Calculations for budding living aerosols on Venus

ChatGPT 6 have done these calculations. I have low trust in all of these.

The entire article series has been built on ideas I cultivated since the 2021 paper https://arxiv.org/abs/2108.02286

The ChatGPT helped me to put it together in sort of readable form.

For full transparency here is the drafting process outlined with my prompts over several chats:

https://chatgpt.com/share/6aa4c21c-ebd8-83ea-8f45-93fec6cfc960

https://chatgpt.com/share/6aa4c259-493c-83e9-97c6-19fbe640b581

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Text below

These calculations accompany "Budding life in the clouds of Venus." They follow a provisioned daughter from its developmental trigger through maternal growth, budding, and descent to a selected hot boundary. All mothers accumulate metabolically produced acid; daughters receive part of the mother's solvent, dissolved resources, and functional biomolecules. The calculation estimates carbon-supported daughter equivalents. Offspring survival and the time spent gathering resources before the trigger require a separate population model.

1. Composition and maternal allocation

The initial daughter diameter is d_D = 0.5 µm, carbon loading c_D = 500 kg/m^3, and bulk density ρ_p = 1,800 kg/m^3. These are selected composition and size assumptions.

$$C_D = c_D \pi d_D^3 / 6 = 3.27249 \times 10^{-17} \text{ kg C.}$$

The daughter contains approximately 32.7 femtograms of carbon. Organic material is represented by CH_2O, giving 2.5 kg of organics per kilogram of carbon. At the chosen density, the total daughter mass is 3.6 C_D = 117.8 femtograms. Its organic inventory is 2.5 C_D = 81.8 femtograms and its acid solvent inventory is 1.1 C_D = 36.0 femtograms.

The bookkeeping reaction is:

$$CO_2 + 2\ SO_2 + 3\ H_2O \rightarrow CH_2O + 2\ H_2SO_4.$$

For each kilogram of carbon fixed, the reaction consumes 3.667 kg CO_2, 10.667 kg SO_2, and 4.5 kg water; it produces 2.5 kg organic material and κ = 196/12 = 16.333 kg sulfuric acid. Reactant and product masses both total 18.833 kg. This equation specifies the bulk elemental accounting without establishing a biochemical pathway or the reaction's free energy in the actual liquid.

Let U be cumulative carbon fixed since the trigger. The retained functional carbon inventory is:

$$C = \min(C_D + U, 1{,}000\ C_D).$$

Maturity occurs after 999 C_D of new carbon has been fixed. Subsequent production replenishes functional material allocated to buds, maintaining the selected maternal inventory. The number of daughter equivalents is:

$$N = \max[0, (U - 999\ C_D)/C_D].$$

Each bud is provisioned with solvent, soluble metabolites, essential ions, pigment, hereditary material, catalysts, and surface material. Organic solutes and biomolecules are included in the CH_2O proxy. Essential elements outside that proxy require the additional nutrient ledger below. Damaged and poorly recyclable material is preferentially retained. This partitioning requires organized assembly: a random sample of increasingly dilute maternal liquid would have a different composition from the specified daughter.

The maternal acid inventory explicitly subtracts the solvent allocated to daughters:

$$A = 1.1\ C_D + \kappa\ U - 1.1\ N\ C_D.$$

The mother has mass $M = 2.5\ C + A$ and physical diameter $d = [6\ M/(\pi\ \rho_p)]^{1/3}$. At maturity, $d = 8.6775$ µm. Production of one daughter equivalent generates 534.5 femtograms of acid, of which the daughter receives 36.0 femtograms. The other 498.5 femtograms remain in the mother. Approximately 93.3% of newly produced acid therefore adds to maternal mass during budding.

The bulk mass balance is:

$$M + 3.6\ N\ C_D = 3.6\ C_D + (2.5 + \kappa)\ U.$$

Likewise, total acid produced equals the increase in maternal acid plus the acid inherited by daughters. The assumed density stays fixed as acid accumulates. Solvent water content, noncarbon nutrients, composition-dependent density, and additional waste need more detailed accounting. No explicit aging or dilution penalty is imposed on maternal catalytic capacity.

2. Atmospheric profile and sedimentation

The reference profile is from Landis, Colozza, and LaMarre, Atmospheric Flight on Venus. Temperature is interpolated linearly between the following anchors; pressure is interpolated logarithmically.

Altitude (km)	Temperature (K)	Pressure (bar)
45	385	1.979
50	350	1.066
55	302	0.5314
60	263	0.2357

The selected developmental trigger is 0 °C at 58.6987 km. Integration ends at 100 °C at 46.6929 km, a descent of 12.0059 km. These endpoints define an illustrative metabolic interval; evaporation or loss of function could end reproduction sooner.

