Universidad Autónoma de Madrid | Escuela de Doctorado

PLAN DE INVESTIGACIÓN (PI) [1]

Título:

Vanadium Electrolytes Development for Advanced Flow Batteries

Doctorando

Nombre: Sabrina Berling

e-mail: sabrina.berling@imdea.org

Director

Nombre: Jesús Palma del Val

Institución: Instituto IMDEA Energía

Co-Director

Nombre: Enrique García – Quismondo Hernáiz

Institución: Instituto IMDEA Energía

Tutor

Nombre: Pilar Ocón Esteban

Fecha de Matrícula: 11/2020

Fecha: 01/02/2021

Tesis en cotutela: ☐ SI ☒ NO

Universidad:

Doctorado Industrial: ☐ SI ☒ NO

Empresa en que el doctorado está contratado: Instituto IMDEA Energía

1 Este documento deberá tener una extensión orientativa de entre cinco y diez páginas, anexos aparte. No será necesaria la cumplimentación de los subapartados 3.1 y 3.2 en aquellos programas en los que las comisiones académicas así lo establezcan.

Actualizado: 20/08/2019

1. Antecedentes y estado actual del tema

Redox Flow Batteries (RFB) are energy storage systems that use electrolytes as charge transport agents. But these electrolytes, typically consistent of vanadium solutions are not stable in a wide range of temperature and at the same time have thermal properties that can be harnessed to improve the efficiency of other systems such as geothermal processes.

Practical RFB systems have been attracting considerable commercial interest in recent years, with several companies currently manufacturing vanadium flow batteries systems (VRB), which operate with vanadium electrolyte, in Japan, USA, Australia and China. The VRB offers excellent cycle life, energy efficiency and reasonable costs for storage capacities greater than 4 hours but its energy density is relatively low compared to Li-ion batteries because it requires large electrolyte volumes containing vanadium species, making it potentially interesting for large-scale energy storage in a range of stationary applications [1–4].

Efforts to increase the energy density of the vanadium redox flow battery have consisted in increasing vanadium species solubility including the use of a mixed halide electrolyte in the case of the vanadium bromide redox battery developed by Skyllas-Kazacos and co-workers from UNSW in Australia [5] and a mixed HCl-H_2SO_4 supporting electrolyte as proposed by researchers at the Pacific Northwest National Laboratory in the USA [6]. In both cases however, the use of HCl and/or HBr in the electrolytes introduces the risk of acid, chlorine or bromine vapors at elevated temperatures or during overcharge, and therefore restricts the operating state-of charge range of the batteries, while also presenting a potential safety hazard.

In contrast to both the VBr and mixed acid vanadium chemistries, the original UNSW All-Vanadium Redox Flow Battery employs sulfuric acid as the supporting electrolyte, so any overcharge reactions produce oxygen gas at the positive electrode, making it a much safer system. Current VRB systems employ solutions of between 1.6 and 2 M vanadium ions in sulfuric acid with total sulfate concentrations ranging between 4 and 5 M and utilize the V(II)/V(III) and V(IV)/V(V) couples in the negative and positive half-cell electrolytes, respectively. Increasing the vanadium ion concentration above 2 M will increase the energy density, however, this is limited by the solubility of the different vanadium ions in the temperature range of 10 to 40°C. The V(II), V(III), and V(IV) ions precipitate as sulfates, so their solubility increases with increasing temperature but decreases with increasing sulfuric acid concentration because of the common ion effect of the sulfate ion. On the other hand, the V(V) ions in the positive half-cell electrolyte can undergo thermal precipitation to form V_2O_5 at elevated temperatures.

The effect of this reaction on the stability of the positive half-cell electrolyte in the VRB was described by Skyllas-Kazacos and co-workers in 1990 [7]. The stability of the positive electrolyte of the vanadium redox cell was studied at various temperatures and at different solution compositions and solution states-of-charge (SOC). The authors found that at elevated temperatures for extended periods, V(V) can slowly precipitate from solution, the extent and rate of which being dependent on temperature, vanadium and sulfuric acid concentration as well as the SOC of the electrolyte. In contrast to the V(V) ions, V(II), V(III) and V(IV) ions will precipitate at temperatures below 10°C at concentrations above 1.6 M in solutions with total sulfate concentration of 5 M. Practical VRB systems thus operate with vanadium electrolyte concentrations between 1.6 and 1.8 M and usually also employ electrolyte cooling and heating systems to maintain the temperature between 15 and 40°C. This limits the energy density of the VRB to levels that are still acceptable for most stationary energy storage applications, however, a higher energy density flow battery electrolyte will allow a wider range of applications to be exploited.

In an effort to enhance the operational temperature range of the VRB, in this thesis it is proposed to develop vanadium electrolytes improved with capacity increase systems through the use of compounds with ability to increase the solubility or enhance the electronic transfer mechanisms. The development of electrolytes with improved capacity is essential to achieve market acceptance of this type of battery without temperature limitations.

1.1. Experiencia previa del Grupo de Investigación

The Electrochemical Processes Unit was created in April 2008, since then, its researchers have been working in the field of electrochemical technologies for energy storage. Specifically, they have specialized in the development of new redox flow batteries, with several projects that support their experience. The most relevant projects related to the proposed thesis topic are detailed below:

- REM: Multipurpose electrochemical reactor for energy and environmental applications. Project coordinated by the company PROINGESA, corresponding to the call 2010, for the Sub-program INNPACTO,
- LPT: The Total Photovoltaic Platform. Research project with reference: RTC-2015-4153-3, coordinated by the company Ingenia Solar Energy, corresponding to the call 2015, within the State Program of Research, Development and Innovation Oriented Challenges of the Society under the National Plan for Scientific Research and Technological Innovation 2013-2016 (Collaboration Challenges 2015).
- Developing Organic Flow Batteries. Private Contract 2016-2018. IMDEA Energy Institute; E22 Energy Storage Solutions and REPSOL.

