When will there be cost-competitive cultured animal products?

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Abstract

Cultured animal products are grown via a cell culture rather than via a farmed animal. If these cultured alternatives were available at a similar price to farmed animal products, there could be a massive decrease in the demand for farmed animal products. Informed estimates about when cultured products could reach such prices range from a matter of months to several decades. Timelines that are so dissimilar have dramatically different implications for ACE's recommendations. This is because, all else equal, the sooner we expect there to be substantial decreases in the number of farmed animals, the more interested we become in causes other than farmed animal advocacy. Even within the cause of farmed animal advocacy, our views of certain interventions could vary quite substantially as a result of changes in our estimated timeline for the availability of cultured alternatives. In this write-up we will compile informed estimates related to cultured animal product timelines and discuss some reasons to trust or distrust them. We will then conclude with our core impressions, offer our own timeline estimates, and provide some brief thoughts on how our evaluations might update in light of our projected timelines.

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The timeline for cultured acellular animal products

"Acellular products" are those that do not contain cells. Examples of acellular animal products include dairy products, egg whites, and gelatin. Our understanding is that these acellular animal products can be cultured through a similar process to the one that has been used for decades to culture insulin and rennet.[1] Currently, invertase and lysine seem to be cultured at a comparable or cheaper cost per dry weight than the cost per dry weight for conventionally produced milk and egg whites.[2] It seems to follow that to

[1] For further information about cultured acellular products see the relevant section of New Harvest's overview of cellular agriculture.

[2] Some evidence of this is the quoted bulk prices for these products on alibaba.com. On April 14, 2017:

- The lowest quoted price for invertase powder was $300 per metric tonne. The minimum order for this price was one metric tonne. We would guess that this product was derived from a fermentation process similar to that used in culturing acellular animal products.

- The lowest quoted price for lysine powder was $100-$300 per metric tonne. The minimum order for this price was one metric tonne. We would guess that this product produced through a fermentation process similar to that used in culturing acellular animal products.

- The lowest quoted price for powdered milk on the first page of results was $240-$280 per metric tonne. The minimum order for that price was 30 metric tonnes.

achieve cost-competitiveness, acellular animal products may only need to replicate the current production costs achieved for similar molecules that are produced through similar processes—rather than achieve new levels of cost-efficiency. This informs our limited impression that lesser progress is required in order for cultured acellular products to become cost-competitive than the progress required for cultured meats to become cost-competitive.

There have been a number of informed predictions about the timelines for cultured acellular animal products. New Harvest has predicted since January 2016 that cultured milk and cultured egg whites will likely be available in the next few years. Perfect Day predicted in August 2016 that their cultured milk product will launch in late 2017 at a price likely on par with organic milk. In 2016, Geltor said that its cultured gelatin should be widely available in the next four or five years. In a 2016 conversation with The Good Food Institute, we were told that cultured alternatives to dairy proteins, egg proteins, and gelatin should be available in 2-3 years.

Estimated cultured ground meat timelines by leaders in the cultured ground meat field

Our understanding is that culturing ground meat products involves providing the necessary environment (e.g., a suitable temperature, gas mixture, and growth medium) needed for animal cell replication to occur outside of its normal biological context, and that culturing techniques can derive many millions of muscle cells from as little as one cell. Cultured muscle cells can then be grown into muscle fibers—each only a few millimeters thick— and these muscle fibers can then be arranged to form ground meat products.

A number of ground meat products have reportedly been successfully cultured. As a general proof of concept, in 2013 a ground beef burger was cultured as part of a project reportedly costing $330,000. A few days after that proof of concept, the project head (Mark Post) reported that with current technology, cultured meat could be produced at a cost of $70/kg—which we believe was intended as the estimated cost if using mass production techniques. In June 2016 Memphis Meats reportedly cultured a meatball at a cost of $40,000/kg. In March 2017 Memphis Meats then reportedly cultured a chicken product at a cost of $20,000/kg. There have been a number of informed predictions about the timeline for the availability and cost-competitiveness of cultured ground meat products. Table 1 summarizes these estimates made by leaders in the field of cellular agriculture.