The particle settles relative to the gas at the slip-corrected Stokes speed:

$$v = (\rho_p - \rho_g)\ g\ d^2\ C_c\ /\ (18\ \eta).$$

Gas density is $\rho_g = p\ M_{gas}/(R\ T)$, with $M_{gas} = 0.04345$ kg/mol and $R = 8.314462618$ J/(mol K). For altitude z in kilometres, $g = 8.87[6{,}051.8/(6{,}051.8 + z)]^2$ m/s^2. The viscosity approximation is $\eta = 1.48 \times 10^{-5}\ (T/293.15)^{1.5}\ [533.15/(T + 240)]$ Pa s. The molecular mean free path is $\lambda = (\eta/p)[\pi\ R\ T/(2\ M_{gas})]^{1/2}$.

The slip correction is $C_c = 1 + (2 \lambda/d)[1.257 + 0.4 \exp(-1.1 d/(2 \lambda))]$. Altitude evolves according to $dz/dt = -v$, using metres and seconds consistently.

At the selected density, particles held at diameters of 5, 8, and 10 µm would traverse the interval in 99.9, 39.6, and 25.4 Earth days, respectively. The modeled mother changes diameter continuously. Particle Reynolds numbers, $Re = \rho_g v d/\eta$, remain below 0.035 in the main scenarios and below 0.052 in the higher-light sensitivity, consistent with using the Stokes approximation at this level of precision.

Wind, photophoresis, evaporation, condensation unrelated to metabolism, and coagulation are omitted. The settling calculation is a still-gas trajectory; it does not determine a population's average residence time in a turbulently circulating cloud.

3. Production capacity and temperature

The reference biomass doubling times are 6, 12, and 24 Earth hours. They describe functional biomass growth at favorable temperature with adequate resources. They are model inputs, not measured properties of Venusian organisms. Terrestrial phototroph growth provides context; for example, Zavřel and colleagues report approximately seven-hour doubling under favorable illumination.

The specific biological production capacity is $\mu(T) = [\ln(2)/t_{ref}] f(T)$. With temperature θ in °C, the selected response is $f = 0.1 + 0.03 \theta$ from 0 to 30 °C; $f = 1$ from 30 to 60 °C; and $f = (100 - \theta)/40$ from 60 to 100 °C. This hypothetical response gives a six-hour reference time an initial biological doubling time of sixty hours at the trigger.

At every point on the trajectory, carbon production Q is the minimum of the following capacities, all expressed in kg C/s:

$$Q = \min[\mu(T) C, F_{net} A_{opt}/e_C, 0.012 J_{SO2}/2, 0.012 J_{H2O}/3].$$

The calculation evolves cumulative production with $dU/dt = Q$. During growth, C increases. During budding, newly synthesized organic material replaces the material allocated to daughters. At full six-hour biological capacity, a mature mother produces carbon for 2,773 daughter equivalents per Earth day. This capacity does not establish that complete daughters can be assembled and separated at that rate.

4. Light budget and optical constraints

The assumed effective construction cost is $e_C = 5 \times 10^7$ J/kg C, equivalent to 600 kJ/mol C or 1.636×10^{-9} J per daughter equivalent. This is an effective biosynthetic cost; it is distinct from the free-energy change of the overall reaction alone.

The main scenarios use $F_{net} = 0.1$ and 1 W/m^2 of effective collecting area, averaged over light and dark periods. These represent selected net powers available for production. Any absorption or conversion loss included in F_{net} must be counted only once. Averaging assumes energy storage or approximates production interrupted by darkness; it does not track a light-dark cycle explicitly.

$A_{opt} = \pi d_{opt}^2/4$, where $d_{opt} = d_D(C/C_D)^{1/3}$. The effective optical diameter reaches 5 µm at maturity and stays at that value as maternal acid accumulates. Physical radius continues to determine gas collection and settling. This effective-area prescription is an assumption awaiting spectral validation.

Reference biomass doubling time	Net power for the initial daughter (W/m^2)	Net power for the mature maternal inventory (W/m^2)
6 hours	0.267	2.674
12 hours	0.134	1.337
24 hours	0.0669	0.669

These powers support the specified instantaneous production rate at full biological activity. At the mature collecting area, 1 W/m^2 supplies the specific production rate equivalent to 16.0-hour biomass doubling, and 0.1 W/m^2 to 160.5-hour doubling. They are local rate comparisons, not elapsed growth or generation times.

Spacek and colleagues' absorption model gives a peak decadic coefficient of 1,278 cm^{-1} at 375 nm for the modeled upper-cloud liquid. The corresponding straight-path optical depth is $\tau = \ln(10)\, a\, L$, approximately 0.147 across 0.5 µm and 1.47 across 5 µm. These wavelength-specific values do not establish broadband power or justify an opaque-particle assumption. Absorption can scale approximately with pigment mass in the optically thin regime. An improved model needs wavelength-dependent absorption cross-sections, pigment distribution, and the local radiation field, including scattering and dilution as the mother grows.