The Electrochemical Processes Unit of the IMDEA Energía Institute has carried out intense research work on the design and building of flow batteries with novel chemistries to improve the technology in two ways: (1) increasing energy density and (2) reducing costs per kWh stored, which allowed the generation of knowledge and its transfer to companies with the protection of several patents.

In recent years, new lines of research have been initiated that include the exploration of new chemistries and cell designs for membrane-free redox flow batteries using either immiscible electrolytes (MFreeB ERC Consolidator project) or microfluidic designs. This particular project will expand the group's know-how in the field of increasing the energy density of redox electrolytes by means of chemical mediators.

2. Objetivos y planteamiento

The main objective of this thesis is to develop a new generation of vanadium electrolytes for emerging applications characterized by better performance in wider temperature ranges. A significant enhancement in the energy density of the VRB is strongly needed to increase the penetration of this type of systems in the market, and with that, their commercialization in the expected terms and volumes. Specifically, the following objectives have been defined in this thesis plan:

- Selection of advanced additives to be used for the capacity enlarging strategy. To fulfill this objective, the screening of compounds and reagents to be included in the electrolytes will be carried out. In this point an intensive characterization of vanadium electrolytes focused on physicochemical and electrochemical behavior will be performed with the aim of analyzing its behavior at different temperatures.
- Development of an enhanced vanadium electrolyte. This objective consists on evaluate the compounds selected in a vanadium electrolyte environment to determine the increased volumetric capacity with the targets of higher efficiency, extended stability and robustness with respect to wider temperature range operation.
- Proof of concept. Integration of electrolytes in a flow cell focusing on the proof of the novel energy storage concept, taking into account the different operational modes in realistic configurations including auxiliary equipment and temperature control systems.

3. Metodología y plan de trabajo

The starting hypothesis is that, either by using complexing agents or by introducing redox mediators, it is possible to improve the capacity of the electrolyte. For this approach the use of inhibitors and redox mediators is proposed and the following work plan has been created:

1. For a more detailed view of the electrolyte and a determination of the limits of the operational range, a physical-chemical study of the solutions and a fundamental electrochemistry characterization of each of the two half-reactions that are needed for the operation of the vanadium flow battery will be carried out. Furthermore, the stability of the electrolytes will be evaluated at various temperatures and at different solution compositions and solution states-of-charge. Additionally, viscosity, density and redox potential measurements will be considered in electrolytes based on high concentrations of vanadium and more dilute solutions. The electrochemical characterization will allow determining the electrolyte´s kinetic parameters like diffusion coefficients, kinetic rate constants and the formal/standard potentials of vanadium electrolytes under different conditions. These measurements will be performed within a wide temperature range from 5 to 50ºC to obtain information which is not accessible in literature and which is necessary to assess if an electrolyte is feasible for a practical flow battery.

2. Selection of compounds for capacity enhancement. This step includes an extensive literature research to screen organic and inorganic materials to be used as additives with the possibility for a capacity increase in the positive and/or negative electrolyte. These will be tested via electrochemical studies and their performance in a three electrodes cell configuration will be evaluated. Moreover, various electrochemical techniques will be performed such as cyclic voltammetry, galvanostatic charge and discharge cycles, chronoamperometry, etc., which will allow to determine the behavior of different vanadium electrolytes with additives and their potential applicability in flow batteries. In addition, alternative analytical techniques will be used for the identification of species and the determination of concentrations such as potentiometric titrations, UV-vis spectroscopy, ICP, impedance, etc.

3. Proof of concept. With the results of the laboratory tests, the evaluation of the concept will begin, with particular attention to the design of the experiments and to establish a protocol of tests that provide sufficient information to validate the capacity enhancement. The tests will be conducted in a simplified laboratory setup, but will include equipment and instruments sufficient to control the supply flow of the electrolytes, their temperatures, and the operating voltages and currents. Tests will be carried out to obtain basic operating data such as capacity, energy efficiency and the number of cycles at different operating conditions. These measurements will be performed within the same temperature range from 5 to 50ºC.

Tasks		Years											
Nº	Description	Year 1				Year 2				Year 3			
T1	Electrolytes Characterization												
T2	Additives Screening												
T3	Proof of Concept												

3.1. Impacto previsto

-Scientific impact: The proposed strategies to increase the energy density of vanadium electrolytes can potentially be applied to any other flow battery chemistries, opening new applications possibilities for such storage technology. On this basis, it is expected to generate knowledge to reformulate the electrolyte composition of batteries to develop prototypes adapted to specific use scenarios. To increase the scientific impact, at least 2 articles will be published in peer-reviewed Q1 journals.

-Technical impact: The improvement in the energy density and thermal stability of the vanadium electrolytes will potentially facilitate the penetration of vanadium flow batteries in large stationary energy storage systems coupled with renewable generation plant. Based on the industrial experience of the thesis supervisors, an exploitation plan is foreseen for results with technological interest. This would include filing patents and stablishing technology transfer agreements with companies.

-Economic impact: The market of energy storage systems coupled to renewable generation is expected to expand in the coming years. The Spanish PNIEC and the Strategy for energy storage recently published foresee an installed capacity of 8 GWh of stationary storage for 2030, i.e. a market over 1000 M€.

