**Variables which cannot be adjusted.**

K42 which is molar mass of oxygen and K56 heat released per mol of O2 consumed. I considered the density of water but that potentially changes with temperature and pressure.

Equation guide

I wrote this as a bit of guide for the equations and I hope it is helpful for understanding some the context for the equations.

**Equation 1 Equation 1. Time of batch**

= calculated based hours per doubling (K26), number of cells in seed bioreactor which is calculated from K6 and K7.

= K14

**Equation 2. Total number of cells in a single bioreactor after maturation**

= K10

= K9 which is a unit conversion of K8. 20 m3 to 20,000 L

**Equation 3. Total volume occupied by cells**

=K24

**Equation 4. Cell mass in bioreactor per batch**

= K25

**Equation 5. Annual ACBM production per bioreactor**

= Calculated using K15/Q20

**Equation 6. Bioreactors needed to match desired annual beef production**

= K11

**Equation 7. Equipment costs equation**

= K12

= N4

= K8

= This is unit conversion to make this portion unitless. It represents m3 since K8 unit is 20 m3. This method is employed as described by *The Food Plant Economics*.

= K16

**Equation 8. Fixed equipment costs**

= K13

**Equation 9. Fixed manufacturing costs**

= K18

**Equation 10. Minimum annual operating costs**

Master equation for operating cost. These variables are obtained using the equations below.

**Equation 11. Cells in bioreactor during growth phase**

= K26

This is the start of the estimation we spoke about. This equation uses desired number of cells in seed bioreactor as starting point co then uses an if statement to determine how long. Essentially a doubling occurs until we reach desired number of cells in main bioreactor at ct. This final number of cells is calculated in U5 using inputs K9 and K10. R5 and S5 are rearrangements of the equation to solve for time (t) i.e. total time in growth phase.

**Equation 12. Glucose consumption rate during growth phase**

= K27

= R64-R78

This again is more of an academic paper equation vs. my means of calculation. It is just stating that glucose consumption rate in the whole bioreactor changes as time changes and this governed by the amount of cells present at the time.

**Equation 13. Total glucose required for growth phase per ACBM batch**

This equation is estimated by summing the amount of glucose consumed during each doubling period. Also, spreadsheet is in moles, however this equation assumes a conversion to mass, but does not explicitly state it. I’ll change it in the supplementary material to stay consistent. The ultimate goal of the equation is estimate media based upon glucose consumption rate which is based on the amount of glucose in the media (K39).

**Equation 14. Total glucose required for maturation phase per ACBM batch**

= Is the desired cells (U5) multiplied by the single cell glucose consumption rate (K27)

=K14

**Equation 15. Total glucose required per batch**

**Equation 16. Total required media charges per batch**

= K39 x K9

**Equation 17. Total media volume required per batch**

= K9

**Equation 18. Total media volume per year**

For by (Q31) calculation see Amount of bioreactor calculation. Uses K10, K9, K8, K24, K25, K15, and K11.

**Equation 19. Total annual costs of media**

=P83= (K32\*N12)+(K33\*N13)+(K34\*N14)+(K35\*N15)+(K36\*N16)+(K37\*N17)+(K38\*N18)+(N11)

Equation 20. Oxygen uptake rate

Academic paper equation. Not in the spreadsheet.

**Equation 21. Initial oxygen in the for the system**

= K40

=K41

= K42 not changeable.

**Equation 22. Oxygen uptake rate changing with time**

= K28

Similar estimation style as glucose consumption rate for the next three equations.

**Equation 23. Total oxygen required for growth phase per ACBM batch**

**Equation 24. Total oxygen required for maturation phase per ACBM batch**

**Equation 25. Total oxygen required per ACBM batch**

**Equation 26. Total amount of oxygen required per year**

For by (Q31) calculation see Amount of bioreactor calculation. Uses K10, K9, K8, K24, K25, K15, and K11.

**Equation 27. Total annual costs of oxygen**

= N25

**Equation 28. Estimation of energy to heat media to required temperature**

= assumes 1 kg/L = K40

= K52-K51

= K53

=K54 this is a percentage

**Equation 29. Glucose combustion reaction**

C6H12O6 + 6 O2 → 6CO2 + 6 H2O + heat

Academic paper equation not used in spreadsheet

**Equation 30. Estimation of energy usage for bioreactor cooling per ACBM batch**

= (R108\*Q31)

= K56

= K57

**Equation 31. Estimation of annual energy usage for cooling of ACBM**

= K11

= K60-K61

= K59

= K62

**Equation 32. Cost of energy per kWh from public supplier**

= N28

**Equation 33. Cost of self-generated electric/energy per kWh from a boiler-turbine system**

= (N29/100) Dividing by 100 is done in the equation cell Q120

= K44

**Equation 34. Cost of energy per kWh**

= K46 these are percentages. If solar is used these could theoretically go to zero

= K45

These are percentages. If solar is used these could theoretically go to zero.

**Equation 35. Annual process water and wastewater costs**

= P86/1000 this just the annual media volume converted to from liter to m3

= N36

= N37

= N38

**Equation 36. Required manpower for operation**

P140 = ((K67\*K91)+(K68\*K92)+(K93\*K69)+(K94\*K70)+(K71\*K95)+(K96\*K78)+(Q30\*K79)+(K80\*K98))

Q30 is the number of bioreactors we previously calculated. All other values are were zeroed out for our scenarios but they could add an additional manpower requirement. We are making an additional program with a user interface which will use this.

**Equation 37. Labor cost correction factor**

=K83

= K84

= K85

=K86

= K87

= K88

**Equation 38. Estimated annual labor costs**

= K15

=N32

**Equation 39. Equity ratio**

= K102 Percentage which can’t go over 100%

**Equation 40. Total debt costs**

= D4 this is cost of bioreactors without financing

**Equation 41. Total equity costs**

**Equation 42. Capital recovery factor for debt**

= K103

= K104

**Equation 43. Capital recovery factor for equity**

= K105

**Equation 44. Annual debt payment**

**Equation 45. Annual equity recovery**

**Equation 46. Minimum annual cost of capital expenditures**

**Equation 47. Total minimum annual cost**