In the Matter Of:

Topsoe, Inc., vs

L'Air Liquide, et al.

HARALD KLEIN

April 02, 2026

IN THE UNITED STATES DISTRICT COURT

BEFORE THE PATENT TRIAL AND APPEAL BOARD

TOPSOE, INC.,
Petitioner
v.
L'AIR LIQUIDE, SOCIÉTÉ ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCÉDÉS GEORGES CLAUDE,

Patent Owner

Case IPPR2025-01173
Patent No. 11,673,805

ORAL DEPOSITION
HARALD KLEIN
APRIL 2, 2026

ORAL DEPOSITION OF HARALD KLEIN, produced as a witness at the instance of the Patent Owner and duly sworn, was taken in the above-styled and numbered cause on the 2nd day of April, 2026, from 9:00 a.m. to 2:55 p.m., before Melinda Barre, Certified Shorthand Reporter in and for the State of Texas, reported by computerized stenotype machine.

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HARALD KLEIN,
having been first duly sworn, testified as follows:
EXAMINATION
QUESTIONS BY MR. ROBINSON:
Q. Good morning, Dr. Klein. Thank you for being here today.
A. Good morning.
Q. Have you been deposed before, sir?
A. No.
Q. Okay. So a couple of basic kind of just ground rules that will make things simpler. The court reporter can't capture anything that isn't verbal. So I'll ask you to answer questions out loud and not while I'm asking. Fair?
A. Fair.
Q. Okay. Thank you. If I ask a question you don't understand, feel free to ask me to clarify.
A. Yes, I will.
Q. And if you need a break for the bathroom or anything else, please feel free to speak up. The only thing I'll ask is that if there's a question pending, that we answer that question and then take a break.

A. Okay.
Q. Dr. Klein, you have been retained on behalf of Topsoe in two IPR petitions, correct?
A. Correct.
Q. And those petitions, I believe, are proceeding at 1173 and 1174. Does that sound familiar?
A. No. I don't recall. What's the number?
Q. So let me ask it a little bit different way. You understand that there were two IPR petitions filed?
A. Yep.
Q. Do you understand that the second of those IPR petitions was not instituted?
A. Yes.
Q. Okay. So we're only here to talk about the first of those two IPR petitions?
A. Exactly, yeah.
Q. Dr. Klein, I'm going to hand you what was submitted with those petitions and marked by Topsoe as Exhibit 1004. Do you recognize that document, sir?
A. Yes. That's my CV less the publication.

Q. So just to briefly walk through your education, sir, it looks like your undergraduate degree was obtained from the University of Stuttgart?
A. Correct.
Q. In process engineering?
A. Yes.
Q. Would you briefly describe what process engineering is.
A. It's different to the States. In the States there is just mechanical engineering, chemical engineering, civil engineering. In Germany we have also chemical engineering but at some universities it's called in German Verfahrenstechnik engineering.
Q. You're going to have to spell that.
A. V-e-r-f-a-h-r-e-n-s technik with a K at the end. It's called Verfahrenstechnik. The best translation for Verfahrenstechnik would be process engineering, but in some schools in Germany it's also called chemical engineering.
So when I was in the States in medicine, I always stated I have an undergraduate in chemical engineering. But to be a little bit more precise, I stated here process engineering.

Q. Does that differ in Germany from what U.S. schools typically offer as chemical engineering?
A. No, it does not.
Q. And so it looks like your master's degree is from University of Wisconsin Madison in chemical engineering?
A. Exactly. I went -- after the bachelor in Germany I went to Wisconsin, and then I finished my American master's degree before I finished my German master's degree in process engineering again.
Q. Okay. And then your Ph.D., I'm going to ask you to translate roughly in 1996 -- maybe that's the subject of your thesis?
A. Investigations on the Thermodynamic Behavior of Thermocompressors.
Q. And can you briefly describe what thermocompressors are?
A. It's a thermodynamic cycle my professor had in mind. It's related to the Ericsson process. It's a gas process. He had the idea of combining that with an internal combustion, a lot of heat regeneration, regeneration of heat. We did experimental studies there; and I did also lots of theoretical investigations, dynamic simulations, thermodynamic simulations. That was my thesis.

Q. You mentioned simulations. Were there any physical prototypes or models built of that system?
A. Yes. We had an experimental setup in our laboratories in Stuttgart.
Q. And that would be a laboratory-scale system?
A. Yes. It's got a piston machine, and we talk about 1 liter of volume.
Q. So I think of 1 liter in terms of displacement.
A. Yes, uh-huh.
Q. Okay. And then it looks like from your Ph.D. you then went to work for Linde Group?
A. Exactly.

Q. And it looks like from 1996 to 2002 you were a process engineer for hydrogen and synthesis gas plants?

A. Yeah. That was a part of Linde Engineering, and one product line was hydrogen and synthesis gas plants. I started at the process design department doing process design work, process design of hydrogen blend, hydrogen-CO blend, methanol blends, ammonia blends.

Q. What did that process design work involve?

A. We did process simulations of the whole process; and then it went down to equipment design, heat exchangers, separation vessels, reactors documenting the process, the equipment and data sheets. And then it went away into the engineering for two years. And then we went back to the process as process engineer -- to the project, sorry, as process engineers for commissioning the plant.

Q. Okay. So initially those simulations and design work involved designing a new plant?

A. Yes.

Q. And what did that plant produce?

A. I was involved in pure hydrogen plants, producing hydrogen out of natural gas. I was involved in designing ammonia plants, producing ammonia, and also methanol plants.

Q. So approximately -- it sounds like you said you started out with design, then spent two years in engineering and then went back to process design with commissioning plants.

A. No, no. Sorry. My time was from '96 to 2002. That was the process design department.

Q. Okay.

A. But our job as process engineers at the early phase in the basic engineering we do the design work, process simulations, equipment design. And then when you at the end want to build a new plant, it goes the way in engineering where we were not involved anymore.

Q. Okay.

A. Instrumentation, 3D layout and so on and then actually the construction on-site. And then it takes two years and then after

two years we step back into to -- in this project what we designed, and then we went to the plant to support the commissioning of the plant.

Q. Commissioning to get it running the way it's intended to?

A. Exactly, commissioning -- well, when you work for an engineering company, you deliver the plant turnkey, lump sum, whatever, and then the operational team of the client is already in the control room. And as engineers from the engineering company, you are more or less responsible for the startup, for the commissioning; and you educate already the new operational team which will run the plant in the future.

Q. Okay.

A. And that was also my job to go to the commissioning jobs.

Q. How many plants were you involved in commissioning during that period from '96 to 2002?

A. I was involved in two big ammonia plants.

Q. Okay.

A. But I went also on-site for troubleshooting, running blends, doing aftersales. I went also to a plant quite often for aftersales, troubleshooting.

And to clear a little bit your question, you said it was designing new plants. That was the main job. But we were also working on retrofitting existing plants doing debottlenecking studies -- that's also the job of a process engineer and engineering company -- a blend which was delivered five years ago, already running for five years. It gets back to the company, Hey, we need more capacity. Can you do a debottlenecking study?

So it was not only designing new plants but also doing debottlenecking studies of existing plants.

Q. Thank you.

A. To be very precise there.

Q. I appreciate that.

So then in 2002 it looks like a relativity short period with Linde-BOC process plants in Tulsa. Can

you tell me about that?
A. Yes. At that period our U.S. office was in Tulsa, Oklahoma.
Q. Okay.
A. And we sold two hydrogen plants to Praxair, both in Texas City. And I went to the Tulsa office to support the engineers there as the lead process engineer for the basic engineering of these two Texas City plants for Praxair.
And this basic engineering -- at the end the process design and the matrix would have been design. That's a typical period of three months. And then I went back to Munich. Then the detailed engineering proceeded, of course, in Tulsa.
Q. So this would have been precommissioning on those two plants?
A. Not precommissioning, just basic engineering. And the commissioning then I was not involved. The commissioning then was two years later.
But at that time I was already in the responsible position of

leading the department; and, therefore, I could not go to the commissioning of the plant, which I would have loved to. But as a manager, you don't have time to do that or they don't give you the time to do that.
Q. So I think I unintentionally asked that question in a precise way I did not mean to.
The time that you were in Tulsa, that was before the time that those two plants were commissioned?
A. Yes, yes, of course.
Q. Okay.
A. Yeah, yeah. We did the engineering. And then two years later after the basic engineering, we have the detailed engineering and the construction and the precommissioning and then finally it was two years later it was commissioned with the Praxair.
Q. Okay. Thank you.
Do you recall what type of separation process those two plants used for separating hydrogen?
A. PSA, pressure-swing adsorption.

Q. And was there any CO_2 capture on those two hydrogen plants?
A. No.
Q. What types of reactors did those two plants use, do you recall?
A. Yes. A conventional steam reformer and a thermic steam reformer with auxiliary firing and then a water-gas shift reactor.
Q. Just to clarify and maybe get to an acronym that will make the reporter's job a little bit easier, when you say steam reactor, conventional steam reactor --
A. Steam reformer.
Q. -- or steam reformer, would that be a steam methane reformer or an SMR?
A. Yes.
Q. So if I say "SMR" today --
A. Let's stick to that, yeah.
Q. Okay. And then on the water-gas shift reactor downstream of the SMR --
A. Yes.
Q. -- can we refer to that as a WGS reactor?
A. Definitely.
Q. All right. So from Tulsa you said

you went back to Munich. Was that the 2002 to 2007 role listed on your CV?
A. Yes.
Q. And that was as the manager for process engineering for hydrogen and synthesis gas plants?
A. Yes.
Q. Okay.
A. My boss retired; and after coming back from Tulsa with the U.S. experience, they thought that I would be the right person to lead the team.
Q. Okay. Just out of curiosity, were you in Tulsa for about a year? Was it less than a year?
A. No, no. That was just three months.
Q. Three months. Okay.
So then as the manager for process engineering for hydrogen and synthesis gas plants, it says you were responsible for the process design department?
A. Yes. I was responsible for my former colleagues, so to say.
Q. That's what I was just going to ask.

That's the same department you started out in '96 to 2002, right?
A. Yeah.
Q. Okay. So it says "steam reforming and partial oxidation." Is this steam reforming sort of the conventional SMR that we mentioned a moment ago?
A. Yes.
Q. And the partial oxidation, can we refer to that as POX today?
A. Yes.
Q. Or POX.
A. POX is fine.
Q. Okay. And then the physical and chemical absorption processes, what did that involve?
A. Physical absorption with a B, very important, that's chilled methanol using as a solvent. That's for scrubbing out CO2 out of synthesis gases, not for synthesis gases from steam reformers, preferably for synthesis gases out of POX processes.
Chemical absorption means using amines, also to take out CO2 out of the synthesis gas but preferably for steam reformer gases, gases coming out from a steam reformer and WGS coming from an SMR and the WGS. Preferably we used chemical solvents like amines.
When we have POX with or without WGS, the preferred solution is physical solvents. And our physical solvent process was -- still is deep cold methanol. That's the distinction between physical and chemical absorption.
Q. Thank you. And then the last is cryogenic separation of synthesis gases. What did that involve?
A. That's the cryogenic separation of at the end separating hydrogen from carbon monoxide, CO, with the cryogenic process.
Q. And then the last sentence there under that manager of process engineering role, it says, "Development of innovative process routes for synthesis gas and CO2-free concepts for large scale energy applications."
What did that involve, sir?
A. Coming back to your question regarding the Texas City plants, whether we did CO2 capture there, that was 2002. It was gray hydrogen releasing all the CO2 to atmosphere.
Then in the mid 2004/2005 this climate discussion came up more and more, and people came up more and more thinking about the idea of capturing the CO2 instead of freezing that to atmosphere. If you do that with a hydrogen plant based on SMR, this is called the blue hydrogen.
But there were also the ideas of retrofitting fossil-based power plants, coal-fired power plants, and also gas-fired power plants to capture the CO2 out of the flue gas of the power plants. And that was a new -- I wouldn't say trend. It was a necessity to discuss that in mid 2005, I would say, to do something against climate change.
That was the philosophy in Europe, yeah. Therefore, we were looking -- of course, we know of the technology; and, therefore, we thought that Linde Engineering will play also a role when we capture the CO2 because we have all the processes already, absorption, PSA.
Q. Okay. And so the -- you mentioned the absorption. That was the, if I remember correctly, physical absorption coming out of the POX reactor and the chemical absorption downstream of a SMR and WGS?
A. Exactly.
Q. Okay. Go ahead.
A. To make the picture complete, if you allow me that, when it's an SMR and a WGS and it's a conventional hydrogen plant at that base at Texas City, we did not take out the CO2.
But we left it to the PSA and then all the CO2 ended up in the -- let's stick to one term for this discussion -- res gas, which is probably the most easiest one.
At that time CO2 had to be taken out when you go -- instead of hydrogen as the product, when you go for ammonia because each ammonia plant is usually parallel. The ammonia goes into a urea, u-r-e-a, plant. And this urea plant

producing fertilizer required the CO2 and, therefore, the CO2 was captured. Not for climate reasons but for the use in fertilizer urea plants.
Q. In that instance was the CO2 separated from the hydrogen before going to the urea plant?
A. It was separated before going to the PSA, and then the CO2 went to the urea plant wherein the CO2 reacts with the ammonia to this urea. So we captured the CO2 out of the CO2-rich shifted gas.
Q. As a feedstock for the urea plant?
A. Exactly.
Q. Okay. So then in 2008 you transitioned to academia, it looks like?
A. Yes, I did.
Q. What prompted that change?
A. That's a good question I have to answer a lot in my life, and I did that a lot the last 18 years.
I was quite happy with Linde. It was a good job. I really loved it. And it was not on my agenda to go back to university. That's the statement,