- Social impact: Energy storage, particularly battery energy storage will be a game changer in the transformation of citizens from energy consumers into energy prosumers. This will greatly impact the social access to energy resources and will promote a transition towards a sustainable society.

3.2. Plan de financiación y movilidad

This thesis receives financial support from the Research project with reference: RTC-2017-5955-3, coordinated by the company Sacyr Industrial, corresponding to the call 2017, within the State Program of Research, Development and Innovation Oriented Challenges of the Society (Collaboration Challenges 2017), which includes the salary of the doctoral student. In order to receive this aid, the evaluation system of the Ministry of Science, Innovation and Universities-AEI took into account the previous experience of the thesis supervisors and the research group in the area of flow battery studies and specifically in the development of new electrolytes.

Within the doctoral program the option of carrying out stays in leading R&D centers in the thesis area is contemplated. Specifically, it is expected to carry out a research stay at a prestigious research group in the European Union for a duration of 3 months. This stay will be funded by IMDEA Energy own resources and, if possible, with the additional funding from "Unidad de Excelencia Maria de Maeztu" funds for mobility actions.

4. Bibliografía inicial

[1] M. Skyllas-Kazacos, M. Rychick, R. Robins, All-vanadium redox battery, Pat. US 4786567. (1988).

[2] M. Skyllas-Kazacos, New All-Vanadium Redox Flow Cell, J. Electrochem. Soc. 133 (1986) 1057. https://doi.org/10.1149/1.2108706.

[3] M. Skyllas-Kazacos, G. Kazacos, G. Poon, H. Verseema, Recent advances with UNSW vanadium-based redox flow batteries, Int. J. Energy Res. (2010). https://doi.org/10.1002/er.1658.

[4] A. Parasuraman, T.M. Lim, C. Menictas, M. Skyllas-Kazacos, Review of material research and development for vanadium redox flow battery applications, Electrochim. Acta. 101 (2013) 27–40. https://doi.org/10.1016/j.electacta.2012.09.067.

[5] H. Vafiadis, M. Skyllas-Kazacos, Evaluation of membranes for the novel vanadium bromine redox flow cell, J. Memb. Sci. (2006). https://doi.org/10.1016/j.memsci.2005.12.028.

[6] L. Li, S. Kim, W. Wang, M. Vijayakumar, Z. Nie, B. Chen, J. Zhang, G. Xia, J. Hu, G. Graff, J. Liu, Z. Yang, A stable vanadium redox-flow battery with high energy density for large-scale energy storage, Adv. Energy Mater. (2011). https://doi.org/10.1002/aenm.201100008.

[7] M. Kazacos, M. Cheng, M. Skyllas-Kazacos, Vanadium redox cell electrolyte optimization studies, J. Appl. Electrochem. (1990). https://doi.org/10.1007/BF01076057.

Firma Doctorando	Vº Bº Director	Vº Bº Tutor

ANEXO I : *Curriculum vitae del director o directores de la tesis*

Adjuntar en documento aparte un *CV abreviado* del director o directores, preferentemente en el formato utilizado por el MINECO, indicando únicamente méritos de investigación y transferencia, referidos solo a los últimos 6 años.

Parte A. DATOS PERSONALES

Fecha del CVA	01/02/2021

Nombre y apellidos	Jesús Palma del Val		
DNI/NIE/pasaporte	02855892M	Edad	57
Núm. identificación del investigador		Researcher ID	G-6914-2015
		Author ID	35791418500
		Código ORCID	0000-0003-1022-0165

A.1. Situación profesional actual

Organismo	Fundación IMDEA Energía		
Dpto./Centro	Unidad de Procesos Electroquímicos		
Dirección	Avda. Ramón de la Sagra 3, 28935 Móstoles, Madrid		
Teléfono	917371116	Correo electrónico	jesus.palma@imdea.org
Categoría profesional	Investigador Senior	Fecha inicio	11/04/2008
Código UNESCO	330309; 330418		
Palabras clave	Electrochemistry; Environment; Energy Storage; Energy Efficiency		

A.2. Formación académica *(título, institución, fecha)*

Licenciatura/Grado/Doctorado	Universidad	Año
Executive MBA	IE Business School	2001
Doctor en Química	Universidad Autónoma de Madrid / CSIC	1994
Licenciado en CC. Químicas	Universidad Autónoma de Madrid	1986

A.3. Indicadores generales de calidad de la producción científica *(últimos 6 años)*

	Ref. WoS	Ref. Scopus
Documentos publicados con FI =	46	47
Documentos en revistas D1 =	34 (74%)	35 (74%)
Documentos en revistas Q1 =	41 (89%)	42 (89%)
Factor de impacto promedio =	7.842	8.30
Citas totales =	1920	2009
Citas por año =	320	335
Índice H =	24	25

Tesis dirigidas = 4 defendidas + 4 en curso
Trabajos de fin de Master / Grado supervisados = 12
Investigadores postdoctorales supervisados = 6

Parte B. RESUMEN LIBRE DEL CURRÍCULUM *(máximo 3500 caracteres, incluyendo espacios en blanco)*

