The In Vitro Meat Consortium
Preliminary Economics Study
Project 29071

V5 March 2008

AMENDMENT HISTORY

Version & Reason For Issue	Date Issued	Brief Summary of Change	Author
V2 Draft for comment by Professor Stig Omholt	5 February 2008	Initial draft	JRV / DD
V3. Final draft for comment by Steering Group	3 March 2008	Removal of SCP as a discrete product. Correction of the wet weight in the medium calculations. Conversion to Euro. NPV explanation.	JRV / DD
V4 Final	14 March 2008	Steering Group comments included in text. No change to economic model. Minor changes to conclusions.	JRV
V5	31 March 2008	Additional point in 3.5.2 Modification to 4.3	JRV

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1 Executive Summary

This study was commissioned by Professor Stig William Omholt to review whether the production of in vitro meat could be financially viable.

Global meat consumption is estimated to be about 270m tonnes pa, growing at the rate of 4.7 m tonnes annually. The environmental impact of meeting this forecast demand from existing livestock systems is significant. Cultured meat technology offers an alternative production route for a proportion of this consumption. This would then allow a downsized livestock production system to continue to be ecologically sound and to meet basic animal welfare needs.

The study built a net present value (NPV) model based on publicly available information on current and recent single cell protein plants. This model was then used to:

- Forecast the cost for large volume production of the medium required to grow mammalian cells.
- Develop the financial model for the technically more advanced in vitro meat production system.

The financial model identified four major areas of cost as follows:

1.	Up front R&D and PR costs.	These will be significant and they have been ignored in the model. It is assumed that they will be met by governments and by charitable donations and that the resulting technology would then be made freely available.
2.	Capital costs	These are unknown until the technology is available. The model uses factored costs from known technology.
3.	Medium costs	These are the most significant component of operating costs and will require further R&D. Assumptions have been based on medium which is commercially available in small quantities for biopharmaceuticals and then discounted to allow for larger volumes.
4.	Financing costs	It will take considerable investment for the world to switch to in vitro meat production. Investment will only be available if the return exceeds the risks. The model assumes negligible business risk on the basis that up front investment has enabled the technology to be proven and made freely available and that public opinion is positive.

It is likely that it will be possible to produce in vitro meat in large quantities for less than Euro 3300 - 3500 / tonne. This compares with the unsubsidised production of chicken meat at about Euro 1800 / tonne. On this basis it makes sense to continue to invest in both;

- developing the process technology for the efficient large scale production of muscle tissue from stem cells.
- developing cheaper and larger volume sources of growth medium that do not contain animal products.

2 Aims.

The purpose of the study is to determine whether the production of in vitro meat is likely to be economically viable when compared with the factory gate prices for say chicken. The study will include;

- Identifying the main cost components involved in building and operating a process plant directed towards the production of engineered meat in large quantities.
- Using a forecast cashflow to identify the key areas that would need to be addressed in order to compete with chicken meat on price.
- Assessing the realism in large-scale production of a serum free cell culture medium at a given price given current technological possibilities. The given price will come from the cashflow.

It should be noted that this study is a very early look at potential viability. If the idea looks to be viable, recommendations will be made for further development / engineering. A large number of assumptions will be made and these will be listed.

3 Conclusions.

3.1 The costs required for R&D and for Promotion to ensure society acceptance of these products will be substantial and have not been included in this analysis. The main areas to focus R&D effort are identified below. Society acceptance includes both acceptance by the regulators (to grant licenses for human consumption) and acceptance by consumers.

These costs will have to be incurred, the problems overcome and the solutions made readily available before manufacturers will invest in the necessary global supply chain.

3.2 Cell growth media costs will need to be about 1/10 the price for commercially available media purchased for small scale pharmaceutical applications. This, together with the need to produce large quantities will require the development of either on site processing or a separate media infrastructure. Single Cell Protein could be used as a component of this media.

3.3 Growing mammalian cells in sufficient volumes to produce a meat–like product for a price which is competitive with meat poses many technical challenges. Growing mammalian cells in suspension in 20k litre bioreactors is currently possible but expensive and increasing the volume will present challenges. Growing cells in a 3D matrix is still in the research stage. The key challenges for the design of the bio-reactor and associated plant are:

- The biology around the choice of cell, the optimum conditions for growth and the method to differentiate into the final product.
- The need to enable nutrients to get to the individual cells and for waste products to be removed within large scale bioreactors.
- The need to minimise shear stress and to maintain constant conditions around all the cells.
- The need to grow the cells on some form of structure and then to release them without damage for harvesting.
- The need for sterile engineering over a considerable scale. Mammalian cells grow slowly and contaminants will out compete them. Plant must be cleanable and sterilisable, Clean in Place (CIP) and Sterilise in Place (SIP) systems will be needed, Standard Operating Procedures (SOPs) will be required and raw materials will need to be pharmaceutical grade.
- Sophisticated instrumentation will be required to measure and control conditions inside the reactors.

