1	Introduction
2	Here's a quick summary of the material I'm going to be covering. First, we're going to look at CO2 in the atmosphere. This is why where interested in sequestration. Next I'll focus on how we sequester CO2 by going over the basics of carbon sequestration. Then finally I'll tackle the where by taking a look at various projects here in New York.
3	On a monthly scale, the amount of carbon dioxide in the atmosphere varies in a predictable way. This is called the keeling curve, and basically what it shows is that in an annual cycle, CO2 levels are highest around April and May, and reach a low around October. This is primarily driven by the uptake of carbon dioxide by plants in the summer time. Now some of you may be thinking "but that's only the northern hemisphere, the southern hemisphere has its summer during our winter." And although that it true, here you can see that most of the land on this plant is in the northern hemisphere, so that is where vegetation will have its strongest effect.
4	Now if we look at graph of atmospheric CO2 over the last 4 years, you can see that annual variation in red, but a lot of times, we want to look at the larger trend, so we use a running average, like this black line, to help look past the annual cycle. As you can see, the concentration of CO2 in the atmosphere has been steadily increasing for the last few years.
5	Now if we look at the last 55 years, you can see this trend is nothing new. CO2 levels in the atmosphere have been increasing for a while.
6	Here we have a graph of atmospheric CO2 concentrations going back 10,000 years. Things seem pretty steady until we get to the 1800's where it just takes off. This sharp increase is linked to deforestation and the industrial revolution when we began burning large amounts of fossil fuels.
7	Let's go back even further. This graph shows CO2 levels for the last 400,000 thousand years. Now we start to see some significant variability.
8	Each of these lows is associated with a glacial periods and each of the highs are interglacial periods. As you can see, we have been in an interglacial period for about the last 10,000 years. Still, notice that present day CO2 levels are significantly higher than any time in the last 400,000 thousand years. Also note that when this graph was made in 2010, 400 ppm was the projected concentration for 2020. We have already hit 400 ppm, and it's only 2014.
9	You might be asking yourself, "How could we possibly know how much CO2 was in the atmosphere 400 million years ago?" The answer is in the ice. Similar to the rings of a tree, the ice at the polar caps has annual layers. Climatologists drill wells and collect ice core that go back hundreds of thousands of years. Not only do the cores have layers, so you can count backward through time, but each layer has hundreds of tiny bubbles that are actually pockets of the atmosphere that became trapped when the ice formed. We can samples these bubble and determine what the atmosphere was like as far back as the core goes.
10	If you want to go back further than the ice cores, say millions of years, then we have to rely on models. These models take many different variables into consideration including volcanic activity, weathering of rocks, plant life, and so on. And different models weigh the variables differently so they don't always agree. Here we have a series of models going back to the PreCambrain over 500 million years. As I said before, these models don't always agree, but there are some trends that many of them follow.
11	For example, this downward dip around 400 million years ago is believed to be at least partially due to the evolution of land plants that consume CO2 during photosynthesis. The thing I want you to take from this is that many presentations on the topic of global warming don't go this far back. They show you the last few slides with our current concentration far above historic levels. But there were many times in Earth's history when CO2 levels were up to 10 times greater than today.
12	So why do we care about CO2 in the atmosphere. I've spent the last 10 slides talking about it, so it must be important, right. Many of you, if not all of you, are probably familiar with the greenhouse effect. That is that similar to the way the windows of a greenhouse let radiation from the sun in, but prevent the infrared ways from escaping; there are gases in the Earth's atmosphere that do the same thing. This is part of what makes the planet livable for us.
13	If you look at the atmospheres of Earth and it's two closest planets, you can see that venus has thick atmosphere with over 95% CO2 and it's average temperature is over 420 degrees Celsius. Compare that to Mars where nearly all of its CO2 is in the ground and the average temperature is -50 C. Now you have to take this with a grain of salt because Venus is also 75 million miles closer to the sun than Mars, but still, it is estimated that without CO2, the Earth's average temperature would be -20 degrees C, or -70 degrees Fahrenheit.

