Title: “Getting Out of a Sticky Situation: What the Hydrogen Economy Can Learn from the Chocolate Industry”
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Format:

[ ] indicates description of slide shown by speaker for that portion of presentation
paragraph below indicates the words spoken over that slide

Transcript:

[close-up image of flowing chocolate and the presentation title]
Good afternoon, my name is Tristan from the University of Minnesota MRSEC and today I’m going to teach you what the hydrogen economy can learn from the chocolate industry.

[diagram showing how hydrogen is produced using electrolysis]
Hydrogen has the potential to address climate change by replacing fossil fuels. The problem is its generation is currently highly inefficient. So if we want to enable the switch to the hydrogen economy we have to improve the efficiency of this process.

[closer look at previous diagram, zooming in on the anode component of the electrolysis setup]
A closer look at this process teaches us that what limits the efficiency is a material inside the electrolyzer called the anode. Now, very much research has gone into exploring new materials for higher-efficiency anodes.

[switches to slide showing the periodic table, highlighting ruthenium and oxygen]
And the most efficient material so far is ruthenium oxide. So our group had a simple goal: We wanted to take this state-of-the-art material, ruthenium oxide, and make it even more efficient by producing it with higher material quality.

[photograph of the Molecular Beam Epitaxy (MBE) equipment used by the UMN MRSEC]
And we set out to do this using a technique called MBE. So it’s quiz time: Who knows what MBE stands for? Does it stand for: A) Molecular Beam Epitaxy? Or B) Most Broken Equipment? The correct answer is, technically... A) Molecular Beam Epitaxy. But, don’t be intimidated by the long name or all this shiny equipment because in principle this technique is actually very simple.

[diagram showing a round vacuum chamber. Ruthenium and oxygen atoms are injected into the chamber. A green line representing a seed crystal in the chamber shows where they are deposited.]
First, you need a vacuum chamber that you suck all the air out of - you can think of this like outer space in a jar, basically. Then you have to supply the constituent elements in a controlled manner. And you do this by evaporating ruthenium at the same time that you leak small amounts of oxygen into the chamber. Then these two beams of atoms and molecules intersect the surface of a seed crystal where high-quality ruthenium oxide is formed. The thing is, our group had a hard time evaporting the element ruthenium because different elements evaporate at different temperatures. So I want to put these temperatures into perspective for you.

[beside the vacuum chamber, another graphic appears, a chart showing different temperatures from outside in the winter, to the temperature required to evaporate ruthenium]

Let's start with something cold, like Minnesota winters.They get down to negative forty degrees Celsius. Now let's think of something really hot, like, I can remember last Thanksgiving I cooked my turkey at one hundred and seventy-five degrees Celsius. But it turns out that if you want to evaporate metals you have to go to much higher temperatures. Iron, for example, requires one thousand, three hundred degrees Celsius to evaporate. And ruthenium, the element we need to evaporate, requires temperatures exceeding two thousand degrees Celsius. This is so hot there's no material that could contain the ruthenium as it's evaporating that would survive such high temperatures. So given this seemingly unchangeable fact about ruthenium how can we possibly proceed? Well, let's not lose hope, and start by understanding why ruthenium is so hard to evaporate in the first place and that might give us some hints as to what we can do about it.

[image showing a solid block of color representing electrons, with circles representing ruthenium atom cores floating around in it]

If you think of a ruthenium atom, as a ruthenium core with electrons orbiting around it, if you put a bunch of these ruthenium atoms together, like, when you buy a piece of metal from a store, these electrons melt into an electron ocean with ruthenium cores floating around in it. And this electron ocean is really the problem because it's kind of sticky, and it prevents you from pulling out the individual ruthenium atoms, which you need to do to evaporate them.

[image showing solid block of color representing melted chocolate, with shapes representing peanuts floating around in it]

If this explanation confuses you, let me provide you with a simple analogy: Imagine a chocolate-covered peanut. Now imagine storing a bunch of these peanuts together in a jar. On a warm day that chocolate will melt into not an electron ocean, but a chocolate ocean. And this sticky chocolate mess will prevent you from reaching in your hand and pulling out individual chocolate-covered peanuts. So if we want to solve this sticky electron problem, maybe we can learn something by first solving the sticky chocolate problem. And lucky for us this has already been solved.

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Because the U.S. military had this exact problem during World War II. You see, the military likes to carry chocolate as an energy-dense, nonperishable foodstuff, and this was no problem during World War I, which was fought in temperate Europe, but during World War II, which was fought in the tropical Pacific, American soldiers couldn't, for example, carry chocolate around in their pockets without it melting.

[shows portrait of Forrest Edward Mars, Sr. And close up of chocolate-covered candy, and a diagram of candy-coated chocolates in a jar showing how they stay separated]

The solution to this problem came from a Minnesota-born entrepeneur: Forrest Edward Mars Senior. And he provided a very simple - and elegant - solution: He said "Stop trying to reformulate the chocolate. It doesn't taste good when you do that. Instead, coat the pieces of chocolate in a thin shell of hard candy. Then, during storage, even if the chocolate itself begins to melt, it'll be contained and isolated in these thin shells of candy. Then you can still reach in your hand and pull out the individual pieces of chocolate when you need them." And this was, of course, the birth of the candy, M&Ms®.

[image of ruthenium atom]

So I know what you're thinking. You're saying, "That's a really cute story, but how can we possibly take anything from that story and apply it to our ruthenium problem? I mean, We can't take our ruthenium atoms and coat them in candy." But maybe we can coat them in something else. It would have to be something smaller... What about ligands? What's a ligand?

[around the ruthenium atom appear other molecules with oxygen atoms binding to the ruthenium]

Well, a ligand is just a molecule that's known to "bite" onto a metal atom. So we tried just this. Let's see the result:

[temperature graph shown, from winter temperatures to the temperature required to evaporate ruthenium, also small insert of the previous ligand explanation slide]

Here is the spectrum of temperatures I introduced earlier. I remind you that ruthenium by itself evaporates above two thousand degrees Celsius. But if we coat the ruthenium atoms in ligands, we can lower this temperature, and lower it substantially. We can even lower it below that at which iron evaporates all the way down to one hundred and seventy-five degrees Celsius, the same temperature I cook my turkey at.

[slide stays the same but at the bottom appears an image showing the organized deposition of ruthenium atoms on a substrate]

This allowed us to deposit ruthenium oxide one atomic layer at a time, as you can see in this microscope image, where each of these white dots is one ruthenium atom, we are able to deposit it with perfect material quality.

[slide showing flowing chocolate in the background with funding and contribution acknowledgements]

I'm Tristan from the University of Minnesota MRSEC, and this was a story about how we got ourselves out of a sticky situation. Thank you for listening.