3.4 The forecast costs for the two in vitro meat products are as follows:

Mammalian cells in suspension	Euro 3300/ tonne
Mammalian cells in 3D matrix	Euro 3500 / tonne

3.5 The recommendations for next steps are as follows:

1. Promotion and Fund raising	• Continue to work through the Steering Group to promote political acceptance and public funding for in vitro meat R&D. • Review the potential impact on global resources and climate change. • Develop a business strategy to enable the roll out of large numbers of these new food plants.
2. Mammalian cells in suspension	• Address and evaluate the challenges associated with stem or progenitor cell production • Review the feasibility and consequences of increasing reactor size. • R&D to develop reactors with new designs • Concept study to confirm design and costings.
3. Mammalian cells in 3D	• R&D to develop potential biological and engineering solutions to the issues listed in 3.3 above.
4. Media	• Reduce the cost of the media for mammalian cell growth and confirm potential yields. • Concept study for on-site media production plant.

	• Consider production of amino acids and glucose by CO_2 fixation (photosynthetic bacteria in combination with secondary organism).
5. Sterility and cleanliness	• Innovate lower cost systems for ensuring cleanliness and sterility for the relevant parts of these large bulk food plants. Pharmaceutical systems are expensive and in-appropriate.
6. Automation	• Develop appropriate probes and control systems for large scale mammalian cell growth

4 Analysis

4.1 A preliminary economic analysis has been carried out in the following areas:

- Production of Single Cell Protein. This is used to validate the financial model as a basis for factoring to create the mammalian cell models. It is also used to generate a price for bioprotein as a component of the growth media for mammalian cells.
- Production of growth media for mammalian cells.
- Production of mammalian cells in suspension.
- Production of mammalian cells in a 3D matrix.

A net present value (NPV) analysis has been used to develop forecast "breakeven" prices for the growth media and for in vitro meat. The NPV method compares cash receipts and payments (not accounting income and expenses) that are expected to result from a capital project. A project is profitable if the NPV is positive – ie the returns exceed the costs when both are expressed in present value terms. For this study, we run the analysis with varying assumptions and generate the "breakeven price" at the point when NPV is just positive. The NPV model will always give the correct answer providing the following assumptions are correct:

- The amounts and timing of the cash flow's are correct. In this case the biggest assumptions concern the capital cost (based on unproven technology) and media costs (based on assumed media component costs and yields). The study reports a range of breakeven prices for different input costs. The next stage would be to tighten the accuracy around these costs.
- The opportunity cost of capital is correctly estimated. This study assumes a low discount factor on the basis that technology will be proven and customer demand will be high for what will be a commodity product in a global market. This would be the case once the market is established; the business strategy for the interim case has not been explored.
- There are no non-financial aspects to consider. For example, the breakeven price does not include any government intervention or incentives.

4.2. Single Cell Protein

The single cell protein (SCP) production model is reasonably well understood. There have been a number of attempts over the past 40 years to produce SCP and most have been abandoned usually because the product could not compete with other forms of protein such as alfalfa, soya, fish-meal etc. Examples of these products include; TOPRINA (British Petroleum), a product from Shell, PRUTEEN (ICI), TORUTEIN (Amoco), QUORN (ICI / RHM – now Premier Foods), a product from Dupont, BIOPROTEIN (Norferm / Statoil).

The SCP economic model is based on publicly available information and assumptions on the QUORN and BIOPROTEIN products because they are still in production. The "BIOPROTEIN" type model is used to generate prices for a component of the mammalian growth media and the "QUORN" type model is used as the basis for the mammalian cell model.

The outline process plant descriptions are in appendix 1 and the summary of the economic model to produce bioprotein for the growth media is in appendix 2. The resulting "breakeven" price for bioprotein is Euro 1850 / tonne.

4.3 Media prices and quantities.

Prices for commercially available media in small quantities and suitable for biopharmaceutical applications are in the region of Euro 7000 – 8000 / tonne. This price reflects the fact that the current market is not designed to produce media in the large quantities required for a global in vitro meat industry. Prices will fall if large quantities are produced.

It is not realistic to consider buying in re-cycled media because the quantities are not available and the quality would be variable (requiring local analysis and make up). Media within an in vitro meat plant would be re-cycled however.

In vitro meat production requires large quantities of media costing less than say Euro 350 / tonne. This may require production to be co-located with the in vitro meat plant and further development of both the recipe and the process plant will be required. A possible recipe at this cost is given in appendix 2.

It has been assumed that about 193kg (wet weight) of in vitro meat can be made per tonne of media. The assumptions behind this calculation are in appendix 2.

4.4 Mammalian cells in suspension

Technology is commercially available in the biopharmaceutical field to grow small quantities of mammalian cells in suspension. The technical leap required is to grow and subsequently process large volumes of these cells.

Possible outline process plant descriptions are used to describe some of the issues involved in developing this technology in appendix 3.

The summary of the economic model is in appendix 4. This has been developed by factoring the capital cost used in the SCP model. The assumptions for the cost of the media and for the yield from the media are described in 4.3 above.

On the basis of these assumptions, it should be possible to manufacture a form of in vitro meat using the mammalian cells in suspension process for about Euro 3270 / tonne.

4.5 Mammalian cells in a 3D matrix.

Technology is not yet available to grow mammalian cells in bulk in a 3D matrix. A very special type of bioreactor or cell factory will be required in order to enable nutrients to get to the individual cells and for waste products to be removed whilst also maintaining the right environmental conditions around the cells.