- The lowest quoted price for powdered egg whites on the first page of results was $100-$3000 per ton. The minimum order for that price was 10 tons.

In these quotes a metric tonne likely refers to a slightly different weight than a ton.

Table 1. A summary of projected timelines for cultured ground meat by leaders in the field of cellular agriculture.

Predictor	Year of Prediction	Summary of Prediction
In Vitro Meat Symposium[3]	2008	The first commercial cultured meat products will be available in the next 5–10 years (i.e., 2013–2018) at prices competitive with European beef.
Mark Post	2013	It will probably take 10–20 years (i.e., 2023–2033) before the product is in supermarkets.
Mark Post	2015	If production were scaled up to the necessary level, cost-competitive cultured ground meat will likely be available in 7–10 years (i.e., 2022–2025).
Mark Post	2015	Felt confident that MosaMeat[4] would bring a product to market in the next 5 years (i.e., by the beginning of 2021).
Peter Verstate	2016	Premium priced cultured products should be available in 5 years (i.e., 2021), and 5 years after that (i.e., 2026) the products should be cost-competitive.
Bruce Friedrich	2016	It will be 3–5 years (i.e., 2019–2021) before cultured products are cost-competitive with organic grass fed beef and closer to a decade (i.e., ~2026) before they are cost-competitive with conventional meat.
Mark Post	2016	It is "just a matter of several years" before they are ready to sell cultured meat at an estimated price of $10–$20 per burger.
Memphis Meats	2016	Expects to have products available for purchase within 5 years (i.e., expects products to be available by the beginning of 2022).
Mark Post	2017	Estimates that it will take 3–4 years (i.e., 2020–2021) before cultured burgers are on the market for £10–11 (~$12–$14 USD) per burger, and in around 7 years time (~2024) they will be in supermarkets at lower prices.

[3] The linked source reports that this prediction was made at the first In Vitro Meat Symposium. We were unable to find the original material for this prediction.

[4] MosaMeat does not currently have a website. A link to their website from their LinkedIn profile goes to a Maastricht University site.

Predictor	Year of Prediction	Summary of Prediction
Peter Verstate	2017	Admitted it will take at least 5–10 years to improve the [production] process and make it cost-effective. Commoditizing the cultured (or 'clean') meat will take even longer.
Mark Post	2017	For small-scale, somewhat expensive products, most companies will have cultured meat products on the market in 3–4 years (i.e., 2020–2021). It will probably take another 3–4 years (i.e., 2023–2025) for the price to come down to the level where it's acceptable for the broader public.

As of early 2017, the prediction that was reportedly from the 2008 In Vitro Meat Symposium seems much too optimistic. Recent predictions from leaders in the field seem to be that some cultured ground meat products will be on the market by around 2021. The recent predictions from leaders in the field seem to be that some cultured ground meat products will be cost-competitive by around 2026.

Estimates from other scientists or informed sources that closely relate to cultured ground meat timelines

In 2015, Givewell spoke with a scientist with 18 years of experience in the tissue engineering industry who predicted that without a major technological breakthrough it seems unlikely that cost-competitive cultured meat will be available in the next 10–15 years. We do not know the identity of that scientist or the considerations that informed that estimate. Still, we think this estimate is most likely made by a credible source because GiveWell has a strong track record of using credible sources in their investigations. We are also operating under the assumption that the scientist's reportedly large amount of experience most likely translates to a large amount of relevant knowledge. As this estimate seems to be the only informed cultured ground meat timeline estimate that is not from a cultured ground meat proponent—and it is a much more of a pessimistic estimate than that of proponents—it therefore seems to provide somewhat significant evidence in support of the hypothesis that timelines predicted by proponents of cultured ground meat are too optimistic. That estimate would also be consistent with a situation in which the scientist is thinking about a different scenario than the cultured meat proponents are thinking of, or is less aware of the desired solutions.

