

Showcasing collaborative research by the Jordanian CO<sub>2</sub> team (JCO<sub>2</sub>T), represented by A. K. Qaroush (The University of Jordan, Jordan), K. I. Assaf (Jacobs University Bremen, Germany) and A. F. Eftaiha (The Hashemite University, Jordan)

#### Inedible saccharides: a platform for CO<sub>2</sub> capturing

Abundant, cost-effective, inedible saccharides represent potential candidates that can be exploited as green sorbents for CO<sub>2</sub> capturing. The efforts of the scientific community on using a wide spectrum of saccharides including cyclodextrins, chitin, chitosan and cellulose to capture CO<sub>2</sub> through physi- and chemisorption via dry and wet scrubbing applications are highlighted. The usage of oligomers, functionalisation of polymers, passing of “supramolecular chemisorption” convention and introduction of a Green tax are also suggested to mitigate CO<sub>2</sub>.

#### As featured in:



See Abdussalam K. Qaroush, Khaleel I. Assaf, Ala'a F. Eftaiha *et al.*, *Chem. Sci.*, 2018, 9, 1088.



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Registered charity number: 207890



Cite this: *Chem. Sci.*, 2018, 9, 1088

## Inedible saccharides: a platform for CO<sub>2</sub> capturing

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The economic viability of eco-friendly and renewable materials promotes the development of an alternative technology for climate change mitigation. Investigations reported over the past few years have allowed understanding the mechanism of action for a wide spectrum of saccharides toward carbon dioxide (CO<sub>2</sub>), in terms of reactivity, reversibility, stability and uptake. Exploiting bio-renewables, *viz.*, inedible saccharides, to reduce the anthropogenic carbon footprint upon providing a sustainable and promising technology that is of interest to different groups of scientists, to overcome demerits associated with the current state-of-the-art aqueous amine scrubbing agents, following a "green chemistry guideline", by employing materials with properties relevant to the environment toward sustainable development. The interdisciplinary nature of research in this area provides a large body of literature that would meet the interest of the broad readership of different multidisciplinary fields. Although many reports emphasize the use of biomass in various industrial products ranging from pharmaceuticals, medical preparations, soaps, textiles, cosmetics, household cleaners, and so on, to our knowledge there is no focused article that addresses the application of saccharides for CO<sub>2</sub> sequestration. In this review, we highlight the recent advances on the use of oligo-, poly- and cyclic saccharides to achieve a reversible binding of CO<sub>2</sub>. The future research directions are discussed to provide insight toward achieving sustainable development through implementing bio-renewables.

Received 31st October 2017  
Accepted 25th December 2017

DOI: 10.1039/c7sc04706a

rsc.li/chemical-science

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## Introduction

The on-going rise of the anthropogenic greenhouse gas (GHG) footprint has a substantial impact on ecological systems,<sup>1-3</sup> particularly in the absence of stringent international policies for climate change mitigation. Although the ultimate goal of the intended nationally determined contributions, which are



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*CO<sub>2</sub> activation where he established the Jordanian CO<sub>2</sub> team (JCO<sub>2</sub>T). In 2017, Dr Qaroush started his tenure track at the University of Jordan, working on CO<sub>2</sub> mitigation (storage, utilisation, recycling) upon applying green technology, polymer chemistry, and organic synthesis.*

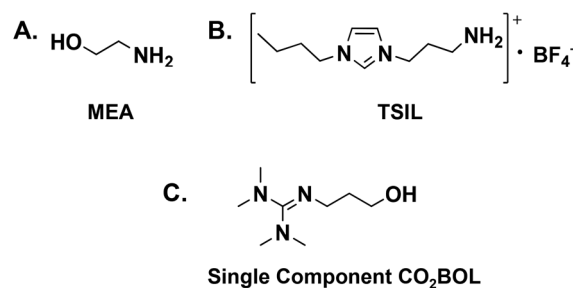


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adopted in the Paris agreement, is to maintain the average temperature of the globe at two degrees Celsius above that of the pre-industrial revolution era,<sup>4,5</sup> preliminary indicators demonstrate that advanced economies have failed to meet their commitments to depress GHG emissions,<sup>6</sup> which keeps the high concentration of CO<sub>2</sub> (the most dominant GHG) as one of the main environmental concerns that should be addressed worldwide through boosting carbon offset strategies<sup>7,8</sup> toward a concrete international climate policy for the benefit of future generations.<sup>9</sup>

