Electronic Supplementary Material (ESI) for Green Chemistry.

Supporting Information

Table S1. Performance comparison of rechargeable batteries employed with lignin-derived materials.

Types of rechargeable batteries	Served component in batteries	Employed lignin	Pivotal adopted strategies	ICE (%)	Capacity retention (%)	Rate capability	Ref.
LIB	porous carbon as anode active materials	steam explosion alkaline lignin	KOH activation	41.6 (200 mA g^{-1})	60.0 (400 cycles, 200 mA g^{-1})	1000 mA g^{-1}, 268 mAh g^{-1}	1
		enzymatic hydrolysis lignin	$ZnCO_3$ activation	54.9 (200 mA g^{-1})	99.0 (10000 cycles, -)	1000 mA g^{-1}, 423 mAh g^{-1}	2
		sodium lignosulfonate	pre-oxidation treatment	44.3 (50 mA g^{-1})	60.0 (400 cycles, 500 mA g^{-1})	5000 mA g^{-1}, 32 mAh g^{-1}	3
		enzymatic hydrolysis lignin	K_2CO_3 activation at 900℃	37.0 (200 mA g^{-1})	78.9 (200 cycles, 200 mA g^{-1})	1000 mA g^{-1}, 223 mAh g^{-1}	4
		sodium lignosulfonate	in situ polymerization of 2-ethylaniline	46.5 (60 mA g^{-1})	86.5 (20 cycles, 100 mA g^{-1})	-	5
		without details	synthesizing lignin-melamine resins	50.0 (100 mA g^{-1})	90.5 (300 cycles, 500 mA g^{-1})	5000 mA g^{-1}, 145 mAh g^{-1}	6
	carbon fibers as anode	organosolv (Alcell) lignin	fabricating lignin–polyethylene oxide, nitrogen doping	82.8 (30 mA g^{-1})	91.8 (50 cycles, 30 mA g^{-1})	2000 mA g^{-1}, 200 mAh g^{-1}	7
		with Alcel extraction process	blending of lignin and polylactic acid	-	-	10 C, 245 mAh g^{-1}	8
		water soluble alkali lignin	lignin/poly (vinyl alcohol) polymer blends, KOH activation	45.7 (10 mA g^{-1})	84.0 (900 cycles, 300 mA g^{-1})	1000 mA g^{-1}, 75 mAh g^{-1}	9

		extracted from black liquor	carbonization at different temperatures	-	94.0 (-, 0.1 C)	2 C, 88 mAh g^{-1}	10
		without details	embedding core–shell silicon/SiO_2	-	80.0 (40 cycles, 0.2 C)	0.2 C, 550 mAh g^{-1}	11
		alkali lignin	surface-functionalization with Fe_2O_3 nanoparticles	80.9 (50 mA g^{-1})	95.1 (80 cycles, 50 mA g^{-1})	200 mA g^{-1}, 430 mAh g^{-1}	12
	conductive framework of anode	lignosulfonate	in-situ synthesizing MoS2@porous carbon nanospheres	-	64.9 (50 cycles, 100 mA g^{-1})	-	13
		sodium lignosulfonate	in situ embedding NiO nanoparticles	84.9 (100 mA g^{-1})	95.8 (100 cycles, 100 mA g^{-1})	1000 mA g^{-1}, 548 mAh g^{-1}	14
		without details	forming functional conformal network crosslinking Si nano particles	62.0 (300 mA g^{-1})	89.0 (100 cycles, 300 mA g^{-1})	9000 mA g^{-1}, 800 mAh g^{-1}	15
	binder	kraft lignin	a low-temperature heat treatment of the silicon–lignin composite, PEO added	81.6 (100 mA g^{-1})	77.0 (100 cycles, 1000 mA g^{-1})	3600 mA g^{-1}, 1500 mAh g^{-1}	16
		kraft lignin	heat treatment of micro-nano SiO_x-lignin	61.0 (100 mA g^{-1})	-	1600 mA g^{-1}, 584 mAh g^{-1}	17
		kraft lignin	interconnected core-shell Si/C composite, PEO added	71.6 (540 mA g^{-1})	89.3 (100 cycles, 540 mA g^{-1})	1440 mA g^{-1}, 1133 mAh g^{-1}	18

