Science AMA Series: We're chemists who are developing solar batteries for the power grid. AUA!

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Abstract

Hello! I'm Dr. Yiying Wu, professor of chemistry and biochemistry at THE Ohio State University, and with me are doctoral students Mingzhe Yu and Billy McCulloch. We want to make solar energy a reality for the power grid. We work at the intersection of synthetic inorganic chemistry, materials chemistry, and photoelectrochemistry to create devices that are hybrids of solar panels and batteries: "solar batteries." So far, we've invented a solar air battery (a "breathing" battery that releases oxygen when it's charged by sunlight) and an aqueous solar flow battery (which has an eco-friendly water-based electrolyte circulating in it). We've seen you discuss our work on r/science, and we will be back at 1pm ET to answer your questions, ask us anything! Solar air battery (study) Aqueous solar flow battery (study) Dye-sensitized solar cells (study) The Wu Group homepage Added: Proof Thanks, everyone! This was pretty intense! But these questions can inspire us to think beyond the scientific questions to the larger issues.

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YIYING_WU R/SCIENCE

ABSTRACT

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Solar air battery (study)

Aqueous solar flow battery (study)

Dye-sensitized solar cells (study)

The Wu Group homepage

Added: Proof

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How much power will the batteries be able to generate? how long would it take to charge the batteries? What challenges have you overcome so far with this?

Ozmar

Our solar battery technology is based on the integration of solar panels and batteries. So the power will depend on the battery chemistry. For example, our recent work is based on the flow battery. The advantage is the separation of capacity and power. That means the power can be adjusted based on the needs using the area of the battery footprint. So it can be adapted from KW to MW scale. Life is another advantage of flow batteries, since the energy storage is in the liquid, not in any solid. And the flow can also provide a convenient repair mechanism; you can replenish the components.

In satellite design, especially as we move towards smaller satellites performing more power-intensive missions, one of our large issues is battery life. We struggle with 1) being able to sufficiently charge the batteries during the time the satellite is sunlit and 2) the size requirements of the batteries which reduce the available space for our payload. Typically, the batteries are stored within the satellite block itself, and they are charged using solar panels extended from the sides of the satellite. The other issue we face is the loss of efficiency with age. With larger satellites, we can just use larger batteries, but as we try to perform more missions with lifespans of five years or more with CubeSats, battery degradation is a serious technical hurdle to overcome.

Here are my actual questions: 1) Does your solar air battery offer us a possible solution to the size and weight issues that we face by using hybrid solar panel and battery? 2) Have there been any advances in batteries that can allow greater depth of discharge (we normally use a limit of ~20% discharge) without having extreme adverse effects on efficiency?

ironicname
Sorry, but we think the answer will be no. We've thought about its application for UAVs, but the specific energy is very crucial. Our current solar flow battery does not have enough energy density for that kind of application. But this is definitely something worth thinking more about, if we want to replace the liquid components.

Hello, and thanks for doing this AMA! Based on your expertise in this field, what is your opinion of the Tesla Powerwall (residential) and Powerpack (commercial)? Is it truly enough to make solar more practical for a significant amount of people?

wesselwessel
Cost is the critical issue. Lifetime is also important. For example, a typical US family uses 30 KWh of electricity per day. For the energy storage part, if the cost can be USD 250 per KWh, so that is USD 7,500 for total initial investment for one house. We think this becomes affordable for significant amount of people.

Hello, thanks for your work towards making this a cleaner environment. I'd like to know if you are experiencing any push back from the energy industry or do you see the industry making a real attempt to change for the better? Thanks for your time!

SixVISix
No pushback. We are talking with some potential partners in the energy industry.

Hi, thanks for doing this.

I have been off grid now for 25 years and have seen some massive changes in that time, but batteries themselves seem to stay the thorn in the side of making it more economical. Solar panels have nicely come down in cost.

So my question is, with the vast array of new chemistries being touted, where do you see the market going in the next few years? Does their seem to be a emerging energy storage solution that stands out as being something to watch and can be the all things to all people solution the consumer is looking for.

