Dipti Kamath: Hello, everyone, and thank you for joining the webinar today. We are going to give the folks another minute to join, so let's wait, and we'll start soon. Thank you.

Okay, then. Let's get started.

Hello, everyone, and welcome to the 2023-2024 Better Buildings webinar series dedicated to bringing you the latest actionable insights from leading industry experts. This annual series is a chance to explore the topics, technologies, and trends that affect your organization, as well as efforts to accelerate the decarbonization and energy efficiency adoption.

Today's webinar – next slide please – is called Getting a Handle on Clean Hydrogen. Before we dive in, there are a few housekeeping points that I would like to cover. Please note that today's webinar will be recorded and archived on the Better Buildings Solutions Center. We will follow up when today's recording and slides are made available.

Next attendees are in listen-only mode, meaning your microphones are muted. If you experience any audio or visual issues throughout the webinar, please send a message in the Q&A box located at the bottom of your Zoom panel. Next slide.

So my name is Dipti Kamath, and I'm your moderator today. I'm an R&D staff member at Oak Ridge National Lab, where I work on techno-economic and life-cycle assessment of emerging technologies for industrial decarbonization. I'm also a technical account manager for the Better Plants and Better Climate Challenge program.

So let me give you what our agenda is going to look like. So next slide.

We'll start with introducing the topic itself to you all, go into a couple of polls, then we'll have our two speakers give their presentations, and we'll have a Q&A and conclusion.

So let's dive in. Next slide, please.

What I want to start off with is looking at the opportunities that industrial facilities have for using hydrogen as a fuel. What you're seeing on the screen is the breakdown of energy use onsite for manufacturing facilities as per the manufacturing energy consumption survey in 2018.

So in 2018, we see that process heating accounts for 51 percent of the energy use onsite, and that gives us a direct opportunity to use hydrogen as a fuel. Now looking at hydrogen itself, next slide, please, you will see that there are – next slide. There are different ways you can produce hydrogen, and that's going to give you different carbon intensities for the hydrogen. Typically, you would have natural gas or coal used as feedstock. That gives you the gray and brown hydrogen. But as you add carbon capture, you get blue hydrogen with natural gas, if you're doing electrolysis with renewable energy, you get green. And as and when you go further down that scale there, you would get lower carbon intensities.

Going into next slide, what you see here is the industrial applications as of now of hydrogen as a fuel. The darker the color you're seeing is currently deployed. So you can see that in refineries, chemical industry, and cement, you're seeing some sort of application of hydrogen, but there's a lot more potential that you are seeing in the light reddish color in almost all the industrial sectors, mainly because the key properties of hydrogen combustion gives you a high temperature, high heat flux. It's able to heat a lot of materials, and you're able to use it in relevant equipment all across.

Going into the next slide, we also have expected hydrogen availability in the US, a lot of storage, 350 gigawatt hours of thermal energy storage with a lot of miles of dedicated hydrogen pipeline. We also have quite a few production projects that are planned or underway, and a lot of availability of hydrogen that can be expected for industrial uses.

Going into the next slide, so this particular slide is talking about what the factors are that are preventing large scale application of hydrogen. So you have factors such as safety, economics, blend challenges, and so on, but also costs. So there's this very interesting aspect of what the private sector's focusing on, looking at the technical aspects as well as the cost aspects, and the public sector or DOE is focusing a lot on bringing down the cost of hydrogen to $1 per kilogram of hydrogen.

So this is a time when we can look at what are these interests when we are looking at deploying hydrogen, and that's at this point that we are bringing the two speakers that we have today to talk about this.

So going into the next slide, I believe we have our interactive platform for Q&A and polling. So, I would ask you all to go to www.slido.com on your mobile device or by opening a new window in your internet browser. So, today's event code is #DOE. So, if you would like to ask any of our panelist's questions, please submit them anytime throughout the presentation. We'll be answering your questions near the end of this webinar.

You can select the thumbs up icon for questions that you would like to be answered first, which will result in the most popular question going up, and we'll bring that to the panelists first. So that's that.

And then what we would like to do is get to know a bit about you. So, we'll start off with a few poll questions. So please join us over at Slido to respond to the following questions. So, if you have any issues, please message our tech support team by using the Zoom Q&A function.

So, yeah, great. Thank you for starting to answer that question. So, have you considered hydrogen use in your facilities? We are seeing a lot of no's there. Okay. And thinking about it is increasing. Okay, cool.

Okay. So, around 45 percent says no, but then there is a mix between yes and thinking about it. A little over 50 percent are either yes or thinking about it. That's pretty promising for hydrogen, and I'm sure we'll have our speakers talk a little bit more on that, and maybe we'll have the no's considering it as well towards the end.

Okay. Thank you.

Going into the next question, I think would be, this is something we wanted to know. What's the biggest barrier to adopting clean hydrogen in your facilities? So, this is going to be you putting in what you're thinking. So cost, yes, safety, availability, funding. Okay, I'll let you add in stuff.

