Jill Engel-Cox: All right. Hello, everyone. And welcome to our webinar on methane emissions and abatement. I'm Jill Engel-Cox, the deputy director of the Joint Institute for Strategic Energy Analysis. The Joint Institute conducts in-depth analysis on energy systems, specifically at the nexus of energy finance and society. Our methane emissions and abatement analysis is part of our analysis looking at the evolving power sector away from coal and towards renewable and natural gas resources.

So today is the second of a there part webinar series on our natural gas analyses that we have completed over the past year. A recording of our first webinar, which was last week, on broad power market trends, will be available on the JISEA website later this week, and you can see that web address on your screen now. Our next webinar, on May 4th, will be on spatial and temporal considerations in energy. You can find announcements for that webinar on the website as well.

The studies presented today focused on methane. I'd like to mention these studies were funded by private sector companies who we thank for their support. Although that should not imply any endorsement of their results. So we have three speakers today. First, Garvin Heath will be presenting on the inventory of natural gas methane emissions. Then Ethan Warner will present on cost effective ways to prevent methane emissions. And finally David Keyser will share the economic impacts of five different methane reduction scenarios.

I want to point out, at the end of the talk we will have time for questions. Each of the talks should be about 15 minutes. Please type your questions into the question box on your screen, and you can type it at any time during the presentation. We will get to them at the end of the three presentations. If you want to direct your question at a certain person, just include their name, or just say speaker number one, speaker number two, and then we'll know who to direct the question to at the end.

So now I'm going to turn over the presentation to Garvin.

Garvin Heath: Thank you, Jill. Thank you to the sponsors of this work, and JISEA. So this first report is focused on the Greenhouse Gas Inventory (GHGI), which is a product of the USEPA, and a discussion about sources of methane emissions from the natural gas sector, uncertainties with regard to estimates, the magnitudes of those estimates from methane emissions, and opportunities for improvement of the inventory.

So we're focusing on methane emissions of course come from multiple sources. We're focusing in this report on the natural gas sector. The purpose of the report was to first off summarize the methods and results of the inventory. And then to identify potential gaps and barriers to improvement of the inventory. And then opportunities that we made suggestions about to improve the accuracy of the inventory with regard to methane emissions from the natural gas sector.

We'll be making observations and suggestions in this presentation that the focus here – and of course additional details can be found in the report itself, the cover shown here, and the link, and the link will be provided in another slide, later.

I want to emphasize, first, in the very first slide, in the contents, that the Greenhouse Gas Emissions Inventory is a critical resource. The EPA, Environmental Protection Agency, is the one who publishes this according to standards and requirements of the United Nations Framework Convention on Climate Change, which the US is party to. The goal of this inventory, adherent to those standards, is to identify and quantify emissions sources and sinks of greenhouse gases from human activity. So it does not include those emissions that might come from natural sources, but just the anthropogenic ones.

And the Greenhouse Gas Emissions Inventory is a resource that many agencies at all different levels, organizations, and researchers rely on for its results, for analyses and decision making that they're conducting. In particular, the critical resource for understanding the US contribution to global climate change in the form of the emissions of greenhouse gases, tracking trends – because it's an annual resource updated annually for a particular year – and then identifying and prioritizing abatement opportunities. That's not the focus of this report, but actually a companion one that Ethan Warner will be presenting. And then finally informing public policy and investment decision making.

So there are concerns about the accuracy of this inventory. But I want to emphasize that the inventory is absolutely critical, and these suggestions are really just to improve it, and not suggest any replacement.

The inventory finds – and we're focusing here on the inventory published in 2014. It was the latest available at the time of the research included in this report. The inventory finds that natural gas produces about 23 percent of US anthropogenic – that is human-caused methane emissions – from four segments that are grouped, grouped together. Production of gas, from well pads. And then the initial transport of that gas. And initial compression of that gas. To where it's moved to the long distance transmission, which is the next – or sorry the processing facilities, if they are used. Not all places in the country use processing. But and that's to remove contaminants. And otherwise – and also coproducts. To get the gas to grade to then transmit it over long distances, as well as store it. And then finally to distribute that gas to the end users.

Some users take gas at transmission pressure, but most take it at distribution pressure, which is lower. And through smaller lower pressure pipelines that works often in urban areas. So you can see that the percentage – there's not quite an equal breakdown, but it's a significant contribution from all four of these segments.

One finding from the report, just as far as the emissions profile is concerned, is that about 43 percent of natural gas methane emissions are from compressors. And you can see in blue that the contribution of compressors to the total in different – each of these four different segments – is nearly complete in the processing segment, and the vast majority in the transmission and storage segment, and then also contributes non-negligibly to the production gathering and boosting, mostly in the gathering and boosting portion.