14	But CO2 is just one of the greenhouse gases. There are several others, like Methane and chlorofluorocarbons or CFC's. So why are we focusing on CO2? This table shows the concentration of each greenhouse gas in our atmosphere. As you can see, carbon dioxide is the most abundant. But I don't think the numbers do it justice.
15	If we make a pie chart from these numbers, it becomes much more clear just how much more CO2 there is.
16	Now we've seen all the graphs of rising CO2 levels, and we've made the connection between CO2 and temperature. Naturally, you'd begin to assume that temperature must also be going up… and it is. The global surface temperature has risen about a degree and a half Fahrenheit in the last 100 years.
17	I know it certainly doesn't feel like it. Especially after the winter we just had. But according to NOAA's National Climate center, most of the world has been experiencing higher than average temperatures this winter. In fact, northern Russia and the eastern US are really the only places that were especially cold. I guess we're just lucky.
18	Now lets go back to one of our CO2 graphs just to see how closely CO2 and temperature are related. Here we have our graph of CO2 concentrations over the last 400,000 years.
19	If we plot temperature over the same time period, you can see that the two show a very strong correlation. In fact we rarely see a lag between the two. So the real question becomes, what's going to happen here? This is the first time in earth's history that we see an outside influence, us, having a significant effect on this pattern.
20	But before you all go running for the hills, let's go back and look at another time when CO2 levels were especially high.
21	This time period, about 120 million years ago is known as the Cretaceous Thermal Maximum
22	During this time CO2 levels were over 1000 parts per million, temperatures were about 5 degrees hotter at the equator, and up to 30 degrees hotter at the poles. There were actually polor forrests during this time and tropical waters extended as far as 40 degrees away from the equator. Sounds great right?
23	This time was also characterized by rapid sea level rise and much of the land was covered by shallow inland seas.
24	This is really one of our main concerns. There are all sorts of models trying to predict what the end of the century is going to look like. They project temperature changes from 3 to 8 degrees Fahrenheit and sea level rise between 3 and 5 feet. I should also note, that although it probably won't happen before 2100, if all of the planet's ice were to melt, sea level would rise over 250 feet.
25	This is cause for major concern since almost 40% of US population lives in a coastal county. This compares well with the rest of the world where over 40% of people live within 60 miles of the coast.
26	I have a few of these illustrations, so I'll run through them quickly. Here we have a map showing what New York City would look like with a 5 foot sea level rise.
27	Here's a 12 foot rise
28	And a 25 foot rise
29	Here we have Boston Harbor
30	And Boston Harbor with a 5 foot rise
31	with a 12 foot rise
32	And 25 foot rise
33	A couple more. Here's Back Bay, New York City today.
34	With a 5 foot rise
35	A 12 foot rise
36	And a 25 foot rise
37	Here's Harvard Campus with a 12 foot rise
38	And here's the Jefferson Memorial with a 25 foot rise

39	Not only is sea level rise a concern, but melting ice dilutes the ocean and can affect the thermo-haline circulation. In fact some climatologist predict that if a significant amount of ice were to melt, some places like western Europe that rely on ocean currents to transfer heat, could actually get significantly colder. In a lot of ways the term global warming is misconceiving, we're talking about global climate change and it will affect different areas in different ways.
40	Now let's shift gears and talk about our contribution to the state of things. New York has the 10th largest CO2 output by volume. But we drop down to 49th when we look at our output per capita. We may produce a lot of CO2, but we have a lot of people.
41	Now if we compare the US to the rest of the world. We are the 2nd largest producer by volume with only China emitting more. Looking at per capita doesn't change much for us. China certainly drops down the list due to their population, but we're stilling sitting at number 2.
42	So let's look at sources of CO2. Most of the country's CO2 emissions come from 3 sources: Transportation, Industry, and Electrical Power. Certainly strides are being made to make cars more efficient, but we're going to focus on these other 2 sources.