Okay. So, I see cost and availability, cost and safety come up quite a bit. I'm going to let it go for a little bit more just to see what other things would come in.

Okay. Okay. Too new of a technology, interesting, yeah. Technician familiarity, retrofit cost, okay. Public perception. Okay. Thank you. Thank you, everyone.

Moving on to the next question, because we want to give our speakers a chance. Have you all heard of DOE's Hydrogen Hub? Curious, okay. That's a lot of no's, okay. So, we'll be sharing resources towards the end of the webinar, so you could take a look at that and that would help you understand more about hydrogen hubs that we have.

Going into our presentation today, we do have a great lineup of presenters today. So, we have two speakers, right? So, we have speaker one, Dr. Marc Gurau, is the Global Technology Senior Manager for Chemours Hydrogen Economy Venture.

Throughout his career, Marc has worked to develop, measure, manufacture, and implement fluoropolymer solutions to help solve challenging problems. In his current role, Marc focuses on the development and commercialization of new ionomer technology aimed at elevating the performance of proton exchange membranes. Marc leads a team of scientists and engineers to support the decarbonization of industries across the globe through the growth of hydrogen as a viable fuel source.

Our second speaker is Praveen Cheekatamarla. Dr. Praveen Cheekatamarla is a senior researcher at ORNL focusing on developing clean energy efficient technologies for buildings and the industry. He has over 16 years of industrial experience in developing products for the remote power market and the US military, and he has also served as a technical leader, director of research, and so on.

His primary areas of expertise include thermochemical processes, reaction engineering, fuels and fuel cells, hydrogen technologies, co-generation, catalysis, energy modeling, system analysis, and integration.

So, thanks to all of you for being with us today, including our great speakers. So, I'd like to start with Marc. So go ahead, Marc, take it away.

Marc Gurau: Thank you, Dipti. And good morning, everyone. If we could advance to the next slide.

So I am here to help support this webinar because Chemours plays a critical role in the development of the proton exchange membrane technology that is critical to the growth of hydrogen in the near future. So, on the next slide, please, I'm going to briefly introduce Chemours and explain the role that Chemours plays within the hydrogen economy. Next, I'm going to talk a little bit about the momentum that we've seen.

So, hydrogen may be new to some of you, but it's not a new technology. What is new is the tremendous growth and emphasis that multiple governments and industries around the world have placed on it in their attempts to use hydrogen as a means of decarbonizing our energy systems and our planet.

And then lastly, I'm going to talk about Chemours' commitment to responsible manufacturing. So, this is a really important aspect of how Chemours brings fluoropolymer solutions to a commercially viable state and helps to support the world with this really essential chemistry.

Next slide, please. So, to start off, let's talk about Chemours and specifically what is Chemours doing within the hydrogen economy. Next slide. So Chemours is a market leader in the production and manufacture of performance chemicals. So, if you look on the left-hand side of this slide, you'll see a list of the markets that are served with these materials.

There are three primary businesses within Chemours. The first one is our titanium dioxide business. Second, we make thermal management and specialized solutions. The last is our work in advanced performance materials. That is where our hydrogen economy venture sits. That is where I work. And I'm going to focus the rest of our talk on some of the technologies that we have in there and show how those technologies are supporting our hydrogen economy venture.

Next slide, please. So really important to understand is that fluoropolymers and fluorinated ionomers are a very special chemistry within our world. The nature of the carbon-fluorine bond is unique. It is the strongest bond within organic molecules, and it delivers properties that you cannot achieve with other materials. These materials are really the only way in which we can provide the methods and the technologies that support not just exotic applications, but your everyday life.

So, if you look through this slide, you'll see comments about the corrosion resistance these materials have, their electrical properties, purity, strength, thermal resistance. All of those directly result from the very powerful chemistry contained within that carbon-fluorine bond. And what you'll see at the bottom on the right-hand side are maybe some of the more familiar brands that

Chemours supports and you might recognize some of these as these support some of the most difficult problems in the world, but also things in your everyday life.

So when you think about cell phones, computers, semiconductors in general, you know, when you think about transportation, when you think about aviation, when you think about many of the technologies that you use directly or the technologies that are used to produce the things that support your everyday life, our fluorinated chemistries are an essential part of those manufacturing chains and the products themselves.

So if you move on, when we talk about a hydrogen economy, we're really talking about more than just making hydrogen. Now that's a really important part about it. So, in our current fuel systems, we harvest hydrocarbons from the earth. In a hydrogen economy, we're able to make our own fuel. So, we would use renewable energy sources like wind, solar, hydro, so carbon-free sources to make a carbon-free fuel. And as such, we can completely decarbonize our energy system. This can lead to significant reductions in greenhouse gas emissions.

Now as you look here in the top right, we're trying to show a little bit about the infographic where you can see multiple sources of renewable energy, and then we use a technology called water electrolysis to harness that energy and make the hydrogen. The reason for doing this is that hydrogen provides us a means of storing that energy in a chemical form, much in the same way that energy is stored in chemical forms today.