So significant amount of emissions coming from these compressors. With regard to distribution segment emissions, and further details on all this, as well as other segments, are included in the report, but for the distribution segment, about 33 percent is from cast iron and unprotected steel, despite having the lowest mileage. And so the contribution is because they have the highest emissions factor. That is the highest emissions per unit of mile. And so these are prioritized in the emissions sources which can then imply or suggest anyway a look at for abatement opportunities in these areas. Although we have to consider economics and operational factors to get a better sense of the opportunities for abatement.

So one of these functions, as I just suggested, of the inventory, is for source level prioritization, which is greatly affected, then, by the emissions estimates, at the source level. And one challenge for the current inventory is when measurement studies have been done, and then comparisons made to the inventory, there have all been found discrepancies between the two. So here's an example of a prominent study, coordinated in a whole series of studies, by the Environmental Defense Fund, University of Texas in Austin. David Allen was the lead author of this paper, published in the Proceedings of the National Academy of Sciences in 2013.

And it looked at four different sources within the production gathering and boosting segments of the inventory. And in measurements of those four sources from a sample, a national sample, from each of those. It made comparisons for each of those individual sources, and also a comparison at the national subtotal, scaling up those individual sources and samples up to a national scale estimate.

And although the conclusion at the national scale was that the measurements were within a reasonable bound of the inventory estimates, when you look at the details of each of the four contributing, obviously there are greater variances between the measurements and the estimates in the inventory.

And so one – ask a logical question – is the near equivalence at the national scale due to compensating errors at the source level? That, therefore, affects the ability of the inventory to inform source level prioritization.

So I wanted to discuss a little bit of nomenclature, because it's going to be used in some of the recommendations we made in the report. There are two categories of studies kind of classified commonly, but with differing definitions, unfortunately. So it's not really consolidated in the literature yet. So called top down and bottom up.

The definitions we're using here comes from a White House report on the climate action plan, and suggests that a definition for the top down studies are that they infer emissions for measurements of atmospheric methane concentrations, or from atmospheric models themselves, whereas bottom up studies focused on specific sources, or activities, causing the emissions, and measuring those, often, but also there can be model based assessments, especially from the bottom up, and, in particular, those are – inventory is one example of those. So in the graphic, we have, from the bottom up, represented the inventory approach, which I won't go into, but the report does.

So both of these types of studies, top down and bottom up, have roles to play to improve the inventory, and both types of studies have been conducted over many decades, but there has been a significant uptick of interest in methane emissions from the natural gas sector, and so there's been many new top down and bottom up studies in the last just few years. Both of them have challenges. And they have uncertainties associated with them. And potential for inaccuracy. Neither, at this point, is so good that we could call it a gold standard or sort of the truth. And yet they both really do have roles to improve the inventory.

For instance, top down studies are useful as potential comparison points to inventory estimates. Any differences between the two can then help generate hypotheses which can lead to future study, and the narrowing of hopefully gaps found between the top down measurement studies and the inventory estimates. We provide some recommendations for areas to improve top down studies, as they have been practiced recently. In the report. We won't go into them here. We're focusing more on the bottom up portion, which, just as an example, we'll give some more details in the next slide, measurement studies from the bottom up perspective can help to update outdated emissions factors, which many – how many of the studies have been both designed and used to date.

So, inventory improvement through bottom up measurement studies. The challenges with the currently used emissions factors are that they're not representative. They're outdated. Many of them come from two or three decades ago. And of course the industry has changed since then. There are concerns regarding the sampling bias. That is the – do we have a representative and random sample of the sources that were measured that then are used to develop an average emissions factor for that source category?

Was there a reasonable sample size? And, in particular, with regard to sample size, are the mean emissions factors capturing what has been called in the – commonly in the literature – the fat tail, or the super emitters, or the extreme value of the distribution within a given source category? And, finally, are all salient dimensions of emissions variability captured in these emissions factors? Regional variability. Variability by market capitalization. Or size of the operator. Variability across by different age. And other factors.

So, some suggests we made in this report about potential improvements are to update emissions factors for prioritized emissions source categories, and we gave some suggestions on those. But there's been many studies that have gone on trying to do just this. But in particular these new studies should focus their effort, or include in the focus of their effort, to ensure that they have robust sample size, strong sampling design, to capture source variability, and the minimization of self-selection bias. These are challenges. They cost – they will often cost more to conduct studies that are more robust in these features. But they will serve us much better in making accurate estimates within the inventory.

Also, to leverage available evidence to explore how to characterize emissions variability within the emissions factor metric. And, finally, regional and other variability dimensions should be explored as well. We shouldn't forget that the inventory includes not just emissions factors, but those are multiplied by account of how many sources, within a given source category, then emit at that average rate. And these are called activity factors. Less attention has been focused on these. Especially in the open literature. But they need attention.

