Technical Feasibility Battery Lithium to Support Unmanned Aerial Vehicle (UAV): A Technical Review

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Abstract

Currently, unmanned aerial vehicles (UAVs) are not only used for the military but have also been applied to agriculture, energy, and transportation. One example of its application is by conducting environmental monitoring, agriculture, and survey applications. This UAV has very specific constraints on the driving force of the drone starting from the power needed, the costs incurred, its weight, and the durability of the flight. The main reason is the fact that UAVs are unmanned, so the weight is relatively less and does not require a life support system for the crew and passengers, making it ideal for this new technology. Also, fuel cells are still too heavy to push large aircraft; they have a lower power density when compared to conventional turbines. In this study, we want to see the development of the technical feasibility of lithium battery packs for drones / UAVs. Because in business developing this lithium battery pack can increase 20% value-added products. The method used is a qualitative method by looking at and comparing similar companies. The purpose of this study is to see the technical feasibility of lithium batteries for drones with a technical review from the literature review and previous research.

Keywords: Feasibility Study, Lithium Battery Pack, Qualitative Method, Unmanned Aerial Vehicle

1. Introduction

Drone sales trends increase every year. Globally, the total revenue from this device will reach the market more than USD 6 billion in 2017. In addition, in 2020, the growth of drones will reach USD 11.2 billion. Based on data released by Gartner in February, in 2017 the sales of drones are predicted to reach 3 million units. Compared to 2016, total growth for this year could reach 39% (Yusuf, 2017). It is also an integral part of zero-emission transport systems using electric drives, whether hybrid petrol-electric, battery electric, or hydrogen fuel cells vehicles for road, rail or sea (Andrewsa, 2018).

Technology is a systematic approach to build and improve the commercial value of technology produced by universities. The form of commercialization can be developed by the College (Nasution, 2009). Based on this understanding, therefore, in the development of lithium battery pack products for drones, it is necessary to use lithium battery pack products for drones. Hence, the products have an additional commercial value that can benefit later universities.

Lithium-ion battery technology was developed in the early 1990s and enabled the portable electronics revolution. The technology is now under development for applications in electric vehicles (EVs) and grid storage. Lithium-ion battery technology is expensive compared to the conventional flooded lead-acid battery technology and, hence, so far has been targeted for premium applications (Jaiswall, 2017).

The flight range of UAV is limited by the amount of fuel it carries. Increasing fuel will increase the total weight to the airplane, which in turn reduces the flight endurance. Although long endurance is achievable with conventional fuels, hydrocarbon-fueled systems are usually loud, inefficient, and unreliable when it comes to those small flying vehicles. On the other hand, batteries do not offer enough power for battery-powered systems for a long duration flight due to the low energy density of the battery system, especially where cameras and other equipment-powered by the same battery as the UAV's propulsive system-are in use. In addition to that, the longer battery charging time is another constraint to limit the pure battery-driven vehicles. Therefore, researchers started developing long-endurance UAVs which rely on new effective sources of energy as their power sources. In addition to high efficiency, long-endurance UAVs' power sources should possess the following properties: (1) high power and energy densities, and (2) fast dynamic response time in changes in power output (Dudek, 2013). Defining the following terms to be used throughout the paper; specific power and power density are the maximum available power that a source can deliver per unit weight (W/kg) and per unit volume (W/L), respectively, whilst specific energy and energy density are defined as the source's energy storage capacity per unit weight (Wh/kg) and per unit volume (Wh/L), respectively.

Hence, it is necessary for a comprehensive and comparative study on the selection of battery cell packaging and other design considerations for the development of an EV battery pack. It is important to improve the understanding of the battery pack design and to deliver the optimum performance of a battery pack so does UAV (Wignjosoebroto, 2009)

2. Methodology

The methodology in this study uses a qualitative approach. A qualitative approach to procedures that produce descriptive data in the form of speech or writing. The reason for this study using a qualitative approach is data obtained from data in the form of writing, words, and documents originating from sources or informants who are researched and can be trusted.

So, the data collection method used to collect data in qualitative research generally uses observation, interviews, and documentation studies. On the basis of concepts, three data collection techniques were used in this study. To obtain primary data using interviews and FGDs then to obtain secondary data using literature studies.

3. Results and Discussion

3.1. Propulsion and Energi Source UAV

UAVs can be powered by a variety of propulsion systems with very different effects on flight performance and environment. The great majority of UAVs use batteries to power the electric flight control system and motors. The most commonly used configuration for small civil UAVs is a combination of Lithium Polymer-batteries and brushless direct drive electric motors connected to a fixed pitch propeller. The advantages are no local emissions, a reduced noise level, and easy thrust control.

