Solar-powered material turns air into water

Educator guide

PAPER DETAILS

Original title: Water harvesting from air with metal-organic frameworks powered by natural sunlight

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DISCUSSION QUESTIONS

	LEARNING STANDARDS
1. What were the authors' reasons for choosing metal-organic framework 801 (MOF-801) as the material for their water harvesting device? Compare the other MOFs studied in Figure 1.	SEP4 ETS1.A PS1.A Structure and Function SP5 EK2.A.1 EK2.D.3
2. How did the authors decide on the appropriate experimental conditions to test the functionality of the material?	SEP1 Cause and Effect SP5
3. Define the terms absorb, adsorb, and desorb? How are these terms related?	Structure and Function RST.9-10.5 EK5.A.2
4. Why did the authors decide to use simulation to predict the function of the MOF and not rely only on experimental measurements?	SEP5 SP7
5. What further improvements could/should be made to the device before it can be practically implemented all over the world?	SEP5 Structure and Function VC6

ACTIVITIES FOR INTERACTIVE ENGAGEMENT

	LEARNING STANDARDS
Writing an abstract Students write a new abstract for the article at a grade-appropriate reading level.	RST.9-10.2 RST.11-12.2 VC1
Locating this study in the larger field Students use the annotated list of references to explain how this research builds on the published work of at least one other independent group of scientists. Students will evaluate whether data from this research supports or contradicts previous conclusions and reflect on the statement that scientific knowledge is a "community effort."	RST.9-10.8 RST.11-12.8 VC1 NS1
Science in the news Students explore news stories in the Related Resources tab and evaluate the stories for tone, accuracy, missing information, etc. They may then write their own news stories on the article.	RST.9-10.5 RST.11-12.5 RST.9-10.6 RST.11-12.6 RST.9-10.8 RST.11-12.8
MOFs in the world Students reflect on the nature of MOFs. What can be modified in order to capture molecules other than water? What other small molecules could it be useful to capture and for what applications?	SEP1 PS1.A ETS1.A Structure and Function SP7 EK2.A.1 NS2
Results and conclusions Students diagram each of the experiments presented in the study (divided up by figure, if appropriate). They then consider the results depicted in each figure, and how these results support the conclusions of the study.	SEP4 PS2.C RST.11-12.8 EK1.A.1
The next steps Students reflect on the design of the final device for water harvesting and design a follow-on experiment to this study. How would they have designed this device given its purpose? What do they think would be the optimal shape/size/orientation and how would they test it?	SEP1 PS1.A VC6

ARTICLE OVERVIEW

Article summary (recommended for educator-use only)

Kim *et al.* (2017) demonstrate the use of a metal-organic framework material to harvest water from the atmosphere at low relative humidity levels and only relying on sunlight as the energy source. The authors performed simulations and experiments to characterize the water-harvesting behavior of the material. As a proof of the relevance of this work, they build a prototype device and tested it in real outdoors conditions, showing that the device can harvest almost 3 liters of water per kilogram of metal-organic framework daily at a low humidity level of 20%.

Importance of this research

This research provides a solution to a fundamental societal problem: The lack of regular access to drinking water that is experienced by billions of people around the world. The device they engineer demonstrates how the design of MOFs can be practically implemented to collect water from the atmosphere, even at low humidity levels. This work can be extended further by tuning the MOF structure to enhance the water harvesting capacity and reduce its cost before it can be implemented in households.

Experimental methods

- Design, creation, and synthesis of metal-organic frameworks.
- X-ray crystallography to determine the MOF structure.
- Experimental measure of water-harvesting capabilities in a laboratory set-up.
- Simulations and mathematical modeling of the harvesting capacity of the MOF to perform a parametric study.
- Device building and proof-of-concept testing in real, outdoor conditions.

Conclusions

- Using solar power, MOF-801 can harvest water in humidity/temperature conditions similar to deserts with no additional power source.
- Water harvesting capability of MOF-801 can be accurately simulated using mathematical models.
- MOF-801 can be implemented in a simple device able to capture about 3 liters of water per kilogram of MOF daily.

LEARNING STANDARDS ALIGNMENT

The following tables provide an overview of the learning standards covered by this article, including the A Framework for K-12 Science Education (Framework), Common Core State Standards English Language Arts-Literacy (CCSS ELA), Common Core State Standards Statistics and Probability (CCSS HSS), AP Science Practices, and Vision and Change for Undergraduate Education. Where applicable, activities and information will be marked with specific standards to which they are linked.