The Open Philanthropy Project's Animal Product Alternatives report lists three different estimates of the possible future costs of cultured meat. The first from Vandenburgh (2004) estimates that cultured meat

would cost $5 million/kg, however we think it is of little use for predicting future costs of cultured meat.[5] The second from Exmoor (2008) estimates that cultured meat would cost €3.3–3.5/kg. The last from Van der Weele & Tramper (2014) estimates that at "not extreme" prices for the medium required to grow cultured meat, the medium alone would cost at least €391/kg of cultured meat and that at the lowest possible cost of the medium, the medium alone would cost at least €8/kg of cultured meat. It is worth noting that many cultured meat proponents most likely want to avoid using the type of medium used in the Van der Weele & Tramper estimate to lower production costs. To give a sense of what the Exmoor and Van der Weele & Tramper estimates imply for cost-competitiveness, the U.S. Bureau of Labor Statistics reports that in U.S. cities, ground beef currently costs approximately $3.5/lb,[6] equivalent to ~€7.20/kg (this includes government subsidies). This implies that at Exmoor's estimated costs, cultured ground meat would currently be cost-competitive and at Van der Weele & Tramper's estimated costs, it would probably be very difficult to achieve cost-competitiveness. We were unable to find any additional cost estimates in a moderate but not extensive literature search.

We are very uncertain about how much cultured meat could cost in the future, and have not thoroughly vetted any of the mentioned estimates. These estimates appear to be back-of-the-envelope style calculations that vary widely. The Exmoor estimate generally seems to support the timelines estimated by proponents but seems preliminary in nature and uses moderately unsupported assumptions that may be too optimistic.[7] The Van der Weele & Tramper estimate is preliminary in nature, possibly pessimistic and

[5] We think that there are a number of problems with interpreting the Vandenburgh estimate to mean that in the future cultured meat would cost on the order of $5million/kg. The estimate was made in a personal communication between Vandenburgh and one of the authors, which we don't have access to and so are unsure what it was based upon. The authors report that the estimate was based on the cost of culturing cells in a laboratory on a small scale and we note that this is quite different from the possible future costs of cultured meat if it were mass produced. This estimate was also not reported in what we believe is the peer reviewed version of the Edelman et al (2004) paper. Furthermore, the estimate appears to have been quite wrong on a number of occasions; for instance, Jonsson (2016) reports that in 2003, in vitro frog 'steaks' were produced at a cost of approximately $650,000 USD/kg, and Memphis Meats' cultured meatball reportedly cost $40,000 USD/kg. As a result of these factors we feel the Vandenburgh (2004) estimate possesses little utility for predicting the future costs of cultured meat.

[6] This page from the Bureau of Labor Statistics provides a time series graph of U.S. city average ground beef prices over the past decade.

[7] The Exmoor (2008) estimate reviews the financial viability of cultured meat and predicts production costs of €3.30/kg–€3.50/kg (~$1.60/lb–$1.70/lb). We haven't closely examined this estimate because its suggested costs do not conflict with the costs that those in the cellular agriculture industry are projecting, and so it seemed unlikely that close examination would heavily influence our thinking about cultured meat timelines. We do note that some aspects of this estimate seem quite questionable; for instance, it contended that the cost of the growth media would drop by a factor of approximately twenty if it was produced at large scale—but that is not clearly true. Open Phil also notes that the estimate's assumption that the cost of growth factors in the growth medium would be negligible is very optimistic and that Isha Datar, now the Executive Director of New Harvest, said this estimate was preliminary and

provides limited justification for some important assumptions.[8] Our current interpretation is that the Van der Weele & Tramper estimate does not strongly suggest that the timelines estimated by cultured meat proponents are off by more than a decade. One important input that significantly differs between the Exmoor and the Van der Weele & Tramper estimate is the cost of industrial quantities of growth medium.