Possible outline process plant descriptions are used to describe some of the issues involved in developing this technology in appendix 3.

The summary of the economic model is in appendix 4 and as for the “mammalian cells in suspension model”; this has been developed by factoring the capital cost used in the SCP model. Since this technology has not yet been developed, these assumptions may be inaccurate. The assumptions for the cost of the media and for the yield from the media are described in 4.3 above.

On the basis of these assumptions, it should be possible to manufacture a form of in vitro meat using the mammalian cells in a 3D matrix process for about Euro 3500 / tonne.

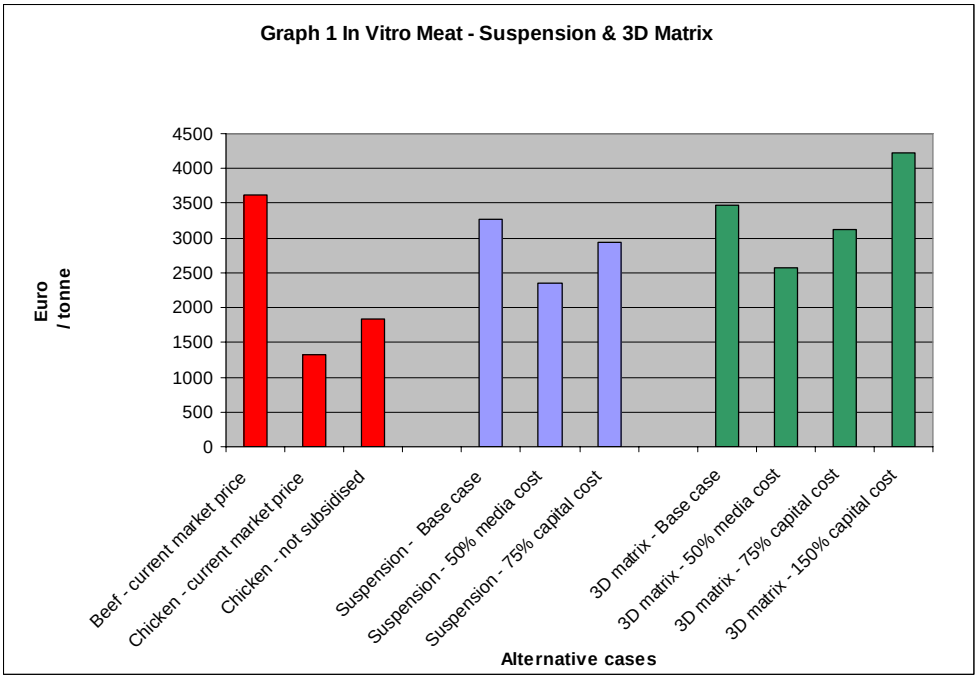
4.6 Sensitivity

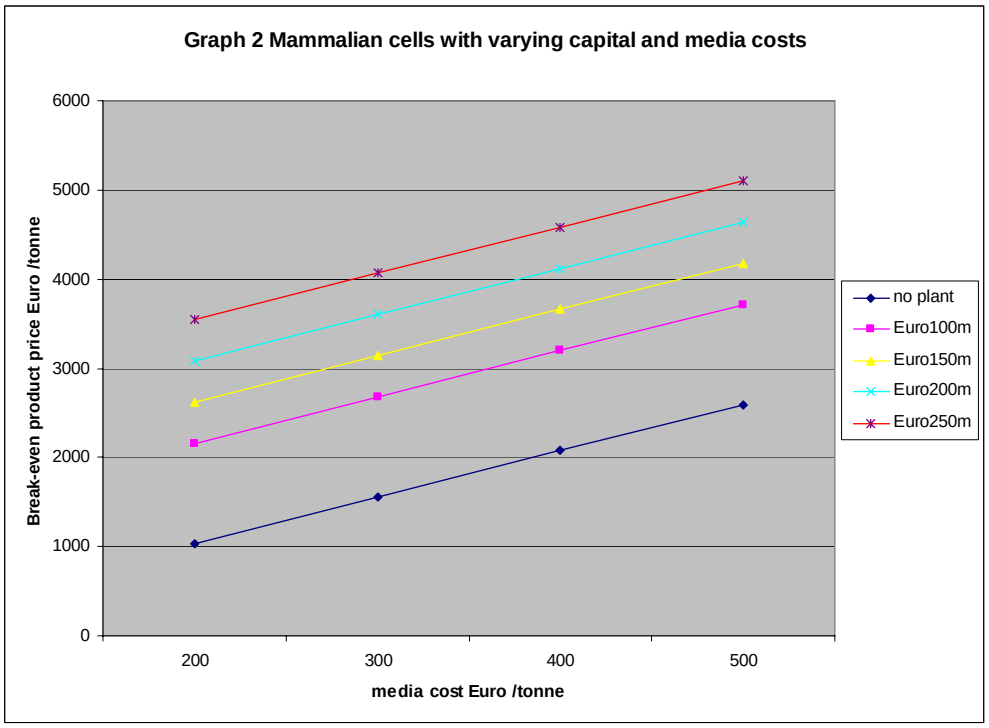
Both of the mammalian cell financial models have considerable assumptions built in. The following graphs show how varying media costs and capital costs affect the “break-even” price of production. The break-even price is virtually equally sensitive to changes in capital cost

and media cost which means that R&D effort will need to be focussed on both areas.

