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Power e-Mergency: Combining Renewable Energy with Current Battery Technology for Emergency Medical Professionals

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TABLE OF CONTENTS

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I. INTRODUCTION

Millions of people around the world rely on batteries every day to power cell phones, airplanes, remote controls, and medical devices.[1] In general, batteries "efficiently transform electricity into some form of energy, store it for a period of time without significant loss, and then convert it back to electricity" to be discharged on demand.[2] Thus, batteries are even central to providing back up energy during power failures.

Batteries are often differentiated between their charging ability as either primary (disposable), or secondary (rechargeable, lithium-ion batteries).[3] Batteries are also classified according to their energy and power densities.[4] Specific energy, or "capacity," refers to the discharge current that a battery can deliver over time.[5] Specific energy defines battery capacity in weight, which is reflected as watt-hours per kilogram (Wh/kg).[6] Products requiring long runtimes are optimized for high specific energy.[7] Power density refers to the strength or wattage of a given current and voltage combination.[8]

Primary batteries have larger amounts of lithium, which gives them greater capacity (often referred to as "capacitance") than the lithium-ion battery.[9] A primary battery measures an average capacitance of 250 Wh/kg, while modern lithium-ion batteries measure about 200 Wh/kg.[10] Primary batteries are commonly seen in wristwatches, remote controls, children's toys, and when charging is impractical or impossible, such as in military combat equipment or pacemakers placed inside a patients' heart or abdomen.[11]

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1. *Batteries in Industries*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-1001: Batteries in Industries") (last visited June 21, 2016).

2. Penelope Crossley, *Defining the Greatest Legal and Policy Obstacle to "Energy Storage,"* 4 RENEWABLE ENERGY L. & POL'Y REV. 268, 268 (2013).

3. *When was the Battery Invented?*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-101: When was the Battery Invented?") (last visited June 21, 2016).

4. J.M. Boyea et al., *Carbon Nanotube-Based Supercapacitors: Technologies and Markets*, 4 NANOTECHNOLOGY L. & BUS. 585, 585 (2007).

5. *Primary Batteries,* Battery University, http://batteryuniversity.com/learn/ (follow "BU-105: Battery Definitions and What They Mean") (last visited May 21, 2016).

6. *Id.*

7. *Id.*

8. Boyea et al., *supra* note 4.

9. *Primary Batteries, supra* note 5.

10. *Id.*

11. *Id.*

In contrast, secondary batteries are rechargeable and are typically found in everyday items such as hearing aids, mobile power tools, electric toothbrushes, or laptop computers. Secondary batteries have continued to dominate the market of energy storage ever since French physicist Gaston Planté invented the technology in 1859.[12] These batteries generally contain ionized lithium, which allows for greater power density, higher output voltage, lighter weight, and a slower discharge rate when not in use.[13] As a result, secondary batteries are the preferred method of energy storage.[14] This article focuses on secondary batteries when compared to new and advanced energy storage technology, and as such, all future references to the term "battery" will be references to the secondary, lithium-ion battery.

Although the lithium-ion battery is the most widely used battery today, several limitations exist.[15] The first limitation concerns stagnant advancement in the technology. Battery technology has largely remained the same for over 100 years,[16] and very few advancements have been made to the lithium-ion battery since Sony introduced batteries into commerce in 1991.[17] Moreover, some lithium-ion battery manufacturers still use the lead-acid system that Planté discovered in 1859.[18] Lead-acid may keep production costs down; however, lead-acid is toxic, takes up to 14-16 hours to hold a fully saturated charge, and must be stored in its fully saturated charge in order to avoid robbing the battery of performance.[19] Stagnant technology is just one limitation of the lithium-ion battery, and limitations go beyond the internal workings of the battery.

Compromised battery conditions, such as overcharging and internal short-circuits, can cause the battery to overheat, potentially resulting in

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12. *Global Battery Markets*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-103: Global Battery Markets") (last visited June 21, 2016); *see also When was the Battery Invented?*, *supra* note 3.

13. Daniel Hsing Po Kang et al., *Potential Environmental and Human Health Impacts of Rechargeable Lithium Batteries in Electronic Waste*, 47 ENVIRON. SCI. TECHNOL. 5495, 5495 (2013); Ronald Reif et al., *Lithium Battery Safety*, PROFESSIONAL SAFETY 32, 32 (2010).

14. *Global Battery Markets, supra* note 12.

15. *Id.*

16. *Early Innovators*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-102: Early Innovators") (last visited June 21, 2016) (Alessandro Volta invented the voltaic cell in 1800 and discovered that certain fluids could generate a "continuous flow of electrical power," and when joined by a power source, circuits today exhibit this same method to generate electricity to power different devices.) *See also* WILLIAM HAYT ET AL., ENGINEERING CIRCUIT ANALYSIS 14 (McGraw-Hill, 8th ed. 2013).

17. *Id.*

18. *When was the Battery Invented?*, *supra* note 3.

19. *How does the Lead-acid Battery Work?*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-201: How does the Lead-acid Battery Work?") (last visited June 27, 2016).

hot cells, ruptured cells, leaking cells, fires, burn hazards, and property damage.[20] Increased battery age can contribute to these defects.[21] Ultimately, consumers are exposed to risk when batteries malfunction. As of January 1, 2008, the Department of Transportation, through the Pipeline and Hazardous Materials Safety Administration, no longer allows passengers to carry loose lithium batteries in their checked luggage, due to the risk of short-circuiting and heat activation if the battery is not contained within the device they power.[22] Beginning in 2000, electronics manufacturers such as HP, Apple, and Dell have issued recalls for the lithium-ion batteries after burn hazards[23] and fires caused significant personal injuries and property damage.[24] In 2006 alone, nearly six million lithium-ion packs were recalled.[25]

Improper battery disposal is also considered a significant limitation. Hazardous materials found in batteries contribute to the problem of electronic waste (e-waste), which is currently the fastest growing hazardous material in the United States.[26] Due to the need to replace lithium-ion batteries frequently,[27] improperly disposed of batteries become problematic when the potentially toxic components that make up a secondary battery (copper, nickel, lead, chromium, thallium, cobalt, and toxic flammable electrolytes) are not properly contained and disposed of.[28] Multiple efforts to minimize the effects of the present e-waste and to reduce the growth of e-waste exist. For example, the United States Code of Federal Regulations supervises lithium battery manufacturers, monitor-

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20. Axel Thielmann & Oliver Rothengatter, *Trends in Battery Technology Patents Indicating the Onset of a New Battery Generation Based on Nanomaterials*, 5 NANOTECHNOLOGY L. & BUS. 391, 399 (2008).

21. Golubkov et al., *Thermal-runaway experiments on consumer Li-ion batteries with metal-oxide and olivine-type cathodes*, 4 RSC ADV. 3633, 3633 (2013).

22. Pipeline and Hazardous Materials Safety Administration, *Traveling with Lithium Batteries*, http://phmsa.dot.gov/safetravel/batteries (last updated Jan. 24, 2013).

23. Consumer Product Safety Commission, *Recent Recalls*, http://www.cpsc.gov/en/Recalls/ (search "Search Recalls And News Alerts" for "lithium-ion"; then search "lithium-ion" in search bar for compilation of computer recall results) (last visited Nov. 26, 2014).