Although batteries are generally more efficient - they are heavy and remain part of the platform for the entire flight. In addition, batteries account for a lot of weight and space when designing a UAV. They currently represent the most limiting factor for endurance. The good news is that new energy sources are currently being examined and will soon offer very powerful flight performances. Gas-electric hybrids are not yet available for small UAVs due to lack of installation space. Hydrogen fuel cells are advancing but are not yet ready for mass production. Solar cells can support an electric system, but they cannot power it from the ground up. The big advantage is that the range can be extended simply by slowing down the discharge process of the batteries.

Table 1. Specifications of Lithium-Ion, Lithium-Polymer, Lead Acid, and Nickel Metal Hydride Batteries

No	Specification	Lithium-Ion	Lithium-Polymer	Lead Acid	Nickel-Metal Hydride
1	Weight (kg)	2.15	2	10	5.5
2	Specific Energy (Wh/kg)	150	150	40	65
3	Initial Cost ($/kWh)	600	-	100	100
4	Typical State Of Charge Window	80%	-	50%	-
5	Temperature Sensitivity	>45^{0}C	-	>25^{0}C	>45^{0}C
6	Efficiency	100% @20-hr-rate 99% @4-hr-rate 92% @1-hr-rate	-	100% @20-hr-rate 80% @4-hr-rate 60% @1-hr-rate	-
7	Voltage Increments	3.7	3.7	2	1.2
8	Charging Temperature	0-45	-	-	500
9	Deep Cycle Life (times)	500	-	-	500
10	Environmental Friendly or Not	Yes	Yes	No (Because of Pb and Acid)	Yes
11	Charge Method	Constant Current + Constant Voltage	Constant Current + Constant Voltage	Constant Current + Constant Voltage	Constant Current Multiple Steps

Sources: Afif (2015)

From the results above, each type of battery has specifications, advantages, and disadvantages of each. When a user will have a type of battery, there are many factors that must be owned. The importance of initial costs, lifetime, mass, volume, temperature sensitivity, maintenance access and access to all products play a role in battery selection. If we compare Lithium-ion batteries with Lithium-polymer, it is better to use Lithium Polymer batteries. Because with a lighter mass, this battery can produce greater specific energy with a Lithium-Ion battery. And if you compare between Lead Acid batteries and Nickel Metal-Hydride, it is better to use Ni-MH batteries. Because this battery has a mass two times lighter than a Lead Acid battery, with a lighter mass this battery can produce higher specific energy. In addition, NiMH batteries are more environmentally friendly, because lead batteries can cause this battery to be environmentally friendly (Afif, 2015).

3.2. State Of The Art Lithium Battery Pack for UAV

Battery technology continues to advance at a steady pace, spurred on by the demand for greater energy density from the consumer electronics and electric vehicle sectors. This improvement affects the cost of battery manufacture, the safety of the materials used, and the energy density of the batteries. Given that UAVs are significantly affected by their limited flight time we are particularly interested in the battery energy density, and how its improvement will improve the performance of the UAV network.

The authors of C-X Zhu (2013) suggest that historical improvement of battery energy density can be approximated as a steady 3% performance increase per year, which the authors point out is far too slow to satisfy the demands of the new, emerging technologies. Current commercially available UAVs use lithium-ion batteries with an energy density in the order of 250 Wh/kg, and the research discussed in T. Nozawa (2018) suggests that lithium-ion batteries may have their energy density improved by 20-30% within the next 5 years, reaching a performance ceiling by around 2025. So-called solid-state batteries which use solid electrolytes are expected to contribute to this performance growth. Sodium-ion batteries are predicted to be one of the new battery variants to act as an alternative to lithium-ion (C. Vaalma, 2018), as the required materials are much more abundant than those used for lithium-ion batteries, which means the battery manufacturing cost would be far less vulnerable to market fluctuations. Unfortunately, sodium-ion batteries have a lower energy density than lithium-ion batteries so it is unlikely they will be a key driving technology for UAV networks. Three battery technologies on the horizon that do promise an improvement in energy density are the hydrogen fuel cell, the lithium-sulfur battery, and the lithium-air battery, with a theoretical energy density of approximately 490 Wh/kg (Plaza, 2017), 500 Wh/kg (Service, 2018) and 1, 300 Wh/kg (Rahman, 2014), respectively.

Unfortunately, these technologies have drawbacks which delay their adoption and commercialization. There are concerns with the safety of both hydrogen fuel cells and lithium-sulfur batteries, while lithium-air batteries are known to be very vulnerable to exposure to the outside environment. Because of these drawbacks, it is difficult to make an estimate on the dates when the new batteries may be adopted into UAV.