Currently the data sources are the Greenhouse Gas Reporting Program, another EPA program that the EPA is trying to utilize more, especially as it's being expanded. But attention could be given to new sources. The methods that are used to develop these emissions factors should adhere to principles of transparency, simplicity, and accuracy. And there needs to be a balance given between the need for a consistent time series – that is, that we can maintain similar methods back-casted to the original inventory, following the UNFCCC guidelines – with the need to improve current accuracy, based on newly available data sources. And we recommend some improvements particularly to focus on these activity factors in the report.

The inventory improvement can also be addressed in terms of completeness and structure. We know that the inventory has gaps. In other words, there are known sources of emissions. These are still anthropogenic sources that are not included in the inventory at all to date. And that's primarily because there's been a lack of information about these. And yet, to improve the accuracy, we obviously need to address gaps, especially ones that could be significant. And so we've – for here there are potentially others as well that could be addressed. And these are listed in our own sense of prioritization order.

But and we know that EPA is trying to address many of these. And we hope that they and partners and others conducting research can catalyze behind filling these gaps as well. The structure of the inventory itself also presents some challenges. The inventory is organized sectorally – that is, by the industry sectors, and then the segments within the natural gas sector, and then the sources within that, within each of those segments. It creates challenges when comparing to a measurement, because this sector definition does not always have a neat spatial domain, because there can be sources that come from the same exact location, but that are organized in a different sector.

So in other words, as an example, there can be gas coming off of an oil well, and, at some point, or the converse, oil coming off a gas well, and that's now a mixed sector, in the same exact area, from the same exact source, that then we measure in the atmosphere and it's hard to discern the difference. And then certain segments are grouped like gathering with production, which we know EPA is proposing to address by separating them, which we think would be useful. So we make some specific suggestions along the lines of this completeness and structure of the inventory.

Uncertainty quantification is critical for informing decision making. Communicating the results of the inventory. And for verification of the inventory estimates with measurements. Currently, the inventory uses the Monte Carlo parametric uncertainty quantification approach, which assumes log normal distributions in almost every case. The reports over the uncertainty range – that is, the percent compared to a base estimate, which of course does change – but the percents haven't changed since 2010 – so there's opportunity to update that, especially knowing that methods have changed over that time.

And then the inventory uses expert judgement to assign uncertainty in particular to activity factors where we don't have a lot of data to inform the distribution of the particular parameter. And so there's – we think there's a great deal of opportunity to strength the uncertainty quantification with the inventory. In particular, sponsored studies should robustly quantify uncertainty. That's not always been the case. And so then the inventory team is left without as much useful information for they themselves to incorporate strong uncertainty analysis. And then of course within the inventory itself, those methods could be strengthened and of course updated.

This is a map that was included in the report. It's already out of date, because there is many new studies that are published all the time. But it just shows the published studies to the date that we built this map. Across the value chain, for the natural gas sector, and of course geographically across the country. Some studies are noted in Canada. Some studies reported nationally within the US. Those are noted under a United States heading in the East Coast and Atlantic Ocean there.

And in the context of having so many studies, and more that are ongoing, and have been published since publication of this map, there is an opportunity to enhance coordination amongst these studies. That of course is always challenging, given differences in sponsors, and the organization themselves conducting the work. But coordination would hopefully leverage complementary efforts, and then more efficiently improve our understanding.

There's also something that's I think critical and has not really ever been done, which is that inventory estimates have never been paired with measurements. That is the inventory has never been performed contemporaneously and systematically at the same time as a measurement campaign to actually fairly compare those two results. And all prior estimates or comparisons, rather, between measurements and inventory, they've used a past inventory, and compared their results to those, where there are differences not only in temporal, but also spatial and sectoral boundaries, which make that comparison really incommensurate.

So the confidence of the inventory could be enhanced considerably, although it takes considerable effort to do so by contemporaneously and systematically pairing measurements and inventories together. So I'm going to pass off the baton to Ethan Warner, who is going to be talking about our marginal abatement cost curve work, which the inventory, the analysis of the inventory of emissions, of course, informed.

Ethan Warner: Thank you, Garvin. Before starting I'd like to thank JISEA and the other sponsors for supporting this work. I highly recommend, folks, go to the report link provided here to look at the details of this report. This is very data driven analysis and report. So I'm going to be covering things at a very high level. If folks are interested in some of the more detailed insights, I recommend seeing the report.

So context for this report. There was interest in getting a handle on what the existing literature says about the opportunities for methane emission abatement in energy sectors such as natural gas, coal, and oil. So we set out to sort of synthesize and analyze pre-existing work in this area to identify where the opportunities were largely being with 10 percent of methane emissions in the US being from anthropogenic sources, seen here in this pie chart, as taken from the US inventory in 2014.