No. 1.
But then occasions come up, as they do, and people try to convince you. Then even when you say at the beginning, No, that's not for me, they tease you. And then you try. And when you try, you want to be good. And at the end you are No. 1, and then you have the decision to do.
It went all the way up to the board of Linde, the CEO. He asked me to his office, and I expected a completely different question. I expected, What shall we do that you state?
But then the CEO said, We as Linde would like that you do that because then we'd have a strategic connection to Technical University Munich. At the end it was my decision. It was not that funny at that date. But at the end a lot of people wanted it, and I wanted it as well. And it was very challenging.
The most important motivation for me was teaching. I like to teach and being back in the classroom.

Being the manager of the process design department, I -- the most fulfilling role for me was hiring young engineers, masters or Ph.D.s, and educating them and telling them within the first year, half year actually sitting on the projects already.
And then I don't want to be too cocky here, but I thought that I have the right language to tell people something what they have to know. That was my biggest motivation to go back to academia.
Q. I have no sense for how academia works in Germany. Are you required to research as well as teach?
A. Yes.
Q. Do you have to obtain grants to fund that research?
A. Yes.
Q. And how do you go about obtaining grants to fund your research?
A. So when you become a professor and you -- when you become professor in the mid-40s, as I became, you're tenured from the very first day; and then they just tell you,

Do research and do teaching.
Teaching is well defined. We have the study programs, basic things like thermodynamics or advanced things like advanced process control. Let's stick by the study programs.
Research you're completely open. And I was in the lucky situation that I got four research positions fixed from the university to get started. But then if you want to grow, you have to apply for grants. You're completely right.
In Germany it works like -- let's say there is -- you can separate it into two areas, public-funded research. I would say if I would be in the States, a lot of that would work with the DOE. And we have similar ministries in Germany. And they put out calls and then you apply for the call and you spend work in the research application -- sorry, in the project proposal application, yes. And then you get the grant or sometimes you do not get the grant.

And when you have the grant, there is usually one, two, three Ph.D. workers you can hire and then you grow your group. Now I have the size of 25. So third-party money how we call it. Public funding with my research is very application related. I don't do fundamental research. So in the research grants I got it's always the companies, industrial companies, industrial partners are involved with, which have also an interest in these topics.

The second is you don't go out for public grants. You agree with the company directly -- or a company approaches you. You approach a company. Hey, I have an idea. The company say, I have a need.

And then you agree on a one-to-one B lateral research coverage; and then the company pays you directly with some overhead, which the university administration takes off, skims off. And then you have also the same situation. You have enough money to hire one, two researchers for that project.

I would say my split is 80 percent public funded/20 percent direct research with the industry.

Q. So 20 percent is industry funded?

A. Yeah. Maybe nowadays even less. It was 20. Maybe it's 10 now.

Q. Approximately what's your total research budget in any given year?

A. 1 million Euro.

Q. Okay.

A. Doesn't matter. Same order of magnitude.

Q. And that's enough for 25 researchers?

A. I have four researchers funded by the university.

Q. Okay.

A. The one I started I still have.

Q. Okay.

A. But our system works if you do not grow, they even cut you the four you have at the beginning.

Q. Okay.

A. So you have to grow to survive.

Q. Okay. How much do you try to grow year over year? Do you have a target?

A. I have no growing targets anymore. I'm actually -- I'm 63. I know my exact retirement date, which is March, the end of March 2030, and I have so many Ph.D. students to graduate.

If I keep on writing proposals, proposals, proposals, I take -- I have income -- I take them in. All have to graduate. I've slowed down the intake now, and I plotted a curve. When I retire, I want to have less than ten left to be graduated.

Q. Gotcha.

A. So no growth plans anymore.

Q. Looking at your list of publications attached to your CV, how many of those before 2020 relate to hydrogen separation plants -- or, sorry, hydrogen production plants?

A. Before 2020 -- the big growth to 25 came actually during COVID, 2020. And that was a time all these hydrogen projects were on the calls. So up to 2020 there was not a lot of hydrogen research in my group. So most of the hydrogen-related publications, they are after 2020.

Q. Okay. I want to make sure I understand something that you just said. Hydrogen projects were on the calls?

A. Yeah, because --

THE REPORTER: On the calls?

A. On the research calls from the government. The German Ministry for Research and Education, that's one important ministry. The other one is Ministry for Transportation.

They have their budget from the government; and then these ministries, they set up -- they create calls. And most of that was hydrogen, hydrogen, hydrogen, green hydrogen.

Since I know hydrogen from my career at Linde, I was quite successful; and they trusted me that this is the right lab to place some of these hydrogen-related projects. That was the reason we did grow so much after 2020.

Q. Okay. And forgive me but "created calls," were those like requests for research? Certainly not telephone calls.

A. We call it the research list. It's published on their website; and they say research groups, research groups along with industry companies.

We have here, to give you an example, H2 Geka [phonetic.] We want to research how can hydrogen electrolyzers become more efficient to be manufactured. Then they tell the number. This was a big one. 30 million. And then they set a deadline and you can try to find partners. You have to find partners, industrial partners. Also industrial partners contact you because they think you're the right research partner.

Then this research call has a deadline. You can write in -- you can hand in a sketch, 20 pages. You outline your research idea. And then they evaluate the sketches, the research ideas.

And if you drop out, you don't get the project. And if you get selected -- Hey, this research sketch sounds interesting -- they notify you. They consult you. And then they say, Go

for a full project proposal now. List all your budget you need and so on.

Then if you don't do too many mistakes, you're through usually.

Q. Okay. So it's almost a request for like research abstracts; and then if they get through that, then they ask for a full proposal?

A. Sketch is probably not good. Research abstract, 20 pages abstract; and then you're through if you don't.

Q. If you don't screw it up?

A. If you don't screw up, yeah.

Q. All right. Do you have a copy of the '805 patent there, Doctor?

A. Yes.

Q. Dr. Klein, just so it's clear for the record, the '805 patent is U.S. patent 11,673,805, correct?

A. Yep.

Q. And that's Exhibit 1001 that was submitted with the IPR petition?

A. Yes.

Q. And you recognize this as the Air Liquide patent that is challenged in this

proceeding?

A. Yes.

Q. So at a high level what is GHR reactor?

A. Gas-heated reformer.

Q. And what is an ATR?

A. Autothermal reformer.

Q. So the '805 patent depicts both series configurations and parallel configurations for the GHR and the ATR, correct?

A. Yes, it does.

Q. And you understand today that the IPR petition we're here to talk about deals with the series configuration, correct?

A. Yes, only the series.

Q. Okay.

MR. PHILLIPS: Real quick so that she doesn't hit you, make sure that he finishes his question before you answer.

THE WITNESS: Yes.

MR. PHILLIPS: She's doing a pretty good job, but you're kind of running on top of each other.

THE REPORTER: Thank you.

BY MR. ROBINSON:

Q. What are the differences between an SMR and a GHR?

A. An SMR is the conventional steam reformer where the heat for the endothermal reforming direction is supplied from an external heat source, which is a firing. That's what we realized in Texas City.

GHR on the reaction side in the catalyst tubes the same reactions take place, also the endothermal steam reforming reaction, along with the water-gas shift reaction.

So SMR plus WGS, in both reformers these two reactions take place on the catalyst side inside the tubes. In a conventional SMR the heat is supplied from external firing. You just burn gases and supply the heat with open flames.

In a gas-heated reformer, GHR -- we can also take that as an abbreviation for you -- the heat is supplied by cooling a general hot gas, no open flame.

Q. Do the operating temperatures differ between an SMR and a GHR?
A. Yes, it does.
Q. How so?
A. The operating temperature of an SMR is way higher. The operating temperature of a GHR is lower.
Q. You mentioned a catalyst. Do the catalysts differ between an SMR and a GHR?
A. No, they don't. Both are nickel-based catalysts.
Q. What about the feedstocks that can be processed in an SMR versus a GHR?
A. The feedstocks are the same. The feedstock is in both cases a hydrogen, natural gas, mixed with steam.
Q. Does the higher operating temperature of an SMR enable a broader range of feedstock characteristics in an SMR?
A. No, it does not.
Q. Are there any other characteristics of an SMR that enable a broader range of feedstocks?
A. No.
Q. By "broader range of feedstocks," I

mean different mixtures of carbons and hydrogens.
A. What do you mean with "hydrogens"?
Q. So, for example -- that was a terrible way to phrase that question.
Different feedstocks, for example, can include natural gas, refinery gas, or naphtha, correct?
A. Yes.
Q. Okay. And all of those can be processed in an SMR, correct?
A. Naphtha can be processed in an SMR. However, if you process naphtha directly in an SMR, there are special nickel catalysts for naphtha reforming as compared to natural gas reforming.
Q. And naphtha generally can't be processed in a GHR, can it?
A. I never saw this application.
Q. You've never seen naphtha processed in a GHR?
A. No.
Q. Okay. Same question for refinery gases. Refinery gases can be processed in an SMR, correct?

MR. PHILLIPS: Objection to form.
A. Refinery of gases. If you mean that hydrogen-rich gases contain already some hydrogen from the refinery. Correct. Yes, these gases can be used as feedstocks in SMRs.
BY MR. ROBINSON:
Q. Can refinery gas be processed in GHRs as well?
A. Yes, they can.
Q. Are there any different operating characteristics required to do that in a GHR versus an SMR?
A. As with the natural gas case, the operating temperature in the GHR will be lower.
Q. So, generally speaking, in an SMR the inputs are methane and steam, correct?
A. When you talk about the natural gas, it's mainly methane and steam; but no natural gas is pure methane. There are always some levels of higher hydrocarbons: ethane, C3, C4.
Q. Okay. The primary target chemical reaction in an SMR is to convert methane and steam into carbon monoxide and hydrogen,

correct?
A. That's correct.
Q. Does the operating temperature in an SMR versus the operating temperature in a GHR impact how much of the methane and steam can be converted into carbon monoxide and hydrogen?
A. Yes, it does.
Q. How so?
A. The reaction of methane and water is an endothermic reaction; therefore, it requires energy; therefore, we have the firing in an SMR. And it's what we call -- in chemical thermodynamics it's called an equilibrium controlled reaction.
It does not proceed completely from the reactants to the products. And because it's an endothermic reaction, there's a principle called Le Chatelier's principle. Maybe there is also a French accent somewhere.
Q. Thank you.
A. It's an endothermic reaction and thermodynamic -- at the end it's the second law of thermodynamics. It says that the

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higher the temperature the higher is the conversion from methane and steam to carbon monoxide and hydrogen.

Q. So all other things being equal, in an SMR a greater proportion of methane and steam will be converted to carbon monoxide and hydrogen than would be the case in a GHR?

A. Yes.

Q. What are the differences between an SMR and an ATR?

A. Okay. ATR. Besides steam and methane, you also add oxygen to the feed. And this oxygen reacts with the methane, but the oxygen is under-stoichiometric. There is not enough oxygen to combust all the methane. And, therefore, the main reaction is the oxidation of methane to CO, carbon monoxide, and to hydrogen.

That's the simplified view what's happening in the first part of an ATR. And that goes to the point that all oxygen is consumed, but there is not enough oxygen to burn partially. At the end we -- we talked about POX. The first part of an ATR is the POX. It's a partial

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oxidation of methane, not to CO2 but to CO. But there is not enough oxygen. It's under-stoichiometric. Therefore, after the oxygen is used up, methane is left to a big portion.

