Non-conventional Energy Resources
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Lecture – 37

Hello, in this class we are going to disassemble fuel cell and reassemble it, and in the process I am going to show you all the interior parts of single fuel cell and I will also explain to you what are the you know possible options that people are looking at for these parts, what are they trying to do with respect to all the you know hardware design the design of the materials that go into the actual membrane electrode assembly and so on.

So, we have seen them in the form of diagrams in some of our previous classes in this class we look at the actual hardware. I will also tell you that this is hardware that we use in the laboratory scale. So, there are some variations when you look at larger scale hardware, but still the similarities are quite significant and I will also alert you to what changes you can expect when you look at a more industrial type of hardware for the same unit ok. So, with this introductory words we will get into this looking at this fuel cell and taking it apart and then looking at its parts.

So, we will begin by of course, putting on some gloves here ok.

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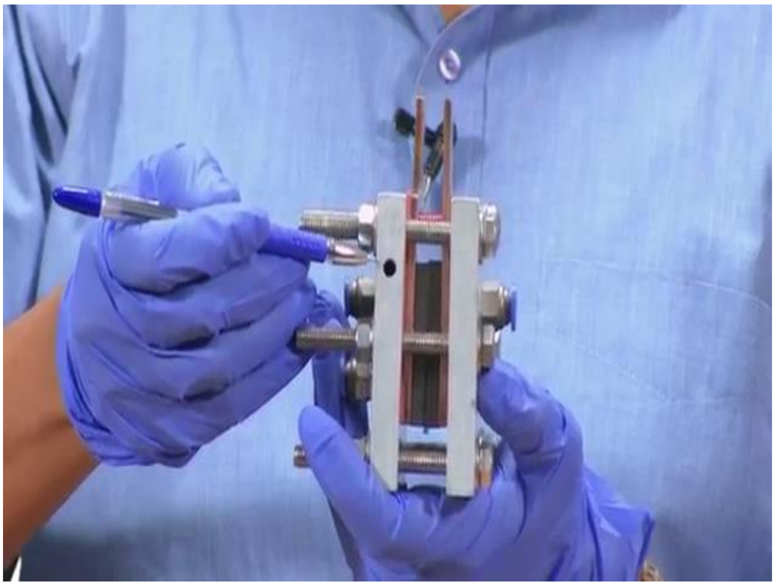

Okay so, we are ready here. I have with me the hardware the fuel cell hardware this is a single cell that I have here. It looks quite bulky quite heavy, as I said that’s because this is you know meant for laboratory testing we want to minimize any you know artifacts to the data coming from the hardware. So, we don’t compromise on the hardware in any manner we are not worried about the weight of the hardware because we just want to get the functioning of the hardware right. The weight is a consideration that’s looked at when this becomes a product ok. So, this is the hardware. So, I will show you even before I disassemble I will show you a few different aspects of this hardware and then when we disassemble it you will get a better sense of what those parts are.

So, if you see here facing you see this is basically an end plate. So, maybe if you see it little closely you will see an end plate here and another end plate this side. So, you see one end plate here and one end plate here. So, these are two end plates and you will see a small hole that is that is visible here. So, this is the hole through which a heater is put inside this hardware. So, a cartridge heater it’s called a cartridge heater, it simply is you know heater in the form of a small rod that is put inside this hardware. That helps us heat up this hardware so that we can run the fuel cell test at a fixed temperature at whatever temperature you want to run it at.

So, if you if I want to run a controlled test with the hardware sitting at 60 degree C then I can do that if I want to set it at 70 degree C or 80 degree C I can do that these are this kind of a cell is typically running below 100 degree C. It’s a proton exchange membrane fuel cell test setup that I am showing you and so it runs below 100 degree C. So, that is what you will see on that hardware.

Now if I turn it the other way complete 180 degrees the other way, you are again seeing the same hardware from the other site same thing to end plates the same to end plates you are seeing from the other side. And you will see two tiny holes here, one tiny hole here and another tiny hole here. So, that is actually there to simply insert 2 thermocouples. So, I can independently measure the temperature of this plate here and I can measure the temperature of this plate here. And that is essential for me for the experiment for us to you know keep track of whether the heater is working correctly or not or to actually give feedback to the heater because there is a controller which is going to decide whether the heater has to be switched on or switched off and that is based on the feedback that is that it is receiving from these thermocouples that are present at these 2 locations.

And you can select which thermocouple you wish to use and in fact, you can also select to have two heaters if you wish on this cell this particular hardware has been set up with one heater, but you can potentially set this up with 2 heaters. So, that is the 2 aspects of the heating of the cell that I indicated in a real hardware for example, you would not really be looking at external heat. There the problem is inverted the cell itself is generating a lot of heat and we are actually trying to manage the heat. So, there we actually send in coolants to remove the heat or at least to keep removing the heat at a rate which ensures that the cell remains at some temperature during the duration of that test.

So, but why do we heat this hardware? We are heating this hardware because we have only have a single cell here. So, it is not a single cell is not generating and it's a small cell I am going to open it and show you it is a very small cell. So, a single small cell does not generate enough heat to heat up this entire hardware whereas, if it were several cells in series and they were large cells it would generate so much heat that the temperature of this hardware would keep on rising. So, that therefore, those two situations are different. So, here in this test setup in order to run this test at some controlled temperature we require an external heater to be attached to it and using that we run this test setup.

I showed you that we can use a cartridge heater, you can also use flat plate heaters on either side different ways you can incorporate this heat into the system. So, that's again and experimental variable that a lot of people in their labs will have opportunity to explore and look at. But this is the one implementation of this hardware that I am showing you ok.

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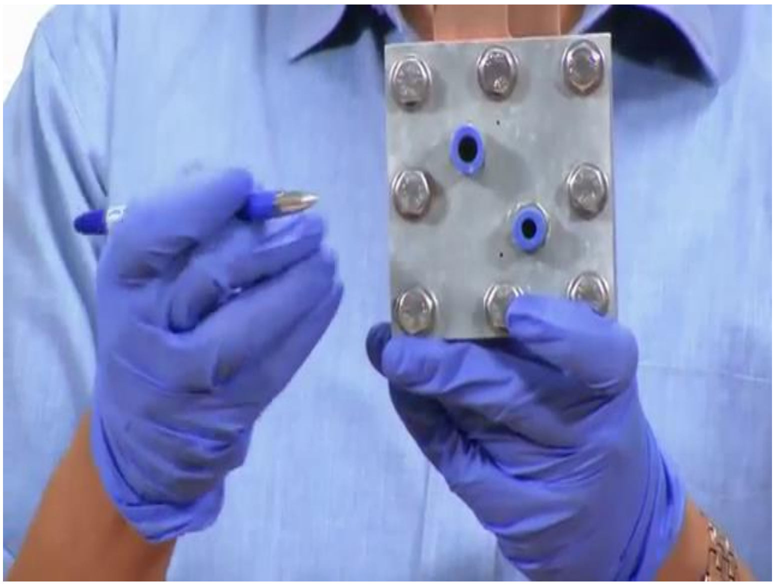

So, now we will look at this side of the hardware. You can see now there are two openings here one opening there and another opening out here. And this is basically the inlet the top one is the inlet and the bottom one is the outlet for one of the reactants it could be any of the reactants I mean we. So, one side of the cell will be receiving hydrogen and the other side will be receiving air or oxygen.