About 40 percent of this is from natural gas, coal mining, and petroleum systems. So there's interest in identifying potential targets for reducing methane emissions, specifically which sectors and which segments of the supply chain of those sectors, and then identify the major strategies for reducing methane emissions from those sources. There's many possible opportunities for reducing methane. But the cost significantly varied among those opportunities, as well as the impact of employing those methods.

So we focused on synthesizing published estimates of emissions reduction potential and cost. Primarily from an ICF report in 2014, an EPA report in 2013. Before going out further, I'd like to thank the research groups involved in those reports. They were very helpful in sharing data with us and helping us produce the marginal abatement cost curve that I'll be showing later on in this presentation. In any case. The synthesis involved providing a comprehensive national analysis of the opportunities in natural gas, coal, and oil sectors.

Identify the largest opportunities for low cost abatement. In the context of the report, we define low cost as being less than zero dollars per metric ton of CO2 equivalent reduced, however, arguably, anybody could take the data from this report and supply their own definitions of what low cost actually means. And then of course _____ _____ report under what conditions these opportunities are low cost. Because obviously costs vary depending on your assumptions about what goes into those costs.

This slide provides a high level summary of the total potential methane that could be reduced. To the left side of the break of this table. By sector. As well as the supply chain segment within sectors. As you can see here, the major identified opportunities at 670 or 67 million metric tons of CO2 equivalent per year, _____ _____ natural gas, with smaller quantities in oil and coal.

On the right side, you can see two scenarios that were examined in the report. Looking for where low cost reduction could occur. On the left side, you can see percentages that show, for example, 32 percent of that 20 million metric tons of CO2 per year could be reduced at quote-unquote low cost, less than zero dollars per metric ton of CO2 reduced. On the basis of being able to capture revenue from the gas you save in all parts of the supply chain segment, except for transmission.

One of the reasons why this scenario was examined in this particular report is previous studies have identified transmission in natural gas as an area where there are significant barriers to being able to capture revenue from gas that is saved. There are many reasons for that. But one such example is that the owner of the natural gas is not the same person or entity that owns the infrastructure transmitting natural gas. So the incentives for reducing methane leakage or venting are not aligned to address those sources of methane leakage.

Obviously, if somehow through policy or some changing of the way industry operates, or other sources, if that revenue from capturing natural gas in the transmission sector could be captured by the owner or the infrastructure, there would be incentive to reduce transmission methane emissions by about 81 percent, based on these studies that we looked at.

Overview of the findings, before going on to the actual marginal abatement cost curves. Many opportunities were already low cost or become low cost through revenue of capturing natural gas as previously pointed out. The four major emissions reductions approaches that were identified that had the highest impact and were considered low cost were detection of leaks and repairs of the sources of those leaks leaking emissions, across the supply chain.

Capturing of vented gas primarily from flaring in natural gas production and oil production. And then replacing various pieces of equipment that vent gas as part of their operations. In this case shown here, high bleed pneumatic devices, and gas powered pumps.

It was found that these low cost emission reductions exist across most of the natural gas supply chain and oil production. But going back to the previous slide, you can see that distribution. There was no quote unquote low cost opportunities identified. Previous studies in this area basically indicated that addressing methane leakage and venting in the distribution sector should probably not be considered only for cost reasons. But there are many other reasons to address methane leakage in distribution sectors, sort of for example related to safety reasons, which is one reason why industry in this – and local governments are looking to reduce methane in distribution in the real world.

Some cautions on this data. The data being presented here represent average national cost estimates for potential opportunities to reduce methane. Actual opportunities are highly variable and site specific. So take these as they are, as a national wide average assessment. And this study does not address many other potential cost and benefits of methane reduction that in theory exist, such as externalities, reduction of other emissions, and then the safety issue, and leaking pipelines.

So before going into some of the marginal abatement cost curves that were constructed, there's just a slide here kind of walking through how to read these curves. The marginal cost of methane reduction is along the Y axis, and the methane reduction potential is along the X axis. And so you can read that the height of an individual box represents the cost per unit of emissions reduction. Whereas the length of a box represents the annual abatement potential of a particular opportunity. And each box represents either an opportunity or a segment of the supply chain or a fossil fuel sector, which will vary from in each individual figure in the next following slide.

And of course the area of the box represents the total annual cost of implementing a given measure, just the cost of the abatement opportunity, multiplied by the size of the opportunity. So on this first example, where all the data is summed by sector and by segment of the supply chain – so you can see here there's production for oil, then coal mining for coal, and then production transmission distribution processing and storage for natural gas.

You can see of these opportunities that are listed here, only about 400 million metric tons of CO_2 per year could be reduced at low cost, given relative current conditions, where revenue can be captured in many of those natural gas sectors. As another example, if, as I was saying before, if the revenue from gas capture and transmission can be captured – transmission then moves from being well above zero to being below zero. If the revenue can be captured from that gas.