That allows us to store the energy over long periods of time. We can use it to level out swings and fluctuations within energy grids. We can use it to transport energy from one place to another, all because of the very stable source of hydrogen that we have and its long-term storage capabilities.

We can transfer that hydrogen through pipelines and other means, including offshore tankers, and even in other forms. We can then use that hydrogen as a fuel directly, as we were talking about, within buildings to support combustion of hydrogen. But we can also use some of the more efficient processes of electrochemically converting it into energy, and that is using the technology that we refer to as fuel cells. And you can see this allows us to power cars. We can power buildings directly. And we can even use that hydrogen in many industrial processes.

The water electrolysis makes a very pure, very high-value hydrogen that can even improve some of our carbon-intense processes like steel manufacture or ammonia manufacture.

Next slide, please. The role of Chemours is as the owner and manufacturer, in fact, inventor of Nafion, which is a fluorinated ionomer that forms a membrane which sits at the center of a water electrolyzer and the fuel cell. This material allows for the electrochemical reactions which make hydrogen and convert it to energy to happen in a very efficient way.

By growing the hydrogen economy, by increasing our Nafion use and supporting the growth of electrolyzer and fuel cell use, we can boost global manufacturing. We can also, you know, change the way in which the supply of these materials is made and provided to different areas, shifting completely away from some of the current limitations of our hydrocarbon-based system.

And most importantly, we can decarbonize our economy. We can make and use energy with zero carbon footprint as long as we use the right resources for the manufacture and the energy that we put in.

And lastly, this can be an area of improving our technology leadership. So Chemours is committed to helping to bring these technologies to the world to use our vast experience with these materials and these systems to help to grow the hydrogen economy globally.

Next slide, please. So, hydrogen itself, as I mentioned, is really having a fantastic moment. The need for decarbonization lines up really well with the capabilities that hydrogen brings to a new energy economy.

Next slide, please. So, Dipti had shown one of these slides before, which was focused on the United States. I will show a global slide, which simply demonstrates how much additional investment and interest there is in bringing hydrogen to the world. So, you can see we have thousands of projects, billions of dollars are coming from various sources in order to bring forth this transformation.

Now this is a significant transformation, not just for energy, but for our whole society. So, it will take some time and you'll see how these projects will play out over multiple years. But we have the opportunity over the next three, five, ten years to completely revolutionize the way in which we create our fuel and use it to power our lives.

Next slide, please. So, in a system where we decarbonize or our net zero scenario, the demand for low carbon hydrogen grows quickly. And it's important to note that hydrogen, as I said, can be made by various sources. The ones that use renewable energy and electrolysis technology are the ones that do the most to reduce the carbon intensity of that hydrogen.

And you can see in 2022 and 2024, the amount of hydrogen represented in megatons is quite small, but it grows very quickly over the next several years, leading to, growing on a path towards 80 megatons almost by 2030. And you can see by the various colors, the multiple applications that hydrogen can support and the various industries that will be aided by the increased use of hydrogen.

Next slide, please. So, some of the specific benefits of hydrogen in terms of the new energy infrastructure is shown here on the left. Overall, hydrogen can provide increased flexibility to our system. There can be significant demand-side flexibility, which allows for us to harness energy when it is cheapest and to make the overall capture of renewable energies more efficient.

Security and resilience are also important. By being able to make and store our own fuel, we will create a degree of energy independence that is not possible within our current hydrocarbon-based energy systems. We can distribute hydrogen production into more places, and we can avoid the overemphasis of control based on geopolitical placements of the different resources.

And lastly, affordability. And this is one that is very important to Chemours. So Chemours is working very hard to help hydrogen to become cost competitive. Our hydrocarbon-based economy has had hundreds of years to improve its efficiency and to find ways of minimizing this cost, and they have done very well. Tremendous engineering expertise has gone into that. But as we bring our engineering expertise to bear on this problem, you will also see advances towards our goal of the $1 per kilogram of hydrogen.

Chemours, with its ionomer technology, can help electrolyzers and fuel cells to be more efficient, and we can help them to be produced more efficiently, all of which, when combined with an appropriate economy of scale, will drive the cost of hydrogen down to a place where it will begin to compete directly with other energy sources. And when you then bring in the benefits of decarbonization, we'll easily displace them as a decarbonized competitive fuel system of the future.

Next slide, please. The last portion of the talk is really based around the responsible manufacturing of these materials. These materials are critical to the hydrogen economy. We will not be able to decarbonize our planet without them. But just as we need these materials, we need them to be made in an appropriate and responsible manner.

So Chemours is committed to not only its own internal decarbonization and environmental stewardship, but also the things that we can do for ourselves and our supply chain to make these materials in the most responsible way possible.

So on the next slide, I'll explain exactly what I mean by that. So Chemours has publicly committed to a series of corporate responsibility commitments. They are grouped into four high-level categories, and we continue to report our progress towards these ten bold goals. So today, I'm going to focus mostly on our commitments around environmental leadership.