Table 2. Comparison between Lithium-Ion battery with other types of batteries.

Battery Type	Lead-Acid	Ni-Cd	Ni-MH	Zn-Br	Fe-Cr	Li-Ion
Energy Density (Wh/kg)	30 - 50	45 - 80	60 - 120	35 - 54	20 - 35	110 – 160
Power Density	180	150	250 - 1000	-	70 - 100	1800
Nominal Voltage	2V	1.25V	1.25V	1.67V	1.18V	3.6V
Operating Temperature	-20 – 60^{0}C	-40 – 60^{0}C	-20 – 60^{0}C	-20 – 60^{0}C	-40 – 60^{0}C	-20 – 60^{0}C
Cycle Life	200 - 300	1500	300 - 500	>2000	-	500 – 1000
Charge Efficiency %	79	-	-	-	-	100
Energy Efficiency %	70	60 - 90	75	80	66	80
Voltage Efficiency %	-	-	-	-	82	-
Overcharge Tolerance	High	Moderate	Low	High	Moderate	Very Low
Self-Discharge	Low	Moderate	High	Low	HIgh	Very Low
Thermal Stability	Least Stable	Least Stable	Least Stable	Least Stable	Stable	Most Stable

Sources: Hanan M (2018)

There are different types of conventional batteries such as lead-acid batteries (Spanos, 2015), nickel-cadmium (Ni-Cd) batteries (Garcia-Plaza, 2015) and nickel-metal hydride (Ni-MH) batteries (Zhu, 2016 and Ren, 2015). Table 2 shows the comparison between the Li-ion battery with other types of batteries. Li-ion batteries are superior in term soft high energy efficiency and power density, which allows them to be designed lighter and smaller in size. Moreover, other advantages of Li-ion batteries include a broad temperature range of operation, rapid charge capability, relatively long cycle life, low self-discharge rate and charge, energy, and voltage efficiency (Fotouhi, 2016 & Lai, 2013). For these lucrative characteristics, Li-ion batteries dominate commercial battery markets for powering bio-implanted devices, medical instrumentations, and portable devices. The typical discharge characteristics of commercially available rechargeable battery sources, namely, lithium ion (Li-ion), lead-acid, nickel-zinc (Ni-Zn), nickel cadmium (Ni-Cd), nickel metal hydride (Ni-MH) and zinc-manganese oxide (Zn-MnO2) (Fotouhi, 2016; Arora 2016; and Sougrati, 2016). Almost all these battery sources specific energy and power levels; however, the Li-ion battery has slightly linear discharge characteristics. Moreover, in Fig. 14, the comprehensible differences among them are revealed in regard to their sizes and weights (Xiong, 2017). Here, it is shown that Li-ion batteries expose the best technology in high energy density with the smallest size and the lightest weight.

3.3. Identification of Potential Environmental Safety and Hazards

Security potential and environmental hazards are an effort to identify potential hazards arising from the production of new technologies and environmental hazards that may occur over the commercialization carried out. Hazard is a potential activity that causes damage (substances, activities, processes, objects) (Hughes, 2007). The production of lithium battery packs is not too dangerous because there are no processes that come into contact with hazardous materials. But the waste of the test results in the form of lithium-ion battery cells can be categorized as hazardous waste types if the battery waste has leaked. According to K2 Energy Solution (2009), lithium-ion batteries if leaked, the risk of fire, explosion, the release of hydrogen fluoride gas and the risk of irritation exposure to materials contained can occur (Atika, 2014). Figure 5 shows the process life cycle and potential hazards.