Estimated timelines for culturing whole pieces of muscle tissue

For many popular animal products, a cultured whole piece of muscle tissue is required for the cultured alternative. For instance, this would be needed for the cultured alternative to steaks, breasts, wings, and filets. Our understanding is that it is significantly less challenging to culture fine strands of muscle than to culture a whole piece of muscle tissue. New Harvest notes that culturing whole pieces of muscle tissue requires technology that does not exist and may take longer than a decade to develop. Open Phil guesses that culturing these alternatives is in roughly the same ballpark of difficulty as creating in vitro organs suitable for transplant operations. However, Open Phil notes some differences: the greater price pressures on the cultured meats, and the fact that cultured meat need not replicate as many natural functions. We don't know how accurate that comparison in difficulty is and we don't have a thorough sense of when we should expect in vitro transplant organs. Based on a cursory examination, it seems likely that in vitro transplant organs are decades away.[9]

"could be largely inaccurate." The Exmoor estimate was also funded by someone who played a key role in the development of the In Vitro Meat Consortium (a draft version was also commented on by this person). This relationship with the In Vitro Meat Consortium may have biased the estimate towards predicting that cultured meat could be produced in a cost-competitive manner.

[8] The Van der Weele & Tramper (2014) estimate is a back-of-the-envelope calculation by academic researchers. We don't know if €1/L (~$1.05/L) is the lowest possible cost of animal-free growth media, and the authors don't explain why they thought this was true. Open Phil thought this seemed correct and also spoke to a scientist who said it would be extremely challenging to reach these costs through the current approaches. We don't fully understand why the authors choose 5 x 10^{11} cells/m^3 as the beginning cell density in their calculation. If a slightly greater beginning density was used, then the cells could have been cultivated to densities higher than 128 x 10^{12} cells/m^3. Cultivating cells to these higher endline densities is not unheard of (Zhang et al (2015), Clincke et al (2013)) and could cause significant reductions in the cost/kg of cultured meat. The estimate doesn't attempt to account for possible improvements that could come from genetically engineering/optimizing cells. The estimate is also moderately dependent on the chosen cell volume and density which are not justified by the authors, and economies of scale for the "not extreme" growth media cost may have been ignored.

[9] From the small amount of research we did into this matter, the only apparently informed estimates that we came across suggested in vitro transplant organs were decades away. For instance: this 2014 report, the estimates reported by two experts in this 2015 article, and the estimate reported in this 2015 article.

Established cultured meat companies MosaMeat and Memphis Meats are currently working on cultured ground meats rather than culturing large whole pieces of muscle tissue. The less established companies SuperMeat and Integriculture are working on the more challenging prospect of culturing whole pieces of muscle tissue. Integriculture recently appeared to predict[10] that by 2019 they would produce cost-competitive cultured foie gras.[11] Last year SuperMeat predicted in their funding proposal (as well as in at least two interviews) that their cultured chicken liver would be available within five years if they received enough funding—though this timeline is no longer listed in SuperMeat's current crowdfunding proposal.[12] If SuperMeat were to culture a chicken liver, it may take more than a decade for that type of cultured meat to become cost-competitive. As a comparison, the current estimate from leaders in the field for the length of time between the proof of concept and achieving cost-competitiveness for cultured ground meat is slightly more than a decade. We would guess it may take longer for cultured whole pieces of muscle tissue to reach cost-competitiveness after the proof of concept because of our understanding (albeit limited) that the technology involved with culturing whole pieces of muscle tissue is more difficult to develop.

