Technology Transfer and Innovation Commercialization for Electrical Energy Storage Technology

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Abstract

Various technological innovations resulting from research and development (R&D) from universities must be used optimally to encourage economic development through down-streaming and commercialization. In the commercialization stage, technological innovations face various challenges in entering the market: product, process, innovation, and business issues. These challenges can lead to the failure of the technological readiness level of the innovations developed to meet market industry criteria. Therefore, the Centre of Excellence for Electrical Energy Storage Technology (CE-FEEST) of Universitas Sebelas Maret, Indonesia, has overcome these challenges so that innovative products can cross the valley of death and emerge in the market. CE-FEEST has developed several strategies and commercial models to act as a technology innovator and technology transfer office within the university and support the down-streaming of research results through a series of innovation and technology commercialization strategies. The CE-FEEST contributes to developing know-how and intellectual property, carrying out the incubation process, and building an ecosystem conducive to the growth of creativity and innovation. Lessons can be drawn from CE-FEEST's journey in developing an innovation ecosystem and responding to the challenges of technology commercialization, especially in mobility and stationary storage applications.

Introduction

Higher education institutions (HEIs) have changed worldwide in recent decades (Bramwell & Wolfe, 2008). Nowadays, HEIs are experiencing a challenge to contribute to social, economic, and technological development (Etzkowitz, 2014; Guerrero, et al., 2015). It leads to how the role of HEIs has developed from serving as conventional research and education functions to actively engage in innovation promotion (Arbo & Benneworth, 2007; Uyarra, 2010; Youtie & Shapira, 2008). Accordingly, HEIs as research centers are now considered significant support for regional economic development (Chatterton & Goddard, 2000) and the advancement of a technology-based economy (Clayman & Holbrook, 2003). Due to this demand and pressure, various technological innovation outputs of research and development from HEIs must be maximally utilized to encourage economic development through downstream and commercialization (Leung & Mathews, 2011).

An innovation process will fall into the valley of death if it has a low level of technological, innovation, and manufacturing readiness (Debois, et al., 2015; Flinn, 2019; Ford & Dillard, 2018; Ward, et al., 2018). As a result, technological items are unable to have a strong commercial aspect, be useful, and join the market. The failure of technological innovations to enter the market is due to various challenges and problems: products, processes, innovations, and businesses. They lead to the failure of the technological readiness level (TRL) of the developed innovations to meet market industry criteria (Chirazi, et al., 2019; Hindle & Yencken, 2004; Osawa & Miyazaki, 2006; Sutopo, et al., 2022). Therefore, it is necessary to strengthen approaches to resolve these challenges so that innovations can cross the valley of death and emerge in the market.

A technology transfer office (TTO) is the spearhead of the innovation system because it is responsible for the technology commercialization process. As an intermediary institution, TTO becomes a bridge that connects technology providers; in this case, technology research and development institutions or universities with technology users, namely industry. In addition, TTO is also seeking funding for advanced technology development (Cunningham, et al., 2020; Khademi, et al., 2014). The existence of technology transfer service offices in universities can overcome various problems in the technology transfer process to facilitate the commercialization of technology (Aqidawati, et al., 2020; Sutopo et al., 2019).

This article used a case study on the commercialization of lithium battery innovation generated by a university. The Centre of Excellence for Electrical Energy Storage Technology (CE-FEEST), Universitas Sebelas Maret (UNS), Indonesia, started researching lithium batteries as a form energy storage in 2012. Currently, CE-FEEST has mastered the development of crucial production formulas and technologies for manufacturing active cathode materials and cells for various lithium battery materials and developing modules and packs of batteries for various applications. In addition, CE-FEEST has also succeeded in fostering several start-ups and has multiple research output patents. CE-FEEST takes on the role of developing intellectual property, carrying out the incubation process, and building an ecosystem conducive to creativity and innovation growth.

