Here is the first paragraph of the text:

The development of economical, stable, and highly active electrocatalysts for the oxygen reduction reaction (ORR) to form water represents a major thrust in the research area of polymer-electrolyte-membrane fuel cells. However, one of the main challenges facing these low-temperature fuel cells is slow ORR kinetics at the cathode, even with the use of Pt-based catalysts. In addition, Pt-based catalysts can suffer from poor catalytic stability and subsequent loss of performance under general operating conditions as a result of their predisposition to dissolution, agglomeration, and sintering. In much of the published fuel cell research, the formation of hydrogen peroxide during the ORR is considered undesirable because it lowers efficiency and often affects the stability of the proton-exchange membrane. However, given that hydrogen peroxide is an important chemical, the ability of a fuel cell to both produce H₂O₂ and generate electricity would be a significant step toward sustainable chemistry and an attractive alternative to the current anthraquinone-based method of H₂O₂ production. This multistep, energy-intensive process requires sequential hydrogenation, oxidation of anthraquinone, and separation of large volumes of solvents, which makes for challenging on-site production. Therefore, the discovery and investigation of stable, earth-abundant ORR catalysts with good selectivity for H₂O₂ are highly valuable.

Several promising studies have focused on selective H₂O₂ production through the ORR by using noble metals and metal alloys, where tuning the relative binding strength of four-electron pathway intermediates and decreasing the propensity to break the O–O bond enables the selectivity to produce H₂O₂ instead of H₂O. Alternatively, carbon materials are particularly attractive because of their global abundance, low cost, high surface area, large pore volume, and good electrical conductivity. Carbon fibers and N-doped porous carbon have previously been found to be active for H₂O₂ production but still have significant room for improvement. The ability to tune the selectivity toward the two-electron or four-electron pathway is one of the main challenges facing these catalysts, because promotion of the ORR often occurs only at high overpotentials, where the production of H₂O is favored. CNHs have been widely explored in many applications because of their unique geometry and lack of metal impurities. Given that they can be generated from pure graphite rods, CNHs can be synthesized with high purity and yield. CNHs also offer significant tunability beyond high surface area and large pore volume because heat treatments can add defects to their walls, through which various molecules can be grafted to give excellent properties for numerous applications. Most of the work investigating CNHs has
Building upon the versatility of CNHs as supports, Prato and colleagues sought to produce an active metal-free CNH catalyst with a high degree of N-doping through the coating and annealing of polydopamine. The combination of the distinctive properties of the CNH support with a unique method of N-doping allowed the authors to combine several critical features—namely, high surface area and porosity, an optimal distribution of pyridinic and pyrrolic N-atoms, and improved conductivity and facilitation of electron transfer—into a single material. Also, the use of the PDA precursor instead of polypyrrole or polyaniline allowed the incorporation of both a higher Npyridinic/Npyrrolic ratio (1.13 for g-N-CNHS, 0.85 for CNHS@pyrr-700, and 0.61 for CNHS@PANI-700) and a higher overall N atomic percentage (5.56 for g-N-CNHS, 6.54 for CNHS@pyrr-700, and 6.73 for CNHS@PANI-700). As a result, Prato and colleagues achieved an electrocatalyst that is more selective than current metal-based electrocatalysts (Figure 1) and maintains high selectivity toward H$_2$O$_2$ over a wide range of pH values. For instance, they measured faradic efficiencies of 98% in pH 1 and 90% in pH 7.4 with working potentials of 0.3 and 0.65 V versus RHE, respectively. The authors attributed the high selectivity toward H$_2$O$_2$ under acidic conditions to the effective protonation of the pyridinic N, which reduces the catalytic center’s ability to break the O–O bond. Furthermore, the N-doped CNHSs exhibited long-term stability with a constant 33 mmol g$^{-1}$h$^{-1}$cm$^{-2}$ H$_2$O$_2$ production rate over a period of 24 hr at pH 1.

With a need for the design and development of industrially viable electrocatalysts for the ORR and continued demand for H$_2$O$_2$ worldwide, it is vital to explore novel synthetic routes to earth-abundant catalysts. Further exploration of synthetic techniques and the materials they yield will eventually lead to clean energy and sustainable chemical production. The work by Prato and colleagues is a clear example of how the rational manipulation of materials at the atomic level can lead to new earth-abundant catalysts with superb performance that matches, or even exceeds, that featured by precious-metal-based catalysts.