One of the most efficient approaches for climate change mitigation is carbon capture and storage (CCS), which allows the reduction of CO<sub>2</sub> emissions while facing the sustained increase in the global energy demand.<sup>10–12</sup> The limitations associated with the state-of-the-art monoethanolamine (MEA, Scheme 1A) solvents such as corrosiveness, volatility and the energy penalty required for solvent regeneration, together with other related CCS based technologies, make implementing the principles of green chemistry,<sup>13–15</sup> which were introduced by Paul Anastas and John Warner, of particular importance to



Scheme 1 The chemical structures of (A) monoethanolamine (MEA); (B) 1-*n*-propylamine-3-butylimidazolium tetrafluoroborate, an example of TSIL prepared by the Jr Davis group;<sup>16</sup> and (C) 2-(3-hydroxypropyl)-1,1,3,3-tetramethylguanidine (a single component CO<sub>2</sub>BOL).<sup>17</sup>

design environmentally benign materials and innovative routes to ultimately achieve sustainable development by eliminating hazardous chemicals and energy consuming processes.



*Shrouq S. Alazzeah is a bachelor student at the University of Jordan who is interested in green and analytical chemistry. She is keen to participate in scientific events, conferences and workshops to improve her skills in order to help her continue in the advancement of her studies after graduating from her BSc degree. She always has the curiosity to discover unknown chemical reactions which motivated her to start improving her scientific skillfulness at a young age. Shrouq is looking forward to being a distinctive researcher.*



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*Ream H. Abeskchron was born and raised in Amman, Jordan. Currently, she is a third-year bachelor student at the University of Jordan. She has developed a passion for chemistry from a very young age, especially in exploring the mechanisms of chemical reactions. Now, she is a research fellow who is passionate to work with green chemistry. Ream is looking forward to getting her MSc and PhD degrees in organic chemistry.*



*Ala'a Eftaiha has been an assistant professor of physical chemistry at the Hashemite University, Jordan since 2014. He obtained his BSc and MSc in chemistry from the Hashemite University. Prior to doctoral studies, he was a researcher at the Jordanian Pharmaceutical Manufacturing Company. In 2013, Ala'a earned his PhD at the University of Saskatchewan under the supervision of Prof. Dr*

*Matthew F. Paige, and subsequently worked at Dalhousie University as an NSERC-DREAMS postdoctoral fellow. In 2016, he was a Fulbright visiting scholar at the University of California Santa Barbara. His research interests include CO<sub>2</sub> capturing, emerging photovoltaic technologies and surfactant monolayers.*

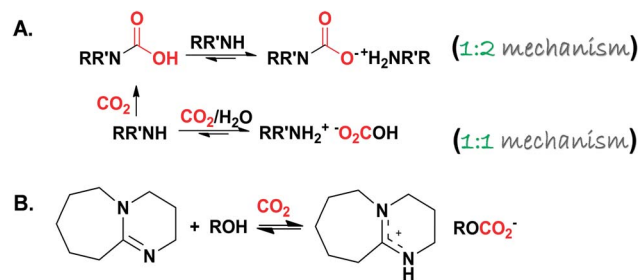


Following the seventh principle of green chemistry, our group established “renewables for renewables approach” which offers an eco-friendly platform to resolve environmental problems using renewable, inedible polymeric feedstocks for CO<sub>2</sub> capturing to promote future development benefiting from their environmental and economic impacts over petroleum-based feedstocks. Examples of renewable feedstocks include, but are not limited to, cellulose, cyclodextrin, chitin and chitosan (chemical structures are shown in Scheme 2).<sup>18–20</sup> A major inherent obstacle that hinders the use and processing of cellulose and chitin, despite their abundance in nature, is the limited solubility in common solvents,<sup>21,22</sup> which represents a significant technical challenge for both academic and sectors that demand the implementation of alternative greener strategies<sup>23,24</sup> other than those reported in the affiliated literature associated with dissolution and activation.<sup>25</sup>