Case of CE-FEEST

CE-FEEST is a Ministry of Research and Technology program of Indonesia to strengthen the institutionalization of innovation in the university environment. This institution is under the leadership of Universitas Sebelas Maret (UNS), which focuses on the development of lithium batteries, starting in 2012 through the Indonesia Electric Vehicle program, which is now being developed into lithium batteries at UNS. CE-FEEST has the vision to become the center for developing energy storage technology for electric vehicle applications, and the leading renewable energy in Indonesia by 2025. As one of Indonesia's research and development (R&D) and incubation centers, CE-FEEST is committed to presenting technological innovations and processing methods in the field of renewable energy, among other areas: development of high-performance battery technology for electric vehicles and renewable energy storage systems, processing of local resources for lithium battery raw materials, advanced energy storage technology with available raw materials in Indonesia, and development of battery integration technology with charging systems and equipment.

The facilities and infrastructure are divided into a battery laboratory, lithium battery mini plant, active material mini plant, test, and characterization equipment, charging station, and training and training administration building. Furthermore, the activities carried out to improve competence are in the form of research and development of energy storage technology, for example, prototyping and materials, cells, and pack development. In addition, CE-FEEST also provides testing, training, industrial consulting, incubation, and commercialization services. This institution has produced superior products such as battery packs, two-wheeled and three-wheeled electric bicycles, convertible electric motorcycles, electric cars, e-trikes, public street lighting, and battery-active materials. To create the best results, CE-FEEST continued to develop next-generation batteries, active materials from local raw materials, and battery-based technology startups, and published a journal of Energy Storage Technology and Applications (ESTA).

CE-FEEST plays a role in conducting regional cooperation for innovation and technology transfer. CE-FEEST has carried out collaborative activities with various parties, including a workshop on battery and energy storage technology (BEST), kick-off battery production, soft launching of lithium-ion batteries, visits to automobile trading companies and the Ministry of Industry, signing of MOU with a national energy company, and the launch of a teaching workshop by the Ministry of Research and Technology of Indonesia. CE-FEEST continues to support the development of battery technology with local resources as Indonesia's future innovation energy.

Technology commercialization cooperation and strategy

A new company needs the right technology commercialization mechanism to deliver the products it sells to consumers. CE-FEEST employs various strategies in bringing the university's research potential into a commercial product with an institutional brand accepted by the market. The mechanism used by CE-FEEST to support the transfer of research technology is through patent licensing, operational cooperation, joint ventures, and technology-based startups.

CE-FEEST has produced many works as a result of the development of technological innovations. Licenses for these innovations have been held for various types of patents, copyrights, and brands. The patents issued for the production of lithium batteries include the composition of battery cathode and anode materials, process and method of making battery materials, Li-ion battery test equipment, and techniques. In addition, CE-FEEST has also successfully registered the brand for Li-ion battery products and active materials.

CE-FEEST has implemented an operational cooperation mechanism to support innovation and technology transfer. CE-FEEST carries out active cooperation with various companies in Indonesia to develop and produce technologically innovative products. Collaboration with a national automotive company was agreed upon to develop an electric bus. In addition, cooperation with household appliance manufacturing companies is carried out to establish portable vacuum cleaner products. Collaboration with telecommunications and electricity companies produces street lighting products. Similarly, cooperation with renewable energy semiconductor manufacturers is aimed to develop outboard ships. In the same way, cooperation with environmentally friendly vehicle manufacturers produces e-trike.

Various university research outputs from technological innovations are managed, maintained, and developed by CE-FEEST's business. In its role of managing technological innovation, CE-FEEST has incubated and fostered until the products were launched. In addition, CE-FEEST has also expanded its business and succeeded in establishing innovation-based startups. Until now, three startups have been continuously maintained: a lithium battery manufacturer and its derivative products, a startup provider of electric vehicle conversion kits, and a battery cathode material manufacturer.

Open innovation at CE-FEEST

CE-FEEST has implemented open innovation in developing energy storage technology to face innovation challenges. CE-FEEST cooperates with many parties at various stages of technological entrepreneurship development. Open innovation was carried out by using the available channels, from knowledge and technology to business development. In this case, CE-FEEST is open to using various external sources of consumer feedback, patent publications, research results, and so on, to encourage internal product/service innovation.

The feasibility study, fundamental research, and perspectives of various stakeholders from numerous organizations are gathered during the idea generation stage. It aims to explore the needs of stakeholders and ensure a common understanding of the technology being developed. This process involves academia, manufacturers, consumers, and the government.

