**Algorithms & Power Systems Architecture:**

**Using Historical Analysis to Envision a Sustainable Future**

**Oral History Project**

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***Abstract*:**

Richard O'Neill, recently retired from the Department of Energy, discusses his educational background at the University of Maryland and his many professional activities. He describes positions with various federal agencies, including the Energy Information Agency, the Federal Energy Regulatory Commission (FERC), and the Advanced Research Project Agency – Energy (ARPA-E). He mentions heading the Grid Optimization Competition. He explains general and partial equilibrium models for the energy sector. He discusses his early work on restructuring oil and gas regulation, and follow-on efforts to translate those changes to the electricity sector. He focuses on the unique physics of electrical systems, different in kind from natural gas networks, and the development of the Standard Market Design used by most of the

Independent System Operators (ISOs) in the United States today. He distinguishes this from the regulated monopoly utility systems, Southern Systems in particular. He briefly discusses unique characteristics of the power system operated by the Electric Reliability Council of Texas (ERCOT) and notes that Pat Wood served on both FERC and the Public Utility Commission of Texas. He explains the challenge of solving optimization problems in the 1980s and 1990s, with both computer hardware and software limitations. He shares an anecdote about the 1999 Next Generation of Unit Commitment Conference, at which Bill Bixby of CPLEX introduced mixed integer programming. He explains that mixed integer program vastly simplified the optimization calculation. He notes that in 2006 the Pennsylvania-New Jersey-Maryland Interconnection (PJM) tested mixed integer programming and realized a savings of $500,000,000 over six months. He describes the role of his office at FERC in encouraging ISOs to adopt mixed integer programming. He reflects on the current lack of demand side participation in power markets. He discusses integration of inverter-based resources into power systems and the market algorithm currently used to address lack of inertia and lack of reactive power. He reflects further on his background in operations research and translating that to power system optimization. He mentions Fred Schweppe's research group at MIT and their role in introducing the notion of competitive markets for power systems. He stresses the importance of establishing a shared vocabulary about power systems to allow collaboration across disciplines and stakeholders. He closes by encouraging engineers interested in working at the system level to study market design in order to understand how physics and economics mesh.

Note regarding Transcript and Timestamps:

Timestamps appear in the transcript but may not align with the recording. Pauses and interruptions may have been removed, and the overall length of the recording may be reduced.

***Transcript:***

Julie Cohn (00:00:00):

This is Julie Cohn. I'm conducting an interview with Richard O'Neill on Friday, October 25th, 2024, online. Daniel Molzahn will assist with the interview, and Sairaj Dhople and Jess Slater are also participating in the interview and may ask questions. Dr. O'Neill, during today's interview, we're especially interested in your work at both the Department of Energy and the Federal Energy Regulatory Commission, and especially your focus on issues related to optimization on power networks. But first, we'd like to ask you to describe your educational background and the professional positions you've held.

Richard O'Neill (00:01:05):

Well, I graduated from the University of Maryland with a degree in Chemical Engineering. I also have an MBA from the University of Maryland, and my doctorate is from the University of Maryland. My doctorate is essentially in operations research but focused on optimization. And I was an academic for about 10 years, and during that time worked in the area of optimization. Then I got a job offer from the Department of Energy to work on what was then called the Project Independence, PIE, Energy System, PIES. And that was the first, large, partial-equilibrium model of the energy sector, since then. At the time, which was around the end of the '70s, computers were not nearly as big as they are, and the algorithms were not nearly as good as they are today.

Richard O'Neill (00:02:32):

So, we were considered to have a very large problem at the time, that we had to solve. As a matter of fact, the solution algorithms took overnight to solve the energy model. It was built essentially for Project Independence, which was an initiative by the Nixon administration to become independent of imported oil. It happened recently, but it took what, 40 years plus, and probably Project Independence had very little to do with the fact that we are essentially independent in the oil and gas area, and gases were exported. I spent about six or seven years at the Energy Information Administration, which is the official information arm of the of the US government. First, like I said, working on the PIES system, then eventually moving to become head of the oil and gas forecasting and analysis group.

Richard O'Neill (00:03:59):

And then eventually moving on to FERC, the chairman of FERC invited me to come work for her as a technical advisor. After a year as the technical advisor, she appointed me head of the office of oil and gas pipeline regulation, which actually included wellhead gas regulation. Then I eventually moved to become the director of the Office of Economic Policy and FERC's Chief Economist, and continued my career there until, what, 2019. And then got a job offer from ARPA-E, the Advanced Research Project Agency - E, for energy, and spent four years at, at ARPA-E, which is basically chartered to be a semi-independent part of the Department of Energy looking at high risk, high reward energy research projects.

Richard O'Neill (00:05:29):

And while I was there, I was head of the Grid Optimization Competition. And had several other projects, energy-related project, that I was the program director of. And I retired from the federal government, they have about six or seven different words for retiring, last November. So, I'll be retired for approximately one year in a few weeks. And I've essentially kept up, to a certain extent, with electric power, which is now my favorite subject, and also optimization in the electric power sector. And that brings us to today.

Julie Cohn (00:06:38):

Thank you. Could you back up for just a moment and explain for anybody who accesses this recording, what a partial equilibrium model is?

Richard O'Neill (00:06:51):

Well, the general equilibrium model is essentially a mathematical model of the entire US, or the entire country. And it is much more explicit with detail for every sector of the economy, whereas a partial equilibrium model focuses in on one sector in the economy and sort of treats the rest of the economy as unimportant, I guess. Doesn't completely neglect it, but it considers it unimportant. I guess that's the best way to say it. And once I moved to FERC, we designed a lot of—not a lot—but auctions to replace regulations, which looked like, to a certain extent, partial equilibrium models.

Julie Cohn (00:07:59):

So, at what point—was your work embracing electric power systems from the beginning? Or did that topic enter your work at a later point?

Richard O'Neill (00:08:13):

Well, in Project Independence, it was a model of the energy sector of the US economy. So, it had an electricity module. So, in working on that project, I became indirectly involved in electric power analysis. And once I moved to FERC, as you could tell from what I just said, I was a general technical advisor to the chairman. Then I worked primarily in the oil and gas sector as the office director. And eventually moved to electricity and spent the latter part of my career at FERC working on electricity markets, in particular ISOs and their auction structure, which are optimization problems.

Julie Cohn (00:09:17):

So, your profession really spanned a little bit of academic time, and mostly you were involved in government research and regulation. Is that how—?

Richard O'Neill (00:09:29):

Yes, I think about somewhere around 45 years in the government.

Julie Cohn (00:09:33):

Got it. Yeah. Okay. So, you described the problem of the late 1970s as being a critical problem, but was that the most challenging that you dealt with, with respect to electric power systems? Or were there others that really stand out as the thorniest?

