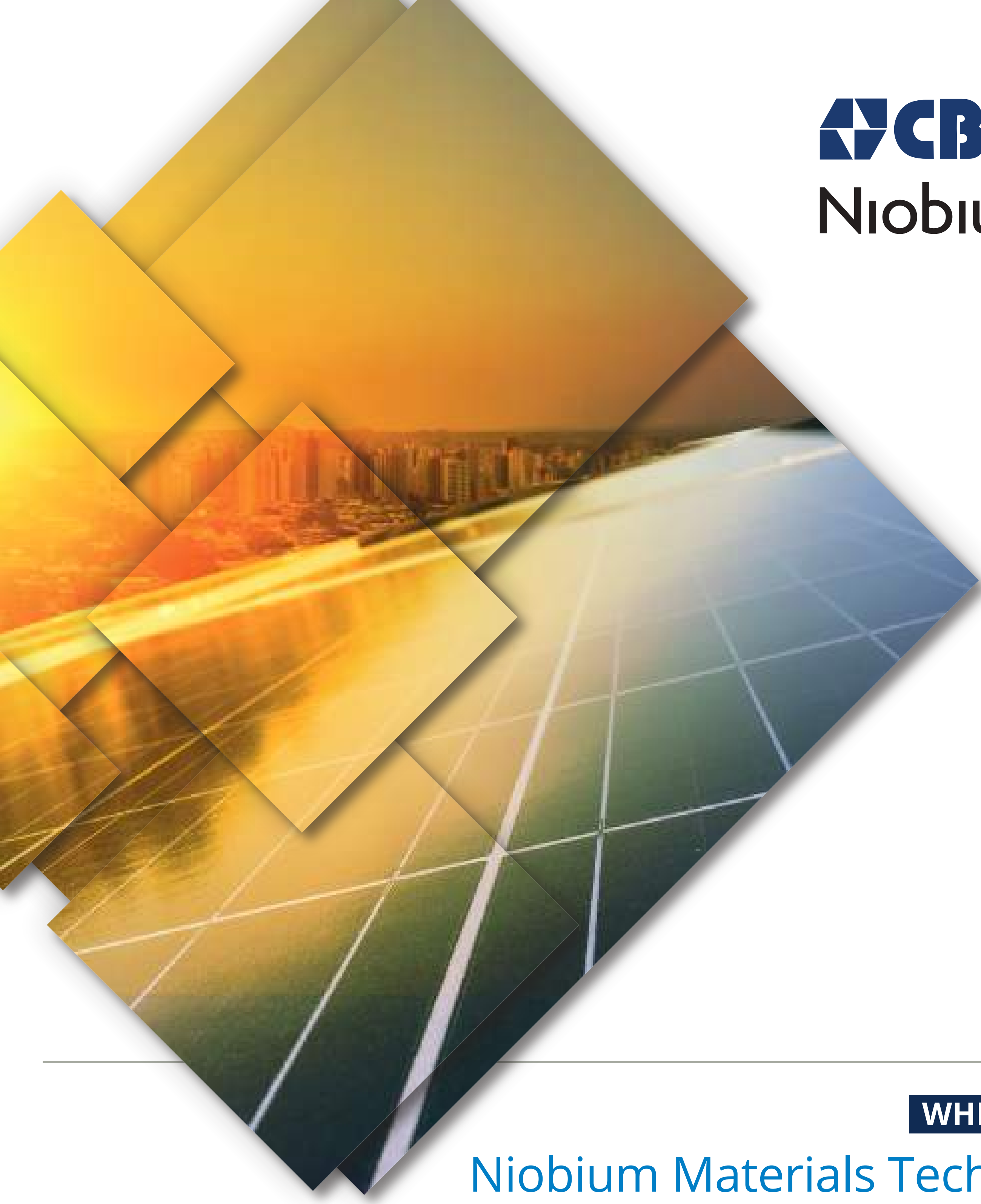

WHITE PAPER

Niobium Materials Technology in the Renewable Energy Sector

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KEY TAKEAWAYS

- Mass adoption of electric-powered vehicles relies on future improvements to battery cell chemistry for faster charging, longer life, lower cost, and improved safety. Recent developments demonstrate niobium oxide used in lithium-ion battery technologies can increase energy storage to significantly improve the range and performance of electric vehicles, and also reduce the risk of short circuits and fires by limiting lithium metal formation.
- Although the cost of solar panels has significantly decreased, the cost of installation is considered high for many property owners due to the project payback. The future trend may drastically reduce the payback time when the carbon credit business model is implemented. Additionally, researchers and developers are focusing on improving the efficiencies of converting photons of light into useable energy to shorten the period for recapturing installation costs. Niobium oxide added to perovskite solar cells – a promising new thin-film technology – is being developed to improve glass properties for greater conversion efficiencies and durability.
- The use of niobium oxide is gaining momentum as an additive in smart windows, which are designed to independently control the transmission of visible sunlight and solar heat into a building, thereby reducing energy use and improving occupant comfort. Another potential benefit of niobium oxide in this application is that it provides separate, dynamic control over the transmission of visible and near infrared light.
- Researchers in the field of piezoelectricity – renewable energy created from mechanical stress – are developing niobium oxide as a replacement for lead-based ceramic applications, for cleaner, safer performance.

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ABSTRACT

During the past several years, niobium (Nb) has made material science technological advancements for both ferrous and non-ferrous renewable energy applications. New product developments within the niobium non-ferrous alternative energy sector are in stage 1 of the product life cycle and in its infancy. Laboratory and prototype trials have revealed promising opportunities for both niobium and its oxides in emerging product applications for lithium-ion batteries (LIBs), solar panels, smart windows and piezoelectricity. (1)

Introduction