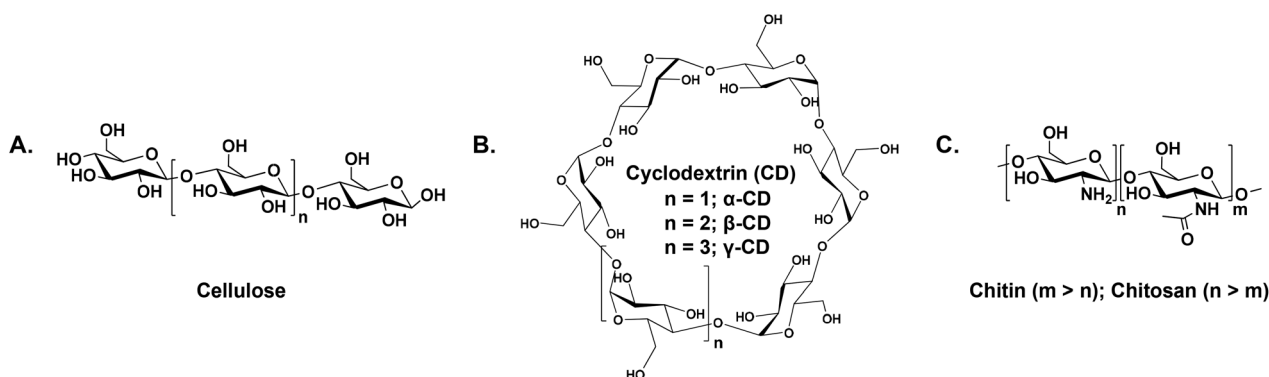
The fundamental aspects of liquid or solution based sorbents (typically utilised in the most mature capture technology) control the overall process in terms of sorption efficiency and kinetics together with regeneration.<sup>26</sup> It is expected that CO<sub>2</sub> is absorbed into the condensed phase in the low viscosity regimes, while it adsorbs at the surface of the sorbing material when the mass transfer is restricted to the bulk for high viscosity sorbents. Regarding the mechanism of action, when physical dissolution or physisorption is the prevailing mechanism, the uptake kinetics is expected to be slow and the desorption process is less energy demanding due to the weak, non-bonding interactive forces. If chemisorption is the dominant mechanism, the carbonation reaction is anticipated to be rapid and accompanied by a large energy requirement to regenerate the sequestered species. Chemisorption is accomplished *via* two different pathways: the first one is CO<sub>2</sub> capturing *via* “amine scrubbing” through the formation of carbamic acid/carbamate (RR'NH-CO<sub>2</sub><sup>-</sup> +NH<sub>2</sub>-RR') following a 1 : 1/1 : 2 reaction mechanism, respectively,<sup>27,28</sup> in which the nucleophilic attack over CO<sub>2</sub> by the amine nitrogen results in the formation of carbamic acid, which reacts with a second mole of amine (sacrificial base) to produce the carbamate salt. In the presence of water, a 1 : 1 reaction pathway takes place resulting in the formation of a bicarbonate (RR'NH<sub>2</sub><sup>+</sup> -O<sub>2</sub>COH)

zwitterionic adduct.<sup>29–31</sup> It is noteworthy that this pathway is followed when a benzylic amine (*o*, *m*, *p*-xylylenediamines) is used.<sup>32</sup> The proposed chemical reaction between amines and CO<sub>2</sub> is summarized in Scheme 3A. Similarly to conventional amine scrubbing agents, task-specific ionic liquids (TSILs and amine-functionalized ILs, Scheme 1B) form carbamate salts when exposed to CO<sub>2</sub>. Although TSILs have several merits over MEA aqueous solution in terms of lower CO<sub>2</sub> binding energies, milder regeneration conditions and higher capture capacities, they are not commercially available as MEA<sup>33</sup> (commercial sources of MEA (≥98%) list the retail price at \$25–\$40 per kilogram<sup>34,35</sup>). TSILs suffer from a huge increase in viscosity when loaded with CO<sub>2</sub> due to the hydrogen bonding (H-bonding) network between the carbamate and ammonium counterparts. This could be overcome by following different strategies such as incorporating an aprotic heterocyclic anion<sup>36</sup> or mixing TSILs with low-viscosity solvents<sup>37</sup> (more reviews regarding using TSILs for capturing CO<sub>2</sub> can be found elsewhere<sup>33,38</sup>).