Recent advances in the cellular agriculture field could be significant progress towards cost-competitive cultured whole pieces of muscle tissue.[13] We haven't yet encountered adequate evidence of such progress, and more substantiated claims could lead us to largely revise our estimated timeline for this type of cultured meat. For this reason, and because we generally have a poor sense of how long it will take to create the technologies required for culturing these products and a poor sense of how long it would take for the products to reach cost-competitiveness once that technology is available, we are the most uncertain about the timeline for this type of cultured alternative.

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[10] See ninth slide.

[11] Note that foie gras is roughly an order of magnitude more expensive per weight than more conventional large whole pieces of muscle tissue from farmed animals.

[12] SuperMeat listed their expected product availability as 2021 in its August 2016 crowdfunding campaign. A timeline where products would be available in 5 years was also mentioned in a Sky News article and a Geektime article. The 5-year timeline was removed from the crowdfunding proposal at some point in February 2017.

[13] On their homepage, Integriculture claims that their new methods have reduced the cost of cell culture by a factor of 1,000. When announcing their seed funding, Integriculture also claimed to have reduced the costs of the growth medium to less than ~$0.10/L and to produce cultured meat for ~$3500/kg. We would guess that the results of the 2015–2016 feasibility study for growing cultured chicken breast funded by the Modern Agriculture Foundation (MAF) were promising because the results seemed to play a major role in SuperMeat's founding. In a 2016 conversation with MAF we were also told that the methods that had been developed by MAF's funding were significantly different from those that had been previously described in other publications.

A short discussion of reasons to trust or distrust the estimated timelines by proponents of cultured animal products

Much of the trustworthiness of the estimated timelines by the aforementioned proponents stems from their apparent expertise on this topic. They seem to have thorough knowledge of the underlying scientific, engineering, and technical challenges involved, and are very informed about the current capabilities of at least some cultured animal product companies. Probably the strongest evidence conflicting with the estimated timelines of some cultured animal product proponents are conflicting estimates from other scientists. Those disagreements include an experienced tissue engineering scientist's estimated timeline and Van der Weele & Tramper's cost estimate. Cultured ground meat proponents are probably more informed on this topic than these other scientists, and the estimates made by proponents are more recent than estimates from scientists who disagree—so the estimates by proponents may be based on more up-to-date information.

However, there are other reasons to think the estimated timelines from cultured meat proponents are optimistic. For one, the reported estimate from the 2008 In Vitro Meat Symposium is most likely much too optimistic. The estimates from proponents also seem to be the result of a selection bias, in that those who are prominent members of organizations in this field are more likely to be optimistic about making progress than those who are not, but we tend to only hear the predictions of those who are. There also seem to be strong incentives for organizations in this field to report more optimistic timelines, as this is likely to result in more media coverage and be more compelling to prospective funders.

We are unsure if the two industry analogs mentioned in Open Phil's report[14] and the previous cultured meat groups who failed or pivoted[15] are the best reference class to use in forecasts concerning current cultured meat companies. Even if these other apparently poorly performing companies and groups were an appropriate reference class, the small sample size would mean that their progress far from conclusively determines what we should expect of cultured meat companies. Another possible reference class that could give a much larger sample size is that of biofuel and algae fuel companies. Our limited impression is that biofuel and algae fuel companies also seem to have performed poorly,[16] but we are unsure about the

[14] Open Phil lists two industry analogs to cultured meat companies. Organogenesis, which uses a process with some similarities to cultured meat to create skin grafts, and Amyris, a synthetic biofuel company.

Open Phil's back-of-the-envelope calculation suggested the manufacturing cost of Organogenesis' skin graft product is ~$90,000/kg and that based on their conversations it seems that over the course of decades the cost of this product has only dropped by a factor of three. We haven't vetted those estimates but we note that the costs of cultured meat appear to be dropping much faster than that (e.g., Memphis Meats' 2016 cultured meatball reportedly cost ~$40,000/kg and their 2017 cultured ground chicken meat product reportedly cost ~$20,000/kg) and we think that is reason to believe that the comparison to Organogenesis may not be highly informative. We also note that from their conversation with a scientist with 18 years of experience in the tissue engineering industry it seems that this skin graft product was likely not produced at the scale that we would expect cultured meat to be produced at in the future. It therefore seems likely that the costs of the skin graft product could still drop with those economies of scale. Additionally, there may be significantly fewer costs involved in meeting agricultural rather than medical standards.

