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BEFORE THE CALIFORNIA ENERGY COMMISSION

JOINT AGENCY SYMPOSIUM AND IEPR WORKSHOP ON METHANE

EMMISSIONS FROM CALIFORNIA'S NATURAL GAS SYSTEM:

CHALLENGES AND SOLUTIONS

In the Matter of:	)	
	)	Docket No. 16-IEPR-02
2016 Integrated Energy Policy	)	
Report Update (2016 IEPR Update)	)	
	)	

CalEPA BUILDING

BYRON SHER AUDITORIUM

1001 I STREET

SACRAMENTO, CALIFORNIA

MONDAY, JUNE 6, 2016

8:00 A.M.

Reported by:

Peter Petty

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Yu Hou, Air Resource Engineer

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Tim Sullivan, Executive Director

OTHER PRESENTERS

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Adam Brandt, Stanford University

Marc Fischer, Lawrence Berkeley National Laboratory

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P R O C E E D I N G S

8:16 A.M.

SACRAMENTO, CALIFORNIA, MONDAY, JUNE 6, 2016

MS. LOZO: And welcome to our symposium, Methane Emissions from California's Natural Gas System: Challenges and Solutions. This is a Joint Agency symposium hosted by the Air Resources Board, the California Energy Commission, and the Public Utilities Commission.

I'm Carolyn Lozo. I'm a manager here at the Air Resources Board in the Oil and Gas Branch.

This symposium is also serving as one of CEC's Integrated Energy Policy Report or IEPR Workshops. We have a lot of information to present to you over the next couple of days, and I think that we'll come away a little more informed, inspired, hopefully, and having sparked some good conversation around the issues surrounding the natural gas that we use here in California.

I have some very general announcements to start with. The restrooms are out of the back of the auditorium to the left, down the hallway. There's also a water fountain that direction. The café is downstairs. It will be open until 3:30 today and tomorrow. We also have some coffee and water out in the little alcove to the right as you go out the doors, the little alcove to the right, so help yourself to that.

Also, if the fire alarm does happen to go off, please go down the stairs, out the front main entrance, and then across the street to Cesar Chavez Park.

Also, please note that we will be posting all of the presentations on our website after the symposium is over, so look forward to that.

Both days of the symposium will be recorded, that's for the CEC IEPR Workshop purposes.

And also for the IEPR Workshop, the CEC will be taking public comments at the end, just at the end of each day, both today and tomorrow. Those public comments are for the CEC IEPR workshop only. They're not for any other regulatory or programmatic purposes. But there are some blue cards at the back of the room. If you do want to do -- or give us a public comment for the CEC IEPR Workshop, please fill out the blue comment cards and you can leave those back there.

We will be having a question and answer period after each presentation, so we've got some microphones set up if you'd like to ask a question.

Also, if you are participating via webcast and you'd like to ask a question, you can send that to us via email. Send it to auditorium@calepa.ca.gov. and we'll try to get to those questions, as many as possible.

Okay, and then finally, we're having two policy panels tomorrow, and another opportunity to ask a question. If you would like to ask a question, we have some white pieces of paper at the back of the room. You can leave your question there and we'll try to get to those questions with the policy panel.

And then also, one last thing, you may have noticed, we have a hashtag, #containmethane. You may have seen the little cards around. If you'd like to join that conversation, please do so, #containmethane.

And beyond that, I'd just like to introduce, to get us started, Floyd Vergara, Chief of the Industrials Strategies Division here at ARB.

MR. VERGARA: Thanks, Carolyn.

Good morning, everyone. Again, I'm Floyd Vergara. I'm the Chief of the Industrial Strategies Division here at the Air Resources Board. Just to give you some context, my shop has oversight responsibilities for a number of our major climate change programs, including Cap and Trade, Low Carbon Fuel Standards, short-lived climate pollutants which we'll talk about a little bit later, oil and gas waste programs, and energy. So all the fun stuff is in my shop.

Again, welcome to this joint symposium of the Air Resources Board and our colleagues at the Energy Commission, and also the Public Utilities Commission. I'm very excited to be here kicking off this very important and timely symposium on methane. This symposium represents one of the many efforts ARB is undertaking to reduce emissions of short-lived climate pollutants, particularly methane. And the symposium also supports ARB's long-term climate goals.

So just to provide some context and framing, methane emissions from California's natural gas infrastructure are an important source for which the state is developing or implementing a number of control measures. For example, the Air Board next month will consider a regulation to implement GHG emissions standards for crude oil and natural gas facilities. The draft proposal was just released last week and covers natural gas storage facilities, as well as production and processing.

ARB is also consulting with PUC on their ongoing efforts to reduce emissions from the transportation and distribution sector. These efforts, along with efforts at the local air pollution control districts and our sister agency at the Division of Oil, Gas and Geothermal Resources, or DOGGR, reflect a concerted multi-level effort to implement meaningful control measures on the emissions of methane gas from the existing production, transport and distribution system.

Overall, we have committed to reduce methane emissions from oil and gas systems within California by 40 to 45 percent from current levels by 2025, equivalent to about 8 million metric tons of Co2 on a 20-year time scale. However, this is does not address upstream emissions related to the imported natural gas we consume within the state.

Recent and past events, including San Bruno and Aliso Canyon, are a stark reminder of the dangers and dependencies we have on natural gas in California where 90 percent of the state's demand is imported from out-of-state resources. At this symposium we aim to understand any additional areas of methane emission reductions in California and begin these important discussions about how we can work to account for and reduce methane emissions associated with natural gas that we import.

As our agencies move forward with reducing methane emissions from natural gas use in California, it's also important to keep in mind that meeting our long-term climate goals will require a rapid decline of oil and natural gas demand and increased use of renewable natural gas in applications where that's not currently feasible.

I'm looking forward to an exciting two days covering a wide variety of methane-related topics. And with that, I'd like to hand the microphone over to our colleague, Commission Karen Douglas from the Energy Commission. Thank you.

COMMISSIONER DOUGLAS: Thank you. Thank you, Floyd.

Good morning everybody. I am, as Floyd said, a Commissioner of the California Energy Commission. And I'm the Lead of this year's Independent Energy Policy Report or IEPR. The Energy Commission's IEPR gathers data and information on a wide range of matters concerning electricity, natural gas, transportation, energy efficiency, renewables and more. And in the 2015 IEPR that we adopted earlier this year the Energy Commission called for an evaluation of the state of the science as to methane leakage, essentially upstream methane leakage from the natural gas system. And so this is a topic that we're very pleased to be working with, ARB and the PUC, on -- with this workshop.

As Floyd mentioned, the importance of this issues was, unfortunately, underscored by a couple of events. And I'll speak more about the Aliso Canyon gas leak that was detected at Southern California Gas Company's storage facility on October 23rd of last year.

In response to this event, a moratorium was placed on injections to the storage facility, as I think everyone here probably has been following this issue. But the governor issued and emergency proclamation calling on the Energy Commission, the California Public Utilities Commission, the California Independent System Operator to work together and take all actions necessary to ensure the continued reliability of natural gas and electricity supplies during the moratorium on gas injections.

And so in response to that we worked first on ensuring winter reliability in terms of electricity and natural gas supplies, but particularly electricity reliability over the winter. And with that secured we've been working closely with agency partners and with Los Angeles Department of Water and Power on summer reliability. And we issued an action report, together with LADWP, a technical assessment and action plan, to analyze and prepare for issues that might arise this summer.

The report shows that Aliso Canyon plays an essential role in Greater L.A. natural gas and electricity reliability. It serves 11 million customers and 17 power plants. And the moratorium on injections there creates the possibility of up to 14 days during the summer in which gas curtailments could cause electricity service interruptions.

We're working very hard to avoid any such curtailments with our partners, with other agencies. We have issued an update to the action plan that calls on all of us to put forward mitigation measures, including prudent use of remaining stored gas, completion of needed safety reviews as quickly as possible, and deployment of efficiency conservation, demand response programs, Flex Alerts, acceleration of other storage opportunities, protection of ratepayers and so on as this situation unfolds. But it is serious and we do have a high reliance on that storage facility.

So we're continuing to work with our sister agencies and utilities in Southern California to monitor summer reliability. And we've started to assess next winter risk. Senator Pavley's Senate Bill 380 sets clear next steps for state agencies in this matter, and we've moving forward in accordance to that bill.

Next year the Energy Commission, again, through the IEPR is going to take on the longer-term assessment called for in the emergency proclamation to consider the role of natural gas in our broader system, in light of our longer-term climate goals.

We've got a number of additional workshops to assess the impact of Aliso Canyon on Southern California refineries -- well, one additional workshop on that topic, but we've got a couple additional workshops on the broader topic this summer.

The purpose of today's workshop is to bring together industry academics, governmental and non-governmental entities and other interested stakeholders to discuss the status of research, science and gaps in the current knowledge and research needs associated with methane emission leakage, and to share ideas to both improve the information we have and improve our knowledge as we move forward in a policy-setting role in this area.

I'd like to thank the California Air Resources Board, in particular, for their hard work in putting this workshop, this two-day workshop, together and their partnership with us in making this a joint workshop. And also thank the CUPC which also contributed a significant amount of expertise and ideas and helped frame the workshop.

So with that, I'll look forward to getting started, and thank you all for being here.

MS. SULLIVAN: Good morning. I'm Tim Sullivan. I'm the Executive Director of the California Public Utilities Commission. I'm glad to be here at this exciting conference, bringing together methane emissions, leak detection and gas policy.

Why is the California Public Utilities Commission a sponsor of this Joint Agency Symposium?

Well, the Public Utilities Commission has 1,000 employees. The commission regulates services and utilities, protects consumers, safeguards the environment, and assures California access to safe and reliable utility infrastructure and services on all California infrastructure, subject to our jurisdiction and oversight. We basically do four things. We ensure access of all

Californians to the services and benefits of the energy, communications and water infrastructure. We subsidize communication consumption at about $1 billion a year. We subsidize energy consumption to the tune of $1 billion a year. We also work to ensure its safety. And as any of you know who have been reading the newspapers, the California infrastructure is aging. And we seem to go from accident to accident, particularly in the gas distribution and transmission system.

We also work to promote the environment. We have $1 billion Energy Efficiency Program. We administer CEQA for most energy facilities in the state. We are the drivers of the State's Commission to Renewable Energy. And with the passage of recent legislation, we are now responsible for reduction of greenhouse gases. We regulate. And those are sort of the things that you do that no one really thinks about.

The basic thing we do is we regulate companies within our jurisdiction to ensure reasonableness of rates and the quality of service.

Now what does that mean for the gas industry?

Well, basically, we regulate the companies that provide virtually all of the natural gas in California. We regulate Southern California Gas which is the second largest gas utility in the country in terms of sales revenue. We regulate Pacific Gas & Electric which is the fifth. And we also regulate Southwest Gas who is, actually, also in the top ten, but they only serve a sliver of the state up by Reno, and Big Bear Lake in the south.

We also regulate storage facilities. Obviously, the famous Aliso Canyon which we've had such a methane catastrophe, but we also regulate Lodi Gas and Central Valley Storage.

Californians also consume a lot of gas, 2.2 trillion cubic feet per year which is the second largest in the United States, just behind Texas. There are 13,000 transmission pipeline of which we share jurisdiction with the federal government. But there are 200,000 miles of distribution pipeline, and that's subject to our jurisdiction. It's basically our job. There are 10.8 million customers.

So what does that -- so what do we conclude?

Californians consume a lot of gas. And the commission is either wholly responsible or shares responsibility with other state agencies for ensuring its safety, for protecting the environment, for ensuring its availability, and for the reasonableness of rates.

Now what's new in our world?

Well, in 2014 the legislation passed the bill known as Senate Bill 1371. And that asked us to step up the regulation of fugitive methane emissions beyond what we have historically done. It restructured the regulation of methane emissions by considering for the first time the environmental impacts and the risk associated with potential emissions. Clearly, there was some foresight there since major disasters have actually followed. But this bill now requires us to rethink and reconsider how we monitor, report and manage this critical infrastructure. This bill directed the Public Utilities Commission in particularly to establish technology-based standards that are focused on the prevention, reduction and repair of methane leaks, monitoring and repair protocols, identifying best practices, developing performance metrics, and annual reporting and evaluation.

Now not just the legislature has tasked us with this, but Governor Brown, who is largely our boss, has directed that California must reduce the relentless emission and release of methane. This, just if you think about those numbers I said before, the 2.2 trillion feet, the over 10 million customers, this will require enormous innovation, research and investment by both the public and private sector.

Why are methane leaks important and where do methane emissions come from?

Well, I'm going to digress here and tell a personal story. A few years ago I smelled gas outside of my house. I checked the meter, it was not spinning. I then crawled under the house. I didn't smell gas there, so I decided that it was probably nothing.

A few weeks later we had a house sitter come by to sit at our house. She was an elderly and stubborn person. She told me that she smelled gas and I should do something about it. So what I did is I called PG&E and they came and fixed a leak at the gas meter.

So the question I have: Is this a big or a small thing?

Well, actually, it turns out it's a pretty big thing. Current estimates are that leaks at the meter account for 45 to 50 percent of all methane leaks in the state of California. These are only estimates. And I have to tell you and I have to praise the Air Resources Board which is funding research by the Gas Technology Institute in order to measure emissions from a representative sample of meter sets and develop a more reliable estimate.

Well, what does this mean?

Well, there are over 10 million meters in California. Checking for leaks and fixing the leaks will not be cheap. If this step is taken it will be the commission, my commission, that oversees the process and changes rates to pay for it. The commission will need to ensure that what the commission does, that whatever regulations or programs we initiate provide value to Californians for the dollars that they pay. Suppose it takes as little as $25.00 to check a meter for emissions. Well, 10 million meters, you've got a quarter of a billion dollars. So whatever we do the money and costs mount up quick.

There are, of course, other sources of methane leaks, and they can occur anywhere from the wellhead to the burner tip. It was mentioned earlier, 90 percent of the gas used in California comes from out of state, so it travels a long way. So we need a collaborative effort in the west to build partnerships between state agencies, between government and industry, between states, and between states and the federal government.

In my view, this symposium could not be more appropriate, more timely or more needed. I want particularly to thank my sister agencies, the Air Resources Board and the California Energy Commission, for working together with my staff to make this event a reality. I want to thank in particular all of you who have made the commitment and taken the time to come to Sacramento today and tomorrow to address this critical issue. I hope this symposium will be viewed sometime in the future as the starting point of a larger regional effort here in the west to not only reduce the environmental impact, but also to improve the economic efficiency of the natural gas industry.

My staff and I look forward to the research you present, and we will be acting on it. The SB -- I can't remember the number -- 1371 has triggered a proceeding. And what we are doing in that proceeding is we're integrating all the facts we can into programs for California.

I want to thank you. And I think I should introduce Kathleen Kozawa of the California Air Resources Board who will now provide an overview of the symposium.

MS. KOZAWA: Thank you, Tim.

And thank you, all the representatives, for being here to speak on agency priorities. I feel like they've really addressed a lot of the things I want to talk about in this overview, so I'm just going to piggyback on some of the words that were mentioned just now.

So first of all -- let me start over here. My name is Kathleen Kozawa. I am a staff in the Oil and Gas Branch. And what I'd like to do in the next few minutes, before we begin our sessions, is provide just a little more context about the discussions and talks we're going to be hearing over the next couple of days.

Now we've already heard a lot about Aliso Canyon. It's been mentioned in all the previous speakers so far. And I think it is important for us to learn from these kind of events and prevent them. But absolutely, this symposium is really -- the primary focus of this symposium, I should say, is about the business as usual emissions that occur every day, like Tim was suggesting, from customer meters or from anywhere else in the natural gas system. So this is where we'd like to really focus our discussions moving forward.

So this diagram here really is a general illustration of the boundaries of things that we're going to be covering over the next couple of days. And this is by no means and exhaustive figure, but there is one thing I want to note in here and that's the -- note and recognize, really, and that's the role of biomethane. Now biomethane is something that's going to be important for us moving forward, but we're really not going to be touching on it here. And we didn't purposely mean to exclude it. But really we thought and we felt that it really needed its own symposium on its own, and I think many of you probably appreciate that.

Next, in terms of the national perspective, and Tim already kind of touched on some of these numbers, but as a whole in the United States we use about 30 trillion cubic feet of natural gas, this was in 2914. California, as Tim mentioned, is the number two consumer of natural gas. And the top end uses on a national level are electric power, industrial and residential uses. And California pretty much looks very similar to this.

Now while California is the number two consumer of natural gas, we only make about ten percent of it. As was alluded to in earlier speakers' comments, we import about 90 percent of our gas into the state for use. Some of that comes from the southwest. Some of it comes from the Rocky Mountains. And then a fraction also comes from our neighbors up north in Canada. So this is why we're not only interested in the emissions that are occurring inside the state, but those emissions that are associated with the gas that we import, as well. And this is going to be important to keep in mind as we move through the rest of the presentations today and tomorrow and as we frame our discussions in the future for reducing methane from natural gas -- or methane emissions from natural gas.

So California has many efforts that are going on right now to reduce methane emissions. They're kind of all under the umbrella of California's 2030 greenhouse gas targets which is, as a reminder, 40 percent reduction of greenhouse gas from 1990 levels by 2030. Also mentioned in our agency's priority speakers previously, the CEC and the CPUC are also heading efforts to reduce methane emissions, for CEC specifically the Integrated Energy Policy Report Update, and for the CPUC, the proceedings on Natural Gas

Transmission and Distribution. Here at ARB, we also have the Short-lived Climate Pollutant Strategy, and ARBs proposed regulation for oil and gas facilities.

Taken as a whole, these strategies are to reduce instate emissions of methane from oil and gas systems by 40 to 45 percent, and this is consistent with the federal goals.

Another thing that we'd like to understand here in California is, and things that we're working on to understand, is lifecycle emissions of methane. So this includes emissions from instate, and also the gas that we import from out-of-state sources. The Low Carbon Fuel Standard includes these lifecycle emissions. And as the models that are used in Low Carbon Fuel Standard, they do get updated occasionally. So as we get more information those numbers will likely be updated, as well. Knowing the lifecycle emissions for methane also can inform other programs, such as incentives. And so what we've done here at ARB is funded a contract to evaluate these emissions.

So with all these efforts going on in the state, it kind of begs the question, well, why are we here?

And the reason is, I believe, we want to keep moving forward, beyond what we're doing already, to address, for example, additional sources, or if there are other gaps that would better inform California-specific emissions and, as I mentioned before, addressing the emissions related to imported gas.

Also another reason why we're here, as Commissioner Douglas had mentioned, this symposium serves as a workshop for the IEPR Update. And so the 2016 Update is supposed to include an assessment of the available studies covering all the sectors that we'll be touching on over the next couple of days.

Finally, another reason why we really want to keep track of the methane issue and move forward with it is because of federal action on methane. The recent greenhouse gas inventory has natural gas and petroleum systems being the number one source for methane sources -- methane emissions in the United States. And this is beating out enteric fermentation and landfills. And while the makeup of the inventory is a little bit different here in California, it's important to recall that, remember, 90 percent of our gas is imported. So any action that's taken on the federal level will trickle down and make an impact here in California. And with the final NSPS issued last month, and EPA's efforts for existing sources upcoming, and we'll see where that goes, but these are all important to consider as we move forward.

Now very quickly, I just wanted to go over some additional, more specific symposium objectives. And we are not all here just to share information, but it’s great. But really we want to discuss the current science of methane emissions associated with dry gas and natural gas that’s used here in California, determine the research and policy gaps, what do we need to move forward, and then how we use this information to inform future policy discussions in this arena.

Last slide. I just wanted to highlight a couple of things in the agenda.

First, Carolyn mentioned this in her beginning notes, but session five, which will be tomorrow afternoon, will be made up of two panels, and this is in your agenda, as well. One will be a regulatory panel, one will be a non-governmental stakeholder panel. If you won’t be able to attend the panel, go ahead and please fill out some white index cards. They are in the back, and there are some boxes. Raquel is holding them up right there. But if you want to see a topic addressed, you’re not necessarily going to be here, this is recorded so you can come back and watch the discussion, as well. This is not to say that you can’t ask questions during the panel. But we just wanted to give everybody this option, as well.

Lastly, the showcase, as you saw, vendors setting up outside of Byron Sher Auditorium, they will be set up today and tomorrow. Tomorrow, however, we will also have a vehicle showcase with vehicles outfitted with methane detection technologies in the courtyard outside where you walked in to come into the building.

And so with that, I'm going to go ahead and move us along into the first session which will be Research, Initiatives and Needs.

Our first speaker will be Yu Hou. Yu joined the Energy Commission in 2015 as an Air Resource Engineer. His work focuses on energy-related environmental research. He holds a Master of Science Degree in Mechanical and Aeronautical Engineering from the University of California Davis, and a Bachelor's Degree in Physics and Mathematics from Lewis and Clark College.

Yu?

MR. HOU: Thank you. Good morning. My name is Yu Hou. I am, as Kathleen already said, I'm an Air Resource Engineer from the Energy Commission. So today I will take this opportunity to provide you a quick overview of the Energy Commission's effort on this topic and give you -- here's the lineup of the talk I have today, and I'll give you a quick historical context on Energy Commission's previous effort, and give you a highlight of the current projects. And at the end I would like to mention, our projects are supported through the PIER Natural Gas Resource Plan, which is the Public Interest Energy Research Plan.

And then at the end we'll talk about some upcoming projects and what we believe to be the next step.

So historical context, so in 2005, more than a decade ago, that working with Dr. Mark Fischer from Lawrence Berkeley National Lab, the Energy Commission had a series of projects that we installed instruments on those communication towers that you see here. And we used this method to determine methane concentrations in the atmosphere and estimate emissions. This turned out to be a very effective way to measure methane emissions. We shared our findings with the Air Resources Board, and the Air Board took over and expanded the project and those measurements to other parts of the state. So this effort is reported in 2007 in the Nature Magazine as the first in the nature to getting that type of original data.

And you saw a similar picture of this before. This is a traditional or a classic view of the natural gas system. And as you can see there, we have the production, processing, transmission storage, and distribution system. And as you already heard in other -- before me, this seems to be an incomplete picture that, what I'm showing here, should be a more complete picture, you know, including those consumers. We heard about, you know, emissions at the meters. Now you can see that we have power plants, we have homes, residential homes, and we have buildings. We have industrial sectors. Also, we have abandoned wells. Those are where the wells are no longer active but possibly still emitting methane.

Therefore, with this picture in mind, I'm going to give you a quick highlight of our core project.

So the first project you have here was Dr. Mark Fischer from Lawrence Berkeley National Lab. This is a quick overview of sort of the natural gas system. As you can see that there are measurements on the capped wells, the picture on the left. And in the middle it's the platform they utilize to making those measurements. And the picture on the right shows you the distribution, measurement and distribution system.

Other sources tested in this project include storage units, natural gas refilling stations, refineries. And what I want to mention is there are ten homes also measured in this project that indicate -- kind of brought us to indicate that there are some emissions from homes.

Which leads to this second project, also with Lawrence Berkeley National Lab. So beyond the 10 homes that are measured in the last project, an additional 75 homes are also measured. And the results, we're expecting to have the report coming in by the end of the year.

And one interesting, from this project indicate, is that the incomplete combustion process from the home appliances also contributes to emissions which mentioned, you heard before, that’s the burner tip; right? At the very end we also see some emission. So we have to look at homes in those two projects. By no means, that’s it, you know, we’ll be looking at more.

But, you know, we want to look at some other sectors. So what about commercial buildings?

So I have two projects. One is the Gas Technology Institute. We’re looking at restaurant and health care facilities. The reason we’re taking those two, because those two are the major natural gas consumers in the sector. ICF International in another project will conduct some tests in other types of buildings, for example, schools, office buildings. And because the findings we had in the previous project about the appliances, those two projects will also do some testing at an appliances level to see what our emissions are. And those two projects are both expected to be complete in 2019.

So we look at another -- several after-meter type of projects. And we take a look at the pipelines and storage facilities. This is a problem that we have with University of California Davis with Dr. Stephen Conley. In this project, as you can see that, a research aircraft is deployed. And the aircraft will fly around an emission source to determine the emission level from the source.

So speaking of storage facility, I figured I have to spend a little bit of time on Aliso Canyon. And as you can see here, the map on the left is a map showing all the natural gas storage facility in California. And so I want to say that when Aliso Canyon leaks happened the Energy Commission is the only agency that had the asset to deploy at the time. And Dr. Conley conduct a series of flights collecting data from Aliso Canyon. As you can see, the X on the picture on the right, on your right, is the leaked gas well. And the white line there is the flight path the airplane took.

The result from the measurement was published in Science Magazine in October 25th of this year [sic]. And based on some new information that SoCal Gas has released, based on their mass filings' analysis, the results are in pretty good agreement, I think about five percent.

So those are the highlight of our current projects, so let's look at some upcoming projects. And what do we want to do next?

I show this picture again just to kind of reemphasize the holistic view of the system we're looking at. Here's a project we will have with -- this is a joint effort between us and Air Resources Board and NASA/JPL. During this project NASA will deploy its infrared cameras, and also research-grade aircraft to try to identify large emitters. Those large emitters, which is a repeated appearance we see from our studies and literature that those large emitters, sometimes they're called super emitters, disproportionately representing a larger amount of emission through the population. And as you can see, that this picture showing, NASA had an image showing a facility leaking methane.

The Energy Commission in this project will be focused on the natural gas system. And the ARB will focus on other sources, like dairies and lead fields. Of course, we're closely coordinating this effort with DOGGR. And this project should start sometime in the fall, I believe.

So while our Natural Gas Resource Plan also identified two other areas that are of interest. If you remember that picture I had, it shows the parts we are interested in, the industrial sector and power sector, but also -- oops, all right -- so also we are interested in the groundwater-related subsidence impacts on the natural gas system. The map I'm showing you on the slides, showing you an overlap, overlay of area impacted by substances and more than 100,000 abandoned cap wells in California. And the picture in the middle, it's a gas well that has protruded from ground because the ground has subsided.

So in summary, the Energy Commission has been working on this topic for a long time. We have made significant process in identification and correct reason of the emissions' sources. We have made progress in measurement techniques, but more work is still needed. So in the future we'll work closely with the Air Resources Board, DOGGR and other entities. We'll continue to support research on this topic through the Pure Natural Gas Program. So thank you.

(Applause.)

MS. KOZAWA: Thank you, Yu.

We actually are running just a little bit ahead of schedule. So if anybody has some questions, we have standing mikes. I see nobody getting up.

I guess we'll go ahead and move on to our next speaker. The speaker is Dr. Jorn Herner. Jorn has worked for more than a decade in the Research Division of the California Air Resources Board. In his current position as the Chief of Research Planning Administration and Emission Mitigation Branch, he oversees the agency's annual research planning effort, the division's vehicle emissions research, and the greenhouse gas ambient measurements and analysis.

Jorn?

MR. HERNER: Thank you, Kathleen. And sorry for hiding in the back during the beginning. I was here, but just hiding out in the back.

So good morning, everyone, and thank you for coming today. I'm going to get a little bit more specific than we have been so far about what we're doing on research initiatives and needs in the state of California to move this ball forward that we're all here to discuss today. So I'm going to start pretty broadly, though.

Why are we concerned with methane?

Really, there are two reasons. It's often co-emitted with pollutants that are of direct health concern or that participate in ozone formation. And most of us today are probably here because it's a very potent greenhouse gas. And we all hear from the IPCC that the GWP or global warming potential of methane over 100 years is 28, but over 20 years it's 84. I wanted to, I don't know, create some kind of picture that kind of puts that into context.

So what I've done here is grab the amount of energy added to the atmosphere from releasing one kilogram of methane and one kilogram of Co2 over 100 years. And you can see that methane in that first year that it's released adds 133 times more energy to the atmosphere than Co2. It adds 133 watts. I use 13 watt CFLs in my house, so I could have ten light bulbs burning 24/7 for a whole year just in that first year that the methane is in there, so it's a lot of energy added to the atmosphere, whereas, you know, a kilogram of Co2 just adds one watt in that first year. It takes about 70 years before methane has been reduced enough to where the overall energy burden to the atmosphere is equal between the two. So it's a very potent greenhouse gas. And that creates this opportunity of if we do something to reduce methane we will get climate benefits very quickly.

A broad overview. This has been kind of touched upon before of the state's climate and methane reduction plans. Most of you are probably familiar with AB 32 which requires the state to reduce overall greenhouse gas emissions to 1990 levels by 2020. We have additional goals in the form of executive orders to reduce another 40 percent from that level by 2030, and another -- and a complete 80 percent by 2050.

Specific to methane, SB 605 required the state to write a plan on short-lived climate pollutants. Methane, of course, is a short-lived climate pollutant, as we just discussed. And this plan was released in April of this year and calls for a goal of reducing methane emissions by 40 percent by 2030.

So how important is methane in our current inventory?

For 2010, using a 100-year global warming potential, methane constituted just less than ten percent of our overall greenhouse gas emissions. But if you use the 20-year global warming potential, it's almost 20 percent.

So certainly you can’t reduce the overall emissions by 80 percent without getting significant reductions in methane, as well. And if rather than using a global warming potential you calculated the instantaneous relative forcing, methane would be an even more important part of this pie.

What are the main sources of methane in California?

Ag and waste sector are responsible for a very significant fraction, three-quarters of the overall emissions in the state. Oil and gas is about 13 percent in the current inventory, so less than the U.S. as a whole. But as discussed, we get -- a lot of our methane is imported. So those additional fugitive methane emissions that occur outside the state are important, as well, and are not accounted for.

And as I will mention later, there is also a question about whether or not the inventory is underestimated. And as we go through finding out why that is, the various size of these pie pieces may change.

So on a very broad level, one of our goals with research in terms of methane is really to understand our improvement of emissions and use that information to find opportunity to get reductions. The end goal has to be the 40 percent reduction by 2030, and then we’ll get another goal after that.

We want to inform our inventories with the work that we do so we have better knowledge of what's going on. Many of our inventory emission rates come from the EPA, so they're kind of national emission estimates. We need California-specific numbers. And then as you hinted at, there may be these high emitters out there. So in terms of opportunities for emission reductions, if we can identify various high emitters and control those first, we could get a lot of reduction for a small effort. So we are looking at that, as well.

So now I'll go into a series of slides on our research efforts. The first was touched on by Yu, as well as CEC. They started this methane monitoring network that in 2010 the California Air Resources Board collaborated with them and have since expanded significantly. As this map shows, we have a number of stations throughout the state. And you take these very highly accurate methane measurements and you couple them with inverse modeling, and you're able to create kind of a top-down inventory. And Mark Fischer at Lawrence Berkeley National Lab has been doing that modeling for us. And it is this effort, along with many other studies, more regional studies in specific air basins of California, that suggested our inventory may be underestimated by 50 percent. I believe that it's not that this effort is completely right and the inventory is totally wrong. The two will converge as they inform each other over time.

But we are continuing this effort. We are going to expand and improve upon our network. And we're hoping that in addition to just having a single top-down number for comparison, that the effort will start to be able to say something about which sources should we be looking at more closely to improve our inventory and anchoring policy.

Next is AB 1496. This has been referred to, as well, by CEC, Yu. This is a bill that as passed in 2015 that requires the state to undertake monitoring and measurements of high emission methane hotspots. On your right you see a map that was generated using satellite data, and it shows a couple of different hotspots in the Western United States. One of them is in the Southern San Joaquin Valley, so we're required by this piece of legislation to take a closer look and monitor that hotspot. And then, importantly, using that we're required to update relevant policies and programs to incorporate what we learned from the effort. And the lifecycle analysis from imported gas has been referred to, as well.

To do that we have this collaboration with the CEC and NASA, with JPL, to have research-grade imaging technology put on planes and fly over various sectors of California where the main emission methane sources are currently -- where we believe they are currently located, and identify these high-emitting sources, as Yu showed on his slides.