The second pathway results in the formation of an inorganic or organic carbonate (M<sub>2</sub>(CO<sub>3</sub>)<sub>x</sub>, M<sup>+x</sup>: a metal cation, and ROCO<sub>2</sub><sup>-</sup>, respectively) following a 1 : 1 reaction mechanism. Aside from M<sub>2</sub>(CO<sub>3</sub>)<sub>x</sub>, the formation of ROCO<sub>2</sub><sup>-</sup> by activating alcohols to react with CO<sub>2</sub> was reported in the literature by two



Scheme 3 (A) Proposed chemisorption of CO<sub>2</sub> by amine based substrates (primary and secondary, the general formula is given for the secondary for clarification) through the formation of RR'N-CO<sub>2</sub><sup>-</sup> +NH<sub>2</sub>-R'R and RR'NH<sub>2</sub><sup>+</sup> -O<sub>2</sub>COH in the absence and presence of water, respectively. (B) The reversible reaction between an alcohol (ROH) and 1,8-diazabicyclo-[5.4.0]-undec-7-ene (DBU) in the presence of CO<sub>2</sub>.



Scheme 2 The chemical structures of (A) cellulose, (B) cyclodextrins, and (C) chitin ( $m > n$ ) and chitosan ( $m < n$ ).







colour turned red which was attributed to the formation of carbonic acid throughout the framework, and returned back to yellow after the removal of CO<sub>2</sub>. It was noteworthy that the CP/MAS spectra of iso-structural CD-MOFs prepared from rubidium fluoride or potassium benzoate (rather than rubidium hydroxide as in the case of CD-MOF-2) revealed identical resonances at 158 ppm, which discard the importance of the hydroxide anion in facilitating chemisorption in comparison with weaker nucleophiles such as fluoride and benzoate anions.<sup>41</sup> The same conclusion was obtained from the substantial difference between the adsorption enthalpy on CD-MOF-2 at near-zero coverage and an analogous acid–base reaction that involved a significant concentration of free hydroxide anions (OH<sup>−</sup>), which suggested that the adsorption took place through the alcoholic functional groups, rather than the interstitial OH<sup>−</sup> (*vide infra*).<sup>42</sup> Adsorption isotherms indicated that chemisorption was the dominant mechanism between 0 and 25 °C with a sorption capacity of ~23 cm<sup>3</sup> CO<sub>2</sub> per g sorbent.<sup>41</sup>

Mechanistic insight into the adsorption of CO<sub>2</sub> on CD-MOF-2 was obtained using calorimetric measurements. The differential enthalpy of the carbonation reaction confirmed that the chemisorption followed two distinct patterns. Firstly, at near-zero coverage with a highly exothermic reaction (−113.5 kJ mol<sup>−1</sup> CO<sub>2</sub>) *via* the most reactive primary hydroxyl groups, followed by a milder reaction (−65.4 kJ mol<sup>−1</sup> CO<sub>2</sub>) through the less reactive primary and secondary hydroxyl groups at a surface coverage between 0.1 and 0.3. At a higher surface coverage (>0.4), physisorption is the dominant adsorption mechanism with a differential enthalpy of −40.1 kJ mol<sup>−1</sup> CO<sub>2</sub>.<sup>42</sup> In our consensus regarding the reaction reversibility, there was unsurprising inconsistency between the results obtained from the isothermal gas uptake and the calorimetric data. The former designated a reversible chemical fixation of CO<sub>2</sub>,<sup>41</sup> the difference between the enthalpy of adsorption at near-zero coverage and the subsequent adsorption cycles indicated an irreversible binding character between the most reactive primary hydroxyl groups and CO<sub>2</sub>, followed by a reversible binding on the less reactive hydroxyls together with the physisorbed CO<sub>2</sub>.<sup>42</sup> The carbonation reaction of CD-MOF-2 is shown in Fig. 2D.<sup>74</sup>

The challenge in synthesizing CD-MOFs with cations other than K<sup>+</sup>, Rb<sup>+</sup> and Cs<sup>+</sup>, is the inability to obtain porous, crystalline frameworks. Very recently, Patel *et al.*<sup>44</sup> demonstrated the partial substitution of K<sup>+</sup> with Li<sup>+</sup> through co-crystallizing KOH and LiOH with  $\gamma$ -CD. As shown in Table 1, the most stable Li/K-CD-MOF with the highest Li<sup>+</sup>:K<sup>+</sup> ratio (0.61:1.18) had a comparable Brunauer–Emmett–Teller (BET) surface area and a characteristic better sorption in comparison with those obtained for other iso-structural CD-MOFs.