Entre 1988 y 1991 realizó su tesis doctoral en el Instituto de Cerámica y Vidrio del CSIC. Desde 1991 hasta 2008 trabajó en el Centro de I+D de Técnicas Reunidas S.A., donde comenzó como Ingeniero de Procesos, luego fue promovido a Director de Proyectos y finalmente a Director del Centro de I+D. En 2008 se incorporó a la Fundación IMDEA Energía para poner en marcha la Unidad de Procesos Electroquímicos dedicada a la investigación en tecnologías electroquímicas para almacenamiento de energía y para aplicaciones medioambientales. Desde entonces, la Unidad ha crecido desde 2 hasta 25 personas; ha conseguido más de 70 proyectos de investigación por valor de más de 10 millones de Euros; ha publicado más de 160 artículos científicos en revistas indexadas en el JCR (84% en el primer cuartil); ha generado 9 patentes; y supervisado 8 tesis doctorales. Los investigadores de la Unidad han recibido 1 contrato ERC-Consolidator, 6 becas Marie Curie, 3 contratos Ramón y Cajal, 2 becas Juan de la Cierva, 4 becas de atracción de talento de la Comunidad de Madrid y 2 becas de la Fundación Iberdrola.
A lo largo de su carrera ha participado en más de 65 proyectos de investigación nacionales e internacionales, siendo investigador principal en unos 45. Ha participado en 14 proyectos

europeos, actuando en 8 de ellos como responsable de la organización participante. Se ha especializado en investigación aplicada, escalado de dispositivos y procesos desde el laboratorio a planta piloto. Tiene experiencia en la elaboración de patentes y negociación de acuerdos de licencia. Sus intereses actuales incluyen *Condensadores electroquímicos; Desionización electroquímica; Baterías de flujo; Baterías de ion-Litio; Otras baterías primarias y secundarias (Al-ion, Zn-Mn y Zn-aire); y Ensayos, modelizado y predicción de la vida útil de baterías.*

Parte C. MÉRITOS MÁS RELEVANTES *(ordenados por tipología)*

C.1. Publicaciones (selección)

1. Antonio Molina, Nagaraj Patil, Edgar Ventosa, Marta Liras, Jesús Palma, and Rebeca Marcilla. "Electrode Engineering of Redox-Active Conjugated Microporous Polymers for Ultra-High Areal Capacity Organic Batteries". ACS Energy Letters, **2020**, 5, 2945–2953. DOI: 10.1021/acsenergylett.0c01577. Impact factor: 19.003 – D1(2019)
2. Antonio Molina, Nagaraj Patil, Edgar Ventosa, Marta Liras, Jesus Palma, and Rebeca Marcilla. "New Anthraquinone-based Conjugated Microporous Polymer Cathode with Ultrahigh Specific Surface Area for High-Performance Lithium-ion Batteries". Advanced Functional Materials, **2020**, 30, 6, 1908074. DOI: 10.1002/adfm.201908074. IF: 16.836 – D1(2019)
3. Wang, Y., Vázquez-Rodríguez, I., Santos, C., García–Quismondo, E., J., Palma, J., Anderson, M.A and Lado, J. J.*. "Graphite Felt 3D Framework Composites as an Easy to Scale Capacitive Deionization Electrode for Brackish Water Desalination". Chem. Eng. Journal, **2020**, 123698. DOI: 10.1016/j.cej.2019.123698. IF: 10.652 – D1(2019)
4. Sanchez, J; Pendashteh, A; Palma, J.; Marcilla, R. "Insights into Charge Storage and Electroactivation of Mixed Metal Sulfides in Alkaline Media: NiCoMn Ternary Metal Sulfide Nano-needles Forming Core-Shell Structures for Hybrid Energy Storage". Journal of Materials Chemistry A, **2019**, 7, 20414-20424**.** DOI: 10.1039/C9TA04322E. IF: 11.301 – D1(2019)
5. Navalpotro, P., Neves, C.M.S.S., Palma, J., Freire, M.G., Coutinho, J.A.P., Marcilla, R. "Pioneering Use of Ionic Liquid-Based Aqueous Biphasic Systems as Membrane-Free Batteries". Advanced Science, **2018**, 1800576. DOI: 10.1002/advs.201800576. IF: 12.441 – D1(2018)
6. Navalpotro, P., Palma, J., Anderson, M., Marcilla, R. "A Membrane-Free Redox Flow Battery with Two Immiscible Redox Electrolytes". Angewandte Chemie - International Edition, **2017**, 56, 12460-12465. DOI: 10.1002/anie.201704318. IF: 12.102 – D1(2017)
7. García-Quismondo, E., Santos, C., Soria, J., Palma, J., Anderson, M.A. "New Operational Modes to Increase Energy Efficiency in Capacitive Deionization Systems". Environmental Science and Technology, **2016**, 50, 6053-6060. DOI: 10.1021/acs.est.5b05379. IF: 6.198 – Q1(2016)

C.2. Proyectos (selección)

1. Title/Acronym: A Hybrid Reactor for Solar CO2 and N2 Conversion Coupled to WasteWater Treatment / HYSOLCHEM. Partners: IMDEA Energía (Coord.), Universidad Rey Juan Carlos, Catholieke Universiteit Leuven, Innova Srl, Amer-Sil SA, Diamond Light Source Limited, Apria Systems SL. Funding Institution/Program: H2020-FETPROACT-EIC-07-2020. Period: 2021-2023. IMDEA Energy external funding: 324.380 €. Role: PI
2. Title/Acronym: Multi-Electron Processes for Light Driven Electrodes and Electrolytes in Conversion and Storage of Solar Energy / LIGHT-CAP. Partners: Fondazione Istituto Italiano di Tecnologia, Ecole Polytechnique Federale de Lausanne, Technische Universitaet Dresden, Justus-Liebig-Universitaet Giessen, Politecnico di Milano, IMDEA

Energía. Funding Institution/Program: H2020-FETPROACT-EIC-07-2020. Period: 2021-2023. IMDEA Energy external funding: 402.190 €. Role: Participant