The pilot studies already done suggest that we may have a list of as many as 5,000 high-emitting sources in California. So this project will create a long list of leads, if you will, that we can look at further. It is the hope that this list will help operators find leaks and seal them.

We are hoping that the flights will happen this fall. And I believe there is a presentation later today that will discuss this project in more detail.

So this is our cartoon -- thank you to Staff for drawing this up -- on the many different resources we bring to bear on trying to understand methane emissions from specific sources, the so-called tiered observation system, starting with satellites, overhead aircraft, aircraft to conduct flux estimates, specifically scientific aviation. We'll hear a presentation from them, as well. Ground-based mobile monitoring, infrared cameras, flux chambers, towers, et cetera. So we have a number of different resources that we're starting to deploy to really get our arms around methane emissions in the state.

We have a long list of external research, as well, that I'll just mention quickly. Many of these programs, PI is probably in the room, so I'll let you ask specific questions to them. I think some of them have presentations, as well. The first two are in regard to the dairies, understanding better how to manage manure from dairies to get reductions there, and also just get California-specific emission rates for dairies.

You mentioned the work to measure emission rates from the other natural gas storage facilities in California. More specific to oil and gas, there's work underway to characterize emissions during well simulation than from percolation ponds, measurements of emission rates from pipelines in California. The testing of natural gas meters in residential homes is undergoing and we need to do more work in that area, and I believe that is underway.

And then, also, an investigation of the different technologies that are available out there now. The technology to measure methane is developing very quickly. We have a wonderful showcase of a number of them out in the hallway today. So how do you create policy that takes advantage of the newest and latest measurement technologies is going to be an important one, as well. And then, of course, lifecycle for the imported natural gas.

So moving forward, we currently have a website on our greenhouse gas monitoring network. We're going to expand that website significantly and present what we're doing broadly on methane. So just the greenhouse gas network will just be one aspect of that. We plan to post data and information and results from all our various efforts there as quickly as we can so that you can have the information that you need.

And then in closing, I want to say it's incredible that can have this many people of your caliber at eight o'clock on a Monday morning in this room because of your interest in something as esoteric as methane. There's a lot of interest in methane in many different corners of the world. If you Google methane today, you get a long list of articles and description of efforts. So there's a lot of new research that really, I think, in a step-wise fashion is giving us better information to get control of this, but we're obviously not done yet. But I'm certainly very optimistic with everything that's going on that we will meet our goal in 2030 and possible even do better, so thank you.

(Applause.)

MS. KOZAWA: Thank you, Jorn.

Are there any questions from the audience for Jorn today?

I have one question, Jorn. I was just curious, because you had mentioned 5,000 super emitters in some of the more recent flights, and have all those been quantified?

MR. HERNER: No, not yet. That's -- JPL has done a few flights. I believe Chip Miller is in the audience and will be giving a talk later. But just from the limited number of flights and how many super emitters that they found, they think that once they cover the areas that's been laid out, that we will -- we could get as many as 5,000. So once you have those identified there would be a lot of work. And we're working with the district and DOGGRs and other to really understand what those sources are and whether or not they're normal emissions or whether it's something that can be stopped right off the bat.

MS. KOZAWA: Thank you, Jorn.

Oh, one question?

MR. DRIVER: Perfect. There you go. Hi. Keith Driver, Cap-Op Energy, based in Alberta, Canada. And one of the comments made was that there's a recognition that the inventory of methane from oil and gas is perhaps not as accurate as we would all like to believe. From the Canadian experience, we've had the same challenge in both B.C. and Alberta, which are two largest gas producing regions.

Has there been any thought about collaborating with other jurisdictions on trying to tighten up those? It seems to be a common problem, and thus perhaps somewhere where there's some opportunity to share.

MR. HERNER: Right, and I certainly agree with that. There's so much going on. You know, EDF has had a huge study recently. And you folks are doing things. We are working with DOE and the federal government on collaborating through the ITRC. So, yeah, there's a lot of collaboration going on and I think that's warranted.

At the same time I will say that every jurisdiction is different. For example, in California we've been controlling emissions of VOCs from the oil and gas sector on a local level for many, many years because of those co-emitted pollutants that participate in ozone formation. So we believe that our natural gas system is much tighter than elsewhere where they don't have that problem.

So I think it's important to collaborate, but it's also important to have local information.

MS. KOZAWA: Thank you. Our next speaker is James Bradbury. James is a Senior Policy Adviser for Climate, Environment, and Efficiency in the Office of Energy Policy and Systems Analysis at the U.S. Department of Energy. At DOE, James contributes to several administration priorities, including the Quadrant Hill Energy Review (phonetic) and the Interagency Methane Strategy. James holds a PhD in Goesciences from the University of Massachusetts.

James?

MR. BRADBURY: Thank you, Kathleen.

Good morning, everybody. Thanks a lot for the invitation to participate here today. I want to say hello to everyone in the audience and to those on the webcast.

Hi, Dad.

Like I think a lot of people in this country, the Aliso Canyon incident got the attention of people we didn't always -- wouldn't have expected to hear from, and that included the phone call from dad asking, "Is this what you work on?"

I said, "Yeah."

So this morning I'm going to give you an overview of all the different efforts, largely from a policy perspective of what we're doing at the federal level. But as I go through those various initiatives I'll touch on where different research needs and R&D efforts are going to be highlighted in my talk, where our priorities are in particular.

So this is another version of a slide I think you saw earlier that Kathleen presented. This is the latest estimate of U.S. methane emissions from anthropogenic sources across the U.S. I kind of pulled out the emissions from the natural gas sector in particular. It's just broken out into these four different shades of gray. So the darker one is the production stage emissions, ND then for processing, transmission and storage, and then the narrow one, the two percent is natural gas distribution. In yellow to the left of the figure, that’s the petroleum system. So all together, this is the 33 percent, about a quarter -- I’m sorry, a third of total emissions.

And just for context, I think you might have already also mentioned this, Kathleen, but this amounts to about 11 percent of total anthropogenic greenhouse gases in the U.S.

A quick point I’ll note on this, so this, of course, inventory, it’s important. And there are ongoing research needs associated with the inventory. I think we all recognize this but I wanted to point it out. And this is something that the EPA is constantly working on, constantly working to update it and improve on the inventory. And the numbers you see here are actually significantly revised from the previous inventory which was released in April 2015, particularly the production stage emissions, both from petroleum sector, increased substantially, by about more than double.

With that said, there was also reduction in some sectors in terms of their estimate that includes transmission and storage and distribution, although they did also say that in the next inventory they’re going to be looking to do more updates and improvements on the distribution side. And these efforts, again, are ongoing.

So the federal government recognized, in particularly through the president’s Climate Action Plan in 2013, that we really needed an interagency strategy to address the issue of methane emissions. And then in 2014, just less than a year later, that came out, and that’s the booklet you see here on the slide. And so that’s really the idea. And the key objective there was to take a collaborative approach across federal agencies with state governments and industry and other stakeholders to carry the strategy forward.

As an update to the strategy, in January 2015 the administration announced the goal to, in particular for oil and gas sector, to reduce methane emissions by 40 to 45 percent below 2012 levels by 2025. And then just earlier this year we announced with Canada that we’re going to be collaborating and coordinating our domestic actions, including addressing existing sources of methane from the oil and gas sector, and I’ll get to that a bit more.

But the three pillars overall of this strategy, which I think is a useful way to frame them and look at these issues, were we’re assessing current emissions data and addressing data gaps, identifying technologies, practices and best practices for reducing methane emissions, and then, of course, identifying existing authorities across the federal government and incentive-based opportunities to reduce emissions. And the first two in particular, of course, are really ripe for research and development. And that's where a lot of the efforts are focused.

I think another aspect of this, including this pretty aggressive target, I would say, the 45 percent reduction by 2025 recognizes that there is a lot of abatement emissions reductions that can happen out there. These are solvable problems. And a lot of the reductions, of course, can be done relatively cost effectively or low cost.

So I'll pause here just to make the point, building on my last point, is that we have learned a lot about methane emissions from the oil and gas sector in recent years, partly thanks to the good work that EDF has done, but other researchers and I'm sure many in the room have contributed to these efforts.

And I'll make the point now which, of course, I'll come back to, and others have mentioned as well, is I think perhaps most importantly we've confirmed what I think a lot of people in this space were aware of, but confirmed that it's true, essentially universally across the sector, is that the probability distribution of emissions has a fat tail. Put another way is super emitters exist. So we do have identified super emitters across the value chain. And this has to be recognized as really a key piece of the strategy when it comes to finding and fixing leaks.

Okay, so this next slide is -- sorry, it’s very wordy. I’m not going to read every word to you. You can breathe a sigh of relief there. So this gives a little orientation to I think a somewhat complicated regulatory landscape when you look across the value chain from wellhead to burner tip. And then within that, cutting across that, all the different types of authorities that apply across the federal government. And so I guess a year ago about we published a paper kind of breaking this down and getting into some more detail on this, because we wanted to better understand where the lines of jurisdiction exist and where there may be some opportunities we might be missing to do more.

But just in a nutshell, so transportation service and siting, this, of course, are state PUCs. At the federal level, Federal Energy Regulatory Commission, FERC, and this oversees the regulation of pipeline siting and transportation service. So these regulators, it says here, focus on cost. They focus on, of course, cost, reliability, and safety primarily, with not a lot of consideration to environmental implications. The one exception, of course, being California as a result of SB 1371. And so that will be, I think, the one statement exception on a regulatory -- from a regulatory perspective.

Safety, of course, pipeline safety is a huge issue. PHMSA is the federal agency, and we'll be hearing, I believe, later today from PHMSA about their research efforts. They have ongoing R&D efforts that focus on risks and pipeline safety. Most states, of course, have pipeline safety rules that are actually more -- that are above the federal minimum standards. But the feds -- and I'll get to this, but PHMSA is updating those, as well.

From an air pollution perspective, of course, Environmental Protection Agency is the main authority, has the main authority there. They currently regulate volatile organic compounds and hazardous air pollutants and, of course, just finalized a rule last month for new and modified sources directly regulating methane for the first time.

There's federal permitting requirements on federal and Indian lands which are regulated by the Bureau of Land Management. And those rules haven't been updated for decades but they're in the process with this proposed rule, and they're working on a final rule now.

R&D, I had to throw this in because I'm from the Department of Energy and we're an R&D agency. Of course, this isn't a regulatory effort, but certainly the work that we do, the analysis we do on emissions abatement technologies advancing our understanding of where the leaks are and the scale of those leaks contributes to our understanding of where regulations and policies should be focused.

Another wordy slide. Again, I won't read every word, but I wanted these to be references for folks, all the efforts we have going on. So a little more detail on what Department of Energy is doing through our Natural Gas Modernization Initiative. We launched this initiative in July of 2014 after having a series of stakeholder roundtables which were headed up and convened by our Secretary of Energy, Secretary Moniz, in collaboration with the White House. The first two items on here really are big research and development areas.

ARPA-E, the monitor program, you'll hear from Nate later today. He'll talk about that initiative which is funding 11 new projects developing low-cost methane sensing technologies for oil and natural gas sector. And then working on setting up an independent field test site to support that program.

The Office of Fossil Energy, we just got this year in FY '16, two new programs, they're related programs for $12 million on methane mitigation. This is mostly in midstream segment. And then also on methane emissions quantification which is across the value chain. And there's a funding opportunity announcement that was posted a few weeks ago that closes next week to support for grants for independent research on that. This is largely supported, as I said, by the Office of Fossil Energy, but also the National Energy Technologies Laboratory, as well. And Cynthia Powell from NETL will be speaking later, I think tomorrow.

Let's see, two more things I'll mention quickly on this. I'm not going to go through all of them.

The Federal Energy Regulatory Commission, which, of course, is an independent entity, we did work with them after the methane roundtables we had to initiate a new policy, and they set a new policy to enable cost recovery for midstream natural gas infrastructure upgrades. It was identified as a barrier, the fact that there wasn't really an incentive or an ability to get cost recovery for investments in safety or environmental improvements that weren't otherwise required by regulation. Recognizing that there are cost effective opportunities, the companies do have an interest in protecting their customers and protecting the environment in many cases. So we set up a new cost recovery mechanism through FERC. And that went into effect last October.

We're working with the National Utility -- NARUC, the National Association of Regulatory Utility Commissioners in a partnership which we just started in February. And this is for DOE to provide technical assistance to state regulators, the PUCs across the country who recognize that there are new technologies coming online, new sensing technologies, and certainly a growing concern of customers and growing interest by companies to do more about reducing methane emissions. And so we're providing technical assistance to support their efforts in that area.

The last thing, building on that, is really we're trying to work with stakeholders and with state and industry as much as we can. And we welcome a chance to talk to any or all of you. I'll be here the next couple of days. Again, we want to provide technical assistance to support shared goals in this area.

So I'll briefly touch on the other agency actions. So Environmental Protection Agency, as I mentioned already, just recently finished a new source performance standard. They've issued an information collection request -- or they've issued a draft information collection request. But they're currently inviting input on what input or what types of information should be in the information collection request when that's officially issued. And so they're soliciting input on that now so they can support effective regulation from existing sources of methane with the oil and gas sector.

They also have a voluntary program, the Methane Challenge Program, which most of the participants are downstream distribution companies and a couple pipeline companies. And they're issuing control technique guidelines for cost effective reductions of VOCs in areas where existing sources are in nonattainment areas NOx, for ozone, and that's for covered oil and gas sources.

I already mentioned BLM's rule which they're updating. I mentioned that PHMSA is updating a transportation rule, of course, their pipeline natural gas transmission rule. And, of course, as many of you know, they released an advisory bulletin earlier this year in response to the Aliso Canyon incident. And they've also initiated regulatory actions on safety of natural gas storage facilities.

The final point here on all the different agency actions, there is an effort convened by the Office of Science Technology Policy, the Interagency Methane Measurement Working Group. And we meet periodically to coordinate and collaborate on different initiatives and effort in the R&D space, particularly on methane measurement, not just for oil and gas but across all sectors. And that's an ongoing effort that has been leading to some great new insights and opportunities to work together going forward.

Wait, where am I? Okay, here we go.

So I wanted to make sure to flag the Interagency

Task Force on Natural Gas Storage Safety. This was established in response to the Aliso Canyon incident. On April 1st the DOE co-chairs this task force with PHMSA, Department of Transportation, and including technical support from a variety of agencies. And we're also, of course, working closely with the state of California and obviously doing a lot on this issue, and in L.A. County and City of L.A., as well.

So the task force is focused on a couple of things. And we're really doing workshops and doing some research and analysis to look at the implications of the Aliso Canyon incident beyond California, recognizing that California, the state agencies are focusing in their state. We want to look at the broader implications in terms of identifying what best practices might be to ensure well integrity, proper response plans, health and safe operations of natural gas storage facilities, and also to assess potentially vulnerabilities to the energy reliability posed by the loss of natural gas facilities. Obviously, this is an acute situation because of the importance of the Aliso Canyon facility here in California, but we want to look at where there might be similar issues in other parts of the country. And the results from this work should be published in about four months. I think I said six months from the start of this task force and that was just a couple months ago.

Okay, so my last slide, I'm just going to finish with some of my thought on what are really our policy objectives when it comes to methane sensing research in particular, not necessarily on the abatement side but on the methane sensing, and kind of, I guess, the three policy goals that are helping to steer our R&D strategies.

The first one is improving the GHD inventory. I already mentioned this. This is really foundational, of course, for policy. And any improvements in the inventory help us set priorities and identify where we should and could be making more progress.

Also, of course, methane sensing technologies are critical for the abatement that we need to do. So methane measurement and leak detection is where we're making a lot of progress in that space. But getting new technologies commercialized and recognized through regulatory processes is a really important objective and, obviously, core to what we're trying to achieve here.

And the last one is establishing emissions monitoring networks. And it's exciting and interesting and I look forward to learning more about what California is doing in this space. It's not something that has happened, I think, in other parts of the country so much. But it's certainly important, number two. And number three, for identifying super emitters and fixing the leaks sooner rather than later, but also just generally having that independent check on our inventory through these top-down methods. They're useful for our understanding of the level of emissions, but also for enforcement and accountability across the board as we move forward on these issues.

So thanks very much. I'm happy to take questions.

MR. NEWTON: I have a question.

MR. BRADBURY: Thank you.

MR. NEWTON: Ed Newton with the Southern California Gas Company.

You made a number of comments about cost effectiveness. In referencing the cost effectiveness, I was wondering, at the DOE do you have any methodology for assessing cost effectiveness, or how do you approach doing that?

MR. BRADBURY: We try to avoid being loosey-goosey when I used the term "cost effectiveness". Apologies if it came across that way. There are certainly -- yeah, we don't have any, I would say, specific methodologies on that point. We did publish a study a year ago looking at the abatement cost curves that have been published earlier by ICF and breaking them down by segment, helping to identify where within the supply chain the abatement opportunities might be in terms of their cost effectiveness. That research, actually, has been recently updated, as you may know. ICF was working with one future initiative to update their cost curves coming to slightly different results as us. And there aren't as many low-cost or negative-cost opportunities out there.

I think the point is since the methane, of course, is natural gas, which is a product that we can sell to customers, there can be cost recovery for captured gas. And so particularly to the extent that you're avoiding really large emissions, emissions from very large sources, a lot of those fixes can be very cost effective in terms of avoided lost product. But we don't have any particularly methods, I think, if that's what you're getting at for that specific question.

MR. NEWTON: And then just a point of clarification. You made reference to SB 1371 on the one slide in the context, I think, of abatement cost.

MR. BRADBURY: Oh, I mentioned in the context of the, I guess, pipeline transportation service and regulation by state PUCs and at the federal level. And so, yeah, California being, I think, the only state that has, at least now legislation and soon to be, I believe, regulation requiring not just reducing leaks for the purpose of not just improving safety, but also abating methane and GHG emissions.

MR. NEWTON: Okay. Yeah. Thanks for that clarification.

MR. BRADBURY: Sure.

MR. WESTERFIELD: Good morning. Bill Westerfield with the Sacramento Municipal Utility District here in Sacramento.

I noticed on one of your slides a reference to the midstream activities. Yeah. There may have been some extra funding from midstream activities at the federal level. I characterize midstream as that area of field after production and before the gas is put into the interstate system.

If that is your understanding, I guess my question is: Where is the jurisdictional reach of various federal agencies for that, I guess, upstream part of the production process? It’s not part of the interstate transportation system at that point. So I wonder which agencies really have jurisdiction? I assume EPA does, but I’m wondering what the nature of that is and whether there are any other federal agencies that can reach into that process to monitor the activities and the leaks that may be happening in those pipelines?

MR. BRADBURY: I don’t want to speak out of turn in terms of where the exact lines are of jurisdiction. Certainly, you know, I guess just to clarify, I think you had a question, when I said midstream I definitely should have clarified that. I think depending on where you sit in the value stream a lot of people of midstream as different things.

So really we're talking about the transportation of natural gas, including through gathering and boosting interstate transmission pipeline systems, and even within the distribution segment, as well, is basically the -- so that's using midstream pretty loosely, I suppose, in that sense.

But with that said, in terms of -- I think you're talking about gathering and boosting in between the wellhead and the processing plants. Certainly EPA, you know, from an air emissions standpoint has jurisdiction there. And the most recently finalized rules touch on that, facilities in that segment. I believe there are some reporting requirements to PHMSA and DOT associated with those pipelines for incidents. But only I think ten percent of those facilities actually do fall into the category where they actually have reporting requirements.

So there's a lot that we don't have a good handle on, I would say, in terms of the school of what infrastructure is even there and where it is. And so I think that's maybe a good starting point, is getting a better handle on where these facilities are and better characterizing them as emission sources. We've made progress but there's more to be done.

Any other questions? Thanks.

MS. KOZAWA: Thanks, James.

Before I introduce the next speaker I just -- not that you guys are going anywhere, but if the speakers for the first session could just stick around, we are getting some webcast questions, so we'll go ahead and do those at the end.

Our next speaker is Adam Brandt. Adam is an Assistant Professor of Energy Resources and Engineering and Center Fellow by courtesy at the Precourt Institute for Energy. He received his Masters of Science and PhD from the University of California Berkeley in Energy and Resources.

Adam?

MR. BRANDT: Great. Thanks, Kathleen.

Good to be here. Very excited to talk about what's been going on. This is a bit of a mixed presentation, a brief overview of many things we've got going on at Stanford. So happy to take questions via email. I'm easy to find if you want additional details on anything I'll talk about here.

I'll start out talking a little bit about a pretty unique and neat thing we've got going on at Stanford. So we have something going on for the last two years or so called the Natural Gas Initiative. It was started by Mark Zoback, who's down here in the picture, who is a geophysicist at Stanford. And he's interested in the use of gas, sustainable use of gas, use of gas to reduce environmental impacts from energy, and coal use, all sorts of issues.

So he said, okay, let's start this institute that brings together all the schools at Stanford, everyone at Stanford who's working on gas, so that we have sort of a unifying clearinghouse and sort of unifying initiative that can help, for example, people in law talk to people in economics, people in economics talk to people in the engineering. So in that way it's a pretty neat thing.

NGI looks at a whole bunch of things. In the background here there's a bunch of small text you can't read around six key areas. But there's three near-term focus points of the Natural Gas Initiative. And this may be of interest to the people in the room.

One focus area is methane leakage around technologies for detection and policies to spur improved use and utilization of detection technologies.

Two is really a more fundamental science initiative around GTL technologies, so developing better technologies to monetize stranded gas or associated gas that's not economic right now and is often flared.

And then the third is an interesting effort between, you know, basically the law business and economics around gas and energy poverty. So can gas be a solution to current energy development efforts, largely in Asia that mostly focused around using coal now, can gas play more of a role there? And that should be an interesting focus area.

Obviously we're, at this talk or at this symposium, focused on the first effort, so I'll talk more there. And Rob Jackson, who's also at Stanford and working with NGI, will also talk a little bit later.

Oh, we're cut off. Oh, okay, I have a different view here.

I sometimes like to start these talks with my summary of sort of the state of the science. And these are things that I think are pretty well established at this point.

One is that U.S. methane emissions have increased over the last ten years and are likely higher than suggested by EPA inventories. These are justified by various top-down studies that have been performed in the last five years or so. It's likely that some but not all of this excess methane is from natural gas and petroleum sources. A bunch of new studies, largely funded by EDF but others, as well, give some insights into sources. So it looks like well pads, gathering and processing, and distribution emissions may be smaller than we expected, but things like pneumatic devices, compressors, and super emitters may be higher contributors.

Fourth, it's pretty challenging to align top-down results with bottom-up inventories. So this has recently been illustrated by a paper in PNAS by the folks at EDF and others, trying to look at reconciling top-down and bottom-up measurements in the Barnett Shale. And they found that they needed to include large emitters in order to have those align.

Lastly, I think this has recently become more important, I think there's attention needed on liquids-rich places. So we've done recent work in the Bakken, and there's also been some work done by David Lyon at EDF, surveying via helicopter over many basins, seemed to suggest that leakage rates are high in places like Bakken and Eagleford where they're not necessarily primarily a natural gas place, but the gas is essentially a byproduct of liquids production, and these have shown pretty high leakage rates. So I think that's an area that needs increasing focus going on.

So that's sort of where we stand and my sort of best current summary.

So what questions remain then? If we, and I think we have, if we have increased or improved understanding of where the emissions are coming from, what do we need to do then? I'll talk about two sort of questions remaining today that are germane to the audience here.

One is a way to rigorously assess which technologies are going to be most effective at detecting emissions in terms of volumes detected and cost effectiveness of detection. And we've developed a simulation tool to do that.

Two is how do we include super emitters and the various new data streams that we've got in existing lifecycle estimates? You know, how do we basically -- how do we bring the knowledge that's been developed over the last couple of years into these tools that are often used in the regulatory realm.

First, how do we compare different detection technologies? This is a question that came to me about two years ago while working on a pre-proposal for RPE.

Everyone and their cousin has a detector technology idea. Why do I know that? Because I have a detector technology idea. When I have an idea it's a pretty bad situation. We've really reached the bottom of the barrel when Adam comes up with an idea. So I thought, oh my god, everyone has an idea. Many are proposed. How in the heck do we assess whether or not an idea is a good idea? How do we rigorously, fairly and cheaply compare different ideas? Should our detectors be higher sensitivity? Should they be more durable? Should they be cheaper? Should they be fast? Should they be labor free; right? What really matters in terms of making an effective detection technology? That's actually a really complicated question.

As I got to writing this proposal I realized I have no rigorous way to argue why my idea is better. Of course, I think my idea is better, but everyone thinks their idea is better. So we developed what we call a virtual training ground for technologies. Every virtual training ground or every model needs a good acronym, so ours is FEAST, the Fugitive Emissions Abatement Simulation Tool Kit. This is an open-source tool. We've actually posted the source code. Anyone can model it or update or use this tool.

So what does FEAST do?

First, you initialize an artificial gas field. Here on the left is a map of a test region we did in the Barnett play. You use things like well counts, distances, equipment counts and component counts. So you initialize this sort of artificial toy gas field. You then initialize a set of leaks. I've actually got a video here. I'm not sure if it can be clicked. It actually works. It's always risky to put a video in. This is a video, in the upper right, of a tank leak in the Bakken Formation taken from about 60 to 70 meters away with our Fligger camera (phonetic), so that’s a leak there. And we initialize these links and we begin to simulate them. So down below in the lower right is just a simple gaussion plume model of what this kind of leak might look like to a simulator.

We then include, using best information from the literature, probabilities of leak generation to add and subtract leaks over time. So we have a daily model that updates with a two-state Markov model. Basically, there are probabilities of leaks being generated or leaks being fixed on any given day. And this includes a background repair rate.

So basically, on a daily basis this model iterates through all the components, creates leaks, fixes leaks. We then simulate, as stated intervals, various detection technologies and estimate given wind speeds that are drawn from realistic wind distributions, given distances, given other parameters of a detection technology, which of these plumes that we simulate when we simulate a gaussion plume for every leak, which of them would actually be found?

We can do things like test frequency of surveys, test the sensitivity of detectors, test leak size distribution. So what if you have super emitters, how effective is the technology? What if you don’t have super emitters, how effective is it? So we simulate on a daily basis if any detector technology is applied and if any leaks are found.

We can then compare technologies and basically create a time series of what might happen. So on the left we have a time series plot of ten years, 3,600 days of operation. The top line is a no repair case, no natural repairs, so leaks are only created. There's no natural process by which operators find and repair leaks.

The next line down is a purple one. That's what we call our Nowell (phonetic) case in which the rate of leak generation and the rates of leaks being fixed in the absence of an ODAR (phonetic) program are approximately equal, so you get this sort of stochastic kind of random walk around a steady state in purple.

The four lines below are the lines realized when you apply four different candidate technologies that we've really just sort of sketched up, including AIR which is an automated airborne infrared system, distributed detectors, so these are sniffers that you place around, a manual IR, and flame ionization detector. Once we get these ten-year simulation trace for our artificial yet statistically representative gas field, we can estimate over this ten-year period, what's the MPV associated with each of these detector programs.

An interesting result from this was that our most expensive technology, the automated airborne infrared sensor, was actually the most cost effective because it was very fast. If you use reasonable flight times, it's very fast and very labor efficient. And so what's pretty interesting is that there's a sharp distinction between cheap detectors and cheap detection, okay? Cheap detectors and cheap detection are not the same thing. And, in fact, the cheapest detection may come from, if there's some sort of satellite of high altitude observation, it could be an extremely sophisticated sensor, extremely expensive, but the thing could serve a huge number of wells per day; right? And so that's the in-member of cheap detectors don't equal cheap detection, okay, especially when labor costs are involved.

Next we're working with my post doc, Arvind Ravikumar, who's in the audience here and is doing a lot of the hard work here. We're trying to use this model and extend it to say, how can we study the effectiveness of proposed regulations? So now that we have this simulator, can we say what's a good detection strategy?

The EPA's proposed methane rules in August of last year requires optical gas imaging on a semiannual basis to start with a fix of found leaks within 15 days, and a frequency change; surveys become more frequent if problems arise, if problems arise or problems are found.

We can ask how well, again, as an artificial but statistically representative gas field, how well does this regulatory format or regulatory structure perform against some other structure, let's say monthly surveys, yearly surveys? Let's say don't use optical gas imaging, use a sensor, cheap sensors mounted on the fence line; right? So how do we actually think about whether or not this regulation is effective or not?

On the right here, these are some initial results not peer reviewed yet. Everything before that was peer reviewed. We were just showing some initial results and we show here the average total leakage rate over a ten-year period associated with different LDAR designs using optical gas imaging. And you can see each stacked bar chart shows the variation with survey frequency, quarterly, half yearly and yearly. And across the X axis you can see how that changes with distance. An interesting thing here is that distance, the distance from which you survey leaks is actually more important than the survey frequency, giving the stochastic process that we modeled that's being generated. So this would suggest that it's quite important that you get up close and see things.

That plume I showed you, my student is doing repeated surveys of 150 wells in the Bakken. You can see plumes in the Bakken from up to 150 meters away. That doesn't mean that that's a good idea for a survey design;

right? It doesn't mean that you should necessarily, for example, drive by on the road and just sort of hold the camera out the window. And, in fact, you'll be more effective if you get up close.

So those are the types of questions. Again, that's just an illustrative tentative result, but these are the types of questions we can ask with this tool. We can say, hey, how do we actually think about, in a statistically representative way, designing a good LDAR program.

We've got a paper that we're submitting this week, Arvind, we're submitting it this week. I've now said it in front of 200 people, so it's going to happen, of course. We've done some experimental verification of our IR camera simulator. So Arvind is a physicist by training and rebuilt our camera simulator from the ground up.

We've collaborated with a wonderful group of folks at Kairos Aerospace, a startup in the Bay Area. They got permitted and paid for some extremely vigorous controlled releases that you can see here on the right. We took our camera out, we flew in airplanes, they flew in airplanes. We imaged from the ground 10 different leak grades, 10 different distances up to 100 meters away. You can see on the left, that's the image from our camera. You can see in the middle, that's actually an image processing methodology called optical flow analysis which basically tracks pixel velocities. And then from that, on the right, we can create a binary representation of the plume.

We're actually -- through this controlled release we basically have verified the simulation tool that Arvind has built, and we verified that this, Arvind's camera simulator, basically simulates what an IR image will look like within a range of error of 10 to 20 percent, okay? So we're actually doing, you know, experimental verification of this simulation tool.

So, okay, so this is the sort of endpoint of this simulation tool is we're publishing soon on this model verification and controlled release study. We're going to be moving into studying regulatory design and thinking about how do we think rigorously about good policy design and good technology implementation.

Moving forward, we've got a project that we're excited about that's just now starting, so happy to announce this. We're just getting approval to work with the Air Resources Board. And we're going to build super emitters and build this new data available on leak size distributions and leak frequencies and component failure rates into lifecycle analysis tools. And so we're going to use -- basically, we're going to adopt or adapt our, what's called OPGEE model that we've developed over the past three of four years with ARB support which right now focuses on oil production emissions. And we're going to basically extend that to include gas sector or dry gas production emissions. We're going to include a much better dataset on fugitive emissions and super emitters. And we're going to be able to look at how these super emitters effect lifecycle choices such as electric vehicles, CNG vehicles, all these sorts of choices. That's a fun project that we're just getting started on. So this will be very helpful for California's efforts in trying to assess natural gas spaced pathways rigorously, compared to things like biofuels or electric vehicles.

That's a just quick overview of everything we've got at Stanford. As I said, feel free to get in touch. I'm easy to find if you want to talk about any of these ideas.

(Applause.)

MS. KOZAWA: Any questions for Adam?

MR. BRANDT: I'm a professor. I'm used to waiting you guys out. I'll just stand here and stare at you until somebody comes up with a question.

MR. MARSALEK: Lucas Marsalek, SCS Engineers.

Have you run that model on the final NSPS rule?

