Yale Talk: Conversations with Peter Salovey
<u>Episode 38</u>: Producing clean water
<u>Guest</u>: Menachem (Meny) Elimelech, Sterling Professor of Chemical and Environmental Engineering
<u>Description</u>: For Earth Day, Professor Menachem Elimelech and President Peter Salovey discuss the development of technologies that make sea and municipal wastewater potable.
<u>Publish Date</u>: April 21, 2023

FULL TRANSCRIPT

Peter: Hello, everyone. I'm Peter Salovey. Welcome to this Earth Day edition of Yale Talk. At Yale, our mission calls us to improve the world for this and future generations through research and scholarship, education, preservation, and practice. The importance of this work has never been more evident as environmental challenges escalate. And my guest today exemplifies how Yale is bringing the full weight of its expertise and resources to bear on them. Menachem Elimelech conducts breakthrough research in nanotechnology enabled water treatment. He is the Sterling Professor of Chemical and Environmental Engineering. And upon joining the Yale community in 1998, he founded an environmental engineering program that quickly gained international renown. He has since received major awards in recognition of his research, among them the Clarke Prize and the Eni Award for Protection of the Environment. A prolific scholar, Meny has authored nearly 500 refereed journal publications. Meny, it gives me great pleasure to welcome you to Yale Talk. Thanks so much for joining me today.

Meny: Thank you, Peter. And I'm delighted to be here.

Peter: Well, it's great to have you and thank you for giving us a little of your time. You know, last month, rising water scarcity impelled the U.N. to hold a conference on the subject for the first time in nearly half a century. The U.N. cautions that in the absence of swift remedial action, there definitely will be a global crisis. Could you tell us a little bit more about the magnitude and scale of this threat? Is there going to be a global water crisis?

Meny: Yeah, indeed. I'm quite surprised that the United Nations did not have a conference on water for such a long time. However, to their credit, there were other initiatives of the United Nations which water was quite important. One example is the Sustainable Development Goals, which were formulated in 2015. The Sustainable Development Goals have seventeen goals to be achieved by the year 2030. Goal Six, which is called clean water and sanitation, is directly related to water. A few other goals are indirectly related to water like Goal Two: Zero Hunger--again hunger related to food and agriculture. And we know that agriculture consume a huge amount of water. And Goal Three: good health and well-being. So let's have some statistics to illustrate the magnitude of the water crisis. As of now, about two billion people around the world still lack access to safe drinking water. This means that we are not on track to achieve Goal Six of universal access to safe drinking water by the year 2030. Forty percent of the world's population are affected by water scarcity, and this will become worse due to climate change.

Pressure on fresh water is projected to increase by more than 40% by the year 2050, and more than 75% of natural disasters are somehow related to water. And again, climate change plays a critical role. 1.7 billion people lack basic sanitation, and millions of girls spend hours each day to fetch for water instead of going to school. So we surely have a global water crisis. And this crisis is characterized by either too much water (floods, and rain, and storms), too little water (which is droughts, water scarcity), and too dirty water (which is polluted water resources).

Peter: You know, I was thinking about water scarcity and I'm remembering in 2018 when there was a historic drought in Cape Town, South Africa, and it brought them to the brink of Day Zero, the point at which the city's water supply essentially runs out. Water is only available for critical services like hospitals, but municipal tap water is shut off completely. So considering the severity of what's at stake, how can we ensure that there is a sufficient water supply in cities around the globe? That Cape Town incident was a real wake up.

Meny: Yeah, quite scary. I agree with you. So good planning and effective use of water resources are critical to ensure sufficient water supply to cities worldwide. In 2018, during the Day Zero in Cape Town, the BBC published an article titled "The 11 cities most likely to run out of water - like Cape Town." On that list, you may see cities in relatively rainy regions that you will never think that they will run out of water, like Beijing, Moscow, London, and even Miami. Some of these cities, like Beijing and Moscow, have water resources that are highly polluted and will need new treatment technologies and major investment. The current treatment plants cannot treat such water. Miami, for example, relies on groundwater, which is becoming saline due to intrusion of seawater to the groundwater because of heavy pumping of water.