Open Phil also reports that despite Amyris receiving more than $700 million in investment, their synthetic biofuel still hasn't become cost-competitive with conventional fuels. It is unclear how generalizable Amyris' difficulties to achieve cost-competitiveness are. If cultured meat companies were to achieve the manufacturing costs per kg that Amyris reportedly achieved, then cultured meat companies would be cost-competitive because conventional meats are more expensive per kg than conventional fuels.

[15] A number of past cultured meat organizations are now defunct. For instance, LifeStock, a startup that reportedly focused on developing technology needed to create cultured meat, and Pure Bioengineering, mentioned in a 2010 Nature article as a cultured meat promoter, are no longer active. We don't have a good idea of how this seemingly high failure rate compares with the failure rates found in other industries, so these previous failures do not presently have a substantial impact on our estimated timelines for cost-competitive cultured animal products. That a relatively large fraction of extant cultured animal product companies seem to have received a moderately large amount of funding may suggest that this seemingly high failure rate will decrease. Modern Meadow—one of the largest cultured meat companies—worked for several years on producing cultured "steak chips." We are unsure why Modern Meadow pivoted to focus solely on cultured leather.

[16] Our limited impression of the poor performance of these companies is based on the following:

- We would guess the rate of poor performance for companies who receive tens of millions of dollars in funding is relatively high. For instance, Range Fuels, GreenFuel Technologies Corporation and Kior all declared bankruptcy after receiving tens of millions of dollars in funding.

- We would guess that a relatively large number of companies originally in the space have now largely pivoted to other industries. For instance, Solazyme and Algenol have now done this.

extent to which these companies are similar to cultured animal product companies. For our purposes, we would probably be more interested in a reference class forecasting method that used industries rather than companies as the unit of analysis. Since we have a limited idea of what the appropriate reference class for forecasting the timelines of cultured alternatives is and what the outcomes for that reference class were, the seemingly below average performance of possible industry analogs and previous cultured meat groups currently causes us to give only slightly more credence to the idea that projected timelines from cultured animal product proponents are optimistic.

Another way of evaluating the accuracy of proponents' claimed timelines is to compare them to the timelines that the valuations[17] of cultured animal product companies would suggest. With this approach, the probabilities assigned to various cost-competitive scenarios would be constrained in order for the estimated return on investments in cultured animal product companies to seem plausible. However, estimating what current valuations imply or what future valuations of cultured animal product companies would imply about timelines for cost-competitiveness seems to involve a significant amount of time and

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- We would guess that a number of biofuel and algae fuel companies estimated timelines relating to the cost-competitiveness of their product were too optimistic. For instance, a 2013 media article quotes a biofuels expert as saying that one particular biofuel "has been five years away for 20 years now."

[17] A valuation is an attempt to determine the present value of an asset. We are unsure about the valuation situation of MosaMeat and SuperMeat. We do know that currently SuperMeat has crowdfunded ~$230,000 of the $500,000 they're aiming for. Integriculture seems to have received ¥5m (~$50,000) in funding but we don't know if that was social investing. Our knowledge of the valuation situation for the other cultured animal product companies is from CrunchBase and is as follows:

- Memphis Meats has raised $3.05 million. Its March 2016 seed funding round raised $2.75 million and seemed to have five investors, but New Crop may have been listed as an investor because it was confused with New Crop Capital. Of the investors, two (New Crop Capital and Fifty Years) seem to be primarily motivated by social impact. A substantial amount of the funding raised in this round may have been from social investors; of the other two more likely investors, IndieBio seems to invest only relatively small amounts ($50,000–$100,000) per investment.

