oozes through most landfills might be sufficiently acidic (or sometimes basic) to dissolve CdTe, my colleagues and I conducted experiments in collaboration with a team at the Catholic University of America in Washington, DC.[1]

Both groups cut 50 mm squares from a commercial CdTe module. My team cracked each square with one hammer blow to simulate the breakage that would likely occur when discarded panels were dumped. We then placed each piece in a closed jar containing 150 mL of citric-acid-based buffer solution with a pH value of either 3, 4, 5, or 6. The last square went into deionized water. The Catholic University team members scribed their samples with a diamond saw to avoid the randomness of the hammered breakage. They used rainwater as the reference and solutions with pH values of 4 for acid and 10 for base.

Over the course of six months, my team analyzed the solutions for cadmium using inductively coupled plasma optical spectrometry. The sample in pure water with a pH of 7 showed no additional damage, and even at the end, the cadmium concentration in the solution was only 7 ppm. The results were markedly different for the acidic solutions. The farther the pH diverged from 7, the faster the cadmium leached into the solution. After three months, the most acidic samples had completely delaminated, and the cadmium concentrations in the solutions in which they were immersed had reached over 100 ppm. We also observed that the higher concentrations had leveled off well before the end of the experiment, suggesting that virtually all the cadmium had leached out of those specimens.

The Catholic University team ran their tests for 70 days. They obtained essentially similar results, with about 3 ppm cadmium for rainwater, 54 ppm for pH = 4, and 140 ppm for pH = 10.

In 2017 a team at the University of Arizona published a study with experiments similar to ours in both method and results.[2]

Even if CdTe-module makers promise to reclaim the products at the end of their useful life and recycle the cadmium, can we be confident that they will actually do so 30 years in the future?

At least two additional tests have shown that CdTe modules present a serious groundwater pollution hazard if they end up broken in a landfill permeated by something other than neutral water with a pH of 7.[3,4] If we are to use such technology, we must guarantee a safe disposal and recycling program, and include its full cost and risks in any evaluation of CdTe photovoltaics.

References

1. J. Allen et al., "Water solubility of cadmium telluride in a glass-to-glass sealed PV module" (2011).
2. A. Ramos-Ruiz et al., *J. Hazard. Mater.* **336**, 57 (2017).
3. W. Wang, V. M. Fthenakis, *Leaching of Cadmium, Tellurium and Copper from Cadmium Telluride Photovoltaic Modules*, BNL-72178-2004-IR, Brookhaven National Laboratory (3 February 2004).
4. C. Zeng et al., *J. Environ. Manage.* **154**, 78 (2015).

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Medieval astrometeorology's legacy

Anne Lawrence-Mathers's article "Medieval weather prediction" (PHYSICS TODAY, April 2021, page 38) is a welcome work of history of science that introduced me to some people and works I had never before encountered. As far as I can judge, it is quite accurate, although Johannes Kepler was surely never a *pupil* of Tycho Brahe.

It is nonetheless a serious failing of the article to not call attention to the most striking feature of medieval astrometeorology: It did not work. That Eyno of Würzburg claimed to have predicted heavy snow three times is no more an indication of success than an occasional win yielded by a gambler's system.

In a follow-up online piece ("The triumphs and failures of astrometeorology," PHYSICS TODAY online, 30 April 2021), Lawrence-Mathers acknowledges that the theoretical basis of astrometeorology was incorrect but states that, on balance, its contributions to scientific developments were positive. She seems to think the complexity of astrometeorology was a beneficial aspect of it. But astrology, which shared features with astrometeorology, was just as complex. So, was astrology a plus for the development of astronomy? Well, in a way it was, but it was also an obstruction to it.

Kepler knew astrology was nonsense but hoped to improve it. His enhancements were equally nonsensical at first, but they drove him toward creating a really good astronomy. I rate astrology a net negative, but nonetheless, we can acknowledge and learn from the ways it was positive. Similarly, while we can learn from medieval astrometeorology, the predictions it produced "worked" only accidentally. I call that a net negative. There is no arithmetic for weighing the pluses and minuses of history. Any such weighing is therefore a personal judgment.

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▶ **Lawrence-Mathers replies:** Astrometeorology was fully compatible with models of the universe going back to the classical period; it was radical in that it made detailed calculations about localized weather. Its power is seen in its practitioners' quest to improve the model by keeping weather records and attempting to correlate them with predictive factors in it. In espousing that tradition, Kepler, and many others, paved the way for the expanded observations of the 18th century. It was that practice, rather than the theoretical model, that was astrometeorology's lasting contribution.

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