Richard O'Neill (00:09:51):

The, the most exciting part of my—and the part of my time where I dedicated almost completely to electric power—was in the starting in the early nineties up until I left FERC, where we had just finished restructuring the natural gas and oil regulation. And it had gone so well that the chairman thought that maybe we should do this for electricity. Of course, the chairman—urged on by some outside forces. And so, we essentially started out with a design for competition and open access to the transmission system, using the natural gas model, which soon became very obvious that it wasn't going to work, due to some of the laws of physics that sort of governed the electric power system. So, we had to essentially adapt our design in a different way. And we ended up with ISOs and ISO markets, which again have generally been considered to be a very positive development.

Julie Cohn (00:11:31):

Before I continue, Dan, Sairaj, did either of you want to jump in to follow up on that?

Daniel Molzahn (00:11:38):

Maybe just a quick follow up on it. Because I've always been kind of curious, you know, I've heard the story told, and the way you described it, that we had restructuring in natural gas, and then we tried to take these ideas to electricity and had to modify them. And so, I'm just curious if you can dig a little more into—what were the aspects that didn't work well and what did work well, and was this completely different in how you changed what you had to do? Or was it basically the same thing with some tweaks?

Maybe from a technical point of view, what were the—I think I suspect I know some of the challenges, but maybe for more general audience—what were those challenges?

Richard O'Neill (00:12:19):

Well, I mean, the physics of the natural gas system—both obviously the gas system and the electric system flow over transmission lines, or pipelines for the natural gas industry and, and electric transmission for the electric industry. And the predominant physics in the electric industry, essentially, was different than the physics in the gas industry. For example, the gas industry has a system that controls gas flows with valves, essentially. And the equivalent of valves didn't work very well, or there weren't very many of them, in the transmission system. And we have this sticky set of Kirchhoff's laws, which basically don't control the flow. They basically, the flow goes over the network in a different pattern than it does in gas and with less of a control system, if you will.

Richard O'Neill (00:13:29):

And so, the model for open access in gas was, I would say, considerably simpler than what we ended up in electricity. And like I said, we tried to take the lessons learned in natural gas over to electricity. But what it turned out is that the Kirchhoff's laws basically demanded a new routine. And the tight power pools in electricity said that, when we proposed open access, they said that that was a step backwards for them. And we started working with them and came up with this model, which was an alternative. We still actually have the open-access natural gas model as part of our open access in electricity. It still operates in vertically integrated utilities like Southern Companies and most of the southeastern utilities. But most of the rest of the companies, basically, well, not immediately, by the way, I mean, initially I think PJM, ISO New England and the New York ISO formed—and California—formed what we called ISOs, which was the alternative to open access, the open-access gas model that we tried to import into the electric sector.

Richard O'Neill (00:15:16):

They chose to form independent system operators, and also at the same time develop auctions to trade electricity. One of the things that happened during that time is a lot of the utility companies sold off their power, their generators rather. Which then created a bunch of independent generators. And we wanted to establish competition between them. And so, we designed this market, which was very close to the optimization model of, of the vertically integrated utilities, except that all the assets weren't owned by a single entity. And so, we had to find a way to mesh them all together. And that required an optimization system to solve that problem. And in some sense, we've been working on that problem ever since. And to some extent, that problem existed in a different form in the industry for 30-plus years, maybe.

Richard O'Neill (00:16:33):

I guess the first paper that I can identify that sort of addressed that was somewhere in the '50s. So, the model's been around for a long time, but the important thing is that we can deal with very large markets mainly because of the increases in computer capability, the hardware, and in the software. And like I said—my own personal opinion is it has done astonishingly well. And that model that started out in the Northeast, and in California, essentially has grown to cover almost the entire United States, with the exception of the Southeastern utilities, who sort of mimic the—or cover—the same area as the Confederacy in the Civil War. So, and you know, I would be glad to go into deeper discussions on any of these topics. But I leave it up to you to choose,

Julie Cohn (00:17:55):

Well, I'm curious about—at what moment did you and your colleagues look at each other and say, this isn't going to work? And who brought that up? I mean, were there engineers from outside the government who were bringing this to your attention? Or regulators? Where was this information coming from? Or was it internal? You looked at it, you said, oh, we understand the physics, this isn't going to work?

Richard O'Neill (00:18:20):

Well, it's interesting that you raise outsiders. We had a professor from Purdue and another professional engineer testify at FERC that if we did what we were proposing to do, it would bring the system down—the entire system. And luckily, we thought that through and dismissed it, to a certain extent. But there were people who basically just didn't like what we were doing. The principle was that we were working with the four tight power pools that I talked about, California, New York, New England, and PJM. And, they had experience in dealing with wholesale electricity trading, but it wasn't quite what we wanted to do in terms of open access. And so, we worked alongside of them, talking to them. California decided to adopt a different model from the one that that most of us liked. And brought the proposal to FERC with a letter signed by the entire California Congressional delegation, essentially saying, don't touch anything.

We've got it right. And what that proved was that they didn't really know that they had got it terribly wrong, and the California system collapsed. And they essentially then adopted what we had reached—originally advocated.

Julie Cohn (00:20:15):

Did Texas ever figure in any of these discussions?

Richard O'Neill (00:20:20):

No. Texas has this weird accommodation, I guess I would call it, where they only are interconnected with the rest of the United States through—or at least the ERCOT part of Texas—through DC connections. Which essentially, through some handwaving and legerdemain, becomes independent of federal regulation. And they eventually, not right away, formed what they called ERCOT. And eventually adopted pretty much the same system that we have in the federal government, except that it's not regulated by FERC, it's regulated by the Texas Utility Commission. But we shared, actually, a chairman, for a time. Pat Wood was a chairman of the Texas Utility Commission. Before that he was an assistant to a FERC commissioner. After becoming chairman of the Utility Commission in Texas, Bush was elected and appointed him Chairman of FERC.

Richard O'Neill (00:21:58):

So, it wasn't that we didn't communicate, it's that communications were, in some sense, not standard. I knew Pat Wood when he was a commissioner's assistant. We went through the natural gas open-access competition when he was there. Then he went to Texas. Then he came back to FERC as chairman. And so, he sort of had the knowledge bridge and ERCOT pretty much did what the rest of the US eventually, or most of the rest of the US, eventually bought into. In this process, we developed something called the Standard Market Design to standardize the ISO markets across the US. And it didn't go over well, possibly because it was considered to be too interventionist.