Kymeera
This depends on the transition from academic lab to industry. We are talking with investors and potential industrial partners now. We hope a reasonable target is to generate a prototype within two to three years for industry partners to scale up.

First, thank you for doing this AMA! Second, so the big problem with a lot of renewables (specifically wind and solar) is instantaneous supply/demand for power. Solar is inherently limited by the night and the question arises of how to successfully store power to serve immediate need like our current grid does. One idea I've seen suggested would be for large, molten salt generators to be kept. Would the work you're pursuing have potentially large scale applicability or otherwise move towards lessen the inherent shortcomings of solar power? If yes, how would you most like to implement them to have the fullest effect?

Keep up the great work you're doing- solar power is the way to go! Thank you again.

hobolow
Our invention solves the instantaneous supply/demand issue since we can harvest solar energy in the day and store it, then we can output the electricity at night or when it's cloudy.

Amazing work, I remember being very excited by this when I first read about it, so thanks for doing this AMA! Question time: traditional solar cells have a power curve that varies with solar insolation and typically utilize some Maximum Power Point Tracking (MPPT) electronics to allow the voltage output of the cell to fluctuate thus achieving maximum instantaneous power. Typically battery cells have a particular voltage/current they prefer to be charged at to improve efficiency (lowered impedence) and lifetime. How do you plan on reconciling this difference between optimal production potential of the solar cell and optimal charging potential of the battery cell?

Similarly, what is the optimal discharge voltage/current? I imagine it changes as the % charge changes. Most batteries have an optimal maximum depth of discharge (don't drop the battery cell voltage below a certain amount else cell will be slightly damaged, effecting lifetime of cell), what is this level for your battery?

Finally, what is the lifetime of your solar battery? How many hours of operation, charge/discharge cycles can it undergo before performance drops 70%? Which aspect is the limiting factor on life: the solar or battery cells?

Thank you for answering my question! I mastered in power electronics for solar/battery systems, so I've been very curious!

KapitanWalnut
The solar charging mechanism and the battery discharge are independent from each other. So we don't need to worry about this issue of reconciling them.

As for optimal lifetime, our solar flow battery is based on the redox flow battery platform, so the lifetime is unlimited because the liquid can be replenished. The depth of discharge can reach 95%. We will give our solar flow battery additional in-depth testing to provide the detailed specifications in the next several years.

As someone who has worked in the battery field for a little bit and is planning on going to grad school for materials engineering related to energy storage, I have a few quick questions about the technology and its viability.

- **Where in the scale of energy storage do you believe this technology will fit best? (consumer electronics, car batteries, microgrid storage, large scale storage)**
- **Will incorporating the solar cells significantly increase the price of the battery such that it may not be as good of a technology from an economic stand point?**
- **In operation, do these batteries operate in ambient air conditions? If so, does this significantly reduce the storage capacity?**

Thank you for doing this AMA, very interesting research and an innovative approach to solving such a problem!

TPNigl
1. Microgrid and large scale storage.

2. We're working toward the opposite, because we think we can reduce the fabrication costs by integrating the two functions together.

3. Yes, it operates in ambient air conditions, and no, this doesn't reduce storage capacity.

I am intrigued by the concept of flow batteries. It seems that they could solve so may more problems than other types because of the ability to separate the energy storage from the conversion mechanisms. I suppose this is nearly science fiction, but it would be wonderful to see a technology that used solar panels to store energy in a liquid where the liquid could be used to recover the energy later for use by utilities or in the home, or transferred into a vehicle for transportation. Of course, the discharged liquid would then be returned to the solar battery station for recharging. Do you see your flow battery research enabling such an infrastructure eventually? Currently, what is the energy density of the aqueous liquid used in your research, perhaps in a watts/liter description for us laymen?

dunegoon
In fact, transferring the liquid to a vehicle is very feasible, and would make refueling as easy as filling with gasoline. The challenge is the energy density of the liquid. Currently, ours is about 25 Wh/l.

Hi and thanks for doing this AMA which brings to light a very important and well researched area right now.

