

ACS AMA: Hi Reddit! My name is Mircea Dincă, a professor of chemistry at MIT. Ask me anything about metal-organic framework materials!

AmerChemSocietyAMA <sup>1</sup> and r/Science AMAs<sup>1</sup>

<sup>1</sup>Affiliation not available

April 17, 2023

### Abstract

ACS AMA I am Mircea Dincă, and I am an Associate Professor of Chemistry at MIT, leading a lab focused on the design and synthesis of new materials for energy and environmental applications. In particular, we are interested in developing a class of materials called metal-organic frameworks, which are very porous. Most recently, we have shown that these “super-sponges” can adsorb record amounts of water, and that one can use this high water uptake to “suck” moisture from the atmosphere and deliver fresh water in water-stressed dry areas of low natural humidity. This work was recently published in ACS Central Science under the title “Record Atmospheric Fresh Water Capture and Heat Transfer with a Material Operating at the Water Uptake Reversibility Limit” and is available free of charge for readers at: <http://pubs.acs.org/doi/full/10.1021/acscentsci.7b00186> This paper is just one example of many ways in which we use metal-organic frameworks for renewable energy applications, including record-setting supercapacitors and smart windows, or for heterogeneous catalysis of importance for large industrial processes such as ethylene dimerization, used in polyethylene production. For an overview of the many exciting opportunities offered by metal-organic frameworks as an up-and-coming class of advanced materials, check out our accessible Outlook on this field, also published recently in ACS Central Science “Grand Challenges and Future Opportunities for Metal–Organic Frameworks” <http://pubs.acs.org/doi/abs/10.1021/acscentsci.7b00197> By way of background, I was born in Romania, and moved to the US for my undergraduate degree, which I obtained at Princeton University in 2003. I completed my graduate work at UC Berkeley and graduated with a PhD in Inorganic Chemistry in 2008. Following 2 years as a Postdoctoral Scholar at MIT, I started my independent research group at MIT in 2010, where I have been an Associate Professor since 2015. For my group’s research I have been awarded a Sloan Fellowship, a Cottrell Award, and a Dreyfus Teacher-Scholar Award. In 2016, I was selected for NSF’s Alan T. Waterman Award. Ask me anything about our work on metal-organic frameworks and its relationship to modern energy or environmental research! I will be back at 1pm EDT (11am PDT, 5pm UTC) to answer your questions. MD logged in, June 20, 12:58pm, EST. Thank you for your questions reddit! MD out June 20, 2:03pm, EST.

[REDDIT](#)

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AMERCHEMSOCIETYAMA [R/SCIENCE](#)

### [ACS AMA](#)

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Ask me anything about our work on metal-organic frameworks and its relationship to modern energy or environmental research!

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#### CORRESPONDENCE:

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Indeed, as the name suggests, metal-organic frameworks are hybrid compounds that are self-assembled from molecular building blocks that are both organic and inorganic. What distinguishes them is that they are typically crystalline (that is, they have long-range order), and most people would consider a MOF a MOF only when it is porous. The response from EvilGiraffes516 is also quite on point so I will not elaborate further.

AmerChemSocietyAMA ,  
r/Science , ACS AMA: Hi  
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I knew about using metal organic frameworks for storing hydrogen gas, but capturing water is really interesting!

What else can you capture, and how selective can you get? Have you considered making a MOF that adsorbs CO<sub>2</sub>? Do they have to be cycled, or could you make a staged system that could be operated continuously where each stage has a higher concentration?

How susceptible are MOFs to radiation damage? Could you capture gaseous fission products?

Thanks!

[3jt](#)

there are indeed numerous examples of MOFs capturing any number of other gases. basically, anything that can fit within the pores of a MOF (typically on the order of 0.5 to 3 nm) will be able to be adsorbed. CO<sub>2</sub> is certainly one of the most popular gases, and there are numerous groups working on that, for both capture and separation. Methane is another, as are many other hydrocarbons, mainly from the perspective of separations, which are very energy intensive. IN my group, we are very excited about capturing/storing corrosive gases such as ammonia, chlorine, bromine, in addition to water (which can be quite corrosive itself!), and we have had some interesting breakthroughs with this recently. Please visit our website for more information and for the actual reports.

Hello Dr. Dincă, I was recently reading your paper on non-pyrolyzed MOFs for supercapacitor electrode materials. I was curious as to if any binder or adhesive was used when applying the electrode material to the nickel foam, or if it was just pressed in.

[jagarcia215](#)

we did not use any binder in those devices reported in the Nature Materials paper. This was precisely to demonstrate that our materials are very conductive. The electrodes were pure MOF, contacted directly on the current collectors/metal electrodes. One of the most interesting features of those devices, besides the very high areal capacitance, was the very low internal resistance. Low internal resistance in a real application means that much less heat dissipation will be needed, which is important for mobile applications such as electric vehicles, especially those that require high power (i.e. "muscle cars").