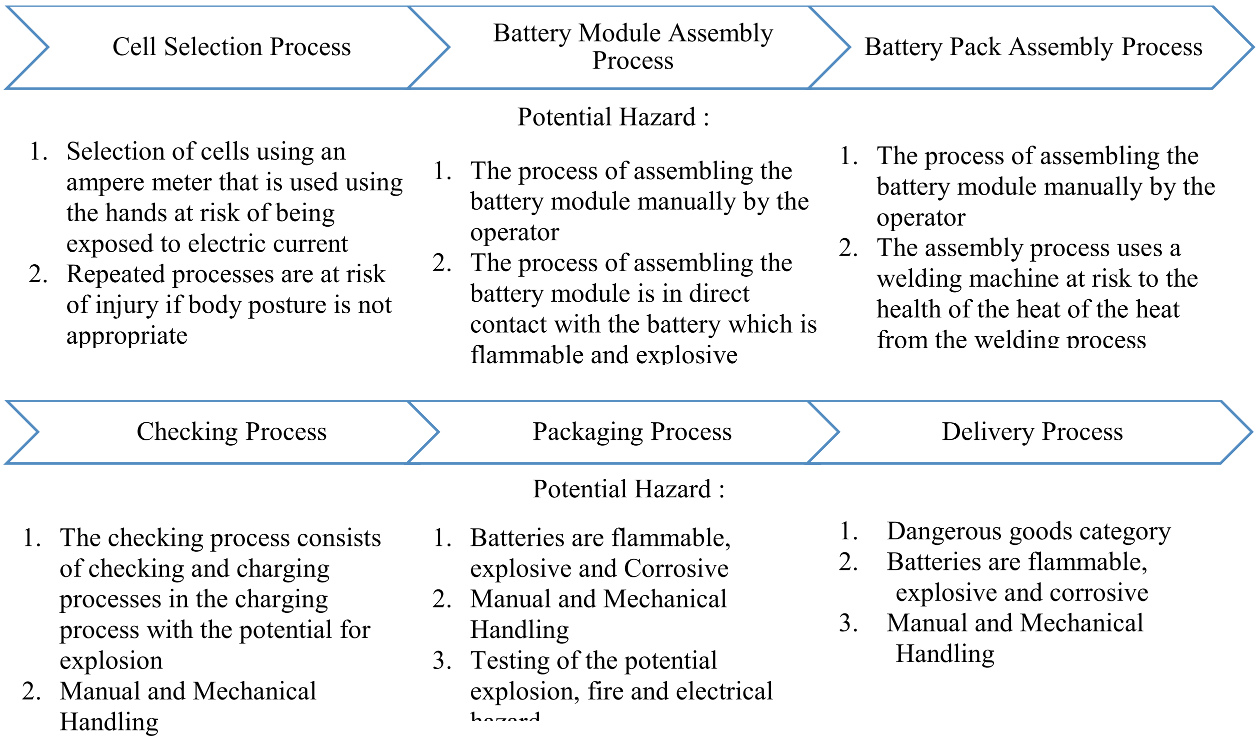


Figure 1. Life cycle process and hazard potential

Unmanned Aerial Vehicles (UAVs), encouraged by recent technological developments, have seen a dramatic interest boost in recent years and are already considered as an integral and indispensable part of modern armed forces (Wazeman, 2007) with an increasing number of dual-use and civil applications (Freire, 2009 & Maple, 2012)). Most developed countries have already acquired UAVs or plan to do so soon. Current propulsion systems are based on different types of internal combustion engines fed by fossil fuels, but with the global energy situation, preceded by the energy crises of the 70s and strategic incentives to make alternative propulsion systems, fuel cells have started to be introduced. These have advantages in terms of endurance, efficiency, emissions, and stealth, which make them ideal for UAV applications (Hordeski, 2009). Starting from the premise that important energy and environmental problems in our society exist, the advantages and disadvantages of fuel cells as an alternative for UAV propulsion systems are going to be analyzed.

Fossil fuels pose a serious environmental and economic problem. They are the main cause for the increase of CO2 presence in the atmosphere, declared to be one of the most important culprits of global warming and the atmospheric emissions of other pollutants (IPCC, 2007). The current economic and financial crisis has been aggravated by high energy prices (US. Department, 2010). There is, therefore, an urgent search for new energy policies based on the diversification of energy sources and their origin, energy-saving policies, and the use of efficient energy conversion systems. Of course, the world of aviation is not an exception to the above considerations. UAVs are in their nascent stage of development (in fact, their regulations are in process of being written), although the implementation of fuel cell propulsion systems is more advanced than in conventional aircraft. The main reason is the fact that UAVs are unmanned, thus, weighting comparatively less and not needing the life support systems for the crew and passengers, making them ideal for this new technology. In addition, fuel cells are still too heavy to propel any large aircraft; they have a lower power density when compared with conventional turbines (Hordeski 2009). In a military setting, there are other key operational advantages such as stealth and a lower thermal signature.

3.4. Production Feasibility

For the initial assessment of manufacturing, there are two parts, namely the contribution to the domestic value-added chain and the availability of raw materials. Value added is a techno-economic process that requires skills and expertise, technology, creativity and innovation, managerial, entrepreneurial, capital, cooperation, and market control to create it. The added value of the battery cell into the battery pack reaches 20%. The main raw material in lithium battery packs is lithium battery cells with suitable characteristics. The availability of raw materials for NCA lithium battery cells in Indonesia is still low. But now UNS has been producing battery cells in bulk with a production target of 1000 cells/day (Khofiyah, 2018; Atikah et al, 2014). Figure 2 describes the value-added chain for making lithium battery packs for drones.