Graph 1 gives the forecast breakeven price for the different in vitro meats with different stated assumptions. It also compares these prices with current market prices for beef and chicken and with the calculated “non-subsidised” price for chicken.

Graph 2 shows how different assumptions for capital cost and media cost affect the forecast breakeven price for in vitro meat. Capital costs can be reduced by reducing the cost of the process plants or by increasing the throughput. Media costs can be lowered either by reducing the cost of producing the media or by reducing the amount used by increasing the yield. The “no-plant” line shows the contribution that media makes to the in vitro meat price.





Appendix 1. SCP and Media - Process Description

1.1 PROCESS DESCRIPTION – Bioprotein type product

1 – Produced from Methane as a nutrient source.

2 – Large Scale of operation – fully automated.

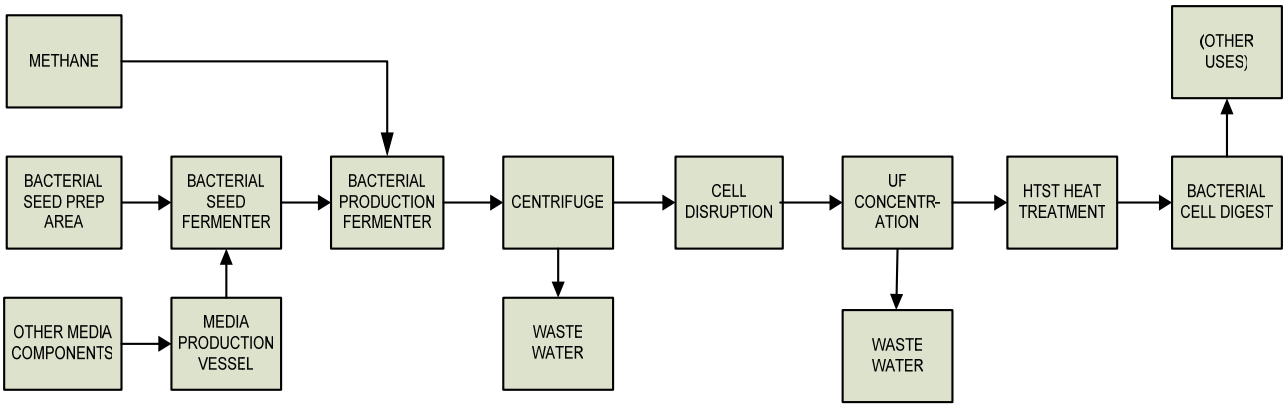
3 - Innovative Bioreactor Design.

4 - Downstream processing is large scale, to meet the bioreactor output, and effective.

5 - Final stage spray drying gives good shelf life and solids handling.

6 - Product currently sold as animal feed, including ‘autolysate’ which has a greater sales value due to the higher nutritional value.