So, if this were the hydrogen side you would have the hydrogen inlet typically this would be at the top, top inlet, top opening here and the bottom would be the outlet. Generally we have the outlet at the bottom because you have a liquid water being generated in the cell and therefore, you would like to use the assistance of gravity to get the water removed from the cell. So, that is the reason why we prefer to have the outlet at the bottom rather are the rather than at the top ok. So, that’s the other aspect of it.

You can see here a lot of bolts you can see there are in fact, 3 plus 3, 6 plus 2, 8 bolts that are there in this hardware and these 8 bolts basically serve to hold the cell together in a in a proper you know uniformly compressed manner. So, there is uniform compression across this entire cell and that is ensured by using these bolts and that also ensures proper sealing through the cell. So, this is the reason you have so many bolts, bolts here ok. So, in fact I am if I am I am just going to turn this hardware the other way around and you can see essentially the same same kind of layout here similarly the same bolts are now, showing up on the other side the nut bolt arrangement is visible here you can see that how it has been implemented here and you also have or the inlet and outlet here the inlet on the top and the outlet at the bottom. So, that is also the same that you see as you saw on the other side.

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You also see here two copper plates which again I will show you in a bit of a close up you can see these copper plates on top one, one that is here and you see another copper plate here there are 2 copper plates here which I will just rotate a little bit. So, you can see more clearly yes there are 2 copper plates there, 2 copper plates. They are the ones that are if I turn it around also you can see the orientation of the copper plate there, and those copper plates basically serve to current the collect the current. So, when you correct connect this hardware to the external circuit this is where the current leads and voltage leads come and click they come and clip to this or they come and clip to this and that is how you create current into the external circuit. So, that is what is done and these bolts go otherwise they go right through all the bolts that you see here are going right across this hardware from this side to that side and that’s how they hold the hardware together.

So, you may wonder that you know you are short circuiting the cell because this bolt is actually coming from this end plate to this end plate and holding it all together. So, it looks like the hardware is short circuited, but actually that is not the case because the end hea the two end plates that you oversee here these two plates that you see here are actually not part of the electrical circuit. There is, there are gaskets which prevent them from being in the external circuit in the electrical circuit and as a result they are actually not participating in the path of the current and therefore, it's okay that they are in contact with each other. So, so this is the basic hardware that that is used in most experimental setups, this is what we have in our lab we sort of got this made to order we designed each part and got it made to order.

But essentially you can get the same kind of hardware there are many commercial setups also which sell you these kinds of hardware we made this in our lab, the you basically have to specify the dimensions and orientation of various things and people can get this made for you, you can machine it and get it. So, if you have a good machining you know workshop in your university you can get one of these made its completely doable right.

So, what I am going to do now is I am going to take apart this hardware, open it up and show you all the interior parts of it and then also discuss more about each of those parts. So, that's what we are going to do now. So, we are going to now take apart this hardware, open it up completely and look at all the parts that are present inside it. And so to do that we are first going to lay it on its side and there are as you can see 8 bolts out here that we need to open and remove. So, we are just going to do that. So, this will take a couple of moments, but that's part of the process. So, let's do it and get to see what is on the inside.

So, by keeping it lying down we also ensure that the materials that are inside are not disturbed and that that helps us, if you were doing this on a tests condition that would allow us to actually open it up without disturbing the materials inside. And then you know doing some examination of those materials and then coming back and reassembling the cell so that you can actually continue with the test setup.

So, this is normally done in all our laboratories we routinely open up these cells put in new materials inside, and then run the test and then partway into the test or after some of the testing has been done. If if you if you want to understand why the performance of the cell is a certain value or if we want to get a sense of what has you know maybe degraded inside the cell or you know some other thing that has happened inside the cell sometimes it becomes necessary to open the cells and then look at the hardware look at the interiors of the cell in greater detail.

So, therefore, this is commonly done and its part of our activity in this fuel cell laboratory testing activities. So, there we are we have removed all the 8, we opened up all the oh we have one more here 8 nuts and bolts have been opened up and. So, I am now in a position to remove the top part of this hardware we do have the washer. So, I will remove them also otherwise they were all going to come tumbling down and so I will just do that so that it becomes easier to handle, all right.

So, all the washers have now been removed and we are now in a position to start opening the cell and taking a look at what is inside. So, the first thing that is going to come off is this hardware on top that we are calling the end plate hardware and so that’s what I am going to remove here and that’s going to gently come right off of this structure. So, this is the end plate, and you can see you already saw the exterior of this end plate here and now I am just going to show you the interior. So, on the exterior side you have these two connectors, these two connectors that are present here and they are basically you know there are different companies that make these connectors you can get any connector that you are comfortable with that ensures a good seal and is a reliable connector. Basically you have to attach a hose here and a hose here and those two should be supplying the you know reactants to the cell.

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So, therefore, you need this to be good connector reliable connector leak free connector, so what you find commercially to do it you can purchase and fix up. So, now, if you turn it the other way around it's basically flat.

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It's flat and this particular piece has been made out of aluminum, you can make it out of stainless steel typically for laboratory purposes those should work. They are; please keep in mind that this is not going to participate in the electrical circuit, this is not going to participate in the and none of the you know reactions are going to happen in direct contact with this surface. And therefore, the material is really what is whatever is convenient for you to use we just need something that's hard and rigid I mean at least in this scheme of activity within within the scope of this activity. So, I mean any metal should in principle work fine. So, what we easily get is either aluminum or a stainless steel stainless steel would also mean it doesn't corrode under the you know the presence of water and so that's something that you can consider.

If you look at say the more industrial implementation of this hardware this particular piece of the hardware then people do look at you know some block of thick block of plastic of different kinds that can be used instead of putting this you know piece of metal there. But this piece of metal really helps us in the test setup that we use mainly because as I said you can you can put in these connections here for putting the heater and you can heat the hardware which or which may not be which will be difficult to do if it were some kind of or plastic. So, you can put this heater here heat it and then that heat will get distributed through this hardware very well and that becomes easy to use. So, that is why we prefer to use this.