3. Title/Acronym: GHz nanoscale electrical and dielectric measurements of the solid-electrolyte interphase and applications in the battery manufacturing line /NANOBAT. Partners: Keysight Technologies (Coordinador); Austrian Institute of Technology; Centro Ricerche Fiat; EURICE – European Research and Project Office; Federal Institute of Metrology METAS; IMDEA Energy; Johannes Kepler University Linz; Kreisel Electric GmbH & Co KG; Pleione Energy; QWED; Ruhr-Universität Bochum; Technische Universität Braunschweig. Funding Institution/Program: H2020-DT-NMBP-08-2019, Grant agreement No.861962. Period: 2020-2023. IMDEA Energy external funding: 190.000 €. Role: PI
4. Title/Acronym: Hybridization of geothermal energy and flow batteries for heating and cooling of zero-energy tertiary buildings/ GEOBATT. Partners: SACYR (Coordinator); Energy Storage Systems; Polytechnic University of Madrid; Carlos III University of Madrid; IMDEA Energy. Funding Institution/Program: Ministry of Science, Innovation and Universities/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2017. Period: 2018-2021. IMDEA Energy external funding: 255.476 €. Role: PI
5. Title/Acronym: Capacitive Deionization of Brines Coming from Brackish Water Reverse Osmosis Plants/ DC-SÓIAS. Partners: GS-INIMA (Coordinator); PROINGESA; IMDEA Energy. Funding Institution/Program: Ministry of Economy and Competitiveness/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2015. Period: 2015-2018. IMDEA Energy external funding: 162.480 €. Role: PI
6. Title/Acronym: Innovative Storage for Stationary Applications Based on Aluminum/ ALIENA. Partners: Albufera Energy Storage (Coordinator); ALEASTUR; GFM; ITMA; IMDEA Energy. Funding Institution/Program: Ministry of Economy and Competitiveness/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2015. Period: 2015-2018. IMDEA Energy external funding: 128.538 €. Role: PI
7. Title/Acronym: Fundamental properties and application of graphene and other 2D materials/ MAD2D. Partners: ICMM-CSIC (Coordinator); IMDEA Energy; IMDEA Nanoscience; IMDEA Materials; Autonoma University of Madrid. Period: 2014-2018. Funding Institution/Program: Comunidad de Madrid/ Program of R&D activities between research groups in Technology. IMDEA Energy external funding: 140.373 €. Role: PI

C.3. Contratos, méritos tecnológicos o de transferencia (selección)

1. Title/Acronym: Investigación de nuevos electrolitos orgánicos con hidroxi-derivados de fenacina / Hidroxi-FEBAT. Company: Bachman Aceleradora AIE (Spain). Period: 2020.
2. Title/Acronym: Testing of batteries for wireless surveillance devices/ BAMOWI. Company: Securitas Direct (Spain). Period: 2019-2021.
3. Title/Acronym: Development of an organic flow battery based on redox pairs for electric vehicles and stationary storage/ BAFO. Company: E22 and REPSOL. Period: 2016-2019.
4. Title/Acronym: Research in electrochemical energy storage technologies/ITAE Company: Inversiones Financieras Perseo (Spain). Period: 2016-2017
5. Title/Acronym: Energy storage with flow batteries in photovoltaic plants Company: Ingenia Solar Energy (Spain). Period: 2015-2017.
6. Title/Acronym: Development of cathode materials for primary zinc air batteries Company: CEGASA Portable Energy (Spain). Period: 2015-2016
7. Title/Acronym: Development of new structural materials for energy harvesting and storage/DESMAN. BE Aerospace (Germany). Period: 2014-2017

C.4. Patentes

1. Application number: EP20382772.0, Title: "Recyclable Electrode". Date of application: 31/08/2020. Holders: IMDEA Energy Foundation. Inventors: Lado, J.; Ventosa, E.; Pérez, D.; García-Quismondo, E.; Palma, J.

2. Application number: EP20382311.7 "Redox Flow Battery" Date of application: 17/05/2020. Holders: IMDEA Energy Foundation. Inventors: I. Montes, R. Marcilla, J. Palma, E. Ventosa, M. Vera, M. Sánchez Sanz.
3. Application number: EP19382473, Title: "An Alkaline Flow Battery Assembly". Date of application: 09/06/2019. Holders: Energy Storage Solutions, S.L. Inventors: Ventosa, E.; Perez, D.; García, G.; Palma, J.
4. Application number: EP18382971, Title: "Redox flow battery for energy storage". Date of application: 21/12/2018. Holders: IMDEA Energy Foundation. Inventors: Ventosa, E.; Paez, T.; Palma, J.
5. Application number: P201730828, Title: "Carbon Nanotube Fibers for Capacitive Deionization". Date of application: 22/06/2017. Holders: IMDEA Materials Foundation, IMDEA Energy Foundation. Inventors: Vilatela, J.J.; Cabana, L.; Santos, C.; Garcia-Quismondo, E.; Palma, J.
6. Application number: PCT/ES2018/070015, Title: "Multifunctional composite Material". Date of application: 10/01/2017. Holders: IMDEA Materials Foundation, IMDEA Energy Foundation. Inventors: Vilatela, J.J.; Senokos, E.; Marcilla, R.; Palma, J.
7. Application number: P201630327, Title: "Redox Battery with immiscible electrolytes". Date of application: 21/03/2016. Holders: IMDEA Energy Foundation. Inventors: Navalpotro, P.; Anderson; M.A.; Palma, J.; Marcilla, R.
8. Application number: PCT/EP2015/071267, Title: "Composite Comprising CNT Fibres and an Ionic Conducting Compound as Part of an Energy Storage Device". Date of application: 16/09/2015. Holders: B/E AEROSPACE SYSTEMS GmbH, IMDEA Materials Foundation and IMDEA Energy Foundation. Inventors: Vilatela, J.J.; Marcilla, R.; Palma, J.; Senokos, E.; Degenhard, D.; Ashraf, S.