Outline process flow diagram



1.2 PROCESS DESCRIPTION – QUORN type product

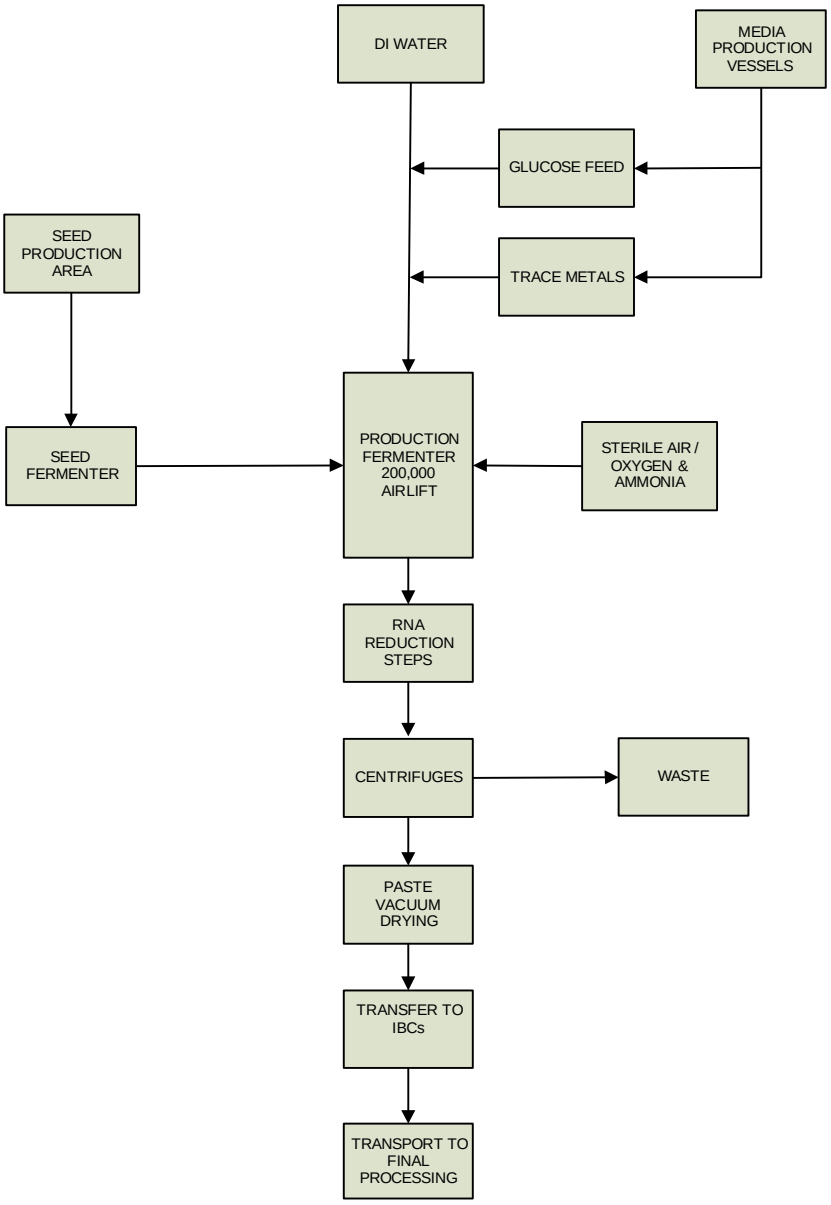
1- Large Bioreactor

2- Mycelial culture

3- Fully automated with CIP/SIP.

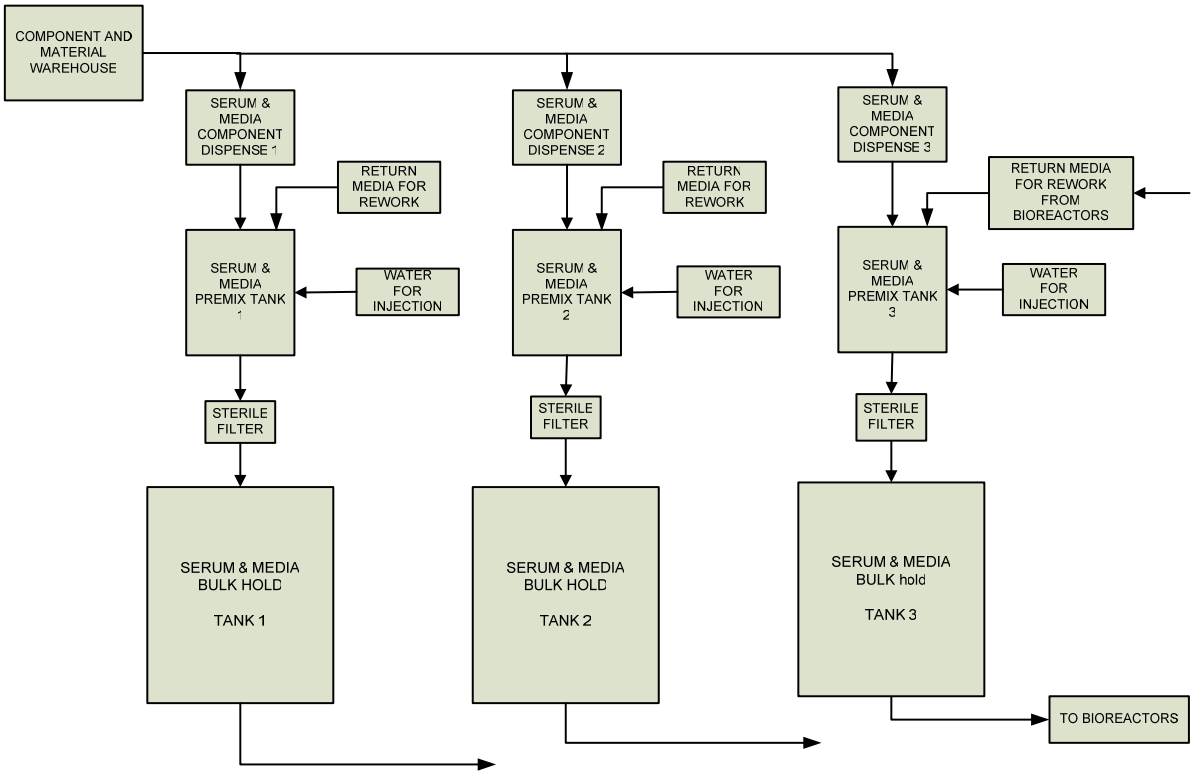
4- Currently commercially sold as a human foodstuff, seen to be low fat and good for vegetarians.

Outline process flow diagram



1.3 PROCESS DESCRIPTION – Growth media for mammalian cells

- Media quality, availability and sterility are essential for process success.
- Internally produced media may be returned from bioreactors to retain components not used, and also allow reuse of media by the addition of components before re-filtration.
- Internally produced media allows formulation development to optimise processes, and to react to changes in quality of externally supplied raw materials.
- The following flowsheet shows a possible Media Production operation, with multiple batch vessels for flexibility. The economic study assumes that some of the media components will come from a Bioprotein type process either on site or delivered to the warehouse. The growth factors will be produced on site in small bioreactors (not shown on this diagram).