In this side as I said other connections the connectors and on the other side you can see as I turn this around you have this heating element location, you also have a small hole for putting a thermocouple if you wish. So, all those elements are available on this hardware and this is a piece of hardware and that's all it does this is the end plate. This is the exact thing that is also there at the bottom of this hardware, what you see at the bottom is also the same thing just another piece of it and when we get to the bottom of this hardware you will see it.

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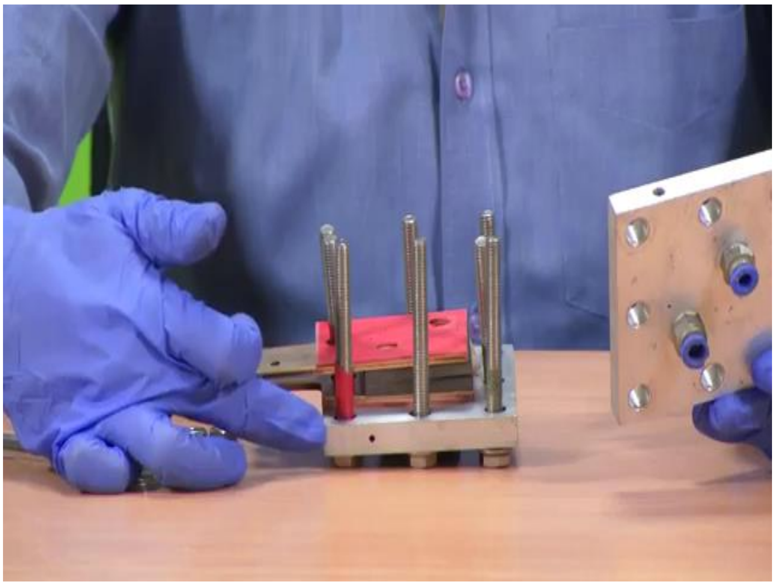

So, I am going to send this aside for the moment and I am going to show you the rest of the pieces one by one. And then after we disassemble the whole cell we will reassemble it, so you will get a sense of what is involved in reassembling this hardware and it will be done bit slowly specifically, so you can see how it is done. And you also get a sense of you know the just you know handling issues that are involved in putting such a hardware together. So, that's the purpose of what I am going to show you. So, that's what you are going to see.

So, I am going to set this aside for the moment we will get back to it in as as necessary. So, just below that hardware that we removed is this gasket that you see that I am peeling

I mean removing from this hardware and it is basically a silicone gasket. This is essentially a non-conducting material it does its electrically non-conducting. So, I am just going to first take it out here and it is specifically there to isolate that end hardware that I just removed from this cell from the rest of this hardware in terms of electrical contact.

So, this gasket prevents the hardware that we just removed which is this one, it prevents this gasket here prevents this hardware from having any electrical contact with the fuel cell setup which is below this gasket right. So, it there is a fuel cell set up below this gasket and it insulates that set up from this hardware. And therefore, that’s how this hardware is no longer in the electrical circuit this entire block that you see here ok. So, I am going to set this aside and that as I said is the gasket; that gasket actually has you can see here there are 3 holes in it, 2 of these correspond to the the fuel or is reactant inlet and outlet and the third one simply is one of the holes through which the bolt one of the bolts goes through this hole and that’s the reason there is a hole there.

So, that I mean so that can actually vary from hardware to hardware. So, you can have a hardware where the third hole is not necessary because maybe the bolt doesn’t go through this gasket. But in this hardware given the way the bolts are arranged one bolt goes through this gasket and therefore, you have 3 holes here. So, that’s what you will see. So, I am going to set this aside and then look at the next part of the hardware.

So, we are just coming top down, now one by one we are taking out. I just took out the end plate below that was this gasket. So, I am going to remove this gasket now. Below that gasket is the current collector.

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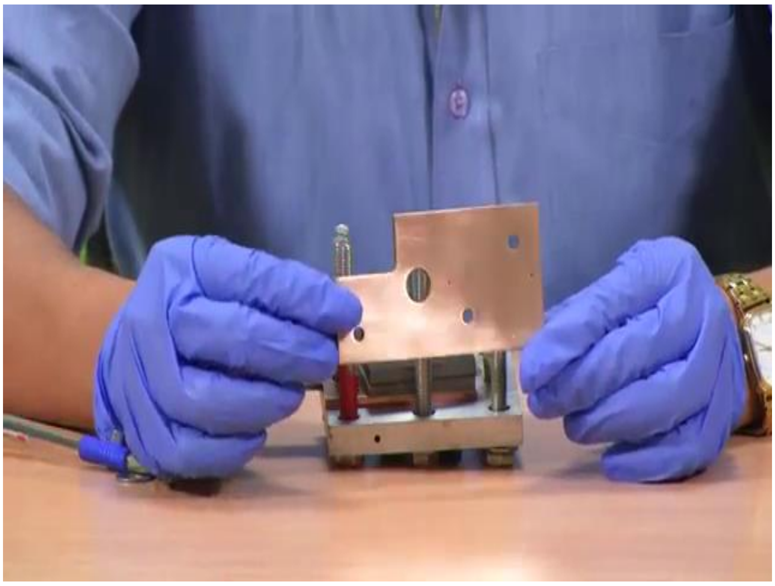

So, this is the one. So, this is a copper current collector. So, I am just taking it out here this is the copper current collector. So, it's made out of copper I just show you this current collector in different angles.

So, that's the current collector, and typically we clip on to it here to get it attached to the external circuit. So, that's where we clip on to it and so that is the current collector you can see the same 3 holes in this as they were as you saw in the gasket and that's because of the bolts that one through one hold the bolt goes through and that is this big this that is this hole here. So, this the bolt is going into the to the through the hardware and so that it holds the hardware together these other 2 holes that you see here are meant for the fuel or reactant in inlet and outlet. So, that is the next part of this hardware. So, this is the current collector ok. So, again I am going to set this aside. So, 3 pieces out now the end plate a gasket, a silicon gasket and this current collector.

So, now since as you as you know as I said this is this is called the current collector it is very much part of the circuit, very much part of the circuit through which the current is being taken from this to the external circuit where you are using it for some particular purpose ok. So, therefore, this is very much part of the circuit and so we need to be aware of what is going on with respect to this and to ensure that it is not accidentally in contact with the opposite side of the hardware. So, that is very important with respect to this piece of the hardware. So, I am going to set this aside now ok.

So, below the current collector comes the next piece of the hardware which is called the flow field or the flow channel and that is this graphite block ok.

