Reviews on Advanced Materials and Technologies, 2026, vol. 8, no. 1, pp. 1–14
DOI: 10.17586/2687-0568-2026-8-1-1-14

A Review on Supercapacitors and Activated Carbon Electrodes: Synthesis, Activation Routes, and Characterization Methods

Shahin Reem [1], A.O. Rodin [1,2]

[1] Physical Chemisrty, National University of Science and Technology MISIS, Leninskiy pr. 4, Moscow, 119049, Russia
[2] Nanomaterials and Nanotechnology, Mendeleev University of Chemical Technology, Mi-usskaya pl., 9, Moscow, 125047, Russia

Received: January 19, 2026 Corresponding author: Shahin Reem

Abstract. Electrochemical supercapacitors are increasingly important for applications requiring high power density, rapid charge–discharge, and long cycle life. This review examines the fundamental charge-storage mechanisms of supercapacitors, with emphasis on electrochemical double-layer capacitance and pseudocapacitance, and discusses the role of core device components. Particular focus is placed on activated carbon electrodes, highlighting how precursor selection, activation route, pore structure, and surface chemistry govern electrochemical performance. Physical and chemical activation strategies are compared, and recent examples of biomass-derived activated carbons are summarized to illustrate structure–property–performance relationships. Standard physical and electrochemical characterization techniques used to evaluate supercapacitor electrodes are also reviewed. Finally, key challenges and future research directions are outlined, emphasizing the need for electrode–electrolyte co-optimization, scalable synthesis routes, and environmentally sustainable activation methods to enable high-performance supercapacitor technologies.

Acknowledgements. This study was conducted in the Department of Physical Chemistry at the National University of Science and Technology MISiS. The researchers extend their sincere thanks to the department and the university for providing the materials and equipment necessary to complete this work.

Citation: Rev. Adv. Mater. Technol., 2026, vol. 8, no. 1, pp. 1–14

View online: https://doi.org/10.17586/2687-0568-2026-8-1-1-14

View Table of Contents: https://reviewsamt.com/issues

REFERENCES

[1] A. ur Rehman, M.J. Sanjari, R.M. Elavarasan, T. Jamal. Sustainability-aligned pathways for energy transition: A review of low-carbon energy network solutions. *Renew. Sustain. Energy Rev.*, 2026, vol. 226, art. no. 116428.

[2] J. Libich, M. Sedlaříková, J. Máca, P. Čudek, T. Kazda, G. Fafilek, J.J. Santana-Rodriguez. Supercapacitors vs. Lithium-ion Batteries: Properties and Applications. *Chem. Ing. Tech.*, 2024, vol. 96, no. 3, pp. 279–285.

[3] P. Phogat, S. Sharma, R. Jha, S. Singh. Electrochemical Capacitors: EDLCs and Pseudocapacitors. In: P. Phogat, S. Sharma, R. Jha, S. Singh *Electrochemical Devices: Principles to Applications*. Engineering Materials. Springer, Singapore, 2024, pp. 225–255.

[4] L. Pandey, S. Sarkar, A. Arya, A.L. Sharma, A. Panwar, R.K. Kotnala, A. Gaur. Fabrication of activated carbon electrodes derived from peanut shell for high-performance supercapacitors. *Biomass Conv. Bioref.*, 2023, vol. 13, pp. 6737–6746.

[5] M. Bora, J. Tamuly, S.M. Benoy, S. Hazarika, D. Bhattacharjya, B.K. Saikia. Highly scalable and environment-friendly conversion of low-grade coal to activated carbon for use as electrode material in symmetric supercapacitor. *Fuel*, 2022, vol. 329, art. no. 125385.

[6] R. Dhilip Kumar, S. Nagarani, V. Sethuraman, Swetha Andra, V. Dhinakaran. Investigations of conducting polymers, carbon materials, oxide and sulfide materials for supercapacitor applications: a review. *Chem. Pap.*, 2022, vol. 76, pp. 3371–3385.