Appendix 2. Media for Mammalian Cells - Economic Model

1. SCP Economic model.

The basic economic model for a SCP plant to produce an un-textured product suitable as a component of the mammalian cell growth media is as follows:

3. Single Plant Model for Bioprotein as basis for Medium:								
Euro million		Factors	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Turnover	Alternative "breakeven" prices to suit alternative assumptions	1850		8.2325	16.465	16.465	16.465	16.465
Costs								
Capital Costs	Based on units of production of Euro 41 m (TIC) for 8.9k tonnes dry product pa. (Advised for BIOPROTEIN). Add client costs +15%.	47	-54.05					-1
	Assumed plant capacity (tonnes pa)	8900						
Maintenance	Assume 3% capital cost pa	0.03		-1.41	-1.41	-1.41	-1.41	-1.41
Variable costs	raw materials = 50% of product price (Advised for BIOPROTEIN).	0.5		-4.11625	-8.2325	-8.2325	-8.2325	-8.2325
Staff & o/head	based on 13 people (9 production related, 4 office - management, sales, finance, pd) @ Euro 50k average	650000		-0.65	-0.65	-0.65	-0.65	-0.65
Net Costs			-54.05	2.05625	6.1725	6.1725	6.1725	5.1725
Discount factor	Assume 8% (4% cost of money, 4% risk)	0.08	1	0.925926	0.857339	0.793832	0.73503	0.680583
Present value			-54.05	1.903935	5.291924	4.89993	4.536972	3.520317
NPV			1.030596					

The model originally included a capital cost of Euro 41m and a very low business risk of 2% to give a breakeven price of about Euro 1440 / tonne dry weight. This closely matches an animal feed plant. The capital cost was then increased by 15% to allow both for an increase in cost to enable production for human consumption and a decrease in cost as technology improves. In addition the business risk was increased marginally to 4% on the assumption that technology is proven and the sales volumes are guaranteed. The resulting “breakeven” price of Euro 1850 / tonne is used in the subsequent calculation of mammalian cell growth medium.

2. Media cost assumptions.

Component	**Raw cost**	**Euro / tonne of media**	**Assumptions**
Bioprotein	Euro 1850 / tonne.	185	Nitrogen source. Assume 100kg bioprotein / tonne media – based on 55kg protein / tonne media
Glucose	Euro 525 / tonne	3	Carbon source. Assume 4.5g / litre
Vitamins and minerals		22	Rough estimate
Growth factors		0	Negligible cost for raw materials. Make on site in small scale bioreactors.
Serum / serum mimic	Euro 29 / litre	147	Assume 10% serum or serum mimic in media. Assume serum mimics can be manufactured in bulk for say 5-10% of this cost.
	Total	Euro 357 / tonne	

3. Media quantities required.

- Assume media kg dry weight (dw) / in vitro meat kg dw = 2.
- Assume media 100kg dw / 850kg = say 120kg dw / tonne.
- This produces 60kg dw in vitro meat from 1 tonne of media.
- Uncooked chicken is about 69% water. Assume the same for in vitro meat.
- Hence 193kg wet weight in vitro meat can be produced per tonne of media.

The assumptions for media costs and yield will require validation and optimisation. The economic viability of invitro meat depends on these assumptions as much as on the capital cost of the plant itself.

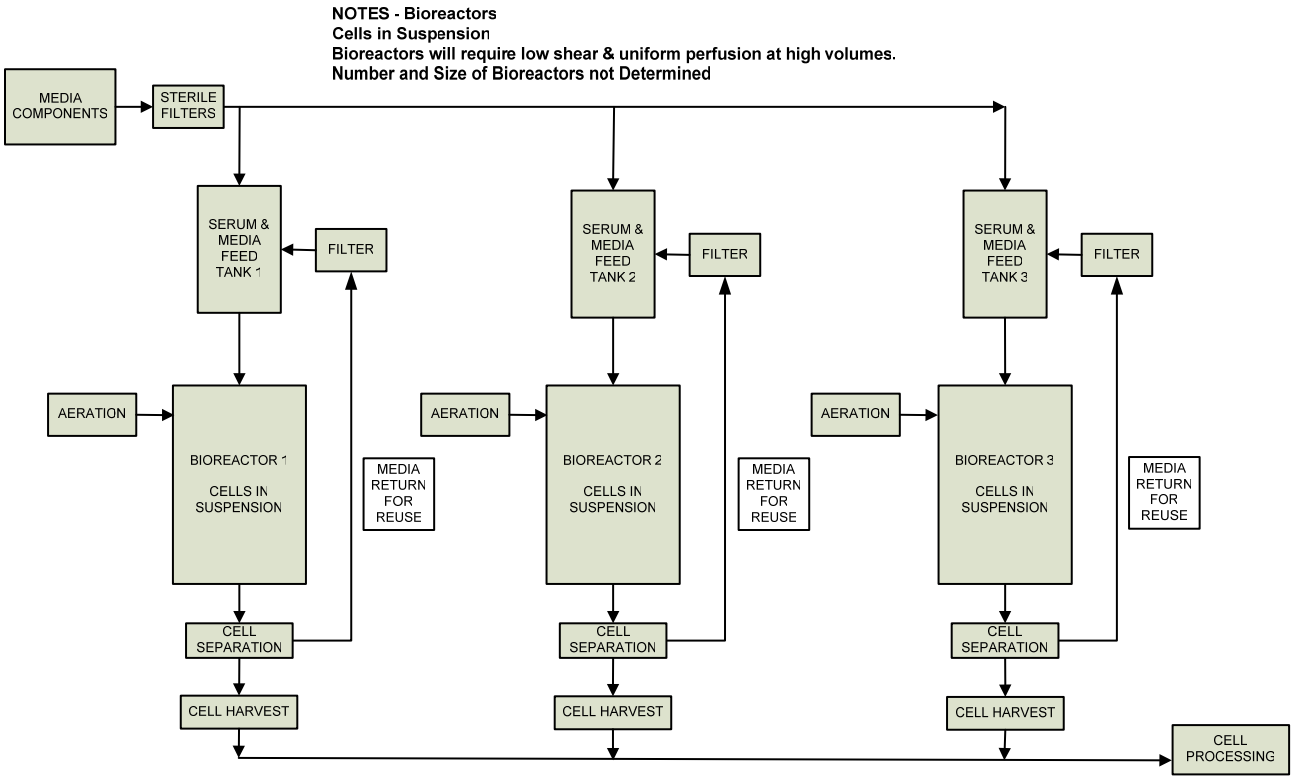
Appendix 3. Mammalian Cells - Process Description