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So, this is a graphite block and I it was phased down I have I am just showing you the back side that the side of it that was on the top that a face that was facing up is this. It is featureless on the top, you don’t see any features on it. What you will not see very if you watch carefully you will see two tiny holes here I am trying to position it so that that becomes visible to you yes that you now we will be able to see two tiny holes. So, I will point to them in just a moment. So, there’s you see one hole out here or at least one indication that there’s something there that said there is a tiny hole there right and at the diametrically opposite end there is a tiny hole.

So, it is through this these are the two holes that line up with those inlet and outlet that you saw in the rest of the hardware and that is how the gas goes in and out of this hardware ok. So, so this is called the flow channel, gas flow field and on the backside of it which is what you are currently seeing it is featureless and that’s and therefore, you will wonder what is you know where is the scope of anything flowing in it.

But in the backside of it there is no reason for anything to flow it simply goes into this hole that you see here and goes to the other side which is the front side of this flow channel and I am going to turn it around and show you the front side of the flow channel. So, the front side of the flow channel is the one that is facing the membrane electrode assembly which is where all the reactions are taking place, so the front side is where you need to have all the features. So, let me turn it around and show you the front side.

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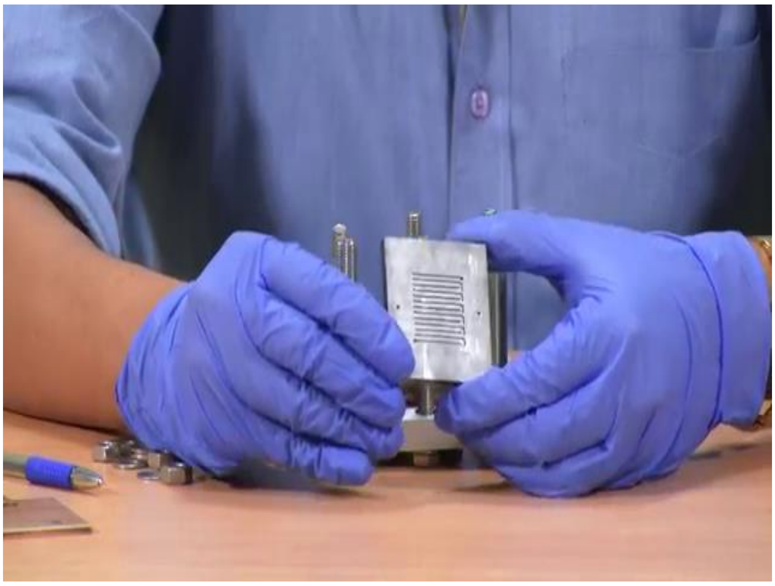

This is the front side of this flow channel you can see that it has some flow pattern in it let me change the position of it. So, you can get a better sense of it.

There you get to see the flow channel. You will see here actually a set of channel channel that goes up and down up and down up and down in a serpentine manner ok. So, it goes up and down up and down up and down in a serpentine manner, its very narrowly spaced set of channels and so that's you have to watch carefully to see it, but you can see that channel. So, what normally happens is the gas enters let's say it enters here and then it is just going to go down and then come up and then go down and then come up etcetera and then come out finally, to the diagonally opposite end and at that point it will come out through the backside of the flow channel and exit out the cell.

Okay so, this is how the gas in this fuel cell is distributed through to the entire cell where the reaction is taking place and that that membrane electrode assembly is very close to this surface it is not in direct contact with the surface there is one more layer in between and so we are going to talk about that layer. But that is the first thing that distributes the gas is this gas flow field and that is what you are seeing out here at the moment. So, I am going to set this aside and then we look at the next few parts that are remaining in this hardware.

So, right now once you come this far into this hardware there are actually you have to come actually very close to the fuel cell itself which is this layer that I am going to start taking out now we are just one sort of one layer away from the actual fuel cell or the membrane electrode assembly. But this new the layer we are currently dealing with has two parts in it, one is the gasket and the other is the gas diffusion layer. So, I am going to take out both of them and then show that to you. So, the first is this gasket, you can see that this is basically a square window of sorts.

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And this is made out of Teflon as the material. It is basically there to ensure that first of all no gas leaks out of the cell. So, you don't want gas leaking out of the cell and so therefore, you need this gasket. And the second thing it does is the thickness of this gasket is a important parameter that decides how much the remaining parts of the cell which consists of the membrane electrode assembly and the gas diffusion layers, how much they get compressed is decided by the thickness of this gasket; because this gasket usually doesn't compress a whole lot.

And so when the hardware comes to a halt at this gasket the gas diffusion layer has been compressed to some degree. You don't, you want the gas diffusion layer to be compressed to some degree because only then you will have good electrical contact to the gas diffusion layer if you just barely touch the gas diffusion layer if the current collector just barely touches the gas diffusion layer or if the I am sorry the gas flow channel I just badly touches the gas diffusion layer then you will not have good electrical contact you will you will lose electrical contact will have high contact resistance.

So, you do need it to be compressed a little bit you want that compression to be there little bit and so that you get good contact with the gas diffusion layer. But at the same time if you compress it too much the gas diffusion layer gets crushed and that is also not particularly good because that will completely destroy the gas diffusion characteristics of the gas diffusion layer. So, you want some compression, but not too much compression. So, that you know limited compression that you want is ensured by putting a gasket of some appropriate thickness this is not very thick it is relatively thin, but the measurement is decided based on that requirement that you need sealing and you need some compression, but you don't want the materials to be crushed that is the purpose of this gasket ok. So, that is there in this layer I am going to set that aside. And this layer that is just alongside the gasket is the gas diffusion layer.

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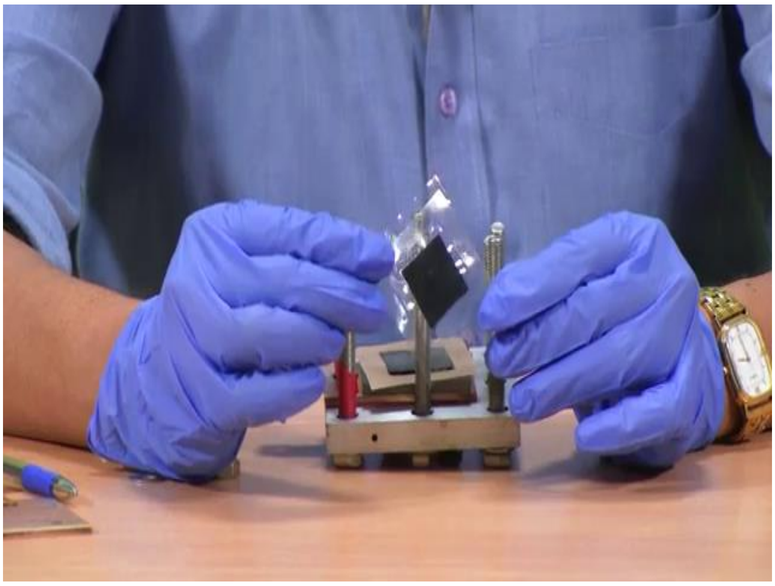