[7] Q. Bao, M. Zhang, J. Li, X. Wang, M. Zhu, G. Sun. The optimal micro- and meso-pores oriented development of Eucommia ulmoides Oliver wood derived activated carbons for capacitive performance. *Renew. Energy*, 2024, vol. 225, art. no. 120209.

[8] A. Tundwal, H. Kumar, B.J. Binoj, R. Sharma, G. Kumar, R. Kumari, A. Dhayal, A. Yadav, D. Singh, P. Kumar. Developments in conducting polymer-, metal oxide-, and carbon nanotube-based composite electrode materials for supercapacitors: a review. *RSC Adv.*, 2024, vol. 14, pp. 9406–9439.

[9] V. Thirumal, R. Yuvakkumar, G. Ravi, G. Dineshkumar, M. Ganesan, S.H. Alotaibi, D. Velauthapillai. Characterization of activated biomass carbon from tea leaf for supercapacitor applications. *Chemosphere*, 2022, vol. 291, part 2, art. no. 132931.

[10] F. Béguin, V. Presser, A. Balducci, E. Frackowiak. Carbons and Electrolytes for Advanced Supercapacitors. *Adv. Mater.*, 2014, vol. 26, no. 14, pp. 2219–2251.

[11] A. Azaizia, M.V. Dorogov. Synthesis of Si/G Composite Anodes for Lithium Ion Batteries: A Review. *Rev. Adv. Mater. Technol.*, 2024, vol. 6, no. 4, pp. 194–213.

[12] M.E. Şahin, F. Blaabjerg, A. Sangwongwanich. A Comprehensive Review on Supercapacitor Applications and Developments. *Energies*, 2022, vol. 15, no. 3, art. no. 674.

[13] J. Sun, B. Luo, H. Li. A Review on the Conventional Capacitors, Supercapacitors, and Emerging Hybrid Ion Capacitors: Past, Present, and Future. *Adv. Energy Sustain. Res.*, 2022, vol. 3, no. 6, art. no. 2100191.

[14] W. Jiang, J. Wang, R. Guo, J. Wang, J. Song, K. Wang. Electrode Materials and Prediction of Cycle Stability and Remaining Service Life of Supercapacitors. *Coatings*, 2026, vol. 16, no. 1, art. no. 41.

[15] B. Chand, P. Phogat, Shreya, C. Ravi Kant. Materials and mechanisms in electrochemical double layer capacitors: bridging high power with energy storage efficiency. *Mater. Sci. Eng. B*, 2026, vol. 324, part A, art. no. 118985.

[16] J.-H. Kim, Y.-J. Kim, S.-C. Kang, H.-M. Lee, B.-J. Kim. Preparation and Characterization of Asphalt Pitch-Derived Activated Carbons with Enhanced Electrochemical Performance as EDLC Electrode Materials. *Minerals*, 2023, vol. 13, art. no. 802.