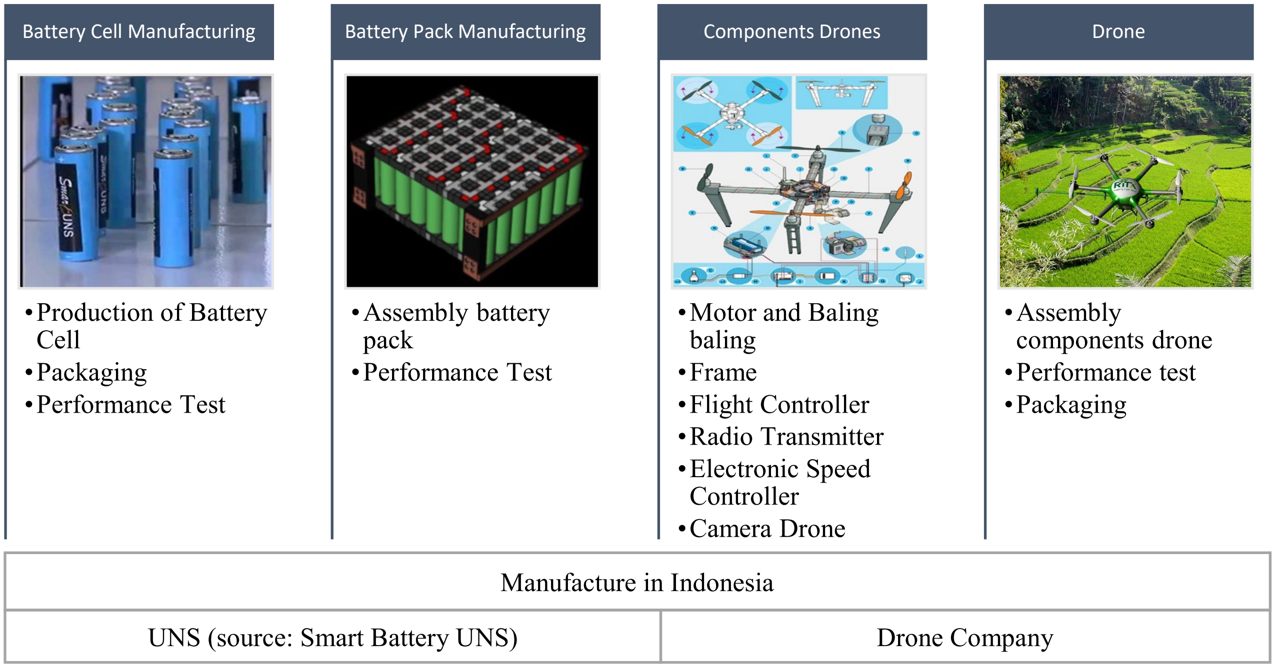
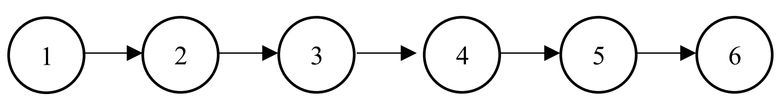


Figure 2. Value-added chain manufacturing lithium battery packs for drones

Production design with engineering to order (ETO) system. This type of production is chosen because it matches the final characteristics of the battery pack product that can be assembled with a variance in cell configurations that vary according to consumer demand (Sutopo & Kadir, 2018). The following figure 3 describes the precedence diagram of the lithium battery pack production. Figure 3 describes Precedence Diagram Production Battery Lithium Pack for Drone.

Precedence Diagram
Production Battery Lithium Pack for Drone



No	Activities	Standard Time (minute/pack)	Elements that precede
1	Sorting Cell	1,89	
2	Assembly Battery Spacer	1,58	1
3	Soldering Positive & Negative Terminal	1,53	2
4	Checking Battery Module	59,52	3
5	Assembly PCM for PU Drone	1,78	4
6	Charging/Flashing	180	5
7	Checking Battery Pack	59,52	6

Figure 3. Precedence Diagram

3.5. Assessment of TRL

After the technical feasibility is built, the next step is to assess the technical feasibility results using the TRL / TKT concept. The calculator is developed by Tatang (2003), there is a readiness indicator that can present the TRL value. Other indicators are assessed according to the level of readiness (Scale 0%, 20%, 40%, 60%, 80%, and 100%). This study assessed the level of lithium battery technology readiness between levels 7 - 9, with the following indicators at each level of readiness shown in Table 3. By mapping the correlation of technical feasibility and TRL concepts have been developed by Tatang (2003), assessing the feasibility of technology can be made with the same minimum value with 80% of the fulfillment of indicators for each TRL stage. TRL assessment is shown in Table 4. Indicators are assessed according to the level of readiness (Scale 0%, 20%, 40%, 60%, 80% and 100%). Assessment the level of lithium battery technology readiness between levels 7 - 9, with the following indicators at each level of readiness shown in Table 3. By mapping the correlation of technical feasibility and TRL concepts have been developed by Plaza (2017), assessing the feasibility of technology can be made with the same minimum value with 80% of the fulfillment of indicators for each TRL stage. TRL assessment is shown in Table 4.