So, this is the gas diffusion layer that I have that I am that I am presently holding in my hand. This typically is a carbon cloth or a carbon paper and there are people doing different kinds of you know research activities to see if there are alternatives to this in different ways in which you can implement this particular layer so that you can get the properties that it's supposed to have or even improve on those properties that it has. But this is the gas diffusion layer gas goes through it and distributes across to the membrane all the active sites of the membrane electrode assembly

It's a porous carbon cloth or carbon paper sometimes it has a layer on top called the micro layer which has better conductivity, but those are all implement various implementations of this gas diffusion layer and if you are really doing active research in this area then those are kinds of parameters that you will focus on and try to make some variations on ok. So, that is what this gas diffusion layer is. So, that is one more part that I am just now going to set aside.

And now we come to the most important part of the fuel cell which is the membrane electrode assembly and that is the layer that I am pulling out now ok. So, as I turn it around yes there you can see clearly the reflection of the membrane all around. So, you can see that there is a larger membrane and in the center there is in the center you see the squarish electrodes, right. So, those electrodes are actually catalysts, catalyst layers that have been painted or you know deposited onto this membrane this clear relatively clear membrane that that I am holding in my hand, clear transparent membrane that you see that's the nature of the membranes used for this is activity and on that you put this catalyst layer on either side. So, actually there is a layer on this side and if I turn it around carefully although you may not be able to see it properly there is a layer on the other side as well.

So, both sides have the same layer and they are aligned on top of each other. So, and since the membrane is transparent you don't I mean looking at it you will it looks like the same thing, but actually this side you are seeing one catalyst layer and as I turn it around you are seeing the other catalyst layer. So, these are the two catalyst layers. And depending on your test they may be the same you or you may actually have 3 totally different compositions on these two catalyst layers. So, you have the option of doing that, but then you also have this membrane, this membrane that is there.

This membrane is the is the important thing in this setup in the sense that is the electrolyte and the two catalyst layers are the ones where the electricity is generated or the reactions occur rather. So, you have an electrochemical reaction occurring at the anode and another electrode chemical reaction and occurring at the cathode and so one of these layers is the anode and what is behind is the cathode. So, let's say we can if we assume that this is the anode or if we have decided that this is the anode then this becomes the cathode layer behind becomes the cathode and in between the two layers is this membrane. So, this is the membrane electrode assembly ok. So, this is the membrane and electrode being assembled together it's called the membrane electrode assembly.

And this is the central part of the fuel cell. On either side of this membrane electrode assembly is a gas diffusion layer then there are two gaskets there are flow channels and then there is a current collector one more gasket and then the end hardware. So, we have come to a center of the fuel cell. So, what remains will be an exact replica of what we just took apart so far. So, I will just pull out those parts and show you that on the other half of the fuel cell also we have exactly the same parts. So, just below it is one more gas diffusion layer and a gasket, so gas diffusion layer and a gasket and this will typically fit inside this will fit inside this regime there. So, you can see that it fits inside, you can pull it apart and then it comes off separately right. So, this comes apart and you can put it together that way. So, so that's how they fit inside each other that's how they are sized if you size it such that they do not overlap that they just about fit's the gas diffusion layer just about fits inside the gasket layer that is provided, right. So, that's that's the way we assemble it.

So, these two are there. So, I am setting that aside and then below it is the next flow channel that you see here. Again you can see the serpentine flow channel, it's called serpentine because it goes up and down and curves it is basically like a straight line that goes straight down then curves and comes right back then curves and goes down again and so on. And that's called a single channel serpentine flow flow pattern. And that's what that's what is implemented in this hardware. You can have other forms of hardware where you can have different versions of this pattern.

I will also tell you that you know in material sense like this is this end hardware that you see here this flow channel that you see here has been made out of a block of graphite ok. So, a block of graphite was taken so that's why it looks like this, you can get commercially these blocks of graphite and and then you can machine whatever pattern you want into it. So, this pattern has been machined into it and then it is being used as a flow channel.

In an industrial setup if you are trying to make fuel cells in larger scale then taking graphite blocks and machining them is not a convenient way to do this. In fact they will break, they are not very easy to handle and they are also kind as you can see here this is you know of reasonable dimension even thickness wise there is some reasonable dimension to it maybe it’s about this probably is about 4 5 millimeters thick and you can see that its several millimeters thick there. So, this is not the way we would do it in an industrial setup. We would actually use composite plates made out of polymer based composites which have enough additives to it maybe carbon based additives to ensure good electrical conductivity. This plate is supposed to have good electrical conductivity because it is whatever electricity you generate in the membrane electrode assembly has to come through the GDL, arrive at this plate from this plate you should go to the current collector and from the current collector it goes to the external circuit.

So, this has to have good electrical conductivity. It should also be non porous unlike the gas diffusion layer where you are where you need porosity to get the gases to go to the reaction sites. This made; this flow channel has to be non porous because you don’t want gas to escape from this flow channel and go to the go outside. So, therefore, this has to remain non porous ok. So, that, so this has to remain non porous and as thin as possible with good electrical conductivity. So, that’s kind of what is decided here ok. So, I will set that aside.

So, what remains in here is simply back we have once again back to yet another current collector that you see here, the same thing that we just saw a short while ago at the top side of the cell. So, I will set that aside. And one more gasket layer, one more gasket layer that we saw here and we are now back to the remaining part of the hardware which is simply this end plate, with all the nuts and bolts.

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So, this is basically the hardware that we have for our fuel cell. So, you have essentially seen the full hardware taken apart all the parts that are involved have been put pulled aside. So, it is also of interest I mean and I have explained to you what are all the requirements we have we have for each of these parts we also discussed them in some of our theory classes this was in an class where I wanted to show you the actual physical hardware and how it all comes apart and how it all comes together.

I have so far shown you how it all comes apart. I will take the next several minutes to put it back together and then show you how it all you know it can be built up. So, to do that we actually need to interview take the help of two tiny assistants and I will introduce them to you. These two tiny wires that you see in my hand that you see there and this one that is on my other hand yes there I think you get to see it now. There you are, yes there you see it.