Peter: So the groundwater is saline?

Meny: Exactly. So existing treatment plants, as we know, cannot remove salt. London draws its water from two rivers, the Thames River and the Lea River, but they are close to the allowed capacity for withdrawal. So cities must plan in advance to develop new water resources or new treatment plants that can treat this polluted water. New water resources in principle can also include unconventional water sources such as seawater, saline groundwater, or domestic wastewater that can be treated to produce clean water. But probably this will require higher level of treatment and more energy and costs. So planning ahead, including investments to develop new water resources, are critical.

Peter: Yeah, I think the first thing I knew about you when you came to Yale was that you had developed ways of taking seawater and turning it into drinkable water. Let's stay with that a little bit. Your lab at Yale basically is incubating transformative solutions, including for the benefit of cities like the ones we're talking about and other inland cities. It develops efficient membrane technology to make seawater or municipal wastewater drinkable. How does that work?

Meny: So indeed, membranes can be used to desalinate saline waters like seawater or brackish groundwater, and even to reuse municipal wastewater. So membranes are semi-permeable polymeric films as thin as the paper that you hold now. And by meaning semi-permeable that will let water go easily and block all the salts. For example, in a seawater desalination, the membranes can remove over 99% of the salt and let water go through. Similarly, when you have a wastewater reuse, the membranes remove most of the contaminants of the salt and let water go through easily. So we pack the membranes in pressure vessels and apply pressure to drive the water through the membranes. The energy consumption for these membranes or these desalination plants is proportional to the amount of salt. The saltier the water, the more energy you need which means also more cost. In fact, in many biological cells we have highly efficient membrane water channels that we call aquaporins. These channels can pass water at a fast rate by block completely all salts and chemicals. That is what evolution can do over hundreds of millions of years. If you can create a synthetic membrane as efficient as the aquaporins, we can significantly reduce the energy and cost of desalination. So we work on this in our lab. So to create such a membrane, we use novel materials and design their structure and chemistry based on the principles of the aquaporins.

Peter: Yeah, so we were talking about cities around the world that are at risk to having a Day Zero event like Cape Town, South Africa. And you mentioned Beijing, and Moscow, and Miami. And all of this was not because they don't get enough rain. It was really because they can't treat enough water. But are there are other cities in the US that have a risk of a Day Zero moment?

Meny: I really don't think any city in the US could run out of water sometime soon. We have heard about restrictions to use water for watering lawns and gardening in cities in California like Los Angeles. But cities are planning ahead to prevent Day Zero in the future. So let's take California as example. San Diego built a seawater desalination plant to augment their water supply. Los Angeles is planning to replace the Hyperion wastewater treatment plant with an advanced wastewater reuse plant. The new plant will produce drinking water by treating 250 million gallons of wastewater per day. Just imagine, 250 million gallons is 750 acres of land followed by one foot of water. So worldwide, in 2019, one year after Day Zero in Cape Town, the city of Chennai, which is formerly Madras in India, simply ran out of water. In that year, the four main reservoirs for the city ran completely dry and residents had to stand in line for hours to get water from government tanks. So good planning and looking for new water resources years before could have prevented the crisis in Chennai.

Peter: Yeah. Now you are from Israel originally, and Israel has been a leader in implementing this kind of technology. I know that they've constructed a series of desalination plants along the Mediterranean Sea. Have they been able to prove that you can basically desalinate seawater at scale in a cost-effective way?