In technology development, open innovation is implemented by collaborating with companies to develop new technologies in a collaborative R&D process. The various collaborations mentioned previously are a form of open innovation that takes place at CE-FEEST. With open innovation, CE-FEEST can obtain resources from other companies and share internal resources to create new products. Thus, CE-FEEST can obtain the company's ideas, technology, knowledge, and capabilities externally.

In addition to technology development, CE-FEEST conducts open innovation for startup incubation. CE-FEEST, together with a national energy company, performed co-incubation for startups, including lithium battery manufacturers, bike-sharing startups, and motorcycle-sharing startups. The co-incubation program intends to support startups for business development and market expansion. CE-FEEST provides facilities by bringing participants to the right partners, opening a business network, providing business consultations with professional mentors, and providing information about the Indonesian market.

UNS, now a university with a State University as Legal Entity, also opens up opportunities for CE-FEEST to cooperate with foreign companies. This opportunity was able to support the derivative startups owned by CE-FEEST. CE-FEEST has increased orders for electric bicycles with the help of university leadership, which has accelerated the growth of startups.

Innovation process and technology transfer: CE-FEEST's role as TTO

A TTO is the spearhead of the innovation system responsible for the technology commercialization process and a bridge that connects technology providers, with technology users. Activities carried out by CE-FEEST in technology transfer, namely, technology disclosure of inventions by researchers, valuation of invention technology, management of intellectual property/patents, and commercialization of patented technology through licenses, spin-off companies, and technology-based startups. It is expected that the existence of CE-FEEST can overcome various problems in the technology transfer process to facilitate technology commercialization. Figure 1 presents the framework for the innovation and technology transfer processes implemented by CE-FEEST so far.

1. Conception and invention

a. Idea generation

The first step in the conception stage is idea generation. Idea generation is a systematic search for a new product idea. Sources of ideas can be internal or external. Internal sources come from research and development conducted by academics at the university. In contrast, external sources come from literature, research, and development results outside the university. Researchers at CE-FEEST started this conception stage in 2012 to address issues that the environment (market, nation, and society) required them to solve. The establishment of CE-FEEST was motivated by automotive technology, shifting from fossil to electrical energy. The proposed idea is to develop energy storage technology as a potential solution to overcome the pollution and shortage of oil reserve problem; as there are abundant renewable energy sources and natural resources available. Starting from a national electric car development project in 2013 with universities in Indonesia, CE-FEEST has the idea that lithium batteries can be used as a critical component of electric vehicles and renewable energy systems.

b. Research and development

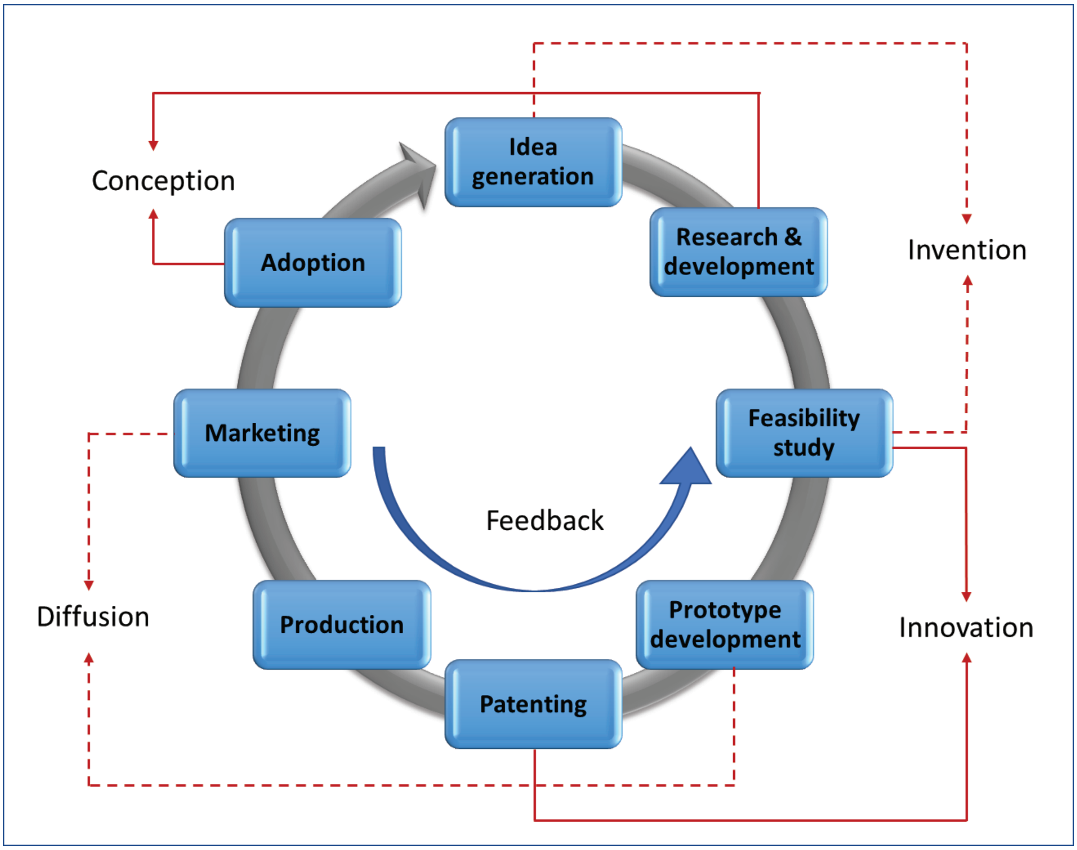
The invention stage started when research and development were carried out in 2012. Various studies were carried out to support the proposed idea of exploring the basic principles of energy storage technology. In addition, we also formulate the concepts and applications of technology needed to answer today's challenges. CE-FEEST researches and develops active materials for lithium battery cathodes using various chemical materials. In addition, research continues to be carried out to generate optimal production processes to yield active materials and design a pilot plant for active material production. Furthermore, it is integrated with the Li-ion battery manufacturing facility to produce high-performance batteries at affordable prices.