And, therefore, after this open flame the POX zone of an ATR, we have another -- we have a catalytic step. The same catalyst as an SMR, nickel based. We had steam at the inlet.

After the flame of the ATR we have a hot temperature. And now this oxygen-free gas, the leftover of methane with the steam, goes into the catalytic bed; and then steam reforming and water-gas shift reaction takes place without heat supply because the heat -- sorry, the energy is in the gas because it has been heated up by combusting part of the methane.

And then it goes into this bed, catalytic bed, to perform the steam reforming reaction and the water-gas shift reaction. And because the steam reforming reaction is endothermic and we don't have

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energy supply, the gas cools down when it goes into this catalytic steam reforming combined with the water-gas shift in the second part of the ATR. So this is the simplified picture of an ATR.

Q. So for an ATR how does the operating temperature in the catalytic step compare to the operating temperature in an SMR?

A. It's higher.

Q. It's higher in the ATR?

A. Yes.

Q. Okay. What is the net effect of that relative to -- let me ask this in steps.

The operating temperature in the catalytic step of the ATR is higher than the operating temperature in an SMR. For a given feedstock how does the proportion of methane converted to hydrogen in an ATR compare to the proportion of hydrogen -- or proportion of methane converted to hydrogen in an SMR?

A. To answer that question, we would have to talk a little bit more on the flame because what I explained was the very short version that the main reaction is methane plus

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oxygen to CO and hydrogen.

Since this is an open flame and no catalyst controls the reaction, part of the methane reacts with oxygen also to CO2 and water. Let's call this the full oxidation. And this reaction actually generates the high temperature.

This reaction is much more exothermic than the POX. We didn't talk about -- but oxidation reactions are exothermic. So, therefore, we increase the temperature to very high temperature, 1800, 2,000 degrees C. But the main driver for that high temperature, it's not the POX of CH4. It's the oxidation of CH4, combusting completely to CO2 and water.

Besides that in the POX we create CO and hydrogen, and hydrogen is very reactive with oxygen. And some part of the just-created hydrogen reacts with the oxygen as well in a highly exothermic reaction to generate water. And basically the full oxidation reactions, they are the main driver to increase the temperature to

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1800, 2,000 degree, to have high-enough temperature inlet of the non-heated catalytic bed of the ATR.

Now, coming back to your question what's the portion of methane converted in the flame, there are two reactions methane as converted to the methane converted in the catalytic bed. That depends how high you control the -- how much -- at the beginning I said there is not enough oxygen to combust -- to partially oxidize all methane.

On the other hand, some of the oxygen takes the methane to full combustion. So the ratio, how much methane at the end you convert in the flame, depends how much oxygen you add to the first part of the ATR. And this defines also then the portion of methane converted in the two reactions as compared to the SMR reaction in the catalytic bed.

I cannot -- this number depends on the temperature -- with the oxygen at the end you do the temperature control and the portion -- if you want the

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number, it's not a -- I cannot tell you right now. Main part is converted in the catalytic bed.

Q. Okay.

A. Because ATR specialists and ATR designers it's more a matter what outlet temperature do you want to reach in both the flame and out of the catalytic bed.

This temperature control works with the amount of oxygen you supply it at the very top. And to control that temperature to -- let's say the outlet temperature of the catalytic bed, it's 1,000, 1,050. This is the main parameter what you have in mind when you do ATR design, not looking so much on the ratio but what's converted in the flame and what's converted in the catalytic bed.

Q. Why is that outlet temperature important?

A. It's coming back to the thermodynamics. The outlet temperature determines how much methane is left because it's an endothermic reaction and it's equilibrium control.

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The higher you are in temperature the less methane you have, and you want to have -- we talk about methane slip. And the methane content, the methane slip, is slower when we have this high outlet temperature. We can go higher in outlet temperature in an ATR as we can go in the SMR.

Q. I want to make sure I heard that right. So the ATR can go higher than the SMR in outlet temperature?

A. Yes, yes.

Q. Okay. At the higher outlet temperature than a GHR. How does that higher outlet temperature on an ATR impact the downstream components in the system?

MR. PHILLIPS: Objection to form.

A. The outlet temperature? The main factor is how much methane is left, how much methane is remaining unreacted in the outlet of an ATR.

BY MR. ROBINSON:

Q. So will each of an SMR -- in a hydrogen production plant will each of an SMR,

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ATR or GHR generally have a WGS reactor downstream of the reformer?

A. If you want to generate hydrogen, yes.

Q. How do the different outlet temperatures of those different reformers impact the design decisions for the WGS reactor downstream?

A. The inlet of the WGS reactor is lower than the outlet temperature of an SMR. So, therefore, the outlet gas of an SMR has to be cooled down.

The same applies to the ATR. It has to be cooled down even more because it's hotter. And the outlet of a GHR does not go to a shift director.

In the setup what we talk about here in the '805 patent, the outlet of a GHR is the inlet of the ATR in the series arrangement. And we talk only on the series.

Q. Okay.

A. In the parallel it's a little bit different, but we talk about petition 1.

Q. In the series configuration is there

a WGS reactor downstream of the ATR then?
A. Yes.
Q. Okay. We've been going about an hour. Should we take a quick break?
(Recess taken)
BY MR. ROBINSON:
Q. Dr. Klein, do the typical operating pressures of gas leaving an SMR versus an ATR differ?
A. No. They don't differ.
Q. How about the outlet pressure of gas from an ATR versus from a GHR?
A. If you have the GHR in series with an ATR, the outlet pressure of the ATR is slightly lower due to the pressure drop through the ATR.
Q. When you say "in series," do you mean in series in the order shown in the '805 patent?
A. Yes.
Q. Does the increased outlet temperature for an ATR versus a GHR impact the outlet pressure from an ATR versus a GHR?
A. The outlet pressure of an ATR is always lower. No matter how you vary the

temperature of the outlet, pressure has to be lower; otherwise, the gas would not flow from the GHR through the ATR, independent of the temperature.
Q. Is the GHR always paired with an ATR?
A. What do you mean with "always"?
Q. Are GHRs ever used in hydrogen production without an ATR?
A. I'm not aware of it.
Q. Can a GHR be used in parallel with an ATR?
A. Yes.
Q. And how do the outlet pressures differ if they're used in parallel?
A. Parallel configuration means that usually -- first it's parallel. So not all gas goes through the GHR. Part of the gas goes directly to the ATR. And then the outlet of the GHR is mixed with the gas going directly to the ATR.
And then these two gases when they mix, they have the same pressure, which is lower than the inlet of the GHR. And these gases mixed go then

into the ATR, and after the ATR the pressure is again a little bit lower.
But when we talk about pressure drops, it's not that we change the order of magnitude of the pressure level. We have only minor pressure drops in the range of 500 millibar or so.
Q. Just enough for the gas to flow through the system?
A. Exactly.
Q. So typically for gas in a given volume, increases in temperature would increase pressure, right?
A. I'm sorry. I didn't get the question. Can you repeat it, please?
Q. Sure. So for a given amount of gas in a given volume --
A. Yes.
Q. -- an increase in temperature will generally increase pressure, correct?
A. Yes, yes. It's the ideal gas law when the pressure is not too high, yeah.
Q. Okay. So if in the series configuration of the '805 patent --
A. Yes.

Q. -- the feedstock first enters the GHR, correct?
A. Yes.
Q. It exits the GHR and enters the ATR, correct?
A. Yes.
Q. And then obviously after entering the ATR it's got to exit the ATR?
A. Yes.
Q. So if the pressure -- given volume of gas, given mass flow rate, the pressure at the exit of the GHR is higher than the pressure at the exit of the ATR, correct?
A. That's the reason why the gas flows through, yeah.
Q. But the temperature at the exit of the ATR is much higher than the temperature at the exit of the GHR?
A. Yes.
Q. What other characteristics of the gas have to change to maintain the same mass flow rate and the lower pressure?
MR. PHILLIPS: Objection, form.
A. When we talk about flowing systems, I think in steady-state operation the mass

flow rate is constant. The mass flow rate is higher through the ATR because we add the oxygen. So the mass flow rate for the GHR is at the inlet and at the outlet of the GHR the same.

We add oxygen, then we have a higher mass flow rate into the ATR; and we have the same higher mass flow rate out of the ATR of both zones, the erection zone and the catalytic zone.

BY MR. ROBINSON:

Q. We have a higher mass flow rate, a higher temperature but a lower pressure?

A. We have a higher temperature, yes, slightly lower pressure due to the pressure drop and due to the oxygen, its mass flow which has to go through both zones of the ATR, the combustion zone and the catalytic bed.

Q. So are there other changes in the characteristics of the gas that avoid an increase in pressure despite the increase in mass and temperature?

MR. PHILLIPS: Objection, form.

A. The gas are reacting in both -- you talk about the ATR now?

Q. The outlet of the ATR.

A. The outlet of the ATR has more -- it has a different composition we generate in several reactions in the combustion zone and also in the catalytic zone. We generate more molecules at the end as had at the inlet.

You can look at the steam reforming reaction. One methane plus one water creates three water hydrogen and one CO. So we increase the molar flow rate, as they call it. The molar flow rate relates directly to the volume flow rate.

When we talk about -- you gave the example of a fixed volume increasing the temperature. We increase the pressure.

In flowing systems we don't talk about the volume. We talk about volume flow rates because everything is in steady state and flowing through. So we have a higher volume flow rate outlet of an ATR as at the inlet of the ATR.

Q. Okay.

A. For two main effects, increase of mols --

THE REPORTER: Of mols?

THE WITNESS: The particles, the molecules, increase of molecules.

A. -- increase of temperature and a slight decrease of pressure, which is not -- the minor effect. The other two are the major effects.

BY MR. ROBINSON:

Q. So volume flow rate exiting the ATR is also higher than the volume flow rate entering the GHR?

A. Yes.

Q. And higher than the volume flow rate entering the ATR?

A. If you add the volume flow rates of the oxygen and the gas coming from the GHR, yes, it's higher.

Q. Would it be higher even than the -- sorry.

It seems like the volume flow rate exiting the ATR would have to be greater than the sum of the volume flow rates of the methane feedstock and the oxygen feedstock. Is that correct?

MR. PHILLIPS: Objection, form.

A. When you talk about the series configuration, the feedstock to the ATR is not methane; but it's the gas from the GHR.

BY MR. ROBINSON:

Q. Uh-huh.

A. With lot of hydrogen already in it, CO2 in it, CO in it and not reformed methane.

But you're right, the volume flow rate is higher at the outlet of the ATR.

Q. Let me -- that's a fair point. Let me see if I can clarify the way I asked that question.

It seems like the volume flow rate of the outlet of the ATR is higher than the sum of the volume flow rate of the gas from the GHR that enters the ATR and the flow rate of the oxygen that's added to the ATR.