Meny: Yes, I will give you a little background. Israel launched a desalination master plan over 20 years ago because they anticipated water shortages in the future, mostly due to population growth and depletion of water resources. So this is an example of good water planning. As part of the plan, as you indicated, Israel built five large desalination plants along the Mediterranean Sea. These plants provide 750,000,000m^3 of desalinated water per year, which is enough to provide 75% of the domestic water supply in Israel. Each one of these plants is at least twice as large as the plant in California that was built in San Diego, just to give you an order of magnitude. So when it comes to desalination, the cost decreases as the plant size increases. This is why desalination plants are large and are not built for small communities. In Israel, the cost of desalinated water is about $0.70 per cubic meter, or 1,000 liters, or 265 gallons of desalinated water. So I think this is a relatively low cost. Just compare it to the bottled water that you buy in the airport. I mean, it's really a major comparison. It is also worth mentioning that Israel recycles over 90% of their domestic wastewater for agriculture, not for drinking water. So water in Israel is a matter of national security. I also think in the future, desalination and water will be an integral part of any peace agreement.

Peter: Yeah, I've heard that for many decades, that if you truly want to understand how to bring peace to the Middle East, you have to understand water, and the availability of water, and the rights to that water.

Meny: Yeah, indeed. Some historians claim that even the Six-Day War, when Israel occupied the Golan Heights, they just wanted to capture all the resources for the Sea of Galilee, which was at that time the major source of water to Israel.

Peter: Water plays a role even in geopolitics. So let me move a little bit to my field: psychology. You could probably anticipate what I'm going to ask you about. An obstacle to wastewater reuse sounds like it's not the development or deployment of membrane technology, or the building of plants, but public perception. Essentially, people are averse to the idea of drinking purified wastewater. And you talked about this during a recent presentation of an event we called *For Humanity* Illuminated. We're holding them all over the world, but you were at the one in New York City, and I think people were fascinated by this problem. You said a memorable quote, "Water should be judged not by its history, but by its quality." And of course, that makes sense. Yet the history of that water, being wastewater flushed down the toilet, and then purified, and now you're drinking it. That scenario disgusts people. And it reminds me of a psychologist at the University of Pennsylvania named Paul Rozin, who studied disgust and found that it's the association that creates disgust, not the reality. For example, he would take a comb for combing your hair and ask someone to put it in their mouth. And of course, they would say, I'm not putting that in my mouth. He'd say, Well, wait a minute, let's take that comb and boil it in water for 15 minutes until it's sterilized. Fifteen minutes after it's sterilized at boiling water, he'd take the comb out, it would cool down, and he'd say, Now would you put it in your mouth? And people still say, No, not a chance. If water should be judged not by its history, but by its quality, how can we help society overcome this 'yuck' factor, this disgust associated with drinking highly treated sewage water?

Meny: Yeah, I love your example of the comb, and probably would have done the same thing. Indeed, it's a very challenging problem. And let's give you some background. Unlike desalination, wastewater reuse for providing drinking water supply is not very common. The technology is not mature, and the public is not aware of the details of this process. For example, Orange County, California, where an indirect potable reuse is being used since 1975. In this case, the municipal wastewater is treated to high quality drinking water, and the purified water is injected in the groundwater where it is mixed with the natural groundwater. So the groundwater moves very slowly, maybe a few centimeters per day, but they pump the water a few kilometers from the injection well, which means the water travels for about one year. So this is what we call indirect potable reuse. The water goes to the groundwater, then pumped for drinking water. Now, this one-year resonant time in the groundwater is enough to degrade or absorb any impurities that leaked through the membrane plant that they are using there. I believe the average person in Orange County does not even think about it as a direct potable reuse. So to overcome the 'yuck' factor, I believe that engineers and water utilities need to work with social scientists, like you maybe, Peter?, to educate the public, to trust the science, and to trust the safety of the water. We can take an example: the city of Windhoek in Namibia. This city is the only direct potable wastewater reuse in the world to provide drinking water. So in Windhoek, detailed water quality parameters are reported daily to the public so they can trust the process. They also educated the citizens of Windhoek and the citizens develop a pride that their city is the only one in the world that practices direct potable reuse.