In terms of either recovery, analysis, or technique, what is the most difficult part of your synthesis process? I did some research on heterogeneous catalysis and there were some very tricky reactions. Also, what kind of catalysts are in your MOFs and how are they attached to the framework?

[Oldcadillac](#)

Most MOFs are made from solution, in self-assembly reactions requiring heating the solutions up to approximately 150C, although often the temperature is much lower, on the order of 60-80C. I would say the most difficult part would be the synthesis of the organic ligands, if these are not commercially available.

How optimistic are you that your line of research and others like it will bring about an end to the age of petroleum? Is a paradigm shift imminent?

[ajarndaniel](#)

As everyone else working on clean energy, I am hopeful that our research will help bring about new, more energy-efficient technologies that will lower the CO<sub>2</sub> output, and thus fossil fuel consumption.

Can a metal-organic framework be selectively porous? For example, could it absorb oil without absorbing water?

[WippitGuud](#)

Yes, in principle it can and there may be examples of this already. My confidence stems from the incredible compositional tunability of these materials, which can be made either very hydrophobic, or very hydrophilic: <http://web.mit.edu/dincalab/papers/paper10.pdf> For your particular application, you would want the former.

Welcome,

What are your thoughts on the longterm feasibility of integrating metal-organic frameworks into photoelectrochemical water splitting systems?

[adenovato](#)

One of the primary limitations of using MOFs in any electrical device is their typically low electrical conductivity. My group, along with a few other groups, are addressing this issue by designing MOFs that can conduct electricity. I see this as one of the most interesting new avenues of research in the field of MOFs. We have made important advances in this area and have produced materials that are as conductive as graphite, for instance. The second point is that you need a catalytic active center, which would need to be combined/embedded in a conductive MOF. Third, you need a light-absorbing element. Putting all these together is an interesting target, and certainly one that is intellectually stimulating. I do think that more work needs to be done on each independent step before one can think about a practical photoelectrochemical device (made of MOFs or not).

Hello prof. Dinca. Thank you for the ama and congratulations on your achievements. Too often people in your position are exemplified as a product of Romanian education and its focus on sciences. However, the reality is often that pupils and students are failed and left behind by a flawed and outdated educational system. Do you see any opportunities from your position at MIT to positively influence educational outcomes in Romania / Eastern Europe? If yes, how are you actually doing, or plan to do, this?

[leolost](#)

I have started to make some connections with the academics in Romania. It is hard to make any serious inroads, I believe, without first trying to understand the political system there.

Hello prof. Dinca. Thank you for the ama and congratulations on your achievements. Too often people in your position are exemplified as a product of Romanian education and its focus on sciences. However, the reality is often that pupils and students are failed and left behind by a flawed and outdated educational system. Do you see any opportunities from your position at MIT to positively influence educational outcomes in Romania / Eastern Europe? If yes, how are you actually doing, or plan to do, this?

[leolost](#)

I am proud of my grade 1-12 education in Romania, and I do believe that it helped me tremendously during my higher education. I also agree that it caters to the better students and is/was not the best in making sure it doesn't leave anyone behind. I do hope that something in the middle can be implemented.

Hi Dr. Dincă! I recently completed a graduate course on "zeolites", and the instructor pointed out that researchers in the field don't really use the strict mineralogical definition; they refer to any of similarly hyper-porous structures, natural or artificial, as "zeolites".

Do some researchers consider MOFs a subcategory in this family of substances?

[Cronanius](#)

MOFs and zeolites are only similar insofar as they are both crystalline materials with micropores (defined by IUPAC as pores smaller than 2nm), although some MOFs can be mesoporous as well (i.e. pores larger than 2 nm). I would say that MOFs and zeolites are otherwise complementary. MOFs are much more chemically/compositionally tunable than zeolites, whereas zeolites have higher thermal stability, for instance. I believe that MOFs can address some problems that zeolites cannot, and vice-versa, which makes the two materials complementary as well. Ultimately, MOFs are their own class of microporous materials that, application wise, can fill niches that no other solid materials can.

What drives the formation of a MOF? Is the process thermodynamic or kinetic control?

Could one create MOFs as a means of wastewater remediation by choosing an organic linker with a large binding affinity to a heavy metal pollutant?

