out at the cheaper end of a normal bored tunnel. And the reason why one gets to that cost is that above ground one is not saving considerable amounts of money from removing other infrastructure. So to the point you get to the green tunnel, you're replacing the green tunnel costs.

496. CHAIR: So the netted off cost of the green tunnel?

497. MR STRACHAN QC (DfT): Up to the green portal but if you go beyond that, above ground there aren't many structures that you're saving on. There are one or two bridges but there's not much you're saving on, and so the costs of the bored tunnel extension from that point becomes much closer to the normal guide of tunnelling costs where you're paying for literally the costs of boring underground and the distance is 1.5 kilometres. I hope Mr Smart can confirm what I've said is correct but he'll tell you if I haven't.

498. MR SMART: That is correct.

499. SIR PETER BOTTOMLEY: So you're sticking to the tunnelling costs but you're saying that most of the offsets by not having to have the green tunnel and the rest come in that first bit, not in the second.

500. MR STRACHAN QC (DfT): Yes.

501. CHAIR: The first 2.6 kilometres. And then the final 1.5 kilometres the cost rise?

502. MR STRACHAN QC (DfT): Well, the costs become very much standard costs.

503. SIR PETER BOTTOMLEY: Gross and net are the same?

504. MR STRACHAN QC (DfT): It works out pretty close to the tunnelling guide.

505. MR GRIFFITHS: Could I just say that obviously the things that we said overall about boring costs and cutting costs –

506. MR STRACHAN QC (DfT): I'm going to address that now. So can we just go back then to… I want to deal with tunnel boring costs. You'll recall from the aide memoir that the petitioners referred to that the principal element of cost difference relates to tunnel boring. It's about, I think, £90 million but it's a principal difference on

those figures. And can I ask Mr Smart to deal with that straight away? Because if one turns into the presentation you've just had, we looked at A1238(38) and Mr Craig referred to tunnel boring rates and, in a nutshell, the issue is that we've put in a tunnel boring rate of 80 metres per week; Mr Craig thinks it should be a faster rate and you can get costs savings by having a faster rate.

507. Mr Smart, I just want you to comment on what's actually on this slide. The first principle that I took Mr Craig to was from the infrastructure study report that's essential to look at the tunnelling machine or the tunnelling method and the tunnelling conditions. And we know from considerable debate over the last few weeks that here we're dealing with a slurry machine and about the nature of the upper chalk and the water.

508. MR SMART: Yes.

509. MR STRACHAN QC (DfT): That's what's required in this section of tunnel we're talking about?

510. MR SMART: That's right. This slide here shows the rates from a number of different tunnelling projects and a lot of those are not in chalk and neither are they in slurry machines. So we contend that we should be using the rate of tunnelling that is applicable to the ground conditions that we're in and the type of machine we are in.

511. MR STRACHAN QC (DfT): So can we just take them in turns? First of all, the Channel Tunnel.

512. MR SMART: Yeah. The Channel Tunnel is a bit like that other great Anglo-French project, the Concorde: the fastest ever rate, I think, that was achieved by any tunnelling machine. And that is really because it's in chalk marl. It's an open faced machine. Those machines were also double shielded so they could continue to tunnel as you were building a ring. So those rates, I think I'm right in saying, have never been beaten; and it's a different machine and it's slightly different ground conditions. As I say, it's open faced: it's not a closed face slurry machine that we have.

513. MR STRACHAN QC (DfT): Just to pause, the closed face was in part necessary to deal with the water content, and we heard evidence last week about going underneath the River Misbourne, for example, and the aquifer in the area and the need to control

that for the purposes of Affinity Water and other things. We heard quite a lot of evidence about that last week.

514. MR SMART: Indeed we did, about Affinity Water and the Misbourne and how we'd have to control tunnelling through those areas because of the sensitive nature of the aquifer and the other water courses.