- Clara Foods has raised more than $3.45 million. Its April 2016 Series A funding round raised $1.7 million from SOSV and we guess that was a profit-motivated investment. Clara Foods' July 2015 seed round raised $1.7 million and reportedly involved eight investors. On initial inspection, it seems that most of those investors are predominantly motivated by profit.

- Perfect Day has raised $2.06 million. Their September 2014 seed funding round was all from one venture capital firm.

- Geltor has raised $250,000. This excludes the amount they raised in a venture funding round in February 2016. Most of the investors in that funding round seem to be primarily motivated by social impact (New Crop Capital and Fifty Years being the exceptions).

uncertainty.[18] There is also some reason to think that the timelines estimated through valuation-based models would suggest roughly the same timelines as those suggested by taking all of the other available information at the time of the valuation into account—otherwise, the valuation would represent a kind of market anomaly. Still, at the time of investing, investors may have been aware of some information that we are not now aware of (and vice versa), or they could have interpreted the same information differently. A credible valuation-based model could give important insights into their conclusions about the timelines. We have not built a valuation-based model to estimate the timeline for cost-competitive cultured animal products—and at the moment, valuation-based estimates of the timelines for cost-competitiveness have quite a limited influence on our estimated timelines for cost-competitiveness. If a credible valuation-based model were to suggest timelines that were different from our interpretation of the other available evidence at the time of the valuation, then it seems likely that we would update towards the conclusions suggested by that model.

Tentative conclusions on the timelines for cost-competitive cultured animal products

We are highly uncertain about the timelines for cost-competitive cultured animal products and do not have a strong understanding of the science, technology, or engineering involved in cellular agriculture. We also did not thoroughly vet a number of important claims, given the time we had available to dedicate to this page. We believe this write-up is still most likely useful because it relatively comprehensively compiles informed estimates that relate to timelines. It also highlights and offers some discussion of key reasons to trust or distrust those estimates, and it details ACE's current interpretation of many important pieces of evidence.

We think that subjective probabilistic forecasts of the timelines for cost-competitive cultured animal products are a suitable way to communicate our current views of the timelines. The general framework that we used to form our own estimated timelines for cost-competitive cultured acellular products and ground meats began with the timeline estimates by informed proponents. We then attempted to account for any reasons to distrust those estimates by ameliorating their estimates in such a way that a previous reason to distrust them would no longer be a reason to distrust them. An example of this type of process would be predicting, as best we could, the timelines proponents would predict if there were no incentives

[18] Usefully estimating profits/losses for different cost-competitive scenarios seems time consuming and laden with uncertainty. Even if we were to usefully estimate those profits/losses, it seems that the probabilities assigned to the various scenarios in order for the valuation to be plausible would still have many degrees of freedom.

for them to report optimistic-leaning timelines. We used a different process to estimate the timelines for competitive cultured whole pieces of muscle tissue because there were no estimated timelines from informed proponents. For this estimate we relied much more upon Open Phil's comparison to in vitro organs suitable for transplants, New Harvest's prediction about how long the technology may take to develop, and a comparison to the predicted amount of time between a proof of concept and cost-competitiveness for cultured ground meat. Basing our prediction on these lesser informed considerations means we are much more uncertain about the timeline for cultured whole pieces of muscle tissue. Adding even more uncertainty to this are the recent claims that, if verified, could lead us to largely change our estimated timeline for cost-competitive cultured whole pieces of muscle tissue. Since we have such large amounts of uncertainty for all of the timelines, our estimates for when there will be cost-competitive cultured animal products could significantly change in the future.