24. Consumer Product Safety Commission, *Acer America Corp. Recalls Notebook Computer Batteries Due to Previous Fires*, http://www.cpsc.gov/en/Recalls/2007/Acer-America-Corporation-Recalls-Notebook-Computer-Batteries-Due-to-Previous-Fires/, (last revised July 17, 2008).

25. *Lithium-ion Safety Concerns,* Battery University, http://batteryuniversity.com/learn/ (follow "Lithium-ion Safety Concerns") (last visited June 21, 2016).

26. 40 C.F.R. § 261.

27. CalRecycle, *Rechargeable Batteries and Chargers: A Personal Perspective,* http://www.calrecycle.ca.gov/ReduceWaste/power/rechbattinfo.htm#WhatToDo (last updated May 12, 2014) (As noted in the above paragraph, lithium-ion batteries have a relatively short life span, ranging from approximately 500 to 1,000 charge and discharge cycles [roughly 2-4 years]. Lifespan is determined by duration of battery charging time: fully charging a dead battery increases battery life compared to short, "as needed" charges.).

28. *Global Battery Markets*, *supra* note 12.

ing toxic exposure risk during manufacture and transportation of the finished product.[29] Organizations such as Retriev Technologies and Rechargeable Battery Recycling Corporation (RBRC) collect and recycle used batteries.[30]

In recent years, increasing both energy and power density has become a primary focus of energy storage research and development.[31] Batteries have high energy density, which allows more energy to store for longer periods compared to other energy storage devices;[32] however, batteries have very low power densities.[33] Power density is the amount of strength or wattage that a device can emit.[34] Industrial equipment, such as forklifts, need a vast amount of power and require multiple battery packs to fuel the operation.[35] Utilizing multiple battery packs in one device becomes incredibly heavy and expensive. Recent developments in nanotechnology have allowed and encouraged researchers to adopt an entirely new way of thinking about energy storage technology.[36]

Years of scientific research[37] and manufacturer recalls[38] of lithium-ion batteries have revealed the significant limitations of outdated battery technology. Millions of people around the world, and nearly every commercial and private industry, would benefit from a "better battery." Nanotechnology, in the form of supercapacitors, has the potential to resolve the limitations that lithium-ion batteries historically face. This article suggests how supercapacitors have the potential to resolve a variety of issues that medical professionals face when relying on portable medical devices.

Nanotechnology has been referred to as the secondary Industrial Revolution.[39] Nanotechnology is a branch of science that fuses together engineering and technology, conducted at the nanoscale.[40] Nanotechnol-

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29. 40 C.F.R. § 461; 49 C.F.R. § 173.185.

30. *How to Recycle Batteries,* Battery University, http://batteryuniversity.com/learn/ (follow "BU-705: How to Recycle Batteries") (last visited May 20, 2016).

31. Thielmann & Rothengatter, *supra* note 20; *see also* Boyea et al., *supra* note 4, at 586.

32. Boyea et al., *supra* note 4, at 586.

33. Thielmann & Rothengatter, *supra* note 20; *see* Boyea et al., *supra* note 4, at 586.

34. Boyea et al., *supra* note 4.

35. *Id.* at 586.

36. Crossley, *supra* note 2.

37. Thielmann & Rothengatter, *supra* note 20, at 399; *see also* 40 C.F.R. § 261.

38. Consumer Product Safety Commission, *supra* note 24.

39. Jarunee Wongimpiyarat, *The Nano-Revolution of Schumpeter's Kondratieff Cycle,* 25 TECHNOVATION 1349, 1349 (2005).

40. National Nanotechnology Initiative, *What is Nanotechnology?*, http://www.nano.gov/nanotech-101/what/definition (last visited June 21, 2016) (explaining that the "nanoscale" converts one meter into a billion nanometers. For illustration, consider that a sheet of newspaper is about 100,000 nanometers thick. Also, if a marble were a nanometer, then one meter would be the size of the Earth).

ogy involves manipulating matter on an atomic and molecular level, and is "anticipated to lead to new medical treatments and tools, more efficient energy production, storage and transmission, better access to clean water, more effective pollution reduction and prevention, and stronger, lighter materials."[41] Nanomaterials are frequently made of activated carbon and carbon-composites.[42] However, researchers have discovered that carbon-nanotubes,[43] graphene,[44] and hemp fibers[45] also have advantageous properties and are less expensive and more effective than activated carbon. Nanomaterials can be manufactured using cheap materials, and the manufacturer has complete control on what materials are used.[46] This highly flexible design capability allows manufacturers to eliminate potentially toxic or hazardous materials that lithium-ion batteries contain.[47]

Nanobiotechnology is the new interdisciplinary study of biology and medicine with a specific nanotechnology focus. Commonplace medical devices such as powered medical carts and beds, automatic external defibrillators (AEDs), ambulatory infusion pumps, anesthesia workstations, portable electrocardiogram (EDG) monitors and ultrasounds, and continuous positive airway pressure (CPAP) and bilevel positive airway pressure (BIPAP) machines all require significant battery power[48] that the battery simply cannot handle.[49] Unexpected battery failure or malfunction during a life-saving or life-sustaining procedure would be catastrophic. An alternative, and more trustworthy, energy source could increase public welfare and safety in any medical capacity—from routine doctor visits to life-saving emergency procedures—and would allow medical professionals to rely on their devices confidently. While supercapacitors may be the next best thing for the energy market, large-scale

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41. *Nanotechnology 101*, The Project on Emerging Nanotechnologies, http://www.nanotechproject.org/topics/nano101/ (last visited June 21, 2016).

42. A.K. Shukla et al., *Electrochemical Supercapacitors: Energy Storage Beyond Batter*ies, 79 CURRENT SCIENCE 1656, 1659 (2000).

43. Boyea et al., *supra* note 4; A. Kiebele et al., *Printed Energy and Power Storage: Batteries and Supercapacitors*, 5 NANOTECHNOLOGY L. & BUS. 7, 15 (2008).

44. Ron Beech, *Nanoscale Graphene Platelets Taking its Place as an Emerging Class of Nanomaterials*, 8 NANOTECHNOLOGY L. & BUS. 3, 11 (2011).

45. Mark Crawford, *Hemp Carbon Makes Supercapacitors Superfast*, American Society of Mechanical Engineers (July 2014), https://www.asme.org/engineering-topics/articles/energy/hemp-carbon-makes-supercapacitors-superfast; Tim Sandle, *Hemp Batteries Could be a Reality*, Digital Journal Blog (Sept. 14, 2014), http://www.digitaljournal.com/science/hemp-batteries-could-be-a-reality/article/403104 (last visited June 21, 2016).

46. Ankan Bhattacharya, *Nano-manufacturing: Government and Firm Incentives*, 4 NANOTECHNOLOGY L. & BUS. 199, 201 (2007); *Top Ten Ways Nanotech will Impact Cleantech*, 5 NANOTECHNOLOGY L. & BUS. 367, 369 (2008).

47. *Global Battery Markets*, *supra* note 12.

48. *Power Solutions to Medical Devices,* Ultralife Corporation, https://www.ultralifecorporation.com/be-commercial-markets-medical/ (last visited May 20, 2016).

49. Boyea et al., *supra* note 4, at 586.

manufacturing and commercialization of the technology simply cannot not occur without substantial financial backing. Funding a proposed technology venture with little history is a large risk that has deterred investors from coming forward. However, researchers may have recently discovered an affordable and highly efficient method to manufacturing supercapacitors for large-scale commercialization.