515. MR STRACHAN QC (DfT): Right, so the purple dots relate to the Channel Tunnel?

516. MR SMART: Yeah. They, again, are more EPBMs.

517. MR STRACHAN QC (DfT): Sorry, that's the purple. The blue is Crossrail, I think you're going to deal with next.

518. MR SMART: Yeah. I should say that in those Channel Tunnel rates they're also the Earth Pressure Balance Machines, not slurry machines that are also in the purple diamonds. You then come to the Crossrail machines and, again, they are Earth Pressure Balance Machines in a variety of conditions, London Clay and Lambeth that I think the Committee have heard about, and indeed chalk. And chalk, I believe, would be showing the rates that are more likely, 80, which we'll come to. And then you have CTRL, again Earth Pressure Balance Machines except for the Thames Crossing which was a slurry machine, and they reflect rates in other material, not just chalk. And then you do have Thames Beckton which is the Lee Tunnel which is about a seven kilometre tunnel, similar diameter to us, just recently completed and that is the pink diamond which you can see is pretty close to our hard average; but they are only going through one shaft I think.

519. MR STRACHAN QC (DfT): There are quite a lot of things referred to in your answer. If we just go to A1238(39) because I just want to see the effect of stripping away other ground conditions and other tunnelling machines. If you strip away the Channel Tunnel for the reasons that you've just given, you're left with, in terms of slurry machines travelling through chalk, the two yellows, the two blues and the pink; is that right?

520. MR SMART: Yes, you are, at this end of the scale. And you are, as you can see,

right down where we are in terms of our hard average rates. That's not to say that you can tunnel faster and there will be tunnel faster rates achieved over the whole drive, but we're looking at the hard average from the machine in the ground to the machine out, and that's the prudent rate in our view.

521. MR STRACHAN QC (DfT): If you could turn to your slide. I think you've got it at P7522.

522. MR SMART: Yes.

523. MR STRACHAN QC (DfT): You actually extracted from the data that exists recent tunnel average drive rates for slurry TBMs in upper chalk.

524. MR SMART: Yeah.

525. MR STRACHAN QC (DfT): And you've identified projects where there are rates per week. And you can see the Lee Tunnel is the top one. That's a tunnel diameter of 8.6 metres. Ours is a wider diameter than that, isn't it?

526. MR SMART: Yes. You can see from there the hard average that's been achieved and they are published. And you can see that they support our hard average. That's not to say that the machines do go faster; in fact the Lee Tunnel in its best week achieved I think nearly 250 metres. But when you look at the average over the drive, that was what was achieved. And then we've also abstracted the relevant rates from the Crossrail and the CTRL drives which are a small diameter, so that's a factor, and don't go through shafts; and they also support our hard average rate but, again, they did achieve faster rates during the overall drive. But we would contend that those are the rates that are supporting the 80 metres.

527. MR STRACHAN QC (DfT): Those are the two yellows and the two blues, I think, plotted on the graph we just looked at a moment ago.

528. MR SMART: Yes, and these are actually backed up by REPA's own report. In fact the Crossrail crossing here is actually the Plumpton to Woolwich drive. And we've heard about the CTRL Thames drive.

529. MR STRACHAN QC (DfT): Thank you. Just for the purposes of planning for

this project, Mr Smart, based on the data you've seen, the nature of the project with the number of shafts to be traversed and what we do know about the ground conditions, what do you say is the prudent rate to adopt in terms of planning for this project?

530. MR SMART: Well, obviously this is the rate we've adopted which is the 80 metres per week. And I should also say that, as the Committee are aware, with bentonite recycling plants that you need for slurry machines, there is also the issue of pumping back and recycling bentonite to a recycling plant. That can sometimes dictate the tunnel rates. Of course you can add bentonite; you don't have to recycle it, you can add bentonite in. But that means a bigger plant and bigger costs. So when you take that all into account; we've heard about the problem with Affinity Water and Misbourne; we know that there are some problems at the start of the drive with fractured ground – indeed, Mr Blaine, in one of his slides, talked about having to ground treat ahead of the tunnel machine – so we think that what we have now is the prudent rate for a drive from one end of 13.4 kilometres.

531. MR STRACHAN QC (DfT): Can I just take that item alone? I'm happy to use the petitioner's slide for this purpose: A3128(63).

532. MR GRIFFITHS: Am I able to cross-question?

533. CHAIR: After the promoter, yes, you get a chance to question.

534. MR GRIFFITHS: Okay.

535. MR STRACHAN QC (DfT): Mr Smart, this is of course a petitioner's extraction of material from that letter I showed you a moment ago. Just taking our bore tunnel, £181.8 million, and REPA's reduction of £102.7 million, which comes through faster boring rates in the costs essentially, that is a figure of -£79.1 million difference. If one sticks with our bore tunnel assumptions, the difference obviously is more likely to come, I think, at about £60 million additional.