That being said, the ranges in our following estimates represent our 90% subjective confidence intervals.[19] That is, we expect the true timeline to be within the range given in 90% of cases. We estimate there is a 5% chance that the cost-competitive alternatives will become available before the lower bound of our range and a 5% chance that the cost-competitive alternatives will not yet be available by the upper bound of our range. We would guess that:

- More than half of the main broad types[20] of conventional acellular animal products will have at least one cost-competitive cultured alternative in 2.5–30 years.
- More than half of the main broad types[21] of conventional ground meats will have at least one cost-competitive cultured alternative in 4–50 years.

[19] The project leader estimated 90% subjective confidence intervals for when there will be cost-competitive cultured alternatives for most of the animal products in each of the three broad animal product groups. He completed this on several occasions over a two week period, with a few days between each occasion. On each of these occasions his estimate was based on all of the information that he was aware of, including his previous estimate(s). The project leader then aggregated his estimates and submitted a draft of the piece for review from the rest of the research team and external reviewers. The research team and external reviewers were then asked to evaluate the aggregated estimates and if necessary, the estimates were discussed until an estimate was reached with which each ACE research team member felt comfortable.

[20] In this context we would say the main broad types of conventional acellular animal products are: milk, cheese, yogurt, cream, gelatin, and egg whites.

[21] In this context we would say the main broad types of conventional ground meat products are: a product mainly composed of ground beef, a product mainly composed of ground chicken, and a product mainly composed of ground pork.

- More than half of the main broad types[22] of conventional whole pieces of farmed animal muscle tissue will have at least one cost-competitive cultured alternative in 10–70 years.

To give a better sense of the subjective probability distributions that we have for each of the timelines, we also provide a series of our approximate point estimates of the probability that these cost-competitive scenarios would occur within certain timeframes.[23]

Table 2. Our approximate subjective probability estimates of cost-competitiveness for some types of cultured animal products

Approximate estimate of the probability that there will be at least one cost-competitive cultured alternative for more than half of the main broad types of animal products within this animal product category in:			
Animal product category	**5 years time**	**10 years time**	**20 years time**
Acellular	15%	40%	75%
Ground Meat	7.5%	20%	55%
Whole Pieces of Muscle Tissue	1%	5%	30%

From writing this page we gained a better overall understanding of cultured animal product timelines and now feel more confident in our estimated timelines. However, the timelines that we have estimated here are not largely different from those that we previously would have estimated. Small updates in our estimated timelines could contribute to important changes in our views, but these small changes by themselves seem unlikely to cause large differences in our evaluations. Our present understanding of the effects of interventions lacks the precision that would be necessary for us to make large updates in our views because of small changes in our predictions about when cost-competitive cultured alternatives will be available.

[22] In this context we would say the main broad types of conventional whole pieces of muscle tissue are: a product that is a whole piece of muscle tissue from a chicken, a product that is a whole piece of muscle tissue from a cow, a product that is a whole piece of muscle tissue from a pig, and a product that is a whole piece of muscle tissue from a fish.

[23] The project leader estimated these point estimates on several occasions over a two week period, with a few days between each occasion. On each of these occasions his estimate was based on all of the information that he was aware of, including his previous estimate(s). The project leader then aggregated his estimates and submitted a draft of the piece for review from the rest of the research team. The research team was then asked to evaluate the aggregated estimates, and they were discussed until an estimate was reached with which each ACE research team member felt comfortable.

Further questions

We did not fully investigate a number of important questions that would have informed our view about when cost-competitive cultured alternatives may be available. Further research on those questions—some of which are listed below—could cause us to significantly update our views.

- Are there any flaws in the reasoning that cultured animal product proponents give for their estimated timelines?
- What timelines for cost-competitive cultured animal products do other scientists in the tissue engineering field estimate?
- How do the methodologies and/or assumptions used in the cost estimates of cultured meat proponents differ from those used in the Van der Weele & Tramper estimate?
- How much would animal-free growth media cost if it were purchased at industrial scale in a few years time?
- Has there been any substantial progress on culturing whole pieces of muscle tissue?

Key resources

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