteer farmers, and because it sells directly, you can purchase a wide variety of vegetables at reasonable prices.

In addition, they were able to tour museums in the Boston area, tourist attractions and historical buildings that are rooted in the area, such as the Boston Museum of Science and the New England Aquarium.

Figure 7: Some of the memorial photos. Top left: Thanksgiving day photo taken at Alexa's house. Araki is second from the right. Top right: A photo of the interior of Symphony hall taken from the second floor seat in the back. Bottom left, center: Haymarket photos. Bottom right: Boston Museum of Fine Arts objects photographed in front of the museum.

5 Acknowledgements

This project was an unprecedented long-term overseas internship, and it was also my first time visiting the United States, so I appreciated all the support from many people. In particular, I would like to express my deepest gratitude to Dr. Michika Onoda, who proposed this activity and provided full support for it, and to Professor Shinichiro Seki, who supported me so that I could focus on research in the United States during my doctoral course research activities.

Being able to meet members in Pure Lithium and many people through a series of activities has been a treasure. I wish you all the best in your future, and I look forward to seeing you again somewhere.

Photo with the team members on the last day of the internship.

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[2] 経済産業省 大企業×スタートアップの M&A に関する調査報告書

[3] 経済産業省 新規事業スタートアップ Web サイト

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[i] Details of the research are omitted as they are confidential.

[ii] These stories are just Araki's personal interpretations based on the discussions.