The reversible chemisorption of CO<sub>2</sub> by CD-MOF-2 was utilised for the electrochemical sensing of CO<sub>2</sub>. Unexpectedly, it has been reported that CD-MOF-2 (either as a pristine powder or pellet<sup>76</sup>) displayed a ~550-fold decrease in ionic conductivity upon exposure to CO<sub>2</sub> for 5 minutes in the presence of MeOH or *n*-hexane, although carbonic acid is relatively more acidic than primary alcohols. This was attributed to the sealing of the  $\beta$ -

windows (small triangular-shape voids of diameter 4.2 Å, Fig. 3) of the [(Rb<sup>+</sup>)<sub>4</sub>( $\gamma$ -CD)]<sub>6</sub> cubic cages after the carbonation reaction, where the reactive primary hydroxyl groups are located, thus reducing the mass transfer of intermediate molecules. The sensor reusability was tested by measuring the change in conductivity of a CD-MOF-2 pellet following sequential CO<sub>2</sub>-sorption and desorption (by heating at ~80 °C for several cycles). It was noteworthy that the conductivity change was higher at low CO<sub>2</sub> concentration (less than 20% in the presence of N<sub>2</sub> gas).<sup>40</sup>

Aside from CD-MOFs, it has been reported that the inclusion complex of 1:1  $\beta$ -CD and aniline (CD–aniline) in association with residual water molecules inside the CD cavity, chemisorbed CO<sub>2</sub> with a sorption efficiency of 0.69 mmol of CO<sub>2</sub> per g sorbent through the formation of bicarbonate according to the following reaction: C<sub>6</sub>H<sub>5</sub>NH<sub>2</sub> + CO<sub>2</sub> + H<sub>2</sub>O  $\rightleftharpoons$  C<sub>6</sub>H<sub>5</sub>NH<sub>3</sub><sup>+</sup> HCO<sub>3</sub><sup>−</sup>. The sorption capacity was decreased by 37% when the sorbent was heated to 100 °C under vacuum, which emphasized the importance of the water molecules to the sequestration process.<sup>75</sup> Although the performance characteristics of the CD–aniline complex were much lower than the corresponding CD-MOFs, it sorbed 0.85 mol CO<sub>2</sub> per mol nitrogen (N) in comparison with the amine efficiency of 0.5 mol CO<sub>2</sub> per mol N following a 2:1 sorption mechanism under dry conditions, which was unlikely to take place in the case of the explored inclusion complex. Unlike CD-MOFs (*vide supra*), the sorption capacity of the amorphous CD–aniline complex (obtained upon grinding) was almost similar to the as-synthesised crystalline material.

Han and co-workers<sup>76</sup> reported the facile and elegant synthesis of CD-based microporous carbon (CDPC) using acid catalysed solvothermal carbonization at 180 °C. The obtained materials were regular spheres with diameters between 300 and 800 nm, BET surface areas ranging from 600 to 700 m<sup>2</sup> g<sup>−1</sup> and high content of oxygen-containing functional groups, such as carboxyl, carbonyl, and hydroxyl as inferred from FTIR and <sup>13</sup>C CP/MAS spectra. As shown in Table 1, the CO<sub>2</sub> gravimetric uptake of  $\alpha$ -,  $\beta$ - and  $\gamma$ -CDPC measured at 0 °C and 1.0 bar were between 2.8 and 3.5 mmol CO<sub>2</sub> per g sorbent. Similarly, it has been reported that grafting  $\beta$ -CD with sulfonic acid functional groups (−SO<sub>3</sub>H) led to the formation of a porous structure (CD–SO<sub>3</sub>H) with a low oxygen content due to dehydration, which was able to physisorb CO<sub>2</sub> 30 times more than  $\beta$ -CD at the same investigated conditions (1.2 of the former against 0.04 mmol CO<sub>2</sub> per g sorbent of  $\beta$ -CD) with high selectivity over O<sub>2</sub>, N<sub>2</sub> and CH<sub>4</sub>, which makes it a potential candidate for CO<sub>2</sub> separation from flue gas.<sup>77</sup>