		alkali lignin	lignin-*graft*-sodium polyacrylate	91.0 (-)	-	-	19
		without details	scavenging free radicals by lignin	-	91.4 (1000 cycles, 150 mA g^{-1})	1500mA g^{-1}, 97.2 mAh g^{-1}	20
SIB	porous carbon as anode active materials	concentrated strong acid hydrolysis lignin	carbonized at 1300°C	68.0 (50 mA g^{-1})	98.3 (500 cycles, 2500 mA g^{-1})	2500 mA g^{-1}, 116 mAh g^{-1}	21
		collected from a delignification apparatus	carbonized at 1300°C	69.0 (50 mA g^{-1})	99.9 (700 cycles, 300 mA g^{-1})	1000 mA g^{-1}, 49 mAh g^{-1}	22
		sodium lignin sulfonate	spray drying process	88.3 (0.1 C)	80.4% (200 cycles, 1 C)	2 C, 150 mAh g^{-1}	23
		collected from Shandong Longlive Bio-Technology Co., Ltd.	forming interpenetrating polymer networks	82.0 (30 mA g^{-1})	90.0% (150 cycles, 30 mA g^{-1})	600 mA g^{-1}, 106 mAh g^{-1}	24
		without details	emulsification interaction between pitch and lignin	82.0 (30 mA g^{-1})	89.0% (150 cycles, 30 mA g^{-1})	300 mA g^{-1}, 162 mAh g^{-1}	25
		alkali lignin	nitrogen-doped, hard-template method	20.0 (50 mA g^{-1})	92.0% (1100 cycles, 1000 mA g^{-1})	6400 mA g^{-1}, 48 mAh g^{-1}	26
	carbon fibers as anode	kraft lignin	well interacting between kraft lignin and cellulose acetate	52.0 (50 mA g^{-1})	-	500 mA g^{-1}, 143 mAh g^{-1}	27

		water soluble alkali lignin	lignin/poly (vinyl alcohol) polymer blends, KOH activation	65.0 (10 mA g^{-1})	-	500 mA g^{-1}, 60 mAh g^{-1}	9
		lignosulfonate	fabricating polyacrylonitrile/ lignin blend	70.5 (20 mA g^{-1})	90.2 (200 cycles, 100 mA g^{-1})	1000 mA g^{-1}, 80 mAh g^{-1}	28
		kraft lignin	carbonization at varying temperatures	89.0 (30 mA g^{-1})	94.0 (100 cycles, 100 mA g^{-1})	-	29
Li–S	conductive framework of cathode	without details	nitrogen-incorporated, KOH activation	-	50.0 (600 cycles, 0.1 C)	3.0 C, 208.3 mAh g^{-1}	30
		cellulose enzyme residual lignin	$NaHCO_3$ activation	-	92.0 (200 cycles, 0.5 C)	0.5 C, 1035 mAh g^{-1}	31
		alkaline lignin	one-step carbonization/activation method	-	64.8 (100 cycles, 0.5 C)	2.0 C, 460.6 mAh g^{-1}	32
	binder	lignosulfonate sodium salt	the negatively charged sulfonate functional group	-	66.7 (100 cycles, 0.2 C)	1.0 C, 710.0 mAh g^{-1}	33
	modification materials of separator	sodium lignosulfonate	negatively charged sulfonic groups	-	74.0 (1000 cycles, 2.0 C)	2.0 C, 707.0 mAh g^{-1}	34
		extracted with benzenesulfonic acid	chemically alleviation of polysulfides	-	65.2 (500 cycles, 1.0 C)	2.0 C, 377.0 mAh g^{-1}	35
Li–Se	conductive framework of cathode	commercial alkaline lignin	KOH activation	-	76.0 (300 cycles, 0.5 C)	4.0 C, 363.2 mAh g^{-1}	36
$Li–O_2$	conductive framework of cathode	alkaline lignin	KOH, H_3PO_4, or steam activation	-	-	0.2 mA g^{-1}, 1.6 mAh g^{-1}	37

Li–NCM811	carbon membrane as framework of Li anode	collected from Shandong Longlive Bio-Technology Co., Ltd.	surface ozonolysis	-	84.4 (135 cycles, 1.0 C)	-	38
Li–NCM333	separator	without details	lignin/polyvinyl alcohol blends	81.1 (0.1 C)	-	5.0 C, 33.4 mAh g^{-1}	39
Li–$LiFePO_4$	separator	without details	lignin/polyacrylonitrile composite	-	95.0 (50 cycles, 0.2 C)	8.0 C, 63.8 mAh g^{-1}	40
Li–NCM523	modification materials of separator	lignosulfonate	in situ reacts between lignosulfonate and Li metal	-	73.5 (100 cycles, 0.4 C)	2.0 C, 98.2 mAh g^{-1}	41
Li–$LiFePO_4$	electrolyte	without details	mixing lignin and poly(N-vinylimidazole)-co-poly(poly(ethylene glycol) methyl ether methacrylate	-	~99.0 (450 cycles, 1.0 C)	10.0 C, 110 mAh g^{-1}	42
Li–$LiFePO_4$	electrolyte	gran lignin fiber	forming uniform suspension	-	97.7 (50 cycles, 0.2 C)	1.5 C, 129 mAh g^{-1}	43
all-solid-state Li–$LiFePO_4$	electrolyte	organosolv lignin	chemical modification and atom transfer radical polymerization	-	99.2 (100 cycles, 1.0 C)	5.0 C, 120 mAh g^{-1}	44

ICE: initial Coulombic efficiency

LIB: lithium-ion battery

SIB: sodium-ion battery

In the table, the electrochemical performances of LIB and SIB are collected from provided half cells.