As a result, the technical feasibility can meet the level of TRL 7, with a fulfillment indicator scale value of 81%. The valuation for TRL 8 is 50% because there are still many aspects that have not been checked to be ready to enter the start-up business, such as market and business aspects. To continue the process of commercialization of technology developed into TRLs 9, further research recommends conducting a more in-depth study on the technology of Li-ion battery technology. Also, it is also recommended to conduct market studies and economic feasibility. Partnering as a commercialization mode has been discussed in the literature on alliances, networking, and licensing (Sergey A, 2011) The following table 2 describes the TRL indicators.

Table 3. Indicator TRL

TRL	Code	Indicators
7	T7.1	Equipment, processes, methods and design techniques have been identified
	T7.2	The process and procedure of fabrication of equipment began to be tested
	T7.3	Process equipment and test/inspection equipment are tested in the production environment
	T7.4	The draft design drawings are complete
	T7.5	Equipment, processes, methods, and design techniques have been developed and started to be tested
	T7.6	Scale-up has been completed
	T7.7	Cost estimation calculation has been validated (design to cost)
	T7.8	Understood
	T7.9	Almost all functions can run in an operating environment
	T7.10	Test the operation of a laboratory scale system in the relevant environment
	T7-11	Complete prototypes have been demonstrated in environmental simulations
	T7 -12	Trials
	T7- 13	Ready for initial production (Low Rate Initial Production - LRIP)
TRL 7 Pass		
8	T8 - 1	The shape, suitability, and function of components are compatible with the operating system
	T8 - 2	Machines and equipment have been tested in a production environment
	T8– 3	The final diagram is finished
	T8-4	The fabrication process is tested on a pilot scale (pilot-line or LRIP)
	T8– 5	Fabrication process tests show acceptable results and levels of productivity
	T8– 6	All functions are tested in the operating environment simulation
	T8– 7	All materials/materials and equipment available for use in production
	T8– 8	The system meets qualifications through tests and evaluations (DT & E is complete)
	T8– 9	Ready for full-scale production (full capacity).

In table 3 is an assessment of the results of the level of the feasibility of lithium battery pack technology. This assessment at level 7 and 8 TRLs at each stage of the technical feasibility carried out. Here are the results:

Table 4. Assessment of TRL

TRL	Code	Technical Feasibility Goldsmith Model					TRL Score
		1	2	3	4	5	
7	T7-1	100	80				90
	T7-2	100					100
	T7-3	80					80
	T7-4	100	80				90
	T7-5	80					80
	T7-6						
	T7-7						
	T7-8						
	T7-9						
	T7-10	60					60
	T7-11	80					80
	T7-12	80					80
	T7-13	100	80	100	80	100	92
TRL 7 Pass							83,56
8	T8-1	80		80		100	86,67
	T8-2	60					60
	T8-3	80					80
	T8-4						
	T8-5						
	T8-6	40					40
	T8-7						
	T8-8						
	T8-9	40					40
TRL 8 Failed							61,33

TRL assessment using Techno-meter the technical feasibility of lithium battery packs for drones on TRL 8 with an assessment result of 61.33%. Due to the TRL8 - 2 rating of 60% because in this indicator the machine, the equipment has not been tested in a production environment, only at the prototype manufacturing stage. Then on TRL8 - 6 with a 40% rating because this indicator has not performed all functions in the simulation of the operating environment and on TRL8 - 9 the indicator is not ready for full-scale production so that it reaches 40%. So it can be concluded for the technical feasibility of lithium battery packs on TRL 8 that the technology system is complete and qualifies (qualified) through testing and demonstration in the actual environment/application.

4. Conclusions

The conclusion of this study is that the technical feasibility of lithium battery packages is feasible and opportunities in the future by looking at 5 technical aspects, namely Propulsion and Energy Sources of UAVs lead to the use of lithium batteries. Then the state of the art of drone explained, Next, Identification of Potential Safety and environmental hazards has been clearly illustrated. Production Feasibility is explained by making precedence diagrams and value-added chains. Finally, the technological readiness is valued by the TRL assessment using the techno-meter with the results on TRL 7 which is 61.33%.