Richard O'Neill (00:23:04):

But in some sense the ISOs have gradually adopted the Standard Market Design that we proposed to make mandatory. Which actually makes you feel better because they took the proposal and they adopted it, but they didn't want it to be law. ERCOT has this strange relationship, but they have somewhat the same problems. They're considered by many to be too small, because they're not interconnected with the rest of the US very well. And recently, 2022, had experienced Winter Storm Uri, which was a huge blackout in Texas. The price went to $9,000/megawatt hour, which was artificially set by the commission and created a lot of issues in Texas. So, everything, almost the entire United States, with the exception of the Southeast, is in an ISO and is using the Standard Market Design.

Julie Cohn (00:24:33):

Thank you. Do you recall the name of the individual from Purdue?

Richard O'Neill (00:24:39):

Nope. All I remember about it is, I think he had an example—the collapse of the bridge in Seattle due to vibration—I forget the name of the bridge.

Julie Cohn (00:25:03):

Tacoma Narrows Bridge?

Richard O'Neill (00:25:04):

The what? Tacoma Narrows? And he used that as a video demonstration of what would happen to the electric system - buckling. It hasn't happened yet, but he was pretty definitive about what he was saying.

Julie Cohn (00:25:24):

Thank you, Dan. I saw you were ready to hop in.

Daniel Molzahn (00:25:28):

I was just going to ask you to as a quick follow up, so why is the Southeast different? I mean, now I have a vested interest living in Atlanta, but was there some—?

Richard O'Neill (00:25:38):

I don't think it's, well, I mean, Southern Companies has told me, in private conversations, that they're the ISO without the "I." They operate a bunch of companies that they own and have a very wide dispatch, as far as my knowledge is. And generally, I believe that that area of the country is still fighting the Civil War and doesn't particularly like to be under federal regulation. And so, they chose to not have ISOs. And that's pretty much the way it is today.

Daniel Molzahn (00:26:29):

So, not due to a generation mix difference or anything?

Richard O'Neill (00:26:33):

Nope. No, I don't think there's any issue other than some lingering politics that says that we don't want to be—I guess, in one sense—we're federalists. We don't want to be under FERC regulation. But they are, I mean, they just don't want to be an ISO under FERC regulation. And I can see no other reason. Now, Southern Companies is so big, they probably are close to ISO size. And I know that they have an internal dispatch model that looks a lot like our markets, but it doesn't have—it's just optimizing the Southern Companies' system and not—it's still an optimization in the ISOs—and in Southern Companies—but the optimization creates the competition among various owners of the facilities. And Southern Companies' optimization is just their own facilities, and I don't think they have any technical market structure.

Daniel Molzahn (00:27:53):

Got it. Very interesting. That matches what I would've expected, given—I have a bunch of students off at Southern Company nowadays. But interesting to hear it.

Richard O'Neill (00:28:04):

The relationship between Southern Companies and Georgia Tech is fairly tight. I was the manager of one of the projects that Georgia Tech had, and oftentimes at ARPA-E, you have a hard time finding a place to demonstrate your project. They had Southern Companies; Southern Companies just opened the door and welcomed them.

Daniel Molzahn (00:28:33):

Yeah, that is one nice aspect of being here.

Richard O'Neill (00:28:38):

Yeah, no, in some sense Georgia Tech has a very good relationship with Southern Companies, which is very amenable to cooperating with Georgia Tech and letting them experiment with—not— “experiment” is probably the wrong word—but use the Georgia Tech system to prove concept.

Daniel Molzahn (00:29:08):

Yeah. I can speak to that firsthand. Yes.

Richard O'Neill (00:29:11):

Yes. I was talking about the project that Sakis has.

Daniel Molzahn (00:29:17):

Yep. I know which one you mean.

Julie Cohn (00:29:21):

Can you talk a little bit more about the role of computer hardware and software in this process? When you started in the industry, utilities used only a handful of digital computing technologies, not necessarily for power system control or optimization. That changed a lot between the, well, I guess the 1960s and 1980s, so that by the end of the 1980s, analog machines were no longer used by utilities. So, I'd love to hear your reflections on that transition, how your work was influenced by the evolution in computing hardware and software. And then to any degree, if you have any thoughts about this, whether your work then influenced developments on the computing side.

Richard O'Neill (00:30:14):

Well, it's very interesting and possibly serendipitous, but my PhD work was in optimization. And I was probably an early person who was actually doing numerical computations, although on embarrassingly small problems now. I mean we were doing computing in the era of key punch machines and card readers. And we measured storage capability in K’s, not G’s, kilobytes rather than gigabytes. But I did study optimization and became an expert in the area. And I moved from the University of Maryland to Louisiana State University, where I got an appointment in the computer science department. So, I actually learned a lot more about hardware and things of that nature. The interesting development—the optimization problems, the standard way to solve the optimization problems in, I guess, in the '80s and

'90s, was either Lagrangian relaxation—that's probably a little bit too technical—and linear programming.

Richard O'Neill (00:31:49):

I actually was pretty knowledgeable about both. And we started off—I think the ISOs were using Lagrangian relaxation to solve the problem. But Lagrangian relaxation had this problem that it—you solve the optimization problem, and because it was non-convex, you usually got an infeasible solution. And about the same time, there was a technology called mixed-integer programming that was essentially about to take off. And I happened to know the developers of the software. And we actually had a conference at Rutgers, which we called the Next Generation of Unit Commitment, which essentially was, as far as the ISOs were concerned, the market software that they would use to solve the problem. That was in late 1999. And it turned out that we had the major software developers come to the conference and also the major utilities.

Richard O'Neill (00:33:04):

And it turned out that while we hadn't been paying attention, the ability to solve these problems had increased by a factor of $10^6$, which meant that they were now able to solve the problems that the ISOs had. In 2006, PJM introduced this technology, which was called mixed-integer programming into their dispatch. And I was talking to the head of the division that operated that market at PJM, and he said, yeah, we tested the software, and we saved a half a million dollars over six months. A billion, half a billion, sorry, millions, billions. Who knows? It was, it was half a billion. And I said, "and you haven't told anybody about this yet?" So, I encouraged them to put out a press release saying that they had switched, and they were getting much better solutions, much lower cost. Because I wanted the other ISOs to adopt this technology, which it was now proven.

Richard O'Neill (00:34:25):

And eventually they all adopted the technology. Although, the last entity to adopt the technology was in 2017. Things don't really always move fast in the electric industry. So, they all actually use this software, and the software has gotten better over time. So, it's a great success. Although my own personal opinion is probably only about half the way through the transition to a sort of more robust market structure. So, there's lots of work to do and especially with the influx of renewable generation, the sort of the precarious economic position of nuclear plants, which now seem to have found a sugar daddy, called data centers. So, there's a lot going on. The interesting thing, the most interesting thing in my opinion, is that the pricing in those markets need to be improved, and the demand side of the market needs to become a greater participant in the in the markets.