Next slide, please. So, our commitments are to drive down greenhouse gas emissions and to reduce fluorocarbon emissions into our environment. And these are not just words. These are actions that we are actively taking and investments we are actively making in order to improve our manufacturing processes.

So here is a global picture of some of the investments that Chemours has put forward in order to improve our emissions and our decarbonization. One of the most important I'm going to call attention to is shown in the top left. You'll see that in West Virginia, Chemours is working with the Department of Energy to institute the ARCH2 Hydrogen Hub. And at the end of the talk, there will be some resources so that you can dig into this more deeply.

Hydrogen hubs are a collaborative effort between government and the private sector to break the chicken and egg that has prevented hydrogen from moving forward in the past. We are going to invest in hub facilities that will make hydrogen and help to jumpstart the demand for that hydrogen. This is the beginning of a U.S. infrastructure for the use of hydrogen.

So for those of you who are being concerned about the availability and the maturity of these technologies, these hubs will make these materials commercially available and begin the commercial supply within the United States. There already is some, but what you will see is that a distribution of these funds across the country and a significant investment in order to kick start our hydrogen economy at home.

Next slide, please. So, our Advanced Performance Materials group is not only interested in helping to make the ionomer that enables the world to decarbonize, but we ourselves are driving internal initiatives that are decarbonizing our research efforts and our manufacturing.

So, as you can see here, by the end of 2023, we exceeded a 60 percent reduction in carbon emissions. So, this was seven years earlier than our corporate goal, but we're not done yet. We still have to path towards achieving our net zero goal by 2050. And you can see on the right our progress towards that. And you can continue to check in on our progress by looking at the sustainability reports that we publish on a regular basis.

Next slide, please. So, we've been able to achieve our carbon emission reductions largely in the same way that many of you are looking to achieve your carbon reductions. We are instituting the increased use of renewable energy, and we are increasing the efficiency of our facilities, enabling them to function with less power use and optimized processing.

Now, we also uniquely do a lot of work to reduce our fluorinated organic chemical emissions, and you can see here that we have completed a significant number of projects achieving a significant reduction in that, well on our way towards our goal of 99 percent reduction.

Now, if I could move on to the last slide.

I'd like to thank everyone for attending this webinar and for their interest in growing the hydrogen economy. This is an effort that we at Chemours are very committed to and very excited about, and we look forward to engaging with our value chain, our end users, and all of you in helping to make hydrogen our fuel of the future.

Thank you very much, and I'll turn it back to Dipti.

Dipti Kamath: Thank you, Marc. That was great. So, a quick reminder to everyone that if you have any questions, you could send it through www.slido.com with the event code #DOE. We look forward to answering all your questions. I've seen quite a few come up, and that's great.

So, I hope Marc was able to come up with some of those barriers that you all talked about, like cost, availability, the discussion on hydrogen hub, and so on.

And now what I want to do is call on Praveen. He's going to talk about fuel flexibility, all that research on how to use hydrogen as a fuel itself. So, the second part of it, the technical details, the newness of that technology and how you can do.

So Praveen, take it away.

Praveen Cheekatamarla: All right. Thank you, Dipti. All right. Thanks for the opportunity today.

Good morning, all. My name is Praveen Cheekatamarla. I'm a senior researcher at Oak Ridge National Lab. Today, I'm going to talk about the end-use side of hydrogen rather than the production side that Marc discussed. So particularly, I want to touch on the thermal energy, how hydrogen can be a sustainable solution in that space.

Next slide, please. So, before we jump into the end-use technology that we have developed, I want to discuss the significance of hydrogen. So, it's a versatile energy carrier, and given its high energy density, it is suitable for both renewable grid stabilization and indirectly the electrification objectives of the governments and countries across the globe.

And if you look at the power plant in use today, the capacity factor varies depending on the core primary energy resource there. For nuclear, geothermal and natural gas, the capacity factor, meaning how much time does the plant work at its 80 percent or more capacity. But when you look at the renewable sources, hydropower, wind and solar, their capacity factor is pretty low. And this is where hydrogen and energy storage comes into play. I'll touch on that in the next slide. But hydrogen is a very good fuel with no greenhouse gas emissions when you burn it or utilize it in power generation, and it's suitable for both electrical and thermal energy generation. And hydrogen is already a key chemical building block as we use it today for manufacturing different chemicals.

So beyond the power and thermal needs, it also serves multiple other purposes in the chemical world. And it can be produced in different manners. For example, you could use thermal energy, solar energy, electrolytic processes and biological routes. And when it comes to the industry, it is ideal fuel for addressing high energy intensity and hard to decarbonize applications.