Part II of this article will review the strengths and limitations of the secondary, lithium-ion battery. Part III introduces supercapacitors and recent developments in nanotechnology, and entertains the idea of combining the traditional lithium-ion battery with supercapacitors to create medical devices with both high energy density and high power density. Part IV concludes with considering the details surrounding deployment of supercapacitors, the obstacles that nanobiotechnology industry faces, and recommendations on various options to overcome these obstacles.

II. A REVIEW OF SECONDARY BATTERIES

A. Strengths: Tenure, Energy Density, Rechargeable

To date, lithium-ion batteries have deservedly captured most of the global battery market.[50] Lithium-ion batteries remain the most technologically "advanced batteries due to high energy densities, a low self-discharge rate, [and] high energy efficiency."[51] Lithium-ion batteries do not contain the highly toxic metals such as nickel, cadmium, lead, and mercury and are lightweight.[52] As previously discussed, lithium-ion batteries have higher specific energy than lead acid batteries (commonly used for wheelchairs), nickel-cadmium (commonly used in power tools, two-way radios, and aircraft), and nickel-metal-hydride batteries (commonly used in medical instruments, hybrid cars, and industrial applications).[53]

Further, lithium-ion batteries are rechargeable and, therefore, are the preferred method of energy storage in portable electronics[54] such as cell phones, computers, hearing aids, electric vehicles, mobile power tools.[55] Battery technology has made few advancements since the introduction of rechargeable lithium-ion batteries by Sony in 1991; however, one notable

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50. *Global Battery Markets*, *supra* note 12 (76.4 percent of all batteries used were lithium-ion batteries in 2009, and in 2015, a projected 82.6 percent of all batteries used will be lithium-ion) (last visited Nov. 11, 2014).

51. Thielmann & Rothengatter, *supra* note 20.

52. *Global Battery Markets*, *supra* note 12; *see also* Thielmann & Rothengatter, *supra* note 20.

53. *Comparison Table of Secondary Batteries,* Battery University, http://batteryuniversity.com/learn/ (follow "BU-107: Comparison Table of Secondary Batteries") (last visited June 21, 2016).

54. Golubkov et al., *supra* note 21.

55. *When was the Battery Invented?*, *supra* note 3.

advancement includes increased battery capacity and safety, which lowered costs due to the usage of cobalt.[56] In spite of a lengthy tenure, current lithium-ion battery technology still harbors significant limitations.

B. Limitations: Power, Safety and Health Concerns

Although the lithium-ion battery technology remains unparalleled, significant limitations inhibit the technology from advancing as compared to other technologies—like smartphones—that gain instant market share.[57] Because lithium-ion batteries cannot deliver lightweight and long-lasting power density comparable to that of a supercapacitor,[58] increased demand for large-scale power density technology warrants a "new generation of batteries."[59] Nearly every industry that relies on battery-powered technology faces power quality problems,[60] and as battery-powered technology advances, lithium-ion batteries are confronted with higher power demand that was not required in 1991 when the technology was commercialized.

Rechargeable batteries are vital for mobile medical equipment used to save lives and diminished power density is increasingly problematic in these contexts. For example, in a 2012 survey taken by healthcare technology professionals, battery management was ranked fourth out of eighteen common battery challenges.[61] Unexpected battery failure could prevent the devices from delivering life-sustaining or life-saving treatment.[62] Some rechargeable batteries are equipped to administer an emergency power supply in the event of device failure; however, these batteries often weigh between 13 and 20 pounds,[63] defeating the purpose of portability and ease of use.

Moreover, increasing urban sprawl has forced power companies to begin facing increased demands to supply power to more commercial

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56. Thielmann & Rothengatter, *supra* note 20.

57. Michael DeGusta, *Are Smart Phones Spreading Faster than Any Technology in Human History?* (May 9, 2012), https://www.technologyreview.es/printer_friendly_article.aspx?id=40321 (last visited May 21, 2016).

58. Boyea et al., *supra* note 4, at 586.

59. Thielmann & Rothengatter, *supra* note 20.

60. Bruce W. Radford, *Service to the 9's? Power Quality in a Tech-Wreck World*, 139 PUB. UTIL. FORT. 52, 56 (2001).

61. ADVANCING SAFETY IN MEDICAL TECHNOLOGY, *AAMI Survey Identifies Top 10 Medical Device Challenges*, http://www.aami.org/productspublications/pressreleasedetail.aspx?ItemNumber=1654 (last visited April 4, 2016).

62. U.S. FDA, *Battery-Powered Medical Devices Workshop: Challenges and Opportunities*, http://www.fda.gov/MedicalDevices/NewsEvents/WorkshopsConferences/ucm355183.htm#webcast (last visited June 21, 2016).

63. *Battery Back Up*, Battery Web, http://www.batteryweb.com/ups-batteries.cfm (last visited May 21, 2016).

buildings and private residences than ever before.[64] Energy is not stored easily, so an unexpected spike in demand leads to reduced power quality and can most commonly cause "voltage sag," and vast power outages in extreme cases.[65] A power outage becomes even more detrimental in cases where hospitals and other medical centers are forced to run on limited emergency back-up power, or transport high-risk patients to other facilities until the power is restored.

In addition to lackluster power density, lithium-ion batteries contain potentially toxic materials and can become unsafe fire hazards without much warning.[66] Researchers at the University of California examined sixteen different batteries that proportionally represented the inventory of the world's largest cellphone recycling facility to "determine the metal content in discarded rechargeable lithium batteries . . . ."[67] The batteries represented the three most common types found in e-waste: lithium-ion, lithium-polymer, and batteries from more sophisticated smartphones.[68] Three industry-standard tests were used to identify the specific chemicals present in amounts that exceed regulatory limits. This information was used to determine the solid waste classification of these batteries.[69] The researchers found that all rechargeable "lithium batteries should be classified as hazardous waste under California regulations due primarily to excessive levels of cobalt and copper, and in some cases, nickel."[70] Other states and the federal government have enacted similar regulatory limits that would classify rechargeable lithium-ion batteries as hazardous waste.[71] Even more, two of the eight lithium-ion batteries were found to exceed the federal level of lead.[72] However small these personal electronic batteries are, their cumulative impact, together with an inconsistent method of enforcing battery disposal violations, substantially contributes to environmental pollution and detrimental health and safety issues.[73]

Consumers will always continue to desire a more affordable and efficient product, and manufacturers have responded to this desire by using low-cost materials like cobalt to produce a cheaper battery.[74] However, two initial problems arise in response to "diluting" the quality of

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64. Chad Hall, *Hybrid Storage*, 148 NO. 6 PUB. UTIL. FORT. 72, 73 (2010), http://www.fortnightly.com/fortnightly/2010/06/hybrid-storage (last visited May 21, 2016).

65. *Id.*

66. Hsing Po Kang, *supra* note 13.

67. *Id.* at 5496.

68. *Id.*

69. *Id.*

70. Hsing Po Kang, *supra* note 13, at 5498.

71. *Id.* at 5502.

72. *Id.* at 5496.

73. *Id.* at 5495.