Richard O'Neill (00:36:03):

Currently, the demand side doesn't participate. I think the principal reason why it doesn't participate is because it never participated in the markets for the last 150 years. That significantly lowers the efficiency of these markets. And I think that the demand side is missing out on profitable opportunities by participating in the market. And those profitable opportunities are changing radically. We are finding ourselves in certain places where the prices are near or below zero, which means that processes like hydrogen electrolysis can become economic. But if you're not participating in the market, you might not see that those prices until it's too late.

Julie Cohn (00:37:19):

Sairaj or Dan, did you want to jump in on this?

Daniel Molzahn (00:37:22):

Yeah, I have a follow up question on this. Because I—this conference at Rutgers that they described—I was not around at the time, but I've heard stories, I think from—I believe it was a keynote from Bob Bixby that he describes. I think it was the same conference, and—

Richard O'Neill (00:37:43):

Yes, it is. That was, that was the speaker that caused the, sort of, the revolution.

Daniel Molzahn (00:37:49):

Yeah. And so, I was curious, what I'm trying to remember from this presentation that Bob gave at one point about—the story I'd heard is he came in with a laptop and he started running the mixed-integer program at the start of his presentation, and by the end, he had a better solution than hours' worth of time on Lagrangian, or—what was that story?

Richard O'Neill (00:38:11):

Well, what happened—well, Bixby came. And he was the principal developer of the system we call CPLEX, which was a system that IBM bought from Bixby. Bixby came to the conference, and we were talking when he got there—because I had known him from before—and we were explaining—he didn't know a whole lot about unit commitment. And we were talking, and there were two standard problems, I believe, that PG&E had put into public domain. One was a week-ahead unit commitment, and the other one was a day-ahead unit commitment. And the week-ahead unit commitment hadn't been solved yet. I mean, they had tried to solve it, and it just—they ran out of computer time, not "they" meaning Bixby, but the industry.

Richard O'Neill (00:39:15):

And so, we emailed him the input data for both of those programs. He went home that night, and he essentially solved both problems with the last four or five versions of the CPLEX algorithm. So, you could see how the CPEX algorithm had improved over time, and in the end, he had solved the mixed-integer program overnight. He didn't have to fiddle and fuss with all the parameters and things like that. Overnight had solved a problem that had previously been unsolved. And that, I think made the industry people there stand up and take notice. But it still took six years before the first ISO adopted the use of this and the adoption, you know, it was the best test possible. It was a true beta test because they ran their existing software against this mixed-integer programming software for six months and with no other change.

Richard O'Neill (00:40:34):

And it had saved about a half a billion dollars in dispatch cost. So, that was, I think, the turning point. And like I said, after that, one by one, all of the ISOs adopted that approach. There was some kicking and screaming by the software developers like IBM. Although IBM was fairly happy because IBM owned that algorithm. Let's see, what, who were the others? Siemens, and what was, Hitachi, I guess. There were a couple other software developers who were resisting switching software companies that supplied software to the ISOs. But eventually they all sort of came around and realized that they were fighting a fairly steep uphill battle to keep their own software on the system.

Daniel Molzahn (00:41:52):

What was the motivation or the justification that, you know, they were using to, to kind of push back, if, it seems like: “oh, this is evidently much faster, much more robust potentially.” Why was there that six-year gap? Or what was the argument for that six-year gap?

Richard O'Neill (00:42:10):

Well, the software companies that the ISOs engaged, delivered a complete package of software, which included a Lagrangian optimization or some version of a mixed-integer programming problem. And they didn't want to switch from that to a foreign algorithm. I mean, most of these the software in those companies were essentially built from the ground up, without any modularity. They were all developed internally in GE, Siemens, or, God, what's the other, I can't remember the other whatever, I think it's now Hitachi, but I can't—. Do you remember what the other was? I think New York had, New York, and I don't know, anyhow, I forget the name of it, but they, they all were reluctant and but eventually realized that they were fighting a losing battle.

Daniel Molzahn (00:43:39):

—I'm sorry, Julie—was it FERC that was pushing them to do this? Or was it, you know, like—?

Richard O'Neill (00:43:46):

Well, it was my office, my group that was pushing it. It was part of our job. I mean, FERC didn't have a formal position on this stuff, but once the PJM data came out and you asked the other ISOs: "why aren't you saving a half a billion dollars?" And there wasn't a good answer to that. So, eventually, you know, they just literally threw up their hands and said, "okay, we're buying into the mixed-integer software."

Daniel Molzahn (00:44:31):

Got it. It's just an interesting, at least from my perspective, really interesting story about how a change happens in this industry—that it's not, you know, I have the better tool, it works, and you should all adopt it immediately. It's not quite that straightforward.

Richard O'Neill (00:44:47):

Well, yeah, I mean, there is a significant inertia in the industry. The industry, first, is very cautious. And secondly, anything you do on the system essentially creates a risk of creating a problem. My favorite analogy is, if you have an app on the internet, you just put it on the internet and see if anybody uses it or is willing to pay for it. Here, you put a new app on the system and the professor from Purdue's testimony sort of becomes true. And boom, you cause a blackout. And so, the industry is very conservative in that sense, and because of the way it's regulated, or at least was regulated, it's even more conservative.

Richard O'Neill (00:46:00):

And in some sense, I've been spending the last couple of years trying to figure out why the demand side doesn't want to participate in this market on the consumption side. And I've come to the conclusion that they don't use the same vocabulary as the electric utility, and they're mostly dominated by chemical engineers. They don't use the same vocabulary that the electrical engineers use, or the electric industry uses. They have been taught that the best way to operate your system is steady state, which means that bidding into the market and responding to price signals and moving your consumption around is not a good idea. And they don't have anybody that actually can calculate how much more profit they would be making if they actually participated in the market. And generally—I have asked large industrial customers why they don't participate in the market. And the most frequent answer is: "we have never thought about it."

Daniel Molzahn (00:47:23):

Yeah. It's an interesting story. It just reminds me of—my brother is also a chemical engineer, had worked at a large refinery, same story, never thought about doing any sort of demand response. And even if they did, it wasn't on the table for them. I'll put it that way.

Richard O'Neill (00:47:40):

If you look at those companies, they have either a very centralized energy procurement operation, which is done at headquarters and not even locally. And if it's done locally, they only have maybe one or two people managing their consumption of electricity and other energy fuels. So, the idea of formulating bids to participate in the day-ahead market just isn't in their organizational structure. When it could be very valuable. For example, you can't produce green hydrogen without basically producing when the price is low, which is when there's a lot of renewables on the system, and you can make a claim that you're producing green hydrogen. And the same is true for what we do today, which is sort of a sin against climate change, is we curtail renewables, instead of trying to find uses for the renewables that are economic when the prices get low. And you can't necessarily predict in advance when the prices are going to be low, but the algorithms, the dispatch algorithms will actually schedule you so that's the case.