A. Yes.

Q. And I believe you testified earlier -- I'm asking you to confirm; I'm not trying to put words in your mouth -- that in any plant for producing hydrogen there will be

a WGS reactor downstream of the reformers. Is that accurate?
A. Having hydrogen as a product, yes, water-gas shift, WGS, reactor would be present.
Q. Downstream of the reformers?
A. Yes.
Q. I'm going to ask you to refer to your declaration, please, Dr. Klein.
A. Yes.
Q. Specifically at paragraph 28 on page 21.
A. Paragraph 28 on page 21.
Q. Second-to-last full sentence on that page says, "It is known by a POSA that steam reforming is almost always accompanied by the water-gas shift reaction shown in reaction 3."
Do you see that sentence, sir?
A. Yes, I see it.
Q. So, first question, what does POSA stand for?
A. Person of ordinary skill in the art. I would consider me as a POSA.
Q. In fact, you're significantly more

qualified than a POSA, correct?
MR. PHILLIPS: Objection, form.
A. I educate POSAs.
BY MR. ROBINSON:
Q. So "almost always" leaves open the possibility that the water-gas shift reaction is not necessarily present in steam reforming, correct?
MR. PHILLIPS: Objection to form.
A. It's always present in the context of the '805 patent and all the exhibits we have here on the table. I put in the always -- the "almost always" because there are some exceptions in syngas technology. And this is in the paragraph -- or in the chapter V, Field of Technology and State of the Art.
BY MR. ROBINSON:
Q. I'm sorry. Chapter V of what?
A. Sorry. The header of that one page back.
Q. Okay.
A. In this paragraph I describe the field of technology and state of the art. And

there are some applications, exceptions where the water-gas shift reaction does not take place; but these are not important for the case what we have here.
For the hydrogen production in the context of the '805 patent the water-gas shift reaction is always accompanied by -- the steam-reforming reaction is always accompanied by the water-gas shift reaction.
Q. What are the exceptions in syngas where the water-gas shift reaction is not present?
A. If you don't want to produce hydrogen but CO-rich syngases, first you leave the shift out, not to convert the CO; but then the CO is still not high enough for your application.
We talk about gas-to-liquid applications or Oxo alcohols, synthesis gas for --
THE REPORTER: Oxide?
THE WITNESS: Oxo alcohols.
A. And in these applications you feed CO2, along with the methane and the steam, to

any reformer; and then the water-gas shift reaction does not take place. It's the reverse water-gas shift reaction which is taking place then; and, therefore, to also cover these cases I put in the "almost."
BY MR. ROBINSON:
Q. I want to make sure I understand that.
So if you don't want to produce hydrogen, then with the methane and steam feedstock to the reformer you add CO2?
A. Yes.
Q. To increase the carbon monoxide output from the reformer?
A. Yes.
Q. Okay. So if we look at the '805 patent in figure 3, is there a WGS reactor in this system?
A. Yeah. It's tech No. 203.
Q. And that's where the water-gas shift reaction takes place?
A. Yes.
Q. And that WGS reactor is necessary for producing hydrogen to implement that

water-gas shift reaction?
A. Yes. You want to convert the CO to your wanted product, hydrogen.
Q. I'm going to ask you to refer to the Reinertsen reference that's marked Exhibit 1005, please.
A. Yes. I have it.
Q. Just so it's clear for the record, this Reinertsen reference is publication No. U.S. 2023/0119784 A1, correct?
A. Correct.
Q. And is that the Reinertsen reference that's referenced as Exhibit 1005 in your declaration, sir?
A. Yes.
Q. So starting with figure 2 of that reference, the Reinertsen reference, please.
A. I have it, yes.
Q. Block No. 6 is a water-gas shift reactor, correct?
A. Correct.
Q. And that's where the water-gas shift reaction takes place in Reinertsen?
A. In 6 water-gas shift reaction takes place, yes.

Q. And what is block No. 7 in Reinertsen's figure 2?
A. It's a unit. It's a block which condensates -- cools down the shifted gas and separates the condensate 72.
Q. Okay. And what is block No. 8?
A. Block No. 8 is a CO2 removal block.
Q. Specifically that's an amine-type separation process?
A. Exactly, exactly, yeah.
Q. And that's one of the chemical absorption processes --
A. Exactly.
Q. I know it's a little unnatural.
Okay. So referring then to, I guess, block 10 in Reinertsen's figure 2, what is that?
A. That's a hydrogen removal block with a PSA.
Q. And when Reinertsen says "PSA," that could be pressure-swing absorption or adsorption, correct?
A. Only "ad" with a D.
Q. I'm going to ask you to refer to paragraph 103 of Reinertsen. About 12 to 13

lines down in the right-hand column do you see where it says, "The known technique of pressure-swing absorption/adsorption (PSA)"?
A. I see it, yes.
Q. That isn't limited to adsorption, is it?
A. It's adsorption with a D.
Q. But Reinertsen also includes absorption with a B as in boy, correct?
A. A POSA would clearly identify that at position 10 here it can be only a D. It's a D.
Q. Why is that?
A. Because pressure-swing adsorption in the context of hydrogen separation has to be D. A pressure-swing absorption, I'm not aware of what that means.
Q. Are you familiar with Torkild Reinertsen, the person?
A. No, no.
Q. I want to be clear. You're not aware of pressure-swing absorption with a B at all or just in this particular location of a process?
A. Pressure-swing absorption. If you

go back to figure 1 with the -- no. We are at figure 1. We are at tech figure 2.
Actually, the amine system for CO2 removal is an absorption with an amine. And in this amine system we have different pressures, preferably a high pressure at the absorption and a low pressure to regenerate the loaded amine.
So, therefore, you could consider 8 as a chemical absorption system where pressure change plays a role along with temperature change as well. So that would be a pressure-swing absorption along with a temperature-swing absorption as well at 8.
So that would be an example of a pressure-swing absorption, but usually that's not classified as pressure-swing absorption. It's just a chemical-based absorption system to separate CO2.
Q. So I want to make sure I understand the pressures that you just described for the amine system at 8.
When you say the absorption

happens at a high pressure, in this instance when capturing CO_2, does that mean that the CO_2 is captured at a high pressure?
A. That's not correct. The shifted gas -- after knocking out the condensate in 7, the shifted gas 71 enters the absorption at high pressure and, therefore, the gas 82 on our picture, which is the CO_2-depleted gas, the hydrogen-rich gas, this is kept under pressure.
So 71 and 82, they have roughly the same pressure. Despite some pressure drop through the absorber, stream 81, which is CO_2, is at low pressure.
Q. Okay. So if 8 is an example of a pressure-swing absorption process, why couldn't 10 for removal of hydrogen also be a pressure-swing absorption with a B as in boy process?
MR. PHILLIPS: Objection to form.
A. The absorption in 8 works with chemical components, caustic components like amines; and they absorb the sour component

CO_2. That's the basic principle of this chemical absorption.
There is no chemical solvent which absorbs hydrogen because hydrogen is not polar molecule as CO_2. So there is just not a solvent available to absorb hydrogen.
BY MR. ROBINSON:
Q. Do you have any other explanation for Reinertsen's use of the word "absorption" with a B as in boy in the context of hydrogen removal?
A. I have no other explanation than it's not. It has to be "ad," not B.
Q. So --
A. A clerical error, whatever.
Q. So Reinertsen was just wrong when he listed absorption in addition to adsorption?
A. I think so, yes.
Q. Did you notice anything else in Reinertsen that is technically incorrect?
A. I didn't see any other issues, no.
Q. And your declaration doesn't say anything about that error of listing absorption in the context of hydrogen removal,

does it?
A. No. I didn't put any comment in my declaration on this incorrect.
Q. So referring then to Reinertsen's figure 3, in Reinertsen's figure 3 No. 6 is the WGS reactor, correct?
A. Correct.
Q. And that's where the water-gas shift reaction happens?
A. Yes.
Q. And what is block No. 12?
A. Block No. 12 is a hydrogen separation with a selective palladium membrane.
Q. When you look at the outputs of block No. 12, what is stream 121?
A. That's hydrogen.
Q. And what is stream 122?
A. That's -- you can characterize it in several ways. It's the retentate. It's the retentate of the membrane process. It can also be classified as a hydrogen-depleted stream or as a CO_2-enriched stream, which is all the same.
Q. And is stream 121 the high pressure

or low pressure?
A. That's at high pressure.
Q. And stream 122, is that at a high pressure or a low pressure?
A. That's at low pressure.
Q. How do you know that?
A. I know it from the principle how a membrane process works. Especially this process works that hydrogen is the permeate, p-e-r-m-e-a-t-e, that permeates through the membrane. And when it permeates through the membrane, you need a driving force; and the driving force has to be a pressure difference between stream 61 and the stream 121.
Q. Wouldn't that mean the stream 121 would be at a lower pressure than the stream 61?
A. Yes.
Q. Okay. And would the stream 121 be a lower pressure than the stream 122?
A. Yes.
Q. Okay. So the stream 121 would be the lower pressure side of the membrane in 12?
A. Yes.
Q. Okay. And if we refer to

paragraph 62 of Reinertsen, it actually says that the retentate is at an elevated pressure, typically above 10 bar, more typically between 20 and 40 bar, but sometimes even at pressures up to 100 bar, correct?

A. That's paragraph 62, yes, correct.

Q. And that retentate stream is the stream 122 in figure 3, correct?

A. Correct.

Q. Then in figure 3 what is block No. 7?

A. Block No. 7, that's a block which knocks out -- separates condensate.

Q. Condensate being water?

A. Being water, yes.

Q. What's block No. 8, sir?

A. Block No. 8 is the same as block No. 8 in the previous figure. It's chemical-based absorption in amine system.

Q. And then what is block No. 9?

A. Block No. 9 is a compressor.

Q. If we can refer to figure 4 in Reinertsen. What is block No. 13?

A. It's a cryogenic CO2 separation unit.

Q. And what is block No. 12?

A. That's the selective palladium membrane.

Q. For hydrogen separation?

A. Yes.

Q. Is it fair to say that the difference between figure 3 and figure 4 of Reinertsen is the use of CO2 cryogenic separation of block 13 instead of amine separation in block 8?

A. Correct.

Q. Figure 4 has a compressor 9 still, correct, downstream of block 13?

A. Yes.

Q. Just to recap, figure 2 of Reinertsen includes amine/CO2 separation upstream of hydrogen PSA separation, correct?

A. If you refer to No. 8, yes.

Q. And in figure 3 there's palladium hydrogen separation upstream of amine CO2 separation, correct?

A. Correct.

Q. And in figure 4 there is palladium hydrogen separation upstream of cryogenic CO2 separation, correct?

A. Correct.

Q. So looking at those three figures, Reinertsen discloses palladium and PSA hydrogen separation, correct?

A. Yes.

Q. And discloses amine and cryogenic CO2 separation, correct?

A. Correct.

Q. But Reinertsen does not disclose any example of PSA hydrogen separation upstream of cryogenic CO2 separation, correct?

A. He doesn't show explicitly a flow sheet. That's correct. If you refer to table 1, which is also labeled as figure 10, you see in column 1 as comparative example -- this is figure 2, yep. This is his comparative example. You see that there is a check in the PSA line, and there is no check in the palladium membrane line.

And then you look at the remaining columns and you compare always the palladium membrane line and the PSA line. You see there's always only one check. So that reads palladium membrane and a PSA are possible for hydrogen

separation. And when there is a PSA, there is no membrane; and when there is a membrane, there is no PSA. So they are either one.

And in Reinertsen this means that the teaching is that a membrane and a PSA can be selected, either one of them, for hydrogen separation. He shows -- sorry. I'm finished.

Q. The comparative example of figure 2 has amine separation upstream of the PSA hydrogen separation, correct?

A. That's his comparative example, yes.

Q. And then every other example has a palladium membrane for hydrogen separation, correct?

A. When you refer to figure 3 and 4, yes, the palladium membrane is the selected method for hydrogen separation, yes.

Q. And if we stick with table 1 in figure 10, embodiment examples 1 through 5 all include palladium membrane for hydrogen separation, correct?

A. His examples, besides the comparative example, all include palladium

membrane, yes.
Q. And in each of embodiment examples 1 through 5 with the palladium membrane and the CO2 leading that palladium membrane at a higher pressure, either the amine separation or the cryogenic separation can follow the palladium membrane, correct?
A. That's correct.
Q. But in the PSA example, PSA hydrogen separation is only downstream of the amine separation in Reinertsen?
A. In his figure 2 the PSA is downstream of the CO2 separation, yes.
Q. So in each of Reinertsen's comparative and embodiment examples, the CO2 separation happens at a higher pressure, correct?
A. Can you repeat? You're referring to his comparative example and also to his embodiments? What do you -- sorry.
Q. Yes. In each of the comparative example and the embodiment examples 1 through 5, CO2 separation happens at a higher pressure, correct?
A. Yes.

MR. ROBINSON: I'm sorry. Can we take another quick bio break?
MR. PHILLIPS: Sure.
(Recess taken)
BY MR. ROBINSON:
Q. Dr. Klein, I'm going to ask you to refer to the Rytter reference marked Exhibit 1009. So it's clear for the record, Dr. Klein, that's International Publication No. WO 2019/162236, correct?
A. Correct.
Q. And that's the Rytter reference referred to as Exhibit 1009 in your declaration?
A. Correct.
Q. So I should refer to figure 2, please. Actually, figure 3.
What is block 12 in Rytter's figure 3?
A. Block 12 is water-gas shift, WGS.
Q. And that's where the water-gas shift reaction takes place?
A. Yes.
MR. PHILLIPS: Objection to form.

BY MR. ROBINSON:
Q. And what is block 13?
A. Block 13 is the CO2 separation.
Q. What type of CO2 separation is used there?
A. It's an absorption system with a chemical solvent.
Q. Is that an amine system?
A. Yes.
Q. And so what is stream 131?
A. That's the retentate of the membrane, the CO stream.
Q. I'm sorry. The CO stream or the CO2?
A. CO2. I'm sorry. Thank you.
Q. And what is block 14?
A. Compressor.
Q. And what is stream 132?
A. 132, that's the hydrogen-rich permeate out of -- sorry, sorry. 132, that's the hydrogen-rich stream out of the CO2 separation.
Q. And what's block 15?
A. That's a PSA.
Q. And what's block 16?