In the development of batteries for battery-based electric motor vehicles, the concept is to domestically produce cell production technology for stationary, electric vehicles and reliable, fast charging by 2024. It was the background for designing a mini plant for lithium battery production.

2. Innovation and diffusion

a. Feasibility study

After the technological product concept had been developed, a feasibility study was carried out to measure and assess the feasibility level of lithium battery



Source: Modified from van Waarden, et al., 2002.

Figure 1. Innovation process and technology transfer framework

production. This activity was carried out to determine how feasible a project plan was. This study is necessary to develop the mini plant business for lithium battery production. In this way, potential bottlenecks can be avoided and the estimated cost to run the project can be determined. In addition to reviewing the economic aspect, we also conducted a feasibility study by evaluating the technical and operational aspects of running a mini plant business, such as production capacity and resources.

Furthermore, market aspects were also evaluated to predict market share, analyze the demand for lithium batteries, and formulate appropriate marketing strategies. In addition, various alternative solutions for research and product development feedback were also proposed based on the evaluation of the feasibility study. Finally, the pilot plant for mass production of lithium batteries was officially launched in 2017.

b. Prototype development

CE-FEEST has mastered lithium battery production technology. The next step is to develop a product prototype. The goal is to develop a product model or design into a final product that can meet user demands. During the product development stage, users can take part by evaluating and providing feedback. The feedback provided can be used as a reference in product development stage. In addition, using prototypes can bring up new ideas that can be developed into a feature to complement the product.

In 2014, the prototype for the cell lithium battery was successfully created. Meanwhile, the battery module/pack prototype was successfully developed in 2015. The resulting prototype was also been tested for suitability in the laboratory. This Li-ion battery product can be applied to various equipment, such as a power bank, laptop, and bicycle. The wide application of Li-ion batteries has prompted CE-FEEST to develop prototypes for products derived from lithium batteries. The research background for developing modules and packs is to support electric vehicle systems and energy storage based on lithium batteries. The products produced from the research that CE-FEEST has carried out include convertible electric bicycles, electric motorcycles, e-trikes, and electric cars.

c. Patenting

CE-FEEST has produced various outcomes through research and development from 2012 to 2021. The outputs of this research have received official legal recognition and protection through patenting. The patents issued for the production of lithium batteries include the composition of battery cathode and anode materials, process and method of making battery materials, Li-ion battery test equipment, and methods. In addition, CE-FEEST has also successfully registered trademarks for Li-ion battery products and active battery materials. Figure 2 presents the patents held by CE-FEEST.