536. MR SMART: Yes, they are REPA's figures. I'm not sure how they calculated those but clearly that would be much reduced.

537. MR STRACHAN QC (DfT): Right. Can I ask you then to deal with fit-out rates?

538. MR HENDRICK: Just before you go onto fit-out, just going on the boring, what did you say the maximum number of metres per week you can do and what's the minimum to give you the 83 that you reckon is the average?

539. MR SMART: Well, the minimum will be nothing because the machine has to have downtime at the shaft. I wouldn't disagree with the figure that Mr Craig gave of 18 days. In fact, our hard average of 80 metres a week assumes going through our shafts in two weeks, which is actually slightly faster than Mr Craig has suggested. But of course it does depend on how much maintenance you do at that downtime, as has rightly been pointed out by Mr Craig in his slides. You have the opportunity going through a shaft to get to the cutter head and re-tool – that's the picks on the head of the machine – and depending on how much wear there is on the machine – and you've heard from Dr Bailey, from an earlier petitioner, about flint in the chalk, etc. – it could be that you have to do more maintenance for that machine at the shaft. So whether it is two weeks; it could be more. So the minimum would be 0 when you're on stop but clearly you can go faster than that and I think the fastest that has been achieved in chalk – I think, I'd have to check – is the 250 metres a week on the Lee Tunnel which has just been completed as part of the Thames Water Ring Main.

540. MR HENDRICK: So what you're saying is that the 120 that's been proposed isn't physically impossible; it's just that you wouldn't want to do it because you want to do proper maintenance and you need certain amounts of downtime and you can't guarantee the sort of chalk that you'll be going through because there would be water and other complications.

541. MR SMART: Correct. It's perhaps a bit like setting out from Dartford Tunnel on the Friday night at rush hour and going right the way round back to the Dartford Crossing and expecting to average 70 mph. You might do 70 mph for some of it but it wouldn't be the average speed. And it is that: it is about the ground conditions, the water, the maintenance and other issues that we might have to stop potentially if we're monitoring water and all of that. And all the rates on the slurry machines have been done like that.

542. MR HENDRICK: Alright. So what you're saying then is that 83 is your preferred average but in good conditions you could possibly reach 100 or 120, given the

conditions that you’re likely to face.

543. MR SMART: Absolutely. And that’s factored into the hard average, as I said. We don’t assume that we’re going at 80 all the time but when we look at the length of the drive, some places we’ll go faster and that’s the average that you get.

544. MR STRACHAN QC (DfT): Can I just pick up on that, Mr Smart? In terms of what you’re describing by way of a hard average, the machine doesn’t set off at a particular speed; you will try and tunnel faster where the ground conditions are better.

545. MR SMART: Yes, correct.

546. MR STRACHAN QC (DfT): But when you encounter the sort of harder grounds or more difficult grounds the machine may slow down. And then as you encounter a vent shaft of course it stops altogether for however long it is for maintenance. But you put all those times together; the figures, the averages you were getting out from equivalent tunnelling come out at the level that we were looking at before, is that right?

547. MR SMART: Yes.

548. MR HENDRICK: My point was not that 80 was not a realistic average. My point was that 100 or 120 is still possible depending on the conditions that prevail at the time.

549. MR SMART: Yes. I don’t think in recent slurry machines in chalk that that has ever come out as anything like an average but it’s certainly achievable for periods of the drive, yes.

550. MR BELLINGHAM: Can I ask, Mr Smart, once the tunnelling has gone under way and you’ve got the equipment in place, you’ve got the infrastructure set up, it’s only the marginal speed of any extended bit of tunnelling that’s going to be quicker, isn’t it?

551. MR SMART: Well, it’s still tunnelling at an average speed of 80 metres a week.

552. MR BELLINGHAM: But surely if the Committee did decide to allow the petitioners to have what they want, would it not be the case that the extra 4.1 kilometres would be done quicker as it would be an extension to what is an existing set of tunnelling?

553. MR SMART: No, you would still assess it at the same rate. So it is still about a year's extension to the drive. That doesn't mean to say we can't mitigate some of that, which we'll come on to which is the fit-out, but we still have to physically tunnel four kilometres more which takes time. And the only way that would be quicker is if we did achieve a faster rate which we would hope to do. But what we're saying is, based on all the information that we have, bearing in mind we haven't yet done some of the geotechnical investigation, etc., based on some of the constraints we have around aquifers and other things we've heard about, that this is the prudent rate that we should be costing and planning on.