3.1 PROCESS DESCRIPTION – Mammalian cells in suspension

1- Produces meat appropriate for 'ground or boneless' uses (hamburger, sausages). This will require the development of the right "mouth feel" and chewing resistance.

2- Process Flow Diagram below illustrates possible processes. Multiple reactors are expected to even out the supply of harvest material and minimise scale-up problems.

3- Seed train and downstream processing not shown.



3.2 PROCESS DESCRIPTION – Mammalian cells in 3D matrix

1- Mammalian cells supported by:-

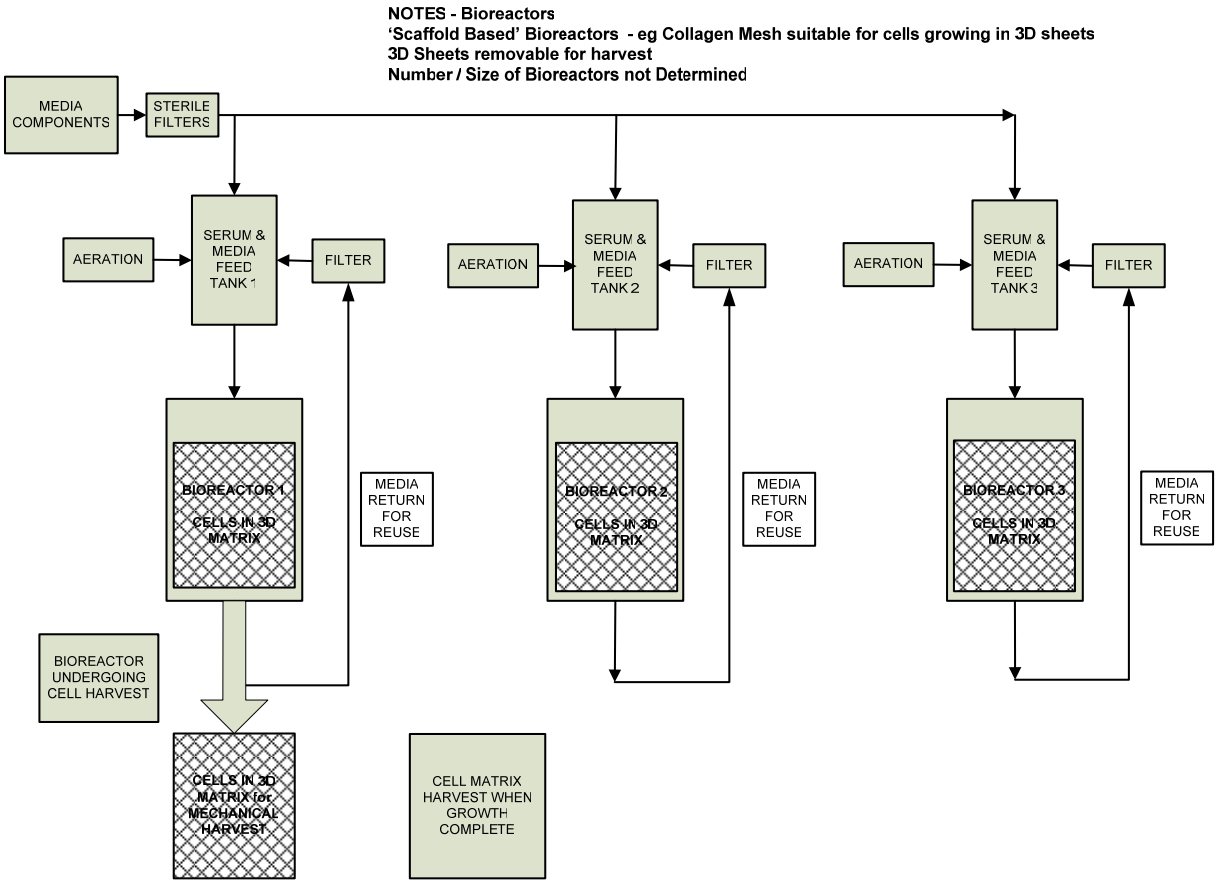
- 'Self-organising' Constructs
- Proliferating muscle tissues in vivo
- Cells attached to microcarrier beads, sheets, meshes or other supports (these might be edible and harvested with the cells or in-edible and removed for re-use)
- or the stacking of cell sheets