A. A compressor.
Q. So this figure 3 in the Rytter reference is similar to Reinertsen's comparative example in that amine CO2 separation is upstream of PSA hydrogen separation, correct?
A. Correct.
Q. What does Rytter's figure 4 show?
A. Figure 4 shows how a hydrogen blend can be implemented into a methanol production plant.
Q. There are, it looks like, three dashed lines from the methanol plant to the hydrogen plant numbered 7141, 721 and 411. Do you see those, Dr. Klein?
A. Yes.
Q. What is stream 7141?
Tell you what. I didn't mean to make this a scavenger hunt. Let's start with stream 411. And I'll refer you to page 15 of Rytter. It's also labeled page 17 of 35, the last line. What's stream 411?
A. That's the pre-reformed gas.
Q. So natural gas?

A. No. It's not natural gas anymore because it's out of the pre-reformer No. 4; and, therefore, natural gas has been pre-reformed already.
Q. So the bottom of the page labeled 17 of 35 literally refers to that as pretreated NG 411. I think you're saying the same thing, but I want to give you an opportunity to confirm.
A. Pretreated natural gas, it can also be labeled as pre-reformed natural gas.
Q. And that pre-reformed or pretreated natural gas is then combusted in block 1 or reformed in block 1?
MR. PHILLIPS: Objection to form.
A. Can you refer to which paragraph in my report you're referring to talking about this block 1?
BY MR. ROBINSON:
Q. I'm actually referring to Rytter at the moment.
Is the hydrogen plant of Rytter's figure 4 similar to the hydrogen plant of Rytter's figure 3?

A. I did analyze figure 4 in my report, right? You're referring to figure 4 in Rytter?
Q. Yes.
A. Okay. If you just take the block labeling, figure 4 and figure 3, the hydrogen blend in figure 4 has the same blocks as the hydrogen blend in figure 3. What's missing is the heat integration between autothermal 2 and reformer 1 in figure 4. That's the difference I can see.
Q. So the pretreated natural gas 411, what happens to it at block 1?
A. It's a gas-heated reformer, steam reforming. And water-gas shift reaction is taking place in 1.
Q. So the treated natural gas is a feedstock for the GHR in block 1?
A. Yes.
Q. Okay. I'd ask you to refer to Exhibit 1008, please, the Darde reference, the basic translation of the Darde reference.
The first page of that exhibit is the Questel translator's certificate of the translation?

A. Yes.
Q. The page labeled page 2 of 3 shows that it's international publication No. WO 2014/091098, correct?
A. Correct.
Q. And that's the Darde reference referred to in your declaration as Exhibit 1008?
A. Correct.
Q. If we refer to figure 1 -- I guess there's only figure.
A. Not annotated, just the figure, the Darde figure.
Q. What is block No. 4?
A. That's an SMR.
Q. That's the steam methane reformer that we mentioned earlier, correct?
A. Correct.
Q. And what is block No. 6?
A. Block No. 6 is a waste heat boiler.
Q. And what is block No. 6B?
A. It's a part of the waste heat boiler.
Q. It's a cooling module, correct?
A. Yes.

Q. What's happening in the waste heat boiler and the cooling module?
A. The hot outlet gas from the steam methane reformer is cooled down to get the correct inlet temperature for the water-gas shift reactor.
Q. And what is block No. 7?
A. That's the water-gas shift, WGS.
Q. And that's where the water-gas shift reaction takes place?
MR. PHILLIPS: Objection to form.
A. Water-gas shift reaction takes place in 7 in the water-gas shift reactor, and it also takes place in the unit No. 4 in the SMR.
BY MR. ROBINSON:
Q. In the SMR?
A. Yeah.
Q. Dr. Klein, during any of our breaks today have you had any substantive discussions with counsel?
A. Sorry?
Q. Have you discussed the substance of your past or planned testimony during any of the breaks today with counsel?

A. You mean with my attorneys?
Q. Yes.
A. On a break today we had a conversation, yes. We discussed how it's going on, yeah.
Q. What was the substance of those conversations?
MR. PHILLIPS: Well, I'm going to instruct the witness not to answer on communications between counsel and his witness.
MR. ROBINSON: PTAB rules are pretty clear that there are not to be any substantive discussions of the testimony during breaks.
MR. PHILLIPS: Okay.
MR. ROBINSON: So if there have been, then I'm entitled to ask about them.
A. There were no substantive discussions on the issue. What do you mean in particular?
BY MR. ROBINSON:
Q. I mean about the substance of your testimony today.

A. No. It was not discussed.
Q. So a moment ago I asked, have you discussed the substance of your past or planned testimony during any of the breaks today with counsel? And you said you had a conversation.
Did that conversation address the substance of any of your testimony today?
A. No.
Q. What's block No. 8 in Darde's figure?
A. That's also a cooling unit.
Q. And what is the purpose of that cooling unit?
A. The purpose is to cool down the shifted gas to separate surplus water as condensates and to reach the suitable temperature in stream No. 9.
Q. Suitable temperature for PSA unit at block 11?
A. 11 is the PSA, yes.
Q. How does the suitable temperature for a PSA hydrogen separation differ from the suitable temperature for chemical absorption

hydrogen separation?
A. Chemical absorption hydrogen separation, that's not known to me.
Q. Sorry. How does the suitable temperature for PSA hydrogen separation differ from the suitable temperature for chemical absorption CO_2 separation?
A. It's in the same range.
Q. Same range?
A. Yes.
Q. Okay. Does the temperature decrease further for the hydrogen-depleted stream at 12 versus the input stream at 9?
A. There is no substantial temperature decrease in a PSA to the residual gas at 12.
Q. What is the pressure of the stream at 9 in Darde's figure?
A. It's a high pressure.
Q. Is the hydrogen stream exiting block 11 high pressure?
A. Yes. Some pressure drop, minor; but the pressure level is high.
Q. How about the hydrogen-depleted stream 12, is that a low pressure?
A. That's at low pressure, yes.

Q. How does the cost of a cryogenic CO_2 capture system compare to the cost of a amine-based chemical absorption CO_2 capture system?
MR. PHILLIPS: Objection, form.
A. What do you mean with "cost"?
BY MR. ROBINSON:
Q. Well, let's start with the initial equipment cost.
A. CapEx, capital expenditures. Okay. It's a comparison between an amine-based CO_2 removal as compared to a cryogenic CO_2 removal? Did I get that right?
Q. Correct.
A. I mean, to determine the exact capital expenditures, you would have to define the boundary conditions. For instance, when you talk about the amine-based system, do you mean the amine-based system downstream of a shift or do you mean the amine-based system as shown in Reinertsen in his comparative example downstream of a PSA? And then we bring in the cryogenic unit for separation, which is always downstream of the hydrogen separation.
So the amine system could be

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upstream or downstream of the hydrogen separation. So, therefore, when we want to compare the costs, we have to define which amine-based system you mean.

Q. Well, let's go back to Reinertsen's figure 10, which is table 1. If we look at embodiment example 1 and embodiment example 2 where you have either amine separation or cryogenic separation downstream of palladium membrane, which one would be more expensive in terms of initial CapEx?

A. I would say they are in the same order of magnitude.

Q. How about in terms of cost to operate? Does the cryogenic separation system require more energy input?

MR. PHILLIPS: Objection, form.

A. The amine-based system would require thermal energy to regenerate the loaded solvent, the amine. When the cryogenic separation is downstream the palladium membrane, as in Reinertsen, the CO2-rich stream is at the same pressure level as at the inlet of the membrane.

Depending on the natural gas

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pressure you have available at the very start before the reformers, this pressure might be high enough to avoid compression upstream of the cryogenic one. But it could also be that, although you keep the CO2 at high pressure as compared to the membrane inlet, there is still some compression required; otherwise, the cryogenic separation would not run in a thermodynamic favorable range.

So the operating cost would depend on whether you have to compress this CO2 rich stream upstream of the cryogenic one or not. So then, as always in chemical engineering/process engineering, it depends a lot on the boundary conditions.

And then we come to a point we have compression energy which is high-volatile electrical energy, and for the thermal regeneration of the amine you have only low-pressure steam to take into account.

And then it comes to a question of the specific site, whether you

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have this low-pressure steam available; how expensive is electricity; do you have to compress or is the natural gas pressure at the end high enough.

So regarding OpEx this question cannot be answered. Besides you do a engineering design and an engineering techno-economical analysis at the end taking into account the cost of low-pressure steam and electricity.

BY MR. ROBINSON:

Q. In a hydrogen production plant is it common to have low-pressure steam available?

A. In a conventional plant like Darde there is steam available. On the figure we just had a look at, this plant is exporting steam, which is a high-volatile steam. It has more energy than required for amine regeneration.

Yes, you could use that steam; but you also could sell that steam probably for a higher price than misusing it for amine regeneration. Steam is available if you want to use it or sell it. It's another design-specific thing

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you can just answer after you do your specific site evaluation.

Q. What about in the Reinertsen plants?

A. Sorry?

Q. What about the Reinertsen examples, is there low-pressure steam available there?

A. The embodiments do not show the cooling off to the ATR in none of the figures down to the water-gas shift; but, of course, stream 12 needs to be cooled in all figures. Usually you use that heat to generate higher volatile steam than just low-pressure steam.

So the same question comes again, do we utilize that steam, getting a price for it; or do we throttle it down, expand it, just to use it in an amine system.

Q. If Reinertsen doesn't use that steam for its amine system, then how would Reinertsen regenerate in its amine system?

A. They can export the high-pressure steam available at 12 for some price and he can -- if he can sell the high-pressure steam created with stream 12, that's then usually a site, a location where you also can import for

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a lower price the 5-bar steam required for amine regeneration.
Q. And if instead cryogenic CO2 separation is put downstream of PSA hydrogen separation, then compression will always be needed for the cryogenic CO2 separation, correct?
A. Yes.
Q. And that generally has to be done with imported electricity instead of steam?
A. Yes.
Q. What kinds of pressures are typically required in cryogenic CO2 separation?
MR. PHILLIPS: Objection, form.
A. The pressure has to be high enough that when you cool down the CO2, that the CO2 condenses at a temperature which is above the sublimation temperature of CO2. So the pressure determines the temperature where it condenses to get separated, and this temperature has to be above the sublimation point.
The extra pressure then depends on the composition of the CO2-rich

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gas, what's the content of the condensable CO2; and what's the content of the components you do not want to condense like not separated hydrogen, CO not shifted, methane not reformed.
BY MR. ROBINSON:
Q. Is it fair to say you want the concentration of the CO2 to be as high as possible for that process?
A. That's a good condition for a cryogenic separation, yes.
Q. Can you give me some typical ranges of temperatures and pressures at which CO2 is cryogenically separated?
MR. PHILLIPS: Objection, form.
A. In the range of minus 60. At atmospheric pressure CO2 would condense at minus 78.5. It's in my report in paragraph 156. And a person skilled in the art that's what thermodynamic calculations will then reveal.
Depending on the pressure what we compress the residual gas to, this temperature will go up from minus 78.5, let's say, to minus 60 as I estimate it.

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BY MR. ROBINSON:
Q. Is CO2 ever cryogenically separated in these types of processes at atmospheric pressure?
A. Not to my knowledge.
Q. What types of pressures are typically used for cryogenic separation of CO2 in these types of processes?
A. It can go up 80 bar.
Q. And is there a lower end of that range?
A. It depends on the -- what do you mean with lower range?
Q. Is there a minimum pressure that would typically be used for a cryogenic CO2 separation in an industrial process?
MR. PHILLIPS: Object to form.
A. Coming back to my point that this minimum pressure will depend on the CO2 content and the content of the other gases, but that's a person skilled in the art with a thermodynamic calculation tool. This pressure will be determined for every application no matter -- or then depending on the composition of the gas. So there is no general minimum

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pressure. It depends on the composition of the gas.
BY MR. ROBINSON:
Q. Well, you said it would never be done at atmospheric pressure, correct?
A. Yes.
Q. What's the lowest pressure at which a POSITA or a POSA would reasonably expect cryogenic CO2 separation to be viable?
MR. PHILLIPS: Objection to form.
A. Depending on the composition, I cannot answer. If there is 20 percent CO2 and 80 percent hydrogen, it's different than 60 percent CO2 and 40 percent hydrogen.
BY MR. ROBINSON:
Q. Well, let's go back to Darde's figure.
What concentration of CO2 would you expect there to be in stream 12?
A. About 50 percent.
Q. So what's the minimum pressure you would expect to be viable for cryogenic CO2 separation of that stream?
MR. PHILLIPS: Objection to

form.