43	Industry and power generation together account for over 50% of our CO2 emissions. They are also both large stationary sources, as opposed to millions of cars, trucks, and planes all moving all over the country.
44	Enter carbon sequestration, also known as carbon capture and storage, or CCS. Geologic carbon sequestration involves the injection of CO2 into porous and permeable rock formations to prevent it from being emitted into the atmosphere
45	There are four main characteristics that a rock formation must have to be a successful carbon sequestration reservoir. The first is high porosity. That is the pore space between the rock grains which is where the CO2 will be stored. The next is permeability. This refers to how well the pores are interconnected. You can have a formation with great porosity, but unless it's permeable, the CO2 won't be able to flow away from the injection site. You also need one or more cap rocks. These are impermeable rock layers that overly the reservoir and prevent the CO2 from escaping upward. And the last thing is depth. We generally look for sequestration reservoirs to be at least 2,500 feet deep so that the CO2 will be stored in a supercritical state.
46	What is a supercritical state? We are all familiar with solids, liquids, and gasses, and how the state of a substance depends on temperature and pressure. Supercritical is actually another state that occurs at high temperatures and pressures. For CO2 it is temperatures greater than 31 degrees Celsius and 73 bars of pressure. Supercritical CO2 is over 300 times more dense than CO2 at the surface. This allows more CO2 to be stored in each pore space.
47	Now once you have found a suitable reservoir and you begin to inject CO2, there are 4 ways that that CO2 becomes trapped in the rock. These occur over varying amounts of time and have different levels of security associated with them.First we have structural trapping which is simply the physical trapping of the CO2 in the pores of the reservoir with the cap rock prevent escape.
48	Residual trapping occurs as the co2 actually adheres to the grains of the rocks so that even if the cap rock were removed, some of the co2 would cling to rock and not escape.
49	Solubility trapping refers to the dissolution of the co2 into the formation fluids.
50	Then finally, mineral trapping occurs as the co2 reacts with the reservoir rock causing precipitation of various carbonate minerals such as illite or kaolinite. This takes the longest, but it is by far, the most secure form of sequestration
51	When people first hear about carbon sequestration, they usually become worried about leaks, and rightfully so. There are various ways that CO2 could escape. Most involve an imperfection in the cap rock, either a thin spot, or an open fault. There is also some concern about old nearby wells that were not properly sealed. In all of these cases, a leak would mean that somebody didn't do their job. Cap rocks must be studied in detail for any type of weakness and all other wells in the area have to be identified.
52	But in the event of a leak, early detection is key. An active sequestration site incorporates constant monitoring at all levels, from the atmosphere, to the soil, to ground water, and the reservoir itself.
53	In fact geologists are actually able to track the injected CO2 using seismic imaging. This figure shows a site over a 14 year injection period. This is a profile view, so this is the cap rock, and here is the injected CO2. And this is an overhead view, with this green blob being the injected CO2.

54	Now a lot of critics like to use Lake Nyos as the worst case scenario for a CO2 leak. Lake Nyos is a crater lake in West Africa that has CO2 feeding into it from a magma chamber below. In 1986 a nearby landslide caused the lake to suddenly emit a large cloud of CO2. Because it was more dense than the air, the cloud stayed low to the ground and flowed down the hillside into a town where it suffocated 1700 people and 3500 livestock.
55	This is far worse than anything that might happen at a sequestration site and these comparisons should be completely ignored.
56	For a better example, there are actually hundreds of natural CO2 seeps all over the world. In fact scientists the university of Edinbugh conducted a study in which they examine 286 naturally occurring CO2 seeps in Italy and Sicily. They found that for the people living near these sites, the risk of death by CO2 suffocation is about 1 in 36 million. By comparison, the odds of being struck by lightning are 1 in 43 thousand. Even the scientists were surprised at how low the risk was. Also, models suggest that leakage from a sequestration site would be lower than these natural seeps. And unlike natural seeps where many deaths were caused by lack of awareness, sequestration sites are constantly being monitored.