[day\\_kid\\_older\\_sister](#)

I would argue that most MOFs are in fact kinetic products because the (overall) thermodynamic product would be the dense "isomer". That being said, most MOFs probably sit on very shallow potential wells, and the particular temperature/solvent system combination causes the formation of one phase versus another. IN the Zn<sup>2+</sup>/terephthalic acid combination, there are over 20 different possible phases, each of which can be made pure, but conditions for making each are found completely empirically. Finding ways to predict exactly which structures are stable is the focus of some groups, but I am not aware of efforts to then tell experimentalists **how** to target even these "most stable" phases

Professor Dincă, thank you for taking time out of your day to answer questions. Here is one that came to my mind immediately:

In the process of absorbing does any filtration of pollutants/bacteria and other unwanted "things" occur. In more simple terms does this supersponge make the water is absorbs potable?

[hamlet\\_d](#)

We envision the fresh water capture and delivery to be vapor processes, in both cases. Thus, the water adsorbed in the first phase into the MOF adsorbent, would then be vaporized and condensed back in liquid form. Because the transfer is always in the vapor phase, no particulates or bacteria should be transferred, and the water will come out pure.

What's your favorite part of working at MIT

[-cringe-](#)

the people are amazing, from students to colleagues. They challenge me each and every day, which is what makes the place great. I wouldn't have it any other way.

What are the practical challenges in adapting MOFs into i.e. large scale industrial settings for scrubbing or other filtering purposes?

[akh12](#)

I think the prospects here are excellent. Several companies are making MOFs for various purposes, some small startups, some established big players (e.g. BASF). People need to realize that some of the myths related to these materials are just that, myths:

**Myth 1:** Price is too high. Response: not necessarily, and depends on the application. If the application is sufficiently high value (e.g. high-value separations, electrical energy storage (our lab), chemiresistive sensors (require very little material), then material price is not the largest component of a given CAPEX.

**Myth 2:** MOFs are not water-stable. Response: most MOFs are indeed not water stable. But many are very water-stable, in a wide range of pH and temperature. This includes our material in the title paper discussed nominally here, on water capture from the atmosphere. Furthermore, there are plenty of applications that require exclusion of water anyway, for instance various catalytic processes using alkylmetal initiators. We showed that one of our MOFs has a world record activity for ethylene dimerization, a process that produces 700,000 tons of butene per year and is run in the complete absence of water. Obviously, water stability is unnecessary in this case.

The most important point to remember here is that there are literally thousands of different MOFs out there, and the price/water stability varies widely. Just like one would not make a general statement about all metal oxides based on investigating one oxide, one should be careful to extrapolate generalities such as water stability or price point to all MOFs based on hearsay about certain more popular MOFs that nevertheless may not be the best for applications.

Hi Mircea! I recently just finished my third year and as part of my undergraduate I did a research placement in a university in Ireland where MOF's were the focus. I am interested in environmental sustainability and I was wondering if/how you are researching MOF's application to help improve environmental issues related to climate change? Or would this be something at all that you would research? Do you just look at energy/environmental applications of MOF's or have you researched other potential applications, for example biological? Sorry for so many questions but I find this quite interesting!

[bexthetyrannosaurus](#)

Our lab is interested in many different aspects of MOF chemistry, from energy storage to corrosive gas capture, to heterogeneous catalysis. This is the case with many other labs out there, so there is definitely a wide open field of potential applications.

Hi Professor Dinca!

Into which application will you think MOFs will be applied first and in which area do you think they have

the greatest potential? Thank you!

[aylina](#)

I do believe that some of the traditional applications: gas storage and separation, which have been researched for the longest time, are close to a breakthrough. There are so many high-value separations out there where MOFs can have an impact. I also believe that some of our own work, with water, for instance, is very attractive for certain markets where water resources are scarce. We are looking to exploit this advantage as well. Finally, I am hopeful that some of our breakthroughs in catalysis and electrically conductive MOFs will lead to real-life applications, such as in sensing devices and electrical energy storage.

what is the subtle most exciting development in metal - organic framework materials and why?

[TallDuckandHandsome](#)

In a bit of a biased response, I will say that imparting electrical conductivity, as some of my students are doing, is very exciting because being able to create electrically conductive materials that have such high surface areas opens up applications that were not possible before. More broadly, I am excited to see the field broadening as well as maturing. There are still important synthetic developments, but also many potential applications being explored. In the maturing process, I see people realizing that MOFs are not zeolites, and the two material classes are not in competition with each other, but rather complement each other. MOFs will not replace zeolites at catalytic processes where zeolites are good. However, there are plenty of catalytic processes where zeolites do not perform well, and in fact no solids perform well. This is where MOFs can have an impact as well, and we are working towards that too. Developing new heterogeneous catalysts that are as tunable, electronically and structurally, as homogeneous ones is very exciting.

Professor Dinca, thanks for the AMA! I'm a first year graduate student in chemical engineering. Why do you think that research in MOFs has grown in the last 10-20 years? I.e what were the enabling discoveries?