Turning to wet scrubbing applications, the hydroxyl groups of the CD macrocycle should be activated to become susceptible to nucleophilic attack prior the exposure to CO<sub>2</sub>. It has been reported that a mixture of  $\beta$ -CD and an organic SB, namely DBU, was able to fix CO<sub>2</sub> chemically as an amidinium alkylcarbonate. Due to viscosity issues, the ratio (in equivalents) of  $\beta$ -CD:DBU was kept at 0.5:1 throughout the work. The carbonation reaction was followed by <sup>1</sup>H and <sup>13</sup>C NMR together with FTIR spectroscopy, following the peaks associated with the quaternary carbon of DBU. The relatively low uptake of CO<sub>2</sub> (1.8 wt%)







at 6.8 (correlated to the ammonium counterpart chemical shift) and 84.7 ppm. The CO<sub>2</sub> uptake of the CS·HCl/NaOH/DMSO solution was quantified volumetrically using an *in situ* ATR-FTIR autoclave. A 10% (w/v) solution chemisorbed 1.60 mmol CO<sub>2</sub> per g sorbent. Remarkably, the formation of the carbonate was four times that of the carbamate, with faster kinetics for the latter as inferred from the sorption profiles. To our knowledge, this was the first organic carbamate-carbonate bond formation.

One of the major concerns regarding the greenness of DMSO was answered by measuring the biodegradability of the explored system. Following the guidelines of the International Organization for Standardization (ISO), the relatively fast degradation of chitosan dissolved in DMSO (80% in 33 days) provided clear-cut evidence for the absence of any tangible negative impact of using DMSO on the biodegradation of chitosan.

### Cellulose-based functionalized sorbent materials

The main uses of cellulose as an abundant biopolymer that functions as a mechanical support and in sustainable porous carbon-based materials, as well as for the preparation of hollow fibres as in membranes for the capturing of CO<sub>2</sub>, are reported in this section.

In 2011, Steinfeld and co-workers<sup>91</sup> reported a novel, eco-friendly, benign synthesis for an amine-based nanofibrillated cellulose (NFC) sorbent applicable for CO<sub>2</sub> capture from air using *N*-(2-aminoethyl)-3-aminopropylmethyldimethoxysilane (AEAPDMS). At 25 °C and after 12 h, 1.39 mmol CO<sub>2</sub> per g sorbent was sorbed with a relative humidity of 40% and 506 ppm of CO<sub>2</sub> concentration in air. The studied material showed persistent stability over 20 consecutive 2-hour adsorption/1-hour desorption cycles. The cyclic capacity of the resultant cycles gave 0.695 mmol CO<sub>2</sub> per g sorbent. Once again, as an augmentation to Steinfeld's<sup>92</sup> early work on NFC, the stability of amine-tethered-NFC for CO<sub>2</sub> capturing from air (400–530 ppm) under temperature–vacuum swing (TVS) conditions was tested 100 times at 30 °C and 60% humidity for adsorption, followed by desorption at 90 °C and 30 mbar. The average adsorption capacity under the applied conditions was 0.90 mmol CO<sub>2</sub> per g sorbent. Due to the presence of O<sub>2</sub>, the sorbent degraded at 90 °C, reducing its adsorption capacity by 30% (after 15 h and dew point of 22 °C). On the other hand, if moist CO<sub>2</sub> was introduced to the sample at the same applied conditions, no tangible loss in CO<sub>2</sub> adsorption capacity was recorded. Sevilla and Fuertes<sup>93</sup> reported on the utilisation of sustainable porous carbon materials that were prepared using the chemical activation of hydrothermally carbonized starch, cellulose and sawdust (one type of biomass) and further tested for capturing purposes. The activation process was carried out under both severe and mild conditions (KOH/precursor = 4 and 2, respectively, within a set of temperatures in the range of 600–800 °C). Samples obtained under mild activating conditions showed smaller pore sizes and surface areas than those materials obtained under harsher conditions. However, they exhibited the best capacity to store CO<sub>2</sub> which is equivalent to 4.8 mmol g<sup>-1</sup> (at 25 °C with KOH/precursor = 2 and activated at 600 °C). According to the authors, this was the highest value for any activated carbon. The