2- Cells are so supported and supplied within the bioreactors such that the natural tissue builds 'self-organising constructs', where the 3D self-organisation of tissues allows the provision of the nutrient supply, aeration, waste removal etc. This subsequently allows cell, and consequent tissue, growth. The full technology for this option is not fully developed.

3- The Process Flow Diagram below illustrates possible processes. Multiple reactors are expected to even out the supply of product for further processing. There are several areas that require development:

- the mechanism for cell support and growth within the bioreactor
- the mechanism for harvesting
- the need for pharmaceutical grade cleanliness and ability to sterilise
- instrumentation and process control.

4- The seed train, process equipment for differentiation and downstream processing are not shown.



Appendix 4. Mammalian Cells - Economic Model

1. The basic economic model for the Mammalian cells in suspension model is as follows:

1. Single Plant Model for Mammalian cells in suspension		factor	year 0	year 1	year 2	year 3	year 4	year 5
Euro million								
Turnover	Alternative "breakeven" prices to suit alternative assumptions	3270		24.525	49.05	49.05	49.05	49.05
Costs								
Capital Costs	Refer to assumptions worksheet	135	-155.25					-1
	Assumed plant capacity (tonnes pa)	15000						
Maintenance	Assume 3% capital cost pa	0.03		-4.05	-4.05	-4.05	-4.05	-4.05
Variable costs	Assume Euro150 / tonne for utilities	150		-1.125	-2.25	-2.25	-2.25	-2.25
Media costs	Assume Euro350 / tonne for media	350						
	Assume 193kg meat / tonne media	0.193		-13.601	-27.2021	-27.2021	-27.2021	-27.2021
Staff & o/head	based on 13 people (9 production related, 4 office - management, sales, finance, pd) @ Euro50k average pa	650000		-0.65	-0.65	-0.65	-0.65	-0.65
Net Costs			-155.25	5.098964	14.89793	14.89793	14.89793	13.89793
Discount factor	Assume 6% (4% cost of money, 2% risk)	0.06	1	0.943396	0.889996	0.839619	0.792094	0.747258
Present value			-155.25	4.810343	13.2591	12.50859	11.80055	10.38534
NPV			1.57461					

2. The basic economic model for the Mammalian cells in a 3D matrix is as follows:

2. Single Plant Model for Mammalian cells in a 3D matrix.		factor	year 0	year 1	year 2	year 3	year 4	year 5
Euro million								
Turnover	Alternative "breakeven" prices to suit alternative assumptions	3470		26.025	52.05	52.05	52.05	52.05
Costs								
Capital Costs	Refer to assumptions worksheet	158	-181.7					-1
	Assumed plant capacity (tonnes pa)	15000						
Maintenance	Assume 3% capital cost pa	0.03		-4.74	-4.74	-4.74	-4.74	-4.74
Variable costs	Assume Euro150 / tonne for utilities	150		-1.125	-2.25	-2.25	-2.25	-2.25
Media costs	Assume Euro350 / tonne for media	350						
	Assume 193kg meat / tonne media	0.193		-13.601	-27.2021	-27.2021	-27.2021	-27.2021
Staff & O/heads	based on 13 people (9 production related, 4 office - management, sales, finance, pd) @ Euro 50k average pa	650000		-0.65	-0.65	-0.65	-0.65	-0.65
Net Costs			-181.7	5.908964	17.20793	17.20793	17.20793	16.20793
Discount factor	Assume 6% (4% cost of money, 2% risk)	0.06	1	0.943396	0.889996	0.839619	0.792094	0.747258
Present value			-181.7	5.574494	15.31499	14.44811	13.63029	12.11151
NPV			0.420179					

3. Several assumptions have been made in these models as follows:

Factor	Assumption
Capital cost	• Base this on the "Quorn" type SCP plant described in 4.2 because it represents a bio-food plant with a downstream processing step. • Factor the reactor (and associated processing) element to allow for the big increase in volume needed because mammalian cell doubling time is say 30 times that of SCP. Also include time for differentiation. Use the following; New capital cost (for reactors) = old capital cost * ratio of capacity ^0.6. • Factor the reactor element to allow for the increased complexity associated with processing mammalian cells compared to SCP. In the base case the following percentages were used: o +10% for mammalian cells in suspension. o +50% for mammalian cells in a 3D matrix.
Media cost and media usage	• Refer to section 4.3 and appendix 2
Business risk	• This is very small in these models on the basis that the technology and customer acceptance risks have already been removed. It assumes that in the future this is a high volume commodity product, using proven technology and selling into a global market with high demand.
Overall Model	• 20 year duration • No inflation and no tax