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

CURRICULUM VITAE (maximum 4 pages)

Part A. PERSONAL INFORMATION

CV date	04/02/2021

First and Family name	Enrique García – Quismondo Hernáiz			
Social Security, Passport, ID number	50864552-Y		Age	41
Researcher numbers		Researcher ID	15060932400	
		Orcid code	0000-0002-7939-9573	

A.1. Current position

Name of University/Institution	IMDEA Energy		
Department	Electrochemical Processes Unit		
Address and Country	Ave. Ramón de la Sagra 3 Mostoles Technology Park E28935 – Mostoles (Madrid) SPAIN		
Phone number	91 737 1132	E-mail: enrique.garcia@imdea.org	
Current position	Senior Assistant Researcher	From	13/02/2018
Espec. cód. UNESCO	330309/330418		
Palabras clave	Electrochemistry, Electrochemical engineering, energy storage, energy conversion		

A.2. Education

PhD	University	Year
Degree in Chemistry	Autonomous University of Madrid (Spain)	2002
PhD in Chemistry	Autonomous University of Madrid (Spain)	2010

A.3. JCR articles, h Index, thesis supervised...

Number of periods of 6 years on research work: Not valid
Number of doctoral theses supervised in the last 10 years: 2
Total citations: 134 (WoS) without auto citations
Average of citations per year in the last 6 years (2014-2020) (not including the current year): 23.3 (WoS)
Total number of publications in the last 6 years: 10 (JCR indexed)
Publications in the first quartile in the last 6 years: 9 (JCR indexed)
h-index: 8 (WoS)

Part B. CV SUMMARY *(max. 3500 characters, including spaces)*

Enrique García – Quismondo is Senior Assistant Researcher at Imdea Energy, with a Ph.D. in Chemistry by Autonoma University of Madrid, his career has been developed in private companies working in the R&D Centre of the battery manufacturer Exide Technologies – Tudor (2003-2005) and in the R&D Laboratory of the engineering firm Tecnicas Reunidas (2006-2011) building up an extensive experience in managing electrochemical engineering projects for the development of energy storage systems.

In 2012 he joined the Electrochemical Processes Unit in Imdea Energy, during these years he has specialized in industry-driven research using new concepts generated in the laboratory for the development of advanced technologies and its transference to companies, having participated in more than 15 projects in the last 5 years. His experience with electrochemical devices development extends to cell, stack and system design, as well as construction and testing of emerging technologies, with special emphasis on energy storage systems such as advanced lead-acid batteries, lithium – ion batteries, redox flow batteries (aqueous and organic), metal – air batteries (zinc and aluminum) and on energy efficient water desalination processes as capacitive deionization.

The fact that he has worked both in private industry and in research organizations has provided him with extensive experience in R&D project management and in technology transfer to the private sector. Proof of this are the most relevant projects in which he has participated, that are the industrial scale-up of All-vanadium Redox Flow Battery technology in collaboration with the company PVH Storage, the adaptation of Capacitive Deionization technology for the brackish solutions treatment in partnership with the companies GS Inima and Proingesa, and the development of Organic Flow Batteries for ultra-fast recharge of electric vehicles in collaboration with the company Repsol, having contributed to the improvement of the employability rate of these companies.

Over his career in academia, his work has led to several scientific publications with a total number of citations in the last six years of 134 and an h index of 8 (by the Web of Science), and he has made numerous contributions to international conferences. He has supervised two Ph.D theses, five master thesis and several undergraduate students' projects, and he has been collaborator in various courses organized by the CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) (2015-2019).

During his career he has also spent periods as researcher at the Universities Polytechnic of Valencia (Spain), Wisconsin - Madison (USA) and New South Wales (Australia) as well as at the research center of the company GNB Industrial Power Exide Technologies (Portugal).

He has been awarded with Research in Energy and Environment grants from Iberdrola Foundation in 2013 and 2016.

Part C. RELEVANT MERITS

C.1. Publications (including books)