prepared materials showed fast adsorption kinetics and easy regeneration with good CO<sub>2</sub>/N<sub>2</sub> selectivity measured under equilibrium conditions ~5.4. Pacheco *et al.*<sup>94</sup> reported on the modification of an aminosilane-functionalized cellulosic polymer sorbent by the anhydrous grafting of *N*-(2-aminoethyl)-3-aminoisobutyldimethylmethoxysilane. The sorption capacity under dry conditions (5 atm, 308 K) was 1.46 mmol per g sorbent with an amine loading of 5.18 mmol amine(nitrogen) per g sorbent. Working under humid conditions facilitated the uptake up to 12% at 1 atm. Moreover, Koros and co-workers<sup>95</sup> reported on the use of another type of cellulose acetate fibres that were aminated with (*N*-(2-aminoethyl)-3-aminoisobutyldimethylmethoxysilane). Using a pressure decay apparatus, the CO<sub>2</sub> sorption capacity was a bit low (0.73 mmol CO<sub>2</sub> per g sorbent at 1 atm).

Heo and Park<sup>96</sup> reported on the preparation of ultra-microporous carbons from cellulose fibres by means of physical activation at different temperatures. Using steam, the physical activation influenced the development of new micropores for CO<sub>2</sub> storage. The adsorption capacity for the synthesized materials was 3.776 mmol CO<sub>2</sub> per g sorbent at 298 K and 1 atm with a good CO<sub>2</sub>/N<sub>2</sub> selectivity of 47.1. The studied material was regenerated 10 times after repeated sorption/desorption cycles. Their work showed the importance of carbon materials with good adsorption abilities without the need for chemical activation. In 2016, Einloft and co-workers<sup>97</sup> reported on the use of rice-husk cellulose-supported ionic liquids for the capture of CO<sub>2</sub>. The uptake experiments were gravimetric with optimal values for cellulose-modified tetrabutylammonium (CL-TBA) of 44 and 71 mg CO<sub>2</sub> per g sorbent at 25 °C and 0.1 and 3 MPa, respectively.

Organoclays, once hybridized with cellulose nanofibers, might be a plausible solution for the incorporation and storage of gases. Such an idea was enhanced by the work of Shah and Imae<sup>98</sup> who reported on the utilisation of 2,2,6,6-tetramethylpiperidine-1-oxyl radical cellulose nanofibers (TOCNF) modified with anion and cation-exchange organoclays, *viz.* hydrotalcite, laponite and sericite. The order of the CO<sub>2</sub> storage ranked among the clays applied is as follows: laponite > sericite > hydrotalcite, with a maximum CO<sub>2</sub> uptake for the laponite-based hybrid material of 24 mg CO<sub>2</sub> per g TOCNF. Hu *et al.*<sup>99</sup> reported on another kind of hierarchical porous N-doped carbon from cellulose in an effective strategy to be utilised as a supercapacitor and in CO<sub>2</sub> capture applications (Fig. 5). The application of such a method emerged from the use of a dissolving-gelling process followed by carbonization in an NH<sub>3</sub> atmosphere, which enhanced the production of both macro- and micropores. The synthesized aerogels had a high adsorption capacity of 4.99 mmol CO<sub>2</sub> per g sorbent which was much higher than those in other porous carbon materials studies as reported accordingly.

ILs and cellulose acetate (CAct),<sup>100</sup> another type of biodegradable polymer as the parent macromolecule, were also exploited for the purposes of CO<sub>2</sub> capturing and separation. Zhang and co-workers<sup>101</sup> reported very recently on the introduction of an ether-functionalized pyridinium-based ionic liquid ([E<sub>n</sub>Py][NTf<sub>2</sub>]/CAct) which was fabricated into





A further recommendation is to find universal protocols to capture CO<sub>2</sub> in terms of gas uptake measuring conditions (volumetric vs. gravimetric), as this may hinder a fair comparison among sorbents.<sup>29</sup> Also, modification/functionalisation of the naturally-occurring polymers might provide better reactivities and performance characteristics.

## Conflicts of interest

There are no conflicts to declare.

## Acknowledgements

AFE acknowledges research support from the Deanship of Scientific Research at the Hashemite University, Jordan.

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