57	Shifting gears a little bit, some of you are probably saying to yourselves “injecting CO2 into the ground sounds ok, but it’ll never happen.” Well, here we have a map showing active sequestration projects across the world
58	We’re going to take a closer look at these 2 projects: sleipner and dacatur
59	Sleipner is an oil and gas field own by statoil off the course of Norway. They’ve been producing oil and gas since 1974 and sequestering CO2 since 1996. This is a very interesting case because the CO2 here isn’t produced by burning of fossil fuels, it’s actually in the gas. The gas being produced at the Sleipner west field contains almost 10% CO2. Normally they would pipe the gas and CO2 back to land and strip off the CO2 and vent it into the atmosphere. But Norway has a tax on CO2 and doing that would cost Statoil approximately a million dollars per day, so instead, they put the CO2 removal equipment right on the platform and the strip off the CO2 right there. Then they inject it into a suitable reservoir called the Utsira Formation. This has saved stat oil over 6 billion dollars in carbon tax.
60	Moving on, here we have the Decatur project in the Illinois basin. This is a test project with the goal of storing 1 million tons of CO2. Their reservoir is the Mt. Simon sandstone which is over 1000 feet thick and over 6000 feet deep near Decatur. They began injecting in 2011 and they reached the halfway point in August of last year having sequestered 500,000 tons of CO2
61	So how do geologists find suitable sequestration reservoirs? It’s essentially the same way we find oil and gas reservoirs, but it’s a little easier because we’re looking for an empty container, if you will, whereas petroleum geologists are looking for a container full of oil. Rock samples are one of the most helpful tools. We can get these in one of two ways but both involve drilling a well. Rock core, drilled with a bit like this, is the most useful because you get an entire cylinder of rock that shows you the rock type and its features. There is also plenty of material to sample for lab analyses. But collecting core is very expensive, and when you’re on a budget, cuttings are the best alternative. When they’re not using a coring bit, drillers use a tri-cone bit like this one which pulverizes the rock. In that case, we can collect the chips of rock, call cuttings, as they come to the surface. Obviously they’re not as useful of core, but you can still tell what type of rock it is, and there is enough material for some lab analysis.
62	Both core and cuttings can be used to make thin sections. These are extremely thin slices of rock that are used under a microscope to look at the grains and the pores. We imbed our samples with blue epoxy so as we look at pictures of thin sections note that the blue is porosity.
63	We also use well logs. Each time a well is drilled, a logging company is called in and they lower a series of sophisticated tools down the well. As they pull them back up, these tools take all sorts of measurements of the rocks.
64	These measurements are plotted on a grid and look like a bunch of squiggly lines, or curves as we call them.
65	Interpreting these curves is a career for some geologists, but I’m going to teach you all how to do it in a few minutes. One of the most useful curves is the density. Different minerals have different densities so this curve helps us identify rock types. Here we have 600 feet of density curve. And here we have a table of the most common densities.
66	Dolomite has a density of about 2.86, which is represented by this pink line.
67	So as you might expect, these intervals are dolomite

68	Now sandstones are made up mostly of quartz which has a density of 2.65, represented by this yellow line.
69	So these intervals are interpreted to be sandstone units.
70	Another useful curve is the neutron porosity curve. This is an estimate of the rocks porosity at a given depth. This curve can confuse people at first because the scale is backwards with higher porosities on the left. Also the scale goes to -10. But you can't have a negative porosity. This is because the tool is calculating porosity based on other measurements and sometimes it has to make assumptions. If those assumptions are wrong, the porosity can go into the negative, but for all intensive purposes, that is 0% porosity.
71	We can use logs to make cross sections connecting wells to see how rock units change over large areas.
72	But to do this, you need wells. NY actually has about 35,000 deep wells, but the majority of those in western NY where natural gas is produced.