So let's go to the next slide, please. So, as I said, hydrogen is a good candidate when it comes to energy storage. If you look at this picture, what I'm trying to show is in the conventional grid today, if you were to deploy these low-capacity factor renewable energy sources like PV and wind, there is always a disconnect between the storage profile, I'm sorry, the production profile and the consumption profile. That's where you need to store the excess energy, which in this case could be via an electrolyzer. And you produce hydrogen, store it and use it for your all hydrogen loads, whether it be power generation, thermal energy generation or direct consumption of hydrogen in the chemical industry.

So given its stability, it can be stored for a long duration. So, from a seasonal standpoint, it can be a very good option and it helps decouple the energy production and consumption disparity. And in a way, it enables renewable energy grid because without storage, renewable energy, given its low-capacity factor, is difficult. It is also suitable in both centralized and distributed scenarios.

So, let's move to the next slide, please. So here, what you see is the production routes. Dipti already touched on this, but I just want to give you a little bit more in-depth idea about the conventional and emerging technologies, which Marc touched on.

In the conventional routes, today's steam methane reforming of natural gas is the major hydrogen production route, followed by byproduct from the chemical industry and in some cases coal gasification. And the carbon intensity of hydrogen actually increases in that order. But when you look at the emerging technologies, three major processes are available to us.

One is electrolysis and how you power that electrolyzer, whether you use renewable energy or nuclear power or grid electricity, that carbon intensity varies. But then if you are using fossil fuel, but actually containing the carbon emissions, then it could be a good resource also with low carbon intensity.

And when it comes to the use cases, today it's mostly used in the industrial world for steel manufacturing, ammonia, methanol and refining. But then the new anticipated applications are possible in all sectors of the economy. For example, transportation and industry and heat and power for both buildings and industry.

So as you see, hydrogen has a significant role to play in both power generation and thermal energy generation, but I want to focus on just the thermal energy side of things today.

Can we move to the next slide, please? All right, so here are some challenges associated with hydrogen. It's not rosy, but a lot of investments are happening, as Marc mentioned. So, the first and foremost, as you all pointed out, the cost of hydrogen is a big factor. And today, depending on the process, it could be as high as two dollars per kilogram.

And the cost is projected to come down to around one dollar per kilogram. And many studies have shown that around half a dollar per kilogram of hydrogen is very competitive, even in a decarbonized net zero world.

And the most important thing beyond the cost is the carbon intensity of this hydrogen. Yes, we can produce carbon at a low cost, maybe today, relatively lower cost, but then the carbon intensity matters. Depending on the process again, that carbon intensity, meaning how much carbon dioxide you are producing to make one kilogram of hydrogen. For some processes, it could be as high as 19 kilograms of CO2 per one kg of hydrogen. But then if you utilize renewable energy, that number could be almost negligible. For example, with green routes, it could be as low as 0.1 kilogram per kilogram of hydrogen.

So and some of the other challenges include the production technology, the maturity of it. For example, in the ancillary markets, the electrolyzers, their efficiency, their cost, all of that is important for building the capacity and producing hydrogen at scale that can fulfill the needs of all sectors of the economy. And for example, renewable energy generation has to grow for hydrogen to become a reality, and that's the path we are on already. So, it's a good marriage between the production and the storage technologies.

And for some applications, high density storage, for example, solid state hydrogen storage is necessary to enable the distribution aspects of it. And when it comes to thermal energy, the combustion could be an issue depending on the process conditions and the overall operation environment. Flashback of hydrogen is a known factor. But if you design it properly, that wouldn't be an issue. Emissions, in some cases, are a concern. And when it comes to distribution, hydrogen, if it leaks, first of all, it poses a safety challenge, but also it has a global warming potential of 5.8. So sensing those and containing those leaks is important. This might sound intimidating, but a lot of investments are happening to address all these challenges throughout the production, distribution and end use sectors.

So, can we move to the next slide, please? Here is another slide showing the carbon reduction potential of hydrogen. The chart on the left shows the amount of hydrogen, as it increases, the amount of carbon dioxide reduction potential also changes. But the key factor here to consider is the carbon intensity of that hydrogen. If the hydrogen is generated from a dirtier primary energy source, then obviously the carbon reduction potential decreases.

But then if that hydrogen is clean, meaning it is produced from renewable energy, then for every bit of natural gas that you would replace with hydrogen, you would save that much CO2 emission. And to give you a better idea, the bar chart on the right shows the carbon reduction potential in industrial heat and other sectors of the economy. So, for every kilogram of hydrogen that you use, you could eliminate around seven kilograms of CO2 today.

For example, to replace the process that is utilizing natural gas. And if that process is using coal as your primary energy, you could decrease your carbon emissions by 12 kilograms if you were to utilize just one kilogram of hydrogen. So that's the carbon reduction potential of hydrogen and depends on what it is replacing.

And the other factor to consider in this case is for some applications, for example, direct heating, the amount of steam produced may matter. So, the process needs to be designed and consider those sorts of challenges.

Can we move to the next slide, please? All right. So now I want to share some of the work that we've been doing in this space, especially using hydrogen for producing thermal energy. Here is a summary of where we stand today. We have developed this infrared heating module. It can be applied both buildings and industrial needs, but mostly for heating applications in these spaces.