MR. BRANDT: Arvind is working on that as we speak.

MR. MARSALEK: Okay.

MR. BRANDT: Yeah.

MR. MARSALEK: That will be interesting.

MR. BRANDT: So that EPA project is really, I mean literally, starting as we speak. We need to get the simulation verification and controlled release paper out the door. And then the EPA work starts in earnest.

MR. MARSALEK: Just curious. Thank you.

MR. BRANDT: That's going to be one of the goals, though.

MR. RHODES: Yeah. I'm Wiley Rhodes with Newpoint.

And my question concerns natural gas liquids. And under pressure natural gas liquids holds a large quantity of methane. And I was wondering, I noticed on the images that you had, the majority of those coming out of the tops of the tanks are natural gas liquids.

MR. BRANDT: Yeah.

MR. RHODES: And is there anybody that's looking and tracking that specifically?

MR. BRANDT: Yeah. So that's a question of very active interest in our group. And I know EDF is very interested, as well. The new paper from David Lyon, EDF spent a great sum of money flying helicopters over, I think 8,000 well pads, was that right, across the country, ten different plays or something like this. Eagleford and Bakken came up very high on percentage of pads with a leak, 10 percent, 12 percent, 13 percent of pads had an observable leak.

A couple of things going on there. These are -- they look like they're flashing emissions from condensate tanks. Stuff is dumped in there from a medium or high pressure separator, flashes, you've got these headspace vapors that come off. One of the interesting things in Arvind's detailed physics simulation of this -- of these IR cameras using these detailed line spectral analysis of basically absorption of infrared light suggests that gases that are enriched in propane and other higher carbon number hydrocarbons actually basically have more resident modes that will absorb these photons. And so they're actually more strongly absorbed.

So it could be -- and we show that rigorously with this simulation -- it could be that part of what's going on at these condensate tanks is they're showing up more because of this increased mole fraction of things like propane which are very actively -- very active in this portion of the spectrum and very easily seen. It's likely that the minimum detection limit for a rich gas stream like that is at least three times lower than like a pure methane stream. And our simulation results suggest that David Lyon's results from the air seem to suggest that. We've done surveys of -- he did surveys in the Bakken that seem to suggest that, as well, so that's an issue. And actually, some good work by Jeff Peischl and others who may be here has shown high ethane in some of these.

(Off mike colloquy.)

MR. BRANDT: Okay. Sorry. Yeah.

MR. O'CONNOR: Hi, Adam, this is Tim O'Connor from Environmental Defense Fund.

MR. BRANDT: Hi, Tim.

MR. O'CONNOR: You talked a little bit about the super emitters issue and started to focus on that.

MR. BRANDT: Yeah.

MR. O'CONNOR: In any of your work have you figured out how to predict the regulatory with which super emitters might occur, where they're located? There's been a lot of discussion about the only way to actually control for them is just to have regularized inspections.

What do you think about that in terms of the effectiveness of inspection regimes for taking care of the super emitter issue?

MR. BRANDT: Yeah. So, actually, James is funding some work that I'm working on with folks at National Renewable Energy Lab in Colorado State on super emitters. We have a new super emitters paper coming out with an extreme values statistician on it, so that's coming soon. Send me an email and I can get you on that as soon as possible. We're in revisions right now.

Beyond that, our work in the Bakken with -- we're -- for the first time my student is visiting every 15 days. He flies to North Dakota and visits the same 70 wells over and over and over and over again. And it is extremely stochastic, very random. So these things are flipping on and off and it's very -- they appear to be happening in some cases repeatedly at the same piece of equipment, but it's very random as to what's happening on a day-to-day basis. And so Ramon, actually, could probably -- he's probably got more on-the-ground experience. But, yeah, it's a very challenging thing.

I would be skeptical if somebody said they could predict when these would happen, I guess, is the short version of that.

So that does seem to suggest, go out every three months, go out every six months, because good luck if you're trying to predict these things.

MR. ZENG: Yousheng Zeng with Providence. I have a question for you.

During the time when EPA was working on that turn to work practice they did some Monte Carlo simulation to determine the equivalency of different monitoring durations and all that. Does you model have any kind of relationship to that type of simulation?

MR. BRANDT: That’s a good question.

This is something that we should look into, Arvind. I’m not sure if we’ve looked into modeling their Monte Carlo method. In some ways it would likely be very similar. I don’t know exactly what they did, but we’ll look into that.

Thanks, everyone.

MS. KOZAWA: Thanks, Adam.

(Applause.)

MS. KOZAWA: I do have a couple of questions from the web. And one is directed to Jorn, but I think if anybody, any of the speakers has any thoughts about it, we do have a few minutes to address those two.

So first, Jorn, on the JPL flyover scheduled for later this year, the speaker said perhaps 5,000 high emitting sources will be identified. How definitive will the flyover locate a found source? In other words, if an elevated methane level is detected will the flight know exactly where the source is to the nearest meter?

MR. HERNER: Yeah. So the resolution of the survey will be one meter by one meter, pretty close. In certain instances and in certain type of infrastructure you do need more specifics than that, and that’s when we’re hoping to be able to go out and visit and see whether or not a specific flange or piece of piping or what exactly it is.

But the survey is supposedly accurate down to one meter by one meter.

MS. KOZAWA: Okay. Thank you. And the second question, and you can start, Jorn, and whoever else may want to chime in, what about the use of drones for methane detection? And we are going to have a presentation about this later today, but maybe you have something to say about it. And how accurate is it and what are the cost savings?

MR. HERNER: Well, I can’t speak to that. I can only say that I hope that we get drones soon because that would be a wonderful way to do a lot of inspections very quickly and easily. I know ARPA-E is looking at some of those. And so I think they’re coming, and I’m hoping that we’ll be able to use them.

MR. BRANDT: Just some results from our simulation. We found that we put in a very expensive drone. I think we cost it out at $250,000 with a ten percent yearly operations and maintenance budget. And it still ended up being cheaper because -- the short version is that people are expensive and if a drone is fast, oil field workers are expensive, that’s the short version. To get out of these technologies however possible, drones can be pretty expensive, and they’re still better than having somebody drive around. Okay.

MS. KOZAWA: Okay. Thank you. And so I think that's it for our questions from the web, for now.

Are there any additional questions from the audience before we go on a ten minute break? Okay. See you in ten minutes.

(Off the record at 10:03 a.m.)

(On the record at 10:21 a.m.)

MS. KOZAWA: Yes, and we are on, yes. I'll get started again.

If the leak surveys in the Bakken that you mentioned showed total random leak populations when those 70 wells are visited repeatedly, why does this suggest a more frequent LDAR is better?

MR. BRANDT: Good question. So let me actually clarify what we've found so far in this. We have six months of surveys on one population of wells and three months of surveys on another population. They were chosen slightly differently, using different sampling methodologies.

Day-to-day variability and detection, some of this is detection randomness in wind direction and temperatures and things like this is like 30 percent. So you just have this factor of sort of 30 percent randomness on a day-to-day basis.

THE REPORTER: You need to speak into the microphone.

MR. BRANDT: Yeah. Sorry.

There is persistence from survey to survey. So if you go to a facility and you go back in 15 days, that aspect is not random. You will see a selection of leaks that appear to be different from randomly selected over a 15-day period, over a 30-day period, over -- but there's seemingly now way that we can explain why things flip on and off on a day-to-day basis, but the event sort of random factor is, or even ahead of time how you might predict which of these might be high emitters versus low.

But there is persistence over time. I didn't want to -- I was speaking too quickly.

(Colloquy)

MR. BRANDT: So I hope that helps. This should be -- Rob is a coauthor on this paper. This should be out, hopefully, reasonably soon.

MS. KOZAWA: Thanks, Adam.

Also, just an announcement. We do have -- because this is a work shop for CEC, we do have a Court Reporter, Peter. If you are going to be making a comment or a question, it would be great if you can go ahead to see him and give him your business card. This way he can make sure he transcribes everything in the record correctly. So there's Peter. Please give him your card if you have a question or you have a comment.

Now I'll turn it over to Laurie ten Hope at CEC.

MS. TEN HOPE: Good morning. I'm Laurie ten Hope. I'm the Deputy Director of Research at the Energy Commission. And our next panel is going to extend before and after lunch. We'll have four speakers before and four speakers after. And this session is on methane emission and measurement, sort of what's the state of the science and what's some of the active research in this area.

Our first speaker to provide background on the California methane inventory and needs and gaps is Anny Huang. And she's the Manager of the Air Resources Board Greenhouse Gas Emission Inventory and Analysis Section. She oversees the development of California's greenhouse gas inventory and leads a technical team that conducts routine and special data analysis to support a variety of climate and energy programs. She has a PhD in Environmental Engineering and Public Policy from Carnegie Mellon, and has industry experience prior to the Air Board. Please welcome Anny.

MS. HUANG: Thank you for the introduction, Laurie.

I just click the red button? Oh, okay. Great. All right.

Good morning, everybody. Yes, that works. Okay.

So I will start out with a brief introduction of greenhouse gas inventory before I go into specifically methane part of it.

So in 2006 AB 1803 gave ARB the responsibility to develop and maintain greenhouse gas inventories for the state of California. We built on the good work from our sister agency, the Energy Commission. We expanded the inventory category since 2006.

So the inventory followed the IPCC guidelines for national inventory development. And the reason why it's very important for California to follow the IPCC guidelines is because having consistencies and comparability with the other national inventory is important for us in terms of having this international dialogue with other jurisdictions.

So the inventory quantify emissions from insubordinate sources. Now they are natural sources of methane, but that is not a focus of our greenhouse gas inventory. We do focus on anthropogenic sources. So the inventory is not supposed to capture everything under the son that you can pick up from the atmosphere.

So later in 2006, AB 32 passed. It provided additional instruction for the greenhouse gas inventory compilation. It explicitly named seven greenhouse gases, so these other six (indiscernible) protocol gases, plus nitrogen triflouride was added in 2009. And it also specified that California shall include the imported electricity greenhouse gas emissions, and this goes beyond the typical boundary of IPCC inventory which kind of ends at our national border. In California, we do go beyond California borders, including importing electricity in our inventory. And AB 32 also instructed ARB to establish the historical baseline, the 1990 emission level which becomes our 2020 emission limits that we will have to meet in a few years.

So this is an overview of our greenhouse gas inventory. This is our current inventory that is on the website right now. And it is based on IPCC fourth assessment report, 100-year GWP. And I know many people have asked the question, why are we still using fourth assessment and 100-year GWP? How come we're not using 20-year? How come we're not using fifth assessment?

And the answer is this, IPCC's national greenhouse gas inventory, right now they are using the fourth assessment 100-year GWP. And again, this is important for California to have consistency. That's why the official greenhouse gas inventory is still using fourth assessment 100-year GWP.

So this shows the 2013 emissions in front of our 2015 edition of the greenhouse gas inventory. The 2016 addition is in the works. It's being currently reviewed right now, and hopefully it will be published soon.

So looking at this pie chart we see that over 80 percent of emissions are Co2. And methane accounted for only nine percent. If you use a 20-year GWP, methane is much larger. Actually, the percentage-wise is twice that shown in this pie chart. And currently our 2013 emission is at 459.

So just a really brief overview of the quantification method. We use a variety, a large variety of different methodologies to quantify emissions for many different sources. Now over 80 percent of the emissions in the inventory are mostly Co2. And these Co2 emissions, we are very confident about. They are subject to a five percent accuracy standard, and these are well known. So most of the emissions' inventory come from these two methods. So we've got the direct emissions' measurements, so these are CEMS, and with Co2 monitor, and some high emitting facilities. So these include refineries and hydrogen production plants, cement plants, and some power plants. And these are measured pretty accurately. And most of the emissions come from direct fuel measurements, so these are fuel-based emissions calculation method.

Fuel use is tracked through our mandatory Greenhouse Gas Reporting Program, our MLR, and also other state and federal agencies such as DOE, CEC, and EIA. So these fuel use quantities are measured so we know what they are. And with the fuel use quantity, then we'll use emissions factor, heat content, and also carbon content which may be either default emission factor that is commonly used, or it could be source-specific factors that's measured periodically by fuel assembling (phonetic). And so this carbon content which determine how much emissions coming out of how much fuel was burned, it is pretty well known. And it is subject to a five percent accuracy under our mandatory reporting program, so we do have a very high confidence level for these emissions. So uncertainty is pretty low.

So we contrast that, the Co2 emission from the fuel-based method, with methane. And first of all, we start off with an overview of the methane inventory. Again, the pie chart is showing 100-year GWP fourth assessment report. And currently methane is 41 million metric ton. And if you are looking at 20-year GWP, it is 118 million metric ton.

So earlier Kathleen showed a pie chart in her presentation that showed the U.S. national methane inventory. And oil and gas is actually a pretty big piece of the pie. And livestock is not as big.

But California's picture is different. In California the agriculture, specifically livestock interior fermentation and manure management, is the largest piece of the pie. It's almost 60 percent. And oil and gas and pipelines, they account for -- together account for earning

15 percent. So it's actually not that big compared to the other methane sources. And benthane was another big one, it's 20 percent. And we also have other emission sources.

So the challenge with methane emission quantification using bottom-up inventory methodologies that these are not combustion sources, they're not directly measured. And in a sense they are kind of like Whack-A-Mole. You know, they are based on biological processes. And sometimes you pop up here, you pop up there, and you're looking at this today and the next day it may be different. And sometimes it rains and you got a lot of emissions. And sometimes cows eat different food and they got different emissions. So it is actually a big challenge.

So these are -- so we have been basing our emission estimation method on modeled or default emission factors and on estimation of activity data from different data source agencies, and also model emissions using models. And a lot of these models are based on indirect factors that go into some kind of equation that can calculate or estimate emissions such as nutrient content, the livestock feed, or the amount and type of waste that goes into the landfill and buried there. And sometimes source tests may be used to determine emission factors that can represent source for -- the source tie for a single for like a group of sources that have similar processes. So methane emissions generally have higher uncertainty. And this is something that we know of, and we're interesting in refining our emission estimation in the inventory to make it more accurate and to reduce our uncertainty level.

So currently this is an overview of the inventory method for methane sources that's currently in the greenhouse gas inventory. So for the oil and gas and TND sector, we are basing our estimation based on two comprehensive ARB surveys that collected 2007 data. And this ARB survey is the most complete, most comprehensive and most detailed dataset that is available out there, that's why we've been using this.

So for the time series of emissions we use surrogate data and surrogate parameter, and we estimate the time series of emissions by mapping the trends in the surrogate data derived from the ARB survey to produce the time series of emissions. And the surrogate data that we use for production comes from USEPA's national inventory, and for transmission it comes from PHMSA, and for distribution we use residential housing unit data.

The drawback of this methodology approach, you know, in the absence of a better method that can produce a time series is that if there have been emission reduction measures that have been implemented, either by the company or by regulation, we are basically assuming that the emission rate, emission factor has not changed in the studies over the years, and it doesn't reflect those changes. So this is one area that we'll be looking at in the next few years to refine our estimation in the inventory.

Now just quickly on the other sources of methane, for landfill we've been using the First-Order Decay Model. This is IPCC methodology. And we have been using CalRecycle's waste deposition inventory, and also their Waste Characterization Study. To input into the equations behind the model we used various parameters, that's a common practice used by EPA, CEC and IPCC, such as carbon content and waste degradation factor.

And for the wastewater sector we are basically just using the standard textbook equation to calculate methane emissions for wastewater. For domestic wastewater we use USEPA's estimation of parameters and the emission factors. And for industrial wastewater the parameter that we enter, we put into the equation for refineries, we use CEC production data, and for agriculture processing we use data from CDFA and USDA. And for other industrial sources we actually use our total organic gas information from our criteria pollutant inventory, and we do that to speciate (phonetic) that to methane, and that's how we estimate those emissions.

And for dairy livestock, we have been relying on USEPA's model for interior fermentation and manure management. Some parameter going to the equation, going to the model include animal age and animal type and what kind of feed they eat, and also the waste type, and also manure management practices.

So the greenhouse gas inventory, every year we compile a new addition of inventory. It is a pretty long process. It takes about seven to eight months every year. And between the inventory compilation cycle we will review our inventory and then identify areas where we could improve on.

So every year we do some routine method and data updates. And some of these routine updates include we would use improved emissions estimation methodology that have been recently developed, and we will update the activity data, and also emission factors that have been recently made available by the data source agencies and other agencies. And we will incorporate our latest knowledge about emission sources that we have learned since the previous inventory addition. And we will also modify inventory categorization in response to program needs to better support different programs. So these routine changes, although they might change the numbers, the emissions numbers, but they don't actually change the scope of the inventory.

So in accordance to the IPCC guidelines which instruct nations to calculate emissions for the entire time series to make sure that we have consistency so we don't have, you know, the first few years of using this method and the other few years use another method. So IPCC's guideline, we have to recalculate emissions for the entire time series from 2000 to the current year. And so because of this, and we do follow this guideline.

And because of this, sometimes when the data source agency updates their statistical data, or if a methodology has been updated using a better method, and you'll see that the emissions from older years might change compared to previous additions to the inventory. And this is consistent with the international standard for greenhouse gas inventory.

So ARB's Oil and Gas Branch under Elizabeth's leadership, they have been busy doing a lot of work. And so the recent development in the oil and gas regulations can lead to several inventory improvements that we're looking for to potentially update the inventory in the future. So we now have better information about high emitter components. So the future emissions estimation for these components can be updated to account for the high emitter. And for large reciprocating and centrifugal compressor emission, previously we have been using equipment counts multiplied by a default emission factor. And now we have actual data for these sources, found operators that we could use to refine our estimation.

And for separator and tank emissions, there has been more comprehensive methods developed as a part of the regulation that we can also refine our estimation.

The anticipated time frame is that our oil and gas regulation process will be completed by mid-2017. So using the updated information, we'll be able to update our 2018 edition for the greenhouse gas inventory covering 2000 to 2016 emissions.

And on the transmission and distribution side of it, so we have SB 1371 which reduces the methane from this T&D sector. Under SB 1371, gas utilities, they submit annual reports on emissions and leak management practices. And whenever possible we will use a higher tier methodology. And so as a part of 1371, instead of using length of pipeline which is what we're currently using in our inventory, using length of pipeline multiplied by USEPA default emission factor, now we'll be able to estimate emissions based on number of leaks or California-specific emission factor. And also under this reporting we also track number of open leaks. So these are all additional information that we could use to refine our greenhouse gas inventory.

So there is a couple of ARB funded studies that's in the works right now. GTI is under a contract with ARB to study, to come out -- to develop California-specific emission factors for T&D and, if appropriate, we'll be able to use the California-specific factor, instead of USEPA's default factor, in the future. So this project has recently been completed and it's currently under review. And, in fact, I think later on in this plenary session they do have a presentation, so we'll hear more about that. And then we also have a customer meter study that's being proposed.

And if you have more questions, I will point to -- I will point the question to Elizabeth for answering. All right.

So other than those emission sources that area already in the inventory that we are looking forward to refining, there are some methane sources out there that still need additional data and method development. So these are sources that's not in the inventory yet. So we have residential appliances' leaks.

Preliminary results from CEC funded study conducted by Lawrence Berkeley National Lab. And I don't know whether Marc Fischer is here. That's Marc Fischer. So some preliminary results from Marc Fischer suggest that this emission might be substantial. So this currently is a project going on. So, again, Marc Fischer will be here this afternoon. I’m sure we’ll hear more about that.

Then abandoned and gas well, this may be significant, but currently we have little or no data available at this time. So we are interested in getting more data to help us understand this source better. And we know that, you know, there’s a lot of abandoned wells out there.

And the next one is petroleum seeps. This is a natural source. And existing estimate for petroleum seep is based on local air district information that is not comprehensive and may be outdated, and we know there are thousands of seeps throughout California. And again, our current estimation is pretty rough and we are looking for different ways to refine this estimation.

And for wetland methane, again, this is a natural source. And currently there is some international dialogue with IPCC and USEPA on developing quantification methods. We will be following that development to see what methane comes out of it, and we’ll consider putting that in the inventory or quantify those emissions.

And we also have methane released from water bodies. And currently, again, we have little or no data available. But what is out there right now does suggest that the methane dissolved in the water can be released when the water is disturbed. And some of the potential sources might include hydropower water discharge, reservoir water releases, water bodies, lakes and ponds, and also near-shore ocean upwelling. So again, some of these are natural sources. These are sources that potentially may be methane sources, but we have little information.

So last slide, so future work for improving the methane inventory, so for sources that are already in the inventory, we will continue to update the data used for emission calculations based on the data's available information coming out of the data source agencies. And we will continue to refine emission estimation methods based on the new research and the studies that are coming out from the academics, and also different groups. And we will also look for ways to account for the benefits of emission reduction measurements going into the future.

And for sources that are not already in the inventory, we will continue to look for potential data sources, and also potential methods to do these emission quantifications. And we will also continue the dialogues among stakeholders and research community on, you know, how to have a better handle of those.

And there are many interesting research and studies by academics and nonprofit groups, and also industry. And so following my presentation there's a more interesting presentation about these methane sources. And we're looking forward to working with the stakeholders and work with the researchers to further refine our greenhouse gas inventory.

And that's it.

(Applause.)

MS. TEN HOPE: We can take a question or two. And I'd also ask the other panelists if they wouldn't mind joining us up here, Ramon, Christie and Rob.

MR. FISCHER: Good morning.

MS. HUANG: Hi.

MR. FISCHER: Very good.

MS. HUANG: Hi. Yes.

MR. FISCHER: Hi, yes, I am here.

MS. HUANG: Yes.

MR. FISCHER: Thank you for --

MS. HUANG: I didn't see you over there.

MR. FISCHER: -- mentioning the work on appliances.

MS. HUANG: Hi. Good morning.

MR. FISCHER: I'm really curious whether your group is starting to -- you want me to hold it -- starting to consider including uncertainty estimates in the inventory along some of the same lines that USEPA now engages in?

MS. HUANG: Okay. Yeah. So for the 2020 limit, there's no uncertainty around it, first of all. So you're right. So uncertainty estimation is something that we have not spent a lot of effort on, but it could be something that we need to look at in the future. But regardless, when we got to 2020 there's no uncertainty associated with it, we meet it or not, 431 is 431. So we cannot really argue whether we're at 431.5, whether we meet 2020 limit or not. So there is a little bit of complication behind that. But, yes, that is something that we have not done much, uh-huh, I acknowledge that. Yeah. Okay.

MS. TEN HOPE: Any other questions?

MS. HUANG: Okay.

MS. TEN HOPE: Thank you.

MS. HUANG: All right. Thanks.

MS. TEN HOPE: Okay, our next speaker is Ramon Alvarez. Ramon is the Lead Senior Scientist at EDF. Since 2008 he's been working on better characterization of air emissions from oil and natural gas operations. He has a B.S. in Chemistry from Duke University, and a PhD from the University of California at Berkeley. He's going to share comprehensive studies on what we're learning in this whole topic.

MR. ALVAREZ: Thank you and good morning, everyone. It's good be back in California again. I gave a talk about a year ago at the California Energy Commission and it covered a lot of the work that had been done through

Environmental Defense Fund-sponsored studies up to that point. So I’m going to talk about really what’s come since then. And available to talk more in detail afterward with anyone who’s interested.

To start, let me just reemphasize the importance of methane. I think we’ve heard a couple of good summaries. But as a reminder, because of methane’s short-term climate impacts it is causing about a quarter of the radiated forcing or the heat absorption of chemicals in the atmosphere today. Certainly for long-term mitigation of climate change we need to address the carbon dioxide problem. But there’s a real opportunity to make short-term progress by dealing with this very potent greenhouse gas that’s accounting for a quarter of our total greenhouse warming today.

About four or five years ago Environmental Defense Fund began a series of studies to try to understand better how much methane was being admitted from the natural gas supply chain. The project has sort of taken the form of 16 discrete projects. And we’ve worked with a variety of partners in academia, in the research community, in industry, totaling over 100. These projects had five common principles, that they would be led by academic experts, published in peer review journals, looking for outside input in the design and analysis of the data, and looking for multiple methodologies to try to make sure that the results we were getting were robust. And one final thing, that all of the results would be made public to ensure transparency and to provide sort of that knowledge for others to act on.

So far there's been 27 papers that have been published. As of last year when I gave this talk the bottom half of the table had not been published yet. I'm going to talk about the bottom half then today, starting with the Barnett Shale campaign that's in a place in Texas, and then some more recent work at the bottom.

Just by way of acknowledgment, this work, while EDF has sort of catalyzed this work with seed funding and sort of organizing, sort of convening the work, this would not be possible without a lot of the research experts that we worked with and the different universities. And for some of the studies, also, the industrial partners that allowed access to their facilities and provided other data to make this information possible.

Starting from the top, I want to make a distinction here that's important and I think sort of one of the sort of most interesting topics, subtopics in this area, which is the persistent difference between results that you get from top-down studies and results that you get from bottom-up studies. And what I mean by that, just to make sure we're all using similar terminology, for top-down, it literally is kind of top-down in the sense that you're making measurements, atmospheric measurements, sometimes from the air, sometimes from space. But they could also include -- sometimes people will define facility-level measurements made downwind as top-down. And in this case I'm calling anything that's facility or component specific as bottom-up, and anything that's sort of atmospheric-based measurements at the regional and larger levels top-down.

So I'm going to have sort of four sort of sections of this presentation. And it's hard to cover, again, everything that we've done, so I'm going to just focus on some things that have particular relevance for the things going on in California, starting with the Barnett Shale campaign. And the reason I'm bringing I'm bringing this up is because it represents the first time that we were aware of where an effort to make atmospheric measurements, top-down measurements using an aircraft of basin-level emissions, were able to be reconciled with estimates based on a bottom-up kind of inventory construction. And it turned out that that inventory that we constructed was almost twice as high as what you would expect from the national greenhouse gas inventory. And so I just wanted to sort of highlight some of the things that caused this to work out.

To start with, the top-down measurements were done by a group led out of NOAA. Colm Sweeney is here today. He'll talk about these results, as well as others, sort of the technique. But this figure shows you the Barnett Shale area in the shaded colors. The core counties are in the darker color in the middle, eight counties that account for most of the production activity there. And the different polygons that are there show you the estimated source regions that they sampled on each of seven or eight different flights during March and October 2013.

From these flights they were able to come up with an independent estimate of total methane emitted in the region. They were also using an ethane analyzer to be able to use it as a fingerprint to identify the methane that came from fossil sources. And so they came up with a total methane estimate from oil and gas sources, and a total methane estimate from all sources in the region. About 80 percent was from fossil sources, as you would expect from a region heavy in natural gas production.

So this summarizes the top-down results. The blue circles represent the seven different days that were reported. The triangles, the orange triangles represent our bottom-up estimate for each of those days. Using the source regions that are shown in those polygons, sort of, we grid it and we estimated the emissions. And those specific areas you get these results, and they vary from day to day, both the top-down and the bottom-up. But on the top line you can see the average was in very good agreement. And this was the first time that this had been reported, this agreement between the top-down and the bottom-up.

And as I mentioned, the bottom-up, which was produced in these papers, is on the right side there. What you would get from the greenhouse gas inventory of that time is on the left side. And I want to call your attention to the two biggest differences being the bottom two sections, the blue and the red, the blue being the production, gas production, and the red being gas gathering. And I'm going to talk about sort of the reasons for that big difference there in those two categories.

Well, the first reason was -- for gathering, the reason that it's so small in the EPA's greenhouse gas inventory is largely due to the omission of facilities that are quite prevalent in the field. There was one of the studies that was done out of Colorado State that looked at gathering facilities nationally. They estimated something like 4,500 facilities around the country. The greenhouse gas inventory had a nominal number of like 12 large compressor stations that were associated with gas gathering.

So somehow these facilities had sort of slipped through the cracks of inventories. They were either nonexistent at the time of the original surveys in the 1990s or just were missed. But a very significant source of emissions nationally. And if you're sampling a heavy production area you're going to see these kinds of facilities, and they all have significant emissions. Emissions for facilities, which basically gather gas from multiple wells, compress it, sometimes they do some dehydration, and then send it on down to processing plants or transmission pipelines. They're very similar in many ways to the emissions from large transmission and storage compressor stations. So a large number of facilities, large emissions missing. So getting a good count of facilities is an indispensable start towards an inventory. You've got to have good facility counts.

The second big reason has to do with what you've already heard about today, which is the nature of facility distributions being skewed. It seems to be, you know, a ubiquitous phenomenon on this field. And sometimes people say, well, that's the effect of super emitters. I think we should always be cautious about the definitions of what's a super emitter and what's a fat tail. But I'm going to focus on the fat tail here, talk a little more about super emitters later.

But the point is that when you account for the influence of the fat tail on the average emission factor of a typical facility you can get a result that you see here.

Like, for example, look at the well pads. These are the production sites. If you account for the full effect of the highest emitting facilities, the very fat tail of the distribution, using a statistical estimate method that we presented in the synthesis paper for the campaign, you get a result that's about twice as large, 1.8 kilograms per hour per site, compared to the simple average of a systematic sample that was taken at facilities in the region. And so there's some behavior that is not captured by the simple average. And it really has to do with capturing the proper influence of that tail. And to do that, you know, essentially you have to use some kind of a distribution that accounts for facilities, even higher than what's already in the measured distribution. And so when you do that you get much higher emissions from these facilities. And you can then get -- if you get the facility counts right, you get the emissions right, you can get this agreement.

So I just want to make a call-out here. Chris Rella from Picarro is here. His data was the systematic sample for production sites that was used in this work. That's a critical component. You have to know how many facilities you measured, including the ones that had emissions that were below the detection limit. In total they produced about 180 sites that had either zeros or detected emissions. It turned out they had a couple of high emitting facilities that sort of started to define the shape of that distribution. And it turned out that that data set by itself actually could produce a pretty reasonable estimate of the emissions in the region when you do the mathematical fit to the data, as opposed to just taking the simple average.

So critical that you have a sampling that gets the zeros and gets the tail, and then critical that you have a methodology, a mathematical method to really account for that full distribution in the analysis.

So takeaway from this, I think for California, I saw that there's some future work going on here to sort of do campaigns in various regions of the state to characterize emissions. You know, a well-designed top-down campaign or a well-designed bottom-up campaign has the potential to get you a good regional estimate of total emissions. If you have them back, that sort of then provides independent checks on them, so that's even better.

And then secondary, the fact that the EPA greenhouse gas inventory, as many people have reported before, underestimates emissions in the case of the Barnett, largely because of the production and gathering.

The second study that I'm going to talk about is a helicopter survey of 8,000 well sites around the country, looking at what we call high emitting sources. And infrared camera mounted on a helicopter is only going to see emissions of a fairly large amount. They took out the -- the detection limit is about one to three grams per second. As Adam Brandt mentioned, the cameras are sensitive to some hydrocarbons more than others. That's we have this one to three gram per second range. If you're seeing things with heavier hydrocarbons you would have a lower detection limit. But these are pretty significant emissions, 25 to 100 tons per year from a single source, just to give it some scale.

This is an example of what you see. Tanks accounted for 90 percent of total observations. So again, the highest emitting sources at natural gas production sites, tanks accounted for 90 percent roughly of those around the country. We sampled seven different basins. On average about four percent of sites sampled had visible -- had a source with visible emissions on them. So if you sample 8,000 sites you would see about four percent of sites like this one with some source of emissions; 90 percent were tanks.

What does it mean? You got sort of more insights into this than we were able to provide in this paper. Adam is talking about further work where they've gone to revisit these sites multiple times. This was just based on one site, one-time visit, basically one or two minutes surveying a site. If you detect emissions you take a video.

Otherwise, you go on to the next one. It was a one-time snapshot. But what does it mean?