[dolphindespiser](#)

It is a very exciting field for chemists because the synthetic space is literally limitless! So for a synthetic chemist with a rich imagination, it is an amazing field. What puts these in the "hottest" category is that the synthetic space is not just fundamental, but its translation to applications is palpable and approachable for engineers, physicists, materials scientists alike. The broad appeal and accessibility is, IMO, what makes the field so exciting and popular, and still growing!

Hello Professor Dincă. I recently got my PhD, and my dissertation was focused on the synthesis and applications of zeolite membranes. I witnessed the transition of academic focus from zeolites to MOFs firsthand - 5 years ago, MOFs were just starting to get popular and now they are considered to be the next big thing. I have seen fantastic and very promising applications of MOFs in the academic literature, including from your group. However, now that I am in industry, I find that MOFs are still considered very exotic materials and not commercially applicable.

My question is, when do you expect MOFs to begin to be competitive with zeolites in industrial processes like adsorption, catalysis etc? Is cost the biggest barrier to commercial application and what are some ways to reduce the cost of MOFs? Thanks in advance.

[erdosbaconator](#)

I replied to a similar question above. Cost is not necessarily an issue depending on the value of the application. There are many companies looking to produce MOFs in large scale, with some real results in isolated cases. I think one of the challenges in reducing cost is, ironically, the great diversity of MOF compositions and structures. It is likely that a scale-up process developed for one MOF will not be applicable to another. But I see this as an important area of growth as well, both academically and industrially.

Is there a concern of toxicity if MOFs are used to transport water to low humidity areas?

[GoodAznBoi](#)

No, because the water recovery would be from the vapor phase, thus any metal ions/impurities/particulates, would be left behind.

I have several colleagues that have worked with MOF's and I'm familiar with the materials in very vague terms. However, most of my colleagues that have worked with them feel that despite all of the hype and significant research being poured into the area (design and synthesis wise); MOF's will not have significant realistic applications in the industrial world.

I understand from a conceptual standpoint the ability for hydrogen storage, water storage, and energy retention with targeted release applications of MOF's. But are there other areas besides the ones I've stated that MOFs are being considered for application wise?

[aggie\\_2012](#)

Please see my answers to some of the other related questions.

Are most MOFs stable enough to be used as an electrochemical catalyst? Water oxidation is super hot (and has been for a few years I suppose) and a super high surface area electrode would be very desirable!

[arden13](#)

Not all MOFs are stable, but some are, and the principles required to make water-stable MOFs are now quite well understood. That being said, to use something as an electrocatalyst, one needs to make sure that the active catalyst is also capable of transporting charges. We have shown how to do this, and we have also shown that once conductive, MOFs can function as very good electrocatalysts, for now in ORR: <https://www.nature.com/articles/ncomms10942>

Have architects/engineers expressed any other interesting applications?

[zandor16](#)

Gas separations, capture, catalysis, are some of the more "traditional" applications of MOFs. With electrical conductivity, we have started to look at electrical energy storage (capacitors and batteries), as well as electrocatalysis (for fuel cell applications, for instance). Other applications include drug delivery and biological imaging. The application space is really wide open.

Buna ziua Dr. Dinca!

You mentioned using metal-organic frameworks for applications like supercapacitors. Are MOFs currently being developed for these applications and how are they an improvement over current capacitors?

Multumesc!

[workacnt](#)

Buna ziua! We have indeed recently published work on supercapacitors., and there are more studies now coming out on this topic. Once made electrically conductive, MOFs turn out to be particularly good active materials for supercapacitors. See this link for more info:

<http://www.nature.com/nmat/journal/v16/n2/full/nmat4766.html>

Hey Dr. Dinca, you mention that MOFs have the promising up and coming role in the field of energy by way of record setting supercapacitors. From your experience, what makes these materials especially good at holding a charge (if you will) within circuits when compared to say a less effective MOF? Or when compared to more traditional capacitors/supercapacitors?

[23in97](#)

For electrochemical double-layer supercapacitors (EDLS), you need very high surface area and very good conductivity. Essentially the only materials that achieve sufficiently high conductivity and have sufficiently high surface area are carbons: activated carbons, nanotubes, graphite, etc. MOFs have much higher surface area than carbons, so if one can make them also conductive, then one has the potential to make a very good EDLS: <http://www.nature.com/nmat/journal/v16/n2/full/nmat4766.html>

Hello Professor, 1) Do you think a person with non-organic chemistry background can succeed in this field? and 2) what is the hardest part about this field?

[IdealisticVenus](#)

I have a PhD in Inorganic Chemistry, as do most people working in this field!