References

7045268, pp. 308-314Buchman, Isidor, 2011, BU-203: Nickel-based Batteries, Germany: Battery University.

Afif, Muhammad Thowil and Pratiwi Ilham Ayu Putri. *Analisis Perbandingan Baterai Lithium-Ion, Lithium-Polymer, Lead Acid Dan Nickel-Metal Hydride Pada Penggunaan Mobil Listrik – Review*. Journal Rekayasa Mesin Vol.6, No.2 2015: 95-99. ISSN: 2477-6041

Albright, Greg, 2012, A comparative of Lead Acid to Lithium-Ion in Stationary Storage Applications, New York: AllCell Technologies LLC.

Andrewsa, John, Shahin Heidari a, Saeed Seif Mohammadi a, Amandeep Singh Oberoi. 2018. Technical feasibility of a proton battery with an activated carbon electrode

Anokhim Sergey, Wincent Joakim, Frishammar Johan. 2011. *A Conceptual Framework for Misfit Technology Commercialization.* doi : 10.1016/j.techfore.2010.12.005

Arora. S, Shen. W, and Kapoor. A. *Review of mechanical design and strategic placement technique of a robust battery pack for electric vehicles*. Renew. Sustain. Energy Rev., vol. 60, pp. 1319–1331, Jul. 2016.

Atikah, N, Sutopo. W, A.H. Al Ghabid, Purwanto, A, Nizam, M. (2014). Technical Feasibility for Technology Commercialization of Battery Lithium Ion. *Proceedings of 2014 International Conference on Electrical Engineering and Computer Science,* 7045268, pp. 308-314, ICEECS 2014

Atikah, N., Ghabid, A.H.A., Sutopo, W., Purwanto, A., Nizam, M., Technical feasibility for technology commercialization of battery lithium ion, *Proceedings of 2014 International Conference on Electrical Engineering and Computer Science,* 7045268, pp. 308-314, ICEECS, 2014

Dudek M, P. Tomczyk. *Hybrid fuel cell-battery system as the main power unit. International Journal of Electrochemical Science*, 2013,8: 8442–8463.

Fotouhi Abbas, Auger Daniel J, Propp Karsten, Longo Stefano, Wild Mark, ‘‘A review on electric vehicle battery modeling: From Lithium-ion toward Lithium–Sulphur," Renew. Sustain. Energy Rev., vol. 56, pp. 1008–1021, Apr. 2016.

Freire L.G, Bouillon, Perfiles IDS : *Sistemas A´ ereosno Tripulados (UAS)*, IDS, Madrid, Spain, 2009.

Garcia M-Plaza, D. Serrano-Jimenez, J. E. G. Carrasco, and J. Alonso-Martinez. *A NiŰCd battery model considering state of charge and hysteresis effects*. J. Power Sour., vol. 275, pp. 595–604, Feb. 2015.

Hannan M, Hoque Md. Marshadul, Yusof Y, and Ker Pin J. 2018. *State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations.* Special Section On Advanced Energy Storage Technologies And Their Applications IEEE Access publication March 21, 2018.

Hordeski M. F. *Hydrogen & Fuel Cells: Advances in Transportation and Power*, The Fairmont Press, Lilburn, Ga, USA, 2009.

Hughes, P. dan Ferret, E. Introduction to Health and Safety at Work 3rd Edition. Butterwoth-Heinemann. Burlington. 2007.

Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007: Synthesis Report, IPCC, Geneva, Switzerland, 2013, http://www.ipcc.ch/publications and data/publications ipcc fourth assessment report synthesis report.htm.

Jaiswall Abhishek. 2017. *Lithium-ion battery-based renewable energy solution for off-grid electricity: A techno-economic analysis*

K2 Energy Solution. *Material Safety Data Sheet*; Document no.K2Q-6-460-0010; rev.8. 2009 [Online]. Available: http://www.acumentrics.com/Collateral/Documents/English-US/MSDS_Lithium-Ion-K2-Energy-Battery.pdf

Khofiyah N, Sutopo W, Nuroho Apri D. B. 2018. *Goldsmith Commercialization Model for Feasibility Study Technology Lithium Battery Pack Drone.* International Conference Electrical Vehicle Technology (ICEVT) 2018

Lai Q, Zhang H, Li. X, Zhang. L, and Y. Cheng. *A novel single flow zincŰbromine battery with improved energy density*. J. Power Sour., vol. 235, pp. 1–4, Aug. 2013.