73	Another tool we have is seismic surveys. This is a source of data that doesn't require any wells to be drilled. Instead a series of detectors are laid out and vibrational waves generated using specialized equipment. the return times of the wave echoes allows geologists to create images of the layers beneath them, kind of like sonar. This is very useful, but doesn't give you any rock material to study.
74	Using all of these techniques, we are able to get a pretty good idea of what the subsurface geology of the state looks like. From North to south, the sedimentary rock layers dip so that a formation that is close to the surface along Lake Ontario is thousands of feet deep along the Pennsylvania border.
75	From west to east, the shape is more like a valley. This is essentially the northern most extent of the Appalachian basin which extends all the way into Alabama.
76	Here is a simplified cartoon to help illustrate the concept of an inclined valley. Notice how the layers dip, but also comform to the shape of the valley
77	Based on our knowledge of the NY geology, we've broken the state into three areas. The red has little or no potential based on the depth or complete lack of sedimentary rocks. The green has some potential, and the yellow is unknown simply because we don't have enough data.
78	Now let's look at some of the sequestration projects across the state. We'll begin here in Jamestown, NY
79	Jamestown is different from most cities in New York because they actually make their own electricity using a 50MW coal fire power plant. However this plant is getting old, and the Jamestown Bureau of Public Utilities would like to replace it with a oxy-coal plant including near-site carbon sequestration. I won't stand here and pretend to know exactly how an oxy-coal plant works, but I do know that it is more efficient than a standard coal fire power plant, and that one of the byproducts is a clean stream of CO_2, unlike other plants where the CO_2 goes up a smoke stack with all the other gases. The Jamestown BPU received a grant from the Department of Energy to investigate the sequestration potential near the city. And that's when we got involved.
80	This is a simplified chart showing most of the rock formations in central and western New York. We'll be visiting this a few times.
81	For the Jamestown Project, we believed our most promising sequestration reservoir would be the Galway and Potsdam Sandstones.
82	So for a project like this, the first thing we do is look for available data that already exists. And as it turns out there are over 6000 wells in Chautauqua County. Most of these produce gas from the Medina Sandstone.
83	Unfortunately, only 10 of those wells reach the formations we're interested in.
84	Using the logs from the wells we do have, we were able to get a good idea of how deep and how thick the Potsdam and Galway formations are. We also broke them down into smaller units. The Galway is characterized by an upper sandstone which we believe correlates to the Rose Run sandstone in other states, then we have the a-dolomite, b-sand, b-dolomite, and c-sand which may be the Potsdam. As you can see, we weren't too creative with our names.
85	The existing data gave us enough confidence to move forward and drill our own well. To save time and money we actually did a piggy back, which is when you find a well that is already being drilled and pay for it to be deepened. Such was the case with the Miller #2 located about 8 miles northwest of Jamestown. Drilling began in March of 2009 and we reached a total depth of 7,308 feet.
86	We collected 155' of whole core from the well. Some from the Little Falls (our primary cap rock) some from the Rose Run Sandstone, and some from the Upper C-Sand.

87	We also collected 31 sidewall cores. This is a technique I haven't mentioned yet. One of the problems with collecting core is that you usually can't afford to collect everything, so you try to just sample particular intervals. But you don't always know where those intervals are until the well has already been drilled, so it's a catch 22. That's where sidewall cores come in. Once a well has been drilled and logged, you can look at those logs to locate your areas of interest, then go back in with a sidewall tool which has a drill bit that can collect a small one inch core from the side of the hole. These samples are quite as good as whole core, but there is enough material for a thin section and some lab analyses.
88	I don't want to dwell on this slide, but I do want to point out that we described the 155' of whole core in detail to define each of the rock types and grain types in the sampled zones
89	For sequestration purposes, the lab analyses are a bit more useful. Here we have a graph with permeability on the y axis and porosity on the x axis. The red dots are samples taken from the Miller #2 core and the blue dots are sidewalls.