554. MR CLIFTON-BROWN: Can I ask you a follow up question? There seems to be a difference of opinion between you and the promoters on average rates depending on the length of tunnel, and they put up your slides that you showed us last week of the block shaped graph: the longer the tunnel the slower it gets.

555. MR SMART: Yes.

556. MR CLIFTON-BROWN: They contend, and they have shown by taking out some of the short tunnels, that actually the longer the tunnel the faster the average rate. So what is the difference between the two opinions?

557. MR SMART: Well, perhaps we should go to that slide.

558. MR GRIFFITHS: 1238(50).

559. MR SMART: What I was actually saying is that, when I was looking at total cost, I was not suggesting that there might not be some economies of scale in longer tunnels.

560. MR CLIFTON-BROWN: Sorry, can we just wait for that slide?

561. MR SMART: Yes. What the promoters are showing, if you like, is the cost per kilometre over a tunnel length. Now, clearly, part of the cost of tunnelling is the high fixed cost of setting up tunnelling, bringing in power, buying the machine and the back up, the locos and the conveyors. And if you spread that over a longer tunnel then of course that will tend to give you the effect of a lower rate. And indeed there is, as we would expect there to be, a better learning curve in longer tunnels because the crew get, if you like, more used to the operations and the logistics, but that can still be tempered

by if you hit poor ground. In fact it was mentioned by one of the petitioners that there's a potential for faults in the chalk. That slows you down and takes time.

562. What I was showing in my slide was in fact cost versus length and that basically says that you have to still pay for that extra tunnelling. And as you go further into a tunnel you have things like vent shafts and mechanical electrical equipment which step up every time you come to a shaft; that adds a chunky piece of cost in every three kilometres. And I think the slide that the petitioners showed, that in the Infrastructure UK report this comes from, it does suggest that there's a very sketchy relationship and there does seems to be some indication that maybe tunnels get cheaper when they get longer; but, again, you have to look at ground conditions, you have to look at the machine that you're operating with. And as you get further into a tunnel you've got more logistic backups. When you're tunnelling from one end and you're 13 kilometres down, even a shift change, taking man riders in on a loco which they would go in on, I mean that could take you half an hour or so just to change the crew. So all of these things tend to kind of add a bit more cost. And it's not just as simplistic to say 'oh well as they get longer then everything gets more efficient and therefore it gets cheaper'. I think you have to temper that by what else is happening in your tunnel.

563. MR STRACHAN QC (DfT): Can I just ask you on that point, Mr Smart, slightly jumping ahead, but in relation to cost of tunnelling we looked at costs of tunnelling for slurry EPBMs in chalk as compared with, for example, longer tunnels through London clay or indeed under the Channel Tunnel through chalk marl which wasn't using a closed faced EPBM.

564. MR SMART: Correct.

565. MR STRACHAN QC (DfT): Can you just explain why it is that there are greater costs associated with the type of slurry EPBM that's necessary for this ground? What's actually going on in terms of connection with the end of the tunnel?

566. MR SMART: Well, the reason that you are using a slurry machine is because the ground is more challenging because there are different groundwater conditions and ground conditions that takes you to a slightly more expensive tunnelling machine, so that adds to cost. And, more importantly, because you're dealing with things like flint in the chalk and fissures and other issues within the material, it's a slower rate and that's

why you use something like a slurry machine because the face pressure which is in order to support the face at the front of the machine is carried out by means of a bentonite slurry and not with Randall and Archimedes screws which you'd have on an EPBM. And all of that bentonite has to go back to the tunnel drive, it has to be pumped out, and it has to go through things like centrifuges, sieves, presses to actually take out the excavated material, which comes out like a cake, and then you recycle the bentonite and send that back to the machine.

567. MR STRACHAN QC (DfT): So that recycling process is happening outside the tunnel?

568. MR SMART: Yes.

569. MR STRACHAN QC (DfT): So the further you go, the further you have got to pump your bentonite back down the tunnel and extract the other material out?

570. MR SMART: Yes, and that's all part of the logistic supply chain. You know, on an EPBM you have conveyors; on a slurry machine you have this pump system. But you've still got to have ventilation for the crews; you've still got to have all the rail back up to take in segments and grout, etc.

571. CHAIR: I think at that point it's lunchtime. Order, order. We'll reconvene at 2.00.