You know, the main thing that we took away from it is that we tried to predict, based on data on the production of these sites, of gas, of condensator oil, of water, the age of the facility, a lot of parameters that are publicly available for these sites, you couldn't predict more than about 14 percent of the observations with the parameters about these sites. So we conclude that it's a stochastic behavior, not really something that you can predict and say that facility based on this data should have emissions, let's go fix it. Well, that's not going to get you very far. So a stochastic problem. And then the question is going to be how persistent are the emissions versus how intermittent are they?

The second point to make is that there was wide evidence for emissions from tanks that should not be occurring because the tanks are supposed to be controlled. So because of a variety of state and federal requirements, most tanks with high production are supposed to have their vent gas routed to a combustor or a flare or captured.

Here's an example, I don't know if it comes up, but on the top right circle there you can see there's a little flare with a flame on it. This site has a flare on it connected to the tanks, yet here's what the tanks look like when you visualize them with an infrared camera. There are significant emissions coming from one of more hatches or vents on those tanks. So the control system was not working. And you see that on a lot of sites, that the controls are there but the emissions are not coming from the flare, they're coming from the tank, suggesting that something is amiss there.

So implications, just to reiterate, tanks are a major source, probably represent a significant mitigation opportunity. And the key thing is going to be a monitoring system or scheme that would allow you to quickly identify and fix the kinds of problems that are observed.

This is work that's now in progress. So you're going to see something that hasn't been published yet. We hope to have this admitted any day now. But I mentioned that in the Barnett Shale we had agreement between the top-down and the bottom-up based on facility emissions, and that the facility emissions were about twice as high as what you'd expect from the greenhouse gas inventory.

So now we're asking the question, going down to the component level, what is the component-level behavior that leads to the facility-level emissions that would measure downwind of a facility?

And what we find is perhaps not very surprising, but we have now sort of the quantitative evidence to show that the expected behavior of components based on measurements that are reported in the literature or in EPA's inventory are not sufficient. Those emissions from the individual components, not sufficient to explain the emissions from sites.

So you see that in two ways here. He top panel shows you the distribution of facility emissions. So on the bottom on the X axis you're going to have the emissions per site ranked from low to high. The top panel shows you in the orange lines what you got from the Barnett distribution. The sites in the Barnett Shale have that distribution. The blue line is what the components aggregation produces. And you can see that, in fact, the components actually over-predict on the low end of emissions, so we can talk about that.

But the main thing is that the emissions at the high end, the high emitting sites at the high end of the distribution are missing. And that's important because the highest one percent of sites, the fat tail, accounts for like 40 percent of the emissions in this distribution. So if you don't have those you can see your going to have a big error in your estimate. And you can kind of see that on the bottom panel which shows you cumulative emissions. Again, sites are ranked from left to right according to total emissions. The orange line shows you what you expect from the site distribution. It shows you going up, all the way out to the highest estimates, highest emitting sites. But the bottom blue line distribution doesn't get -- those sites are missing. That chunk of emissions is missing in the total. And so your components are not producing the behavior that is evident when you survey sites.

And what we conclude in this paper, which is still not published, is that this is the evidence of the super emitters, that they're not being captured in the emission factors that are reported in the literature or in the inventories. They're hard to sample. They're rare. They're, you know, perhaps things that occur less than five percent of the time. And so -- but that behavior is occurring there.

We believe it is stochastic in the sense that you can't predict it. It may not be persistent for long periods of time, but it is causing a big chunk of emissions. And it's critical again for these to be sought out through frequent or continuous types of monitoring schemes to find them and fix them.

For California, what does all this mean? I guess I would say a couple of things. A lot of the work that was done under the EDF sponsored studies was in other parts of the country. There was some local distribution data from California that's relevant, but I will say that I think a lot of the results for some of the discrete industry segments will be relevant. I think transmission and storage compressor stations, the behavior nationally, there's no reason to believe it will be different in California. So I think there's a starting point for you to sort of mine some data there. I think of the behavior of super emitters and the influence of super emitters is likely relevant. I think the design of campaigns, top-down and bottom-up campaigns, to give you a comprehensive picture is relevant for the state. And I think that abandoned and orphaned wells, there was a pilot study done on those. There's also a second paper that published out of Princeton that shows some abandoned and orphaned Wells. Starting point of information there that you can look at.

But beyond that, I've heard a lot today about sort of the state inventory and the interest for lifecycle modeling of what's going on upstream. And so I'm going to sort of cheat a little bit and preview some information that Colm Sweeney from NOAA is going to prevent later. They've flown, not only in the Barnett Shale, which I presented their results, but they flown in at least six other basins that have been published already. There's unpublished work as well that's still to come. But this shows you in the circle, the red circle, the bottom-line results terms of the leak rate. The natural gas emitted relative to the natural gas produced, there's a big range there ranging from less than a percent to almost ten percent in the different basins. But each basin has its unique characteristics, including different levels of production of gas, also different production of oil. But forget everything else on this table and just look at the bottom box. If you take all of the averages in the different basins and you average them, weighting them by production, so a basin with more production has higher weight than a person with lower production, you end up with 1.9 percent in these seven basins as the average of gas emitted over gas produced.

So let's just take that number and say what does that mean for California?

So first of all, that's the emissions from production basins. You have to add to it the emissions from the transmission system to bring that gas from the production basins to the state. In the Barnett synthesis paper we did an analysis for the effects of the natural gas emissions, natural gas leakage on a power plant, natural gas power plant versus coal plant in the basin. And there we estimated if you were going to do an analysis in other basins downstream, like say in Chicago on the eastern seaboard, you would probably have about half a percent additional leakage due to the transmission pipeline and compressor stations.

So let's just add those together, 1.9 percent as the production estimates, upstream estimates, plus half a percent for transmission and storage, 2.4 percent. You can change the numbers very readily. I'm happy to provide the spreadsheet to calculate this. And what you get is a distribution here. And I've shown the red line as a continuous distribution because people always report the 20-year or the 100-year average. This is using a technique we call technology warming potential which assumes continuous production and use of natural gas. If you wanted to consider just a pulse, which is the more conventional approach, one pulse admissions for a year or something like that, the bottom line is you get the gas coming into the state of California on a 20-year basis ads about 60 percent extra warming to the climate than if you just consider the combustion of the gas alone.

So the bottom line is that upstream leakage matters. It increases the 20-year climate impact of natural gas use by 60 percent. On the 100-year impact it's about 20%. That sounds kind of abstract. What does it mean if you just -- you know, Anny Huang presented the total greenhouse gas inventory in California for methane was 41 million metric tons. The data that's presented up here shows that on a 100-year basis you would have about 20 million metric tons from that upstream leakage associated with the gas consumed in California, so almost half of the current inventory would be due to this Upstream impact that's not being right captured now.

And to give that some context, that represents about 6six coal plants on a 100-year basis, about 18 coal plants on a 20-year basis, so pretty significant. I think it points to the fact that this is important from a climate management standpoint. And in other work that we've done we talk about the opportunities to reduce these emissions which, you know, I think we agree with the state here that there's plenty of opportunities to reduce those. So I'll stop there. Thank you very much.

MS. TEN HOPE: We are running a little tight, But I'll take one question if we have a quick question from the audience. All right. Well, thank you very much.

Next up is Christine Wiley. And Christine is going to share specific information on methane emissions from the natural gas pipeline. Christine is the program manager for GTI's Environmental and Methane Emissions Program. She's worked in the natural gas industry for 15 years and has expertise in both field measurement and methane sensing and leak detection. She has a BA in Biology and an MBA from the University of Chicago. Thank you.

MS. WILEY: So Ramon gave a very good overview of all of the EDF studies that they've been conducting. And a lot of the past presentations have been focused on methane measurement studies, more upstream operations focused. So I'll be focusing specifically on some of the emission estimates that we've been doing for the distribution sector.

So just for those of you who may not be familiar with GTI, we are a not-for-profit search organization. And we do R&D for the entire value chain of the natural gas industry, so everything from exploration and production of natural gas to a utilization of natural gas. And our headquarters is just outside of Chicago. We have a little over 300 employees. We actually have a few offices out here in California, and we have a growing presence here in California with a lot of the projects that were doing, specifically with the California Energy Commission, and the Air Resources Board.

So, you know, we developed this project a few years ago specifically with the Air Resources Board. And we recognize that there is various sources of methane emissions within the distribution sector. But, you know, working with the Air Resources Board and with some of their project constraints, we decided to focus specifically on looking at emissions from distribution pipelines. And so the project was approximately 24 month. We just completed it last year. And the final report is still undergoing review, which I think was mentioned by Anny. But we were given the opportunity to present some of our results, so going to give an overview of that. But hopefully the final report will be available very soon.

And so we worked with three of the largest utilities in California, so SoCal Gas, SDG&E, and PG&E in terms of soliciting sites for field measurement campaigns and being able to coordinate that through those utilities. And really the objective was to quantify fugitive emissions from natural gas distribution pipelines. So we conducted field measurements to basically establish improved emission factors from known leaks. So, you know, that's something that I want to specify is that, you know, we were with the utilities and so we were going out and measuring leak grades and emissions, specifically from existing non-hazardous leaks. So it's very different from the studies may be that are evaluating different leak surveying technologies where it's independent of the utility and they're just going out and randomly conducting a leak survey and determining if, you know, they're getting hits of methane concentration. Here we're actually going out to known leak sites with the utility crews.

So you're probably familiar with the methods for estimating methane emissions, basically utilize an emission factor. A lot of the emission factors that are currently being used today were developed from GRI which is a GTI predecessor, and EPA back in 1996. And then you couple that with an activity data, basically, for example, for pipelines it would be the miles of pipelines, and then that's how you get emissions estimates. You know, recently, especially with some of the EDF studies that have been conducted, EPA has updated their greenhouse gas inventory. And so their newest inventory, which was released, I believe in April of this year, included new data from EDF’s study on distribution sources, specifically with Washington State University, as well as some studies that GTI, in collaboration with OTD did, more specifically focused on M&R stations.

So as I mentioned, we worked directly with the utilities. We targeted distribution underground Pipelines, so specifically plastic means, and then unprotected -- plastic means and services, and then unprotected steel means and services. You know, we wanted to target the emission factors that would be the most relevant, so a lot of the cast iron has already been replaced with in the state of California, and there is very little copper service, so we really focused in on the plastics and unprotected steel.

And then as I mentioned previously, we measured emissions specifically from the non-hazardous leaks. So those are your Grade 2s and 3s which, you know, utility companies are required to monitor based on federal and state requirements. So we didn't go after the Grade 1s which are obviously safety hazards that have to be fixed immediately. And then working off of the utility records, then we just randomly selected sites to include in our field measurement campaign.

So this is the method that we used to measure emissions from the distribution pipelines. So, you know, once we went out to the sites we worked closely with the utilities. We surveyed the area and then mapped out the leak area using a combustible gas indicator. So we wanted to utilize tools that the industry currently uses. And then we used an enclosure and then use the high-flow sampler to measure the emissions at the surface. And then actually for a subset of the sites that we went to, we also did some additional validation and correlation to below-ground measurements, so I'll talk about that setup and a few slides. But basically we replicated what was done in the previous grievance 1996 report to measure emissions at the source.

So you know, we initiated this study about two years ago actually prior to that GIT had several projects that were focused on national level. And so when we were originally developing the methodology about how we would go about measuring the missions from pipelines, we held a workshop at GIT. We actually invited -- Ramon was there.

We invited representatives from EPA, from NIST, from our industry partners. And we really wanted to get their feedback on what methodologies would be appropriate to utilize. And actually the methodology that we used is also very similar to what the WSU-EDF study used, as well, for their national campaign.

And so here's a picture that shows the above-ground measurements that we utilized using the high-flow sampler, so we basically have that enclosure. We met at the lake area, and then we use the high-flow sampler specifically to measure the leak rate. So it’s a pretty standard tool within the natural gas industry. Originally it was developed to determine leak rates specifically from above-ground assets, but adapted it so that we could utilize it to measure leaks at the surface from distribution pipelines.

So as I mentioned, we also did a subset of validation measurements where we replicated what was done in the GRI-EPA study. So in that study when they measured what the leak rates were from specific leaks in the distribution pipelines, they actually isolated that section of pipe where the leak was. So it was actually very burdensome to the utilities because they had to isolate and cut and cap that section and then measure the flow rate using a laminar flow element which is shown here in the picture. So that actually provide them a correlation between what we're seeing at the surface and then what's actually coming off from the pipe.

So we went out and we conducted our field measurements, again with three large utilities in the state of California. And then we measured emissions from means and services of underground pipeline leaks and focused on the unprotected steel and plastic. So within the study, you know, it was a limited budget, but we were but we still to collect 78 measurements. And so that's using the high-flow sampler, so at the surface, and then also conduct the additional nine validation measurements doing the below-ground technique that was utilized in the GRI-EPA study. And then we tried to, you know, get samples from across the state of California in different socioeconomic areas, as well. And so this chart below here shows the average leak rates that were determined from the measurements that we took in the field. So it shows the mean, as well as the 90 percent upper confidence level. And these were all from a boot-shop analysis, those 50,000 samples. So you can see that the highest be great actually is from plastic means, and then the lowest is from the unprotected steel services.

So this was talked about a little bit in that the distributions that we typically see from emission rates from the natural gas industry are not normal and they have kind of a fat-tailed distribution. And, you know, it's largely due to I guess what people refer to as super emitters. I would say for the distribution center, because of the grace that we typically see you're much, much lower than what you would see more extreme than an operation such as production or processing, and in my talk I'll just refer to it as, you know, larger leaks. But you can see here that it's not a normal distribution, and you have those few large emitters that are contributing to a higher average leak rate. In our data set actually I think about 50 percent or a little over 50 percent of the measured leak rates that we had were less than one standard cubic feet per hour.

So in addition to looking what the average leak rates were for the different categories, whether that's plastic means and services or unprotected steel means and services, we also took a look at the data to see if we could figure out, you know, what's the likelihood of different leak rates that would occur. So based on the data that we collected in the field and using some Bayesian statistical analysis, we were able to determine what those probabilities were for each asset class and then for each leak rate category. So the chart at the top is for unprotected steel means. So it's broken down by leak rate category. so the first one is less than or equal to one standard cubic feet per hour, and then goes all the way up to greater than 45 cubic feet per hour. And in the analysis you can break it down however you want, but this is we chose just based on the data that we collected. And what this tells us, then is that, for example, for the unprotected steel mains we expect that roughly 52 percent of the time a leak would have a leak rate of less than 1 standard cubic feet per hour, but it could be as high as 64.7 percent, just based on the upper competence limits associated with those mostly likely values. So it's just another way of looking at the data to see, you know, what's the probability of specific leak rates within each category. And then we did the same analysis for the unprotected -steel services.

So again, this chart, we did the same analysis for the plastic names, and then the plastic services. But really what's it telling us is that there is very low probability of these large leak rates occurring. And so, you know, the data suggests that, you know, a lot of the leaks that we were seeing are very small. And then, for example, if you look at a large leak rate of let's say greater than, you know, 30 standard cubic feet per hour, there's a very low probability of that occurring. And again, this is just based on the data that we collected. But it kind of provides some insight as to, you know, what you can expect ,and then the confidence limits around that.

So I mentioned that, you know, EDF and WSU conducted a study to look at what emissions were specifically from the distribution sector. One portion was focused on M&R stations, and then the other portion was focused specifically on distribution pipelines. So they made that data available, the actually raw leak rate data. So we were able to conduct the same analysis we did on our data through this ARB study and then we, you know, did some comparisons.

So the data that we show here from WSU, that's just from our own statistical analysis. So, you know, will utilized the same bootstrap method, so it’s not from what’s reported in their paper. But you can see basically that, you know, what we measured here in California, the average leak rates are higher but within, specifically unprotected steel means and services, within the confidence limits of the WSU data, which was national. So they went out to a number of sites across the U.S. and developed emission factors, so it wasn't specific for California. You know, we wanted to be able to compare it specifically to the data that they collected from California, but all of the sites are blind and confidential. So we just compared it to the national averages that we determined.

And then you can see for the plastic means and services, there's actually a pretty big difference between the average leak rates that we measured versus what was in the WSU study, so much so that the confidence limits don’t even intersect.

So in general, you know, the study that we did specifically for California, you know, the leak rates in general are higher than what was seen in the WSU study, although they more than what was originally developed and the GRI 1996 EPA study. And so I think it's been talked about a little bit more, but we do need some better characterization of admissions. And so we do have a proposal under review to look specifically at emissions from customer meters, and probably focus specifically on residential meters. And then I think this was mentioned as well, but there's existing research programs out through DOE NETL that's looking to address mitigation and qualification of methane emissions. And it's focused in on the midstream area. So for distribution, actually, they're going to be looking at improving the characterization specific to industrial meters, looking at different differences between vintage plastic pipe versus PE, and then also looking at if there's differences and if there’s a warranted need to create new categories for lined cast iron and unprotected steel versus unlined.

So then my last slide here is really, you know, Yu actually talked about it a little bit in his presentation, but we have an existing project with the Energy Commission to quanta emissions from commercial buildings. So we're going to develop and pilot test a method to measure fugitive emissions within commercial buildings. And we’re going to focus specifically on restaurants and health care for the phase. And we're working directly with Mark Fischer and LVNL. He's obviously done a lot of work in this area. And as I mentioned, it was just kicked off so we haven't conducted any of the field measurements yet, but that's hopefully soon to come next year.

I'm happy to take any questions now.

MS. TEN HOPE: Thank you.

Do we have time for questions? Please come up to the microphone.

Thank you very much.

Our last speaker is Rob Jackson from Stanford. And his research has included hybercarbon emission upstream from the well pads and downstream in cities, including some of the first maps of natural gas leaks across urban pipelines in Boston and Washington D.C. Rob has directed the DOE National Institute for Climate Change Research for southeast U.S., co-chaired the recent U.S. Carbon Cycle Science Plan, and currently chairs the Global Carbon Project. Thank you.

MR. JACKSON: Thank you, Laurie. Thank you everyone for being here, Kathleen for organizing. Kathleen is gone. So I'm actually pretty new to California. I moved here about a year or year-and-a-half ago to Stanford. I was at Duke for about 15 years before that, so I'm still learning. I have a lot to learn about California, how things work here. I have a people to get to know. So feel free to please come up and introduce yourself at breaks or anything because I'd love to meet some of you.

All right, I’m going to talk about I guess building on what some of our other speakers have discussed, some of the work that we've been doing, and even a little bit of other people's work, too. But mostly this is an introduction, I guess, to some of the things that we do and some of the examples of how we think and the kind of approaches that we use. So, you know, we’ll, as Laurie mentioned, look a little bit upstream. We'll also look downstream.

This is just an example of a well pad I took from a helicopter. And, you know, you see the hydraulic fracturing operation that's going on there, but then you also see the house in the background. And you might imagine how your view of that operation might differ depending on whether you own the mineral rights to that operation or not. And I think that's one of the reasons that hydraulic fracturing as a process causes some of the controversy that it does, because it puts industrial operations very near people in areas that perhaps they weren't used to.

So the main thing that we do when we're working in oil and gas-related or energy it is to try to minimize the environmental footprint of different technologies. In my group we spend about as much time on water issues as we do on methane and leakage and such. I won't talk about water today but with colleagues we did the first study of drinking water quality and hydraulic fracturing back about five or six years ago in the Marcellus and the Barnett and elsewhere. In a couple of weeks we have a new paper coming out here for California that provides a new estimate of groundwater availability for the Central Valley and such. So we do a lot of water-related work. But that’s not the topic for today.

The topic today is methane, obviously, and natural gas. Laurie, at the end, mentioned the global carbon project. This is a group I share with Naki Nakicenovic in Vienna. We released an annual CO2 budget every year that integrates not just the fossil fuel emissions, but also the natural sources which are also very important. So we do deforestation ocean uptake and emissions, as well, land use change overall and try to put all of these pieces together. We also have a methane budget. We just submitted the second methane budget globally yesterday globally to the journal, and that's an effort led by Philippe Bousquet in Paris. And

I'll talk just very briefly about that in a second.

And then we have lots of other activities on outreach, urbanization, and the new nitrous oxide budget that we're just beginning globally too. And these budgets really include exactly the kind of spirit that Ramon and Anny and others talked about, this reconciling of bottom-up and top-down, because can do the same thing on global scales, as well; right? So the atmosphere is the ultimate judge on what's actually in the air and what latitude the gas enters the air from. So we can't tell necessarily where on the planet something is coming out, but we that more is coming out in the tropics then comes out of temperate systems or boreal systems. So that's the kind of information we do. We spend a lot of time with his team of many, many people looking at inversions and such trying to back out, you know, what the atmospheric numbers mean for emissions from different sources and such.

For the new methane budget that Philippe led, as I mentioned, actually some pretty common threads. I know you can't read that, so don't try, but some common threads.

First of all globally, the anthropogenic sources of methane are about half or a little more than half of the natural sources. However, the agricultural emissions are about two-thirds of that, 60 percent of that anthropogenic component. And industry fossil fuels are about 30 percent of that, so a large part but not the largest part. We've already heard a bit about some of these agricultural sources. And, of course, those sources are the largest estimate for California, as well. And our ratios are about the same globally, pretty similar really to what we see in California.

And there a lot of uncertainties. Wetlands emissions are one of the big uncertainties. We have some uncertainties in geologic seeps, so naturally occurring seeps of natural gas that you can't tell apart from say looking at methane-to-ethane ratios and such, or not necessarily that you can, and other things, as well. So that's, as I mentioned, just been submitted. And it's actually a paper that's available for comment online.

Okay, so a few examples then of upstream studies and downstream studies. So now we're going to focus on the U.S. And just as a background, I think no news to people in this room perhaps, but there are many issues or many reasons to focus on methane and other hydrocarbon emissions for not just the greenhouse gas component, but also interactions with heavier hydrocarbons that are admitted, other air quality and health interactions for workers, emissions from compressor stations, you’ve already heard a bit about this, and these are some of the various places that the different kinds of emissions might occur.

All right, now Ramon mentioned the paper that David Lyon led, and this was a paper that's only been out about a month or two. And I don't know if you want to fire that video up, that's great. If you can't, don't worry about it. But you've probably all seen images of well pads with leaks. But just to go back, and I'll give you a summary, this is the paper that Ramon discussed briefly where we flew about 8,200 well pads around the country, across the six plays. And the reason for doing this -- if it runs, if it doesn't run don't worry about it. All right, so there you see a source. These are tanks, obviously, probably a hatch, I can't tell from looking at the scale. But the reason for doing these top-down studies, now these don't give you a number for emissions, you have to come back and fly an airplane or something else to get that number, but these do give you a sense of how often large sources occur. And you only see these kinds of emissions from far away using an -infrared camera for pretty large sources.

So out of those 8,200 slides that we studied, let me just give a slightly expanded summary to what Ramon referred to. So the four percent nationally, now this is not four percent of methane being emitted, of course, this is four percent of the number of sites that we see those kinds of emissions coming from, they range from about one percent in the Powder River in Wyoming to about 14 percent in the Bakken. The Powder River and Wyoming is hard (indiscernible) methane, so a different technology at play there.

I think is the most interesting thing for my standpoint that may apply to California is that emissions were observed three times more often in oil and condensate producing plays than in dry gas plays. And even within a region like the Barnett, the number of sites where we saw these kinds of emissions were 20 times higher in the heavier condensate and oil producing parts of the same basin than the dry gas parts of the basin. I think that's interesting because it suggests it's the same regulatory body, same process going on, so it's something about the operations most likely. And about 90 percent of the 500 or so detected sources were tanks, tank vents and hatches -and such.

All right, so why this result for oil? Well, we don't know exactly but there are a couple of possibilities. The first one is shown in that photo on the right I took from a plane in the Bakken and you have more tanks, you have more stuff on some of these condensate and oil producing pads, as opposed to, you know, just a well itself on a dry gas pad and maybe a few other small things, and a pipeline that takes the gas away. So it’s -probably almost certainly an activity factor issue.

But there’s also flaring going on. And I think it’s fair to say that if you're flaring natural gas instead of getting it to market, perhaps you're not as careful with that natural gas as when the natural gas is the core of your business. It was probably a combination of these different factors, but anyway it gives us a sense of how likely you are on a randomized, a stratified random basis to see these kinds of large sources.

Then one other thought to build upon, what Adam mentioned this morning, and Adam was part of the study with David, too, there was a question earlier about the stochasticity. And that's absolutely true that these processes are stochastic. So no one, at least that now, can predict a priority, which well pad is likely to leak. We're not that good yet. But once you know a well pad leaks and you keep going back through time, it’s much more likely than average to continue leaking, at least from based on our surveys and such. And so that, I think, is a pretty good justification for going back and finding these because they persist in many cases for a long time.

Okay, there other studies being done. You heard a bit about abandoned wells. There are conservatively at least a couple million abandoned wells around the country. We really don't know what that number is. These are just four I took in Pennsylvania. These are all in the photos I took in Pennsylvania in the Marcellus. So thinking about what activities, what things now, could be issues in the future on how we shepherd these wells going forward. And it's not to suggest that these kinds of situations are what we're looking at in the future, but thinking long-term about these.

Mary Kang is a post-doc in our group. She and her colleagues at Princeton did the first study of emissions from oil and gas wells for the Marcellus for abandoned oil and gas wells. They estimated at about give to eight percent or so of these states sort of fossil fuel-based emissions were coming from them. So it was substantial number but not a dominant number across that state level budget.

We're just following up with a second paper for the Marcellus that not only includes about a hundred extra wells, but also spends a lot of time and effort where we went back in historical records. So you've already heard the importance of activity factors today. It’s not just about estimating a number of molecules coming about, coming out of the site, it's also knowing how many sides are how many valves are how many tanks and such are there. And so we went back and spent a lot of time and effort on the historical data to try an estimate, get a better number on the number of abandoned wells and how we know and how much confidence we should have kinds of numbers. So I don't know as much about abandoned wells and sort of the history and the confidence for those numbers here in the state, but states that I have worked in the number of actual abandoned wells are uniformly higher than the numbers estimated or released in the state inventories, sometimes by you know a factor of three to five or more.

So we do have work we're doing here in California. So let’s see, NETL has done some extra work, new work on abandoned wells. Amy Townsend-Small has done some work back east, as well. And I believe there is some work being done for USGS. But we're working primarily this summer to quantify emissions from abandoned wells here in California. California is definitely the toughest place I've ever done this kind of work in for a couple of reasons. First of all, the policy in California is to cut the well off below the surface. So that makes it much harder you know to put a chamber around, like you're seeing in that left to lower photo there that I took of Mary and crew working. The fields are closed in a sense, you know, less peppered across the landscape and such, so it's more challenging. But anyway we and other groups are working on this and are interested in trying to narrow down the estimates from the band and Wells.

And let me finish with just a few minutes on Pipeline issues. Most of this will be focusing on the eastern U.S. This is a much bigger issue in the eastern part of the U.S. than it is in the western part of the U.S., primarily because of a predominance, well, not a predominance but a greater occurrence of older piping, you know, cast iron piping and unprotected steel and such. So I'll show you a few results and images of laser-based, in this case this is a Picarro instrumental you're seeing in the upper right. Chris Rella will be talking earlier. And this was with a Nathan Phillips at Boston University.

So we did the first studies, published first studies to put these kind of laser-based instruments in cars and drive block by block across cities like Boston, Washington D.C., Manhattan and such and trying to get an estimate of how likely those leaks are.

So in the case of Boston, this came out in 2013, we identified about 3,400 leaks across the network there. The number depends on what criteria you use, and you can, you know, tweak that number up and down depending. But on average the number one predictor of a leak in Boston by neighborhood was old cast iron piping, no surprise there. So red were road miles driven and yellow where the leaks that we have service.

All right, that's the study. We got some things done. The mayor of Boston, then Congressman Markey, now Senator Markey, both commented the day the paper came out.

The good news there was that in July of 2014 the state passed a new pipeline safety bill that accelerates pipeline replacement for the state, so it allows the companies to obtain more money to repair those pipes. Because, of course, the distribution companies are interested in repairing the pipelines but they're limited and how much money they can obtain from the public utility commissions. So this bill in Massachusetts has essentially front-loaded that repair process. It costs consumers about $1.00 a household. Consumers will get a little bit of that back because, as most of you know, we the consumers pay for the gas that leaks out of the distribution system. So that’s a fee -that’s passed on to users.

All right, now that for the state was passed before we did the greenhouse gas budget. This was work led by Kathryn McKain and Steve Wofsy's lab at Harvard. But it's hard to go from bottom up. You can, and we’ve already heard some examples of these studies with the high-flow meters and such. But another way to do it is to go top-down. And in this case we went top-down from the top of skyscrapers in the city where you put sensors on buildings in the city and have some sensors outside the city. And then as the wind blew across the city you could watch the concentration of methane and ethane build up in the air. And then, you know, try to get a budget to estimate how much of the gases were there, but also to ascribe a certain amount or proportion of that methane observed to fossil fuel sources.

So the way we did this was to measure the ratio of methane to ethane. And our hypothesis was that if it was dominated by a natural gas source, then it should be in the same ratio of those two gases that you see in the pipelines running through the city. That information is publicly available. So that ratio of methane to ethane is approximately represented by that light blue line that you see on the figure there. The dots are sort of instantaneous hourly-daily types of measurements. The red line is what we observed, in this case and winter. So winter wheat estimated that about 90 percent of the methane in the air over Boston is coming from the natural gas infrastructure. We did that because that slope is just off a little bit of what you would expect from pure pipeline gas. So microbes and sewer systems and wetlands and such don't give off that, and they don’t give it off in winter because it's cold. In summer it was about 60 percent of the methane in the air. The amount was the same. The proportion was lower because you had other sources they were active in the system.

All right, so pretty good confidence in that number, 2.7 percent loss of the gas passing through. Now that is not representative of the country overall. This is a system with by far much, much older infrastructure than most cities have. And, of course, here in California, SoCal and PG&E have both phased out all of their cast iron piping and completed those replacements, so they have zero cast iron piping. But anyway, it was about two-and-a-half times higher than the state inventory suggested that it was.

And finally it's important to say that it's not just the pipelines. This is integrating all of the sources, so some of this could be coming from meters, downstream in buildings, industrial applications and things like that. So we can't tell t0hat apart from this approach.

Okay, just to finish, we mapped Washington D.C., identified about 6,000 leaks across the D.C. network, another old city.

How might you use the information? Well these were the top 50 concentrations that we observed across Washington D.C., so they might help you prioritize places to repair pipe. We're working with PG&E on some similar approaches using more information than just concentration, of course. And they have a very extensive set of measurements that they've been taking for -a number of years now.

And then finally we can ask, who's doing a good job? Because I think it's more important to show the success stories. But here's a graph that we published a year or two ago, just going back over a decade of replacement times and asking what are different companies, different cities actually experiencing? So the higher the bar on here the longer it will take that City or that company to get rid of all of their old cast-iron and unprotected pipe. At the top of that list was Baltimore, Maryland, and that in 2014 it was on track to finish theirs in about 140 years. And at the end of the spectrum with Cincinnati, all right, where they're basically done

All right, so we used this kind of information to do our last study that came out in the fall, and that was to specifically look at cities that had close to or had replaced these old pipes. So we looked at Cincinnati, Ohio, we looked at Durham, North Carolina, two cities that had completed their pipeline replacement programs. We also mapped Manhattan. What we found was that 90 or 95 percent fewer leak densities in the cities with the pipeline replacement programs, compared to both Boston and Washington D.C., and to the new data that we obtained from Manhattan. So these programs really do work.

So all in, just saying, and this slide really targets downstream emissions, it really is more focused on the eastern half of the U.S., but I think most of these justifications apply two other aspects of methane. So these people pay a couple billion dollars a year for the gas that leaks out of pipelines. Pipeline replacement repair creates jobs. In very rare cases there are accidents. Most of these fatalities, of course, are from contractor error or homeowner error, somebody is a hole in the ground and forgets to check.

But we other rare cases where things go wrong. Air quality and health interactions through, you when you reduce the sources of methane and ethane to the atmosphere, in many situations you're reducing other things we care about, as well. And then finally, greenhouse gas emissions and climate change.