And also, there's some issues with the pricing system that I don't want to go into, unless you want me to, that need revision.

Julie Cohn (00:49:35):

Stepping back for a moment, did Bob Bixby talk at all about the problems he was trying to solve when he developed CPLEX?

Richard O'Neill (00:49:48):

Well, mixed-integer programming has an interesting history. There is a broad range of problems, industrial problems, that can be modeled using mixed-integer programming. Any industrial process that has start-up or fixed-cost plus marginal-cost is amenable to this. And today we have a huge set of examples that are operating in the industry very successfully. But the first set of what we call mixed-integer programs took forever to solve. And some large corporations would not let their engineers develop these programs because they just ate up computer time and they never really solved the problem. But then Bixby came along, and he and two partners developed an optimization system that was much better than the existing technology and actually was able to solve some of these industrial problems in a very short period of time.

Richard O'Neill (00:51:15):

And the ability to solve mixed-integer programming problems allows you to much better model the industrial process. And I think the algorithm that Bixby started developing sometime in, I guess, the early '90s or thereabouts, and today is probably $10^9$ faster than it was in 1990. About 50% of it is the increase in speed of computers and the size of storage. And the other half is better technology to essentially find an optimal solution, better approaches. So, you can just imagine that, if we were to turn the clock back 10 years on the open-access process, that we wouldn't have the technology available yet to solve these problems with mixed-integer programming. Now, I mean, up until then the electrical engineers did fairly well solving these optimization problems with heuristics. And even though they worked fairly well, once you used the mixed-integer programming software, the mixed-integer programming software was significantly better. And that's the standard today.

Julie Cohn (00:52:57):

So, do you think it was simply kismet or knowledgeable interactions across different sectors in the world that brought changes in the regulatory framework for the industry into play at the same time that computing power was changing, that these other industrial processes were changing, that economists like you were developing new approaches to optimization, that sort of thing? I mean, it's kind of interesting that it all came to pass in the '90s.

Richard O'Neill (00:53:35):

Yeah, I mean, it definitely was the—first of all, understanding how to properly manage the dispatch problem, which was the optimization problem; the fact that computers were getting much faster during this period of time; and the fact that that the technology was developed for mixed-integer programming that made it much faster. All three of those had to come into confluence at the same time, or we would probably still be struggling with finding better solutions. And we still are struggling as I said before. The demand side of the market just hasn't shown up in these markets. They show up as a fixed point, which is to the disservice of the market and the disservice of the demand. And one of the things I was trying to do, and still are trying to do, is convince large consumers that they would be much better off if they were to participate in these markets. And to date, we have not been very successful. But who knows?

Julie Cohn (00:55:07):

Sairaj, did you want to jump in at this point?

Sairaj Dhople (00:55:13):

Sure. So, this is all quite interesting. I have a related question, maybe not directly linked to what you said, Richard, but you know, you talk about a time when we had technology debt, in terms of the software and the optimization algorithms, and it took several years in order to resolve this. And at that time, at least maybe my understanding is incorrect, but it seems like the hardware was fairly static. There wasn't as much innovation from the generation side, at least compared to today where you have power electronics and inverters getting deployed left, right, and center, and it's easy to push over-the-air updates and have these things do, you know, whatever. I just wonder, in this new environment, how do you see the role of optimization and markets shaping up and whether we are prepared to deploy the massive numbers of inverter-based generation at the rate at which we are doing it?

Richard O'Neill (00:56:19):

Well, you know, it is an interesting question about how inverters are going to play in this market. But the ISO markets are—I hate to say this, but pretty much ignore reactive power. And to a certain extent, ignore things that happen in the less-than-one-minute timeframe. And it's the responsibility of a different group to keep the system in balance. I know we're still actively debating the role of inverters and whether they can take over the role of inertia, but those are issues that are important issues, but they don't exist in these markets. Mainly because it's managed offline and the markets cannot accommodate—the markets themselves are a linear approximation of the AC power flows.

Richard O'Neill (00:57:35):

So, until you can solve a mixed-integer, nonlinear AC power flow, you have to do a lot of the reliability work offline. Now the market algorithm sets aside generators to deal with n-minus-one reliability and things of that nature. And they set aside generation to keep the market in balance at all times. But that is managed under different people, I guess I would say. Most of the reactive power issues are local issues and are controlled by the local utility. The big thing that the markets do is they schedule the real power in an economic way. And like I said, leave the stability issues and the reliability issues, real-time reliability issues, to be managed by a different group.

Richard O'Neill (00:58:56):

And they are what they are. Any power system operation has to keep its real and reactive power in balance. It's got to keep its voltages within a certain range. The technology for solving a mixed-integer AC power flow problem is, we're fairly close to it. I was the project manager of the Grid Optimization Competition where we were solving mixed-integer nonlinear optimization problems, which are the AC power flow problems. And we could get good solutions in a reasonable amount of time. Now, exactly how much value there is in solving these problems, we don't know yet. How far off of the optimal solution we are when we make these linear approximations—that's still an issue to be resolved.

Richard O'Neill (01:00:07):

But I certainly believe it's coming. We'll probably have a GPU to solve it at some point, if there's enough space on the system after ChatGPT does its work. No, we're not stopping in any sense. And, if nothing else, the inverters will have to prove their worth in action. In California, there's times when they're exporting power because they got too much renewables and in other ISOs they're curtailing renewables.

That, in some sense, is bad system management. But you know, those things, those are still problems that need to be solved.

Daniel Molzahn (01:01:11):

Dick, maybe If I can follow up on that question, because I was also very curious about your experience with the GO Competition, the RP Grid optimization competition that you just described, and solving these mixed-integer AC problems. Do you see that as kind of the next big software advance for these markets? Or, I know for instance, you've also done a lot of work in topology optimization and switching problems. Is that the next big thing? Or is there an equivalent of a mixed-integer programming solver revolution that can happen?

Richard O'Neill (01:01:45):

Well, I mean, certainly the transmission switching problem has gotten a lot of attention. Pablo Ruiz probably is the leading practitioner of transmission or topology optimization. And he's done work in France and in the UK, SPP, MISO. They are all looking into these transmission switching things. There's an interesting study that he did for SPP where they literally found a topology change that essentially allowed them to not curtail a bunch of wind generation. And it, in some sense, there's a sort of intuitive nature to topology optimization and renewables, because renewables are essentially much less controllable than the fossil generators. And so, you may not need topology optimization as much in a fossil world, but if the wind is changing and the sun is moving around, there seems to me to be a lot more opportunities to reconfigure the topology of the system to get a better answer.