74. Thielmann & Rothengatter, *supra* note 20.

the lithium-ion battery. First, since cobalt is a naturally occurring material,[75] costs could skyrocket should cobalt ever become scarce, effectively making the switch to cobalt to save money futile. Second, the more persuasive problem exists simply in the inherent hazard that cobalt exudes.[76] As demonstrated above, electronics manufacturers began a massive recall in laptop batteries starting in 2000 due to the potential fire hazard these batteries posed.[77] Thermal runaway reactions occur under compromised conditions such as "overcharge, over-discharge, and internal short-circuits . . ."[78] These conditions can lead the battery to overheat. When heat is released within the already-overheated battery, the internal temperature of the battery increases and further accelerates the volatile chemical processes; this internal stimulation is called thermal runaway,[79] and can result in fires or explosions.[80]

The need for consistent enforcement of battery disposal violations and policies surrounding clean energy storage is paramount to monitoring potentially toxic levels of hazardous materials that pose a risk for both the environment and consumers. Researchers have found that the battery, by itself, is not the only option for energy storage, and nanotechnology has allowed the energy storage conversation to shift from battery-recon to cleaner and safer options for both the environment and consumers.

III. A REVIEW OF SUPERCAPACITORS

A. Strengths: Potential to be Environmentally Friendly, Power Density, Rapid Charging, Lifespan

A recent shift away from the use of toxic or hazardous materials is occurring, and renewable energy sources are expected to supplement and possibly replace the stagnant battery technology.[81] The increased demand for power in today's mobile and computerized world has created a very important energy storage concern in our 21st century. Supercapacitors, like batteries, are devices that store and deliver energy and power; however, supercapacitors are replenishable and charge and discharge incredibly fast, making the supercapacitor unique and especially useful to

75. *Id.*

76. *Id.*

77. Consumer Product Safety Commission, *supra* note 24.

78. Golubkov et al., *supra* note 21.

79. *Id.*

80. Thielmann & Rothengatter, *supra* note 20.

81. Crossley, *supra* note 2; Expert Report and Affidavit, Advanced Bionics Corp. v. Advanced Neuromodulation Systems, Inc., No. 4:04cv131 (E.D.Tex. Mar. 10, 2006).

certain electronic devices.[82] Every industry that relies on battery power would benefit from what the supercapacitor has to offer.[83] The supercapacitor's advantages are best highlighted in large-scale devices that require high power densities, or alternatively, in small, specialized computer devices that requires improved and precise power performance.[84]

Nanomaterials are also expected to be less expensive to manufacture than batteries because they can be made from cheaper, manufactured materials as opposed to materials mined from the earth.[85] Currently, researchers are working to make this technology even more affordable without compromising their quality.[86] Most of these components are manufactured from cheap and naturally occurring materials or agricultural waste products that can be fine-tuned to create the most effective technology.[87] While wholly replacing battery technology is further away, supplementing battery technology with supercapacitors to form a "hybrid technology" could both reduce the amount of toxic e-waste that batteries yield and provide life-saving medical devices with a reliable and powerful source of energy that emergency medical professionals could rely on. Implementing supercapacitors into medical devices will require both state and federal governments, technology companies, medical professionals, and financial investors to work together to prepare and propose a research and development plan that complies with state and federal laws and can be accomplished by using environmentally friendly, cheap, and light materials.

Among the various advantages of nanotechnology, component manufacturing would allow the manufacturer to control precisely what materials are used, thereby allowing safe and environmentally friendly options to be required by government regulation. Supercapacitors could reasonable exceed energy safety standards by utilizing non-toxic and nano-sized component parts, a limitation that has prevented traditional lithium-ion batteries from significant advancement.[88] Clean technology will undoubtedly play a significant role as researchers continue seeking an alternative to the traditional lithium-ion battery.[89]

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82. *See* Kiebele et al., *supra* note 43.
83. Hsing Po Kang, *supra* note 13, at 5498.
84. John Chmiola & Yury Gogotsi, *Supercapacitors as Advanced Energy Storage Devices*, 4 NANOTECHNOLOGY L. & BUS. 11, 14 (2007).
85. Bhattacharya, *supra* note 46.
86. A. Kiebele et al., *supra* note 43, at 15.
87. *Global Battery Markets*, *supra* note 12.
88. Thielmann & Rothengatter, *supra* note 20.
89. *Top Ten Ways Nanotech will Impact Cleantech*, *supra* note 46.

Supercapacitors are lightweight, but solid, and have much greater power densities than lithium-ion batteries. To grasp the power density difference between typical lithium-ion batteries and supercapacitors, notice that batteries have an average power density of less than 0.1 kW/kg,[90] while supercapacitors have power densities ranging from $1.0x10^2$ to $2.7x10^{10}$.[91] Also distinct from the battery's electrochemical energy storage is the supercapacitor's ability to store the electric charge physically on the electrodes' surface.[92]

Due to the significant power difference between batteries and supercapacitors, supercapacitors are preferred for applications that demand a high surge of power. For example, researchers at the University of California, Davis opine that light rail transportation systems could rely on the supercapacitor to accelerate the train car and would have the ability to charge while the train car is braking.[93] Additionally, supercapacitors function as "bridge power" for industries that require a reliable and uninterrupted source of power, such as the telecommunications industry.[94]

In addition to the supercapacitor's high power density, another advantage of the new technology is the rapid charge rate. The intricate schematic of the electrochemical double layer supercapacitor allows the device to charge and discharge within seconds,[95] compared to the lithium-ion battery that takes approximately three hours to fully charge.[96] While lithium-ion proponents would argue that the average consumer could find three consecutive hours to charge their electronic device (during sleep, perhaps), a practical consideration limits the persuasiveness of this argument—fully charging a lithium-ion battery is not recommended.[97] Complex battery charging cycles even warrant battery manufacturers to disclose charging "tips" to consumers to avoid the harmful effects of over-charging a lithium-ion battery.[98]

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90. Boyea et al., *supra* note 4, at 586 (expressing the power-to-weight ratio as kilowatt per kilogram).

91. *Id.* (expressing without exponents for effect, supercapacitors have a power density range of 100 kW/kg to 27,000,000,000 kW/kg).

92. Bhattacharya, *supra* note 46.

93. Boyea et al., *supra* note 4, at 586.

94. *Id.*

95. *How does a Supercapacitor Work?*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-209: How does a Supercapacitor Work?") (last visited May 21, 2016).

96. *Charging Lithium-Ion*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-409: Charging Lithium-Ion") (last visited June 21, 2016).

97. *Id.*

98. *Why Lithium-Ion?,* Apple, https://www.apple.com/batteries/why-lithium-ion/ (last visited June 21, 2016).

Rapid charge rates allow supercapacitors to have a much longer lifespan than those of batteries.[99] As we have seen above, batteries only possess a charge/recharge lifespan of anywhere between two to four years, and can withstand anywhere from a few hundred to one thousand charge cycles.[100] In contrast, supercapacitors used under normal conditions typically lose only 20 percent capacity in ten years,[101] and have the ability to sustain the charge/recharge cycle a few hundred thousand times.[102] Circumstances like keeping a fully charged computer connected to power while running the device, leaving a battery-powered device in a hot car, and charging devices wirelessly will all increase the temperature of the battery and decrease the battery's lifespan.[103] These everyday occurrences are reasonable situations, and the supercapacitor user would enjoy a power supply device with an increased lifespan.