2014	2019	2021
1. Cathode composition, method of producing lithium secondary battery cathode composition 2. Monitoring Battery Discharge Using an Arduino Uno Microcontroller Based on LabVIEW 3. Algorithms and Methods for Calculation of State of Charge (SOC) and Degree of Discharge (DOC) batteries for electric cars 4. LiFePO4 Battery Test Equipment and Method 5. Graphite-Based Battery Electrodes Used in Primary Batteries 6. Application of Budget Monitoring System and Digitalization of Financial Accountability Documents MOLINA 7. SmartUNS	1. Process of Manufacturing Battery Separators from PVDF/SiO2 . Nano Fibers 2. NMC (Nickel-Manganese-Cobalt) Li-Ion Cathode Manufacturing Process 3. Lithium Nickel Cobalt Aluminum Cathode Material Manufacturing Process 4. Oxide (NCA) SiO2/C Composite Li-Ion Batteries from Coal Derivatives 5. Lithium Nickel Cobalt Aluminum Oxide NCA Cathode Material Composition and Manufacturing Method 6. Composition of Carbon Silica Anode Composite Material from Fly Ash and Manufacturing Process 7. NCA Cathode Manufacturing Process with Environmentally Friendly Chelation Materials	1. The process of making a battery separator from PVDF/SiO2 . nanofibers 2. SiO2/C composites from coal derivatives in Li-ion batteries 3. Method of making lithium nickel cobalt aluminum oxide (NCA) cathode material 4. Material composition of lithium nickel cobalt aluminum oxide (NCA) cathode and method of manufacture 5. Composition of carbon silica (C-SiO2) anode composite material from coal fly ash (fly ash) and its manufacturing process 6. The Process of Manufacturing Lithium Nickel Cobalt Aluminum Oxide (NCA) Cathode Materials with Environmentally Friendly Chelating Agents 7. The process of recycling lithium nickel cobalt aluminum oxide (NCA) cathode material from waste lithium ion battery production (certificate production) 8. The Composition of Lithium Nickel Cobalt Aluminum Oxide (Nca) Cathode Materials And The Manufacturing Method 9. Method of Manufacturing Lithium Nickel Cobalt Manganese Oxide Rich Nickel Cathode Material 10. Polymine

Figure 2. Patents generated by CE-FEEST

d. Production

In 2012, UNS became one of the five universities to manufacture the National Electric Car (Molina). After three years of development, UNS, through CE-FEEST, has demonstrated the advantages of its specialization in lithium batteries and is now able to produce with a target of 1000 batteries per day. CE-FEEST has successfully built a pilot plant of a production unit for lithium battery cells in 2015 and active cathode materials in 2019. This entity has been used to validate various models, methods, and supply chain network designs and an ongoing basis for evaluating production and service quality.

Smart UNS, the lithium battery found by CE-FEEST researchers, has two types, namely lithium iron phosphate ($LiFePO_4$; LFP) 18650 and NCA 18650, with a voltage of 3.2 volts and 3.7 volts and capacities of 1400 mAH and 2700 mAH, respectively. Using LFP technology, this battery has high safety because it does not cause an explosion in the event of a short circuit. In addition to being rechargeable and economical, this battery has a long service life of up to 3000 cycles of use, is longer than current commercial products (500 cycles), and can withstand relatively high temperatures, namely up to 70°C.

The production process does not produce waste harmful to the surrounding environment. In addition, the production process is equipped with equipment that meets the standards. This product can be applied to electric cars, bicycles, public street lighting, notebook PCs, toys, UPS, and power banks. For production funding, CE-FEEST has collaborated with the national energy company, the Ministry of Education, Culture, Research, and Technology, and the Indonesian Endowment Fund for Education.

e. Marketing

At this stage, energy storage technology is developed in such a way that it reaches a point where the technology can be applied to a profitable production or consumption activity. To get CE-FEEST products on the market, marketing is used. In this situation, learning how to conduct product research that can survive the valley of death and compete in the market is crucial. Thus, a proper commercialization strategy is needed. In order for an innovation to meet market requirements, it must be technologically prepared so as to avoid failure. Readiness is needed to not result in the technological readiness of the innovation being developed failing so that it can meet market criteria. The commercialization strategy carried out by CE-FEEST, namely Li-ion batteries and their derivative products and electric vehicles, into commercial products with institutional brands has been accepted by the market. The commercialization strategies implemented are through patent licensing, the establishment of technology-based startup companies, joint ventures, and operational cooperation.

f. Adoption

From the whole innovation process, from idea generation to marketing, adoption is the last stage that determines the success of the diffusion of technological innovations carried out by CE-FEEST. The products produced, such as e-bikes, e-motorcycle, and power wall, are real examples of the adoption of energy storage technology.