A. If I answer that, it would be just an estimation. I have some thermodynamic experience, but that's not a back-of-the-envelope-calculation to determine with modern tools. A person skilled in the art will do it. I would estimate 40, 50 bar.

BY MR. ROBINSON:

Q. But that's highly dependent on a particular configuration of the overall system?

A. Exactly.

Q. And dependent on the composition of the feed stream entering that system?

A. System is the whole plan and feed stream is the natural gas, or is the system the separation part?

Q. Let me make sure I'm asking that in the way I understand, too.

So if the -- if we just look at Darde's figure, the combination of system components will impact the composition of the stream 12, correct?

A. It depends on the reformer temperature, unit 4, the outlet temperature.

It will depend what kind of WGS system you select in unit 7. And it's also dependent how much steam you add in stream 22 upstream of the reformer. We call that steam-to-carbon ratio. So these are the three main parameters.

And the minor impact is natural gas, 98 percent methane or is it only 90 percent or 85 percent methane? How high is the content, the concentration of the C2/C3. That all determines the composition of 9 and then at the end of 12.

Q. So if a cryogenic CO2 separation system requires 50-bar pressure and a CO2-rich stream enters at 50 bar, then compression wouldn't be necessary?

A. 50 percent, 50 bar? It would work in principle. It depends what CO2 recovery you want to achieve in your cryogenic separation unit. And also depending not only on the recovery rate, also on the purity you want to have out of your cryogenic CO2 separation unit.

Q. What if the cryogenic CO2 separation

requires 50 bar, but the CO2-rich stream enters at 55 or 60 bar, would that eliminate the need for compression?

A. Instead of -- eliminate? Sorry. I didn't understand it.

Q. If the cryogenic CO2 separation requires 50 bar of pressure --

A. Yeah.

Q. -- but the CO2-rich stream entering it is at 55 or 60 bar --

A. Then that would be beneficial for the separation process.

Q. And may eliminate the need for compression?

A. If the CO2-rich stream is available already at 60 bar, depending on the CO2 recovery you want to achieve and the CO2 purity, a process calculation simulating the cryogenic process would give the answer. It will result with 60 bar at a certain CO2 recovery. When you talk about CO2 purity, this would require a more complicated cryogenic separation unit.

We talk about the main steps are cooling it down to a partial

condensation, but we do not condense only CO2. We also condense some methane, even some hydrogen. And to bring that out you have to install then -- after the one- or two-step partial condensation, you have to install also a thermal separation called distillation. And when you do that, you make the CO2 more pure. On the other hand, you lose also some CO2.

And if you don't want to lose the CO2, then you have to take -- then we go into a very detailed thing. Then you have to operate your distillation column with a reflux to bring back the CO2, and this would require energy. And you can take out -- and you have to take this energy from the high-pressure feed gas at the end.

So at the end the answer can be answered only if you define the recovery rate you want to have and the purity.

Q. And so to make sure we're clear, when you say recovery rate, do you mean the percentage of CO2 in the -- the percentage of

CO2 removed from the CO2-rich stream that enters the cryogenic capture system?

A. Exactly. And percentage means not concentration percentage but just the amount you bring in, exactly.

Q. And then the CO2 purity is the concentration of the CO2 that's actually captured?

A. Exactly.

Q. Okay. It's generally desirable to have high CO2 purity?

MR. PHILLIPS: Objection to form.

A. Did you say general?

BY MR. ROBINSON:

Q. Sorry. Is high CO2 purity desirable?

MR. PHILLIPS: Same objection.

A. It depends on the application, what you want to -- where you want to utilize or store the CO2. If you go for high purity CO2 for food industry, it's another requirement as compared to probably future applications where we want to store the CO2 underground.

BY MR. ROBINSON:

Q. Dr. Klein, in your declaration I don't see anywhere where you describe or define a particular level of skill in this field. Is there somewhere in your declaration where you explain what degree or what level of experience a person of skill would have had?

A. Yes. Paragraph 55.

Q. Oh, okay. So a person of skill in the art would have had three to five years of experience with steam reformer methane, partial oxidation, water-gas shift process, and synthesis gas separation and a graduate degree in chemical engineering at the master's level?

A. Yes.

Q. Would a POSA have had experience with cryogenic CO2 separation?

A. That's covered in the synthesis gas separation. I put it more broad here instead of listing amine and PSA and all the other options.

Q. So synthesis gas separation would have necessarily included experience with cryogenic CO2 separation?

A. Yes.

Q. Do you consider SMR, GHR, ATR all examples of steam reforming of methane?

A. Yes.

Q. Would a POSA as of August 11, 2020 have had experience with each of those types of reformers?

A. If we define it in that way without experience working in the field after graduation, yes.

MR. ROBINSON: Why don't we pause just a second and go off the record.

(Luncheon recess)

BY MR. ROBINSON:

Q. All right, Dr. Klein. Would you refer back to the Reinertsen reference, please.

A. Yes.

Q. Specifically at paragraph 82. Do you see where Reinertsen says that gas can be separated based on the different properties of the gas molecules? The first sentence.

A. The paragraph starting with, "Gases in the mixture after the shift reactor," right?

Q. Yes.

A. Yes.

Q. And the examples of the most common techniques are absorption with a B as in boy, adsorption with a D as in dog, and cryogenic distillation. Do you see that?

A. Yes.

Q. And then it goes on to say specifically that CO2 is an acid gas, and the most widely used method to separate CO2 from other nonacid gas molecules is absorption with a B as in boy. Do you see that?

A. Yes. Just for clarification, what's entitled here as acid gas I said in the morning sour gas, which is the same meaning.

Q. Then it goes on to describe aqueous solutions of alcoholamines for CO2 separation?

A. Yeah. That's what we -- that's the amines we talked about, yeah.

Q. Okay, great. Then in the very last sentence it says, "Other absorption," with a B as in boy, "technologies rely on alternative physical liquid absorbents like methanol at reduced temperature."

A. Exactly. I said in the morning deep

cold temperature. Anyway ...
Q. Deep cold?
A. Yeah, very cold temperature. Here it's reduced, minus 40.
Q. Then in paragraph 83 it describes membranes to separate hydrogen, one example of which would be a palladium membrane?
A. Yes.
Q. Correct?
A. Yes.
Q. Then paragraph 85 goes on to describe combinations of solid membranes and liquid membranes. Do you see that?
A. Which paragraph? Sorry.
Q. First sentence of paragraph 85.
A. 85. Sorry. Yes. I got that paragraph.
Q. Then it lists PSA as an alternative for separating hydrogen, correct?
A. Exactly.
Q. Okay. And down about seven or eight lines it says, "It," PSA, "operates at near ambient temperatures and differs significantly from cryogenic distillation techniques." Do you see that?

A. Yes.
Q. Then the last sentence of that paragraph Reinertsen explains that, "Alternatively, temperature can swing instead of pressure."
Do you see that?
A. Yes.
Q. So rather than pressure-swing adsorption, it would be temperature-swing adsorption?
A. Temperature-swing adsorption is a process known, yes, for separation of gases.
Q. And it looks like known for separation of hydrogen?
A. Theoretically it's possible, but I'm not aware of any large-scale process which separates hydrogen based on a temperature-swing adsorption.
Q. So if we go to Reinertsen's figure 4, block 12 is a palladium membrane hydrogen separation unit. Is that correct?
A. Correct.
Q. And stream 122 is at high pressure, correct?
A. 122 is at high pressure, yes.

Q. And block 9 is a compressor?
A. Correct.
Q. Block 7 is a dryer, correct?
A. It takes out condensate and plugs the gas, yes. Can be considered as a dryer.
Q. So Reinertsen does not disclose a compressor between palladium membrane at 12 and the CO2 capture unit at 13, does it?
A. No.
Q. I'm going to ask you to refer back to the Rytter reference, please, Exhibit 1009, specifically beginning at line 30 of the page labeled page 11 of 35.
A. Which line?
Q. Beginning at line 30.
A. Yep.
Q. This language appears to be very similar to that that we just reviewed in Reinertsen in that gases can be separated more or less completely based on the different properties of the gas molecules.
A. (Witness nods head affirmatively.)
Q. And, then again, the most common principles are absorption with B as in boy, adsorption with D as in dog membranes and

cryogenic distillation. Do you see that?
A. Yes.
Q. It then goes on, "similarly to describe CO2 as an acid gas for which the most widely used method is absorption" with B as in boy. Do you see that?
A. Yep.
Q. Similarly to Reinertsen, it goes on to describe aqueous solutions of alcoholamines of which one is an amine, correct?
A. (Witness nods head affirmatively.)
Q. And then again mentions alternative liquid absorbents like methanol at reduced temperature, which I think you referred to as deep cold.
A. Yes.
Q. Okay. Similarly, Rytter goes on to explain beginning at line 10 on page 12 of 35 that different types of membranes can be used. Do you see that?
A. Yes.
Q. And then at lines 19 and 20, similarly mentions a combination of solid membranes and liquid membranes, correct?
A. That's correct.

Q. Looking at Reinertsen's figure 4, does your declaration include any simulations or comparative analysis showing the differences in hydrogen production and CO2 capture if PSA unit were substituted for a palladium membrane at block 12 for hydrogen separation?
MR. PHILLIPS: Objection to form.
A. No. I didn't perform any of these process calculations.
BY MR. ROBINSON:
Q. Looking at Rytter's figure 3.
A. Yes.
Q. Does your declaration include any simulations or comparative analysis showing the difference in hydrogen production and CO2 capture if a PSA unit were substituted upstream cryogenic CO2 capture?
A. No. I didn't perform these calculations.
Q. Sticking with Rytter for a moment, does your declaration include any simulations or comparative analysis in terms of reliability of a system with PSA hydrogen

separation upstream of cryogenic CO2 capture versus a system using amine CO2 capture?
MR. PHILLIPS: Objection to form, vague.
A. No. I did not perform any of these calculations.
BY MR. ROBINSON:
Q. Referring back to Reinertsen's figure 4, does your declaration include any simulations or comparative analysis in terms of reliability of the systems shown in figure 4 relative to a system like that of figure 4 but with PSA hydrogen separation instead of palladium membrane hydrogen separation?
MR. PHILLIPS: Objection to form, vague.
A. No. I didn't perform any of these reliability calculations.
BY MR. ROBINSON:
Q. Sticking with Reinertsen's figure 4, does your declaration perform any modeling or cost comparison between the system in figure 4 with palladium membrane hydrogen separation versus a system similar to figure 4 but with

PSA hydrogen separation?
MR. PHILLIPS: Objection to form, vague.
A. No. I didn't perform these calculations.
BY MR. ROBINSON:
Q. Referring back to Rytter's figure 3, did your declaration include any modeling or cost comparison between the system of Rytter's figure 3 and the modified version of this that you proposed with PSA hydrogen separation upstream of cryogenic CO2 separation?
A. No. I didn't perform these calculations.
Q. I'll ask you to refer back to your declaration, please, Dr. Klein, specifically at paragraph 159.
A. Yes. I have it.
Q. So this sentence scanning pages 107 and 108 says, "Thus, Reinertsen explicitly mentions a cooling step that is to be carried out at a pressure where CO2 is liquefied, which a POSA would view as corresponding to a compression step."
Do you see that sentence?

A. Yes.
Q. As we discussed earlier, if a CO2-rich stream is headed to a cryogenic capture step but that CO2-rich stream is already at a pressure sufficient for the cryogenic capture, then there would be no need for additional compression, would there?
MR. PHILLIPS: Objection to form.
A. If the pressure would be high enough, yes. No compression required.
BY MR. ROBINSON:
Q. Referring back to the Rytter reference in figure 3, CO2 is separated at block 13, correct?
A. Correct.
Q. And that's with an amine process?
A. Correct.
Q. Is the CO2 stream at 131 at high pressure or low pressure?
A. It's at low pressure. Sorry. You mean 13 ...
Q. 131.
A. That's at low pressure, yes.
Q. And 132 is high pressure?