In the report, the data is sliced and diced a bunch of different ways. Just an example here. I'm not going to go through where examines the opportunities by the opportunity type across all parts of the supply chain, and then also looks at all the individual opportunities across each individual segment of the natural gas supply chain. So I just want to conclude and thank the funding for this, and support of JISEA, as well as the contributors who provide thoughtful comments and inputs on the report and the organization of the data into MACC curves.

I'd like to hand this off to David Keyser, who is going to talk about some of the data that was taken from these marginal abatement cost curves, specifically around the gas and boosting transmission and distribution sectors of natural gas. And use that in the analysis of jobs.

David Keyser: Thank you, Ethan. All right. Moving onto jobs estimates. So Ethan presented a lot of great information about the marginal abatement cost curves and estimating costs of different natural gas abatement scenarios. And back in 2004, I mean 2014, we took this information, and used it to estimate gross jobs and other economic impacts that could be supported by these different scenarios. And I'll talk about what I mean by gross jobs in just a second. But first of all, I would like to thank the Department of Energy for funding this research. And especially James Bradbury, whom we worked with very closely on this project.

This report – there is a link to it at the bottom of this page. When the presentation is sent out after this webinar, you can click on that, and it'll take you to the larger report. As Ethan and Garvin have both mentioned, a lot of this work is really data intensive, and there's a lot of information that's in the reports that we just don't have time to go over today, or we're going over at a very high level. And so if this is something that's interesting to you, I really encourage you to download the report and take a look at that.

The analysis that we did is looking at five specific scenarios that are in published literature. Most of them came from ICF International. The ICF scenarios were enhanced leak detection and repair. So this scenario is moving to quarterly inspections of compressor stations instead of annual inspections. And that's ongoing. The second is a gas capture scenario. So when transmission stations are vented, we're estimating the impacts from capturing that gas instead of venting it into the atmosphere.

Then there is low bleed pneumatic devices, and this is assuming we're going to replace 60 percent of high bleed pneumatic devices with low bleed devices, and then 50 percent of intermittent bleed devices with low bleed devices. By pneumatic devices, I'm talking about things that are like pressure regulators, valve controllers, and devices that control liquid levels in the distribution segment.

And then the pump down scenario. And this is similar to gas capture, basically. Pipelines are vented prior to any work being done on them as a safety consideration. And we're estimating capturing that instead of releasing it into the atmosphere. The final scenario is a pipeline replacement, and this was taken from a different source. It's actually from a blue green study. And there's a link to that in the overall report. And this is estimating replacing about 9 percent of aging distribution lines.

So by no means is this a comprehensive set of measures that could be implemented, but it is a subset of options. One important caveat here is that the impacts of these were estimated separately. So in other words, we're not estimating implementing all five scenarios, or one or two in conjunction with one another. So there may be synergies and cost reductions that occur as a result of implementing more than one at one time, and these were not estimated.

The methodology we used in this study is using an input-output model, specifically the IMPLAN model at the national level. Input-output models have the advantage of being commonly used for this type of analysis. And also are a very comprehensive way of modeling economic activity that isn't just related to a project. And by that I mean it looks at a wide section of economic activity. So for example, if you're constructing a pipeline and we want to estimate the impacts from constructing a pipeline, the input-output model would also capture economic activity in iron ore extraction or steel production. And these aren't – and just from looking at construction.

And I'll get into a little more detail about what I mean by that in a moment, and where those are captured in the results. But these models certainly have certain limitations. And I'll get into the limitations, and how to interpret results momentarily. But first I want to talk about the taxonomy of results. There are two types of results that we present in the study, direct and indirect. Direct are the ones closely associated with the project.

So for in the example that I just gave, pipeline construction, the direct impacts would be the construction crews that are out there actually doing the pipeline replacement. If we're looking at purchasing a generator, these would be jobs that the generator manufacturer would be another example. Indirect are really the spinoff, or ripple effects, throughout the economy. These are those second order impacts.

So this would be the natural resource extraction and steel production I just mentioned. Or, in the case of purchasing a generator, it might be copper wire production. So those are those spinoff effects, but they're much more broad than that. They capture things like business to business services. You might have financial legal services, accounting services, basically all the other economic activity that would occur in the economy to support those direct effects.

But, as with any kind of estimate, there certainly are limitations to doing this. As I mentioned earlier, these estimates are gross, and not net. By that, what we're looking at is expenditures on these projects. We're not taking into consideration a lot of other things that could affect the overall impact of it. For example, there might be changes in land use. Really big construction projects might cause changes in local wages. And that can certainly have economic impacts.