So, these are two basically wire like structures they are wires essentially, they are used as aligning pins. So, I have to use this to get these are all thin layers that I just showed you I need them to line up correctly and perfectly and so I use this to assist me in the process and there is just an aligning pin. So, I will insert this in this hardware and use this aligning pins to help me align all the layers that come one on top of the other and when I am done with assembly I will simply pull out these aligning pins from this hardware and at that point this aligning pins are no longer necessary for this build for the rest of the testing. So, so that's what we are going to do now and the first by we will insert the aligning pins into this hardware and then start from there.

So, there is a tiny hole which is down here that I can see and so I first insert this aligning pin carefully through that hole. So, this is a little bit of a slow process because we need to do this correctly and so it takes a little while to assemble a cell. If you ever were to do this kind of yourself testing you will find that you know at least in your initial tests to get the cell to be built correctly without any leaks, assembled properly is itself a reasonable challenge. We do in fact, after we do the assembly we do a leak check and we do a short circuit check we want to ensure that there are no leaks and there are no short shortcircuits. And just ensuring those to it is the first few times you build a fuel cell can sometimes be a little frustrating till you figure out all those small minor details that help you set it up. So, that there is no leak and no short circuit.

So, in any case now I have inserted the two aligning pins I am going to take this hardware and then make it horizontal area. You got it horizontal and on this I can start building my cell. So, as I said the first part that will go on is the is a silicone gasket that helps us isolate this hardware from the from the the circuit and so that is this gasket that we were referring to and it has 3 holes. So, one is for the bolt and the other two are for the gas flow channels that are present in this. So, that's the orientation. So, we have to look at the orientation. So, now, I have 3 holes here they are oriented, so that one lines up with this one lines up this one lines up with the bolt and these two that are here line up with the inlet and outlet of the flow patterns.

There are also two tiny marks in that on it which which are the places where the aligning pins have to go through and. So, I am going to send the aligning pins through it and then assemble it. So, there I am putting the aligning pin through this here and I also have to line it up with the aligning pin on the other side, so we do that. Yes, it's now into the aligning pins and I begin to slide it down, I also get the bolt to go through it and it goes all the way down and it settles down here. So, when I do that you can see here now that I have got it in position like that.

We can see that the holes are lined up the inlet and there is the outlet or yeah. So, the two yeah inlet and outlet for the reactant streams have been lined up correctly with the gasket that I just put, right. So, now, I can put it back to flat position, push the gasket back down and I take the current collector current collector is there. So, again I have to get this current collector to go in with the alignment pins going through the current collector. So, all these parts have this tiny hole through which that alignment pin has to go.

Only then it lines up correctly and it goes right through and I put it down. There are a few extra o rings that are also put at the inlet and outlet stream to ensure that it stays leak tight, but that is not immediately of most importance to us in this what we are discussing. But here it is I have now put the current collector in place. So, I will show that to you. There you go.

The current collector is in place and so is the first gasket layer. So, what I put there the silicone gasket layer as far as the current collector are all lined up correctly with the rest of the hardware. So, that was the purpose of those aligning pins, and you can see that now that the aligning pins are I mean because of those thin two thin wires that we had of the aligning pins we are able to do that quite effectively there is a pin here which I think you can see that maybe that you can probably see the pin here. So, that's one pin and this is another pin that is out here that is that I am holding out here. So, that's those are two pins that are sticking out and using that I have done this alignment.

So, now, I am going to put it back in the flat position and then assemble the rest of the hardware and then we look at it ok. So, now, that we have these pieces in place our next part to put here is the flow field. So, the flow field I have in my hand. So, flow field has to be an electrical contact with the current collector. So, therefore, we are not putting any silicone gasket between them It still, it has it also has alignment pins. So, we have to line up with the alignment pins and put it in. So, I is exactly what I am doing I put the alignment pin through it and another alignment pin here through it ok. So, it is all done goes neatly back down.

So, that's the flow channel you can see here now with the flow channel how the hardware looks. As I tilt it towards you, and show it to you. So, this is with the flow channel in place you can see everything is in place and they are all lined up because of the alignment pins. So, the alignment pins are very critical for us I am able to hold it in one hand and show it to you because of the alignment pins and you can see all of them all of those layers are now one on top of the other.

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The silicone gasket is not visible because it is behind the the copper current collector and between the copper current collector and the end plate. So, that’s why it is not visible, but you see the end plate, you see the copper correct current collector and you also see the gas flow channel all 3 of them are visible.

So, again we lay it back in the horizontal orientation, and we will stop now assemble the cell itself. So, to do that first thing we need is one more gasket that square gasket that we spoke about. So, that we will put here, yes, that side went through the aligning pin, now I got to get this side to go through the aligning pin. Yes, it’s through the aligning pin and its down to the bottom, then I am going to put the gas diffusion layer that is just going to go and sit there.

So, now, is those two are sitting there I cannot lift this up well I can let me try to lift it up and show you because I have to ensure that the bolts also don’t just fall right off,there you are you can see how this thing is oriented and all those units are there. So, I will just put it back down. I think I had one bolt come off, but that’s okay I can put it back there we got everything in more or less. Only one bolt is off we put that in just a moment. Yes, there we are we have got everything in and everything in place.

So, now, the next thing that comes is the membrane electrode assembly that you have here membrane electrode assembly. So, that’s what I am going to put on top of the arrangement that we have so far that also has those two small tiny holes for the alignment pin. So, that helps us align in aligning it correctly. So, I got it through on one side, trying to get it through on the other side let's see, yes, it is through. So, we have got the membrane electrode assembly also to go in. So, it is now sitting on the hardware with everything the way we just described and so that is in place. You can sort of see it even from that orientation as I rotate it along you can see that it is sitting in here, that's the membrane electrode assembly.

So, on top of this I am going to put the next GDL gas diffusion layer; so the gas diffusion layer that was put in the beginning the previous gas diffusion layer or some one side of the membrane electrode assembly. Now, I have put one more gas diffusion layer which is on the other side of the membrane electrode assembly and I am going to put this next gasket.

So, that's what this gasket is I am going to put it up here. Same thing we have the alignment pins I have to line it up and then put it through. Yes, it's in, one aligning pin and almost in here not yet yes that's it. So, I have got the second gasket also in. So, on both sides of the membrane electrode assembly I now have gas diffusion layer as well as the gasket on both sides. So, a peripheral gasket and in the center there is a gas diffusion layer. So, centrally there is a gas diffusion layer and on the periphery you have this gas the gasket and this is there on both sides of the fuel cell. So, this is the peripheral gasket both sides of the membrane electrode assembly.

So, we got several of the major parts in now I am going to on top of this the next part that needs to come is the other flow channel, flow channel on the other side of the cell. So, we have already seen one side of the cell we are seeing the other side of the cell. So, this flow channel needs to come on this side of the cell and so again we take the aligning pins and the line it up with this line up this part with the aligning pins and send it through. So, that it lines up correctly.