[17] M.S. Sayed, D. Aman, M.G. Fayed, M.M. Omran, T. Zaki, S.G. Mohamed. Unravelling the role of pore structure of biomass derived porous carbon in charge storage mechanisms for supercapacitors. *RSC Adv.*, 2024, vol. 14, pp. 24631–24642.
[18] J. Lu, J. Zhang, X. Wang, J. Zhang, Z. Tian, E. Zhu, L. Yang, X. Guan, H. Ren, J. Wu. A review of advanced electrolytes for supercapacitors. *J. Energy Storage*, 2024, vol. 103, part B, art. no. 114338.
[19] S. Ahankari, D. Lasrado, R. Subramaniam. Advances in materials and fabrication of separators in supercapacitors. *Mater. Adv.*, 2022, vol. 3, pp. 1472–1496.
[20] A. Abdisattar, M. Yeleuov, C. Daulbayev, K. Askaruly, A. Tolynbekov, A. Taurbekov, N. Prikhodko. Recent advances and challenges of current collectors for supercapacitors. *Electrochem. Commun.*, 2022, vol. 142, art. no. 107373.
[21] M. Ibrahim, M. Souleiman, A. Salloum. Methylene blue dye adsorption onto activated carbon developed from Calicotome villosa via H_3PO_4 activation. *Biomass Conv. Bioref.*, 2023, vol. 13, pp. 12763–12776.
[22] Q. Fan, P. Guo, D. Xu, C. Zhang, K. Wu, H. Huang, J. Xu, M. Huang, N. Hu, Z. Guan, F. Luo, D. Wang. Exceptional electrochemical properties of coconut shell carbon–phenolic resin composite for supercapacitors. *J. Energy Storage*, 2025, vol. 113, art. no. 115731.
[23] J. Kongtip, N. Kanjulkeat, T. Ninneit, N. Phanapadipong, N. Chaiammart, A. Eiad Ua, R. Munprom, G. Panomsuwan. Green synthesis of activated carbons from coconut coir dust via steam activation for supercapacitor electrode applications. *Chemistry*, 2025, vol. 7, no. 6, art. no. 184.
[24] R. Sharma, R. Yadav. Charge storage performance of porous activated carbon derived from bamboo stems for symmetric supercapacitor electrodes. *Energy Storage*, 2025, vol. 7, no. 4, art. no. 70178.
[25] K. Aruchamy, K. Dharmalingam, C.W. Lee, D. Mondal, N.S. Kotrappanavar. Creating ultrahigh surface area functional carbon from biomass for high performance supercapacitor and facile removal of emerging pollutants. *Chem. Eng. J.*, 2022, vol. 427, art. no. 131477.
[26] M. Vinayagam, R. Suresh Babu, A. Sivasamy, A.L.F. de Barros. Physical activation assisted porous activated carbon from Strychnos Potatorum shells for high performance symmetric supercapacitors. *Mater. Lett.*, 2024, vol. 371, art. no. 136961.
[27] I. Hamidah, R. Ramdhani, A. Wiyono, B. Mulyanti, R.E. Pawinanto, L. Hasanah, M. Diantoro, B. Yuliarto, J. Yunas, A. Rusydi. Biomass Based Supercapacitors Electrodes for Electrical Energy Storage Systems Activated Using Chemical Activation Method: A Literature Review and Bibliometric Analysis. *Indonesian Journal of Science and Technology*, 2023, vol. 8, no. 3, pp. 439–468.
[28] Y. Chen, Y. Yu, X. Zhang, C. Guo, C. Chen, S. Wang, D. Min. High performance supercapacitors assembled with hierarchical porous carbonized wood electrode prepared through self activation. *Ind. Crops Prod.*, 2022, vol. 181, art. no. 114802.
[29] Y. Zou, H. Wang, L. Xu, M. Dong, B. Shen, X. Wang, J. Yang. Synergistic effect of CO_2 and H_2O co activation of Zhundong coal at a low burn off rate on high performance supercapacitor. *J. Power Sources*, 2023, vol. 556, art. no. 232509.
[30] A. Taurbekov, A. Abdisattar, M. Atamanov, M. Yeleuov, C. Daulbayev, K. Askaruly, B. Kaidar, Z. Mansurov, J. Castro Gutierrez, A. Celzard, V. Fierro, T. Atamanova. Biomass Derived High Porous Carbon via CO_2 Activation for Supercapacitor Electrodes. *J. Compos. Sci.*, 2023, vol. 7, no. 10, art. no. 444.
[31] A. Ahmad, M.A. Gondal, M. Hassan, R. Iqbal, S. Ullah, A.S. Alzahrani, W.A. Memon, F. Mabood, S. Melhi. Preparation and Characterization of Physically Activated Carbon and Its Energetic Application for All Solid State Supercapacitors: A Case Study. *ACS Omega*, 2023, vol. 8, no. 24, pp. 21653–21663.
[32] R. Fan, B. Xue, P. Tian, X. Zhang, X. Yuan, H. Zhang. Sustainably transforming biomass into advanced carbon materials for solid state supercapacitors: a review. *Chem. Commun.*, 2024, vol. 60, pp. 14303–14317.