5. Gas delivery and nutrient allocation

The screening calculation holds SO_2 at 1 ppm and water vapor at 10 ppm throughout the interval. For gas i, the assumed usable uptake is:

$$J_i = \varepsilon\, 4\, \pi\, r\, D_i\, x_i\, p/(R\, T) \text{ mol/s}.$$

Here r is the actual physical radius, x_i is the mole fraction, and $\varepsilon = 0.01$ for both gases. This factor represents effective transfer and utilization relative to continuum diffusion to a perfectly absorbing sphere; it is not a measured sticking probability. The common approximate diffusivity is $D_i = 10^{-5}(T/320)^{1.75}(60{,}000/p)$ m^2/s, with pressure in pascals.

At 55 km, an 8.6775-micrometre mother has sufficient SO_2 encounter supply for a production rate equivalent to 8.92-hour biomass doubling at the selected uptake. Six-hour full biological capacity would require 1.49% effective uptake at 1 ppm SO_2, or 1.49 ppm SO_2 at 1% uptake. The corresponding water supply supports a rate equivalent to 1.34-hour doubling. These comparisons use the full reference capacity; the actual biological rate also includes the temperature factor.

In all six main descent scenarios, light or biological capacity sets production before SO_2 or water delivery does. The closest SO_2 margin is approximately 1.84 times the actual rate, in the six-hour, 1 W/m^2 case. Additional acid enlarges the mother's gas-collecting radius during budding. Actual vertical gas profiles, depletion by neighboring particles, surface permeability, and internal transport remain unconstrained. The continuum encounter expression also needs refinement for the smallest particles, where molecular mean free paths become appreciable relative to radius.

Every essential nutrient must obey its own allocation balance. For nutrient i, let $B_{i,0}$ be the inventory at the developmental trigger, $I_i(t)$ cumulative usable uptake, $B_{i,M}(t)$ the inventory remaining in the mother, $q_{i,D}$ the amount assigned to each daughter, and $L_i(t)$ other losses. Then:

$$B_{i,0} + I_i(t) = B_{i,M}(t) + N(t)\, q_{i,D} + L_i(t).$$

Organic molecules included in the carbon proxy and acid solvent are already transferred by the explicit budgets above. Nitrogen assimilation, phosphorus, and required metal quotas and usable uptake rates are not specified numerically. The predicted daughter counts are conditional on meeting these additional budgets. An inherited reserve could sustain a burst of reproduction, but continuing daughter allocation eventually requires replenishment. Meteoric infall contributes phosphorus and metals to the atmospheric inventory; delivery to individual droplets in usable form requires its own calculation. Carrillo-Sanchez and colleagues model the meteoric phosphorus input.

6. Main results

Numbers below are carbon-supported daughter equivalents. Each is assigned the original daughter's solvent allowance and functional organic composition. The results do not independently demonstrate adequate trace nutrients, successful assembly, hereditary fidelity, or daughter survival.

Reference biomass doubling time	Daughter equivalents at 0.1 W/m^2	Daughter equivalents at 1 W/m^2
6 hours	1,724	10,096
12 hours	1,684	8,830
24 hours	1,599	5,919

Reference time (hours)	Net power (W/m^2)	Days to maturity	Days of budding	Total days after trigger	Final diameter (µm)
6	0.1	30.91	16.82	47.73	11.61
6	1	17.07	10.54	27.61	18.16
12	0.1	40.42	16.63	57.05	11.56
12	1	29.58	10.63	40.21	17.46
24	0.1	58.04	16.21	74.25	11.44
24	1	50.00	11.79	61.79	15.58

All cases reach the selected maturity inventory, with diameter 8.6775 µm. In the six-hour case, maturity occurs near 54.74 km and 31.3 °C at low light, and 57.67 km and 8.0 °C at higher light. Across the main cases, peak carbon supply during budding is approximately 104 to 1,037 daughter equivalents per day. Functional maternal biomass is maintained while acid accumulation increases total mass, dilutes the average biomass concentration, and accelerates descent.

7. Sensitivity and interpretation

For the six-hour reference case, increasing net light from 1 to 3 W/m^2 at the same 1% effective uptake raises output from 10,096 to 15,647 daughter equivalents. Maturation remains at 17.07 days, the budding interval contracts to 8.54 days, and final diameter reaches 20.75 µm. Biological capacity limits production throughout this higher-light trajectory; increasing net input to 10 W/m^2 or increasing uptake to 10% adds no production under the same assumptions. These tests identify a saturation point within the selected model without establishing the actual illumination or uptake efficiency in Venus's clouds.

The most consequential unmeasured properties are spectral energy capture, effective gas uptake, noncarbon nutrient supply, temperature-dependent catalytic rates, maternal organization under dilution, and the speed of assembling complete daughters. A smaller maturation inventory would permit earlier budding. Maintenance, repair, terminal aging, changes in composition, and survival outside the selected temperature interval need explicit treatment before interpreting these outputs as reproductive success.

The coupled production and descent equations were integrated adaptively through maturity and the selected hot boundary. An independent calculation using normalized carbon and descent distance as the integration coordinate reproduced each main output to better than 0.002 daughter equivalents and the displayed times and diameters to their reported precision. Carbon, bulk reaction mass, and acid allocation balances were checked along the trajectories. Numerical agreement does not constrain the uncertain biological and environmental inputs.