Another contributing factor to the supercapacitor's increased lifespan is the durability of the technology. For example, supercapacitors "have the ability to perform within a wide range of temperatures as opposed to batteries . . . which require a more significant structure to support their rotation and stave off negative effects of the cold."[104] This significant difference is due to the charge being stored electrostatically on the surface of supercapacitors.[105] Unlike the resilient supercapacitor, extreme heat can kill batteries: lithium-ion batteries suffer more stress when exposed to temperatures over 86 degrees Fahrenheit than during charge cycling.[106] In other words, supercapacitors do not inherently store a charge like a traditional battery. Batteries undergo physical changes each time a charge is transferred, and lifespan is affected by lost material.[107]

Considering supercapacitors as a method to enhance the reliability and durability of a medical device serves three overarching goals:

> First, medical providers use devices that require high power density such as the powered medical carts and beds, AEDs, oxygen

99. Expert Report and Affidavit, Maxwell Technologies, Inc. v. Nesscap, Inc., No. 06cv2311-JAH-BLM (S.D.Cal. Nov. 1, 2006).

100. Chmiola & Gogotsi, *supra* note 84, at 12; A. Kiebele et al., *supra* note 43, at 12.

101. *How does a Supercapacitor Work?*, *supra* note 95.

102. Chmiola & Gogotsi, *supra* note 84; *Top Ten Ways Nanotech will Impact Cleantech*, *supra* note 46.

103. *How to Prolong Lithium-based Batteries*, Battery University, http://batteryuniversity.com/learn/ (follow "BU-808: How to Prolong Lithium-based Batteries") (last visited June 21, 2016).

104. Ioxus, http://www.ioxus.com/renewable-energy/ (follow "Renewable Energy") (last visited May 21, 2016).

105. A. Kiebele et al., *supra* note 43, at 12.

106. *Id.*

107. *Id.*

concentrators, ambulatory infusion pumps, portable ventilators, anesthesia workstations, power surgical drills, portable EEG and ECG monitors, portable ultrasounds, and CPAP and BIPAP machines.[108] All these devices require significant battery power and any unexpected failure or malfunction could possibly forbear medical provides from employing life-saving techniques.

Second, EMTs and paramedics would likely find the rapid charge rate desirable since the profession depends on mobility and waiting for a device to charge via electrical power source is not feasible.

Finally, especially for first responders, heat exposure could damage the batteries used in their equipment. Increased heat exposure could render the battery inoperable or cause the battery to malfunction.

The benefits that supercapacitors could bring to the field of medicine are vast. At the very least, it would be responsible for researchers to advocate for, and the medical field be receptive to, the consideration of supercapacitors as a viable contender for energy storage in medical devices. As we will see, supercapacitors are made of cheap materials that promote the powerful delivery of energy. Supercapacitors are also frequently manufactured using non-toxic and natural resources, therefore contributing to an environmentally-friendly goal to reduce e-waste.

B. What are Supercapacitors Made of?

For optimal capacitance and lifespan, materials "should include high cyclability, long-term stability, high surface areas, and resistance to electrochemical oxidation/reduction."[109] Because energy is stored on the supercapacitor's surface, a greater surface area allows for higher energy storage. Additionally, a primary goal of supercapacitor research and development is rooted in the desire for cleaner technology, so the materials used are often non-toxic and safe for both humans and the environment.[110] Graphene-based supercapacitors have proven to be less expensive, highly dependable, and have been regarded as the model material for supercapacitors to date. However, researchers have recently discovered that supercapacitors manufactured from the stalk of hemp plants may vastly exceed the benefits of carbon-based supercapacitors.

Carbon materials have traditionally been used to manufacture supercapacitors due to their high surface areas.[111] When charcoal is

108. *Comparison Table of Secondary Batteries*, *supra* note 53.
109. A. Kiebele et al., *supra* note 43.
110. *See* Thielmann & Rothengatter, *supra* note 20.
111. A. Kiebele et al., *supra* note 43.

heated to increase its absorptive power, activated carbon is created. Activated carbon is very cheap, accessible, and has a high surface area; unfortunately, although very porous, activated carbon is not porous enough to support the supercapacitor's double layer construction, thus resulting in a strained or reduced power density.[112] Thus, carbon-nanotubes[113] and graphene[114] currently remain the most frequently used carbon-based materials in supercapacitor manufacturing.

The carbon nanotube is comprised of a network of long, thin carbon cylinders that allow the electrical current to flow greater distances within the network more quickly.[115] This complex chemical and mechanical stability allows carbon nanotubes to be more conductive than activated carbon.[116] Graphene, a thin layer of pure carbon, has various properties that make this material appealing to a wide variety of industries looking to renewable energy sources.[117] Tests have revealed that graphene has the highest thermal conductivity,[118] has low density resulting in a lighter weight,[119] and has a very high surface-area.[120] Most prominently, graphene-based supercapacitors permit a significant amount of energy storage—a key limitation of the activated carbon supercapacitor.[121] While graphene is less expensive to use than other nanomaterials, mining and chemically processing the mineral requires manufacturers to charge roughly $2,000 per gram.

Although carbon-based supercapacitors have dominated the nanomaterials market, Dr. David Mitlin, a chemical and materials engineering professor of Clarkson University in Alberta, Canada, has developed a manufacturing process that makes the commercialization of supercapacitors more feasible.[122] Mitlin discovered that pressure-cooking hemp fiber waste from the stalk of a hemp plant results in multi-layered, carbonized material.[123] These hemp-based nanosheets have extremely high surface areas, which make them good conductors. The hemp

112. Boyea et al., *supra* note 4, at 590.

113. *Id.* at 596; A. Kiebele et al., *supra* note 43.

114. Crawford, *supra* note 45.

115. A. Kiebele et al., *supra* note 43.

116. Boyea et al., *supra* note 4, at 590.

117. Crawford, *supra* note 45.

118. Alexander Baladin et al., *Superior Thermal Conductivity of Single-Layer Graphene,* 8 NANO. LETTERS 902, 906 (2008).

119. Crawford, *supra* note 45, at 5.

120. *Id.* at 7.

121. *Id.* at 8.

122. Crawford, *supra* note 45.

123. *Id.*

nanosheets act as the electrodes and an ionic liquid acts as the electrolyte.[124]

Mitlin tested the nanosheet at varying temperatures and at "an extreme current density" and concluded that the hemp properties "favorably place the material among the best power-energy characteristics ever reported for an electrochemical capacitor."[125] To Mitlin's surprise, this "unique graphene-like nanomaterial . . . outperforms [graphene-based]" supercapacitors by nearly 200%.[126] Mitlin expects this novel technology to benefit a wide variety of applications that require energy and uninterrupted power, including portable electronics, load leveling, hybrid electric vehicles, and medical devices.[127] In addition to the hemp nanosheet's superior electrochemical properties and low manufacturing cost, the hemp fiber that is used to manufacture these nanosheets is merely agricultural waste, and thus, is biodegradable.[128] The hemp nanosheet's cost-effective and environmentally friendly characteristics are desirable for both manufacturers, consumers, and the sustainability of our environment.

C. Limitations of Supercapacitors: Energy Density, Risk of New Technology

While the strength of the supercapacitor technology lies in the high power density, supercapacitor energy density is much less than lithium-ion batteries.[129] While modern lithium-ion batteries measure about 200 Wh/kg, conventional capacitors hardly register at less than 0.05 Wh/kg.[130] Poor energy density is a significant obstacle to devices that would require a large amount of energy storage.[131] Large cafeterias and universities are two examples where high energy density is needed.[132] The well-known energy density limitations of the supercapacitor have been met with innovative researchers designing electrodes with high surface-area in mind.[133] In spite of continued research and development, supercapacitors have not seen much of an increase in energy density.