So, I take that up here I see an aligning pin here. So, hole for the lining pin; so I am going to send that it in yes that's in on that side yes, it is it on this side as well right. So, it just goes straight down you can see it going down goes down down down down down and sits in perfect. So, we can see that you know this is now settled in correctly we ensure that by just holding it down we don't have any non uniform I mean improperly aligned hardware we just ensure that you know its aligned properly and so the next piece of hardware that needs to come on top of this is the other current collector which is the copper current collector.

So, I have one more of these here. So, that's what we need to put here and so that's what we are going to do. So, I am going to take it up here and you can see here again there's an there are 3 holes in this. So, two are for the gas inlet and outlet that is this and this and this is where one of the bolts goes through as I mentioned that is just the design of this hardware that has this is a situation. So, now, I am going to do that and build it up. So, we will put this aligning pin here, yes it's through the aligning pin and this other aligning pin is lined up there. Yes, it's through. So, the two aligning pins are now through and it also goes through the bolt and it comes right down.

So, that is our cell with the two current collectors that have been assembled. So, we just need to put one more gasket layer on top of this and put the rest of the end hardware and close the cell. So, that gasket layer is what I have here it consists of those same 3 holes that I mentioned, one for the inlet and outlet piece this spare is for the inlet and outlet this is the inlet this is the outlet and this is where the bolt will have to go through. So, same same drill move it up here we line it up with the alignment pin, yes that went right through and this side I had to put it through the alignment pin, yes that's also through.

You can see its now standing on those two alignment pins and as I slowly slide it down you see it goes through the bolt, I can slide it further down and its now all the way down. So, you can see now I will just tilt it up tilt it over and then I will show you how it is all lined up there you are I managed to do it without having it all fall apart. But there you can see if I rotate it you can see the two holes and you can even see that the hole is going right through you can see you can see that hole of the current collector also lining up with this gasket. So, you need that because the gas has to go through, right.

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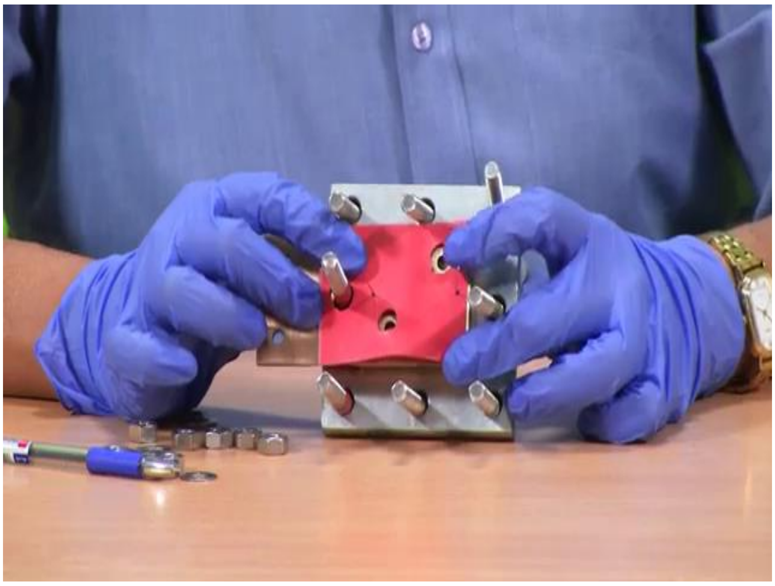

So, I am going to hold that together and make it all lye down. Yes, there we are. So, last part remaining here is the end plate that I am going to put on top which is the same as the end plate that you see at the bottom and with that we can close the cell we can put the complete the nuts and bolts and that completes this cell hardware.

So, that's what I have here the hardware, the end hardware this side has to face the cell and this is the external side. So, I keep make sure that I don't get that wrong and also the same orientation should be there for those two inlets and outlets with that in mind I take it up. Again there are the same two aligning pins are there holes are there for that. So, I have to make sure it goes through that, yes the first aligning pin went right through and let's look at the second one. Yes, it went right through too.

So, now, you have all the holes for the bolts and I just have to line them up. So, that they all neatly go through their respective sockets. Yes, there you go then I just look and make sure it's all sitting correctly and then I put all the washers.

So, at first in any of these hardware builds that you make usually it's all set up like this such that everything is sitting horizontal that way you can align things well. So, what you saw here for example, was a single membrane electrode assembly in the middle and. So, it only had one pair of GDLs, and one pair of flow channels, one pair of electrodes. So, this is what we had one we had a single membrane pair of electrodes on either side which were already sort of you know attached to that membrane and then one pair of GDLs on either side of that and one pair of flow channels.

Now, if you actually have a stack which we discussed in the class then you will actually have several such cells in series. And therefore, you need to assemble after you put the flow channel the flow channel will then touch the flow channel of the next cell. So, the backside of the flow channel of one cell will touch the front side of the flow channel of the second cell. So, in fact what they do is they have plates which are called bipolar plates they will have the flow pattern of the anode on one side and the flow pattern of the cathode on the other side so that one side becomes the anode of one cell and the other side becomes the cathode of the other cell.

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So, when you do that you have to have everything horizontally located. So, you can put one cell, and then on top of it you can put the next cell, then top of it you can put the next cell, and so on.

So, you keep on building the cells and so in that process you stack it up steadily and. So, you will put one end plate at the bottom and then you instead of just one cell here you will put the second cell, third cell, fourth cell, fifth cell, whatever if it’s a 10 cell stack you will have 10 cells and only then the second hardware will come this second end plate will come on top of the tenth cell. Other cells will be attached connected in series. So, usually you will have all these bolts standing vertically up and then all of these parts coming in one by one. So, you sit and assemble them one by one till you get all these 10 to line up correctly and then you put this bolts and then you tight them up. So, in the I mean tighten them up.

So, in normally also we first you simply hand tight them the way I am just doing it right now. And so that's the first stage of this build which is to hand tight everything. So, that they are you know firm they are not loose. So, if the hand tighten all of them and at that point its actually quite to for you to lift it up and you can see the hardware it's not going to fall apart it is going to stand on and so on its already you know tightend the way we want it to be tightened. What remains is actually simply based on this build the specification of the build we will look at we can you know specify a torque, torque value for each of this bolts.