I recently read somewhere i forget now, that a solar cell was created i believe in California that had achieved an efficiency rating of something like 90+%. just like to know your thoughts on this and the difficulty and implications of bringing something like this to market.

thanks

kma

kma181
We agree with r/HowitzerIII in that 90% is pretty much impossible, because it's against the thermodynamic limit. There are some technologies that can reach 50%, but they are VERY expensive.

Thanks for doing this work. The battery is what is keeping me from investing about 100k in a solar system. I can't wait until we have great storage options. Realistically, when do you see whole house (I mean big house with 60 amp HVAC systems, etc) batteries available at a reasonable price (10-20k usd)?

Thanks.

liberty4u2
Tough question. We think a typical house needs a 30 kwhr battery to be off the grid. Right now the price is about $300 for the Tesla powerwall, so you'd need 30 x $300 = $9,000 plus the installation fees. To be off grid, you'd need solar panels as well. Or some other energy source, like wind. So $10,000 would be a low estimate. Maybe the tipping point is if the price comes down by another two to three times, then people could more easily use renewables, because the time to recoup your investment on energy savings would be significantly shorter.

About 3 years ago, I developed a very enlightening future for myself by pursuing a job in alternative energy. I'm currently getting by B.S. in Electrical Engineering. I've been told that a great route to get into to solar panels and their operations is to study material science. more specifically, semiconductor devices. I still have a great passion for alternative energy, and I'm wondering if you have any advice or direction you could provide. Thanks again for all you do!

Chasethelogic

Thank you! You're on a good path to do that. You would definitely need some chemistry knowledge to design new materials. This is a very multi-disciplinary area. Materials scientists, electrical engineers, and chemists all work together on solar energy. Good luck!

Most solar cell installations offer 11-15% of energy converted to electricity. Your results show roughly 4% energy. If your system is 20% more effective storing energy then you're still considerably below the current efficiency. What's your plans to reduce cost or to increase efficiency to make your idea competitive with what's on the market?

MrSparks4
The efficiency is not the only consideration. The cost is more important for the market penetration. So, right now, our solar battery has a small photocurrent. That's what we are working on. We are targeting a 10% efficiency.

What are the batteries made of, and are there any environmental concerns about using them?

thiney49
In our solar flow battery, the process is similar to natural photosynthesis. We capture the light using a dye-sensitized photoelectrode (TiO2), and then we store the energy in an aqueous flow battery, so the electrolyte is water. So as long as the electrolyte is properly contained, there is no environmental concern.

What is your maximum wh/kg and wh/l performance of a battery that you currently have developed with what one would consider normal cycle durability. Also, what are you looking at costwise on such batteries?

Better batteries will change the world, but unfortunately I'm ignorant on the current field of batteries in development.

schockergd
The maximum is about 20 Wh/kg and 25 wh/l since our technology is based on the redox flow battery platform. The advantage of our technology is to solve the intermittent nature of sunlight availability. So we are integrating the solar panel into a battery directly.

Costwise, we think we can decrease the system cost by removing the packaging of both solar panels and batteries separately. And we can reduce the materials cost by removing the redundant components from both.

what is your solar conversion yield? What is your projected maximum for it and why arent you there yet? What obstacles do you face in your research/production?

neuromorph
Our solar conversion efficiency is quite low at the moment and our goal is a 10% efficiency. We are currently not there yet because there many obstacles in optimization and preparation of the electrodes and other materials. Because we want to go with a water based solvent for the flow battery, that means we need to operate the solar cell in the same conditions. This in itself is a challenge because aqueous based dye sensitized solar cells (different from the crystalline solar cells we see today) are not well developed and lack the efficiency of their non aqueous counterparts.

How big do you think a future workable battery that could store the energy to power a city for a month would be?

AdrianBlake
How big a city? New York? Or Telluride in CO (recently there for a chemistry workshop). It was teeny-tiny! So it varies. But seriously, the real advantage for technology based on flow batteries is that it's scalable.