If you have a large scale project in an area, it could also affect migration. I mean you think about the economic impact of Bakken formation in North Dakota, where you have a lot of people coming up there and that changes all sorts of other economic metrics we're not looking at. Like changes in prices. Changes in property values. And as prices change, producers may change inputs that they use. We're not looking at those kinds of things. We're just looking at impacts that are solely associated with the expenditures of – made to implement these measures.

We're also not looking at opportunity cost. So whether it's a good investment to invest in a pipeline, or a good investment to sink the money into the S&P 500, we're not looking at those kind of things. We're just looking at the projects. The other thing about input-output models is that when you look at these scenarios, it's assuming prices are constant. So again were not looking at changes in wages. We're not looking at changes in relative prices of different inputs. And then as I mentioned earlier, we're looking at all these inputs, all these scenarios, independently. We're not capturing synergies between scenarios.

And then looking at the cost and abatement data, one thing that pops out almost immediately is that pipeline replacement is significantly different from the other four scenarios in that it's significantly more expensive. The cost for this project is approximately $46 billion. And then the abatement potential is a little bit lower than the others. The scenario with the highest abatement potential is actually enhanced LDAR, which is the most expensive of the ICF scenarios, but again, has the largest abatement potential. That's followed by gas capture, and pump down.

And I'll get – I'll bring these costs back up later on, after we've had a chance to go over the economic impacts. I think just so you –

once we see the potential economic impacts from these, I think it's helpful to look at the costs again, to kind of put that in perspective. So I'll start out with pipeline replacement, since that's the biggest scenario. And certainly it has the largest potential employment impact. The annual employment supported just on construction would probably be somewhere in the range of about 46,000 workers nationally. Remember, these are national not local.

And so this is spread out geographically. With a total impact of about 83,000 jobs. In terms of earnings for these jobs, the highest earnings are probably the people actually doing the construction projects, not necessarily in the supporting sectors for the indirects. So on site, doing the construction, that's about probably about $75,000.00 annually per job. And so that brings a total annual average earnings to about $68,000.00. With GDP of about $39 billion.

For the LDAR scenario, employment is quite a bit lower than that. But remember, the cost for that scenario is also quite a bit lower. So on actually doing the work at the compressor stations, it's probably about 570 jobs annually, for a total of about 1,600. These jobs are a lot more specialized than the construction jobs that might be supported by the pipeline replacement. And so the _____ _____ and this is really reflected in average annual earnings. And so the onsite – those are about 100,000, and then the overall average is about 87,000.

Now, what I want to mention about this annual average earnings figure that I didn't mention before is that this isn't just wages and salaries. This includes benefits and employer contributions as well. And so that's why if you're looking at those, thinking maybe that's a little bit high, that's why those numbers are – might seem a little bit high. So they do include employer benefits. So from an employer's perspective, it's kind of like payroll.

The gas capture is a little bit lower as well. Employment nationally for this scenario would probably be about 150. Annual average earnings are actually pretty similar to the LDAR scenario, because you do have that specialized labor in there. So for the direct, that's about 95,000, and, overall, that's about 79,000. And then the total job impact is about 490. And I'll bring up a summary table at the end, so you can have more of a comparison between all of these. But you can see this is a little bit lower.

And low bleed pneumatic devices is lower as well. Nationally, the direct impact of this will be about 30 jobs. But, again, they are fairly well earning jobs, at about 95,000 annually. And then the overall impact, you can see, there's a lot more of an impact in the indirect effects here than the direct effect. There's a lot of supporting economic activity that would be supported by low bleed pneumatic devices.

And last but not least is pump down. This is a little bit smaller, but overall the average earnings are higher on this for pump down than they were for the previous ones. About 160,000 annually for the direct, and 118,000 overall. As with low bleed pneumatic devices, you can see that there's more supporting activity than there is in the direct activity. So probably a lot of manufacturing and supplying various components, capital components.

So overall, all of these scenarios could support of a total of about 85,000 jobs. Remember, this is looking at the implemented separately. But overall most of those are being driven by the pipeline replacement scenario. Among the other four scenarios, low bleed pneumatic devices would probably support the highest number of jobs, whereas pump down would probably support a lower number. But, again, remember the cost figures that pipeline replacement was the most expensive, and then pump down was the least expensive.

One thing that I don't really have time to go over in this presentation, but it is in the report, is the value of captured gas. I think certainly that's something to at least consider when looking at the costs of these different scenarios. In the report, we do estimate it at various discount rates. But Ethan made an important point earlier. Which is also made in the report. Which is that the people who would be funding these infrastructure improvements aren't necessarily the people who would be benefiting from captured natural gas. And so you can't necessarily say that – can't necessarily offset the cost of these investments with the value of the captured gas, because those aren't necessarily accruing to the same parties.