- Lado, J.J., Cartolano, V., García-Quismondo, E., García, G., Almonacid, I., Senatore, V., Naddeo, V., Palma, J., Anderson, M.A. "Performance analysis of a capacitive deionization stack for brackish water desalination". Desalination 2021, 501, 114912. Free Access. Q1
- Wang, Y.; Vázquez-Rodríguez, I.; Santos, C.; García-Quismondo, E.; Palma, J.; Anderson, M.A.; Lado, J.J. "Graphite felt 3D framework composites as an easy to scale capacitive deionization electrode for brackish water desalination". Chemical Engineering Journal, 2020, 392, 123698 IF=10.652. Q1
- Santos, C.; García-Quismondo, E.; Palma, J.; Anderson, M.A.; Lado, J.J. "Understanding capacitive deionization performance by comparing its electrical response with an electrochemical supercapacitor: Strategies to boost round-trip efficiency" Electrochimica Acta, 2020, 330, 135216. IF=6.215. Q1
- García-Quismondo, E.; Almonacid, I.; Cabañero Martínez, M.A.; Miroslavov, V.; Serrano, E.; Palma, J.; Alonso Salmerón, J.P. "Operational experience of 5 kW/5 kWh all-vanadium flow batteries in photovoltaic grid applications" Batteries, 2019, 5(3), 52. IF=2.93. Q1
- Santos, C.; Lado, J.; García-Quismondo, E.; Vázquez, I.; Hospital, D.; Vilatela, J.J.; Palma, J.; Anderson, M.A. "Interconnected metal oxide CNT fibre hybrid networks for current collector-free asymmetric capacitive deionization" Journal of Materials Chemistry A. 2018, 6, 10898-10908. IF= 9.931. Q1
- Santos, C.; Lado, J.; García-Quismondo, E.; Soria, J.; Palma, J.; Anderson, M.A. Maximizing Volumetric Removal Capacity in Capacitive Deionization by Adjusting Electrode Thickness and Charging Mode. Journal of the Electrochemical Society. 2018, 135, 294-302. IF=3.662. Q1
- Muñoz, D.; Leung, P.; García-Quismondo, E.; Ventosa, E.; Anderson, M.A.; Palma, J.; Marcilla, R. "Investigation of Different Anode Materials for Aluminium Rechargeable Batteries". Journal of Power Sources 374 (2018) 77–83. IF=6.945. Q1
- García-Quismondo, E.; Santos, C.; Soria, J.; Palma, J.; Anderson, M.A. "New Operational Modes to Increase Energy Efficiency in Capacitive Deionization Systems". Environmental Science & Technology. 2016, 50 (11), pp 6053–606. IF=5.393. Q1

- Leung, P.; Palma, J.; García-Quismondo, E.; Sanz, L.; Mohamed, M.R.; Anderson, M.A. "Evaluation of Electrode Materials for All-Copper Hybrid Flow Batteries". Journal of Power Sources, 2016, 310, 1–11. IF=6.333. Q1
- García-Quismondo, E.; Santos, C.; Palma, J.; Anderson, M.A. "On the challenge of developing wastewater treatment processes: capacitive deionization". Desalination and Water Treatment, 2016, 57, 2315-2324. IF=1.272. Q2

C.2. Research projects and grants

Title/Acronym: GHz nanoscale electrical and dielectric measurements of the solid- electrolyte interphase and applications in the battery manufacturing line /NANOBAT. Partners: Keysight Technologies (Coordinador); Austrian Institute of Technology; Centro Ricerche Fiat; EURICE – European Research and Project Office; Federal Institute of Metrology METAS; IMDEA Energy; Johannes Kepler University Linz; Kreisel Electric GmbH & Co KG; Pleione Energy; QWED; Ruhr-Universität Bochum; Technische Universität Braunschweig. Funding Institution/Program: H2020-DT-NMBP-08-2019, Grant agreement No.861962. Period: 2020-2023. IMDEA Energy external funding: 190.000 €.

Title/Acronym: Hybridization of geothermal energy and flow batteries for heating and cooling of zero-energy tertiary buildings/ GEOBATT. Partners: SACYR (Coordinator); Energy Storage Systems; Polytechnic University of Madrid; Carlos III University of Madrid; IMDEA Energy. Funding Institution/Program: Ministry of Science, Innovation and Universities/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2017. Period: 2018-2021. IMDEA Energy external funding: 255.476 €.

Title/Acronym: Capacitive Deionization of Brines Coming from Brackish Water Reverse Osmosis Plants/ DC-SÓIAS. Partners: GS-INIMA (Coordinator); PROINGESA; IMDEA Energy. Funding Institution/Program: Ministry of Economy and Competitiveness/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2015. Period: 2015-2018. IMDEA Energy external funding: 162.480 €.

Title/Acronym: Innovative Storage for Stationary Applications Based on Aluminum/ ALIENA. Partners: Albufera Energy Storage (Coordinator); ALEASTUR; GFM; ITMA; IMDEA Energy. Funding Institution/Program: Ministry of Economy and Competitiveness/ State Program of Research, Development and Innovation Oriented Challenges of the Society. Collaboration Challenges 2015. Period: 2015-2018. IMDEA Energy external funding: 128.538 €.

Title/Acronym: Fundamental properties and application of graphene and other 2D materials/ MAD2D. Partners: ICMM-CSIC (Coordinator); IMDEA Energy; IMDEA Nanoscience; IMDEA Materials; Autonoma University of Madrid. Period: 2014-2018. Funding Institution/Program: Comunidad de Madrid/ Program of R&D activities between research groups in Technology. IMDEA Energy external funding: 140.373 €.

C.3. Contracts

Title/Acronym: Investigación de nuevos electrolitos orgánicos con hidroxi-derivados de fenacina / Hidroxi-FEBAT. Company: Bachman Aceleradora AIE (Spain). Period: 2020.

Title/Acronym: Testing of batteries for wireless surveillance devices/ BAMOWI. Company: Securitas Direct (Spain). Period: 2019-2021.

Title/Acronym: Development of an organic flow battery based on redox pairs for electric vehicles and stationary storage/ BAFO. Company: E22 and REPSOL. Period: 2016-2019.

Title/Acronym: Research in electrochemical energy storage technologies/ITAE Company: Inversiones Financieras Perseo (Spain). Period: 2016-2017

Title/Acronym: Energy storage with flow batteries in photovoltaic plants Company: Ingenia Solar Energy (Spain). Period: 2015-2017.

Title/Acronym: Development of cathode materials for primary zinc air batteries Company: CEGASA Portable Energy (Spain). Period: 2015-2016

C.4. Patents

Application number: EP20382772.0, Title: “Recyclable Electrode”. Date of application: 31/08/2020. Holders: IMDEA Energy Foundation. Inventors: Lado, J.; Ventosa, E.; Pérez, D.; García-Quismondo, E.; Palma, J.