90	For carbon sequestration we generally like to see porosities greater than 5% and permeabilities over 1 millidarcy.
91	But as you can see, the majority of Miller 2 samples plot well below that.
92	This is confirmed by looking at the logs. Here I've highlighted porosity from 5 to 10%, so we'd like to see the blue line in that yellow area as much as possible, but as you can see, there are only a few spots where it does, and most of those are just spikes, or thin beds.
93	Now compare that to one of the Liddell, one of nearby wells that we looked at before drilling, we see that a majority of the neutron curve was in the yellow. So something funny is going on with the Miller 2.
94	When we look at the thin sections, we do see some sandstones with good porosity. These are quartz and feldspar grains, and the blue is porosity.
95	But more often we see this, which is a sandstone, but all of the space between the grains is full of dolomite.
96	We've interpreted this dolomite to be secondary mineralization. This means that the sandstones probably had great porosity when the we formed, but at some point afterward, mineral-rich fluids flowed through the rock and dolomite precipitated between the grains. This filled all the porosity making the miller 2 site not suitable for sequestration. The project is on hold right now, but there is some interest in drilling another well, possibly to the south of the city.
97	Our next project is located in central NY along Cayuga Lake.
98	The AES Cayuga power plan is a coal fired powerplant that produces 306 mW of electricity and over 2 million tons of CO2 per year.
99	As part of her PhD dissertation a grad student from Cornell University, Katie Tamulonis, investigated the potential for sequestration in the Queenston Formation near the power plant.
100	Here again, we started by looking for available data. In this case, the museum had some Queenston core from the Delaney well about 20 miles north of the power plant. With our help, Katie described the core and looked at thinsections. Fortunately this well had been studied before, and the previous study involved taking porosity measurements from the core. As you can see, the values vary, but the average is about 10%.
101	The next question is, do those values project down to the powerplant? A rock formation can change a lot in 20 miles, as jamestown has shown us. It turns out there is also a well near the power plant, the Barron Well. We compare the logs of the Barron well to the Delaney and find that the porosities appear to be even higher. In addition, Katie was able to acquire some seismic data that show the Queenston is especially thick in the area beneath the plant. She calculated that in the 5 square mile area surrounding the plant, the queenston could hold about 35 million tons of CO2. That's 16 years of the plant's output. Now it's up to AES to decide if they want to sequester. Without a carbon tax in the US there isn't much incentive for them right now.
102	Next we'll take a quick look at the Trenton/Black River formations in south central NY.
103	The Trenton – Black River Formations are low-porosity limestones across most of the state, but there are some areas where they occur as dolomites. These are the areas we're interested in.
104	Similar to the Jamestown site, there are areas where these limestones have been affected by secondary fluids. Only in this case the process actually increased porosity. These are referred to as hydrothermal dolomite bodies, and they make great containers.

105	These long linear dolomite bodies are the largest natural gas producers in the state. In fact, In 2005, the largest onshore gas well in the country was drilled right here in NY into one of these dolomite bodies. This play peaked in the mid 2000's and most of these fields are seeing a decrease in production every year. Eventually the pressure in these fields will get to the point where it is uneconomical to extract anymore gas and they will be plugged. Companies will typically leave as much as 30% of the gas behind.
106	This makes them perfect candidates for EGR, or enhanced gas recovery. The concept here is that by injecting CO2 on the perimeter of a reservoir, you can repressurize the field and push the remaining gas toward a production well to extract gas that would have otherwise been left behind. You can use the amount of gas that has been produced to figure out how much CO2 can be stored. Here are 6 of the largest producing TBR fields and we estimate that all together they can hold about 27 million tons of CO2, and that number continues to rise as more gas in produced.
107	Our next project takes us to Rockland County, and I'll start by saying that the geology here is totally different than what I've shown you so far.
108	NY is fortunate enough to share a piece of the Newark Rift Basin. This one of several large valleys created during the breakup of Pangea.
