[AUDIO LOGO]

RICHARD DE NEUFVILLE: So I'm going to explore this basic trade-off between big versus small from an economic point of view in this short presentation. And it's all based on an old analysis from a simple case. And the real situation is more complex. But this analysis leads you to some simple, intuitive understanding of the trade-offs, which is what I want to use. And by the way, this was built upon the experience of building steel plants in India back half a century ago.

So here's the picture when it all comes out to. Let me explain the picture first, then let's talk about the explanations. So I have on the horizontal axis is this alpha, which I've been talking about. And he ran the numbers because it's a simple analysis actually, which I'm not going to repeat. You can look it up. But it's not a crucial to the understanding.

So that from our purposes, the economy of scale factors is in the range between 0.6 and 100. And so this is the economies of scale on the horizontal axis. On the vertical axis is how often, if you're going to have modules, how often should we repeat them to be efficient. And it's based upon the simple analysis that it's a linear growth. But again, having made that analysis, it gives you the trade-offs, which I'm going to be looking for.

So here is the cycle time, which also translates in the size because, if you have 10% growth a year, if you're supposed to build it every eight years, it's talking about 80% growth. So the size of the plant, of the module, basically, is, in this way. And this is the economy of scale. And it shows the-- that's the setup for it.

And now let me explain what's happening. It's the same graph as before. So it says if I have higher discount rates-- so this is from 10% to 15%-- higher discount rates-- sorry-- higher discount rates mean that you ought to build smaller, which says, again, that, in fact, if you're looking at it from here to here, you go from say 70% factor for economies of scale, you go from about 7 down to about 4 and bit. So you make it basically about 40% smaller is your size of your module.

And on the other hand, if you have greater economies of scale, you build it larger. If you have no economies of scale, there's no benefit to building more than the existing demand. So you have the two factors that it's a trade-off between economies of scale and discount rate. Greater discount rate, build smaller.

Greater economies of scale-- sorry-- greater economies of scale, which means smaller numbers here-- there's a little bit of cognitive dissonance. Smaller numbers mean greater economies of scale. You build larger. That's the basic trade-off, which I was trying to express earlier. So that is a graphical representation of the kind of thing that can happen.

Now well, how sensitive is all this? So here's the thing that happens. So here is now the total cost of the plant, and the cycle time is how big you make it considering a constant growth per year. If I go from 4 to 8, I double the size. So the response is, the observation is the optimum is flat. What do I mean by that?

If we're here, since these things can't be predicted that precisely, that going from say a size of based on four times the growth rate to up to about here, about 10 or 12 times the growth rate, it doesn't make that much difference. So it makes a great deal of difference that you want to build some time in advance. But the optimal is not that significant.

But you don't want to be building for 15 or 20 years in advance because then it really starts hitting you. Now this was calculated for a particular set of values. And it changes at other times. But the notion is, well, if you look at a relatively small unit, you can have it better, not for 15 years, not for 20 years.

So the implications here are, which I wanted to bring out through this, is that, for industries with economies of scale such as electric power, chemical processes, and so forth, and assuming that you have a steady growth indefinitely, small plants, those very small ones are uneconomical. The optimal size is associated with growth from between about 5 and 10 years of growth.

And they're not especially sensitive to the higher end, and that's good because the forecasts are not accurate, so modest size. But now, this analysis assumes that growth is going to continue on indefinitely. But what happens if the growth stops, decreases? What's the risk?

Well, you risk building capacity that's not needed. What can you do about it? Well, you build smaller, so there's less reliance on the future. This is similar but not the same as Eli's comments that the oil company, I think it was that he was working with, built two plants so as not to be vulnerable in case something happened, in this case, not that the capacity would stop but because they wanted to be able to be assured that they could meet their client's needs or their market share and, therefore, wanted to have them smaller.

So the trade-offs that we're talking about here is between the higher cost per units for small plants when operating capacity versus saving by not paying for extra capacity. So there's a trade-off here that you need to think about very particular to the specifics of your situation between taking advantage of economies of scale, which is a typical driving force behind planning for a lot of industry, versus building it incrementally and smaller, which gives you advantages of it.

And I will be talking later on about doing this in South Australia where they are building not only-- they had build a water supply plant, which was built at a terrific size for economies of scale. And they were thinking about doing the same thing for an LNG plant. And it illustrates the advantages of that trade-off and how you want to modulate between the capacity and when you implement it.

So the takeaways from the discussion so far is, if there's no economy of scale, don't build in anticipation of demand. Expand as needed. If there are, then you might want to build somewhat in the future but not aggressively in the future. The more uncertainty there are, the small increments, when big capacity is not fully used or even needed, that is the risk of not needing it for whatever reason is a reason not to build as big as the engineering might like to have.

So I want to now add in the effect of learning, which I mentioned emphasizes the effect of the discount rate. So here is the tail end of the Manne's analysis basically. So I've taken it from 0.6 to 0.95. There's basically a discrete representation. That's why they're bumps in these curves with no learning and at different interest rates.

And I'm comparing this to another case with learning. And you have no learning, which is up here. And if you have higher amounts of learning, it really decreases it. So I can attend by this as an illustration of the idea that learning adds on to the effect of discount rates in terms of arguing against larger plants, which is all in the context that it's nice to have modules as a way of dealing with uncertainty.

So the summary here is uncertainty is a main driver. Against are the pervasive economies of scale that impel designs for large capacity. And for are the discount rate and the learning, in addition to the uncertainty. So the big picture I want you to leave you with is that economies of scale are widespread. And in that way, they have been a mantra for engineering design to build big plans.

And you see this very easily in the electric power industry where this has been the norm for a bigger plant as opposed to smaller plants, which you can then distribute around the landscape and don't have the same distribution costs. And it's also been the pattern of oil platforms of being large, as being more efficient, and so on as opposed to smaller ones, which reduce the risks or the uncertainties associated with the performance of the field.

And in that context, smaller units may be better. So there's an argument for the investigation of smaller units. And our work with BP and subsequently with the one we did with Eli Dweck, in particular, was really interesting with BP because it was so against the idea of looking at smaller units but is proven actually quite productive for them.