Peter: That is a wonderful potential collaboration between social psychologists and chemical engineers, environmental engineers, and other experts on water reuse.

Meny: In fact, I wish we have more engineers that work with social scientists. But again, engineers like numbers, modeling, and they think that these social scientists are quite soft in a way. But we can learn so much from them because many of the problems are really not engineering, but more like culture, education, and outreach.

Peter: We talk about the gap between finding the solution, which is often the engineering challenge, and then being able to implement the solution and make it public policy. And that gap is usually a social science kind of problem, right? How we communicate, how we persuade, how we get over natural reactions of disgust kind of wired into us. All possible, but we don't always do the work. I'm reminded of Tony Leiserowitz in our School of the Environment, who does research on how to communicate about climate issues in ways that make them more understandable, more palatable, to a public who might be skeptical about climate change. Something similar here might be possible.

Meny: Indeed. Another example we always hear about water in developing countries like sub-Saharan Africa. The issue there is not technology. We have the technology to transform any water to any water quality that you need. But the problem there is really the culture. If you had one drop of Clorox or chlorine to the bucket of water, it would be quite safe. But they don't want to do it because they are used to drink the water with a certain taste. So we can build some treatment plans there for them, but again, you need to find some way to maintain them, to service them.

Peter: I think even Americans, if you told them, we're putting a drop or two of Clorox in your water supply, they'd be nervous about it.

Meny: Indeed, this is why many people drink bottled water.

Peter: No, exactly. You know, really, anytime I speak with one of our most well-known faculty members in any field—science, engineering, social science, humanities, arts—I'm reminded of the fact that there is no way at Yale not to be part of our teaching effort. Everyone does that, including you. And so I thought we could end our conversation with just a little bit about your teaching, and I'd be very interested in what courses you teach, and who do you teach them to.

Meny: So I teach an undergraduate course, Environmental Transport Processes, and a graduate-level course, Environmental, Physical, and Chemical Processes. In the undergraduate environmental transport processes, I teach processes that govern the transport of chemicals and contaminants in aquatic systems. After covering the fundamentals, theories for water transport and chemical transport, we cover the transport behavior of contaminants in groundwater, other aquatic environments, and engineered systems. We also discuss real-world examples like the well-known arsenic contamination of well water in Bangladesh that caused many cancers, contamination of groundwater by landfills and industries, and transport of viruses and bacterial pathogens in the subsurface environment. We must teach them the fundamentals so they can have the tools to analyze other new scenarios not encountered before. For the graduate-level course, I teach the principles and applications of processes and technologies for water treatment, wastewater reuse, and desalination. I also discussed the analogous processes in the aquatic environment. For example, filtration of pathogens in the subsurface environment, or adsorption of contaminants to soil. Students appreciate both the theories and application, and also like to hear about real-world stories related to these technologies that accumulated in many years through consulting conferences and visiting real plants.

Peter: Those sound like fantastic courses for environmental engineering students. And I know that your teaching has been recognized, and your mentoring has been award-winning--absolutely a great researcher, a great investigator, a great educator and mentor, but also a great person who impacts real-world problems--improving the world today and for future generations, just like our mission suggests. Meny, I'd like to thank you again for joining me on Yale Talk. The challenges that lie ahead for our climate are both grave and ever-growing. But when I walk around campus, I'm filled with hope. And that hope is because faculty members like you, Meny, are pushing the boundaries of what's possible, deploying your intellectual might for a planet in need. Yale's collective work is a down payment on what we owe future generations. And I'm optimistic that we will make good on our obligation.

To friends and members of the community, thank you for joining me for Yale Talk. Until our next conversation, best wishes and take care.

The theme Music, Butterflies and Bees, is composed by Yale professor of music and director of university bands Thomas C. Duffy and is performed by the Yale Concert Band.