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124. *Id.*
125. *Id.*
126. *Id.*
127. *Id.*
128. *Id.*
129. A. Kiebele et al., *supra* note 43.
130. Boyea et al., *supra* note 4, at 586.
131. *Id.*
132. Barry W. Brook, *The Catch-22 of Energy Storage*, http://bravenewclimate.com/2014/08/22/catch-22-of-energy-storage/ (last visited June 21, 2016).
133. A. Kiebele et al., *supra* note 43; *see also* Crawford, *supra* note 45, at 7.

Additionally, human and environmental safety is paramount in considering alternative technology for energy storage, and it is important to avoid replacing one evil with another. Although nanomaterials are being proposed, in part, to decrease the potentially toxic and hazardous materials contained in lithium-ion batteries, certain nanomaterials, such as titanium dioxide and CNTs, may pose health and environmental concerns.[134] Another difficulty and uncertainty of the supercapacitor involves the intricate and numerous particles that comprise the device called "airborne nanoparticles" that should not be inhaled, ingested, injected, or make contact with skin.[135]

Albert Lin, Professor of Law at the University of California, Davis, reviewed technology from the past and describes lessons to be learned for future technology.[136] Lin cites "technology control" as the core dilemma of managing new technologies, because it is difficult to predict what social and environmental consequences will arise; however, once they arise, it is increasingly difficult to remedy the situation.[137] Despite this concern, researchers can use available information to reasonably hypothesize about the potential hazards,[138] and attempt to address as many of them as possible. Mandatory information disclosures, technology assessments, environmental impact assessments, and lifecycle assessments are methods that could facilitate greater prediction and detection of possible hazards.[139] Lin also urges the legal community's assistance and public participation.[140]

Currently, a single device that produces both high energy and high power densities does not exist. As constructed, supercapacitors lack the required energy density to meet the demands of large-scale devices that require an energy storage capacity or a continuous flow of energy. On the other hand, rechargeable battery power is insufficient to power devices that require a significant surge of power. Power conditioners, spinning reserves, pumped-hydro, flywheels, and high-pressure air have previously served to supplement battery power.[141] However, a

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134. Albert C. Lin, *Lessons from the Past for Assessing Energy Technologies for the Future*, 61 UCLA L. REV. 1814, 1853 (2014).

135. Bhattacharya, *supra* note 46.

136. Lin, *supra* note 134.

137. *Id.* at 1816.

138. *Id.* at 1817.

139. *Id.*

140. *Id.* at 1818.

141. Hall, *supra* note 64 (explaining that (1) a "power conditioner provides an alternating current signal that doesn't vary in frequency," (2) a "spinning reserve is expensive and inefficient, with power plants idling and burning fuel for long periods of time," (3) the "pumped-hydro method . . . produce[s] energy at a relatively constant rate" and compensates for both high and low energy demand, (4) "flywheels us[e] power during period of low demand to put energy into flywheels which

combination of supercapacitors (high power density, low energy density) and batteries (low power density, high energy density), is likely to resolve a significant power problem and leverage the advantages of the battery.[142]

Researchers have entertained the idea of combining the traditional lithium-ion battery with supercapacitors to increase battery performance and lifespan,[143] and to address the low power density that limits the battery.[144] The power problem exists primarily due to the expansion of sophisticated technology and population increase that demands higher power quality, which batteries are unable to provide.[145] Supercapacitors would complement the lithium-ion battery with a higher power density, allowing the combined technology to deliver a vast amount of current for a longer amount of time.[146] The combination also serves as back-up power source during intermittent power interruptions,[147] substantially decreases battery charging time,[148] and extends battery life due to reduced thermal, chemical, and mechanical stresses that the supercapacitor absorbs.[149] For example, Ioxus, a supercapacitor manufacturer, reports that their supercapacitors function normally in extreme temperatures.[150] The need to start your car twenty minutes early on a cold winter morning would not exist if supercapacitors replaced the component part of the battery that inhibits a quick start of the engine in cold temperatures.[151] Hybrid storage would also "reduce the size, weight, and the number of batteries in a system."[152] Finally, combining batteries and supercapacitors would allow developers to separate the energy and power components.[153] Component separation would be advantageous in devices where energy and power output are not always equal, and a fluctuating demand for either exists.[154] In this situation, the device would

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energy is recaptured when demand increases," and lastly (5) "high pressure air is accumulated when demand is low and used to drive a turbine under conditions of increased demand " in compressed-air energy storage systems).

142. Chmiola & Gogotsi, *supra* note 84. *See* Ioxus, *supra* note 104.

143. Thielmann & Rothengatter, *supra* note 20.

144. Hall, *supra* note 64, at 72.

145. *Id.*

146. *Id.* at 73.

147. A. Kiebele et al., *supra* note 43.

148. Hall, *supra* note 64, at 74.

149. *Id.*

150. Ioxus, *supra* note 104.

151. Chmiola & Gogotsi, *supra* note 84, at 12.

152. Hall, *supra* note 64, at 82.

153. *Id.* at 81.

154. *Id.*

know to trigger the source of either energy or power that it required, and the chosen part would deliver.[155]

Presently, hybrid storage seems to be the most likely implementation of supercapacitors in the immediate future.[156] The high power density characteristic of supercapacitors complements the energy-dense battery, and establishes a device with the ability to deliver and sustain high power-to-power-intensive devices.[157] As a specific example, medical carts and powered stretchers would directly benefit from having an increased power supply, decreased device charging time, longer battery life, and a lighter device. These seemingly small considerations do not appear to be a substantial concern when analyzed individually; however, the advantages of incorporating supercapacitors with the frequently used rechargeable battery would likely serve as a significant benefit to medical professionals in the furtherance of patient care and treatment.

IV. NEW TECHNOLOGY DEVELOPMENT

Battery technology has only slightly advanced since 1991,[158] and widespread deployment and commercialization of advanced, clean energy storage has not yet occurred.[159] Compared to other recent technological advances, energy storage technology seems to be moving at a glacial speed. However, hybrid storage appears to be the most promising technology for the immediate future.[160] As the nanotechnology industry continues to improve and establish itself in a variety of markets,[161] it is reasonable to envision the eventual replacement of traditional lithium-ion batteries with nanomaterials.

As with most new technology, barriers to research and development, funding, and deployment arise at every turn.[162] The specific type of nanotechnology energy storage described in this article seems doubly problematic. First, the energy market alone is colossal and well established. Conversations on nanotechnology will require precision targeting in order to interest and persuade investors to devote their resources to this clean, alternative energy. Although moving towards clean energy storage via nanotechnology may seem visionary at best, the

155. *Id.* at 82.

156. Thielmann & Rothengatter, *supra* note 20, at 400.

157. Hall, *supra* note 64, at 73.

158. Thielmann & Rothengatter, *supra* note 20, at 399.

159. Crossley *supra*, note 2, at 281.

160. Thielmann & Rothengatter, *supra* note 20; *see also* Hall, *supra* note 64, at 72.

161. Chmiola & Gogotsi, *supra* note 84; A. Kiebele et al., *supra*, note 43.

162. Felix Mormann, *Requirements for a Renewable Revolution*, 38 ECOLOGY L. Q. 903, 905–909 (2011); Bhattacharya, *supra* note 46; see also Crossley *supra*, note 2, at 269.

energy industry has responded well to technology advancements that conform to present times.