So I'm glad to be here. As I said, I have a lot to learn about California. I'm looking forward to working with some of you, and thank for your time.

MS. TEN HOPE: Thank you. Questions for Rob?

MR. JACKSON: In my group in class we call on people. I'm not like Adam, I don't, but I don't know any of your names. See, that's not true.

MS. TEN HOPE: Thank you.

MR. JACKSON: Okay. Thank you.

MS. TEN HOPE: Do we have questions on the web? All right.
Do you want to make the announcement?

MS LOZO: It's 12:15. Yeah, we're very close to on time. So lots of very good information. Let’s do lunch until quarter after 1:00

Oh, do we question? Sure, Ramon, question?

MS. TEN HOPE: Come on up to a microphone.

MR. ADDY: Sorry about that. I thought you would take questions for the panel generally. McKinley Addy with a company called AdTra. And my question, Ramon, is about your 2.4 percent estimate of the upstream methane emissions. If the upstream leak control regulations and the possible mitigation technologies that might be implemented are looked at, by how much might that 2.4 percent estimate change? Just, you know, I thought.

MR. ALVAREZ: That's a difficult question because, A, I’m not 100 percent sure how the newly-passed regulations sort of apply throughout the supply chain. So I've just been focused on the science, not so much the policy. But the goal, the federal goal, and I think I heard the California goal is the same, is to reduce emissions by 40 to 45 percent. So as a starting point I would answer your question by saying that the current goal is to cut the emissions across the supply chain by 40 to 45 percent.

Does the current adoption to get you there? I guess I'm going to be a little provocative, maybe not so provocative and just say I don't think so because the federal rule that just got adopted only applies to new sources. So eventually, when all sources out there comply with these rules, all new sources built after today, right, you will get lower emission rates over time. But right now you have all these existing sources that are responsible for the admissions today. We need to bring those emissions down, the you only do that with regulations that apply to existing sources. So those are missing.

And so while we have a goal to maybe cut emissions in half, the current rules in the books at the federal level are not going to get those. Some states have rules for existing sources and those are going to be a different story.

MR. ADDY: But you might agree that those regulations and mitigation Technologies could reduce that 2.4 percent estimate?

MR. ALVAREZ: Yes.

MR. ADDY: Okay.

MR. ALVAREZ: Yes.

MR. ADDY: All right, if I might just make another comment for, I think it's Robert Jackson. It's not a question for him as much as I was intrigued by his observation that the leak rates from oil and condensate plays might be as high as 20 times the leak rates from dry gas plays. Is that a correct characterization of what I heard?

MR. JACKSON: Close but not exactly. So the percentages that I was talking about, I think I was quite clear about, were not the volume of gas leaks into the air but the number, the proportion of sites. So that doesn't tell you that the admissions would be, you know, 20-fold higher. If the emissions were the same on average from those sites, then you might draw that conclusion. But we don't have the data to say that.

MR. ADDY: But the point is that you are observing somewhat higher nothing leak rates from oil and gas or oil and condensate plays than dry gas wells. The reason that I'm sort of trying to highlight this is I'm wondering whether that might be something for the Air Resources Board staff to pay attention to as they consider the updates to the OPGEE model in characterizing the carbon intensity of crude?

MR. JACKSON: Yeah, I agree with. I mean, I would say more than somewhat higher. I mean, they were substantially higher than the proportion, you know, different somewhat across the plays. But in all of the oil and heavy condensate producing plays, they were substantially higher, at least in terms of the number and proportion of facilities that we observed. That's where I would start if we were putting additional effort here in California would it be to, you know, focus on those, at least initially.

MR. ADDY: Thank you. Just again, if Elizabeth is here and Adam is here, I’d just like to highlight those observations. Thank you.

MS. TEN HOPE: Do we have any final questions for a panel?

MR. ZENG: I have a follow-up question the number of observed. Is that based on -- what method was used to determine those tanks linking? Is that based on the IR camera or based on something else?

MR. JACKSON: No. So that survey of the 8,200 well sites was based on the IR camera from helicopters. But as that has come up before, that's a mix of not just methane, that’s a mix of the heavier hydrocarbons, as well, which actually puts out more than –

MR. ZENG: Which is the reason my question relates to, is we have done pretty comprehensive research on the relative basically sensitivity between methane and other compounds. So afterwards we exchange some -- we actually put that on the website so that you can check the relative sensitivity among different compounds. But propane, for example, if kind of the presumption is that the well contains more or other C2 through C4 or 5, it's generally going to have a much more visibility in IR camera compared to methane. Methane is roughly about a third on the volume metric basis. But if on the mass basis, then it makes up because then the methane molecular weight is smaller. So if you go back to the mass basis then you've got a different conclusion. But on the volume metric basis, definitely methane is not as visible as propane or anything.

MR. JACKSON: The company's specs are quite clear about that, by the way.

MS. TEN HOPE: Sir, would you identifying yourself for –

MR. ZENG: I'm Yousheng Zeng with Providence.

MS. TEN HOPE: All right, well, I think now we'll take our lunch break to 1:15. And then this panel will resume.

(Off the record at 11:59 a.m.)

(On the record at 1:17 p.m.)

MR. CROES: Afternoon everyone. I’m Bart Croes. I’m the Research Director at the California Air Resources Board. And I’m very pleased to the start of the session which continues our morning discussion of various methane measurement technologies to try to understand large emissions sources, as well as individual source. So we have a very good group of speakers this afternoon, really the best in the country at what they do.

And we're going to change the format just slightly from this morning’s. We're going to reserve all our questions to the end, and then hopefully have a longer discussion to get into the issues.

So our first Speaker this afternoon is Dr. Steve Conley who holds a PhD in Atmospheric Science from UC Davis. So Steve's been working in this area as a project scientist and has started his own company, Scientific Aviation. So he actually flies planes through methane clouds and is very, very instrumental in work here in California on Aliso Canyon, as well as other gas reservoirs in the state, and transmission lines. So very pleased it's easier to share information with us.

Steve?

MR. CONLEY: Well, hello. So we've been, for the last few years, flying over sort of a combination of different types of oil and gas sources from sort of a large regional scale to point sources to pipelines. And so what I'm going to talk about today is sort of the culmination. So basically there's two things that we've been trying to do, at least with our plane. On the one side we're trying to do, if we don't know what we're looking at, like a pipeline, where we're just attempting to locate leaks, so that's our first mission is whether it's a pipeline or an oil and gas field is can we just find where leaks are? And the second one is if we have a known leak, can we figure out what the leak rate is? So those are our two goals that we've been using with the airplane. And this is the one place that I kind of been starting everything that we sort of think about it in terms of our goals, is that catastrophic failures like Aliso Canyon are going to happen. And it doesn't matter how careful we are, I mean, it matters in terms of how frequently they happen. But no matter how careful we are, mistakes will happen, earthquake happen, these catastrophic failures are going to happen.

And so the question is how are we going to respond? How fast can we respond and how well?

So this is the aircraft that we use, or of the two. These are Mooney. We have two Mooney aircraft. And they were chosen for several reasons. One of them is that they actually have dual electrical systems which makes running these science instruments on board nice because you don't get interference from the engine or engine start. The other one is that they can fly high, they can fly low, and they can fast or slow. They're sort of very versatile airplanes. So we've got these ones outfitted. They're all outfitted the same way, that they can measure the wind. So if you want to talk about an emission rate or a flux you have to know the wind, so both of them can measure the wind. And then they can carry a variety of equipment.

So normally we’ll carry, for these oil and gas projects, we carry a Picarro methane analyzer and an Aerodyne ethane analyzer. We carry them together. And you can see on the wing there, that little red box indicates these air inlets that we've got sort of out away from the exhaust. So the idea is that they're not corrupted by airplane exhaust.

Here's the sort of the big picture to me of how to respond to these events. So there's essentially four aircraft, at least that I know of, that are always configured to handle this type of event. We have two of them, one in California and one in Boulder, Colorado. On the west coast here, Laura back here has the NASA alpha jet, just figured similarly. And then at Purdue, Paul Shepson has a Twin Duchess. These circles indicate the single flight radius for each of these aircraft. And what see from this is that in one of flight one of these aircraft could get anywhere in the country, with some small exceptions. In a flight-and-a-half you can cover the entire country. So the idea being if you have an event like Aliso Canyon, the BP oil spill, anything like that and you need to know what's going on quickly, in four hours you could have an answer, pretty much anywhere in the country.

So the basics of what we do is just a simple what came in, what when. So the cylinder here is like we’re basically we’re drawing around a source. So the little red smoke cloud coming out is some source that we want to measure. And essentially all we're doing is calculating the difference between what came out of our cylinder and what went into it. And so to do that we will do one of two different types of lights that also you shortly.

So these are the two flight type that we do. And basically our ideal flight is to do these circles where we'll fly something like 30 circles around a facility at different altitudes to capture -- we basically construct that cylinder you saw on the previous slide. And the goal is that we're capturing what came into the cylinder and what went out of it, both sides. We have as many up wind measurements as we do downwind as we do crosswind. The idea of the circles is that we get everything.

Unfortunately, we can't always do circles. Sometimes there's other neighboring sources. Sometimes there's terrain. Aliso Canyon, for example, which is what is shown on the left up there, the terrain was just, you know, thousands of feet over a few hundred meters. And there's no way to do a circle around that. So in situations like that we sort of revert back to the old style of just doing downwind transects. And if we have our choice we do the circles. If we are forced by terrain we do the downwind transaction.

So this is what we did at Aliso Canyon. And this particular method that was in the science paper shows three different distances of transects which we were just doing to compare. But where you see the sort of density of our transects is where most of them we're done. And it using these transects basically what we do is we simply integrate how much methane came across our flight path. And we have a waiver from the FAA that allows us to fly down as low as 200 feet. And so what we do is we simply start out low and we keep climbing up until we stop and see nothing or stop seeing a methane gradient anyway.

In this particular case, I'm sure everybody's heard about the sort of shock that we had on the first flight that, you know, for most or all of the other flights that we've done over oil fields where we typically see methane that goes up to four or maybe five parts per million, and on our first flight at Aliso Canyon we saw 70. And just the sort of moment of disbelief at what we were looking at. We also, on some flights, including one of the Aliso Canyon flights, we took whole air samples. And we'd eventually take a canister up and collect for later analysis where you can get dozens of different chemicals. And then you can sort of do like a kind of Tracer mentality, doing ratios to get fluxes of other chemicals, as well. And typically each of these measurements, whether it's a circle are these transects, takes about an hour. So to get enough data, enough statistics to be believable, you're going to spend about an hour on the site.

And this is what one transect of Aliso Canyon looked like. So what you can see is that as we're coming -- in this case we're going from west to east. And what you can see is that as we get into the plume you're seeing both methane and ethane spike almost together, and methane going up from something like 2 to something like 18 parts per million, and then coming back down. What so what we do is integrate how much of that gas we sort of saw in that enhanced area. And just as a confirmation, the bottom of plot here shows where the wellhead is. There's a processing plant and a landfill. And as expected, you the enhanced plume, the red, right downwind of SS-25, the well site. So just sort of something to double-check that what you’re seeing is coming from where you think it is.

And then this is what you see in the vertical when we take all those legs and put them together, you see a situation where sort of toward the bottom you get your largest flux, and then as you go up eventually you get to zero. And once you get to zero is when you can stop climbing. And so that’s what we did on all these flights, we would just keep climbing up until we got enough sort of above that zero line that we felt comfortable, that we weren’t missing anything above.

This shows a comparison of all the different estimates that have come out to date. So in this plot, the top plot, the red line is sort of what we published in the science paper. The yellow lines are -- Aerodyne has been on site since, I think it was December 19th, and our first flight was November 7th. And so the yellow dots or yellow squares show the Aerodyne estimates for that. They basically bracketed our flights where they would be there for the day before, the date bob, the day after. And they got somewhere around 500 transects. That's about to be published by Scott Herndon. And so as you can see, there's no are somewhere around ten percent below ours. And then the two blue dots, this was a paper that just came out last week from Dave Thompson, and so they had two flights on January 12th and 14th. And so I just superimposed them on this also. And those were also within something like 12 percent of the numbers that came out of the airplane.

And then the other thing that I sort of thought was instructive to compare, so there's three estimates of the total emission over the whole 112 days, that’s bottom plot. The red line shows where we had to put it from integrating that line up at the top at the 5 billion cubic feet or 97,000 metric tons. And then the Aerodyne number is 86. And SoCal Gas actually did an inventory shut in and they came out with 84,000. And so all these numbers agree within 13 percent. So we feel fairly confident about that number.

The one sort of the unknown in this whole thing is we didn't get there until two weeks after the league started. And so there’s this period from October 23rd to November 7th where there is no data.

And so what we've done is we've assumed that the first three points before SoCal Gas started draining the reservoir, we assumed that those represent a good average, which is totally reasonable. But before November 7th there was exactly one kilotemp (phonetic), and that was the day after the leak started, so October 24th. So it's reasonable to think that from October 24th to November 7th there's no major changes, but obviously that's not something we know for sure. So that's an assumption that we've made, that we can average those and sort of extend that back in time to get the total. And the fact that it's fairly close to what the SoCal Gas inventory suggest does give us a little bit of confidence, but obviously there's still uncertainty.

So the next thing we talk about is our standard circle pattern which is, like I said, our preferred method of measuring these. And this is a site that you're seeing on the right near Denver Airport actually. And what we do is we’ll select an optional radius which is based on a couple of things. One is: What's nearby? So we want to make sure that we don't include any other sources in our flight path. And, two, we want to make sure that we're far enough out, so this is based on the wind speed. If we're into closed we're going to get into a situation where will see the plume once and we’ll miss it once.

And I’m sure you saw in the infrared videos from the previous slides that close in this methane plume looks more like a snake than a large cloud. And so if we are in that close it's going to be easy for us to hit and miss. So we try to get out far enough that we get to where we're going to see it every time, but still in close enough that we get a big enhancement and we don't include other sources. So basically what we do is we go circles, starting as low as we can, and we go until we stop seeing it, higher and - higher.

And then this is what we kind of hope to see. So when we sort of do our quality check and want to see that, A, the enhanced area is downwind of the facility. We want to see, B, in it that top right plot, we want to see that when we got up to a certain point we stopped seeing a signal. And then we calculate, the bottom right shows the variability in methane is a function of altitude. And we want to see that when we got to our top altitude we don't have any more variability. And that tells us that, A, we got high enough, that we included all of the emissions from it and, B, what we were seeing was actually from that facility and not just some upwind signature.

So this was a test that we did with Aerodyne where they actually released ethane. And we selected this site that was like 100 miles northeast of Denver, so it was sort of out in the middle of nowhere, where there were no sites nearby, so kind of ideal test case for us. It was also one where we can fly as low as we wanted because there was no houses nearby. And on that particulate site our, you know, estimate came in with and something like seven percent of what they were releasing. So sort of a confirmation of this method which we'll be describing. The circles' method will be described in a paper that's coming out hopefully in the next few weeks.

So that's the first half of what we do, which is measuring the leak rates.

The next one is trying to use our technology to detect water leaks are. And this was especially useful. It was actually initially started in the partnership with PG&E when we were trying to fly downwind of their Pipelines to see what we can see from an airplane. And so this plot shows one of these tests that we did down in Texas, actually, in Mineral Wells along and an enbridge pipeline. And what you see is the locations where we saw spikes are indicated sort of off of the pipeline. And then we backtrack using sort of the wind variability to give us a cone of uncertainty on the pipeline of where it came from. And that ended up being a very successful test. And then able to see 80 percent of the leaks that we needed to find.

So the big question that we always ask and everybody asks us is if we fly a pipeline and we don't see a leak, does that mean there isn’t one? And so to answer that what we looked at is how many times do we have to fly or make a pass before we can say with some confidence? In this case we chose a 95 percent confidence interval, that if we didn't see an enhancement, it isn't there.

And so what we did is we went up to a facility north of Sacramento that we've measured a bunch of times, and so we know the size of it. We know it's kind of a moderate 30 kilogram per hour leak, sort of like what we see on pipelines often. And so the question was if we had a leak of that size and we flew a bunch, what kind of statistics did we see?

So we flew 112 laps around this facility. And in the end the results were encouraging. We detected an enhancement that would have triggered our spike algorithm on 75 of the 112 laps. So given that, that means that if we flew three passes along any pipeline and we didn't see any enhancement on any three, we can say with 95 percent confidence that there’s nothing there. So it was an encouraging result that this does work, as long as you're willing to make three passes.

So a couple of conclusions from this. One of them is on situations like Aliso Canyon, BP oil spill, anything where you need a quick number on what the size of the magnitude and what's the scale of the problem, aircraft are tough to beat. You can get them there in a few hours. If you're trying to locate leaks, we can do flying down wind of a suspected source. After three negative indications we can be 95 percent confident that it's not there.

In terms of estimating an emission rate, we can use either of our techniques, the circle or the lines. The sources tend to give us better numbers, but the lines are sometimes forced on us. And that when sufficiently sampled these methods have been shown to be accurate to better than 20 percent. And it seems like that's just getting better as we continue to refine these methods.

(Applause.)

MR. FISCHER: Thank you. I know we are all dying to ask Steve what it's like to fly through heavy doses of mercaptan and go around to 30 times in a circle.

But we're going to hold off questions until the end and welcome our next speaker, Dr. Mark Fischer. So Mark has a dual appointment. He's a Staff Scientist at Lawrence Berkeley National Lab, an Associate Researcher at UC Davis. So Mark works on identifying and solving energy and climate problems. And he's done a lot of the seminal work here in California on understanding greenhouse gas emissions and comparing that with -inverse modeling of atmospheric data.

So welcome, Mark.

MR. FISCHER: Bart and all, thank you for having me. I'm going to tell you a little bit about work we've done very recently, sort of in the last two to three years with Energy Commission support -- oh, I have a thing here -- a brief outline, the problem overview. Natural gas methane, you've heard a lot about it. Probably know a fair bit already. Some work that we've done on bottom-up estimates that will perhaps surprise or be interesting. And then most of the talk is about measurements that we've been making for the last couple of years and a collaboration with many groups. This will include regional natural gas methane emission estimates for the San Francisco Bay Area. Really the second part will be summarizing the airborne measurements that Steve and Ian and their students have been doing at natural gas facilities. I'll also say something about what we called the LVL plume integration method. This is essentially a ground-based approximation of what Steve does with an aircraft, but looking at very small spatially localized leaks. And then work on residential buildings and appliances.

The big picture of this talk really is that everywhere we've looked we found measurable and quantifiable natural gas methane emissions across the natural gas sector.

In terms of our collaborators, there's a very long list. I just want to call out the UC Davis Group, the UC Irvine group, the Bay Area Air Quality Management District, the CEC, ARB, NOAA. There have just been -- we could not do this by ourselves. And this something that's a community effort. This particular work was largely supported by the Energy Commission.

In terms of a problem overview, you’ve already heard, natural gas provides a big fraction of California's energy. It's a very potent greenhouse gas. Now looking at ways to (indiscernible) emissions, and the first step is understanding where they're coming from. And I think we've heard really good -talks already about a larger scale of this problem.

We've attempted, in this project, to go after each of the different what I would call subsectors of natural infrastructure in California and just start to poke at the problem. We haven't finished it.

In terms of a bottom-up estimate, we in sort of 2012 through 2014 we're constructing methane emission maps, I will call them a model, based on activity data and emission factors largely produced by the Air Resources Board and the CalEPA. We were doing this for the regional scale estimates. And we constructed something in 2013-14 that was specific to natural gas, looking at where the wells are, how much they are likely to be emitting, transmission, compression, storage, distribution. And we added this consumption sector which we posited was potentially important. The total in that estimate was about 300 gigagrams of methane a year with some large uncertainty bounds, perhaps they should even be larger.

We found that comparing with some top-down studies that we're done during the Calnex campaign, and also by the Caltech group, that our bottom-up, at least for SoCAB, is not too high. It's probably too low.

We've very recently started looking at the USEPA revisions to their emissions for the continental scale U.S. And we found the their estimates increased production emissions and decreased distribution emissions. I'm not convinced that's right for California. I’ll give some evidence for what we're starting to see. And then I guess I would say, you know, the bottom line here is natural gas is not the end of the story for methane, it’s sort of a tip of an iceberg, but we’ve got a lot of cows -and landfills.

To give you a very quick overview of where we believe natural gas methane is coming from, you can see on the lower right, Sacramento Valley, the San Francisco Bay, San Joaquin Valley, the Central Coast, South Coast Air Basin, and San Diego, with differing contributions that may be sort of hard to see from where you're sitting. The red bar is production. Green bars, processing. Blue bars are transmission. And then the purple bars at the top, violet bars at the top, distribution and consumption. And you can see that in some areas, particularly the ones with lots of people, there's lots of distribution associated with that, and that’s not just the pipes. That's also all the end use. Even after the meter we believe there are -leaks.

Now how do we actually go about measuring this?

We’ve essentially adopted or developed techniques that are trying to be specific to the particular spatial and temporal scales that we’re trying to study. At regional scales were using tower measurements and atmospheric inversions, and I'll say a little bit more about that later. What it boils down to is making measurements of how much extra methane there is in the atmosphere above California relative to the air flowing into California, and then using a meteorological model to say how much would we have to add in different places to give us the signals we have observe? Now that's great at a regional scale. It takes a lot of averaging. There's a lot of noise in that process. But we'd like to know really more in detail where are the methane leaks occurring.

And while we cannot attempt to do this with the same kind of sort of spatial resolution that the imaging techniques are now capable of, we have used the readily quantifiable measurements from Steven's work to look at a host of what I would call sort of isolated large facilities. And then scaling down further, we've looked at individual leaks in either roads or fixtures and urban areas with this mobile plume technique that I'll say a little bit more about, and Yu spoke about this morning. Last, we looked at buildings, and I will say something -about that.

Oops, too quick.

So this is work that we just recently completed and we're trying to get into a paper, so it's, I would say, beyond completely preliminary but it's certainly not done yet. In October through December we sampled at six Bay Area collaborative sites. Some of these were sites that we operate as part of sort of the California-wide network. Some of these were very impromptu. Some of these, and I have to call out to the Bay Area Air Quality Management District, thank you to all of the folks who contributed to that. We made a combination of methane, ethane, pentane, toluene, CO, and other VOC measurements at each of these sites. At the Livermore site operated by the Bay Area, we had continuous VOC measurements, and we added a methane analyzer. At the other sites we collected daily samples which were analyzed for some of the sites at NOAA -and some of the sites at UC Irvine.

We then combined with that mixture of methane and other VOC data with previously measured ratios of VOC to methane compositions, either for PG&E’s natural gas or for mobile sources, refining, and made an estimate of what the emissions distribution or the subsector specific emissions were. We started with a bottom-up model for the Bay Area where we constructed something at one kilometer. We mapped out where every landfill, every dairy that we could identify, and there are some gaps there, are, where the roads were, where the storage facilities are, et cetera, et cetera, and where the population is, and that’s an approximation here. We assume that distribution emissions essentially scale with population. It’s not perfect but it's a start.

And the bottom line here is that natural gas is a small part of Bay Area total emissions, but we wanted to go after it. And using the multiple VOCs we have a handle on it. What we did was to construct essentially what -- those of you who have played with inversions have some sense of already – we’re effectively comparing the concentration enhancements above background, that's on this equation, the left-hand side, with what we would expect based on emissions scaled by scaling factors which are on the far right, with assumptions about how much each of the different sources contributes a given amount of VOC and a given amount of methane. We then did what's called a Hierarchal Bayesian

Inversion which simultaneously found the best solution for a whole host of actors, including the best estimates for those VOC ratios.

And in the bottom plot what we show is a figure showing biological natural gas and petroleum emissions, either in the prior in red or in the green, blue or purple, where green, blue, and purple are using successively more information from the VOCs. In other words, the first one is only using a ethane. The next one is using a ethane and pentane. The last one is using ethane, pentane, and toluene. And really we get most of the bang out of this from using just ethane. But the toluene and the pentane help us constrain the petroleum emissions. This works well in the Bay Area because we don't have any large petroleum production. We don't have any petroleum production in -the Bay Area. We have some refining and we have mobile sources.

The bottom line here is that when we put all of this together we end up with emissions from the Bay Area that are roughly .3 to .5 percent of natural gas consumption in the Bay Area. And that is actually on the low side compared to what Dr. Alvarez mentioned this morning. And I'm sort of interested to see whether that’s reproducible. But I'm also fairly confident that it's not inconceivable. It’s a reasonable sort of number.

I would close this little section of the talk by saying this approach, I will argue, is amenable to any location where you want to do a region estimate, but what you you'd got to do is combine methane and other tracers. And in principle, with other tracers you could even distinguish some of the different biological sources, landfills from dairy, et cetera. And Allen Goldstein, for example, from UC Berkeley has done some work in that area.

Now we then tried to go and pinpoint facilities within California. And here we have looked at first a production field in the southern San Joaquin Valley. Steve and I flew an education in Mark's air sickness in April of 2014. And after many, many loops, and I won't go into more detail, we got a reasonably good measurement of the Belridge South Petroleum Production Field. And Steven and Ian's group made essentially this Gauss theorem divergence calculation of the methane emitted into that control volume. And it came out fortuitously similar to what one would expect from the annual average in our bottom-up. I don't think that's something that is necessarily -- no, I will just say no, it is not proof that the emissions from that field match the bottom-up. It is just, I think, a fortuitous example.

We have flown other places and found emissions quite variable. In particular, we've done some work at the Kern River which is really still preliminary which showed quite variable emissions depending upon the well completion activities that appeared to be occurring on the ground.

So continuing, we've gone and started looking, this is actually much before Aliso Canyon, we went and started looking at natural gas storage facilities in sort of the Sacramento, Bay Area, and north up into the Sacramento Valley. We observed four sites three to eight times, and four others more recently. The emissions range from essentially non-detection at some of the sites to more than 400 kilograms of methane an hour at one of the others. The median emissions, if compare them with the voluntary reporting for storage facilities, is roughly one to two times the annual voluntary reporting.

And so I would say, if you look at this slot on the bottom right, many of those are below what one would expect for sort of the average storage facilities. But we have at least one where there's a pretty clear detection. And we’re starting to work with the utility on measuring in more depth why that's occurring, and perhaps, if we could be so fortunate, how to mitigate it. I'd note that the ethane to methane is pretty clearly indicative of natural gas.

And I would close this section on storage by saying that single-point failures carry enormous risk. I hadn't really thought beyond the San Bruno incident of 2010 until Aliso happened. But I think that a take-home message here which everyone might absorb and some might agree with is that whenever you have a facility that is handling an enormous amount of gas, that when you have either an operator error or some failure of the infrastructure, it can lead to a very large emission in a short time just because the facilities are handling so much. And that's not a negative thing. I mean, this is an enormous public service that's being provided by the facility. But we have to have a way of sort of providing more rapid response, and Steve spoke to that. I have another idea for that which I mentioned in -the recommendations.

Next, we've made some preliminary measurements of petroleum refining. This is in the Sacramento River Delta. We have the refineries three to five times. The emissions varied from site to site and between the different flights, but with quite significant emissions in several sites at several times often onward or an order of magnitude greater than the voluntary reporting for those refineries, I think this deserves a little bit more attention. The methane and ethane here was not always characteristic of pure natural gas. It had heavier component. And so we think that that is a mixture of either natural gas -leakage or some industrial process.

Last, we've been looking at very localized emissions. And this is something that Rob and Ramon spoke about earlier. When you drive around urban environments, wherever there's natural gas pipelines and, now I'm going to argue, any form a sort of natural gas use, there's a potential for a leak. I'm embarrassed to say that when I took a sniffer to my house we found ten leaks between the meter and all the different appliances because the gentleman who owned the house before us believe that he could do all of his plumbing himself. And I'll speak to sort of the house issue later.

But what we've done here is to construct a car, which is in the upper right there, with a tall mast on it. So because we can't fly our car up and down, think about that, we instead put inlets on the mast and we drive down the street slowly, the wind carries methane plumes across the motion of the car. And this lower plot shows a concentration versus height diagram. And what you can see is the purple in sort of the center of the plot is where the highest concentration occurs, and it drops off above. And so in that particular fortunate case we were able to capture most of the methane. And when we're able to do that, and we budget using these measurements, we can then, using the same kind anemometry flux product calculation, estimate the total amount of methane being emitted in a particular plume when the wind is reasonable. And using a c-13 analyzer, thank you Picarro, we are able to identify it as unambiguously natural gas when it has the right to C-13 signature.

We've done this test set up at many times and believe that we can get within about 30 percent accuracy on emissions in three passes. It's not perfect but I think it's, you know, an essential step to actually getting quantitative information. And so we, you know, have gone this way and terms of developing a measurement technique. I'll give you some examples of how that -works.

We started these what we call local plume measurements during a visit to the Bakersfield area and 2013. And here we surveyed about 80 kilometers of Bakersfield public streets and detected 20 large on order PPM or greater leaks above background, that is the plume was enhanced relative to the background. Forty percent of those total emissions from those leaks -- am I out of time? This says I have four minutes. Oh, well, then I really got to go quick. I thought this was before questions. Okay.

Forty percent of the emissions were within half a kilometer of a large distribution pipeline that, you know, was available in maps. The total immigration is sort of a round number indicating that about a third of a percent of the gas consumed in Bakersfield might be leaked in those distribution-related leakages, sort of similar to our bottom-up.

We then have also done this for capped wells in the Sacramento River Rio Vista area. We haven't looked at very many. We did this sort of as a what can we see experiment. We looked at 13 wells and found we could measure about four of them pretty clearly. Two of them, we didn't see anything, so zeroes, non-detect, very clear non-detect. And then seven sites were not accessible to the car under the wind conditions and the public -roads. I look forward to being able to obtain permission to drive onto private land and actually measure more of these, but -that's something that needs to be arranged.

We've gone to, in contrast to Bakersfield, I did a relatively short drive, 30 kilometers, around the Berkeley-Oakland area. And in that particular drive I found very small enhancements above background in general. That particular part of the East Bay appeared very clean. The leaks were measurable, very small, you know, sort of third of a gram per hour equivalent. And where we found the bigger emissions they were occurring where there was food service operations or sort of other, sort of I would call it commercial scale where there was more gas usage.

Finally, I'm not going to spend that much time on this because Yu spoke about it this morning, we’ve measured on order of ten homes using essentially a mass balance technique where we depressurize the home, knowing the flow rate and the increment of methane in the house relative to outdoors can estimate the amount being added by the house, and found that that's equivalent, in the houses we've looked at so far, a small sample of about 2.2 percent of the house consumption. We're now -working on a much larger study with a subcontractor

Finally, we have looked at combustion appliances. And I was surprised, and those of you who have on-demand water heaters might be surprised to hear that when you turn on that very concentrated flame in your on-demand heater you get a fair amount of methane, and much less so from cooktops and clothes dryers that we looked at so far. We're going to do this much more exhaustively and we'll have a much better number for you in about a year.

In summary, methane emissions are, as far as we can tell, present across all subsectors of the natural gas system. The regional inversion suggests on order of .3 to .5 percent of the consumption. Production fields, very limited measurements were roughly consistent with our bottom-up. But there were some measurements, particularly when we could see that there was wells being completed where the emissions were higher, that should not come as a surprise.

Gas storage facilities were generally roughly consistent with the reporting, with a little bit of an exception. Petroleum refining appeared to be considerably higher in the spot measurements we did. This I think comes back to the point that when natural gas is not the focus of your activity, and methane is not the focus of your activity industrially, there is more likelihood that you're going to get emission just because it's not, you know, considered the product.

With respect to recommendations, I know this is not surprising that I would say this, but I think we need to have concerted tower measurements across California that combine VOC and methane in a concerted fashion so that we have a really good handle on where the methane is coming from. And I would follow that by saying if we're going to try to fix it, those tower measurements are not enough. They're enough to say we really have fixed it, but we've got to start a campaign. And I think Bart -- I mean, the Air Resources Board and the CEC are starting this now with plume imaging.