So the primary benefits, I will discuss and share results of what I mean when I say some of these benefit factors. It is both atmospheric and premixed designs, and it produces infrared emission, which is clean and also very efficient in transferring that thermal energy to the process that you're heating. And this module can accept a wide range of hydrogen concentration, meaning you can run it on natural gas, 100 percent natural gas or 100 percent hydrogen or any concentration of hydrogen and natural gas mix of those two gases and without making any changes.

And if you were to compare the efficiency of this thermal source, it could save 20 percent energy compared to a blue flame generated thermal energy. And so the NOx emissions is another factor. Even with natural gas today, those emissions tend to be much higher. And with this technology, NOx emissions are below two nanograms per joule. And the module is capable of modulating the fuel so you can turn down the energy produced on the same module. And it can generate temperatures up to 1200 degrees Celsius. And for some cases where your energy intensity or energy density is critical, it can go up to 3000 BTU per hour for every square inch of surface area.

And it is scalable, and it can be built as a planar architecture or a tubular architecture, depending on the needs. And it is suitable for both direct heating and indirect heating. Direct heating, you can heat up your product directly with the infrared emission. And for indirect heating, indirect heating, you would heat up your fluid, whether it is hot air or water, to transfer the thermal energy to your process.

And it is suitable for industrial process heating and drying applications and for commercial kitchens, commercial food service, quick service restaurants and wherever high energy intensity is needed.

Can we move to the next slide, please? Here is a slide talking about the fuel flexibility and safety of this technology. So, the first chart on the left top side, what you're seeing is a green line. Green line represents the continuous variation of the hydrogen concentration in natural gas. You start with 100 percent natural gas and then slowly blend hydrogen without making any changes. It's all done in a single test.

You can move it from zero to around, in this case, 85 percent hydrogen without making any changes. This is done in an atmospheric burner, meaning there is no air blower. It's directly taking in the hydrogen, using the multi force of the fuel to entrain the air and burn it cleanly and safely.

So you are, as you see, the overall energy produced is almost constant and then the temperature is almost there. And we have also tested it. The first application for this core concept has been in a cooking range where you can see the pictures in the bottom. A cooktop running on hydrogen and also an oven burner running on hydrogen. And in this case, it was blend of around 75 percent or so.

So, yes, it is safe to operate in many scenarios. For example, one thing we did was we introduced perturbance in the hydrogen concentration and also the flow rate just to mimic what happens in your distribution line. If there is instability in the distribution network, what happens, right, your concentration could change.

And what happens in those scenarios? It is safe, as you can see in the bottom chart. And we have also operated it in a premixed burner mode where on 100 percent hydrogen. So, it is safe to accept hydrogen or any concentration of it and operate in a safe manner and clean manner.

Move to the next slide, please. And here is another slide talking about the energy efficiency. So, what we have done is we compared a process. In this case, it was a simple heating up the water to a certain temperature using a known amount of energy. In one case, it was using natural gas with a blue flame burner that you're all familiar with. And in another case, it's the infrared burner still operating on natural gas. So, we can compare apples to apples.

And in the hybrid infrared heating, the total energy consumed was around 15 to 20 percent lower compared to the blue flame. And that is purely because of the efficient radiant heat transfer to the process. In this case, it was simply heat transfer to the water in a container. But you get the idea.

And we move to the next slide, please. And then talking about the emissions, again, we did comparison with a traditional blue flame burner again operating on natural gas and compared that with this new technology, infrared emission. And in natural gas with blue flame, the total NOx emissions were around 24 nanograms per joule. And in the case of infrared burning technology, it was less than two nanograms per joule.

So this is emanating from the fact that the thermal NOx formation routes are suppressed in the flame mode. The temperature reaches almost 1600, 1700 degrees Celsius. And that's when nitrogen in the air reacts with oxygen and forms NOx. And in this case, in the infrared, because of a lower operating temperature of 900, 1000, 1100 degrees Celsius, that thermal route is suppressed, and NOx emissions are no longer to be seen.

And then introducing hydrogen again doesn't do much because that temperature still resides in whatever we design it for. We can design it for 500 degrees Celsius or 1200 degrees Celsius. It all boils down to the energy density per unit surface area. So that's the emissions.

And can we move to the next slide, please? Another slide talking about the safety aspect of it. In some instances, these modules will have to undergo a lot of operating challenges. For example, you would start and stop the heating process intermittently.

So what happens in that case, for example, in a cooking range? Yes, you tend to see those sorts of occurrences. And also, you may want to just start it. And for some reason it stops, and then immediately, if you have to start it, ultimately, we are dealing with sensitivity of hydrogen, the safety aspect of it.

So this module is capable of addressing those operational challenges, meaning hot restart. What happens when you start it, stop it, and then the burner is still very hot, but then you try to restart it. Does it flashback? And in all these scenarios, no safety concerns were noticed. It operated smoothly. And so thermal cycling wise, it is also capable.