Over the course of history, energy has come in many forms, including coal, natural gasses, waterwheels, petroleum, windmills, steam engines, alcohol blends, hydrogen fuel cells, solar power, electric power plants, diesel, hydroelectric power plants, fossil fuels, atomic energy, wind farms, and biofuel.[163] Lack of financial backing, rather than hostile reaction from the energy industry, was frequently the cause of advancements not flourishing.[164] Updating energy sources and energy storage is necessary to keep pace with the increased power demands from population increase and more sophisticated applications requiring high power. Additionally, research and development funds are so pivotal to a new invention's success that without the proper finances, even a great idea will not succeed.[165]

Second, the nanotechnology industry may be hindered by a lack of streamlined commercialization processes that the more established industries have acquired and enjoy. This hindrance could be a product of various motives: investor reluctance based on uncertain returns, inconclusive guidance and delayed responses from policymakers, and public hesitation to a new and complex industry. All of these motives could slow down the process to get supercapacitors on the shelves for consumers. However, these hindrances will not likely inhibit supercapacitor technology from eventual implementation altogether. With sophisticated and complex technology comes investor reluctance, but reluctance has not inhibited existing technology from getting where it is today. Also, establishing different organizations to lobby state legislature and Congress could encourage policymakers to act more swiftly. Last, many researchers had tenure in the traditional energy industry and simply shifted their focus to the new and emerging field of nanotechnology.

The following sections will explain the obstacles to implementing supercapacitor technology and suggest policy considerations for each of the obstacles. This article will conclude with funding and research and development proposals for the future of nanotechnology and supercapacitors.

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163. *History of Alternative Energy and Fossil Fuels,* ProCon.org, http://alternativeenergy.procon.org/view.timeline.php?timelineID=000015 (last updated June 13, 2013).

164. Hsing Po Kang, *supra* note 13.

165. *Id.*

A. Obstacles to Deploying New Technology

When a new technology is in its infancy, it is nearly impossible to determine the precise possible social and environmental risks or limitations of the product.[166] Understanding the obstacles that a new technology could face will better assist in narrowing the scope of remedy. Continuous research is essential to ensure that nanotechnology does not replace one evil with another. Obstacles to deployment of supercapacitors generally fall into two main categories: financial and political. A third category will capture obstacles that do not fit within the first two. The categories do not operate in isolation but will be reviewed separately for clarity.

1. Financial Obstacles

Funding new technology is an expensive and risky venture for private investors and investment firms.[167] Investors are reluctant to invest any significant amount of money due to the high capital and exposure to technical, economic, regulatory, market, and patentability failure.[168] Stanford Law fellow Felix Mormann names the "spillover effect" as the most common reason for undersupply of financial backers.[169] The effect occurs when an investor provides financial support to further research and development of a particular innovation. The investor is never the only one that enjoys the benefits from the research—like knowledge and learning experience—but the investor is the only one who pays for it.[170] Thus, until the investment is financially promising, risk-averse investors will wait while someone else finances research and development, and when more information becomes available, then decide whether investing would be profitable to them.[171] This business tactic is counter-productive to technology advancement and dampens innovation because investors understand that they would bear the brunt of the initial costs that others can profit from. Assuming a risk-averse position seems reasonable when investing in any new and radical venture; however, without adequate financial support to research and analyze the data, new technologies are unlikely to survive.

In addition to the spillover effect, distant deployment[172] is another factor that investors try to avoid when possible because they are seeking

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166. *Id.*
167. Bhattacharya, *supra* note 46.
168. Hsing Po Kang, *supra* note 13, at 1819.
169. Mormann, *supra*, note 162, at 916.
170. *Id.*
171. *Id.*
172. Bhattacharya, *supra* note 46.

the maximum return in the shortest possible timeframe. If the expected return appears to be too far away, many investors would not risk tying up or losing their money unless they were confident that the delayed return would be worth the wait. While supercapacitors can be manufactured rather quickly, distribution and implementation can be severely delayed until companies commit to having supercapacitors power their product.

Numerous component parts may require separate or incremental implementation,[173] and the layered-nature of the supercapacitor could also deter an investor from supporting a new energy storage product. The more complex the technology, the greater the risk the investor is likely to perceive. Similarly, with new technology comes new facilities necessary to accommodate the manufacturing process. While not always a deal-breaker for an interested investor, building new plants or processing facilities can prove expensive, and zoning regulations could make the building permit approval process lengthy.

The factors above are not meant to be exhaustive, and no one factor alone would disclose the complex financial methods each investor employs when determining whether to accept the risk or not. Prominent players in the medical field could certainly play a significant financial role in supercapacitor research that is tailored to their medical facility needs. The UW Medical Center, Cedars-Sinai Medical Center, and Johns Hopkins Hospital are just a few institutions that would greatly benefit from supercapacitor research and development. Moreover, these medical giants could provide further insight on exactly what type of energy storage and power supply they would benefit from. Offering to tailor a supercapacitor's design to a specific medical center may incentivize greater financial participation.

2. Political Obstacles

In addition to financial concerns, some investors believe the energy storage industry is largely controlled by and dependent upon inconsistent and volatile policymakers who have not historically been helpful to the energy industry.[174] However, the true source of investor frustration can more likely be attributed to the lack of a universally accepted legal definition for energy storage technologies.[175] The lack of a definition hinders policymakers from offering subsidies or other financial incentives because the new technology either doesn't fit within the scope of the current regulation or is unintentionally, but expressly, excluded

173. Hsing Po Kang, *supra* note 13, at 1819.
174. Mormann, *supra* note 162, at 918.
175. Crossley, *supra* note 2, at 274.

altogether as a result of an outdated rule.[176] A policymaker who does not understand energy storage is not going to independently advocate for an amendment to an existing statute on energy storage and supercapacitors.

B. Overcoming the Policy Obstacles to Deploying New Technology

It is important to discuss relevant policy considerations that directly address the above obstacles to supercapacitor deployment. Battery deficiency and battery failure are issues that medical providers should not have to think about when administering life-saving techniques with advanced medical equipment. Further, the potential for toxic exposures to humans and the environment, coupled with inconsistent and ineffective policies on battery disposal, justifies additional research and development for a new technology that is on the rise. The following sections propose solutions that could curtail some obstacles, leading to the eventual deployment of supercapacitors as a supplemental power supply in medical devices. First, political obstacles are taken up to address the lack of a consistent definition that inhibits policymakers from truly helping the energy market. Next, financial obstacles will be addressed, with a specific focus on increased governmental funding. Lastly, environmental concerns are lessened by a reassurance that supercapacitors would not, nor should not, get to the deployment stage without increased scrutiny of the potential hazards they could pose.

1. Involving the State and Federal Governments

"Government investments are critical to basic research [because] basic research is necessary to fuel innovation and economic growth."[177] Government support often comes in the form of research grants, subsidiaries, and tax credits.[178] Since 1997, multiple environmental agencies have requested an increase in their funding, ranging from a "mere doubling to a tenfold raise."[179] The energy industry is vast, and attempting to implement an entirely new type of energy storage is going to be costly and cutting-edge, so the advancement of technology needs the government's support. If the U.S. wants to be a leader in this emerging field, substantial increases in funding must be considered.