Richard O'Neill (01:03:27):

The interesting thing about the ACOPF mixed-integer program is, we don't yet have a study of how valuable it is. We don't know how much better the system is going to improve if we include an AC optimization. Because even today, when we don't have AC, or reactive power, in the optimization system, we manage the voltage and the reactive power in various different ways. My favorite example of a mistake we make in reactive power is that today, in most of these markets, they—when they need reactive power—reactive power is pretty much a local phenomena—they put a constraint into the system that limits the import flow into a given area, which forces an old generator to be started up and operated to generate reactive power.

Richard O'Neill (01:04:43):

The rule of thumb is reactive power is the marginal losses that it takes to generate reactive power. In this case, the cost of getting more reactive power is the cost of starting up an old generator, which is expensive, running it at a minimum operating level, which is uneconomic for real power. And we insist that the marginal cost of the reactive power is the losses in generating reactive power. Who caused the startup cost and the minimum operating level? It was the need for reactive power. So, there are instances where reactive power is being terribly underpriced and is distorting the market. For example, we don't optimize transformers in the current market. We don't optimize capacitors. What is done is done offline in a manner that I'm not terribly sure how it's done.

Richard O'Neill (01:05:53):

And most of those operations are for reliability and not for economics. But with the penetration of renewables and penetration—we haven't even talked about data centers yet, which is the new and sexy topic to talk about in the business—and how they are going to essentially operate on the system. And they're also a prime example of a consumer that should be participating in the market and to some extent participates in the market in, at least in Texas, by getting off. The Bitcoin miners get off the system when they can no longer be profitable, which is good. Because when the system is stressed—high price, that is—they get off the system. Which is good news. So, you know, but everybody's sort of all aflutter about: "are data centers going to take the system down?" Or whatever. So, there's lots of work to be done.

Julie Cohn (01:07:14):

Well, I can tell that Dan has a question there. But let me just ask you to look—well, Dan, ask your question and then I'll ask you for one more look back.

Daniel Molzahn (01:07:25):

I guess it's just a quick follow up on that, because that I think was really insightful discussion. So, my question is, do you see, are there studies going on, or efforts in place to assess that? To figure out what would be the benefits? So, looking back to the mixed-integer programming case, it was very clear you saved half a billion dollars a year. This was straightforward to sort of sell, or more straightforward to sell this as a technology. Here, it seems like we're missing that case study to show. Are there efforts in place to develop those case studies now?

Richard O'Neill (01:08:03):

Well, no, not to my knowledge, just put it that way. The GO Competition essentially was terminated when the director and the deputy director left ARPA-E—who were the main champions of the GO Competition and study in this area. As far as I know those issues—there's a whole bunch of data from the competition about consumers participating in the market. But it hasn't been analyzed yet. And it will take us an effort. The other thing is, which is a little bit more difficult, is to compare optimization with a fully developed AC flow system, and against what they have today. And just to add something on to the tail is that, you know, we have this really interesting problem of the stochastic nature of the renewables. And the fact that we're curtailing renewables is disturbing, because it's a lack of a better transmission system or a lack of demand to consume the cheap power. Which—that shouldn't be happening, let's put it that way.

Julie Cohn (01:09:55):

I have actually two look-back questions. So, the first relates to the Bob Bixby story again. So, 2007, PJM demonstrates that this is a better algorithm to use. The other software companies have been reluctant to adopt it. And I'm trying to understand, so they had software packages that did multiple jobs for a utility, and were they reluctant to try to pluck out their algorithm for this particular optimization challenge and figure out how to add in somebody else's proprietary software? Was that basically the challenge for them?

Richard O'Neill (01:10:41):

Exactly.

Julie Cohn (01:10:43):

Okay, great.

Richard O'Neill (01:10:43):

They had built these software packages so that they were almost impenetrable, and certainly they were not modular. Which means you could unplug one software system and plug in another software system without a whole lot of effort. But PJM, principally Andy Ott, decided to press his software supplier, which was IBM [GE] at the time, or no, what it was, it was—they changed names all the time, so I can't remember. But they literally fought tooth and nail to, not to modularize that system. And I think you've pretty much nailed it. That—why can't I remember that name of that software system? But anyhow, they, they did not want to make their systems modular because their systems would then be vulnerable to competition.

Richard O'Neill (01:12:03):

Even though it would've been good for the ISOs to be able to find the best software package to do whatever the task was. Up until then, they pretty much had built one software package, and it was very hard to penetrate that stuff, that package, without a major modification by the software company, which was going to cost, which wasn't cheap. I can't quite quote a number, but they charged a lot of money to make that kind of a change to their systems. I don't know whether it's finished or not, but I think the—oh, it's GE, it was the GE system, not the IBM system. And the—now I've lost my train of thought. The system owners of these big packages basically did not want to make them modular.

Richard O'Neill (01:13:20):

And the GE people who—GE served New England, PJM, MISO, and SPP. So, there was a fairly big—and the GE system dominates the US market. And they, all of the ISOs got together and said, look we want you to make the system more modular. Exactly how that, I've lost track of the status of that process, but it was ongoing. I don't know whether it's finished or not, but it makes a lot of sense from a whole lot of different angles. For example, we're going to have inverters that we're going to have to integrate into the system. Obviously, it's happening in California, it's happening in SPP and they're managing it. And also, in ERCOT. All of those entities have lots of renewables. And even though the academics may be still arguing about how to integrate this stuff and how to operate the inverters, we're doing it. So, there's lots of work to be done.

Julie Cohn (01:14:55):

So, a different kind of a look-back question, your training was as an economist is my understanding?

Richard O'Neill (01:15:03):

Well, my training, well, my undergraduate degree is in chemical engineering, then I got an MBA with a significant dose of economics. But then in my PhD program I did operations research and mostly optimization theory. So, I was trained as a chemical engineer, studied economics, and then studied optimization. And as a chemical engineer, that's why I came up through the system in the oil and gas business, and then eventually switched over to electricity. And I had to train myself in electricity because I didn't have much of a background. But in the process, I questioned a lot of things and had questions that people couldn't answer. For example, probably one of my favorite issues is the value of lost load. Now, you would think that the value of lost load was the value of lost load, but it's not. It's the cost of a combustion turbine operating four or five hours a year. And so, there are a lot of terminology in the electric industry that, as far as I'm concerned, don't make any sense. But everybody sort of understands what they're meant to be or what they should be or something of that nature.

Julie Cohn (01:16:56):

Were there particular individuals or, I guess individuals, whose work prior to your work in this area really influenced how you thought about the problems you were addressing and faced those problems?

Richard O'Neill (01:17:15):

Well, at MIT, in the seventies there was a group run by a professor named Fred Schweppe, who was starting to conceptualize greater participation in a market sense. And Schweppe's main goal was to get consumers to participate in the market, strangely enough. But, but as a general philosophy, he wanted to create markets where buyers and sellers could trade electricity. He died prematurely. But, before that he wrote a book on how to develop these markets, which I read from cover to cover. I also read Power Systems by Vijay Vittal cover to cover as part of my getting up to speed to work in the electric area. I think most people agree that Fred Schweppe and his group at MIT led the idea of developing markets to trade electricity.