What are the limitations on the elements you can use? Do your batteries have to be lithium based? Is iodine essential?

jkjl456456
No limitations. Doesn't have to be lithium based, nor is iodine essential. We can use organic, inorganic materials. We are working on some organic components right now.

Dye-sensitized solar cells currently have only achieved a maximum efficiency of 11.9% and progress has be slow. How much higher can we go theoretically? Are they cheap enough to manufacture to warrant their use despite the low efficiency?

Thank you for taking the time to answer our questions :)

thecake90
The dye-sensitized photoelectrode is only one option... we can use a semiconductor photoelectrode. Moreover, cost is another crucial factor in the commercial application, as well as lifetime. We believe they are cheap enough to warrant their application, which in fact is the main advantage for dye-sensitized solar cells.

I'm a recent graduate, currently working as a solar panel system designer. With all the hype of solar power in general, and the possibility of commercial battery systems around the corner, I ask what can I do as a consumer and as a professional to take advantage? How can we invest/ educate/ prepare ourselves most effectively before the battery boom takes place?

JiveTurkey
Batteries are definitely a crucial component for renewable energy to penetrate the market. With a reduction of the cost of solar panels, the cost of batteries is becoming the limiting factor.

How to educate yourself? Study chemistry! :-)

What are each of your all-time favorite organometallic compounds?

p1zz1cato
We all have the same favorite! Ru tris(bpy)! The workhorse of photochemistry.

When do you realistically think this will reach an average consumer? I've always seen all these talks about new batteries and better uses, but they never show up. Just wondering when should people anticipate something like this to appear for them to be able to use it.

mirageraptor
Please see our above reply to r/Kymeera.

Serious question here - Will these actually become a thing? We've heard about and seen stories on batteries removing our demand for the grid for 10+ years now. What makes these any different from the dozen or so other folks that have promoted things here that we've never heard of before?

NESpahtenJosh
What makes this different is that we're combining solar cells and batteries into one device, and we are building the new devices based on developed technology. So we believe that to be a less risky approach. We still need to pass the "valley of death" out of academia into commercial development.

Do you guys utilize any "novel methodology" of nanoparticles in any of your experiments? The photocatalytic process seems like it could be pretty important in solar cells.

SpankThatDill
Our use of nanoparticles is based on a commercial product called P25, for paint. Not a novel methodology in that sense, but good, because it's cheap!

I'm so glad I checked reddit this morning! I'm an OSU chemistry undergrad and I (coincidentally) spent yesterday afternoon reading about some of the work your group does!

My question: In your 2013 study on the development of your innovative K-Air battery, you noted that the formation of an insulating layer on the metal electrode has a less-than-desirable effect on the cycle life of the battery. In the time since publishing, have you made any changes to the design of the battery that have resulted in an increase in the cycle life?

Also, I enjoyed the OHIO shout-out in your 2006 paper on the DSSC.

soaral
Hi! We have made progress in developing the membrane technology to improve cycle life of the K-O2 battery. Stop by and see us about a job!

I've always had great interest in solar batteries sense I was a kid. I live in rural Arkansas where even at a local university where I graduated there were no classes of this sort. I curently work for an irrigation company and have always wanted solar batteries to be implemented in farm irrigation. Where do you go to get into this field? I'd go back to school in a heartbeat for this if I only knew where.

fuadmins
If you are interested in studying many of the problems that solar batteries can solve, then many of the top chemistry programs in the country would have programs in photochemistry and battery research, including Ohio State. UC Berkeley, Stanford, MIT, those are definitely good places to start.

First of all its awesome you are guys are at THE Ohio state University! (Right down the road from me)

How far away are these products from becoming available to consumers who want to use clean energy in their homes? and are these new ways that you invented easier/cheaper to make than the current methods?

asoep44
Go Bucks! Please see our earlier replies. We do think that our device will be easier and cheaper to make.

For someone who has no idea how this works, could you explain it? Also I am very interested in investing in such technology, will this become available for consumers?

Maxzon

We can use photosynthesis as an analogy. The solar panel captures the light, and the battery directly stores the energy as chemical energy. So when there's no sunlight, the stored energy can be released as electric energy. How's that?