Early supply chain to accelerate technology commercialization

Regarding the issue of lithium battery innovation, there are several reasons for integrating the supply chain into the commercialization process at an early stage, namely, the supply chain has a special and unique component. In addition, each product of technological innovation has its own unstable and evolutionary supply chain. Furthermore, innovation would lead to modification of the supply chain. Supply chain integration with technology commercialization processes can also provide support-seeking options to shorten the time to market with intervention. Therefore, early supply chain engineering can be used as an intervention instrument to help startups survive and win the market by creating a competitive advantage.

CE-FEEST has produced research outputs that can address the technology commercialization challenges. Figure 3 explains the early supply chain engineering to solve commercialization challenges. The research outputs produced by CE-FEEST have resulted in five intervention options to increase the level of technology readiness more quickly and at a cheaper investment:

1. Technology development and standardization;
2. Incubation cycle;
3. Engineering, procurement, and construction in production facilities;
4. Material sourcing and selection; and
5. Distribution and marketing cycle.

In order to discover a successful solution that would enable the faster adoption and diffusion of technology, an open innovation system with collaboration between supply-chain players, universities, and the government is needed.

1. Product challenge

The challenge of product development and innovation does not necessarily have a standard reference for development. CE-FEEST has mastered the development of formulas and critical production technologies for manufacturing cathode-active materials and cells in various lithium materials. Technological innovation needs to be supported with standard references. Standards should encourage innovation rather than hinder it. The efficient standards have been designed with necessary and sufficient conditions that have a solid correlation to increase product competitiveness. The economics of standard implementation has been modeled, considering the testing entity's strengthening and technology readiness (Aqidawati, et al., 2019, 2022). The research also contributes to the availability of five standard references and national standards related to testing and product quality standards for cells, modules, and battery packs. Cost-estimation models for lithium battery cells, modules, and packs have been developed as an accurate business decision tool.

2. Innovation challenges

The challenge with innovation is that the developed technology must be maintained and promoted through commercialization. The lessons learned from the development of lithium battery technology include the creation of new methods for effective technology transfer and open innovation as well as a number of proposed entity-strengthening models in the licensing, joint venture, and startup processes. The intervention for accelerating incubation time uses a co-incubation approach with battery user companies. The technopreneur model was used to strengthen human resources who exceled in the development and management of technology-based companies.