And the next step beyond the plume imaging, that I think, Chip, you're going to talk about, will be these mass balanced flights that Steve has been doing because I think that there is still some work to be done before the plume imaging is really quantitative, except for large sources. And the mass balanced is unequivocally quantitative. I will also argue that for the high volume, high throughput, high value facilities like refineries, it may be a useful thing to have onsite continuous monitoring of emissions. And I think the ARPA-E program that was discussed this morning will go some distance in making that possible.

Finally, energy efficiency programs are going to be, I think, effective in adding better leak detection and repair and revising standards guidance for low-emission appliances.

And with, I'll stop.

MR. CROES: Okay. Thank you, Mark.

Our next speaker, and Mark has already provided a good segue, is Chip Miller. So Chip is a Principal Investigator at NASA's Jet Propulsion Laboratory. He normally works on arctic carbon reservoir issues, but glad that he's now working on California issues in a partnership with the Air Resources Board and the Energy Commission.

MR. MILLER: Thank you, Bart. Thank you to everyone for coming this afternoon.

So what I'd like to talk to you about is I'd like to take some of the ideas that you've heard presented this morning about mobile surveys, the idea that Steve was talking about earlier with mass balance flights from aircraft, what Mark has been talking about with inversions, and put this all together in a concept that we like to call a tiered observing system. So we would like to integrate all of these things together to attack the methane problem because the methane problem. Because the methane problem, beyond just the natural gas infrastructure here in the state of California, is quite challenging. It spans multiple economic sectors from agricultural to oil and gas production. You've got landfills and reclamation and other activities going on. All of these are contributing towards this signal that we're trying to unravel. And we believe that because it is so complex and complicated that it takes not anyone single observing system but a systematic integration of all of these systems together.

So what I'm showing here -- and the laser doesn't really work. All right, so you'll get the idea that we're going to be talking about looking all the way from space through with airborne measurements down to mobile measurements, we'll also integrate the kind of tower measurements that Mark was talking about so that we can look at the methane problem from regional scales all the way down to the individual wellhead, or if you like, from a very, very local perspective up through the city into the state, and even the national and international perspectives.

What we're showing here is a kind of conceptualization of this over the Los Angeles area. And this is the concept behind what we were developing for the Mega Cities Carbon Project where we're looking at large urban areas and trying to quantify the greenhouse gas emissions from those. That's one of the initiatives that we are working with here.

We also have a policy science interface which is called Understanding User Needs for Carbon Information. And additionally, we are working with Air Resources Board, the CEC, and others here in the state of California for an upcoming survey of methane statewide. And you can see that each one of these undertakings is not a small effort and involves many different organizations.

The Mega Cities Carbon Project is kind of the focus for where we started thinking about the interface of measurement technology and policy. And so if one looks at greenhouse gas emissions around the world, increasingly more and more and more of the anthropogenic emissions are concentrated in large urban areas, the so-called mega cities with extended areas and populations in excess of 10 million people. Los Angeles happens to be one of those. And we are located there, as well as Caltech, UCLA and others. And so we had kind of an already built-in infrastructure with which to begin operations. We currently have partner cities in Paris and Sau Paulo. And we're working on establishing methodologies and infrastructure that might be exported to other cities.

Because I am from JPL, one of our primary interests here is how do we port these types of measurements to space so that we can look back with satellite-based instruments and sample in places that we might not have access to. Mark very eloquently talked about the problem with getting access to individual sites. From space or from the air it’s easier to look down. But when we started thinking about making satellite measurements over mega cities we realized that we had no valid verification of the measurements that we were making, so we didn’t have any way to calibrate or put metrics on them. So another reason for spinning up this Mega Cities Project was to be able to have some ground-based validation data to use against the satellites.

You can see some of the questions that we’re asking there. The current network is on the order of 15 sites, towers and rooftops where we’re making measurements continuously throughout the Southern California Air Basin.

Here’s an example of the current network sites. And you can see the yellow star there shows you were Aliso Canyon is. We’ll talk about that in just a moment.

And, yes, and so this just gives you an idea of what some of the different sites look like. We have multiple towers. We have rooftops. We’ve been making measurements since about 2012 at the sites, and we’re currently spun up and operating again from sites that range from in the middle of the city, like in Compton or at Cal

State Fullerton. We also have sites on San Clemente Island. So that helps gives us background, as well as Victorville and up in the Mount Wilson area.

Okay, why aren't you advancing? There were go.

So again, going back to the tiered observing system, looking down from space and averaging together many years of data, Eric Kort, Christian Frankenberg, were looking at the SCIMACHY data, and they found two spots, one of which Colm and Steve and others flew around earlier which was the Four Corners area over near Colorado, New Mexico, Utah and Arizona, all coming together in a single spot. And they found some really neat stuff there that had to do with coal mining and oil and gas production.

But there was another hotspot which showed up, and that winds up being in the southern San Joaquin Valley in and around the Bakersfield area. And if one looks at the infrastructure, et cetera, that are available or information on the infrastructure and things that are available there, you can find that it's, in fact, kind of divided into this almost schizophrenic distribution; right? There are 30,000 or so wells confined to within something like about 500 square kilometers in the Kern River area, so 30,000 or more potential sources there.

And then about 50 kilometers away you have a concentration of 30, what we could call mega dairies. So you have over 175,000 cattle there. And these dairies are highly active and productive and are thought to be one of the biggest sources of methane in that part of the state. And there is the well-known difference of opinion between various researchers on whether California's methane challenges are due to agricultural or oil and gas production. And you can find literature reports that tilt one way or the other depending on which of the literature papers you like to read. So one of the things we were interested in is going in and looking at that and trying to resolve it.

Also there's this problem with super emitters that many people have been looking at now where just a few of these very large emission sources might be accounting for well over half of the total emissions. And so within this framework of the tiered observing systems, one of our goals is to be able to identify and quantify, as well as locate these super emitters.

And so we had a quick aircraft campaign. Again just showing you going from the view of the state of California, there are some flight lines set up over the Kern River area, kind of in the upper right, and down in the dairy area which is lower center. We also flew further west, some other oil and gas production area. And then you can see in Panel C what some of the oil fields look like.

I'm having a challenge again.

And then here's what we think of as some transformational information that we're getting now. So we've put on aircraft some imaging sensors, one of which we call AVIRIS which operates in the near infrared, another one which is HyTES that operates in the thermal infrared. And because these are not just radiometers but they're actually dividing the light into different spectral components, we have channels in each one of these sensors that are sensitive to methane and those that are sensitive just to background.

Additionally, we're getting infrared images which are the kind of gray scale composites that are being shown there. And we have approximately two to three meter spatial resolution for these. So we've done some careful testing doing kind of controlled release experiments, like Steve talked about that he did near Denver, looking at ethane and methane sensitivities. We've done similar experiments and kind of have a threshold understanding for how sensitive these detectors are. And the great thing about this is combining the sensitivity of -- so imaging individual plumes, you can see here that the HyTES will continue to show up in green because of the way those algorithms are done, and then here's an AVIRIS image shown over one of the oil fields in white on a blue background there.

This is down in the diary area. And this whitish rectangle on either side there, those are the manure lagoons. And this is actually -- what we're seeing is a plume coming off the manure lagoon itself, not a plume coming off from the nearby sheds where all the cattle are. And so not only are we talking about being able to identify spatially where the plumes are coming from, but we're now delving down two, three, four layers into the sectorial attribution and getting real process-level information.

This, by the way, on the right-hand side I believe is one of the very few wells that we saw leaking in the Kern River area. Most of the wells of the 30,000, I think we only found 6 or 7 that were actually emitting considerable amounts of methane when we did our surveys. And we believe that those were all areas with active drilling.

All right, so continuing onward, yes, that one, now looking at Aliso Canyon with the Mega Cities Network and some of the assets we have there, we've got the combination of being able to look down with aircraft as it's shown on the right-hand side from some panels there. And also looking down from the top of Mount Wilson, we have a remote sensing instrument that we call the PanFTS that's up on the California Laboratory for Atmospheric Remote Sensing or CLARS, so you'll hear me call this the CLARS data. And what this is 1.7 kilometers up above the Los Angeles Basin on the top of Mount Wilson we have a remote sensing sensor, looking down, also making measurements in the near infrared, like we do from the Orbiting Carbon Observatory or that will be done from other space-based measurements.

And this is our very, very low flying satellite simulation of what one might be able to get from geostationary orbit. And so there we're able to look down. As long as the sun is shining it's looking at sunlight reflected off the surface down in the basin. We can get measurements on an hourly basis. We can get measurements every day. We're limited only by instrument uptime, and also when the sun is shining in cloud-free conditions.

And so what you see on the lower left-hand side there is a field representation integrated together of what we saw for methane concentrations just prior to when Aliso Canyon started. And then here's an example of what we're doing with some LES modeling and asking questions about Aliso Canyon.

And so let's begin to look. And this is one of the images, again integrated up from CLARS, showing you now in the upper left-hand portion -- sorry, I wish I had a laser that actually worked -- in the upper left-hand portion you can see the considerable increase of methane concentration as the wind is blowing towards the southeast and beginning to bring that methane from the Aliso Canyon leak into the L.A. Basin.

And next up. Okay, yes.

And now we're going to integrate in also airborne measurements and begin to look at various different aspects of this tiered observing system, ground-based measurements, mobile measurements, et cetera.

All right, so from the NASA ER-2 we made measurements with the AVIRIS sensor shown on the left-hand panel there. That's an image of what the plume looks like. You're seeing approximately a five kilometer long plume extending to the south because the winds were blowing out of the north this day. These are favorable conditions for the kinds of measurements that Steve talked about. To the north the terrain is very steep and rugged and not really conducive to airborne mass balance experiments, and so keep that in mind.

Also, we saw from the Hyperion sensor on EO-1, we saw this same plume. So there's what it looks like on the overpass on the right-hand panel. And this is the David Thompson paper that just came out last week that was mentioned earlier.

All right, here are multiple overpasses with AVIRIS. These are spaced about 30 minutes apart. And you can actually see the temporal evolution of the plume under changing environmental conditions. So you can see it kind of moving back and forth, snaking around as the wind changes, as the eddies take place, as the temperatures, et cetera, change during time of day. And so that’s the kind of information that we’re now getting on the spatial extent of the plume that compliments very nicely the quantitative measurements made from the mass balance experiments.

Here's a day where the wind is actually blowing from the south and moving the plumes north. On the left-hand side you see the HyTES measurement. On the right-hand side you see the AVIRIS measurement. These over flights we're about seven minutes apart if I recall correctly. What I'd like to highlight here are what's showing inside of the circles, which is the bloom didn't come only from the blowout at the SS-125 well, but that there were neighboring plumes coming from other areas nearby. There was also a wellhead that we found from a separate oil production facility that was leaking. But we find that there is a much more complex emissions scenario then has previously been assumed, and that these secondary sources have a much higher variability primary source.

Okay, and so I just wanted to highlight now that we think that this methane emissions problem, especially the super emitters, is really tractable and provides a tremendous benefit to all sectors of society. So the key is to have an efficient way for identifying and analyzing and being able to then visualize and understand these data.

And so we are putting together a new project which is called the Methane Source Finder which combines all of these aspects together, as well as the transformative nature of those imaging sensors that I showed you in terms of being able to pinpoint not only where the sources are, but when combined with GIS information you get tremendous insight into process and sector attribution.

Here's an example of a couple of early entries from the database. So the map that is down there shows different colors, all the potential sources in the Southern California air basin. Probably not all. We don't believe that it's comprehensive yet. But it's in the neighborhood of 17,000 or 18,000 at this point. Most of them are oil and gas wells. But it also shows pipelines and landfills, et cetera. The two yellow stars, the one down here by the coast is actually this oil and gas facility.

So here not only are we talking about facility level information, but you can see the six storage tanks easily in the relief image here. And, in fact, the one on the lower left-hand side that is starred is the one that was found to be emitting when we did the high-test over flights there. So you can see the green coming out and blooming from that. And repeat surveys show that, in fact, it was that storage well along the six. So this is the level of detail that we're being able to discover with these new Imaging sensors.

Likewise, over here we have one of the local landfills. So not only are we saying emissions coming from the fill, we're able to pinpoint within a few meters actually we're in the landfill area that the emissions are coming from. We think that this combination remote sensing Imaging and the GIS is going to be revolutionary in helping us understand what's going on.

And with the help of Bart and ARB and the CEC and others, we are getting ready to spend up a California-wide survey. The emotional areas of where we would be flying the imaging sensors are outlined in green there. These are still under discussion, but the idea is that with a few well-chosen air of order five or six, we believe we can isolate approximately 80 percent of the emission for the state of California, and then to do surveys and find out and characterize and identify the super emitters and get statistics that will go not, only for the natural gas infrastructure, but also across agriculture, et cetera, and give us an understanding of how methane infrastructure in the state of California is operating and how well or poorly we can find some of these different leaks. So this is going to be a really fun challenge.

There was mentioned before several times about catastrophic events and how do we respond quickly to those. For instance, earthquake rupture of a pipeline is something that would be extremely important to get on right away. And so we are looking for some real time options for actual onboard analysis of this is very complicated remote sensing imagery and the ability to use that to identify, and even give it first order quantification to the plumes that are being admitted.

I'll put up my summary points there. But I would really like, if you take home nothing from the talk, to think about the words tiered observing system, and to use different sets of measurements to take advantages of their strength and by bringing together different kinds of observations for different spatial-temporal scales, and soap for different quantifications of methane leaks that we have an ability to take on this big challenge from the local level up through the regional and state levels. Thank you.

MR. CROES: Thank you, Chip.

Our final speaker this morning -- or this afternoon is Colm Sweeney. He's the Lead Scientist for the NOAA Carbon Cycle Aircraft Program, as well as a Research Scientist at University of Colorado Boulder. So he works on very large scales, from Arctic to Antarctica, looking at sources and sinks of greenhouse gas emissions.

So welcome.

MR. SWEENEY: Thank you for having me, and hello everyone. I'm not going to tell you anything that actually hasn't been told before in the multiple talks that have gone on before me. Fortunately, I've had the pleasure of working with all of the speakers and they've done a pretty good job of describing what we've done together. Starting with Chip's talk which talked about tiered observing systems, I’m sort of bringing a perspective of that from some of the experiments that we've done just looking at this, you know, this idea of scaling down to drill into what the real, you know, what we're trying to find with methane emissions and where they're coming from.

But before I start I wanted to start with where I come from, what's my perspective on this is. I'm not going to talk to you about California, except for the fact that one of the first times we ever used the mass balance, and that's really where our group has sort of added to the conversation is these larger regional mass balances. And we did one of our first mass balances in trying to understand how much Co2 out of Sacramento, and that's is a paper that we wrote about eight years ago.

But since then we've done -- you know, our focus is on global methane and Co2 in particular. In the middle panel you can see where all of our sites are. Where are mostly ground-based sites, but we also -- one of the big things that I do is I contribute. And on the upper left-hand corner you can see sites that I run that are every two weeks. We have a small Cessna type airplane that will go up to 25,000 feet and take flasks as it's circling down. And these form a basic background for all of the measurements that we do in a vertical profiling situation, and I will sort of get back to that later on. But as I indicated, there's also a lot of work that's we do up in the Arctic, as well as looking at urban plumes from aircraft using this mass balance. And then I will talk some about our commercial aircraft ventures that we are to embark on, which I hope will help solve this problem from a national level and add something to the discussion.

But the main point of today's discussion is what we've contributed to the sort of national discussion about natural gas and oil production, and the emissions are. So what I've got up here are percentages of the total production, so these are not leak rate, but they're percentages of the total production in the different basins that we've visited in the last three or four years. There is a lot to there, it represents 40 percent of the U.S. total natural gas production, and there's about 70 percent of the shale gas production.

We found out some pretty interesting things.

Ramon mentioned earlier on, what I'm showing here, this is the leak rate of various sites that you saw on the map before. And what I've done is scaled them, as Ramon showed you, to production. So the width of the bar is the relative productivity of that given well. So what you can see there immediately is that the smaller producing fields tend to be the bigger leaking fields. There were other observations made with Rob and Ramon. There is also the sense that if there is more gas production there's more incentive to actually keep the gas for yourself and sell it rather than leave it. These are sort of the things that we are learning from aggregating all of this data into one.

It's interesting to note that the EPA has just revised its inventory. So what I've done here, the red and the blue bars indicate sort of what's happening from production and processing, and that's what we measure during the mass balance. We don't see down into transmission or distribution.

But what you can see is that in the previous inventory last year EPA was estimating that that took a 0.8 percent of the leakage rate, and now that jumped up to now when 1,2 percent. Next to our emissions estimate, which 1.6, Ramon noted a 1,9 number. This will move around as we sort of zero in on what, you know, fields we're including in that estimate.

So we've talked a lot about top-down/bottom-up estimates. I like to think of this is sort of a scale, a time-space regime. The bottom-up tends to be, you know, moving from very small scale to a large scale, whereas the top-down is sort of the other direction. And as Chip mentioned, it's sort of, you know, the satellites are envisioned as our outermost large-scale observing system, and then you work down through the aircraft and eventually you reach the facility level.

And as has been mentioned many times, we have this fat tail. This offers us a great opportunity. The big leakers are going to be the ones that our going to make the difference. If we can get ahold of those big leakers, we can do a lot of damage to the emissions that we see for oil and gas. And so from that that perspective it's a relatively simple and low-cost problem and we just need the detection infrastructure to see it. And as Chip pointed out, this is not a one -- you know, there's not one tool for this. Every place we go we need different tools. We want to combine the processes that Steve Conley showed earlier of circling one individual source to the large-scale mapping that was shown earlier.

I want to show an example of one such field. This was the Four Corners. Again, Chip showed you this picture. The four corners area came out as a big red dot, as outlined by that white square. And what we realized is that we need to figure out what is going on there, what is the source of these emissions? And this is a paper that Eric Kort and others wrote showing that you could actually estimate based on the imaging of the SCIAMACHY satellite, you could estimate about 0.6 teragrams of methane coming out of that area.

So what's going on in the area? Mostly it's -- the big thing is coal-bed methane. It's the biggest source of coal bed methane in the United States. There's also a lot of tights and oil -- I mean gas and oil coming from there. There is active coal mining going on. There are geological seeps. There is large power plants. But if there is a very little sort of agricultural or other emissions. So this is sort of, you know, a variety of different sources. Better than that we can eliminate some of the agricultural and natural sources that's we see, wetlands in other areas.

So as I said before, we wanted to take a multi-scale approach. The first highest level approach is to actually do a mass balance. And that's simply taking Steve's circles and expanding them to a whole entire basin. So we have an upwind measurement and we have a downwind measurement and we look at the difference, and from the difference we infer a flux.

And then that next step is the point source verification. JPL brought their AVIRIS and their other sensors to help us look at and Survey this field. I also had Steve on site, and he mowing the lawn, as I like to call it, with his aircraft, going back and forth and picking up all the individual point sources. And then that information could be passed on to the ground teams who all then would follow up with FTRI or in situ measurements made on the ground and really understand what process was contributing to the emissions.

So this is another look at this. On the far left you have a mass balance. If you have a good Wednesday you can measure upwind. And the red line is where the wind is coming from. And you can see the red is indicating high methane in the northern part of the basin, and the low methane on the other side. All the wells are located in the middle of that house-like pattern that we drew there. The second frame indicates the mowing of the lawn. And this was something that Steve was doing to try to understand where, in fact, the leaks were. And then a day later, back to those same leaks and actually quantifying the biggest ones so that we could then understand what fraction of the total these enormous balance -- what fraction of the total each one of these individual leaders contributed to.

So at the mass balance looks like this. This is one that we did in the Barnett region where we were flying.

The magenta arrows are showing the wind direction over at the time of the flight. Then you can see at the end of those arrows is where we did the downwind flight. So we did the back and forth five times. And then on the right what you see is at each altitude that we flew you can see the outline of the plume. And you can see that each time we flew over, represents a different attitude. That plume perfectly reproduces itself over that time period. Knowing if the height the boundary layer, we can then estimate the total amount of a mass coming out that down when grid that we did.

As Steve pointed out, the point source side of identification and flux estimate for particular point sources is estimated here. See that shows a nice demonstration of this in his talk, and we're doing it the same thing in this basin, so that we could identify that no more than -- no one source accounted for more than about five percent of the total emissions in this field.

So then we took -- we also had tests in AVIRIS which was what Chip was showing, and we went through there. What you can see -- I don't know if you can -- how well you can see it, but where is a red shaded area which is where the HyTES went. And then the blue shaded area, which sort of covers a much greater area, is the AVIRIS.

And between the two of them we were able to see multiple ignition sources that accounted for about 0.4 tons of the total that we expect in that region of about 0.6 based on our mass balance. And we were also able to put together a distribution of those emissions throughout the region and during the two-week time period that they were there.

So it was a really -- it was a nice compilation from the air. And then we were able to have the ground team go and actually check out these individual plumes with the FTRI -- I mean, sorry, the FLIR camera and the in situ measurements that they had on site. And at the top are the two vans that we used to do that.

So they take away points for our top-down kind of estimates are we've been to multiple fields, and I think one of the things that I always say is there's no silver bullet, there is well one way to do this really well. It's important to merge, as Ramon showed, it's really important to merge what we learn from the top-down with the bottom-up, that one approach is not necessarily the right way. There is a lot of advantages to the bottom-up in the sense that you can put together a time series, we have trouble doing from an observational point of view on the top-down approach.

The other big thing that's been brought a little bit today, which is that in either method that we use we have to really understand what the uncertainties of those methods are. And it doesn't stay the same, it's all different everywhere we go.

So I want to actually take one moment because there's been some recent articles that have come out using satellites. And although we really had to success with the satellites and SCIAMACHY identifying a source in the Four Corners, there's been a lot of other estimates that have been, well, I don't know, they are more questionable. And I think this sort of gets back to what Chip had mentioned, which is we always need to use as many different types -- we need to solve this problem in as many ways as we can.

So I want to direct you to a GRL article that was published in January, suggesting from the GOSAT satellite that nothing was increasing by 2.5 percent per year in the last 12 years. So one way that I can do this, that I can check this data is to look at data that I have been taking over that same time period. So what time is showing you is these aircraft profiles. And this is a time series at the bottom. You can kind of see that in the boundary layer, which is marked BL, there are enhancements. Every year there is this cyclic and enhancement. And then if I compare the free troposphere, which is the upper part, with the boundary layer I can get a change and methane over time if there's been an increase in methane. So I can do this at multiple sites. So the blue lines are showing where those sites are that we have and compare them to what is in the red, which is about two percent growth rate in methane indicated by GOSAT. And what you see here is in none of those sites do I see any enhancements. But when I look at something like propane, which comes from, you know, things like oil and gas, I see significant increases in every one of those locations. What does that mean? I'm going to leave that as a question.

But, you know, the final thing is that one of my -- as I mentioned earlier, one of the things at NOAA that we are going after is really developing a commercial aircraft Network where we would have Picarro-type sensors on multiple aircraft, making a hundred profiles a day. With ten aircraft that's all I need, and I can really start to pick up signals like that.

So anyways, I’m going to leave it that -- I think I've talked long enough, but you very much for your attention.

(Applause.)

MR CROES: We’re going to invite the speakers up here and encourage people to ask questions.

Well you're gathering your thoughts I thought I would just kick it off. So this idea of a fat tail distribution is something, you know, we've seen with cars for the last 40 or 50 years. And understanding this fat tail actually helped us reduce differences between top-down and bottom-up for our emission inventories. And it helped us to identify which cars needed to be repaired. And actually the higher emitter problem is still there, but much diminished over time.

And so I have a two-part question for you. When is, these high emitters, do they have the potential to explain some of the differences that Mark talked about between various bottom-up and top-down estimates? And Colm talked about that, as well, on the U.S. scale. And then it, too, have you guys been involved in any studies that tried to fix these high emitters and track those fixes over time?

MR. MILLER: How's that? All right. So one of the things that were very interested in, only with the work that we've been doing at JPL, much of the work is that we are about to embark on with this California survey is identifying the super emitters, because we feel that that is probably the most tractable means for medication. And we're not in this to point fingers at anybody, but we really want to help understand what causes these particular events to take place, why where is this super another characteristic that seems to go across every single individual sector that we've looked at so far. It applies to agriculture. It applies to the landfills. It applies to the natural gas infrastructure, oil and gas production, just to go across the board and you see it in every aspect of methane it related to science. So there is some really neat science that you can be understood that they are, as well as the possibility for having a very significant societal benefit in terms of policy and science interaction.

MR. SWEENEY: I mean, you know, the study that Ramon did, you know, led in the Barnett really showed what a difference it made to actually start to incorporate that fat tail distribution in the estimate. So, you know, he had a great example of how much difference it really made to incorporate that. And I think it was really important that that was done.

But he also pointed out that there are some other basic issues that need to be dealt with, which just basic counts of facilities that hasn't been done thus far in most basins.

MR. ALVAREZ: Thanks. Ramon Alvarez with Environmental Defense Fund. Just two quick comments, maybe a reaction from Mark.

But first I just want to emphasize that a lot of conversation about super emitters, and, yes, they're important, but all of the emissions don't you just come from super emitters, and it depends how much exactly is super emitters contribute. They might contribute half, they might contribute two-thirds, the remainder is just the regular stuff and there are opportunities to reduce those two It's a different kind of strategy, but let's not forget about those.

And, Mark, issues and clarification, that you referenced your results for Bakersfield, and go for it the Bay Area, 0.3 to 0.5 percent of local gas delivered. Being a lower number than I presented, I just to clarify. I didn't mean to say anything about sort of anything beyond the city gape. All the numbers I gave are sort of upstream production gathering maybe, and transmission. So I don't know if you were referring it to something specific maybe, the Boston at work that Rob Jackson mentioned where they had like 2.7 percent Boston gas delivered, more than that.

MR. FISCHER: My comment was only that the prior assumptions, like they were lower than the estimate of 0.5 percent that you had mentioned, but are top-down work, appears to be at ballpark with caveats that have to do with whether we lump in the consumption side.

MR. ALVAREZ: I guess then just to clarify that, that's when I said 45 percent for long distance transmission, it really is just a transmission? A couple of times today I have heard the transmission and distribution. I think important to distinguish those.

MR. FISCHER: Yes.

MR. ALVAREZ: It's a different infrastructure. So that's really transmission to the city gate, local distribution in a consumptive area like the Bay Area with the additional. You might get a little bit of transmission, you know, from that the larger Bay Area. Maybe there's one or two compressor stations across there, I’m not sure. But it's not going to be the same aggregate total that you get from thousands of miles of transmission.

MR. FISHCER: You're absolutely right. Your comment with respect to transmission, I do distinguish transmission. We haven't done our work really addressed transmission directly. It has started to do that for some of the pipelines, but it is not exhausted.

MR. BRANDT: Adam Brandt hear from Sanford. Hello? Quick question about sort of multiple scales. One thing that has always struck me, we've got about a million operating oil and gas -- okay. Hello? Yeah, okay. We've got a million operating oil and gas Wells or so, two-and-a-half unit kilometers of pipe and that sort of thing. It strikes me that this -- I understand the need for the occasional pointed nearest source sort of a plume character. It strikes me that a lot of these methods that seem good for a scientific analysis don't scale well at all.

So this keeps pointing at me back towards something that looks like a satellite, I don't know what exactly it is but it's something with that sort of scale if you're talking millions of kilometers, 500 million wells.

What's on the Forefront for the use of satellite? And is this something that we in the community should expect is possible, if it's physically possible? I know that it's possible that high res -- or at low resolution. Is it possible at high resolution? If it is, is it too expensive? I don't know. I'd like -- from that space scientists I'd like to get a sense of what's out there for this very large scale characterization.

MR. MILLER: All right, so one asset that will be coming online either late calendar year 2016 or early in 2017 is the European Space Agency’s TROPOMI. That will have a sensor similar to that of the SCIAMCHY instrument. It operates in the near infrared. It looks as reflected sunlight. And it will have a sensitivity to channels that will give it nothing detection cable. It’s spatial resolution at Nadir would be approximately seven kilometers. And so you're going to be able to see better spatial resolution than you would with SCIAMCHY, but not certainly down to the individual point source or facility-level. The initial calculations that I've seen from the preflight test result suggest that it should operate very well and have considerably better sensitivity then what you're saying from

SCIAMCHY. But the design of TROPOMI is not necessarily to get at these point sources. Actually to look at global methane science, and it's looking for large-scale changes background concentrations, as well as concentration changes that might be do it to Wetlands or tropical forests, things like that. So it's not dedicated to this pursuit.

Add JPL and within NASA we have known for many years what it takes to design and build such a satellite. It would be very similar to what we were looking at it from the technology that's on the Orbiting Carbon Observatory which in an early incarnation did, in fact include sensors for methane and carbon monoxide, as well as carbon dioxide. And if one is looking at trying to have a kind of continuous monitoring at capability for say the continental United States area, then we are looking at opportunities for geostationary flight which allow you to basically sit and stare over that specific special region and get multiple, perhaps even hourly observations, every day that you don't have cloud cover over an area.

MR. FISCHER: Adam, I might add, and Chip should chime in and correct me. I understand that there is also a commercial methane sensor that's being launched this summer by a Canadian company which is by some estimates capable of detecting sort of ends of meter scales a plume corresponding to emission in sort of round numbers of a couple hundred kilograms per hour. So a non-trivial but not Aliso scale sort of leak. I mean it, that is comparable some of the storage facilities that we have measured. Chip should correct me because there may be a caveats that the proponents of that didn't make it clear when I listen to them that.

MR. MILLER: We have spoken with this aforementioned Canadian company, they don't really share any technical details at this point. They tell us to just wait for the first data to come back from space. So we remain interested to see what happens with that.

MR. SWEENEY: I just have one other thing to add, is that when I walked in this morning I heard mention of the throne, you know, the myth of the drone, the myth of the satellite. I mean, I think again it comes back to multiple tools and really making sure that you have multiple tools and that you don't set up a system which doesn't have a backup system to understand this.

MR. BRANDT: Sure. Fine. I feel you. But I can go to Google and in three seconds find out that my mom was parked in the driveway on a particular day --

MR. FISCHER: Right.

MR. BRANDT: -- in the house I grew up in. And so likely if I knew where you grew up I could find out if your mom was there --

MR. FISCHER: Right.

MR. BRANDT: -- right, and in another four seconds. So that kind of thing did not exist when we were taking aerial imagery. My wife's father was a geologist and he still gets stereograms to look for slides and things like this, aircraft-taken photos. That sort of thing didn't exist 30 years ago --

MR. FISCHER: Right.

MR, BRANT: -- because you didn't have ubiquitous imagery. So it strikes me that for a million wells, I understand you like to fly your plane, but there's a million Wells and two so what's the-and-a-half million kilometers, so sorry, present scale. So what's the --

MR. FISCHER: Oh, but it does. I mean it, you know, I guess we didn't talk enough about inversions and how you can actually use multiple --

MR. BRANDT: I understand how inversions work.

MR. FISCHER: Right.

MR. BRANDT: But the problem is if you need to solve the problem you need to know where the problem is.

MR. FISCHER: Right.

MR. BRANDT: Right. And so if you can do something if it's like building-scale or facility-scale, which my understanding is you can't really do with inversions with the current sensor network or anything that looks like a feasible sensor network to the well pad sort of scale, which I can look at Wells in the Bakken and see where the pump is, where the pipes are; right?

MR. FISCHER: You know, for instance --

MR. BRANDT: I'm just curious what the possibility is?

MR. HOU: Okay, Yu Hou from Energy Commission. I have a question for MR. Sweeney that I got dance of the commercial jet; correct? So the idea is putting sensors on commercial jets, since they're flying anyways, flight information? But I remember that, you know, from Mark's talk that you have to be downwind, you have to fly in circles. Are we talking about a completely different set of instruments? Because I don't see us getting jetliners to circle; right?