In this paper, an overview of the emerging non-ferrous niobium technologies for the renewable energy sector are described – LIBs, solar panels, smart windows, and piezoelectricity. Niobium product applications in this sector are in stage 1 of the product life cycle. Early results demonstrate several key benefits to using niobium-containing technologies, including achieving substantial efficiency improvements. A cost-effective process technology is evolving. With continuous improvement in the manufacture of these products, consumer prices for renewable energy non-ferrous materials will continue to fall, thus improving the potential of mass market adoption of sustainable, alternative technologies associated with the generation, transportation and consumption of energy.

Lithium-ion batteries (LIB):

A step-change breakthrough is needed to facilitate the transition of fossil-fueled transport vehicles to cleaner forms of mobility, such as electric-powered vehicles (EVs). Technological improvement for LIBs is a high priority within the renewable energy sector. LIBs can convert stored chemical energy into electricity. Niobium application in these LIBs is capable of meeting the increased demand for higher performance, longer life, shorter charging times and safer batteries. Cathode materials typically are cobalt, nickel, manganese, iron, phosphorus and aluminum. Anode materials are graphite and fixed oxides based on lithium and titanium. Transport is the largest source of greenhouse gas emissions in the U.S. as reported by the United States Environmental Protection Agency, exceeding 1,800 million metric tonnes of carbon dioxide per annum. Niobium addresses nearly all the barriers relating to EV adoption as summarized in Table 1. (2)

Table 1. Niobium Solutions to Overcome Barriers to EV Adoption.

Consumer Concerns	Barriers to EV Adoption	Niobium Solutions
Driving range anxiety	Consumers worry about the travel range and performance variation with an EV compared to an internal combustion engine vehicle.	Niobium increases the energy density of batteries providing more range, and improves performance at lower temperatures.
Charging time	Charging times may take several hours; charging station infrastructure in development.	Niobium materials can increase the rate at which batteries charge and discharge.
Performance/ Longevity	Batteries have a relatively short operating life as materials degrade during the charge/ recharge cycle.	Niobium increases the stability of the battery so it can withstand more charging cycles.
Costs	Even with subsidies, EVs are more expensive than fossil fuel vehicles.	Niobium is readily available and determined to be cost effective compared to other battery materials.
Decision-making	There are only a few fully battery operated EVs, and a limited number of hybrid vehicles.	With niobium developments, improved efficiencies and effect on carbon footprint, the implementation time is changing rapidly.