109	About 245 million years ago North America was part of the Pangea supercontinent and NY was very close to the equator.
110	As the contitnent began to pull, or rift, apart, large valleys began to form. This is similar to the way an old rubberband starts to crack when you stretch it.
111	Over the next hundred million years
112	This separation continued
113	And the Atlantic Ocean was born
114	Those valleys then became lakes and began to fill with sediment washed in from rivers.
115	Those valleys then became lakes and began to fill with sediment washed in from rivers.
116	So the Newark Basin started to look something like this. With sediments coming in from the west, the larger sand grains dropped out first and the smaller mud particles traveled further east.
117	Then to complicate matters, there was a series of magmatic intrusions in which molten rock was injected between the beds.
118	The most famous of these is the palisades sill which can be seen along the western bank of the Hudson River near New York City.
119	In 2009 a team of geologists formed the TriCarb Consortium and proposed to investigate the potential to sequester CO2 in the Newark basin.
120	They received money from the Department of Energy on the condition that the states match those funds 1/3. For every $3 the DOE gave them, the state had to give $1. Both New Jersey and Pennsylvania backed out, Only NY was willing to participate,so the group was left to work at the tip of the basin in NY. And we got involved.
121	We started by looking at existing data, which there isn't much of. There were a series of shallow wells drilled across the basin in the mid 90's, and this one, the Princeton well went into lower sandstone, called the Stockton. This was our target.
122	We visited Rutgers college in NJ where the Princeton core is stored and we took samples from the Stockton sandstone, and overlying Lockatong shale, which would be our cap rock. Lab results had good porosities averaging 9% and permeabilities close to 1 mD
123	Using our results from the Princeton core as justification, we sited a well to be drilled in Rockland County NY. This is actually a park'n'ride lot off of exit 14 on I87. That's the Garden State Parkway, and down just a little further would be the Palisades Mall. It isn't often you get to drill a well across from a star bucks.
124	But before drilling, we conducted a seismic survey consisting of these three lines.
125	Here we have the uninterpreted West to East seismic line. It's not much to look at unless you're a geophysicist.
126	And here we have the interpretation. The red layer is the Palisades Sill, green is the bottom of the basin, and it was these units that we wanted to sample.

127	We began drilling the tandem lot well in August of 2011 and I think this well was cursed from the start. Some of you may remember the little storm that rolled through in late August of 2011 known as Hurricane Irene. The drillers had to stop everything and take down the rig while the storm rolled through. We also had trouble drilling through the sill, and the coring tube kept jamming. Still we were able to collect 150' of core, 50 sidewalls, and a full suite of well logs. I should also mention that the well was plugged when we were done and if you visit the site today, you can't even tell it was there.
128	When you're drilling a well like this, all the budgeting is based on time. Time is money as they say, and all of the setbacks we encountered we simply didn't have the money to drill as deep as we had planned. The well was supposed to look something like this, going through the sill, into the layers below and then ending in what we call the basement.
129	Instead it looks like this. We squeezed every penny out of the budget to get through the sill and we were only able to collect a couple sidewalls from the sediments below.
130	The core we collected is from this area just above the sill.
131	After analyzing the core, we found that there were some zones with good porosity
132	But most looked more like this, pretty tight stuff. Not too surprising considering this was not our original target.
133	When we collected sidewall cores, on the other hand, we were able to use the logs to narrow in on promising zones. We collected a few from this area referred to as the Reservoir Flow Unit.
134	These samples were amazing, and I'm not exaggerating, over 15% porosity. So much you don't even have to look at it under a microscope to see it. And some of the highest permeabilities I've ever seen in NY rocks. Over 250 mD.
135	Here's another one of those samples showing similar characteristics.
136	But we still really wanted to sample the units below the sill, so we sited another well farther east where these units are much shallower, in fact the sill is at the surface and half of it has been eroded away.
137	This well was drilled on Lamont Doherty Campus, which is a science facility owned by Columbia University. They already had a few wells on the campus, but none of them went deep enough.