Hi thanks for doing this AMA. While I myself fully support the development of solar panels and ways to use green energy such as batteries, I am wondering to what extent the power companies are willing to support these kinds of efforts. Having people generate their own power simply takes income away from the power companies and they will therefore try to dissuade efforts such as these. What are your thoughts on this issue?

sjap
We are talking with potential partners in the energy industry, so they are potentially willing to support development. The consumer is the driver -- it all comes down to cost. Consistent public support for renewables would help, regardless of fluctuating gas prices. On the other side, any renewable energy needs to reduce cost to penetrate the mass market.

Hello, am really glad that you guys are doing this AMA, and have a couple of questions with regards to renewable energy storage solutions.

1) What are your views on the scalability of this technology in terms of amount that can be stored? Can it be deployed on a utility scale level? Will the stock of potassium be sustainable in order to facilitate mass roll out?

2) What is the incremental cost to the Solar panels and are there any indicative LCOE for this new Solar technology as compared to current C-Si technologies? Understand that this would be difficult as the storage will come into play only when generation exceeds peak demand. How much of that generation would it be able to store?

3) As a follow up question, currently, Wind and now Solar in China is facing issues of grid curtailment. Would the Solar air/aqueous solar flow battery help in alleviating this situation?

Appreciate your thoughts on this as we are all looking for the boost that can help take renewables to greater heights.

AnthonyHilton
The amount of the energy can be stored in the solar flow battery depends on the capacity of the liquid tank, so as long as we have a tank large enough, the energy can be stored. It can be easily scaled up, even to grid scale.

The stock of potassium is high enough to be sustainable, 1000 greater than lithium. More importantly, potassium is evenly distributed across the world, making it great for the general public.

The main benefit of grid scale energy storage is to make better use of solar and wind energy. With the battery, the full potential of renewable energy can be realized.

Ours is a dye-sensitized solar cell-based photoelectrode, which is cheaper than the current si-based solar panels, but we also sacrifice efficiency.

What are the biggest challenges for you? Storage? Distribution? Politics? Or?

OriginalNameHereOK
The biggest challenge is always the "valley of death" -- the transition from an academic lab to commercial application, which requires patience and fortitude.

I was thinking of following this career pathway. What made you chose this career and how did you get into it?

pabziD
Yiying Wu: When I was a little boy...jk. I chose chemistry first, and then all the discussion on global warming and CO2 concentration increase made me choose to study renewable energy.

Mingzhe Yu: I think it was my curiosity and the feeling that I could create things to make real life better.

Billy McCulloch: I didn't really know what I wanted to do. I just knew that I was interested in chemistry, so that's what I pursued as an undergrad. And then later, in graduate school, you find a problem that you are passionate about and work to solve it. For me, that's renewable energy.

Hi there, first of all go Buckeyes, second is there a reason why solar power for individual households hasn't caught on with the expectations for adoption we had for it about a decade ago?

IdrankSUPERglue
There are two issues: cost and current infrastructure. Cost needs to come down two to three times for solar electricity. But we don't think the infrastructure will be an obstacle necessarily, because our designs integrate with current infrastructure. But if everything goes to renewables, then we'd have to switch from a centralized energy infrastructure (power plants) to a more distributed structure, and that would be a big change.

With current batteries, it seems like the number of charge/discharge cycles the battery supports is the biggest limiting factor to widespread use. (Musk/Tesla's new powerwall, for example, is not meant for buffering solar on a daily basis.) Are there any technologies that look promising either for very high numbers of charge/discharge cycles, or that could be repair simply to allow for more cycles?

NinjaKoala
Your are correct in that one of the limiting factors is the low cycle life of solid state lithium ion batteries. Just think about how fast your laptop battery fades. Flow batteries in particular have the advantage in that it has a much longer cycle life compared to solid state batteries where energy is stored in the solid electrode.In flow batteries, the energy is stored in a liquid electrolyte. However the disadvantage is the low energy density of flow batteries which make them hard to implement for small consumer electronics.