References:

1. W. Zhang, J. Yin, Z. Lin, H. Lin, H. Lu, Y. Wang and W. Huang, *Electrochim. Acta*, 2015, **176**, 1136–1142.
2. Y. Xi, S. Huang, D. Yang, X. Qiu, H. Su, C. Yi and Q. Li, *Green Chem.*, 2020, **22**, 4321–4330.
3. Y.-F. Du, G.-H. Sun, Y. Li, J.-Y. Cheng, J.-P. Chen, G. Song, Q.-Q. Kong, L.-J. Xie and C.-M. Chen, *Carbon*, 2021, **178**, 243–255.
4. Y. Xi, D. Yang, X. Qiu, H. Wang, J. Huang and Q. Li, *Ind. Crop. Prod.*, 2018, **124**, 747–754.
5. Z. W. He, Q. F. Lu and Q. Lin, *Bioresour. Technol.*, 2013, **127**, 66–71.
6. Z. Yang, H. Guo, F. Li, X. Li, Z. Wang, L. Cui and J. Wang, *J. Energy Chem.*, 2018, **27**, 1390–1396.
7. S. X. Wang, L. Yang, L. P. Stubbs, X. Li and C. He, *ACS Appl. Mater. Interfaces*, 2013, **5**, 12275–12282.
8. M. Culebras, H. Geaney, A. Beaucamp, P. Upadhyaya, E. Dalton, K. M. Ryan and M. N. Collins, *ChemSusChem*, 2019, **12**, 4516–4521.
9. E. Stojanovska, E. S. Pampal, A. Kilic, M. Quddus and Z. Candan, *Compos. Part. B-Eng.*, 2019, **158**, 239–248.
10. A. P. Nowak, J. Hagberg, S. Leijonmarck, H. Schweinebarth, D. Baker, A. Uhlin, P. Tomani and G. Lindbergh, *Holzforschung*, 2018, **72**, 81–90.
11. O. Rios, S. K. Martha, M. A. McGuire, W. Tenhaeff, K. More, C. Daniel and J. Nanda, *Energy Technol.*, 2014, **2**, 773–777.
12. X. Ma, A. L. Smirnova and H. Fong, *Mater. Sci. Eng. B-Adv.*, 2019, **241**, 100–104.
13. F. Chen, L. Wu, Z. Zhou, J. Ju, Z. Zhao, M. Zhong and T. Kuang, *Chin. Chem. Lett.*, 2019, **30**, 197–202.
14. Z. Zhou, F. Chen, T. Kuang, L. Chang, J. Yang, P. Fan, Z. Zhao and M. Zhong, *Electrochim. Acta*, 2018, **274**, 288–297.
15. X. Niu, J. Zhou, T. Qian, M. Wang and C. Yan, *Nanotechnology*, 2017, **28**, 405401.
16. T. Chen, Q. Zhang, J. Pan, J. Xu, Y. Liu, M. Al-Shroofy and Y. T. Cheng, *ACS Appl. Mater. Interfaces*, 2016, **8**, 32341–32348.
17. T. Chen, J. Hu, L. Zhang, J. Pan, Y. Liu and Y.-T. Cheng, *J. Power Sources*, 2017, **362**, 236–242.
18. T. Chen, Q. Zhang, J. Xu, J. Pan and Y.-T. Cheng, *RSC Adv.*, 2016, **6**, 29308–29313.
19. C. Luo, L. Du, W. Wu, H. Xu, G. Zhang, S. Li, C. Wang, Z. Lu and Y. Deng, *ACS Sustain. Chem. Eng.*, 2018, **6**, 12621–12629.
20. Y. Ma, K. Chen, J. Ma, G. Xu, S. Dong, B. Chen, J. Li, Z. Chen, X. Zhou and G. Cui, *Energ. Environ. Sci.*, 2019, **12**, 273–280.
21. D. Yoon, J. Hwang, W. Chang and J. Kim, *ACS Appl. Mater. Interfaces*, 2018, **10**, 569–581.