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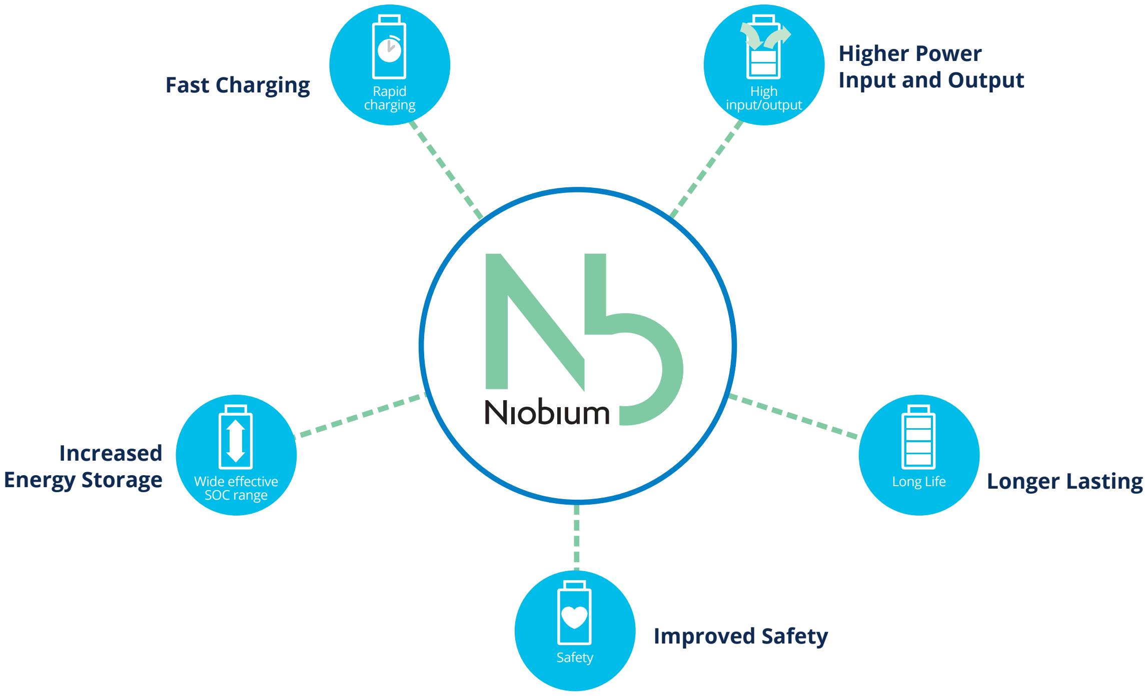
Scientific material benefits of niobium are associated with electrical conductivity, increased rate capability and ionic conductivity, faster charging, greater energy density and safety. The consumer expects these product benefits. Electrical conductivity, which controls the speed of transferring electricity to and from the battery, is a major barrier to improving LIBs. Adding small amounts of niobium can make cathodes nearly one billion times (1,000,000,000x) more conductive, thereby improving EV performance and generating faster delivery of electric current. (3)

Increased rate capability and ionic conductivity are important for improving charging/discharging rates. The challenge is that as the rate increases, the amount of stored electrical charge generally decreases. However, coating cathodes with lithium niobate ($LiNbO_3$) increases the rate without reducing capacity, creating a battery that releases more electricity at a faster rate and with higher efficiency. This process also improves battery longevity and safety in the following ways: 1) enables the battery to withstand increased charging cycles, 2) prevents dissolution of the manganese and 3) lowers the charge-transfer resistance. (4)

Greater energy density is of paramount importance to extend battery life and driving range while reducing the anxiety for the driver of the vehicle. Lithium is used in batteries because it is lightweight, and has a high charge and power-to-weight ratio. Consequently, batteries with more lithium can store more energy. A new technology has created a cathode material with a disordered structure containing niobium that can increase lithium ions by 30%-50%. This breakthrough creates greater energy capacity (>250 mAh.g-1 capacity higher than typical capacities). Tests have shown that performance of this electrolyte is nearly pure lithium. Higher energy density increases the range and performance of EVs. (5)

Faster charging is achieved with niobium materials currently being developed for battery anodes that improve the mobility of lithium-ions. By creating inter-atomic spaces in the anode material, lithium-ions can easily move in and out of the anode. This structure creates an extremely high charge/discharge rate. The materials are used with titanium to create titanium niobium oxides (TNO). This new class of niobium-modified anode materials demonstrates nearly three times the amount of energy storage compared to traditional LIBs. The technology is being considered by manufacturers as a pathway to significantly reduce charging times. (6)

Safety is a primary concern as EV popularity grows. As LIBs age, there is a risk of short circuits that result in fires. The condition is caused by the formation of lithium metal coming in contact with the cathode, creating excessive heat. As a result, major manufacturers have experienced significant product recalls. Based on materials science engineering research to date, it has been observed that niobium prevents the formation of lithium metal, thereby reducing the danger of short circuits and fires. (7)



The scientific material benefits of niobium are associated with improvements to lithium-ion battery technology, thereby overcoming the barriers to EV adoption. (2)

Solar panels:

Solar panel costs have decreased dramatically over a two-year period. However, the high cost of solar panel installation for property owners remains a barrier to mass scale adoption. More efficient solar panels lead to a shorter period for recapturing installation costs. Consequently, producing panels that are more efficient in converting sunlight to electricity is a key focus of solar research and development. The silicon-based cells that comprise a solar panel possess a theoretical efficiency limit of 29%. Practical efficiency rates in the low 20% range are considered excellent for commercial solar panels. It is noteworthy that researchers at Kaneka Corporation, a Japanese chemical manufacturer, have built a solar cell with a photo conversion rate of 26.3%, improving the previous record of 25.6%. Although the increased efficiency is just 2.7%, such improvements in commercially viable solar cell technology are increasingly recognized. By comparison, boiler efficiency is in the 30% range.

A special type of transparent conductive oxide glass is used in solar panels to maximize efficiency and durability. Panel manufacturers are constantly attempting to add value to their product. Using niobium oxide to improve the glass is one approach. The application of niobium oxide improves the glass properties, leading to considerable inroads in development. Improving the properties of the glass improves panel efficiency, extends the life span and reduces another barrier to renewable energy technology.

Converting sunlight to electricity is a clean technology due to an abundant, renewable source. The efficiency of conventional solar cells from inorganic material, such as silicon, has reached 24%. However, the process still requires the use of more pure materials that are expensive. New technologies are needed to develop low-cost solar devices that can be produced on a commercial scale. A wide variety of methodologies for converting solar energy is currently being developed, including dye sensitized and hybrid all-solid solar cells. A major improvement of such devices has been achieved over the last 10 years. During that period, the efficiency of solar cells has reached 14%. However, a recent discovery revolutionized the field of photovoltaic devices. It has been demonstrated that devices consisting of organolead trihalide compounds with perovskite structures are able to efficiently convert solar energy to electricity. After discovering the capability of these materials during two years of research, the efficiency of these cells reached 17.9% (certified) with a performance expected to attain up to 20%. Moreover, the system is promising for commercial application due to easy processing and low-cost materials. (8)

Perovskite solar cells have attracted attention due to their high conversion efficiency and low cost. Nb_2O_5 is used as an alternative, compact hole-blocking layer in conjunction with mesoporous TiO_2 and CH_3NHePb_{13} in perovskite solar cells. A study revealed that Nb_2O_5 layer thickness strongly influenced the J-V hysteresis of the cells. Devices constructed with 50 nm Nb_2O_5 have small or undetectable hysteresis, which become detectable and more prevalent with increased Nb_2O_5 layer thickness. For the best device, energy conversion efficiency of up to 12%, short circuit currents of 17mA/cm2 and fill factors of 74% were identified. These parameters are comparable to the best performance of similar devices in which the compact layer is TiO_2. In addition, the use of Nb_2O_5 improved the stability of solar cells under illumination. These improvements are attributed to a more efficient extraction of photogenerated electrons in the perovskite layer.

Niobium oxide is emerging as an additive in smart glass windows, which independently control the transmission of visible light and solar heat into a building, thereby reducing energy use and increasing occupant comfort.

Smart windows:

Niobium oxide is emerging as a possible additive in smart windows, which independently control the transmission of visible sunlight and solar heat into a building, thereby reducing energy use and improving occupant comfort. The use of smart windows provides separate, dynamic control over the transmission of visible and near infrared (NIR) light. The material properties require high optical contrast, fast switching times, long cycle life and low manufacturing costs. Conventional materials possess significant drawbacks related to cost, durability and functionality. (9) Studies involving niobium glass with nanomaterial show that niobium oxide glass with nanocrystals can produce dynamic switching behavior, enabling control of solar radiation transmittance. The glass blocks NIR and visible light selectively, and independently enhances optical contrast fivefold with 96% of charge capacity retained after 2,000 cycles. Research is underway to improve production processes and extend application to polymer materials and coatings. Successful development could lead to windows that maintain a cool building in hot weather while allowing light, as well as reducing additional lighting and air conditioning costs.

Piezoelectric applications:

The definition of piezoelectricity is an electric polarization in a substance (especially certain crystals), resulting from the application of mechanical stress. For example, people walking on the floor could generate piezoelectric energy created by the mechanical stress of the activity. Research and development into niobium oxide has shown it can replace lead in these piezoelectric applications, allowing for more widespread use. The manufacture and synthesis of different ceramic oxides have been the main challenge. (1, 10) Relaxor ferroelectric perovskites are highly polarizable and can exhibit giant coupling between elastic strain and an applied electric field. (10, 11)

With piezoelectric structures located on the ground, the act of walking can produce electricity. Lead oxide based ferroelectrics are the most widely used materials for piezoelectric actuators, sensors and transducers due to their excellent piezoelectric properties. Considering lead toxicity, there is interest in using niobium as a replacement in piezoelectric applications for more widespread use.