A. Yes.
Q. I'd like to briefly compare Rytter's figure 3 with Darde's figure.
A. Yep.
Q. So in Darde's figure there's a stream 9 that goes into the hydrogen separation block at 11, right?
A. Yes.
Q. How do the pressure, temperature and composition of stream 9 compare to the pressure, temperature and composition of stream 121 in Rytter's figure 3?
Actually, strike that. Let me ask that a little bit differently. How do pressure, temperature and -- well, strike that.
Does your declaration analyze the differences between the pressure, temperature and composition of stream 9 in Darde's figure with the pressure, temperature and composition of stream 121 in Rytter's figure 3?
A. Regarding the composition, stream 9 and stream 121, they contain the same components: hydrogen, CO, CO2, methane, some

water vapor. Regarding pressure and temperature, they are also in the same range.
Q. Is that in your declaration somewhere, Dr. Klein?
A. Are you referring to a specific paragraph?
Q. I'm asking if you can find a paragraph where that's described.
A. So regarding Darde, you find the information on the composition in paragraph 80. Regarding Rytter you can refer to paragraph 77, "to produce synthesis gas enriched in carbon dioxide and hydrogen 121 shifted gas."
Q. Paragraph 77 describing Rytter it doesn't say anything about percentage or concentrations of any of those components, does it?
A. No, because -- no, it does not disclose the -- the report does not list the concentration.
Q. You said that the temperature and pressure of stream 9 in Darde's figure versus the temperature and pressure of stream 121 in Rytter's figure 3 would be in the same range.

What does "in the same range" mean?
A. For both processes, Rytter and Darde, we start from natural gas. At the same -- let's say we have the same natural gas for both processes, 40 or 30 bar. Then we have a Darde reformer in the Rytter GHR, ATR, including a pre-reformer. Then we have the water-gas shift reaction.
When you take the same natural gas -- take a round number, 40 bar -- we have pressure drops all along down to stream No. 9 and all the way down to stream No. 121. The target in syngas technology is always to utilize as much of the natural gas pressure available in stream 1 or in stream 31 to get the highest pressure at 121 and 9.
So we want -- a designer wants to minimize the pressure losses through -- pressure drops through all these units and wants to minimize the pressure drops through all the units of Rytter.
And assuming that the pressure drops are the same in the

water-gas shift reactor of Rytter and of Darde, a slightly higher pressure drop in Rytter because he has two, a GHR and an ATR; Darde has only an SMR. Rytter also has a pre-reformer which is not shown in the Darde one. So we have two more units in the Rytter, which causes probably .5 bar more pressure drop in the Rytter as in the Darde reference. And that's what I mean with having the same range when we start from the same natural gas pressure.
If it would start from different natural gas pressures for both processes, that would not be a good comparison. So we have the same starting pressure. And then taking into account a slightly higher pressure drop in the Rytter, the Darde pressure would be .5 to 1 bar higher.
Let's say altogether we would have probably 8 bar pressure drop for all these units. So we would end up at 32 or 32.8.
Q. So what dictates the pressure at which natural gas is available at a given

plant site?
A. Depends on the natural gas grid the plant is linked to, whether it's a high-pressure natural gas grid.
But pressure is only -- let's say it's 40 bar. A hydrogen plant would lift with that. If it's 10 bar, you would install a natural gas compressor to bring the natural gas feed to a pressure of 30 or 40 bar.
Q. If natural gas is available at a site at a pressure higher than 40 bar, would you use that higher pressure as the starting point?
A. How high?
Q. How high might natural gas be available from the grid at a given site?
A. I don't know about the U.S. grid. With the Darde reformer conventional SMR, if there would be natural gas available at 80 bar, twice the number, you would not be able to utilize that pressure in the conventional SMR of the Darde type.
Q. So you'd have to reduce that pressure before you could put it into Darde's

SMR?
A. Yes.
Q. How much would you have to reduce the pressure?
A. I would say 40.
Q. And what if you've got Rytter's combination of reformers? At what pressure -- could you use 80 bar natural gas feedstock for Rytter's system of figure 3?
A. Probably not 80, but you could go higher than 40.
Q. How high could you go?
A. That's a detail design question which I cannot answer right now. I'm not involved in the latest design what the engineering companies can achieve regarding pressure in an ATR and in a GHR.
Q. What would have been achievable in 2020?
A. 40, 50 bar.
Q. Any higher than that?
A. I don't think so.
Q. Is a given plant -- well, is the pressure at which natural gas is available for a given plant a boundary condition for which a

plant is designed?
MR. PHILLIPS: Objection to form, vague.
A. If you design a plant, you have to take into account this -- we call it battery limit condition.
BY MR. ROBINSON:
Q. Battery limit?
A. Yeah, battery limit.
Q. So the battery limit refers to the pressure at which natural gas is available for a given site?
A. Battery limit means just the boundary between the plant and the surroundings. So battery limit also applies for other supplies from outside, cooling water, what's the battery limit condition, yes.
So the battery limit condition of the natural gas is very important if you design a synthesis gas plant.
Q. So the battery limit conditions of the natural gas could include the pressure at which the natural gas is available?

A. Correct. That's an important parameter, yes.
Q. And the battery limit conditions of the natural gas could include the assumed volumetric or mass flow rate at which natural gas is available at that pressure?
A. It's important. You'd need enough natural gas to feed your blend.
And, again, when you design a big plant, you need to be at the gas pipeline, which has a high delivery rate. If you get to the limits of your gas supply, you just cannot design a plant bigger than that.
Q. And the pressure at which natural gas is available at a site impacts or is a condition that can impact design choices for the entirety of the plant, correct?
MR. PHILLIPS: Objection to form.
A. It impacts the design. When the pressure is low, then the design of the plant would require a natural gas compressor; and, therefore, it impacts the design of the plant definitely, yes.

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BY MR. ROBINSON:
Q. And it could impact the type of processes that you select for reformers?
A. Yes, it could.
Q. And the pressure at which natural gas is available at a given site could impact the type of process that you choose for hydrogen separation?
A. Could be.
Q. And the pressure at which natural gas is available at a given site could impact the type of process that you choose for CO2 separation?
A. If theoretically you go with the Rytter process -- sorry, the Reinertsen process with a hydrogen separation via palladium membrane, keeping the CO2-rich stream at high pressure -- and you asked whether it's possible to have a cryogenic separation downstream, a Reinertsen membrane without compression, this would require that at the end the natural gas pressure is so high that you end up at a high-enough pressure downstream the membrane for the CO2 to drive your cryogenic process without any compression

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step.
This is just a very, very, I would say, generic case. I didn't see a blend like that designed. From a theory, it would work. In reality, even if you take the membrane separation from Reinertsen and keep the CO2-rich stream at high pressure, in reality this pressure is not high enough to get from your CO2 separation cryogenic base both the recovery, the yield, and the purity.
Q. So just to clarify my original question, the pressure at which natural gas is available at a given site could impact the type of process that you use for CO2 separation?
MR. PHILLIPS: Objection, form.
A. If you have a separation process with a membrane, palladium membrane, which keeps the CO2 stream at high pressure, theoretically that impacts then the selection of the CO2 separation.
BY MR. ROBINSON:
Q. So it could impact the decision of whether, for example, to use amine separation

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or cryogenic separation for CO2? And let me ask that in one piece so it's not confusing.
The pressure at which natural gas is available at a given site could impact the decision of whether to use cryogenic separation or amine separation for CO2, correct?
MR. PHILLIPS: Objection to form.
A. If you use a PSA as upstream hydrogen separation, then this does not impact the choice of CO2 separation.
BY MR. ROBINSON:
Q. But if you use membrane separation for H2, for hydrogen, then the pressure at which natural gas is available at a site could impact the decision of which type of separation to use for CO2?
A. If you would use the membrane system, you keep the CO2 stream at high pressure, then it impacts the choice of the CO2 separation, yes. Not for the PSA separation.
Q. Is it possible to use PSA separation for hydrogen and have the hydrogen output at

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high pressure?
MR. PHILLIPS: Objection to form.
A. That's always the case when you use PSA. You always have the hydrogen at high pressure.
BY MR. ROBINSON:
Q. Is it possible to use PSA separation for hydrogen and have the hydrogen output at low pressure?
A. No.
Q. Completely impossible?
A. No. It's not possible. The principle of the PSA is to keep the hydrogen at high pressure.
Q. And there are no exceptions to that rule?
A. Not for PSA.
Q. Are there hydrogen separation processes other than PSA and chemical absorption that would output the hydrogen at low pressure?
A. Sorry. Can you rephrase your question.
Q. Are there hydrogen separation

processes other than PSA and chemical absorption, like amine processes, that output hydrogen at low pressure?

A. I don't understand your question because you phrase -- other options for hydrogen separation than PSA and amine absorption?

Q. Sorry. Let me try that again.

Are there other options for hydrogen separation other than PSA or membrane separation that would output the hydrogen at low pressure?

A. Still the question is not clear because you phrase processes besides PSA and membrane which keep the hydrogen at low pressure. That's misleading because at PSA the hydrogen is kept at high pressure.

Q. Okay. I'm not trying to imply that PSA outputs hydrogen at low pressure. I'm asking if there are options other than those two that separate hydrogen and output the hydrogen at a low pressure.

A. Membrane separation delivers the hydrogen at low pressure. That's the only option I have in mind now. The other option

of separating hydrogen is the PSA, and this process keeps the hydrogen at high pressure.

Q. Are the PSA and membrane processes the only ones available for separating hydrogen?

A. And you're asking for a gas outlet from a shift -- so we talk about separating hydrogen out of a shifted gas as in the context we discuss here?

Q. Yes.

A. The only process which is proven on large scale and realized in large-scale production plants is the PSA process. This has a very mature level. We call it in Europe TRL, technology readiness level. It's the highest you can get.

The membrane process, as suggested by Reinertsen, has not been realized besides pilot scale so far. There is no big hydrogen production plant which operates on a palladium membrane-based hydrogen separation. So ...

Q. Regardless of whether they've been realized in large-scale operation, are there

other processes besides PSA and membrane that are available for separating hydrogen downstream of a WGS reactor?

A. No.

Q. None at all?

A. Not on a large scale.

Q. I specifically did not limit that to a large scale.

A. If you -- there are other separation principles. The amount of research and lots of research laboratories and research groups, there are other principles. But these are far away from technical realizations.

Q. What about for separating CO2, are there alternatives to amine separation and cryogenic separation?

A. Yes. There are alternatives.

Q. Are there proven alternatives?

MR. PHILLIPS: Objection to form.

A. There is also a PSA technology available to separate CO2. That's a PSA system which goes into the vacuum for regeneration. So a vacuum CO2 PSA. That's an option. And there is also CO2 permeable

membranes available, and that's also an option.

There are more. You can think about going to very deep temperature, and then you freeze out the CO2. This is a big research topic all over the world because we talk about CO2. We try to capture CO2 out of the air. This also can be up or at. So CO2 there is a lot of research going on trying all kind of separation principles.

I think the most mature one we cover with solvents, either chemical or physical, cryo, vacuum PSA and CO2 selective membranes.

BY MR. ROBINSON:

Q. Those were all known in 2020?

A. Yes.

MR. PHILLIPS: Counsel, when you get at a breaking point, can we -- I don't want to interrupt if you're in the middle of something.

MR. ROBINSON: I appreciate it.

MR. PHILLIPS: I think we've kind of been going for over an hour.

So might be good for a bathroom break.
MR. ROBINSON: I'm happy for a bathroom break and to pass the witness if you've got any.
MR. PHILLIPS: I'll just have a couple questions, but let's take a quick break. Are you done then? You're going to be done in the next segment? Is that the idea?
MR. ROBINSON: I'll pass him now. I may have some recross depending on what you ask him.
MR. PHILLIPS: Let's take a break.
(Recess taken)
EXAMINATION
QUESTIONS BY MR. PHILLIPS:
Q. Dr. Klein, I want to take you back to paragraph 28 in your report.
A. Got it.
Q. And I think we talked about this sentence earlier; but do you see the sentence that says, "It is known by a POSA that steam reforming is almost always accompanied by the

water-gas shift reaction shown in reaction 3."
Do you see that?
A. Yes.
Q. What part of the hydrogen production process is that sentence referring to?
A. To the steam reforming part.
Q. And so do you see a couple of sentences later it starts, "The exit gas" and then goes to the next page?
A. From a steam reforming unit, yeah.
Q. "The exit gas from a steam reforming unit, therefore, typically contains CO, CO2, H2, CH4 and steam."
Do you see that?
A. Yes, I see that.
Q. Can you explain what you meant by that sentence.
A. It contains the reaction products from the steam reforming reaction, hydrogen and CO. It contains the product of the water-gas shift reaction, CO2. It contains CH4, which is not reacted. And it contains steam, which is also not reacted; and steam is available in big excess. So unreacted steam and unreacted methane is also there.