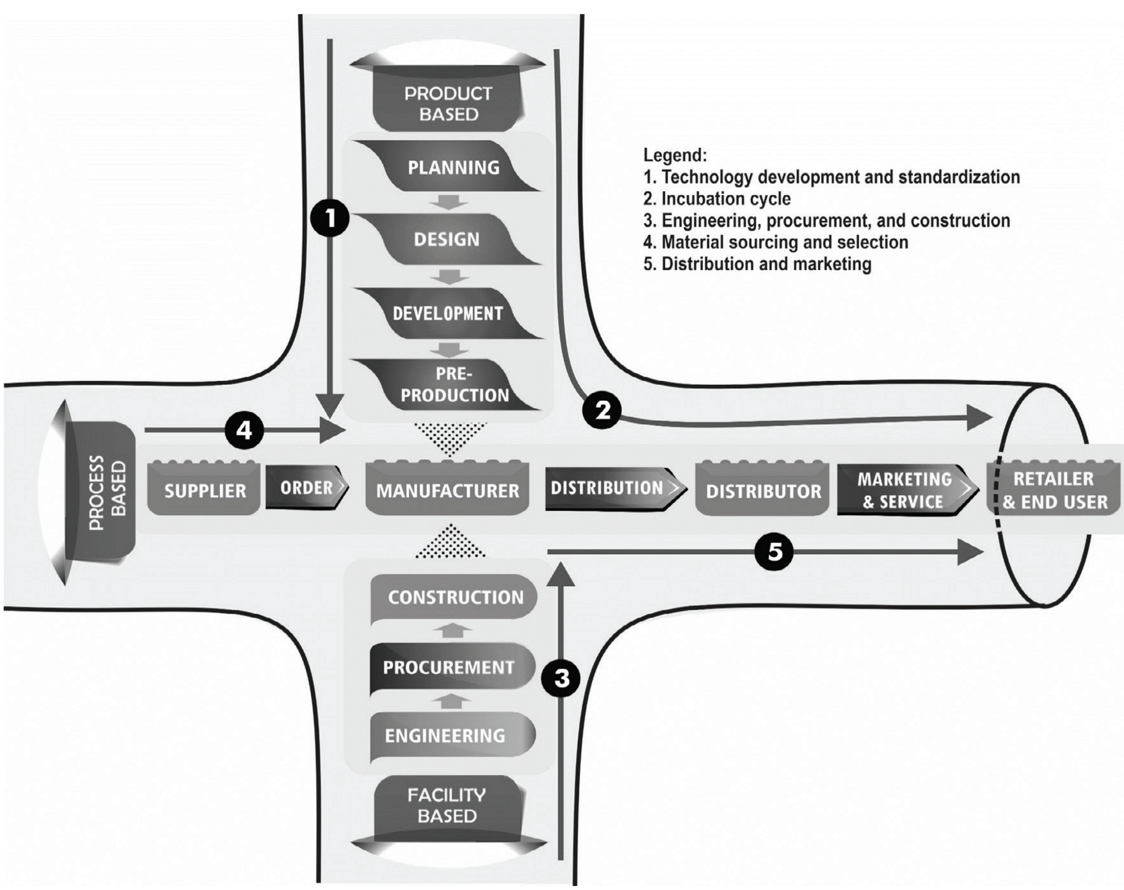


Figure 3. Early supply chain framework

3. Process challenges

In order to build a low-cost product manufacturing process, it is necessary to look for lower investment options from the engineering, procurement, and construction phases of production facilities. Process improvement was carried out by material sourcing and vertical integration from the stage up to the incubation stage, followed by the co-incubation stage with battery pack users in various product applications that use lithium battery packs. The intervention option has recommended strengthening the entity providing raw materials with a benefit, opportunity, cost, and risk (BCOR) analysis to obtain cheap and safe sources of raw materials. Strengthening inbound logistics through entities providing raw materials and outbound logistics for battery pack users was also used to create product competitiveness. The initial distribution and marketing process was carried out to shorten the time to market through the business-to-business (B2B) and business-to-consumer (B2C) market segments.

4. Business challenges

Developing new models, methods, and systems have been tested in a natural business environment. Using research funding from various sources, UNS built a lithium battery cell production unit in 2015, and an active cathode material production line in 2019. Lithium battery packs made by CE-FEEST are suitable for use in a range of electric vehicle systems and products. These production entities have been used to validate various models, methods, and designs of supply chain networks and, on an ongoing basis, to evaluate the quality of production and distribution services. Efforts to minimize investment for business acceleration have been tested in real terms. In early 2020, a startup was formed due to the co-incubation of CE-FEEST with a national energy company. The startup has been used to validate commercialization acceleration intervention options for electric bicycle battery packs, a startup for electric motorcycle battery packs, and other users for various lithium battery pack applications.

Lessons learned: CE-FEEST-technology innovation enabled go-to-market

CE-FEEST was established as the estuary of a long journey of battery research at UNS. CE-FEEST focuses on activities related to the development of lithium batteries and advanced energy storage technologies to support electric vehicles and renewable energy. As one of the critical components, batteries have an important role in adopting electric vehicles. CE-FEEST focuses on developing lithium batteries, placing concerns ranging from raw materials, cells and pack manufacturing, and battery management systems to battery testing and safety. Furthermore, CE-FEEST is also concerned with battery applications. CE-FEEST provides derivative products of Li-ion batteries, such as power wall, street lighting, e-bike, converted e-motorcycle, and e-cars. Therefore, CE-FEEST can create the capability of storage and charging system products that are robust, reliable, and a substitute for imported products (Figure 4).

The cooperation is being developed through collaborations with academics, businesses, and the government approach. CE-FEEST has collaborated with companies from various sectors, testing and certification centers, and national standardization bodies. In addition, startups also have foreign cooperation in supplying battery cells.