138	Drilling took place last summer, and we cored just about everything.
139	We drilled down about 650 feet then started collecting 4 inch core through the last bit of sill.
140	Then we switched to 2.5 inch core and went another 1000 feet. And it was mostly sandstone, so we believe this is equivalent to the Stockton Sandstone that we were hoping to find.
141	We just got the first set of lab results back about a week ago and they look pretty good. Not as good as the sidewalls from the last well, but better than most of the other stuff in the state.
142	I should point out that neither of these wells was ever going to be a sequestration well, these wells were both drilled with permits for scientific study. The Tandem Lot well was certainly not in a location to be an injection site, and the Lamont Well was far too shallow. This is just the first step in what will hopefully be an ongoing project. So far we've identified two promising sandstones and now we need to find out if they exist in other parts of the basin suitable for sequestration. With additional funding, we'd like to get NJ on board and drill another investigation well in the middle of the basin. I think what we've found so far would justify it.
143	OK, one more project, and I'll try to make this quick. Our last investigation doesn't actually occur within the state boarders.
144	We've begun to look offshore
145	In 2005 NY joined what is called the MRCSP, or Midwest region carbon sequestration partnership. It is one of 7 state partnerships with a focus on carbon sequestration research. For the first 5 years we focused on onshore research, but then in 2011 NJ joined the partnership and between NY, MD, and NJ we were looking at over 400 miles of coastline. So we decided to take a look offshore.
146	We also note that this coastal area is one of the areas most crowed with CO_2 emissions.
147	Here we have a contour map of the basement. I don't expect you to stare at this too long, but notice that from the edge of NJ, the basement drops from 2000 to 16000 meters in a very short distance. That's 46,000 feet in about 50 miles. Imagine this as the edge of big bowl

148	Now compare that to a satellite photo of the same area. That bowl is full.
149	This area is known as the Baltimore Canyon Trough and there's over 40,000 feet of rock here.
150	We don't know a lot about the geology here, but we have some basic knowledge of the area. Most of the basin is full of cretaceous sandstones and shales. Just what we want for carbon sequestration.
151	For our first pass, we've been looking at the Logan Canyon sandstones and the Dawson Canyon Shale
152	There is some well data, but not a lot. However there is much more seismic data available because it's easier to shoot seismic from a boat.
153	There was a bit of petroleum exploration on the edge of the Baltimore Canyon during the mid 1900's. And we have logs from most of these wells. All the ones shown in green here.
154	So let's make a cross section to learn a little more about the basin. We'll include these wells which make a section from the south west to north east.
155	I won't dwell on this too long, I know it's getting late, but what we see is that the rocks are relatively flat lying and our primary cap rock, the Dawson Canyon, is about 6,000' feet thick. And here we have the upper and lower logan caynon with the sable shale between.
156	We haven't collected any of our own porosity or permeability data yet, but we can look at older studies from oil and gas exploration. These shelf margin sandstones have some porous zones with an average of 18%.
157	Based on some very preliminary data, we've calculated that a 2000 square mile area of the Upper and Lower Logan Canyon could hold 19 to 77 years of CO2 output from the nearby coastal states. I realize that's a big range, but this is just the begining of the study and that's a very rough (back of the envelope) calculation.
158	For future work, we are about to start a new 4-year phase of this research which will entail collecting some samples from offshore cores currently stored in Delaware. From those samples we run our own porosity and permeability measurements. And we'll take a closer look at the seismic data. And this is just the beginning. A lot of additional data collection and analysis would take place including the drilling of multiple new wells would take place before sequestration could occur.
159	And I just want to leave you with one more note. Carbon Sequestration is not going to solve all of our problems by itself. It is just one piece of the pie that can help reduce our CO2 output. These are two different models for reaching our target by the end of the century, both include CCS, but it's only part of the solution. And finally, in the end…
160	Remember who we're doing this for