Richard O'Neill (01:18:45):

And at that time, almost all the trading was done by adjacent utilities. And a lot of it was for reliability and things of that nature. And the way that vertically integrated utilities are regulated, using cost of service regulation, you make money by investing in capital assets. So, the more capital assets you can convince your utility regulator to build, to let you build, the more profit you make. And so, a lot of people, economists especially, saw that that was not a very efficient way to operate a market, if you could have a market. When the generation, transmission, and distribution are all owned by the same entity it's very hard to have a market. But things evolved in a certain way. A lot of utilities didn't see making profits in generation, and sold off their coal units, and sold off their nuclear units.

Richard O'Neill (01:19:57):

And so, became essentially transmission and distribution companies. And that allowed the competition to be created in the electricity market. So, I would credit Fred Schweppe and a bunch of people at MIT. Off the top of my head, I can't identify any other groups that were pushing for this. And even Fred Schweppe was sort of focused on getting the consumers involved in the market, and probably, and not that much the generators, because I guess I assumed that the politics of competition was so far off that he focused on consumers. But, you know, that was probably the center of the idea of having markets.

Julie Cohn (01:20:54):

How interesting that that's brought you full circle to the consumer side.

Richard O'Neill (01:20:59):

It's been a big issue, and I consider it a big gap in the optimization of power systems and the ability to adjust to renewable energy. And obviously, if you're going to have electric cars, they are active consumers and can consume in a way that minimizes their cost. And so, the electric system that we are moving to is even more important to have the buyer side of the market, in the market. Otherwise, you curtail renewables, which is just a bad idea. It's economically cheap and it's green, not to curtail renewables.

Julie Cohn (01:22:02):

We've kept you talking for nearly an hour and a half. I'm going to see if Sairaj or Dan want to ask any additional questions that are technological in nature. And if not, see if Jess has something that takes us in a different direction.

Daniel Molzahn (01:22:19):

I have many questions, more technical that I could ask, but maybe slightly less technical question that I'd have though, is, so I feel like I was really fortunate with the software conferences that you ran every summer—to be able to attend—and you had the ISOs in the room and the academics and national lab folks, and those were just, really, from my point of view, really insightful gatherings. And so, I was wondering, kind of, what was the history of those and is that the main way that a lot of these communities would get together? Are there other examples of how we've collaborated between academia, national labs, ISOs, regulators? It is one of the few locations I know of where all those groups were together in one space.

Richard O'Neill (01:23:06):

Well, what happened was that when Jon Wellinghoff was chairman at FERC, Wellinghoff is a sort of, as a side issue, does computer stuff. He is very knowledgeable in the area of computers. Surprisingly. I didn't know that when he first came to the commission. And he—I mean, I guess I convinced him that better, faster software and better market algorithms were a good idea. And he agreed. And he gave me a budget and said, "here—." And I suggested to him that we have conferences on developing software for the electric utility industry. And it turned out that there was a big demand for this. And there were groups that didn't talk to each other, as you said. I mean, there were industry groups, there was ISOs, there were consumers, there were software developers. And this was a place where it was a very focused conference. It wasn't like the IEEE summer meetings where you basically have six hotels full of electrical engineers going to meetings. They were very focused, and they were focused principally on the development, the further development of ISOs through software, but not exclusively through software. And I think that proved to be very fruitful. And it still exists today.

Daniel Molzahn (01:25:06):

I'll say, “thank you,” because I've found those very useful, and it just was a very unique opportunity and I appreciate your effort pulling that together.

Richard O'Neill (01:25:17):

No, it was part luck.

Julie Cohn (01:25:21):

Sairaj. Any, anything further from you at this point?

Sairaj Dhople (01:25:26):

No, no technical questions from me. Thanks.

Julie Cohn (01:25:28):

Okay. Jess, did you have any questions you wanted to ask?

Jess Slater (01:25:31):

Yes, I have two, but they are connected which they, yeah. During your time at FERC, how did you manage collaborative projects involving engineers or other professionals from different backgrounds? When they each have their own approaches and technical languages?

Richard O'Neill (01:25:50):

Carefully. At FERC, FERC is essentially run by lawyers. Most of the commissioners are lawyers. There's a very big legal staff. And you have to convince lawyers, who sometimes stop studying mathematics at algebra, of what you were doing made a lot of sense and conformed with the laws that we operate under. And it's not exactly easy. I mean, we have a fairly big group of electrical engineers. A fairly, I wouldn't say large, group of economists. And, you know, I mean, just having a vocabulary to discuss things is a challenge. Because the lawyers have their vocabulary. The electrical engineers have their vocabulary. And the economists have their vocabulary. For example, the economist would say, the problem of dispatch is a problem of maximizing market surplus and finding a Pareto optimal solution.

Richard O'Neill (01:27:21):

The electrical engineers would say, let's find the cost-minimizing solution. They happened to be the same in a sense, but they're not. And the lawyers ask: "is this process just and reasonable?" And so, you have to basically develop a vocabulary to even discuss these things. And I don't think dumbing down is the right thing, but to basically explain things using their vocabulary. I've had many a discussion with commissioners who are lawyers about what constitutes a just and reasonable price. That's the law. FERC has to establish just and reasonable prices. And also, not unduly discriminatory prices. And that, again, is in the law. And the language itself implies that there are just and reasonable discriminatory prices. And it is literally—it's almost like United Nations.

Richard O'Neill (01:28:43):

You need simultaneous translations when you're having policy discussions. And to a great extent, there are gaps and there will be gaps. For example, you'll find a lot of people saying that the ISO LMP prices clear the market. Well, they don't. But that's sort of the way we talk about them. Now, unless you put that language into the court and the court figures out that you've been misstating your position, there's sort of no harm done. But anyhow, there is a lot to be said for being able to bring people together and come to an agreement. And oftentimes you can do that, and oftentimes you can't. I remember one conversation I was having with a lawyer on transmission interconnection, or generator interconnection to say it better.

Richard O'Neill (01:29:59):

And I said that the rule, Order 2003, says you can't build transmission under the interconnection rules. And I said to the person, who was the lawyer who was in charge of the program, that they were building transmission. And her response to me was, no, they're not, because the law says they can't. And yet they were building a transmission line under this thing. And it's that kind of discussion where the technical issues are clear. They're building transmission, but the law they says they can't be. It was always a lot of fun. It was a challenge convincing the lawyers what the right thing to do was.

Jess Slater (01:30:50):

Thank you so much. And just to follow up on something you said, this shared language that is between like engineers and lawyers and the economists, is this something that you just learn on the job, or is this something that should be incorporated into the curriculum? What is the best way to help students coming into this?