[33] Q. Qin, J. Wang, Z. Tang, Y. Jiang, L. Wang. Mesoporous activated carbon for supercapacitors derived from coconut fiber by combining H_3PO_4 assisted hydrothermal pretreatment with KOH activation. *Ind. Crops Prod.*, 2024, vol. 208, art. no. 117878.
[34] Y. Zhang, X. Xu, Q. Geng, Q. Li, X. Li, Y. Wang, Z. Tang, B. Gao, X. Zhang, P.K. Chu, K. Huo. Redefining the Roles of Alkali Activators for Porous Carbon. *Chem. Sci.*, 2025, vol. 16, no. 4, pp. 2034–2043.
[35] K. Liang, Y. Chen, S. Wang, D. Wang, W. Wang, S. Jia, N. Mitsuzaki, Z. Chen. Peanut shell waste derived porous carbon for high performance supercapacitors. *J. Energy Storage*, 2023, vol. 70, art. no. 107947.
[36] Y. Yuan, Y. Sun, C. Liu, L. Yang, C. Zhao. Influence of $KHCO_3$ Activation on Characteristics of Biomass Derived Carbons for Supercapacitor. *Coatings*, 2023, vol. 13, no. 7, art. no. 1236.
[37] Y. Tong, X. Liu, Q. Zhai, M. Liu, Y. Wu, J. Li. Recent progress on lignin derived electrode materials for supercapacitor applications. *J. Mater. Chem. A*, 2023, vol. 11, no. 3, pp. 1061–1082.
[38] K. Yang, X. Huang, Y. Zhang, P. Fu. Cellulose based activated carbon aerogels as electrode materials for high capacitance performance supercapacitors. *New J. Chem.*, 2025, vol. 49, pp. 223–233.
[39] T. Qiu, W. Cao, K. Xie, F. Ahmad, W. Zhao, E. Mostafa, Y. Zhang. CO_2 capture performances of H_3PO_4/KOH activated microwave pyrolyzed porous biochar. *Sustain. Carbon Mater.*, 2025, vol. 1, art. no. e004.
[40] D.A. Bograchev, Y.M. Volfkovich, S. Martemianov. Diagnostics of supercapacitors using cyclic voltammetry: Modeling and experimental applications. *J. Electroanal. Chem.*, 2023, vol. 935, art. no. 117322.
[41] J.-H. Bang, B.-H. Lee, Y.-C. Choi, H.-M. Lee, B.-J. Kim. A Study on Superior Mesoporous Activated Carbons for Ultra Power Density Supercapacitor from Biomass Precursors. *Int. J. Mol. Sci.*, 2022, vol. 23, no. 15, art. no. 8537.
[42] P. Pascariu, M. Homocianu, L. Vacareanu, M. Asandulesa. Multi-Functional Materials Based on Cu-Doped TiO_2 Ceramic Fibers with Enhanced Pseudocapacitive Performances and Their Dielectric Characteristics. *Polymers*, 2022, vol. 14, no. 21, art. no. 4739.
[43] Y. Zhang, X. Li, Z. Li, F. Yang. Evaluation of electrochemical performance of supercapacitors from equivalent circuits through cyclic voltammetry and galvanostatic charge/discharge. *J. Energy Storage*, 2024, art. no. 111122.
[44] K. Panchal, K. Bhakar, K.S. Sharma, D. Kumar, S. Prasad. Review on electrochemical impedance spectroscopy: a technique applied to hollow structured materials for supercapacitor and sensing applications. *Applied Spectroscopy Reviews*, 2025, vol. 60, no. 1, pp. 30–55.