Both state and federal governments have an interest in seeing clean energy alternatives succeed, and they can do this by providing incentives to companies who research or manufacture supercapacitors, or by informing the public that issues such as pollution, energy sustainability,

176. *Id.*
177. Bhattacharya*, supra* note 46.
178. Hsing Po Kang, *supra* note 13, at 1818.
179. Mormann, *supra* note 162, at 943.

and resource consumption are being addressed.[180] For example, the federal government created the Small Business Innovative Research program to encourage start-up companies to lend their research to the commercial market by providing the companies with capital.[181] A government that could sustain its commitment to energy research and development would incentivize the particularly risk-averse investors to join public entities in advancing this new technology.

On August 5, 2009, President Obama announced a $2.4 billion grant under the American Recovery and Reinvestment Act to drive projects to accelerate the development of U.S. battery manufacturing and deployment of electric drive vehicles.[182] The President declared that this "is the single largest investment in advanced battery technology for hybrid and electric-drive vehicles ever made."[183] The fund is intended to "establish American leadership in creating the next generation of advanced vehicles."[184] This goal assures us that the government understands the importance of advanced battery technology; further advocacy is needed to nudge officials in the right direction to include nanotechnology in their advanced energy storage technology considerations. President Obama's 2013 budget proposal included allocating $32.3 billion dollars to the Energy Department, $16.6 billion of which would go towards "Energy Programs."[185]

At the very least, the state and federal government could sponsor educational campaigns[186] to inform the public and encourage the community to get involved. Multiple foreign nations have successfully recruited community members to participate at a level that has generated widespread approval of renewable energy, but the U.S. model of awarding tax incentives to corporations and their investors does little to incentivize public participation.[187] The public can influence the level of government involvement through political pressure, and the rate of technological advancement by direct participation and fundraising. Increased public involvement would certainly invoke a response from the policy makers who strongly influence the future for supercapacitors.

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180. Bhattacharya, *supra* note 46, at 203; *see also* Crossley *supra*, note 2 at 274.

181. Bhattacharya, *supra* note 46, at 203.

182. Press Release, Office of the Press Secretary, The White House (Aug. 5, 2009) (on file with author) https://www.whitehouse.gov/the-press-office/24-billion-grants-accelerate-manufacturing-and-deployment-next-generation-us-batter.

183. *Id.*

184. *Id.*

185. *Four Ways to Slice Obama's 2013 Budget Proposal* (Feb. 12, 2012), http://www.nytimes.com/interactive/2012/02/13/us/politics/2013-budget-proposal-graphic.html?_r=0 (last visited on May 21, 2016).

186. Mormann, *supra* note 162, at 910.

187. *Id.* at 963.

Further, individual states should be encouraged to implement their own system to introduce supercapacitors to citizens. For example, states could choose to employ supercapacitors in devices held by government officials such as police officers' radios or firefighters' flash lights. This state-by-state model is a small-scale approach that might prove to be more efficient than introducing supercapacitor alternatives at the federal level because states can more efficiently distribute new technologies to government agencies than federal agencies are able to do. Additionally, states have greater influence on local manufacturing and national campaigns for complex technology can be expensive and ineffective.

Last, one of the primary obstacles that inhibits deployment of any new type of energy storage is the lack of a consistent and universal legal definition.[188] Due to the complexity of the subject matter, researchers and scientists in both the nanotechnology and medical fields need to be present during the regulatory re-drafting process that policymakers should initiate. Once policymakers define nanotechnology jargon, agencies can regulate and define the comprehensive nanobiotechnology industry within one of the established fields of biology, medicine, or nanotechnology. As of this writing, a legal definition for this new type of technology does not exist.

2. Nanotechnology in a Viable Marketplace

When considering whether nanotechnology could establish a viable marketplace within the energy storage industry, several considerations exist. Fluctuating energy prices directly affect the energy market, and investors may be discouraged from providing financial support when the profits are uncertain at best.[189] Also, big companies like Duracell, Energizer, Trojan, and Panasonic all likely have significant stakes in the energy storage market, and investors may not want to compete with these known powerhouses. Tax incentives and private partnerships could be used to alleviate these marketplace uncertainties and remove some of the concerns with respect to supercapacitor development.

Additionally, instead of hostile competition, well-known battery companies could move towards collaboration with nanoscientists to combine their well-established battery with the new technology of the supercapacitor. Combined efforts would facilitate an all-around quicker process to commercialization. Battery companies would not have to feel threatened that nanotechnology will immediately put them out of

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188. Crossley, *supra* note 2, at 277.
189. Hsing Po Kang, *supra* note 13, at 1819–1820.

business, and nanotechnology would undoubtedly benefit from deploying in an incredibly opportune position in a lucrative new market.

Moreover, commercial consumers, such as hospitals or emergency dispatch centers, may be incentivized to test the new technology if supercapacitor manufacturers could offer the option of product customization tailored to the commercial consumer's unique industry. Supercapacitor's back-up power capability becomes very valuable specifically in these medical contexts.

3. Safety Considertions for Consumers' Health and the Environment

Finally, specific attention should be paid to the claims that nanotechnology could pose a similar or additional health or environmental risk that lithium-ion batteries have been criticized for.[190] Specifically, researchers have raised the implications of "airborne Nano Particles" if inhaled, ingested, injected, or touched on the skin.[191] The government has an interest to protect its citizens from hazardous materials. If nanotechnology is found to contain hazardous, or potentially hazardous, materials, government support and funding seems unlikely.

Reviewing similar technology to inform the public health and welfare determination could provide valuable insights into potential drawbacks in this new technology. In addition to established and consistent legislation governing battery disposal, manufacturers could be required to fund the cost of recycling or proper disposal of their devices that contain potentially hazardous material.[192] Holding manufacturers accountable for their products would certainly encourage stricter compliance at the manufacturing level. Mandatory reporting requirements would allow the government to monitor compliance and course-correct when necessary. This reporting requirement would serve two purposes: 1) discovery of hazardous materials will be detected, 2) without having to reinvent a safety monitoring system for the newly implemented technology.

Lastly, at least initially as a precautionary measure, treating supercapacitors as if they were hazardous until proven otherwise would act as a risk management method that would prevent potentially hazardous materials from harming humans or the environment. Both requiring manufacturers to work in a sealed and protected environment and developing initial exposure levels of hazardous materials that should

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190. Bhattacharya, *supra* note 46, at 203; *see also* Hsing Po Kang, *supra* note 13, at 1853.

191. Bhattacharya, *supra* note 46, at 203.

192. *Poison PCs and Toxic TVs*, Silicon Valley Toxics Coalition, 1, 22–24, http://svtc.org/wp-content/uploads/ppc-ttv1.pdf (last visited June 21, 2016).

not be exceeded, would assist in protecting humans and the environment. Of course, these policies can be fine-tuned once more research has been done on the components of supercapacitors.

V. Conclusion

Supercapacitors have the potential to radically change the way power and energy is stored and supplied. Emergency medical providers rely on portable life-saving equipment that may require a backup power supply, and the traditional lithium-ion battery falls short. With increased funding from both the private and public sector, nanotechnology will have the potential to flourish into an environmentally-sustainable energy source alternative to the lithium-ion battery.