A Framework for K-12 Science Education		
Science and Engineering Practices	Disciplinary Core Ideas	Crosscutting Concepts
Asking Questions and Defining Problems (SEP1) Science begins with a question about a phenomenon and seeks to develop theories that can provide explanations to such questions. A basic practice of a scientist is formulating empirically answerable questions about phenomena, establishing what is already known, and determining what questions have yet to be satisfactorily answered/ **Analyzing and Interpreting Data (SEP4)** Analyze data using tools, technologies, and/or models (e.g. computational, mathematics) in order to make valid and reliable scientific claims or determine an optimal design for a solution. **Engaging in Argument from Evidence (SEP7)** Evaluate the claims, evidence, and/or reasoning behind currently accepted explanations or solutions to determine the merits of arguments. Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.	**PS1.A: Structure and Properties of Matter** Each element has characteristic chemical properties. The substructure of atoms determines how they combine and rearrange to form all the world's substances. The varied properties one encounters can be understood in terms of the atomic and molecular constituents present and the forces within and between them. **PS2.C: Stability and Instability in Physical Systems** Events and processes in a system typically involve multiple interactions occurring simultaneously or in sequence. The system's stability or instability and its rate of evolution depend on the balance or imbalance among these multiple effects. **ETS1.A: Defining and Delimiting an Engineering Problem** Criteria and constraints also include satisfying any requirements set by society., such as taking issues of risk mitigations into account, and they should be quantified to the extent possible and stated in such a way that one can tell if a given design meets them.	**Cause and Effect** Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. **Structure and Function** Investigating or designing new systems requires a detailed examination of the properties of different components to reveal its function and/or solve a problem.

Common Core State Standards English Language Arts-Literacy		
Key Ideas and Details	Craft and Structure	Integration of Knowledge and Ideas
RST.9-10.1 Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions. **RST.9-10.2** Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text. **RST.11-12.1** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account. **RST.11-12.2** Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.	**RST.9-10.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 9-10 texts and topics. **RST.9-10.5** Analyze the structure of the relationships among concepts in a text, including relationships among key terms (e.g., force, friction, reaction force, energy). **RST.9-10.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, defining the question the author seeks to address. **RST.11-12.4** Determine the meaning of symbols, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context relevant to grades 11-12 texts and topics. **RST.11-12.5** Analyze how the text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas. **RST.11-12.6** Analyze the author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.	**RST.9-10.8** Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem. **RST.9-10.9** Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts. **RST.11-12.8** Evaluate the hypotheses, data, analyses, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information. **RST.11-12.9** Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

AP Science Standards	
AP Science Practices	AP Chemistry Content Standards
Science Practice 5 (SP5) The student can perform data analysis and evaluation of evidence. **Science Practice 7 (SP7)** The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.	**Essential knowledge 1.A.1 (EK1.A.1)** Molecules are composed of specific combinations of atoms; different molecules are composed of combinations of different elements and of combinations of the same elements in different amounts and proportions. **Essential knowledge 2.A.1 (EK2.A.1)** The different properties of solids and liquids can be explained by differences in their structures, both at the particulate level and in their supramolecular structures. **Essential knowledge 5.A.2 (EK5.A.2)** The process of kinetic energy transfer at the particulate scale is referred to in this course as heat transfer, and the spontaneous direction of the transfer is always from a hot to a cold body.

Connections to the Nature of Science	
Vision and Change for Undergraduate Biology Education Core Competencies and Disciplinary Practices	A Framework for K-12 Science Education Understandings About the Nature of Science
Ability to Apply the Process of Science (VC1) Understand the process of science and how scientists construct new knowledge by formulating hypotheses and then testing them against experimental and observational data. **Ability to Understand the Relationship between Science and Society (VC6)** Identify social and historical dimensions of chemistry practice: evaluating the relevance of social contexts to chemical problems, developing applications to solve societal problems.	**Scientific Investigations Use a Variety of Methods (NS1)** Scientific inquiry is characterized by a common set of values that include: logical thinking, precision, open-mindedness, objectivity, skepticism, replicability of results, and honest and ethical reporting of findings. Scientific investigations use a variety of methods, tools, and techniques to revise and produce knowledge. **Scientific Knowledge is Based on Empirical Evidence (NS2)** Scientific arguments are strengthened by multiple lines of evidence supporting a single explanation.