MR. SWEENEY: Yeah. No. So at this gets back to, you know, the response I had for Adam, which is that you have been observing system in place that has a really good high accuracy measurement, can't get small gradients between one place and another. And if you know it where the wind is coming from on any given day you will inadvertently be sampling the whole entire country. At one point or another in any given profile you're always going to have different winds on different days. And so over time you gain observational capability of 360 degrees around you.

MR. HOU: So it's more of a national level of information gathering --

MR. SWEENEY: Right.

MR. HOU: -- instead of point source identification and quantification?

MR. SWEENEY: Well, this is really where the scaling argument comes, if you have a tier -- whether it is a satellite or the point is that you identify the hot spot in that, and let you go and you send Steve or other, AVIRIS, to actually figure out where exactly those plumes are coming from actually at the facility level.

MR. HOU: I see. All right. Thank you.

MR. CROES: Okay, we are on time for the break. So please come back in ten minutes, and let's thank our speakers.

(Off the record at 2:56 p.m.)

(On the record at 3:13 p.m.)

MR. O'CONNOR: Great. Hello, everybody. Welcome to the late afternoon session. We'll be talking a little bit more about technology now, less about what we've been measuring from satellites and airplanes, and more sort of at the ground level. And as we look through this next session and looking into tomorrow's session I think we're going to be starting to talk about sort of where we're going from here.

And EDF has been looking at the vehicular mobile monitoring and stationary monitoring for a number of years and trying to figure out how to integrate some of this new technology into regulatory systems, not necessarily for the purpose of having more information but for making better decisions about how California and other states in the U.S. can start to really implement technology into their rule makings.

This road map of the discussion, I'm going to take half the time to talk about vehicle-based system, and then the second half to talk more about stationary continuous monitors. I'm going to talk a little bit about the mapping studies that we worked on, how those were used in California and elsewhere. Folks have already started to alluding to it about stuff in Boston, you know, what we've seen from emissions. But we're going to really start talking about why is all of this relevant for the rule-making context, and then we're going to get into the stationary side and go through the same framework.

Our mapping project started about three years ago. And it was in a partnership with Google where we outfitted some Google street-view cars with Picarro instruments and drove them on a defined path on the streets, first in Boston, and then later in Staten Island, Indianapolis, three cities in Los Angeles. We've done parts of Jacksonville, and Dallas, and Chicago. And as we did these mapping studies we saw with very high levels of precision elevated concentration of methane at certain points along the way. Driving at about 20 miles per hour, generally just during the day, and over a defined path using, with help from researchers from Colorado State University, Jovan Fisher, we were able to do some, first, controlled releases to verify and prove out the methodology, and then later verify it using field-level measurements.

And this isn't just about a car driving around and picking up methane, it's about using computational algorithms, that as the car drives through a methane plume it can determine the size of the geographic extent of the elevated concentrations of the methane, the maximum concentration, how it changed over time, and we feel has developed a methodology that is usable by utilities across the United States to both identify point sources of methane or natural gas emissions from subsurface and surface-level equipment for the purpose of integrating that into Distribution Integrity Management Plans.

The mapping we did in Southern California, this is just one city, in Pasadena, identifies multiple points of elevated levels of methane. And by looking at the relative size of these peaks you can tell roughly the relative size of an emission, of an emission point. Now there's some question about the relative accuracy of any one PPM reading and whether you can correlate that to a specific volumetric flow rate.

And we've never actually said that we should be trying to take this data and go to five decimal places, you know, what a particular flow rate of a piece of equipment is or of a leak. But we can do is we can evaluate the relative size of a series of individual leaks and help to prioritize. We think this could be used to help prioritize investments in utility infrastructure to ensure the money, if you will, the ratepayer funds, are spent in a manner which goes after leaks that have, A, the highest bang for their buck, and really do the right thing with respect to engaging in the best highest-yield investments. And that's where we were at the beginning of this.

And fast-forward to where we are today. And we see that just like the instrumentation that's out there in the hall, if you had this symposium last year you wouldn't see probably as many folks. You wouldn't see the backpack that Picarro has out there that's only 25 pounds. You wouldn't see Los Gatos Research with three different types of methane analyzers on their table, you'd see much less than that.

And so this type of mapping work, you know, is now really sort of going to a new level on a month-over-month basis. We see CenterPoint Energy using this to map their systems, their utilities located in Texas and in Arkansas. And we see PG&E, of course, using it as well. And in their regulatory filings, regulatory documents they say, look, we use this technology. We put it on vehicles and we can survey our systems faster. We find more leaks, leaks that are there that we wouldn't have seen otherwise because the equipment is more precise. And not only do we see more leaks, but we can actually integrate this into a whole new way of managing our infrastructure. This isn't any more just about finding the dots on the map, but actually about integrating this into new spatial analytics platforms for the purposes of improving overall decision making.

On the graph you'll see -- or on the slide you'll see a heat map. On the left, that's something where when you evaluate the location of leaks and you see a clustering, you can identify and maybe prioritize what's known as a super crew method. It's something that both PG&E and CenterPoint use for targeting a specific geographic area and going after more investments there, or overlaying this onto systems that allow for pipe age, proximity to sensitive receptors, things of that nature, to really enhance and improve Distribution Integrity Management Plans across the board.

And why is this important? Well, we've all heard about, of course, the fat tail emissions trend where a small portion of the leaks that are out there are contributing a disproportionate amount of the emissions. And this graph shows that it holds true, not just for well pads and gathering stations, but for local distribution systems, as well. And when we think about how we put this new mapping and technology framework into decision making we see -- and this is an excerpt from a recent PricewaterhouseCoopers paper they just put out looking at utility systems integrating this data into new decision management frameworks -- we see that these efforts can be fed into new predictive modeling programs that can help to improve asset management integrity, make better investment decisions in deployment of people, processes and technologies. And when you're doing that, and when you're doing it, obviously, with ratepayer funds, it certainly pays dividends.

And so the next thing, you know, moving off of the mobile is about a project that we were doing with stationary. And when we put all this together at the end I think the main thing, of course, I want to make is this is a space of incredible growth, incredible innovation, incredible, you know, movement. If five years ago I knew what was going to be happening I'd probably be investing in a methane detection company, who knows. But I think that the stuff that we see now from the mobile is directly translatable to what we're seeing in the stationary

We started a project a couple years back called the Methane Detectors Challenge. The goal of this was to help to foster the market for low-cost high-sensitivity stationary equipment so that we can help to grow the space of methane detection from one which has individual detection devices costing $100,000 instead of one where they're costing, you know, $1,000 or $5,000, really creating the opportunity for a ubiquitous sense of methane detection monitors around the U.S., and the world really. And the idea was to sort of create a smoke alarm, if you will -- sort of on the top there, that's our smoke alarm -- that if it found methane it would just sort of beep. Like everybody has a smoke alarm in their house, we thought at the beginning of this that everybody should sort of have a methane alarm on their well pad.

And so we partnered with a number of industry players from oil and gas companies to technology providers. And we convened a series of meetings and essentially asked for as many ideas as people could have. Something that would meet our specifications would be low cost, would be high sensitivity, would be highly reliable, would be able to work in all different types of environments, would be able to act remotely, would be self-powered.

And we had about 25 different applicants come to us. And from those applications, we vetted a number of them and we got down to about five or eight different folks where we invited them in to actually test the equipment. And from there we've narrowed it down to two technologies which are being bench tested and are being deployed at this moment.

And this is generally what we're getting. We're getting the sort of, you know, self-contained solar powered with batteries remote-capable methane detectors. So when they detect an elevated concentration of methane they send a signal via like cell phone over to an operator or to a SCADA system that automatically alerts the operator to the background.

And the reason we chose these two, and there were several others that were very close but didn't emerge in the final grouping, is that when we bench tested them we found when they were operating side by side with the highly sensitive Picarro instrument they worked really well, pretty simple. They correlated with a low degree of error and with a high level of precision. And these methane detectors, when you look at them being deployed over a period of time, they can learn background concentrations, so you can put it in any type of environment.

Let's say you have an area that is a high level of oil production, and so background methane concentrations are just generally higher. You know that after a period of time, as it learns what the baseline is, the sensors can then detect concentrations above that baseline, or the methane sensors themselves can detect when the baseline is eroding and thus alert that it needs help, that it -- that there’s something wrong with it. And so these types of sensors, one of them is an open-path laser sensor and one of them is a point source, we think can be deployed in various ways.

For example, you have, let’s say in example number two here, you have your well pad or a production site with a few tanks, a flare, some pumps. And by putting sensors at various corners an open-path laser can then essentially create a perimeter around the site where you can detect methane concentrations elevated as it flows away from the site.

Now why does this really matter? Well, there’s two reason.

One is we have some sites here in California which are unreasonably close to where people live. There’s a site really close to my house, the Jefferson Drill Site. There’s a building, actually, where people live right next door to it. It’s about five feet away from the site.

Funny store. You know, when the drill site was actually put in the operator actually had to sign a contract with the city that they would buy the building right next door to it, a big apartment building, and it would sit there vacant. And nobody could live there because it was so close to the oil production site, the prevailing winds pushed it that way, and over time it would act as a buffer, you know, for the community that also lived there.

Well, back in the late '90s the city planner agreed to a change in the permits of this particular building, and now it's for international students, low-income students that traditionally go to USC because it's very close to USC. They're only there for about nine months to a year, so if they start complaining of smells and headaches after about six months they're sort of moved away. And there is no monitoring. There is no way to tell, you know, what's going into these buildings.

And so now we have a regulatory regime in California where there's a rule making, one proposed by DOGGR, another currently at the Public Utilities Commission, another at ARB here, where they're looking at whether continuous monitoring can be a part of this. And when we look at these sensors that can continuously set a perimeter for about $5,000 on a well pad site that's producing roughly 40,000 barrels of oil today, that really, as a cost of doing business, is quite low.

And so when we think about the relevance of this, of course it's better, faster, automated leak detection.

And you can use them in communities and high-consequence areas. The technology, of course, is less expensive and it can help to reduce product waste, if that's what methane emissions are. And greenhouse gases, of course, are reduced if you actually act on it.

But really it's about helping to inform better decision making, both by the operator, by the Air Resources Board. And in creating this new technology that's out there we think we can sort of see the ground for other innovators, not just, of course, these two, but to show that there's a rule-making here in California that can also be mirrored in other places.

Now when you look at the technology that's being deployed by Picarro, and we're going to hear from Picarro here in just a second, it's fantastic. It's expensive but it's very, very precise. And a couple of years ago, you know, when we saw the development, now we see, for example, Los Gatos Research with another piece of equipment. And it's coming in with different capabilities and is being purchased by other utilities. And we know that Picarro is being purchased by, you know, many utilities across the U.S. And it's about this proliferation of it all, which is what we're looking for.

We think we're still at the tip of the iceberg. And we think this sort of stuff is going to need to be commonplace as we think about how to protect our communities and environment moving forward.

So that’s me. I’ve sort of lectured you all on the environmental side of this. Now we’re going to hear from the real technology geeks.

MR. O'CONNOR: Now we’re going to hear from the real technology geeks, and first we’re going to start with Nate. Nate Gorence.

Nate is a technology to market adviser at the Advanced Research Project Agency, ARPA-E, where he helps prepare breakthrough energy technologies for transition from the lab to the market, and deepen ARPA-E’S private sector engagement.

Previously, Nate directed various aspects of strategy, research design, analysis, policy development and advocacy related to a broad range of energy and environmental issues at a leading think tank. He holds an MBA from Yale and he also went to Dartmouth.
Thank you, Nate.

MR. GORENCE: Those are embarrassing, so thanks for bearing with.

I’m Nate Gorence, tech to market adviser with ARPA-E. I manage the commercial activities of our MONITOR Program, which is about a $38 million effort to really advance and ultimately commercialize novel low cost systems to detect and quantify methane.

I'll kind of breeze through the portfolio today, talk about our activities going forward and leave some time for questions.

But just briefly about ARPA-E. We are kind of the rogue stepchild of the Department of Energy. We basically invest 280 million bucks a year in crazy ideas. We want some of them to stick, and the ones that do we hope will be transformative, so we invest in things from flying wind turbines to robots that follow you around with a specific temperature envelope, to new fusion reactors and low cost methane sensors.

Our mandate is pretty encompassing. It's to reduce imports, improve efficiency and reduce emissions, and this MONITOR Program is very squarely focused on the latter.

And as I mentioned, we're not really trying to create evolutionary gains, we want revolutionary ones. We want to fundamentally change the learning curves that we are on, and when we do that we recognize that some of the technologies we invest in are going to fail, but again, the ones that work are going to be very impactful.

So getting to the MONITOR Program, I think the mantra of it is the old management adage that you can't manage what you can't measure. And I think that right now, although I'm inspired today with all the discussion about quantification and localization that we’ve heard from some of the other speakers today, but really today we have the ability to locate leaks, but we can’t really do it at low cost. Labor is expensive. A lot of the equipment is expensive. And we don’t have the ability to quantify in a commercial fashion.

And that’s really what we’re aiming to do today. We want to quantify emissions at low cost and improve the continuity of emissions monitoring for methane and potentially other VOCs in the oil and gas supply chain.

At ARPA-E we’re a very metrics driven organization. What we do when we create a program, we do a lot of due diligence for about six months. We poll experts, we assess state of the art, and then we come up with what we feel are very ambitious targets, and then tell the innovative community in the U.S., hey, give us your best ideas on how you’d achieve them.

For the MONITOR Program in particular we have a detection threshold of 1 ton per year, equates to 6 standard cubic feet per hour.

As I said, cost is very important. We have a capital and operation expenditure limit of $3,000 per site per year.

We want to be confident that we can actually find and then fix the leaks that are out there. We want a 90 percent reduction rate with a 90 percent confidence interval, which basically means on average you have to be able to find a leak every 18 days.

A lot of the sites in the country are remote. False positives cost money, time, and effort, and hinder actual responses, so we have a very ambitious target for false positives.

And as I mentioned, really we want to quantify the mass flow rate of the leaks. We don’t just want to -- detection is great, but ultimately we want to be able to quantify to know what leaks are happening and having the most impact, and then prioritize where we can put our resources to fix those leaks.

Lastly, we want to -- well, not lastly, but we also want to locate it to within 1 meter. We want to be very specific about where the leaks are.

We also want to be able to transmit wirelessly to a remote location so that you can understand when there’s a leak and when you need to fix it.

And finally, we want to encourage enhanced functionality. We’ve heard a lot today about speciation, the differentiation between thermogenic and biogenic methane. Some of the higher order hydrocarbons are also important to detect and we want to encourage those applications as well.

So the way our portfolio breaks down is basically we have six technologies that are complete systems, which by the end of the program will be able to hit, if they're successful, all the metrics that I just listed. And then we have five other projects that are partial systems, and so they will bite off one or two pieces of the metrics apple, but may not end in a complete system.

Applications. We have point sensors, we have an imager technology, we have a couple long distance applications. UIVs were mentioned this morning. We have a couple aerial applications, and I'll just tick through these quickly.

I'll start with the point sensors.

AERIS Technologies, start-up out of the Bay Area. The CEO, Jim Scherer is in the back of the room. I highly encourage all of you to go talk with him.

But essentially they're creating a tunable diode laser absorption spectrometer, and it's going to be a stationary measurement system that can deduce flow rates and localization.

What's really interesting about AERIS is currently the state of the art is about $100,000 for a microwave size spectrometer, and what AERIS is doing through a novel multi-pass cell is they're basically shrinking the detector to about the size of an iPhone and putting that system into a portable unit that's basically a lunchbox size.

It's highly sensitive. Without temperature control it could get down to the tens of parts per billion, and with temperature control it can get down to the single parts per billion.

They're partnering with Los Alamos National Labs, who are combining a neural network dispersion model for the leak localization and mass flow rate, and AERIS is making fantastic progress.

I highly encourage you to go see Jim's spectrometers out at the booth. Currently they're taking early orders on its mirror systems which includes both a rack-mounted and a portable unit.

LI-COR Technology is a small business out of Lincoln, Nebraska. They do a lot of ediflux covariance and other instrumentation like that.

For this project they have a very similar application to AERIS except that they're producing a frequency comb with an enhanced optical feedback cavity. This has been hard to do. Alignment issues are challenging. They're partnering with a contract manufacturer called Generation 8 to bring that cost down. If it's successful the cost reductions will be about 10X and it'll be a high resolution spectrometer.

Another project is with IBM. They're also creating a tunable diode laser absorption spectrometer but instead of creating a detector to the size of a lunchbox, they're actually going to make it on a chip, about the size of a Triscuit, which will include a laser sampling cavity detector.

One other interesting thing about IBM is they're known for their data management and cloud analytics. They're going to create a self-organizing low power moat system where essentially each moat passes data back to one another until it gets uploaded into the cloud, and that's combined with a dispersion model.

It doesn't have the craziest resolution but it's going to be very cheap, about 100X in cost reductions from comparable TDLAS spectrometers, on the order of a couple hundred dollars. And as you can imagine, a distributed network like this has interesting applications in a variety of complex fields and sites.

PARC is creating another point sensor. It's going to be chemical sensors. PARC is a spinoff research arm of Xerox. They're known for their printing technologies, and what they aim to do is to print very low cost chemical sensors with carbon nanotubes.

And essentially what they're going to do is they're going to dope each sensor with different metal oxide and then put anywhere from 16 to 20 on a site and each sensor will basically create a slightly different response, and together they'll be able to detect a fingerprint of the chemical composition of the gas that's on the field. What's interesting about this is if it works, the sensors are going to be exceptionally cheap. They're going to be a thousand times on the order of a couple dollars per chip. They're also combining with a mesh, with a low power mesh network to communicate their analytics and mass flow rates.

Duke University, they're creating a miniaturized coded aperture mass spectrometer. As you can see in the upper left, it's a lab size instrument, and what they're trying to do is basically shrink that down to the size of a shoebox.

This is going to be a little bit more expensive than some of the other technologies that we have, but what's interesting is that it can detect a wide range of hydrocarbons, including aromatics, in particular benzene. We think that refineries and gas processing are going to be interesting applications for this.

Moving along, we have two long distance technologies.

The first is University of Colorado Boulder partnering with both NIST and NOAA.

Essentially, they are creating a dual frequency comb based system. How that works, it's really impressive physics. It's basically controlling two waves. It's basically controlling about a hundred thousand lasers in one straight line.

What's interesting about this is that it can cover exceptionally long distances, up to a handful of miles. It has to have retro reflectors around a field, but as you can see with the map there, it can easily reach a 5 kilometer radius.

The laser can spit out, hit a number of retro reflectors around a site and basically cover densely populated wells in the tens if not hundreds at a single time.

Here's a quick video, a stylized version of what this might look like on a field, but as you see, it's a portable unit. Sends a laser to a retro reflector, and it would basically scan in a circular fashion and come up with measurements that way.

GE is creating an optical sensor with a hollow core fiber. What's interesting about this technology is that you might be able to lay it pipelines or other complex storage facilities.

Drones were discussed earlier today. We have a couple of interesting technologies.

We have Paul Wehnert from Heath Consultants, who is partnering with Physical Sciences, Inc. to create essentially it’s called the RMLD Sentry.

Right now if you go out to their booth you will see that they have a backscatter spectrometer, which means you shoot it out, bounces back and detects the path length with methane concentration on it.

It’s about the size of a briefcase and looks like a radar gun. We’re basically funding them to miniaturize the device to about 300 grams, essentially the size of a Coke can.

And then from there, PSI has developed a very interesting quad copter. It was originally built to withstand sand storms in Afghanistan. Has about a 350 gram payload, and Heath Consultants and PSI is going to put this system, the miniaturized RMLD on a drone.

As you can see here, the idea is to have continuous monitoring where you will have the drone in the bird’s nest on the periphery. It will do fence line perimeter monitoring. If any gas convects across that plain, it’ll initiate a flight pattern where the Instant Eye, which is the name of the drone, can basically follow a circular flight pattern until it localizes and quantifies the leak.

I encourage you to talk to Paul about that.

Bridger Photonics, a company of Bozen, Montana, they also are producing a back scatter spectrometer. What’s interesting about their technology is that they're combining it with LiDAR.

Bridger is known for its distance measurements, and what this system will be able to do is not only detect methane but produce georeferenced high resolution tomographic images.

And so it's very interesting to think about characterizing a complex facility. You'll get a 3D representation that's georeferenced along with any gas detection on that.

Currently they're looking at both UAV, fixed wing, and stationary applications.

We do have one imaging camera technology.

Rebellion Photonics out of Houston, Texas. As you can see in the picture on the right, that big instrument is their original multispectral imaging system. It looks like a small oven, cost about $300,000.

They are also miniaturizing this to about 350 grams, about the size of a Red Bull can, and bringing the cost down considerably.

And then their application that they want to do is actually to mount it on a helmet for safety. So the idea would be that you actually mount this imaging camera on a number of helmets for oil and gas workers who then either have a visualization, who then either look through an apparatus like Google Glass and basically visualize the leak directly, or have a notification system on an iPad or an iPhone to show them the actual leak image.

We have one enabling technology.

Thorlabs. A lot of the laser work today has been done in the 1.6 micron range. That's good because the lasers are very cheap. It's what telecom lasers use. Except that for both methane and ethane, the 3.3 micron range is vastly more sensitive. For methane it's about 200 times better than a 1.6 laser. For ethane it's about 6,000 times.

The problem is that there's just not high demand for these, and they basically cost about 20,000 bucks today.

We're funding Thorlabs to basically commercialize a tunable vertical cavity surface emitting laser affixal for a couple hundred dollars, and the application could potentially be employed in some technologies like PSI and AERIS, but has very strong absorption bands.

So that's a snapshot of our 11 technologies of the MONITOR portfolio.

We are also funding a test facility.

Unfortunately, I can't -- we released a funding opportunity announcement about that earlier in January and we're hoping to make that announcement very soon.

But one of the things with RP is that we don't just fund research for research sake. Everything that we fund we have to ask the question, if it works is it going to matter?

And what we want to do with this test facility is actually prove these technologies in a realistic simulated well pad environment and potentially extend it even farther downstream.

One, to make sure that the technologies hit the metrics that we've tasked them with, but two, to engage the broader community, both industry, the regulatory community, because we want these technologies to actually go in the field, and the only way you can do that is to actually test them under real world conditions.

So that should be announced shortly. Testing we hope to commence at the end of this year.

I will note prioritization will be given to the MONITOR technology portfolios, but it is likely that other technologies will also have the potential to use the site.

This is a stylized layout of what it might look like. Again, several simplified well pads, and getting more complex over time.

And as I mentioned, really we don't want to do this in a vacuum, that's why we try to get out. My colleague, Brian Wilson, and I try to engage the community in a very robust way. We connect with all sectors of the oil and gas industry.

This program is focused on the well pad but we do think that the applications will span the well pad all the way down to the burner tip.

We engage the environmental community. EDF has been great partners with us, they've done great work, very complementary programs.

And then we've really done a big pulsing the regulatory community. I think it's important. There's been reference to several of the state regulatory actions today, also EPA's new source performance standard.

And what we want to do is we want to make sure that the technologies that are coming out sooner than we think have an opportunity to deploy for regulatory purposes, and we don't want anything to be boxed out.

And while there has been a step change from Method 21 to optical gas imaging, we think the technologies of tomorrow are vastly superior in a number of ways, not just in fidelity but also cost, and if we can bring those down we stand a much better chance of more ubiquitous deployment. And on that note, we have sponsored work with the Interstate Technology and Regulatory Council. It's a group called the ITRC, which basically pools resources from state regulators for complex technical challenges.

And we've tasked them to create technical and regulatory guidelines that essentially come up with a methodology to compare apples to oranges technologies, because the imaging camera is vastly different than a system of point sensors with an inverse dispersion model, and we want to make sure that those technologies can compete with OGI and others, and ITRC over the next year will come up with a methodology that will be available to both state and federal regulators to help onramp these technologies and show that there is at least equivalency if not superiority.

Lastly, we've done a lot of work with BLM, EPA, and others to make sure that we have this technologic onramp, but policy and technology, they influence one another and eventually, as was talked about, there's fat tail for sure, but 50 percent of methane emissions come from other sources, and what we want to do is we actually want to move away from just detection to a quantification regime that allows you to prioritize which leaks are worse and fix those accordingly until we can actually get down to the smaller leaks.

And so we've been really pushing that we want to move toward not just concentration thresholds but mass flow thresholds and continuous monitoring.

With that, here's a quick timeline of where our program stands.

We're one year in, as I mentioned, especially with the technologies in the room but then even others in the portfolio and made great progress over the previous year and I look forward to even better progress over the next two. I invite questions, comments and partnerships both on the technologies. Happy to put you in touch with any of our performers.

Also, if you want to talk about the test site facility and how you all might get engaged, I'd be happy to take questions on that as well.

Thanks.

(Applause)

MR. O'CONNOR: Well, that was an impressive list of technology. I don't really want to wait for questions until the end because it could be hard to remember everything that Nate said, so if anybody has any questions about any of the technology that he talked about, we could take a moment to ask him now.

Nate, which one's your favorite? Which is the one that's going to save the world?

MR. GORENCE: I have two children in here so I can't really choose.

MR. O'CONNOR: Got it.

Anybody have any clarifying questions? You have to speak into the microphone.

MR. PARSONS: Are you currently with anybody that's using wireless HART self-organizing mesh networks for gas detection?

MR. GORENCE: Both IBM and PARC have wireless self-organizing systems.

MR. PARSONS: And are they using the ISA 100 standard or the WiHART standard?

MR. GORENCE: I actually don't know the specific answer to that.

MR. PARSONS: Thank you.

MR. ZENG: This is Yousheng Zeng with Providence. I have a question about the laser that was going to be developed by -- I don't remember the company, Thor?

MR. GORENCE: Thorlabs?

MR. ZENG: Yeah. You said it's tunable, and is the intention to be just a very narrow beam or is a wider range flood of laser to cover larger area.

MR. GORENCE: It's going to be tunable for a larger area.

MR. ZENG: I think the purpose of having that is to be able to do all those optical related to the technology using that laser, but if it's a larger area is there any concern about eye safety and all that other things?

MR. GORENCE: That's probably a question best addressed offline.

MR. ZENG: Okay. Thank you.

MR. O'CONNOR: Okay, great. Well, barring no other clarifying questions at this moment, we’re going to move on to Dr. Lance Christensen.

Dr. Christensen, he’s been at JPL for 13 years as a principal investigator of the airborne laser infrared absorption spectrometer instrument, and has participated in seven NASA sponsored field campaigns studying atmosphere chemistry and processes.

He’s also part of JPL tunable laser spectrometer team which measures methane on MARs and from the Curiosity Rover.

He’s a PI of the open path laser spectrometer for methane, which is also currently being field tested.

So, Dr. Christensen.

DR. CHRISTENSEN: So what I want to propose is that this project is about making parts per billion methane measurements anywhere with affordable platforms. So it isn’t about drones.

It’s about making a point source measurement of methane wherever you want it to be, in a low cost repeatable robotic fashion, so that’s what we’re really going after.

And so this research has been funded by the PRCI, which is a consortium of energy companies, and the ones that have been particularly involved in this are PG&E, SoCal Gas, and Chevron.

And if you have any questions, please feel free to contact myself or the program manager, Cary Greeney, of PRCI, and I have a booth out there if you want to talk more.

So where this comes from is, I work in the group that it turns out that we want to measure methane on Mars, and the purpose there is, is it life or is it coming from some sort of rock reaction.

To get there, NASA had to invest in making tunable -- they invested heavily in laser devices that could operate at thermoelectric coolers, so you didn't have to have liquid nitrogen cooling. So I think NASA can take partial credit for helping push the laser technology to where it is now.

Also, to land these things on the surface of Mars, it's over 100 Gs and you can't go back up there to realign, so there's a lot of engineering that I've sort of borrowed from my project.

An interesting corollary here to some of the attribution studies is that we also for the Martian studies wanted to get at the attribution, and one way we could do it is through ethane. In that case, it turns out rock reactions, they produce C2, C3, C4, so if we measure ethane on Mars we can help attribute that it didn't come from life, so it's an interesting corollary to the studies that are going on here.

Some background.

We started the PRCA project back in 2014. We just took an open path tunable laser spectrometer. Again, the point is that we're trying to get rid of instrument response functions. We want it to be indicative of the parcel of air without having been sucked in by a pump, without delays in your measurements. You can just think of it conceptually as that is the measurement of that point without having to multiply it by some instrument response function.

The second thing is that we wanted this to be as small as possible. It was always the vision back in 2014 that we did want it on UAVs, so it was always push things as small as possible.

And as I get more and more involved with the FAA and the NASA airborne programs is that the smaller you make this thing, the less chance that does damage to people, infrastructure. It's easier to base a service company around a smaller, less infrastructure, less amount of -- it's much easier to operate smaller UAVs. So that is sort of the guiding principal why we're trying to shrink this as much as possible.

One thing I want to clarify is that these midair lasers these days are on the 8 to 9K per unit and it estimates around 3 to 4K if you buy about a hundred. So it's starting to get into the reasonable cost range given their capability.

So the vision. Again, it's the smallest UAVs we can put them on, and the vision here was that back in 2013 we did this study at a storage facility out in Wyoming called RMOTC, so that's where we got this idea of go from well pad to well pad and try to survey as many wells as possible in a given amount of time.

At that point this whole UAV drone thing, all the capabilities has grown exponentially. At that point there wasn't a company out there that provided a self-recharging platform, so now there is.

You can actually think about landing it on some charging pad, charge up the batteries and redo it, so you can have a completely autonomous system that's monitoring your facility.

So again, it started out in 2014 with hand held unit which we field tested at the PG&E Livermore facility, and so I have this little movie here to illustrate an idea of the work we're doing and some of the rationale for why we're doing it.

So anyway, the point is that we start off walking around with this hand held unit. The hand held unit makes measurements on the tens of parts per billion level per second.

And in these complex neighborhoods you always have to have ancillary measurements, and the most important ancillary measurement is probably the winds, so back calculate where most likely the leak is.

So for these complicated environments with a lot of topography, we do these back calculations and it points absolutely the wrong direction. The real leak is around one of those houses there, not way off to the left there.

And the point of that is that making these measurements, even with these ancillary sensors like anemometers, you can get easily confused where exactly your leak is coming from, so we have to take this account into your model.

And I know that was discussed ad nauseum today (inaudible). That's something we're very aware of for this project.

So as with any of these sensors, you have to do a few performance metrics in the lab. We intercompare them with the gold standards like the Picarro and the LGR. We put them outside on the roof. With the Picarros and LGRs you have to have an inlet, put that in front of the inlet.

One thing that our end users and people who end up thinking about commercializing this want is measurement from tens of parts per billion all the way up to percent, so that puts a -- it causes more design constraints in this instrument.

So they want to use it not only to stick it on a quad and fly it downwind and find where a leak it; it's they want to grade, do a bore hole and then see if there's if you can grade the leak, so this one instrument has to accommodate all these desires.

So where we're at right now.

So we started the UAV portion of this project earlier this year, and so far we have mounted it on a couple different UAV platforms. One is the Procerus Indigo and the other one is a 3DR platform.

The reason why we chose the Procerus Indigo is they can fly about 45 minutes with the payload, so that gives you a lot more capability. You hit a button, wait 45 minutes for it to do it's waypoint measurements, mass balance, or whatever you choose, and then you've got 45 minutes worth of data repeat.

So it's a really good way of iteratively studying the stochastic processes and coming up with good models for some of these things, and I'll point out one of the important models that we're trying to address later.

The 3DR platform, that's open source, so we can get in there.