Summary:

There is considerable potential for niobium technology to be used in the renewable energy sector, including LIBs, solar panels, smart windows, and piezoelectric applications. Improvements to products associated with the generation, transportation and consumption of energy are in various stages of niobium product development and implementation and are demonstrating viable solutions to sustainability.

References

1. “Emerging Role of Niobium in Advanced Technologies,” CBMM, November 2017. https://www.cbmm.com/-/media/CBMM/Resource-Center/Videos/The-Emerging-Role-of-Niobium-in-Advanced-Technologies/the-emerging-role-of-niobium-in-advanced-technologies.mp4

2. “Niobium in Lithium-Ion Batteries,” CBMM, 2018. https://www.cbmm.com/-/media/CBMM/PDF/PDFs---Misc---Eng/Niobium-in-Lithium-Ion-Batteries.pdf

3. Chung, Sung-Yoon; Bloking, Jason; and Chiang, Yet-Ming. “Electronically Conductive Phospho-Olivines as Lithium Storage Electrodes.” Nature Materials, no. 1, (2002): 123-128.

4. Zhang, Zhi-Jia; Chou, Shu-Lei; Gu, Qin-Fen; Liu, Hua-Kun; Li, Hui-Jun; Ozawa, Kiyoshi; and Wang, Jia-Zhao. “Enhancing the High Rate Capability and Cycling Stability of $LiMn_2O_4$ by Coating of Solid-State Electrolyte $LiNbO_3$.” ACS Applied Material & Interfaces, vol. 6, no. 24, (2014): 22155-22165.

5. Yabuuchi, N; Takeuchi, M; Nakayama, M; Shiiba, H; Ogawa, M; Nakayama, K; Ohta, T; Endo, D; Ozaki, T; Inamasu, T; Sato, K; and Komaba, S. “High-Capacity Electrode Materials for Rechargeable Lithium Batteries: Li_3NbO_4-based System with Cation-disordered Rocksalt Structure,” Proceedings of National Academy of Science, June 2015. https://doi.org/10.1073/pnas.1504901112

6. Griffith, Kent; Forse, Alexander; Griffin, John; and Grey, Clare. “High-Rate Intercalation without Nanostructuring in Metastable Nb_2O_5 Bronze Phases.” Journal of the American Chemical Society, vol. 138, no. 28, (2016): 8888-8899.

7. Griffith, Kent; Wiaderek, Kamila; Cibin, Giannantonio; Marbella, Lauren; Grey, Clare. “Niobium Tungsten Oxides for High-Rate Lithium-Ion Energy Storage.” Nature, vol. 559, (July 2018); 556-563

8. Fernandes, Silvia; Veron, Anna; Neto, Nilton F. A.; Nuesch, Frank; Dias da Silva, Jose; Zaghete, Maria; and de O. Graeff, Carlos. “Nb_2O_5 Hole Blocking Layer for Hysteresis-Free Perovskite Solar Cells.” Materials Letters, vol. 181, (15 October 2016): 103-107.

9. “Smart Windows Case Study,” CBMM, 2018. https://www.cbmm.com/-/media/CBMM/Resource-Center/Videos/The-Emerging-Role-of-Niobium-in-Advanced-Technologies/smart-windows.mp4

10. Prado da Silva, Marcelo; da Rocha, Daniel; de Andrade Gobbo, Luciano; dos Santos Azevedo, Luciana; Louro, Luis; Machado Costa, Andrea; and de Campos, Jose. “Synthesis of Piezoelectric and Bioactive $NaNbO_3$ from Metallic Niobium and Niobium Oxide.” Journal of Biomedical Materials Research Part B: Applied Biomaterials, vol. 104, no. 5, (July 2016): 979-985.

11. Al-Zein, A; Dammak H.; Papet, Ph.; Mathon, O.; Hehlen, B.; Levelut, C.; Haines, J. and Rouquett, J. “Role of Zinc and Niobium in the Giant Piezoelectric Response of PbZn1/3Nb2/3O3.” Inorganic Chemistry, vol. 53, no. 8, (2014); 3885-3990. DOI: 10.1021/ic402409f

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