Richard O'Neill (01:31:10):

I came through an engineering program myself and took a course called Engineering Economics, which was completely worthless. It was mostly probably because of the professor that taught it. But I think that it isn't taught well enough in undergraduate or even graduate school. And by the way, competition in the electric industry is new. I mean, ISOs have only been around for about 25 years. So, that means that most of the senior management in these companies, who are engineers, haven't had a formal education in the economics of Independent System Operators. They use and misuse the language because they've never been educated otherwise. I don't know exactly what the current generation of electrical engineers coming up, get. I know that some universities have programs dedicated to ISO markets or courses dedicated, but, I mean, I'm a big fan of making sure we all are talking with the same vocabulary. I mean, quite frankly, things mean different, words mean different things to economists than they do to electrical engineers, than they do to lawyers. And it's almost like you would go into a meeting and you'd hand out a sheet of definitions or vocabulary, so you knew what each one was talking about.

Jess Slater (01:33:08):

Interesting. And that kind of falls perfectly into that second question is, I was asking about the collaborative project because I was wondering, you mentioned in the early '90s, after successfully regulating oil and gas, FERC's chairman recognized the need to apply similar strategies to electricity, ultimately leading to the establishment of the ISOs. So, I was curious, what did that collaboration look like? Like what did that transition look like?

Richard O'Neill (01:33:38):

Well, it started out, we had a process where we created open access on the pipeline system to encourage competition. It worked fabulously. Although it took a while to get everything tuned properly and to get the i's dotted and the t's crossed. But it really worked well. And because it worked so well and there was—confluences are important in major policy changes. There was a law passed in '78 called PURPA, which essentially required certain types of independent systems, to be hooked up to the utility systems. And the utilities had to buy power from them. And they included wind, geothermal, solar, co-located—what do you call them—I forget—anyhow, certain types of generators that were used where the steam was used for process heat and things like that.

Richard O'Neill (01:34:51):

It created a group of owners of generators who were not utilities, who needed access to the system, and a market to sell their power to. That became a political force. And that force essentially saw themselves as building cheaper generators, and they wanted a market to sell it to. So, the only way to do that was to have an open-access program and allow them to sell their power into the market. Without them, there probably wasn't the political coalition to do electricity open access. So, it was, again, somewhat fortuitous, because this law was passed in '78 and we didn't start doing open-access stuff until the '90s. But, the accumulation of independent generators, from '78 to the '90s, was a significant enough political force to push the open-access system.

Richard O'Neill (01:35:58):

And Congress and the courts were very friendly to our reforms to create more competition in both the natural gas and the electric industries, that it was so often a hot knife through butter, as it went through the courts. The courts could have easily just sort of said: "no, we're not going to let you do this." But things worked out. At least in my career in this industry, you have to bring a coalition together to create the political pressure to do this stuff. And in the case of electricity, it was this seemingly innocuous provision in this law called PURPA that had a significant effect. And probably we would be doing the same thing we were doing 50 years ago today, if it wasn't for that sector of the industry.

Jess Slater (01:37:17):

You mentioned almost like this political side seemed to be smoother. Was it also like that with the engineers who were working with the oil and gas, because I noted you said something—there was additional laws of physics, or not additional, but there was other constraints dealing with the electric system. Was there any tension between the engineers or any, you know—?

Richard O'Neill (01:37:40):

Well, we all recognized that the applied physics of natural gas and electricity were different. And that was one of the reasons why the old, the natural gas system wouldn't work. I mean, the gas system had valves, they could control flow with the valves. Valves in electricity—are not easily ported to the electric grid. They have this—the flow model is basically—distributes the power differently over the lines. And so, it's much more difficult to have individual transportation agreements. And so, the ISO was the way to deal with this problem. We have financial transmission rights, but technically I don't think we have any physical transmission rights to speak of anymore. They're all basically hedging transmission prices. Which is again, another thing that is really interesting in both the gas industry and in the electric industry, is that along with all this competition comes a lot of hedging. And, a lot of financial rights trading, that we didn't talk about at all. But it's just complementary and it helps people deal with risk and things of that nature.

Jess Slater (01:39:21):

Thank you so much.

Julie Cohn (01:39:22):

Thank you, Jess.

Richard O'Neill (01:39:25):

Oh, by the way, one of the biggest differences between gas and electricity is the natural gas laws gave FERC eminent domain over building pipelines. That didn't happen in electricity. And the eminent domain process is really, sort of screwed up in the electric industry. And most of the eminent domain authority rests at the state level. So, building transmission is difficult, just because of the way the laws evolved. Congress has tried several times to give FERC the authority that they have in natural gas, but it never seems to completely get through Congress.

Julie Cohn (01:40:15):

Thank you so much. I suspect we have at least five other topics we could raise, but I think we've kept you in this interview for a couple of, almost two hours now. So, we don't want to overextend—

Richard O'Neill (01:40:30):

<laugh>

Julie Cohn (01:40:33):

I mean, one topic I'd love to explore maybe separately would be the intertwined nature of the gas industry and the electric power industry and what that implicates for the future. But we'll save that for another day.

Richard O'Neill (01:40:49):

No, that's also a very interesting topic. Things happen that, that we're not really sure how they happened, but they happened, and things work out.

Julie Cohn (01:41:01):

It is the case that Sairaj has a closing question for most of our interviewees. Did you want to close that, Sairaj?

Sairaj Dhople (01:41:08):

Sure, I can do that. I usually ask what advice you have for a future generation of power engineers, but I realize that your background may not directly be related to power, since you said you came from chemical engineering. So, maybe I can broaden that a little bit. Do you have any words of advice for, you know, the future generation who thinks about these issues related to the electric power system and what they should do to structure their careers?

Richard O'Neill (01:41:36):

Well, it's certainly how they want to focus on their careers. But if they want to become system operators, if they want to participate in electricity markets, they need to have the training in order to do that, just like anything else. But if they want to develop the next best transformer, they probably don't have to worry about the economics. I mean, they should go focus on building the next best transformer or the next best inverter. And, in a sense, if you want to develop hardware or things of that nature, you don't need to understand the markets. But if you want to work at a system level, then understanding the markets and understanding how they develop and why we have them, you need to, to adjust your curriculum to that set of facts. I wouldn't want to comment on somebody building the next transformer or the next inverter or a superconductor or things like that. You know, that's pretty much a technology project. But when you're interfacing between the physics and the economics, it's important to understand that—how those two mesh.

Julie Cohn (01:43:22):

Thank you so much. We really appreciate the time you've spent with us. I hope it's been of interest to you as well. And we look forward to future opportunities to chat.

Richard O'Neill (01:43:34):

Okay. Glad to.

*[End of interview]*