Next slide, please. Here are some pictures of different prototypes we are working on at the moment. Again, these are all small scale, maybe suitable for buildings, but this is definitely a scalable technology which can be applied even in the industry. And in some cases, the modules, for example, the 100,000 BTU module is a building block for some of the infrared heating solutions for industrial heating and drying today. So, it's a direct replacement of those burners or those infrared emitters.

So the pictures, the ones on the left are for the oven burner operating in both blue flame mode and infrared mode. That goes by the energy intensity factor. And another burner for the RVs, a cooktop in the RVs and boilers and furnaces, high-capacity ones, and then a generic heater, 30,000 BTU.

So the upshot is, you know, it is geometry agnostic. It can be built in both tubular and flat configurations. And it is scalable, and it can be turned down safely, meaning the modulation of the energy and temperatures up to 1200 C. And one important thing from an industrial standpoint, whenever you talk about infrared, the wavelength of that infrared emission is critical for certain processes.

And you can tune that wavelength by modulating the fuel, get the right wavelength so maximum amount of energy can be absorbed by your product that you are treating, heat treating or drying or whatever the process may be.

And similar production costs at 1000. We have done techno economic analysis of a 30,000 BTU burner and compared to a blue flame burner, the production cost is comparable at a production quantity of 1000.

So next slide, please. So, what's the outlook for hydrogen? Well, globally, it is a key net zero energy pillar, as Marc and Dipti mentioned before. And it is the ideal solution for hard to decarbonize sectors of the economy. And it definitely offers an energy independence pathway for some of the countries with minimal natural energy resources. And the evolution of renewable energy grid will naturally create the demand for clean hydrogen technologies. You need to store that energy. You need to stabilize your grid. Well, hydrogen is the solution, given all of its good properties.

And so for when considering the industrial heating and drying and any other high intensity thermal needs, it can be used in a safe and clean manner. As I said, the technology that we developed is flexible enough to accept a wide range of combinations of fuels, including propane and biogas, and it is flexible for adapting in different existing combustion and thermal heating devices, and it also provides you higher energy efficiency and lower pollutions. So, these are all desirable characteristics when utilizing these precious green fuels to decarbonize our economy.

With that, I conclude. Thanks for your attention and thanks for the opportunity.

Dipti Kamath: Thank you, Praveen. That was great. Okay, so I wanted to take this opportunity to thank both our speakers today for their insightful presentations. And before we transition to the Q&A, I wanted to encourage you all to download our additional resource handout. The link has been put up in the chat feature today. We have all the links to all the reports and all the data that was presented today in there. I hope you'll find all that useful.

So now moving on to the Q&A, we've seen quite a few questions. Can I just pull it up? Hold on. Okay, thank you. So I'm going to go with the first question since and I think Praveen would be able to answer that about how hydrogen generation versus batteries might compare in qualitative or even cost terms. Do you have any insights on that?

Praveen Cheekatamarla: Well, cost is a major factor today, but it wouldn't be a factor ten years from now. Right. So, if you were to compare the energy density aspects of the batteries versus hydrogen, then I think the way I see it is the batteries and hydrogen are not competing technologies. They are actually complementary technologies. So, from a grid standpoint, the big picture scenario, I think they are complementary. Well, yeah, from a cost standpoint, it may not be there yet, but in some applications, it could be an ideal solution. So, yeah.

Marc Gurau: And I would add to that the electrochemical opportunities with hydrogen enable it to take advantage of a lot of the advances that are going on within electrification. So as we increase the electrification of our systems, you know, not only the pure electrical, but also the electrochemical power sources can benefit from that. So the work that we're doing to electrify vehicles and other aspects of our society will also bring that benefit to an electrochemical energy source like hydrogen.

Dipti Kamath: Thank you, Marc. Thank you, Praveen. Yeah, I also wanted to ask Marc, like there is a question later in the chat, I know not in the chat, like in the list about the best production method for hydrogen and how they compare. I know I'm going off the thing, but it came up quite a few times. So, Marc, if you could take it.

Marc Gurau: Happy to. So, there is a lot of work to be done in order to decarbonize our society, and there are several different technologies for the production and utilization of hydrogen. Oftentimes people try to oversimplify this question and they assume we're going to pick one and move ahead with it. I'm not sure that's necessarily the case.

So, while there are lots of methods of doing that, they have complementary aspects to them. Some may find opportunities in certain applications, some in others. So, as we continue to develop the technologies, I think we will find probably a mix of technologies that end up really bringing us forward. But to focus on some of the key technologies, for Nafion, the discussion that we had, we're really focused on proton exchange membranes or PEM electrolysis and PEM fuel cells. So, this is a technique that uses pure water as an input. It uses the proton exchange membranes in order to make hydrogen. And then those same PEM based systems can be used in fuel cells to convert hydrogen back to energy.