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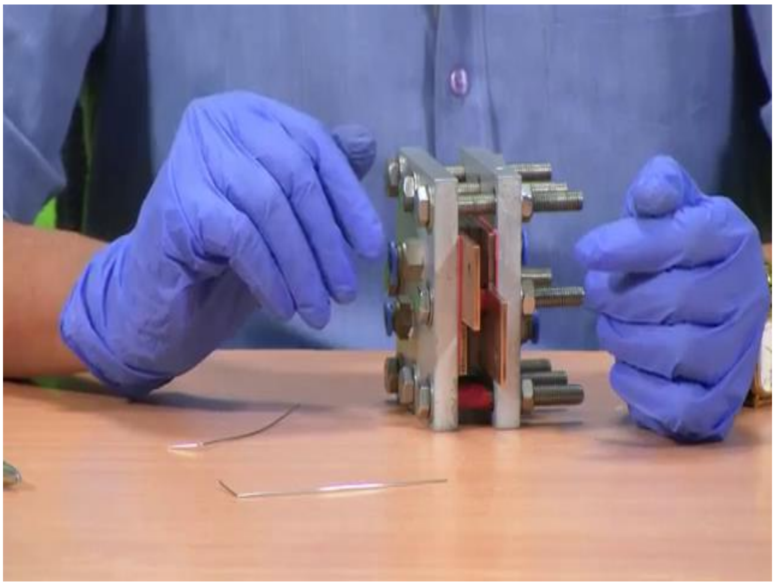

And therefore, you can put a torque wrench and then you know hold it on one side, so like this. So, you will hold it on one side and you will have a torque wrench on the other side and then you tighten it till you reach the correct torque.

So, on each bolt you can reach the correct torque and that way you ensure uniform compression of this hardware in all directions. So, right now I have only done hand tight on, hand tightening on all the bolts, but that's for the first step of this build. You actually have to have a torque wrench with which you will apply a predetermined amount of torque and then at that point you put the right kind of compression on this hardware so that it both seals as well as there is good electrical contact at various locations within this hardware. So, that’s how you would build this hardware.

Of course, one last step remains once you are done with this complete hardware building you still have this aligning pins that are sitting in this hardware which I can which I can slide out. So, I can I can show you here this is one aligning pin, and I can pull out this other aligning pin here which is sitting here. So, there are two aligning pins here there is one here and there is one here. So, if you see carefully you can see those aligning pins, one here and one here. So, I am I am just going to pull it out slowly.

So, let me line it up here and then you can possibly see it and begin to pull it out there you see the pin I am pulling it out. So, that’s the pin, pull it out, pull it out it comes right out there the pin has been removed the aligning pin has now been removed from the cell. So, one aligning pin was removed in that format and I am going to remove this other aligning pin here. Hopefully you can see that, yeah there you can see the pin and I can just pull it right out it is being pulled out.

So, both the aligning pins are out if the align aligning pin remains it does do some short circuit of the cell because it is going from one side of the hardware to the other side of the hardware it is connecting one current collector to the other current collector. So, it will do a short circuit of the cell. So, you cannot leave the aligning pin in while you still do the test at least not a metallic alignment pin. If you do have a plastic alignment pin you can do that that is not a problem or a non conducting align alignment pin.

So, based on your hardware the exact details of each of these parts may vary, but or wherever you are working on this kind of activity, but broadly what I just showed you is what is there in a fuel cell hardware. Very broadly speaking this is what is there in a fuel cell hardware this is what we use in our lab to do our testing and so it’s a pretty good representation of what you can expect in a fuel cell test setup and also in a fuel cell hardware anywhere that you encounter it. At least you will be able to relate what we have seen here to any part that you see in the in any other hardware that you see you will see some variations on it you will see some variations on the pattern that is used in the flow channel, the sizing of the flow channels, sizing of the overall electrode area also.

So, for example, the electrode area I just showed you was two and a half centimeters by two and a half centimeters. So, an active area of about 6.25 centimeter square, but that is just because it is a test cell that we want a controlled area over which across which we know what the test conditions are. But real hardware we may have 10 centimeters by 10 centimeters which is the 100 centimeter square active area. So, that will be much larger. So, you will have significantly large you know 10 centimeter by some 10 centimeter kind of situation and so, that that sized square you will have that is just the active area. As opposed to the small stamp sized active area that we that we just saw in this test hardware.

So, those kinds of variations you will have. Variations on the dimensions of this end hardware, variations in the way in which it is bolted together how many bolts you are using, what kind of bolts you are using there. You will also have variation the thickness of those flow channels and as I said know is it a graphite flow channel, is it metallic flow channel, is it composite flow channel. So, we have wide range of varieties like that. And the flow pattern inside it can be different. The gas diffusion layer material can be different, MEA can be different, but where whatever hardware you see I think you can pretty nicely relate it to the what you have seen here.

I also showed you this hardware with flat gaskets. You may have gaskets that are circular in cross section. And also because it’s a single cell we have some liberty in the sense that some advantages in the sense then I can comfortably set it up such that on one side I have the flow inlet and outlet for one gas and I can just turn it around and I have the inlet and outlet for the other gas right. And this I am able to do only because it happens to have only one cell inside it.

If I have a series of cells inside it, lot of cells inside it first cell, second cell, third cell, fourth cell and so on, then it is not easy for me to, I cannot just have one gas from coming from one end and another gas coming from the other end because it is not only there it has got more than two sides. So, you need gas hydrogen gas to go to the anode side of each cell. So, if I keep it like this if there is a first cell and then there is a second cell and a third cell let’s say, there are 3 cells here first, second and third. I need hydrogen gas to come to the anode side of the first cell, then not go to the cathode side, but come to the anode side of the second cell not go to the cathode of the second cell, but coming in to the anode of the third cell and so on.

So, similarly air, air would also have to come to the cathode of the first cell, skip the anode of this of the second cell, come to the cathode of the second cell, skip the anode of the third cell come to the cathode of the third cell. So, that is the kind of control I need to have on the path occupy traveled by the gas and so that is done based on a different layout of how the gas flows from cell to cell to cell. So, some, some changes like this you will see in the hardware, but I think what you saw today we will give you a much better perspective of any hardware that you get to see for a fuel cell activity.

So, I think that was the purpose of this class. And I think you will find this informative to you if you ever happen to look at fuel cell hardware.

Thank you.

KEYWORDS:

Fuel Cell Hardware; Parts of Fuel Cell Hardware; Single Cell; Current Collectors; Catridge Heaters; Gaskets; Connectors; Flow field; Flow Channel; Gas Diffusion Layer; Membrane Electrode Assemble (MEA); Anode; Cathode; Electrode; Catalyst; Aligning Pins; O – Ring; Stack; Torque; Uniform Compression; Active Area

LECTURE:

The assembly of disassembly of a Single cell PEMFC hardware is demonstrated, and the significance and function of each component is explained in detail.