I'm below average when it comes to grades in my science classes, but I absolutely love chemistry and biology. How can I prepare myself in high school to be a chemist or biochemist without being caught off guard in college/beyond? Thanks

ChaseLB
Our science writer is going to commandeer this question:

Hi - I wanted to be a scientist when I was in school, but I just wasn't very good at it. But I loved science. Luckily, I found a job that would enable me to learn about science, but not have to actually practice science. I get to interview people about the cool things they do, and then write about them. So if I were to offer you some encouragement, it would be to think about related jobs that let you learn about science, but let you practice something that you are good at. And actually enjoy doing!

In battery business, is there anything like Moore's law?

Batteries are getting more and more efficient over the years (thanks to research groups like yours!), but are they following any well known trend like Moore's law in electronics? If there is, can you give us a ELI5 explanation?

Thanks!

isison
As far as battery technology goes, there is no analog to moore's law in electronics. Take laptops for examples they are not getting smaller and lighter due to better battery technology. What is getting smaller is the more energy efficient and smaller computer components which is what is increasing the battery life of your electronics. Li-Ion has been the standard and still is the current standard. To really improve battery technology we need collaboration between university and industry.

Hello, are you collaborating with any other universities with your studies? also, do you have a time frame in which you could see these discoveries making it out of the lab and into the market?

TesttyCalls
Not yet. We are interested in working with people with expertise in flow batteries in order to scale up our designs.

Looking at the increase in sales of Hybrid and Electric cars, Have y'all looked into experimenting with solar panels installed on the roof of a car to help charge the battery when the car is moving and stopped. The long term implications would be widespread use on all passenger vehicles, 18-wheelers, and Locomotive trains? I exclude aircraft because of the lift/weight ratio that all aircraft are subject to.

Kickstand8604
That's an interesting idea. The main problem is the footprint. Solar energy is pretty dilute energy, so consider the footprint of a car and the sunlight that will hit that area. It's just not enough energy to power a car. Same for 18-wheelers or locomotives. So a more realistic idea would be a solar farm to collect solar energy on a large scale, and then charge cars, etc.

flexible solar panels. Are they the future?

Jshaln
They are a possible future! In some special applications, people are trying to make fabric into objects like backpacks, that can charge devices. We are not currently working on that. Pretty cool, though.

Do you see a future scarcity problem with the materials needed to build batteries capable of your strategic aims?

Nivekrst
We use abundant and cheap materials like air and water, TiO_2, so we're not really worried about scarcity right now.

I am currently doing my grad program in optics and we have the choice of doing Solar Cells as an specialization, but I am not too confident there is a booming industry worldwide that is truly supporting solar (except a few european countries but that is beyond the point).

My question is, how do you feel the gap between academic and industry interest at the moment could affect prospects of proper funding for solar in the next 10 years?

ondasgamma
We get most of our funding from DOE for this project, and interest there is strong. We think it's extremely crucial to fill this gap b/w academia and industry so that the public can see the benefit of federal grants for research.

Thanks for taking the time to answer questions! What has been the most difficult aspect of developing these Batteries? What has been the most rewarding?

robmacgar
It's easy to say that the most rewarding part is to see so many people caring about what we do! (Thanks, reddit!) The most difficult aspect is what's next -- commercializing it.

Is it possible to store energy in the form of hydrogen and oxygen and have a ready to use fuel that can be converted when need be rather than a electrical energy battery?

JimmmyRustles
This is basically the idea of solar fuels. There are a lot of research activities surrounding solar fuels. This is an option. The potential challenge is the storage of hydrogen. Our solar battery solves this problem by storing this energy in the battery chemistry.

Hi Dr. Wu, this is awesome work. Do you think the aqueous battery could be used in everyday consumer electronics? Would it lose efficiency as the size is scaled up?

Thanks!

dongbroker
It's like what we said above regarding vehicles. You'd probably use a solar farm to gather the energy, and then charge devices, rather than putting a solar panel on a cell phone.

Would you be willing to fly to the UK to speak at an event on Energy storage?

FelonyT1
Why not? Email us the info. You never know.