There is also alkaline electrolysis. It's a different technology, uses a different membrane, but instead of using water as an input, it uses a highly corrosive caustic solution. In addition to that, it does have some limitations in terms of its current density and efficiency. So it is a widely used technology today, but my opinion or read on the technologies is that you will see the PEM technology, which is also commercially viable, beginning to play more of a role in that.

In addition to those two, there's some other technologies, the use of solid oxide fuel cells and also potential within alkaline electrolyzers. AEM anion exchange membranes are a potential opportunity. Those are less mature. There's a lot of great work that is going on to advance those technologies, but they're not quite at a position of commercial viability or technology readiness that would allow them to really perform at the industrial scale needed.

So there's a lot of work going on in those areas. And as I said, kind of the summary is you'll probably see multiple technologies all making different contributions and helping us to advance the hydrogen economy full.

Dipti Kamath: Thank you, Marc. That was great.

Praveen, do you have anything to add, or can I go to the next question?

Praveen Cheekatamarla: Let's go to the next one.

Dipti Kamath: Okay. So, I wanted to address the natural gas infrastructure for hydrogen use, like blending and so on, because I think that's something people are interested in.

So do either of you have any insight into that? I do have some that I can pull up.

Praveen Cheekatamarla: Yeah, I'll go first. From what I know, hydrogen in pipelines is actually, you know, it already exists, whether it is the public infrastructure or private infrastructure for the industries. For example, Hawaii Gas, you know, for decades, they supply 12 percent hydrogen in their pipeline, distributing the natural gas. So, it is a known technology. But, you know, as you increase the concentration, that's when challenges tend to occur. So, there's a lot of R&D work in that space. But my understanding is, you know, up to a certain percentage, the current infrastructure can be utilized, but once you cross the threshold, things need to change.

Dipti Kamath: Thank you. That's what I also know. There are quite a few utilities that are blending hydrogen into their pipelines, and so on, and there's more research being done about the blending levels and, you know, the materials that go in the pipeline itself. I know Praveen answered the NOx question and some of the other things, but because we are coming really close to the end of the session, I would like to stop the Q&A and go into some of the resources that we have.

Apologies for that. But I feel we had dense information that both Marc and Praveen presented. So going into this, thank you, everyone, for all your questions, to our panelists, for all the responses that you had.

So this webinar is our final installment of the 2023-24 Better Buildings webinar series. All the webinars from the series are available to watch on demand on the Better Building Solutions Center.

We look forward to seeing you this summer during our summer series, as well as for the 2024-25 webinar series. Webinar topics will be announced soon, so keep an eye out for that.

Next, we are pleased to announce registration for the 2024 Better Buildings, Better Plans Summit. It's open right now and the summit will be in the heart of Washington, D.C. on April 2nd through 4th. In addition to engaging and interactive sessions, attendees can look forward to plenty of opportunities to network with their fellow industrial peers, experts and so on.

Explore the session tracks and book your accommodations on the Better Building Solutions Center. We also have one more announcement. The Better Climate Challenge Roadshow Cleveland edition is here. Watch now as the DOE energy experts visit several of our Better Buildings and Better Plans partners to see how organizations are putting decarbonization strategies into action. From Cleveland Cliffs to City of Cleveland and Cleveland Clinic, these industry leaders are making major headway in emissions reduction and sharing strategies for others to follow suit.

Rock on and tune into the full series on the Better Buildings and Solutions Center today.

With that, I would like to thank our panelists again, Marc and Praveen, for taking your time to be with us today and also for all the people who are attending this.

Feel free to contact our presenters directly with additional questions or if you couldn't get to your question during the Q&A period. I encourage you to follow the Better Buildings Initiative on LinkedIn and X for all the latest news.

You can find our handles by the respective icon on the left side of the slide. You will receive an email notice when today's recording slides and transcript are available on the Better Building Solutions Center.

With that, thank you, everyone, and have a nice rest of your day.

[End of Audio]

Additional Resources

Learn more about the topics discussed on the webinar by visiting the resources below.

Better Buildings Resources

- Department of Energy H2 Matchmaker website
- Department of Energy U.S. National Clean Hydrogen Strategy and Roadmap

Explore more resources on the Better Buildings Solution Center

Other Resources

- Hydrogen Tools Portal
- Hydrogen Production and Infrastructure Projects Database
- Hydrogen's Decarbonization Impact for Industry Insight Brief
- Deloitte Assessment of Green Hydrogen for Industrial Heat
- HyNet Industrial Fuel Switching Report
- 2018 Manufacturing Energy Consumption Survey Consumption Results
- The Renewable Thermal Vision website
- Decarbonization Hydrogen in the US Power and Industrial Sectors: Identifying and Incentivizing Opportunities to Lower Emissions website

The 2023-2024 Better Buildings Webinar Series

This webinar was our final installment of the 2023-2024 Better Buildings Webinar Series. We hope you will join us for our 2024 Summer Webinar Series. Webinar topics will be announced soon!

Follow Better Buildings on Twitter and LinkedIn

@BetterBldgsDOE

company/better-buildings