It turns out for all these UAV measurements, having the capability to dig into the code, stick in your own sensors -- like in our case we're finding that you have to have LiDAR or sonar, or you want to add some sort of avoidance detection, and so you may want to institute that in the high frequency common filter, or you may want to push that back a little bit. Like you don't want to have it at that level, you want to have it just not impact the IMU type control.

So we need to have that flexibility to figure out where exactly do you put these ancillary necessary sensors into a UAV, so that's why we do the open platform or the open source code, and Merced is very good at that.

So one of the first questions that always gets asked of me is, yeah, you're flying on a quad, the prop wash, it's going to screw up your point source measurement.

So that was one of the first things we addressed. So PG&E funded this work and it was done at UC Merced, and we purposely placed our sensor at some location outside the prop wash where, again, the props don't affect the measurement. There's no instrument response function that we have to account for. And we've done the verification with this with detectors out in the field.

For every platform we believe there's going to be a slightly different location you want to place the sensor under certain wind conditions.

So in this case for the 3DR you want to place it X amount of positions from the center of mass. Always have it pointed into the wind, and the wind has to be a certain speed. And in those conditions it's essentially a point source going around and through the space with the measurement.

So this is an indication of where we're at in terms of performance for this system. I guess on the to do, 11 parts per million scale, that's the upper left there. What that shows is us circling to calibrate what we're seeing there. We have a leak 35 meters away. The leak is 6.4 standard cubic feet per hour. And we keep on circling this leak, and every time that we get downwind of the leak, we should get a hit.

So I sped this up a factor of three. The thing doesn't move this quickly.

So the yellow thing is just a forward trajectory of where the plume is relative to the source, and we're just circling around this plume.

You can see that every time we hit the plume, but sometimes you're in a grade area underneath it is small. In this case that blip is several hundred parts per billion. That's 500 parts per billion peak. Sometimes it's huge. But the great thing about having this robotic system is that you can just keep on iterating on this. So for these stochastic systems where you have to build up a large dataset to describe these PDFs and stuff, this robotic autonomous system lends itself to developing parametric stochastic models to describe your data.

The point of that is that eventually you want to get to that state where, like was said earlier, how many times do you have to be in the vicinity of a leak to get a 95 percent confidence level that you have actually assessed whether it's leaking or not? So that's what the point of these studies are.

So again, the first thing we tackled with the UAV was stick it on a 3DR and just see how far downwind from a leak we can see, how far can you see the leak downwind. And so these environments are a lot different from the earlier environments I showed where we're in a fake neighborhood where it's coming out and there's energy deposited by the fences and trees and whatnot and spreading out the lateral and height distribution.

This is an open field, and so given a 5 standard cubic feet per hour leak, you can go hundreds of meters downwind and still easily see the leak. In these sort of open environments it's easy.

The problem now then becomes -- before I go on to the problem, first this gets at this point of having the ability to not worry about the instrument response function of the instrument. That is, if you're sucking in the air do you have to worry about the integration or the residence time of the gas inside the instrument.

Again, we are at least conceptualizing -- and somebody can prove me wrong -- that it’s an instantaneous point source measurement. And so at 50 meters away you see these leaks are very sharp.

At 280 meters away, the leaks are very -- the level of sharpness is much less. You can leverage this information and try to figure out where exactly you are in respect to the leak. So that’s another area of study that we, now that we’ve got the system up and running, we hope to make something of this.

A very important point of our measurement set now is the vertical aspect. We’re not going to be always in open fields. We need to be above tree lines. We have to, at some point that plume has to come up and we have to be able to assess it. So we go 280 meters down we do do vertical transects, and what we find is it hugs the ground basically. It stays within 5, 10 meters. At 300 meters down there, it’s still relatively low.

There are, as I’ll show later, cases where that plume gets pushed up, so this impacts how we think of the operation. Hopefully in these cases where you have not a whole lot of topography to generate uplift of the plume, you’re going to have to hug down low.

And then also we’re going to have to start examining through modeling or through these experiments what does topography -- how much vertical uplift do these features add so we can assess whether there's a leak or not.

And to show some of the strategy that we employ here for our measurements.

If you're driving a car with a Picarro in it, I would guess that you try to do the measurement when you have the air column's down, everything's hugging.

For this, for this UAV, you have trees and you have to fly high, you want to go the opposite of it. You want a lot of solar insulation. You want a lot of surface roughness. You want to go during those times of the day when you have uplift and the atmospheric stability class goes toward A.

And another thing that these (inaudible) models tell you is that you have to go -- under the typical stability classes that we measure on, so far in between January and now we've been looking at B and C type stability classes. We have to go 300 meters down to see a vertical uplift in the galcian terms of 30 meters.

So this description, if you extrapolate that back to 100 meters, we're talking about 10 meters of uplift at the 1SD level. That's telling you at 15 you're going to really encounter that plume a whole lot.

However, that's not the case. We find that when we go down 50 meters we do oftentime run into plumes at the 15, much more than a galcian distribution indicates. So we talked to modelers at JPL who do LES modeling, and it turns out that JPL and NASA invested a lot in convection surface roughness modeling to get at this GCM type characterization of pushing boundary layer air up.

And they want to think it from the global perspective. There's just a few more percent air from the boundary layer getting pushed up. That has huge global implications for inverse modeling.

Here what we want, we want to use the same models to tell how often are we going to run into a plume that's been pushed up by convection.

We've now got the system online, and the point I'm bringing up here is that now we're starting to investigate these phenomena.

So the conclusions I have.

We've now flown this 250 gram instrument on two different commercial UAV systems. We've demonstrated that's around 20 part per billion per second noise.

We do anticipate that we want to have a plug-and-play system for an UAV, not just limited to these two UAVs, but you can put them on whatever service provider or energy distribution company, whatever UAV they choose.

One thing I didn't talk about is that not only are we planning to work on VTOLS, but it's also fixed wings and hybrids, because they have much longer persistence.

The capabilities again got changed exponentially, so now you have both a mixture of fixed wing and VTOL. They combined the best attributes in both, and so we're working with some companies to utilize or leverage those strengths.

I also want to emphasize that now I think that we have the OPLS instrument working. We can start to perform iterative experiments. We can start tackling those really interesting problems like surveillance, localization and quantification. So hopefully by next year we'll have plenty of this data to talk about.

Thank you.

(Applause)

MR. O'CONNOR: Great, thank you. I think we're going to stop and see if there's any clarifying questions from the audience. We do have one from the web, so before we get onto our final speaker, I'm sure he's the fourth speaker of the fifth session of the day, he can't wait to get going. But the question from the web to Nate.

So did DOE select for the third party evaluator for the ARPA-E MONITOR and when will the test site be running?

MR. GORENCE: Unfortunately, I can't release the name of the selectee yet. An announcement will likely be made shortly. We hope to get the test site up and running by the end of this year.

MR. O'CONNOR: Excellent.

Were there any clarifying questions for Dr. Christensen? Okay.

So without further ado, Chris Rella, who is a research fellow at Picarro who is the primary focus on the development of mobile atmospheric measure technology solutions for the natural gas industry. He has a PhD in physics from Stanford University.

And Chris, they're all warmed up for you, so I'll pass it to you.

I am all that stands between you and Happy hour, so that's the bad news.

The good news is that all the speakers today, we've had 19 of them, they've done a lot of the heavy lifting for me, I can almost skip right to the conclusions. I won't because I spent so much time on these slides, but it's really important to me that you see them all.

Before I continue, I want to thank especially there are a lot of people both in Picarro and outside who have helped out, people from NOAA, a list of different places. I want to highlight two in particular.

One is EDF, who funded us to work in the Barnett shale, which you saw some this morning and you'll see a little bit more now.

And PG&E, who were so generous and supportive of us as we've tried to develop our technologies to solve problems that they face day in and day out.

Everyone had a map like this, I got a map of the natural gas production and distribution system.

I think I like the idea of a tiered network. It's like a layer cake and we're one layer of the cake. I've been focused on ground-based measurements so that's my hammer and I'm going to be looking for nails that I think can shed light on some of the problems we face as we try to deal with the problems in this infrastructure.

The key challenge that I think we're all facing is not just -- I really like what Adam said, it's not a detector, it's detection. And it's not detection of methane and PPM, it's detection of emissions and kilograms per hour or whatever units you like, and as you think about that challenge, how are you going to do that?

You need some way of getting at this really dramatically large structure. There's half a million wells, there's millions of miles of distribution line, so you have a scalability challenge, and that's what I have at the top of the slide.

So we think we have a technology that we're deploying and have been demonstrating for the last couple years. I work at a company, we have to have acronyms. Ours is MFP for mobile flux plane. This technology is used to quantify the emissions from all of these point source leaks. Why is methane and why in the natural gas are they point source leaks?

Well, as I like to point out, unlike coal, you can't make a pile of methane. You have to put it in a container and if there's a little pinhole in the container, it's going to come out.

Now, our container is huge and multi-various in all its forms, but it's a pretty good container so it comes out in these little leak points, and that's what we need to find, the constellation of little and big leaks that contribute to the problem.

So I'm going to highlight three areas of the production and distribution system.

One are production well emissions, that's the Barnett study you heard about earlier.

I'm going to focus on downstream emissions in the downstream system.

And then I'm going to look at underground storage emissions. And I have no idea why they used a park with two trees as the icon for underground storage, but they did and I like that slide so I'm going to go with it.

So what is the mobile flux plane method?

You've seen a lot of mass balance talks today so I don't need to talk to you about having -- you measure the gas coming into a volume and out of a volume and you can count up the molecules.

We just don't instead of in the air like Steve did, we do that on the ground, and so we have to make our own plane. We can't drive the car high and low, so we have inlets on a pole on a mast that we then use to gather the methane and make a picture, an image of the plume that we transect.

This is just you see here when you're near the leak the concentration can be very high but it's in a very small volume because the plume hasn't spread yet. As you go further and further downwind, as you saw in the last talk, the concentration goes down, the plume gets bigger. But in these slices of planes, the total amount of methane hasn't changed, it's the same amount going to the surface. So if you can quantify the amount going to the surface, you're going to get a pretty good emission rate.

Another picture. There are four key elements of a flux plane.

You have to have horizontal and vertical special specificity. The vertical comes from the inlet position. The horizontal comes from the GPS.

You need to know the wind because that's what carries the molecules through your surface and that's from a sonic anemometer we have mounted on the vehicle. And then you have to measure the methane. You can see in there I have a Picarro. Keep in mind I work at Picarro, so we use them to hold open doors and prop up our monitors. But I want to highlight that you can use a lot of different methane measurements.

You're seeing, I think in this session and in others, methane measurements will become a commodity, if not this year the next. If not next year, the year after that. We know that as well.

What we're really looking at is how do you employ these detectors to come up with an emissions detection, and we think we have a pretty good way to do that.

So this is Version 1. We had six different inlets and we took the gas into tubes. No one vented them, they're called air cores. And then we measured them one by one. And as you drove through the plume, you snapped some valves and then you can measure them and it took about five minutes to do the analysis.

And this is what we did in the Barnett. That's what it looks like. Our mechanical engineer was a wind surfer, so yes, that's a wind surfer pole on the front, which I thought was pretty cool.

So when you take a measurement, this is an example of measurement of a plume. The source sits down low near the ground, so we are pretty close to it so the plume was also near the ground.

And at the bottom of the slide you can see there's a very simple equation, at least it's simple to me. you're going to integrate over this image. That's that middle term, C of xyz. You're going to subtract off the background. We get that from the edges of the image. You multiply by the wind through the surface, and then you get the emissions.

It's important to remember there's no calibration parameters, there's no free parameters, there's no atmosphere transport model, no inverse modeling. It's a very simple direct measurement of the number of molecules that went through the system. That's why people like using mass balance.

Before we went to the Barnett we wanted to make sure this thing worked, so together with Eben Thoma at the US EPA in North Carolina, we went out into several different places, fields, packed earth, and pavement, and released a known amount of methane and then we went to see if our system measured the same known amount of methane, and it does. There's a nice picture there to show that it does. The mean is about within 10 percent of 1 ratio.
It's a bit noisy because the atmosphere is a noisy thing. Sometimes it carries a lot to you, sometimes it doesn't give

you as much, so you get about a factor of 2 on either side, but otherwise it’s quite accurate.

So then we went into the Barnett. I won’t show you too much about this, you’ve seen this before. This is part of that coordinated campaign that EDF did such a good job funding. It was very nice, and I’m not just saying that because Jim’s sitting over here.

And so the goal that we had, our piece of it was to try to -- there are roughly 18,000 wells here. We wanted to select as randomly as we could -- we didn’t want to just go for the big ones -- but as randomly as we could we wanted to pick over a hundred well pads and try to measure the emissions from them, and we were able to do that.

So we got 115 wells from which we got measurements and then about half of that number, about 60, we didn’t see any detectable emissions.

This is a histogram of them. The blue is the actual data. And you can see that we saw some wells all the way down at just a fraction, just 20 grams per hour. That’s roughly our detection limit. All the way up to 50 kilograms per hour.

The reason we were stuck with 115 and not more is that five-minute time period, and we because we had to be on public roads that were downwind of well pads, and lots of them weren’t close enough within about a hundred meters for us to measure, but this is a very, very wide distribution, ranging from .1 to 20 or more kilograms per hour.

So I'll do the same plot everyone does, but mine's upside-down. I always make my fat tail go this way so you have to stand on your head if you want to see it the old way.

And so it is a pretty fat tail. This includes the ones that didn't have any detectable emissions, and half the emissions are from 6, 7 percent of the sources. It really is an 80/20 rule in this case, 80 percent from 22. And then half of the well pads contribute less than 2 percent and you can ignore those.

So I think this highlights, and I'm not going to beat this dead horse. Finding the big ones, fixing them is a really productive way to reduce emissions and save product, so that's one of the things that we liked about this study.

So I'm going to move on to the distribution system, and the distribution system is in some ways harder, we don't know where the well pads are, you can't see them with your eyes. You don't know where the leaks are in the downstream system, so we need again a scalable way to measure emissions.

Now we didn't want to live with this five minutes, so we had to work on something faster, so we ended up working on Version 2, which is a real time flux plane measurement.

So now because I really like inlets, I put 16 on this mast and I combined them into a single analyzer. I lose the vertical resolution on seeing what the plume looks like, but in the end I'm only going to put it into a -- I'm going to do an integration at the end vertically, so rather than do that digitally in a computer, I did it in analog form by combining the gas streams in a specific way. So I do the vertical integration automatically in analog and then do the normal digital one in the instrument so I can get, again, to a flux measurement.

We want to test this again now. Downstream has trees and has houses, so the winds aren't the same as an open field, and I think you saw that in the last talk as well. We wanted to make sure we can still do these measurements in a real environment.

So this is the vehicle. You can see the 16 inlets on the front, and somebody handsome driving it and it's not me, so I'll just say that right now.

It takes about ten seconds to drive through the plume and make a measurement, so this is PG&E's test facility in Livermore. Thank you very much, PG&E. This is a very, very handy facility. It's basically a mock neighborhood with very small houses and fence and things like that with leaks located around it. The nice thing about it is we can put in a known amount of methane and measure what comes out and see how well we do.

So this is rank ordered by the flow that we put in, anywhere from about half to five or six standard cubic feet per hour. And you see that the black dots are the actual data and the green dots are what we measured. You can see generally we do pretty well. Sometimes we underestimate, as in Leak Number 3, and we rarely overestimate.

So why is that?

Well, we did learn a little bit more about it, and it's the kind of problem you might imagine.

So this is now looking at these same data now as a function of distance from the leak, and you can see that when you're very close to the leak, maybe about 50 feet, 75 feet, you get the full plume capture. The plume is captured fully by our 10, 11 foot mast. It doesn't go overhead so we catch all the emissions.

When you're greater than that, then the plume goes overhead. The red line is a galcian model to say roughly how much should go overhead. But of course you have structures and buildings which are going to accelerate the mixing, which is why we tend to see it a little bit lower. But still you get greater than 40 percent plume capture out to a couple hundred feet.

And if you think about 40 percent, when the emissions can range over factors of 10 or more, that's a pretty decent estimate of the emissions.

So once we validated it, we went out into PG&E territory again. That was very kind of them to let us do that. Where it's located in Santa Clara there right in the middle because we didn't want to drive far.

But we looked at these areas in red. There's about 16 square kilometers, and what we did, we didn't just go to find where the leaks were. We drove every single street 20 times because we're trying to get too much data. It took us a couple weeks, and in that process we found using our detection algorithms, we found about a hundred different leaks, which adds up to 1.4 hours of leak, including all the time we're driving where there are no leaks and the fact that we drove by each leak 20 times, which we don't really need to do. About 5 is probably plenty.

So the first thing we did was total it up. So if you take the total emissions and you take our uncertainties, including the fact that at distance we tend to underestimate and we rarely overestimate, then you get something about 80 standard cubic feet per hour from these 16 square kilometers, or 5 standard cubic feet per hour per kilometer squared.

That’s just kind of an emissions factor for those areas. We can see how quickly you could imagine doing this throughout the distribution system very efficiently.

So I’ll then take these 104 leaks and put them on a cumulative distribution plot. The data is in black and the Lamb et al Washington State paper which we’ve heard referenced earlier, for plastic mains and plastic services are shown here in the two colors of blue, dark blue and light blue, and you can see that our measurements are right in between.

It kind of makes sense, we’re measure ingredient a combination of leaks the main, leaks on the services and ever meter sets, which are not in that study, so it’s not an unreasonable set of measurements.

But now let’s do again my inverted fat tail. In this case it’s the black again, so the blue and the two blues are from the Lamb paper.

The tail is not quite as fat. It’s not really a super emitter kind of a situation, but it’s still a pretty skewed distribution. So 40 percent of the emissions are now from the top 10 percent of sources, and then half the sources account for 80.

So that’s, again, an interesting commentary on if you’re going to prioritize repairing, it would be good to prioritize to repair the ones that are leaking the most, and we think that's a very powerful way to save product and reduce greenhouse gas emissions, so it seems like a win-win.

So finally, just because of the timeliness of storage facilities, I wanted to highlight what this technology might be able to do on a storage facility. And again, to PG&E, thank you. They let us drive on their Los Medanos underground storage facility, which is really up in the hills not so far from here, you can see in the picture in the upper right. There are several injection well pads dotted over this hillside landscape of about a kilometer. I'll zoom in on just one of these.

You can see -- Tracy. Tracy Thai is in the audience and she drove all those circles, so I think she got pretty dizzy. So this is Steve Conley's circles now at a really, really small scale where you're just driving around the individual well pads.

But we know when you're thinking about an underground source facility, there's not only the injection wells but there's also all this other, there's compressors, there's other equipment there that can be leaking methane and you don't want it to confuse your measurements to say, hey, I see methane when of course the operator will say, yes, you should, it's right over here being emitted from this pneumatic valve. In this way by driving around specific aspects of the infrastructure you can measure the emissions.

So the little colored arrows you see there are scaled by relative emissions on a long scale, so blue is fairly small at our detection limit of just a couple grams per hour, all the way up to larger.

And as you highlight, so the yellow arrow is kind of pointed to this well pad because you see upwind of it there are no emissions.

The scion arrows maybe are suggesting there's emissions here, given where you do and don't see emissions, and then maybe there's a small emission here.

So from this kind of data, and this only took I think about an hour on this specific well pad to get this data. And again, it's oversampled. I think we drove more than the 120 times that Steve flew around his. You can get a lot of very interesting measurements.

So I think I'll stop there. I dare not go longer. I want to thank you for your time and thank the organizers for the invitation to come speak.

(Applause)

MR. O'CONNOR: Thank you, Chris.

So I think at this point we're going to jump into the Q&A section for this session, and then after that we'll have a wrap-up session for the day. So if anybody has any questions for any members of the panel, be happy to take them now.

Okay. I have one here. Oh, Elizabeth, you have one? Okay.

MS. SCHEEHLE: I had two different questions related to how some of the technologies might work in California fields, considering a couple of different things. One, what's important in California is also the UFC's as well as (inaudible) methane which is that's what we're looking at for this. But I'm also curious if any of the technologies also looked at VFC and how we can incorporate some of what we're doing for ozone purposes for methane.

MR. O'CONNOR: Who wants to take that one?

MR. CHRISTENSEN: The tunable laser spectrometer, you know, the C2's, the larger the molecule you'll get, the more difficult it becomes exponentially to measure. So say the Picarro LGRs, those higher alkanets are going to be hard to measure.

MS. SCHEEHLE: And the other question I have was related to the density at California fields. A lot of the fields here are more dense than they might be in other places, so I was wondering if you took that into account of how that might play with some of the different technologies.

MR. RELLA: I can answer that, at least from our side.

As we think about, the disadvantage of ground vehicles, you have to have a vehicle and someone to drive it now, although Google is trying to change that, of course. But the advantage is that there are lot of utility vehicles already being in play in these areas, and if you can think about deploying these kind of sensors on the vehicles, you can actually get a lot of unintentional but very useful transects across different areas.

And if you can imagine if you have several wells within a certain region, if you've at least localized it to that, then you can say, hey, somewhere in this 10 by 10 meter are you've got a pretty big leak you better take care of.

So I think, again with the tiered approach, the ground level technology seemed to have at least a place to play in that arena.

MR. GORENCE: I'll just echo. I mean, if you can incorporate some of the point sensors into the work practices on the field today, that's one avenue.
I think also in particular a couple of our log path technologies like UC Boulder and then some of our distributed network systems, they're ideal to over a densely packed field of equipment or wells.

MR. O'CONNOR: So I have a question.

When you think about methane detection equipment, the cost has been coming down over time, and we heard a lot of your discussion, Nate, about the ARPA-E, you talked a lot about lower and lower cost and smaller and smaller. How far down the cost curve can we get with this technology? I mean, Chris, there's a natural sort of conclusion point for how cheap a car of instruments can get because of all the analytics that go into it.

Or Lance, in terms of your work with Mars, you probably can't get that cheap.

How inexpensive are we talking about this is going to become in the next five to ten years?

MR. RELLA: Well, at Picarro the way I look at it is -- and I think, again, Adam brought it up really well earlier. It's not about detecting the molecules, because I think you can do that quite cheaply and quite well, and it's becoming more cheap and even better day by day, but it's about interpreting that information in a way where you can get some actionable information.

I think that the tricky part that a lot of the ARPA-E companies are really grappling with is not only just measuring it but interpreting it so that you can quantify the emissions from an area or a point or a region, because that's what matters.

Everything leaks a little bit, right? A molecule of methane is going to come out of almost anything, but being able to quantify how much is coming out is a tricky bit. And so cheaper sensors help but it’s really about the analytics, how you deploy the sensors, whether it be on drones, vehicles, planes, the long path. I think all of these tools can get at what are the emissions, how do I find out and in a remote reproducible way so we can go do something about it, but also do it in a cost effective way. So I think that’s the part that’s harder to deal with.

MR. O'CONNOR: I don't know if commodity prices are around the corner for this, but I do think depending on where you’re actually measuring in the natural gas supply chain, the work practices are very different. And as we heard before, labor costs are expensive. It depends on what type of vehicle you’re deploying, what are the communications? What’s required for personnel oversight and training? Do you have to drive a truck out there?

But I do think over the next couple years, especially with the hardware, there is real opportunity to hit economies of scale and really come down. And then to the extent that you have autonomous vehicles or UAVs or long path or distributed networks where you get a very large denominator, the costs are going to come down very, very significantly.

MR. NEWTON: Hi, Ed Newton, SoCal Gas. I wanted to talk a little bit about the application for mobile mapping technologies and leak quantification using mobile technology specific for distribution applications within the urban environment.

SoCal Gas has been working, of course, with Picarro since 2012 and worked closely with EDF and Colorado State University on the mobile methane mapping of the four cities within our service territory, and we've consistently seen in terms of correlation the results of the mobile methane mapping technologies to actual leaks on distribution main and service, including customer meters of about 40 to 50 percent correlation.

Leaks in the urban environment can be attributed to activity within the population itself, and as we heard today, emissions from appliances and yard lines, things that are downstream of the meter, it's very costly as a utility to follow up on that volume of indications.

Then from a leak quantification perspective, like we heard from Lance and others, there's a lot of variability in that environment that you have to deal with in terms of quantifying and actually calculating emissions, and we've seen that it is really difficult to get, when you're comparing the results of those technologies to actual surface expression measurements, we haven't seen yet a good correlation.

So I was just wondering. I recognize that advancements are being made all the time and there's a lot going on in that space, but can you comment on any advancements in terms of differentiating pipeline leaks from leaks downstream of the pipeline and improvement of leak quantification?

MR. O'CONNOR: Chris, Ed is saying that there's a lot of false positives, so what do you think about that?

MR. RELLA: Sure. So I think the distribution system and the leaks that come from it are embedded in a pretty complex environment that has other kinds of methane sources. So for one, you need to be able to distinguish as best you can, either by space or by the other gasses associated like ethane or isotopes or other gasses that either coexist or don't with your natural gas, which one's an actual natural gas leak under the ground versus a sewer gas or some other source like that.

So we have technologies that do that. Others have technologies as well, and I think technologies and tracers in particular can help a lot along those lines now. Upstream and downstream of the meter is a different challenge, of course, because that's the same gas, just from a different location, and I'm very interested to see what Mark Fisher and other collaborators and folks working on that learn about the emissions from within buildings and within structures.

The only difference I see as I drive, if I have a leak that's a point source, relatively close point source in the open area between the vehicle and a building, it's going to look different to my plume sensor being near the ground versus what's coming out of a building which could tend to come out of the air conditioning vents or the windows in a more diffuse way.

So it may be able to be possible from, because we have a plume image, to be able to tell from the image, well, that's not a ground based leak plume, that's a building plume, so I think that's one way you can maybe distinguish that, but that's an open area for research.

As to the second question, I think you see some of the ways in which emissions quantification are improving. Our focus, and mine in particular, is driving toward better and more accurate measurements of emission rate when you go by a leak, because I think the real key is you don't want to know about all the leaks in a system, you want to learn about the big ones, and that's really not about concentration, that's about emissions.

And it's a tougher problem, but I think we're making strides. I think that's why we always go back to these validation experiments where we're releasing a controlled amount.

And I should have mentioned that we also did high flow on the leaks presented in the PG&E test facility to see if it matched with what we do. And in fact, it does in a surprisingly powerful way.

But more work needs to be done there to really validate the technology, so I agree with you there.

MR. NEWTON: Do you see the leak quantification being applied initially to (inaudible) locations or trying to quantify during the mobile detection phase of the operation?

MR. RELLA: You're asking about the quantification, whether we'd apply it to known leaks or to fresh?

I think both ideally. There's a lot of benefit if you have just randomly 100 leaks that you know about and you only have money to fix 20 of them, well, wouldn't it be nice to fix the 20 biggest if you have no other reasons other than that. And this you could do, just drive around and quantify the emissions from each of those 100 and say, okay, these 20 are the ones I want to fix. So that's one aspect.

On the other hand, you can see what we were doing in our area with the 16 square kilometers was just our standing driving protocol, and the measurements just come out for free. It's not anything special that we have to do. I think that's also fairly powerful in understanding the greenhouse gas impact of the distribution system in a way that it would be very difficult to do any other way.

MR. NEWTON: That study actually shows you the emissions from both parts of the system, not just the main services, also measuring the downstream emissions from the homes?

MR. RELLA: It’s a good question. I don't know the answer to your question.

What I do know is we don’t quantify emissions from landfills because we look for sharp features that are only a couple meters wide, plumes that are only a couple meters wide, and so you wouldn’t see a broader leak plume. Whether the plume from a building, I don't know what it’s going to look like, so I don't know the answer to that question. But if it shows up like a point source leak would look on the surface, then yes, we would be quantifying that as well.

MR. NEWTON: Thank you.

MR. O'CONNOR: Seeing no further questions, it does look like we’re about out of time, so we’ll thank the panelists and move on.

(Applause)

MS. KOZAWA: Before we close today I just wanted to make a few announcements and then we do have one popup comment that has popped up. And if any of you have comments for the IEPR workshop, now is the time to come up and give your comment as well.

But first, thank you very much to our speakers today, to our moderators, and especially for you, the audience for lasting this long. And we did end on time so I'm really happy for us for that.

I really appreciated the discussions that we had today on (inaudible) super emitters, but also the fact that business as usual and trends are also going to be important. For tomorrow start time is a little bit more friendlier, 9:00 a.m. here. Tomorrow also is a continuation of the CEC IEPR workshop, so we'll be accepting public comments again and hearing them about the end of the day.

And also, if you have not submitted a panel question and if you'd like to, please do so at the back of the room, the clear boxes on white index cards. So with that, I'd like to go to the public comment period. We have one comment card.

Ed Newton, I know you weren't here before, but you're okay with comment? Okay, I guess that's good. And is there any comment?

MR. LEYVA: Melissa, this is Luis. Are there any questions on the phone?

PHONE OPERATOR: And it looks like we do have a question. It'll be one moment, please. And we do have a question from Lorraine Lundquist.

Your line is open.

MS. LUNDQUIST: Thank you. I actually had a public comment. Is this the right time to do that?

MR. LEYVA: Yes, go ahead.

MS. LUNDQUIST: Okay. Thank you. My name is Lorraine Lundquist, and I am a resident of the San Fernando Valley, not too far from the Aliso Canyon disaster area. I wanted to say thank you to all of the presenters and thank you for the enlightening data on methane detection and all of the monitoring information that's been presented today.

My comment is that it's very clear from the prevalence of leaks along all parts of the oil and gas system that priority really needs to be given to cutting off the source of these leaks completely by shifting away from a fossil fuel economy as fast as possible. This is a much more important strategy, and maybe even more doable than tracking down and fixing each and every one of these many, many leaks that we can see are present all throughout the system.

We certainly can do both. We can do both leak reduction and energy shifting, but it's really crucial that throughout the process we maintain the energy transition as the top priority, and that needs to take priority over any kind of leak detection and fixing, so phasing out fossil fuels has to come first and it has to be the most important.

Which brings me to the Aliso Canyon disaster. It really could be considered an opportunity to test how fast we can move away from fossil fuels and away from natural gas reliance. This summer Aliso Canyon is largely offline and it provides an excellent test case scenario to discover how fast we can shift our electricity systems toward conservation efficiency and demand response. We need to really rise to this challenge and use this as a catalyst to shift Los Angeles away from natural gas.

This one disaster has already cost more than the value of the storage facility in the first place, so it doesn't make sense to risk reopening it and risking another ultra high emission event when instead we can use this moment to protect our health and our climate and just shut down the facility forever and learn how to do that for the other facilities that are existing and eventually all of the fossil fuels that we are relying on altogether.

And it's particularly important to begin planning for the winter. There was a reliability workshop for the summer, but we can examine how much we can reduce our direct natural gas dependence by starting now to look at the winter and see how much solar water heaters and efficiency and demand response programs for gas and electrification and everything else that we can install now using this crisis as an opportunity to shift as fast as we can away from fossil fuels, protect our health and our climate and move toward the clean energy economy.

Thank you.

MR. LEYVA: Thank you for your comment.

Are there any more over the phone?

PHONE OPERATOR: I do not have any further questions on the phone.

MR. LEYVA: Okay, thank you, Melissa.

MS. KOZAWA: Okay. I guess with that we'll conclude our public comment period and we'll see you guys tomorrow morning at 9:00 a.m.

Thank you so much.

(Whereupon the Joint Agency Symposium and IEPR Workshop on Methane Emissions from California's Natural Gas System: Challenges and Solutions adjourned at 4:52 p.m.)

REPORTER'S CERTIFICATE

I do hereby certify that the testimony in the foregoing hearing was taken at the time and place therein stated; that the testimony of said witnesses were reported by me, a certified electronic court reporter and a disinterested person, and was under my supervision thereafter transcribed into typewriting.

And I further certify that I am not of counsel or attorney for either or any of the parties to said hearing nor in any way interested in the outcome of the cause named in said caption.

IN WITNESS WHEREOF, I have hereunto set my hand this 22nd day of July, 2016.

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Notary Public

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July 22, 2016