Various output products are licensed into registered patents, namely, patents for lithium battery active materials and patents for battery production. The copyrights are managed in the same manner and a business is developed through sophisticated commercialization technology. Thus, startups were established, and one of them is PT Batex Energy Mandiri (Batex).

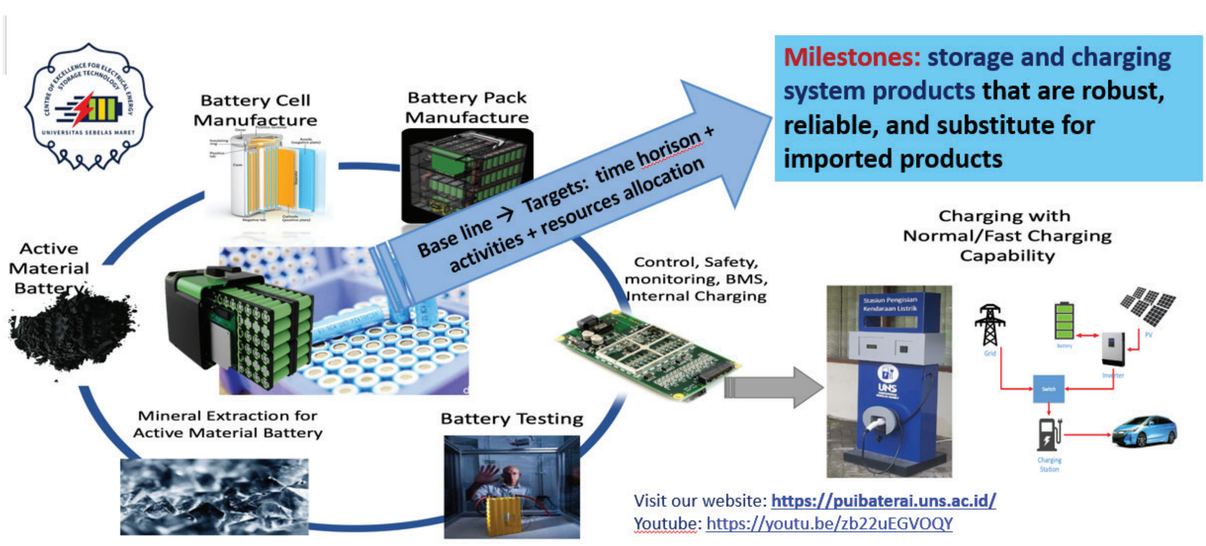


Figure 4. CE-FEEST capabilities

Batex is a tech startup that provides lithium-ion batteries and its derivative products and serves a range of critical applications, and meets the needs of various markets. Batex was formed due to the co-incubation of UNS with a national energy company, PT Pertamina. This startup is used to validate commercialization acceleration intervention options. Batex, as the first lithium battery manufacturing startup in Indonesia, uses all of its domestic resources, from materials to labor.

Batex has produced LFP-type lithium batteries, which are very safe, durable, stable at high temperatures, and economical. Battery products are suitable for use in tropical climates such as Indonesia.

Batex produces lithium batteries in the form of cells and packs. Its products have been used for e-scooters in several cities in Indonesia. In addition, Batex also provides power walls, e-bikes, and public street lighting.

Batex continues to collaborate with companies, incubators, and government agencies to provide high-quality products that meet market expectations. Collaboration is also done to get support in dealing with challenges in the development of energy startups, such as product development, market access, and capital. Therefore, Batex can create energy security in Indonesia. Figure 5 shows the products provided by Batex.

Conclusion

CE-FEEST has played an important part in technology transfer and innovation commercialization. In carrying out its role, CE-FEEST has established various regional co-operations to support downstream research results, startup incubation, and new product development. The process of innovation and technology transfer carried out by CE-FEEST generates several things: lessons learned from innovation and technology development, lessons learned for startups; development tenants through incubation; fostering business/startups in TTO; and measuring the effectiveness of commercialization strategy.

Figure 5. Batex products: (a) Lithium iron phosphate (LFP) battery cell, (b) LFP battery pack, (c) battery management system, (d) e-bike conversion kit, (e) foldable e-bike, and (f) power wall

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