CONVERTING WASTE TOILET PAPER INTO ELECTRICITY

Waste toilet paper (WTP) is not often considered an asset. In fact, most people usually prefer not to think about it at all. Yet it is a rich source of carbon, containing 70-80 wt% of cellulose on a dry basis. On average, people in Western Europe produce 10-14 kg waste toilet paper per person per year. Accumulating in municipal sewage filters, it is a modest yet significant part of municipal waste.

At the same time, waste toilet paper is a businessman's dream because it is one of the few raw materials with a negative cost. While this may vary across countries and regions, in the Netherlands wastewater treatment facilities pay around 70 €/ton to get rid of WTP. It is therefore an extremely attractive resource since people will actually pay you to take it off their hands.

Being such 'true waste', WTP offers a great opportunity for closing loops, increasing resource efficiency and creating a truly circular economy. For the UvA's chemists, using WTP as a resource for generating electricity therefore 'the ultimate waste recycling concept'. The Amsterdam region alone generates some 10,000 tons of WTP per year, enough to power 6400 homes.

What's more, since the cellulose in WTP comes from trees, the electricity produced is renewable. This offers a great opportunity for matching society's demand for renewable energy. Renewable resources often show discontinuous peaks. Plant stems can be recycled, but only after the harvest; sunlight is available in the daytime (and depends on cloud cover); and wind supply is as predictable as the weather. Waste toilet paper, however, is a continually available resource.

The Amsterdam-Utrecht research project, led by UvA professors Gadi Rothenberg and Bob van de Zwaan of the UvA's Van 't Hoff Institute for Molecular Sciences, proposed a simple two-step process for the conversion of WTP, creating a direct route from unwanted waste to a useful product. Master's student Els van der Roest examined the possibility of combining devices for the   of WTP (step 1) with high-temperature solid oxide fuel cells (SOFCs) able to directly convert the WTP-gas into electricity.

The project's goal was to assess the feasibility of such a WTP-to-electricity system at a scale of 10,000 ton WTP per year, based on real-life parameter values. Using techno-economic analysis methods, the team presented a basic process design, an overall energy balance and an economic study for this concept. Data for the experiments and calculations were obtained in collaboration with the Amsterdam waste-to-energy company (afvalenergiebedrijf, AEB).

In an open-access paper published in the international peer-reviewed journal Energy Technology, the researchers present the basic system design, as well as its electricity yield and overall efficiency, based on detailed mass and energy balance calculations.

The overall electric efficiency is 57%, similar to that of a natural gas combined cycle plant. The levelized cost of electricity (LCOE, a measure used for consistent comparison of electricity generation methods) is 20.3¢/kWh. This is comparable at present to residential photovoltaic installations.

The system's capital costs are still relatively high, mainly due to the fuel cell investment costs. But these are expected to decrease as the market for fuel cells develops. The operating costs are relatively low, partly thanks to the high thermodynamic efficiency (ca. 70%). The researchers expect learning effects could make the system more competitive in future, with an LCOE of about 11 ¢/kWh.

The project team concludes that there is a future in turning waste toilet paper into electricity. 'When we discuss these results with companies, people get very excited', says Prof. Rothenberg. However, no Dutch company or municipal authority has as yet been willing to invest in further development. The team is now considering taking their concept abroad: 'We might see the first WTP-to-electricity plant being built in China', according to Rothenberg.

While the human race will always leave its carbon footprint on the Earth, it must continue to find ways to lessen the impact of its fossil fuel consumption.

"Carbon capture" technologies -- chemically trapping carbon dioxide before it is released into the atmosphere -- is one approach. In a recent study, Cornell University researchers disclose a novel method for capturing the greenhouse gas and converting it to a useful product -- while producing electrical energy.

Lynden Archer, the James A. Friend Family Distinguished Professor of Engineering, and doctoral student Wajdi Al Sadat have developed an oxygen-assisted aluminum/carbon dioxide power cell that uses electrochemical reactions to both sequester the carbon dioxide and produce electricity.

Their paper, "The O_2-assisted Al/CO_2 electrochemical cell: A system for CO_2 capture/conversion and electric power generation," was published July 20 in *Science Advances*.

The group's proposed cell would use aluminum as the anode and mixed streams of carbon dioxide and oxygen as the active ingredients of the cathode. The electrochemical reactions between the anode and the cathode would sequester the carbon dioxide into carbon-rich compounds while also producing electricity and a valuable oxalate as a byproduct.

In most current carbon-capture models, the carbon is captured in fluids or solids, which are then heated or depressurized to release the carbon dioxide. The concentrated gas must then be compressed and transported to industries able to reuse it, or sequestered underground. The findings in the study represent a possible paradigm shift, Archer said.

"The fact that we've designed a carbon capture technology that also generates electricity is, in and of itself, important," he said. "One of the roadblocks to adopting current carbon dioxide capture technology in electric power plants is that the regeneration of the fluids used for capturing carbon dioxide utilize as much as 25 percent of the energy output of the plant. This seriously limits commercial viability of such technology. Additionally, the captured carbon dioxide must be transported to sites where it can be sequestered or reused, which requires new infrastructure."

The group reported that their electrochemical cell generated 13 ampere hours per gram of porous carbon (as the cathode) at a discharge potential of around 1.4 volts. The energy produced by the cell is comparable to that produced by the highest energy-density battery systems.

Another key aspect of their findings, Archer says, is in the generation of superoxide intermediates, which are formed when the dioxide is reduced at the cathode. The superoxide reacts with the normally inert carbon dioxide, forming a carbon-carbon oxalate that is widely used in many industries, including pharmaceutical, fiber and metal smelting.

"A process able to convert carbon dioxide into a more reactive molecule such as an oxalate that contains two carbons opens up a cascade of reaction processes that can be used to synthesize a variety of products," Archer said, noting that the configuration of the electrochemical cell will be dependent on the product one chooses to make from the oxalate.

Al Sadat, who worked on onboard carbon capture vehicles at Saudi Aramco, said this technology in not limited to power-plant applications. "It fits really well with onboard capture in vehicles," he said, "especially if you think of an internal combustion engine and an auxiliary system that relies on electrical power."

He said aluminum is the perfect anode for this cell, as it is plentiful, safer than other high-energy density metals and lower in cost than other potential materials (lithium, sodium) while having comparable energy density to lithium. He added that many aluminum plants are already incorporating some sort of power-generation facility into their operations, so this technology could assist in both power generation and reducing carbon emissions.

A current drawback of this technology is that the electrolyte -- the liquid connecting the anode to the cathode -- is extremely sensitive to water. Ongoing work is addressing the performance of electrochemical systems and the use of electrolytes that are less water-sensitive.