And so if you want to contact us, if you have any questions or comments about the study, we welcome that. The authors of the study are listed here. Myself and Ethan Warner, with National Renewable Energy Lab, and Christina Curley with the Department of Economics at Colorado State University. With that, I think I'll hand it off to Jill.

Jill Engel-Cox: Thank you very much to all the presenters. There we go. Now we'd like to go to questions. We've gotten some questions so far. Thank you very much. We'll go through those first. But if you have additional questions, please go ahead and type them in the question box, and we'll get to as many as we can before our time is up. So the first few – actually, a few questions for Ethan right now. So why don't we go ahead and start those?

The first one is _____ _____ low cost reduction economic analysis, have we factored in technical feasibility of the scenarios suggested, and, if so, how is it done?

Ethan Warner: Depends what you mean by technical feasibility. As I said, these were sort of gross national estimates. So there is not really an assessment of what are the barriers you might encounter in particular regions of the United States, or in particular cases. Really, the costs should probably be considered as average costs of a sample of data that's been collected by EPA and other sources. So, to some extent, the data represents real world cases that have addressed – probably addressed some of those technical barriers to the implementation. But because it's a sample size, it's probably pretty small. It's probably missing some of the extreme ends of the technical barriers to implementation.

Jill Engel-Cox: Great. Thank you very much. And the next question is for you as well. So related to the emissions and oil production section, the highest carbon dioxide, or even the methane emissions in this section, come from associated gas flaring. Therefore it has the highest potential of emission abatement. While there is no accurate emission factors for gas flaring, there is no emission factors reported in EPA. And so how have you addressed this issue, and what are the attempts to estimate methane emissions associated with gas flaring?

Ethan Warner: So I'm not really exactly familiar with the flaring emission factor from EPA, but it is an important point to note, that because the marginal abatement cost curves, as their basis for potential emissions reduction, use the USEPA inventory, any issues associated with US inventory also apply to how the data is used to produce these marginal abatement cost curves and existing studies. Garvin, do you have any thoughts on the emission factor of methane? I'm not sure if that sounds right or not. Could you repeat the question for him?

Jill Engel-Cox: Yeah. It's basically related to emissions flaring. And it is not – there's no emissions factor reported in EPA.

Garvin Heath: For oil?

Jill Engel-Cox: And so how do we address flaring in our emissions? Related to oil.

Ethan Warner: Doesn't sound right to me.

Garvin Heath: Yeah. I'm maybe a little confused by the question. General answer is we use the results reported in the inventory. And to the extent that there are gaps, there is improved information that's become available from other studies, or other factors, they're only addressed as we've felt important to comment on, and not as a result of – and so we don't deviate from what EPA themselves have published.

Jill Engel-Cox: Okay, excellent. So the next at least two questions are for you. Actually, I think the next three questions are for you, Garvin *[laughs]*. The next question is how – so this follows on, in a way, from the previous question. How are your results impacted by the new methodology used by EPA for estimating methane emissions in the just released 2014 report?

Garvin Heath: Yeah. I expected a question like this one. EPA's methods are changing every year, in particular for methane emissions for the natural gas sector, which I know that this questioner, and probably others in the audience, know quite well. Because of the amount of attention on this particular industry, and the methane emissions associated with it, the importance of methane, and considering fuel sector, as well as other factors. And EPA, to their credit, continues to evolve those methods over time with more – with new information and other kinds of improvements.

Some of the recommendations in our report are dated, because EPA themselves have said that they want to address that particular topic. Most of the statements that EPA has made have actually not made it into new reports, but some have. And we applaud EPA for continuing to improve this area of the inventory for – importance that I think we all share in that. And yet I would say that many of the recommendations, suggestions that we made, especially if kind of abstracted, perhaps, even beyond specific applications, are still very much applicable.

So we know that for instance EPA has read our report, and considered its recommendations. And Department of Energy, in funding work that would help support improvement to the inventory, have also considered the recommendations of this report.

Jill Engel-Cox: Excellent. Thank you very much. The next question they say is a simple question. I don't know if it is. Have the total US methane emissions risen or dropped since 2000? The EPA website suggests that the 2014 emissions are below the 2000 levels. But it's not clear if this includes the updates measures as described by you, Garvin. So what is the – things have gone up or down since 2000? Do we have a sense of that?

Garvin Heath: So I wanted to show another slide, if I could, that's in the supplemental slides. It might take me a second to get there. Can I? Click, click, click *[laughter]*.

Jill Engel-Cox: There we go.

Garvin Heath: Okay. No. Not that one. So of course we have lots of other material that we included in there. This is the one. And the specifics are not important. The story is that EPA, in changing their methods, has back casted those change in methods to previous inventory estimates. So this slide shows the inventory estimates for the year 2007, from each inventory that's been published since the first that published those results. There's always a lag. So the year 2009 was when the first inventory for the year 2007 emissions was published.