Q. Thank you. Do you recall a few moments ago Mr. Robinson asked you a series of questions relating to replacing PSA hydrogen separation instead of the palladium membrane separation and doing that before cryogenic CO2 separation? Do you remember that?
A. Yes.
Q. And I think he specifically asked you about whether you performed calculations, whether you did modeling and whether you did cost comparisons. Do you remember that?
A. I remember, yes.
Q. And what was your answer to those questions?
A. The answer was that I did not perform these calculations.
Q. So my question to you is did you need to perform the calculations in order to do your analysis?
A. No. I did not need that.
Q. And why?
A. To evaluate the '805 patent and all the exhibits, the references we have on the table, to evaluate and to judge the process combinations, you can ask for effects, what is

the positive effect if you have a membrane separation instead of a PSA.
The discussion is okay. The advantage having a membrane separation you keep the CO2 at high pressure, which saves you some energy for the maybe cryogenic CO2 separation; but then you have to compress the hydrogen.
And vice versa. When you go for a PSA, you keep the hydrogen pressure and you have to compress definitely the CO2-rich stream if you go for a cryogenic separation.
So the effects are pretty much clear. And to compare the actual investment costs or energy consumption figures, you would have to do the exact calculations. But to find a general judgment of all the options and the pros and the cons of all the options, it's not required to do a detailed calculation.
For instance, what's quite obvious is when you want to do the membrane separation, you keep the CO2 at high pressure but you lose the hydrogen

pressure and, therefore, you would have to compress the hydrogen. And a person skilled in the art knows that hydrogen compression is much more complicated, both CapEx and OpEx wise, as compared to CO2 compression because hydrogen is the molecule with the lower molecular weight. That's a physical law.

And, therefore, some judgments like, Yeah, let's keep the hydrogen at high pressure and taking in a PSA, instead invest the energy compressing the CO2, there is no detailed calculation required to judge that at the end the -- and actually for hydrogen compression would be higher. Therefore, a POSA could do the evaluation even without any detailed process calculations as you asked.

Q. That's all I have.

MR. PHILLIPS: Pass the witness.

RE-EXAMINATION

QUESTIONS BY MR. ROBINSON:

Q. At what pressure is hydrogen

typically transported?

MR. PHILLIPS: Objection to form.

A. Transported from the production site to consumer site, you mean?

BY MR. ROBINSON:

Q. Sure.

A. Okay. When you transport it in a gaseous form, the pressure shall be 600, sometimes up to 900 bar. You also can liquefy it. Then you have also the storage density, the volumetric storage density. Then it's transported at slightly elevated pressure, 3, 4 bar, but then at deep cold temperatures.

Q. So if we look at Darde, for example, in Darde's figure, the hydrogen coming from the separation unit 11 --

A. The PSA.

Q. -- previously you said might be at 32 bar. Do you recall that?

A. Yes.

Q. So if it's going to be transported in gaseous form, it's still going to have to be compressed --

A. Sure.

Q. -- by a massive degree?

MR. PHILLIPS: Objection to form.

BY MR. ROBINSON:

Q. And if it's going to be liquefied, there's going to be a ton of energy added to liquefy it, correct?

MR. PHILLIPS: Objection to form.

A. Correct.

BY MR. ROBINSON:

Q. Okay. Referring back to paragraph 28 of your declaration, the sentences spanning pages 21 and 22, "The exit gas from a steam reforming unit, therefore, typically contains CO, CO2, H2, CH4 and steam," what exactly is a steam reforming unit?

A. A steam reforming unit can be a simple SMR as discussed and described by Darde. I would consider this as a steam reforming unit.

Steam reforming unit can be an ATR stand-alone, just an ATR, which is the first case which is described in the

'805 patent. Steam reforming unit can be a GHR. It can also be a GHR in combination with an ATR.

Q. Would a steam reforming unit include the WGS reactor?

A. No.

Q. How do you know how much CO2 is present in the exit gas of the steam reforming unit?

A. The exact number would have to be determined by a detailed process calculation depending on the feed gas, the steam-to-column ratio, the exit temperature.

Q. And it's possible, isn't it, to adjust the parameters of an ATR, for example, to avoid CO2 production in the exit gas?

MR. PHILLIPS: Objection, form.

A. I'm sorry. Can you repeat the question.

BY MR. ROBINSON:

Q. It's possible to adjust the parameters of an ATR to avoid the production of CO2 in the exit gas, isn't it?

MR. PHILLIPS: Objection to form.

A. Production of CO_2 in the exit gas. Production is taking place before the exit gas is formed, right?

BY MR. ROBINSON:

Q. Let me ask it a little bit different way so it's clear. It's possible to adjust the parameters of an ATR to avoid the presence of CO_2 in the exit gas, isn't it?

A. That's not possible.

Q. Why not?

A. Because the water-gas shift reaction always is accompanying the steam reforming reaction. Water-gas shift accompanies the steam reforming reaction.

Q. Why is that?

A. It's the second law of thermodynamics which drives the components of air, hydrogen, CO from the steam reforming reaction, reaction No. 1. And steam is also there.

So as soon as CO_2 is formed from the steam reforming reaction, there is a driving force of the reaction CO plus water to CO_2 and hydrogen-rich No. 3 on page 23. Driving force can be expressed a

little bit more rigorously in terms of second law of thermodynamics.

Q. What is the driving force of reaction 3?

A. The driving force of reaction 3 is -- we call it Gibbs free energy of reaction.

Q. Is that G-i-b-b-s?

A. And that takes into account the energy driving force, so to say, and the energy driving force and also the entropic driving force. When you look at the number of mols on the left and the right-hand side, they are the same. So this reaction has almost no entropic driving force. You keep the disordinas [phonetic] constant. But there is an energetic driving force which drives the reaction to the right side.

Q. Is the energetic driving force temperature dependent?

A. It is.

Q. Is there a minimum temperature that needs to be present to drive that reaction?

A. It's an exothermic reaction. And when you go up with temperature, the driving

force goes down. If you go down with the temperature, the driving force goes up. That's the way you look at equilibrium controlled reaction when you assume you have all molecules in your reaction space.

At the very beginning when you just have methane and steam, reaction No. 1 kicks off. So you generate CO and hydrogen. Lots of steam and lots of methane also is still left. But at the very first moment there's only the feed CH_4, water, and then the initially formed CO and hydrogen.

And no matter which temperature you have, if you don't have CO_2 in the feed, there is no CO_2 on the right-hand side of reaction No. 3. And, therefore, no matter how high the energetic temperature driving force is, it has to form CO_2 to fulfill the equilibrium condition to push some CO plus hydrogen, to push it to the right-hand side to create some CO_2. And then more and more CO_2 is created, and this is like a resistance to move on.

And like this resistance, when you have enough CO_2 on the right-hand side and then the temperature, we come to a thing called equilibrium condition; and that can be calculated. And this determines then how much CO_2, along with all the other components, come out of the GHR and come out of the ATR -- or come out of the SMR of Darde.

Q. Doesn't equilibrium require some sufficient amount of time in a reformer, meaning if the gas is passed through a reformer fast enough, it will never reach equilibrium?

A. I agree. Equilibrium is only one side of looking at -- or one aspect how we have to look at reactions. The other question is how long does it take to achieve equilibrium? Can we reach equilibrium?

Then it comes to residence time in a GHR, in the catalytic bed of an ATR. Then it comes to a design parameter, let's say, catalyst volume. And for steam reformer the designing parameter for the catalyst volume is reaction No. 1, which

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is the steam reforming reaction.
And if a person technically skilled in the art designs any reforming unit with a high-enough catalyst volume to go close enough to equilibrium for reaction 1 with naked catalyst, then the kinetics of the water-gas shift reactions on this naked catalyst tells that the reaction 3 is at equilibrium. It's faster than the reaction 1. The catalyst volume is designed for reaction No. 1 so we have enough catalyst volume for reaction 3 that equilibrium is established.
That's the common -- that's what you see in theoretical calculations of steam reforming units. That's what you see when you take samples on actual running plans, on pilot scale plans. You always see that reaction No. 1 is a little bit away from equilibrium, but reaction No. 3 equilibrium is reached.
Q. Are there any documents cited in your declaration that explain that relationship in speed and completion between reaction No. 1 and reaction No. 3?

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A. 1017. Exhibit 1017, 1027, 1028, 1016.
Q. Can you point me to where 1016 describes that.
A. I cannot show you the paragraph right now where Appl describes that. But this is -- I don't have it with me.
Q. And those paragraphs of your declaration don't cite a particular part of 1016 that describe that, do they?
A. In my declaration I don't cite 1016, no.
Sorry. I knew there was something. Paragraph 31.
Q. That doesn't point to a particular page of 1016, does it?
A. No.
Q. Okay.
A. It's just citing Appl.
Q. Okay. If you look at Darde's figure briefly, how would you expect -- would you expect the mass flow rate of hydrogen produced to be larger than the mass flow rate of CO2 produced, captured?
A. The mass flow rate of CO2 will be

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higher.
Q. Higher than the mass flow rate of hydrogen?
A. Yes.
Q. Do you know approximately how much higher?
A. No.
Q. Would it be double or less than double?
A. I would say more than double.
Q. Would you expect it to be more than triple?
A. Four times higher.
Q. Again, just approximately, I want to make sure we're saying the same thing. You would expect in Darde's figure the mass flow rate of CO2 captured at stream 14 to be roughly four times the mass flow rate of hydrogen exiting the PSA 11?
A. Can we do a back-of-the-envelope calculation because I ...
Q. Sure.
A. So the ratio is 44 divided by 8, which is 5 point something.
Q. So roughly 5.5. So in Darde's

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figure you'd expect the mass flow rate at stream 14 of CO2 capture to be approximately 5.5 times the mass flow rate of hydrogen exiting the PSA 11. Is that correct?
A. Assuming ideal conditions, that the recovery rate of hydrogen in the PSA is a hundred percent, the CO2 recovery rate in unit 13 is a hundred percent. But we use about 10 percent of the hydrogen in the PSA, and we use also some CO2 into streams -- well, 15 doesn't matter. It comes back. In stream 16. Let's say 5.
Q. Okay.
A. The volume flow rate of hydrogen is four times higher.
Q. All right.
MR. ROBINSON: Pass him back if you've got anything else.
MR. PHILLIPS: Yeah.
RE-EXAMINATION
QUESTIONS BY MR. PHILLIPS:
Q. Dr. Klein, just one more question. I want to take you back to paragraph 28 for a second in your report.
A. Yes.

Q. So for a steam reforming unit in a hydrogen production plant, can you describe any situations, any scenarios where there is not at least some CO_2 in the exit to the steam reforming unit?

A. There's always CO_2 in the exit.

Q. That's all I have.

MR. ROBINSON: Let's go home.

(Proceedings concluded at 2:55 p.m.)

CHANGES AND SIGNATURE

WITNESS NAME: HARALD KLEIN

DATE OF DEPOSITION: April 2, 2026

PAGE LINE CHANGE REASON

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I, HARALD KLEIN, have read the foregoing deposition and hereby affix my signature that same is true and correct, except as noted above.

____

HARALD KLEIN

THE STATE OF _______________)

COUNTY OF __________________)

Before me, ____________________________, on this day personally appeared HARALD KLEIN, known to me or proved to me on the oath of _________________ or through __________________________ (description of identity card or other document) to be the person whose name is subscribed to the foregoing instrument and acknowledged to me that he/she executed the same for the purpose and consideration therein expressed.

Given under my hand and seal of office on this _____ day of __________________, _______.

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IN THE UNITED STATES DISTRICT COURT

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BEFORE THE PATENT TRIAL AND APPEAL BOARD

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TOPSOE, INC.,

Petitioner

v.

L'AIR LIQUIDE, SOCIÉTÉ ANONYME POUR L'ETUDE ET L'EXPLOITATION DES PROCÉDÉS GEORGES CLAUDE,

Patent Owner

____

Case IPPR2025-01173

Patent No. 11,673,805

REPORTER'S CERTIFICATE

ORAL DEPOSITION OF HARALD KLEIN

April 2, 2026

I, Melinda Barre, Certified Shorthand Reporter in and for the State of Texas, hereby certify to the following:

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That a copy of this certificate was served on all parties and/or the witness shown herein on ____________________.

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