22. S. Alvin, D. Yoon, C. Chandra, H. S. Cahyadi, J.-H. Park, W. Chang, K. Y. Chung and J. Kim, *Carbon*, 2019, **145**, 67–81.

23. C. Li, Y. Sun, Q. Wu, X. Liang, C. Chen and H. Xiang, *Chem. Commun.*, 2020, **56**, 6078–6081.

24. H. Zhang, W. Zhang, H. Ming, J. Pang, H. Zhang, G. Cao and Y. Yang, *Chem. Eng. J.*, 2018, **341**, 280–288.

25. Y. Li, Y.-S. Hu, H. Li, L. Chen and X. Huang, *J. Mater. Chem. A*, 2016, **4**, 96–104.

26. L. Du, W. Wu, C. Luo, D. Xu, H. Guo, R. Wang, T. Zhang, J. Wang and Y. Deng, *J. Electrochem. Soc.*, 2019, **166**, A423–A428.

27. H. Jia, N. Sun, M. Dirican, Y. Li, C. Chen, P. Zhu, C. Yan, J. Zang, J. Guo, J. Tao, J. Wang, F. Tang and X. Zhang, *ACS Appl. Mater. Interfaces*, 2018, **10**, 44368–44375.

28. J. Jin, B.-j. Yu, Z.-q. Shi, C.-y. Wang and C.-b. Chong, *J. Power Sources*, 2014, **272**, 800–807.

29. K. Peuvot, O. Hosseinaei, P. Tomani, D. Zenkert and G. Lindbergh, *J. Electrochem. Soc.*, 2019, **166**, A1984–A1990.

30. J. S. Yeon, S. H. Park, J. Suk, H. Lee and H. S. Park, *Chem. Eng. J.*, 2020, **382**, 122946.

31. J. Xu, B. Liu, L. Wu, J. Hu, H. Hou and J. Yang, *Ind. Crop. Prod.*, 2019, **129**, 269–280.

32. F. Yu, Y. Li, M. Jia, T. Nan, H. Zhang, S. Zhao and Q. Shen, *J. Alloys Compd.*, 2017, **709**, 677–685.

33. J. Jeon, J.-K. Yoo, S. Yim, K. Jeon, G. H. Lee, J. H. Yun, D. K. Kim and Y. S. Jung, *ACS Sustain. Chem. Eng.*, 2019, **7**, 17580–17586.

34. T. Lei, W. Chen, W. Lv, J. Huang, J. Zhu, J. Chu, C. Yan, C. Wu, Y. Yan, W. He, J. Xiong, Y. Li, C. Yan, J. B. Goodenough and X. Duan, *Joule*, 2018, **2**, 2091–2104.

35. Z. Zhang, S. Yi, Y. Wei, H. Bian, R. Wang and Y. Min, *Polymers*, 2019, **11**, 1946.

36. H. Zhang, D. Jia, Z. Yang, F. Yu, Y. Su, D. Wang and Q. Shen, *Carbon*, 2017, **122**, 547–555.

37. G. Zhang, Y. Yao, T. Zhao, M. Wang and R. Chen, *ACS Appl. Mater. Interfaces*, 2020, **12**, 16521–16530.

38. L. Tao, Z. Xu, C. Kuai, X. Zheng, C. E. Wall, C. Jiang, A. R. Esker, Z. Zheng and F. Lin, *Energy Storage Mater.*, 2020, **24**, 129–137.

39. M.-J. Uddin, P. K. Alaboina, L. Zhang and S.-J. Cho, *Mater. Sci. Eng. B-Adv.*, 2017, **223**, 84–90.

40. M. Zhao, J. Wang, C. Chong, X. Yu, L. Wang and Z. Shi, *RSC Adv.*, 2015, **5**, 101115–101120.

41. J. Liu, R. Xu, C. Yan, H. Yuan, J.-F. Ding, Y. Xiao, T.-Q. Yuan and J.-Q. Huang, *Energy Storage Mater.*, 2020, **30**, 27–33.

42. S. Wang, L. Zhang, A. Wang, X. Liu, J. Chen, Z. Wang, Q. Zeng, H.-h. Zhou, X. Jiang and L. Zhang, *ACS Sustain. Chem. Eng.*, 2018, **6**, 14460–14469.

43. S.-D. Gong, Y. Huang, H.-J. Cao, Y.-H. Lin, Y. Li, S.-H. Tang, M.-S. Wang and X. Li, *J. Power Sources*, 2016, **307**, 624–633.

44. D. Jeong, J. Shim, H. Shin and J. C. Lee, *ChemSusChem*, 2020, **13**, 2642–2649.