Application number: P201730828, Title: “Carbon Nanotube Fibers for Capacitive Deionization”. Date of application: 22/06/2017. Holders: IMDEA Materials Foundation, IMDEA Energy Foundation. Inventors: Vilatela, J.J.; Cabana, L.; Santos, C.; Garcia-Quismondo, E.; Palma, J.

C.5, C.6, C.7… (e. g., Institutional responsibilities, memberships of scientific societies…)

I am a Fellow of two professional societies: The Electrochemical Society and International Society of Electrochemistry

ANEXO II: Cuestionario sobre implicaciones éticas

Indicar si la propuesta del plan de investigación contempla alguno/s de los siguientes aspectos:

A: Investigación con seres humanos o uso de datos personales.................................... ☐ SI ☒ NO

B: La investigación implica contacto habitual con menores.. ☐ SI ☒ NO

C: Utilización de muestras biológicas humanas o información genética....................... ☐ SI ☒ NO

D: Experimentación animal.. ☐ SI ☒ NO

E: Utilización de agentes biológicos de riesgo para la salud humana, animal o para las plantas ☐ SI ☒ NO

F: Uso de organismos modificados genéticamente (OMGs).. ☐ SI ☒ NO

En caso de haber contestado afirmativamente a uno o más ítems, y <u>después</u> de que el Plan de Investigación haya sido evaluado por la Comisión Académica del Programa de Doctorado, el doctorando debe enviar copia de este anexo (junto con la documentación requerida) al Comité de Ética de la Investigación (CEI) de la UAM a la dirección de correo electrónico:

comite.eticainvestigacion@uam.es

Si el trabajo se hace dentro de un Proyecto de Investigación más amplio que cuenta con la aprobación de un Comité de Ética de la Investigación (CEI), especificar:

- Título del proyecto:
- Investigador Principal:
- Fecha y código de aprobación por el CEI-UAM[2]:

Si el trabajo de investigación <u>no</u> se enmarca en un Proyecto ya aprobado, se ha de enviar, junto al presente Anexo, el Plan de Investigación, que debe incluir las actividades a realizar, y especificar la metodología y el material –en su caso- que se va a utilizar.

Aparte del Plan de Investigación con sus anexos, se adjuntará la siguiente documentación:

- En el **supuesto A** , si la investigación es prospectiva, se deberá aportar el documento de **consentimiento informado** que se utilizará, donde conste la información detallada que recibirá el participante en el estudio. Si la investigación es retrospectiva se deberá establecer un **compromiso de confidencialidad** sobre los posibles datos identificativos de los participantes. En cualquier caso, se detallará si los datos o el material obtenido serán **anonimizados o codificados** y cómo se custodiarán. También deberá indicarse el**modo de reclutamiento** de los participantes. Si se trata de experimentación clínica se debe adjuntar el informe del Comité de Ética del Centro en el que se llevará a cabo la experimentación, señalando la extensión de esta autorización (usos restringidos al proyecto, o para otros usos relacionados).

---

[2] Que puede ser el CEI-UAM o, en su caso, el CEI de otra institución colaboradora con el Programa de Doctorado, que tendrá que especificarse y adjuntarse.

- En el **supuesto B,** se deberá adjuntar el documento del Registro Central de Delincuentes Sexuales. [3] En el caso de estudiantes extranjeros (incluidos los nacionales de Estados miembros de la Unión Europea), este certificado deberá ser complementado con certificado equivalente expedido por el país de su nacionalidad, pudiendo aceptarse la aportación por parte del interesado del resguardo de haber solicitado el certificado a las autoridades de su país junto con una declaración responsable [4]con carácter provisional hasta la aportación del certificado original.
- En el **supuesto C,** si la investigación es prospectiva, se deberá aportar el documento de **consentimiento informado** a utilizar donde conste la información detallada que recibirá el participante en el estudio. Si la investigación es retrospectiva deberá presentarse la autorización del uso de las muestras, que deberán tratarse de forma **anónima**, a menos que se justifique adecuadamente la necesidad del tratamiento de forma no anónima, en cuyo caso se necesitará **consentimiento informado y documento de confidencialidad**.
- En el **supuesto D,** se deberá adjuntar el Informe del Órgano Encargado del Bienestar de los Animales (OEBA) y, en su caso, del Órgano Habilitado.
- En el **supuesto E,** se debe adjuntar el informe del Comité de Bioseguridad o del Servicio de Prevención de Riesgos Laborales del Centro en el que se llevará a cabo la experimentación. Asimismo, se deberán enumerar los agentes biológicos a utilizar y describir las medidas de contención del laboratorio donde se van a realizar los trabajos.
- En el **supuesto F,** se debe adjuntar el informe del Comité de Bioseguridad o del Servicio de Prevención de Riesgos Laborales del Centro en el que se llevará a cabo la experimentación. Se debe declarar la categoría de riesgo de los OMGs empleados y su procedencia, así como los organismos receptores y donantes empleados y los vectores utilizados.

Datos necesarios para la tramitación por el CEI:

- Título de la Tesis:
- Doctorando:
- Teléfono del doctorando:
- Correo electrónico del doctorando:
- Programa de Doctorado en:
- Director:
- Tutor (si el Director es externo):

Firma Doctorando	Vº Bº Director	Vº Bº Tutor
	(y del Codirector en su caso)	(en su caso)

Fecha:
26/02/21

[3] http://www.mjusticia.gob.es/cs/Satellite/Portal/es/ciudadanos/tramites-gestiones-personales/certificado-delitos

[4] http://www.uam.es/otros/ceiuam/documentCEI.htm