And you can see how much it changed over time. I think many in the audience are quite familiar with this. But the 2014 – so now almost two years ago – inventory, of course, made changes from the previous, which made changes from the previous, which actually was maybe the same as the other. But these method changes over time do happen. And that affects the time series, and our understanding of the time series, and it kind of jumps around in both directions. They can increase or decrease depending on the change in methods that happened.

EPA in doing their continuous improvement, makes these changes, and so the results that we analyzed do differ in the current inventory than when they were published at the time that we were doing our analysis. Those – I think they are improvements that EPA has made. They're giving us I think a better understanding of those emissions sources. But they also continue to evolve in the context of new studies that are being published on an ongoing basis. It seems like almost every week that there's some new study that EPA then would be considering.

So have emissions changed in which direction since the year 2000? Our understanding of that is changing as new information is evolving and EPA incorporates them in the inventory. It differs by segment. And I look at – just brought up the inventory report itself. And for methane emissions there's a hole – it looks to me like it's very consistent between 1990 and 2014, using the currently used methods. In the natural gas sector, I couldn't quickly get this up to – and respond to the question. But we could take that more specifically offline, maybe, if you want to.

Ethan Warner: I got the answer. So in that regard, it has decreased from 2000 to 2012. Based on the 2014 inventory.

Garvin Heath: Yeah. And that's been a trend that the inventory has noticed for many years. But there still remains questions, because of how measurements, when they have been done and compared to inventory, understanding of course that we're not always comparing apples to apples, but, as best as we can, when those comparisons have been made, it's been shown that there are discrepancies. So there's still more work to be done to improve the accuracy of the inventory.

Ethan Warner: And also it's probably worth noting that a lot of those reductions that have occurred have occurred in the production segment of the natural gas sector. Which is one of the reasons why in both my report and David's report, even though we present results on natural gas production, a lot of the discussion analysis is on other segments where not a lot of historic methane reduction has occurred, according to the US inventory.

Jill Engel-Cox: Excellent. Thank you. And I think we've actually covered the next question, which was related to updates in the EPA, updates in the methodology, and how that affects your recommendation. So I'm going to skip to – given the time, I'm going to skip to the next question, which is for David. Which is – how is the LDAR cost considered for upstream cost reduction opportunities that would require LDAR to be located? It is clear that it has not paid for itself in general, but it is also clear that some large sources can be controlled economically. Is the cost of finding those opportunities incorporated into your cost analysis?

David Keyser: It is not. Again, we're only looking at potential gross impacts that could be associated with these. We do estimate discounted value of captured gas over a five year period. But we're not using that to try to estimate whether or not those expenditures or those investments are actually economical or not. So whether it's cost effective or not is something we did not estimate in the study.

Jill Engel-Cox: Okay. So I'm going to throw this last question out to everybody. If anybody has an answer to it. How can we overcome the bias in emissions measurement from the effect that operators may behave differently when they know they are being watched or that there is a measurement going on?

Garvin Heath: I can address that one. I think that's a real challenge. It's hard to know the magnitude. And potentially even the direction of bias. Because we don't know the counterfactual. We don't know about the behavior of those who are not studied, who are not measured. By using methods of measurement that are offsite, that do not require site access, or otherwise requiring permission, is one way to avoid that. But those methods are, themselves, challenged, because often there are improvements to the accuracy of the use of those measurement methods, such as tracer leaks, when you release your tracer onsite, versus from another location, across the boundary form this particular site.

So we have challenges from some of the approaches that we have to get offsite, and therefore not require operator cognizance and support. And yet I should also say that operators, when working together with and sharing information with researchers, can greatly improve the – I think probably the accurate interpretation of the measurement results themselves. In other words, we take a measurement, we get an answer that says emissions are X at this time, well, why were they X? What was going on at that site?

We take a sample. Now let's say 50 measurements. Two of them look different than the others. Well, why was that? Well, if you don't have cooperation of the operators, you can't often understand that and then be able to properly interpret it. So having the support of operators in doing one's studies can be a real advantage to interpretation. And yet we have this concern that there might be bias, and therefore a change in behavior.

So it's a real challenge. I say it's still a conundrum. We don't have a clear path forward, but we'd like to continue working with operators, and also do other measurements to try to test that.

Jill Engel-Cox: Okay, great, thank you very much. That's all the time we have. Our next webinar is May 4th. So please go to the Joint Institute website if you'd like to sign up for that. Relating to spatial and temporal considerations for energy decisions. So thank you very much for all of you attending this. The slides will be made available on the website, as well as a recording, in probably about a week. So if you missed this, or you want to review anything, or you want to share, please feel free to do that. Thank you very much for attending.

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