Maple D, M. G. *S´anchez Jim´enez, J. M. Sanjurjo Jul, and C. Calvo Gonz´alez-Regueral,PerfilesI DS: Sistemasno Tripulados*, IDS, Madrid, Spain,2012.

Nasution Reza A, Djuanda Dadan, Rachmah Rifa. 2009. *Literature Study on the Commercialization of Technology in Higher Education: Processes, Potentials, Models and Actors.* Volume 8 Number 2. 2009. http://download.portalgaruda.org/article.php?article=126458&val=2215

Nozawa T. *New Battery Technologies Still Years Away*. Nikkei Asian Review, 2018. [Online]. Available: https://asia.nikkei.com/Tech-Science/Tech/New-battery-technologies-still-years-away?page=2

Oswal, Mehul. 2010. *A Comparative Study of Lithium-Ion Batteries*, USA: University of Southen California

Plaza J. *Will Hydrogen Fuel Cells Help Drones Stay in the Air.* 2017. [Online]. Available: https://www.expouav.com/news/latest/hydrogen-fuel-cells-drones/

Rahman M.A, X. Wang, and C. Wen. *A Review of High Energy Density Lithium-air Battery Technology*. Journal of Applied Electrochemistry, vol. 44, no. 1, pp. 5–22, 2014.

Renn, G. G. Ma, and N. Cong. *Review of electrical energy storage system for vehicular applications.* Renew. Sustain. Energy Rev., vol. 41, pp. 225–236, Jan. 2015.

Schneider, Brian. 2012. *A Guide to LiPo Batteries*. USA: Roger's Hobby Center.

Service R. F. *Lithium-sulfur Batteries Poised for Leap*. Science, vol. 359, no. 6380, pp. 1080–1081, 2018. [Online]. Available: http://science.sciencemag.org/content/359/6380/1080

Sougrati M. T, Darwiche Ali, Liu Xiaohiu, Mahmoud Abdelfattah, Raphael P. Hermann, Samuel Jouen, Laure Monconduit, Richard Dronskowski, Lorenzo Stievano. *Transition-metal carbodiimides as molecular negative electrode materials for lithium- and sodium-ion batteries with excellent cycling properties.* Angew. Chemie-Int. Ed., vol. 55, no. 16, pp. 5090–5095, 2016.

Spanos, Constantine, Turney Damon E, Fthenakis, Vasilis. *Life-cycle analysis of flow assisted nickel zinc-, manganese dioxide-, and valve-regulated lead-acid batteries designed for demand-charger eduction.* Renew Sustain Energy Rev., vol. 43, pp. 478–494, Mar. 2015.

Sutopo, W., Kadir, E.A. *Designing framework for standardization case study: Lithium-ion battery module in an electric vehicle application*, *International Journal of Electrical and Computer Engineering,* 8(1), pp. 220-226, 2018

Tatang A. Taufik. *TRL: Concept and Policy Issues, mappers-planning Workshop Technology and Measurement Technology*. Agency of Assessment and Application of Technology , Indonesia, 2003

U.S. Department of Energy. *Transportation Energy Data Book*. 2010. http://cta.ornl.gov/data/index.shtml.

Vaalma C. *Cost and Resource Analysis of Sodium-ion Batteries*. Nature Reviews Materials, vol. 3, 2018.

Wezeman, S. *UAVs and UCAVs: Developments in the European Union*. http://www.europarl.europa.eu/RegData/ etudes/ etudes/join/2007/381405/EXPO-SEDE ET%282007%29381405 EN.pdf.

Wignjosoebroto, Sritomo. 2009. *Tata Letak Pabrik dan Pemindahan Bahan*. Guna Widya, Surabaya

Xiong R, Tian J.P, Mu. H, and Wang. C. *A systematic model-based degradation behavior recognition and health monitor method of lithium-ion batteries*. Appl. Energy, vol. 207, pp. 367–378, Dec. 2017.

Yusuf, Oik. 2017. *Makin Populer Penjualan Drone terus Menanjak*. https://tekno.kompas.com/read /2017/04/16/16230037/makin.populer.penjualan.drone.terus.menanjak

Zhu. Y, W. H. H. Zhu, Z. Davis, and B. J. Tatarchuk. *Simulation of Ni-MH batteries via an equivalent circuit model for energy storage applications*. Adv. Phys. Chem., vol. 2016, Jan. 2016, Art. no. 4584781. [Online]. Available: http://dx.doi.org/10.1155/2016/4584781

Zu C-X and H. Li. *Thermodynamic Analysis on Energy Densities of Batteries*. Energy & Environmental Science, vol. 4, no. 8, p. 2614, 2011. [Online]. Available: http://xlink.rsc.org/?DOI=c0ee00777c

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