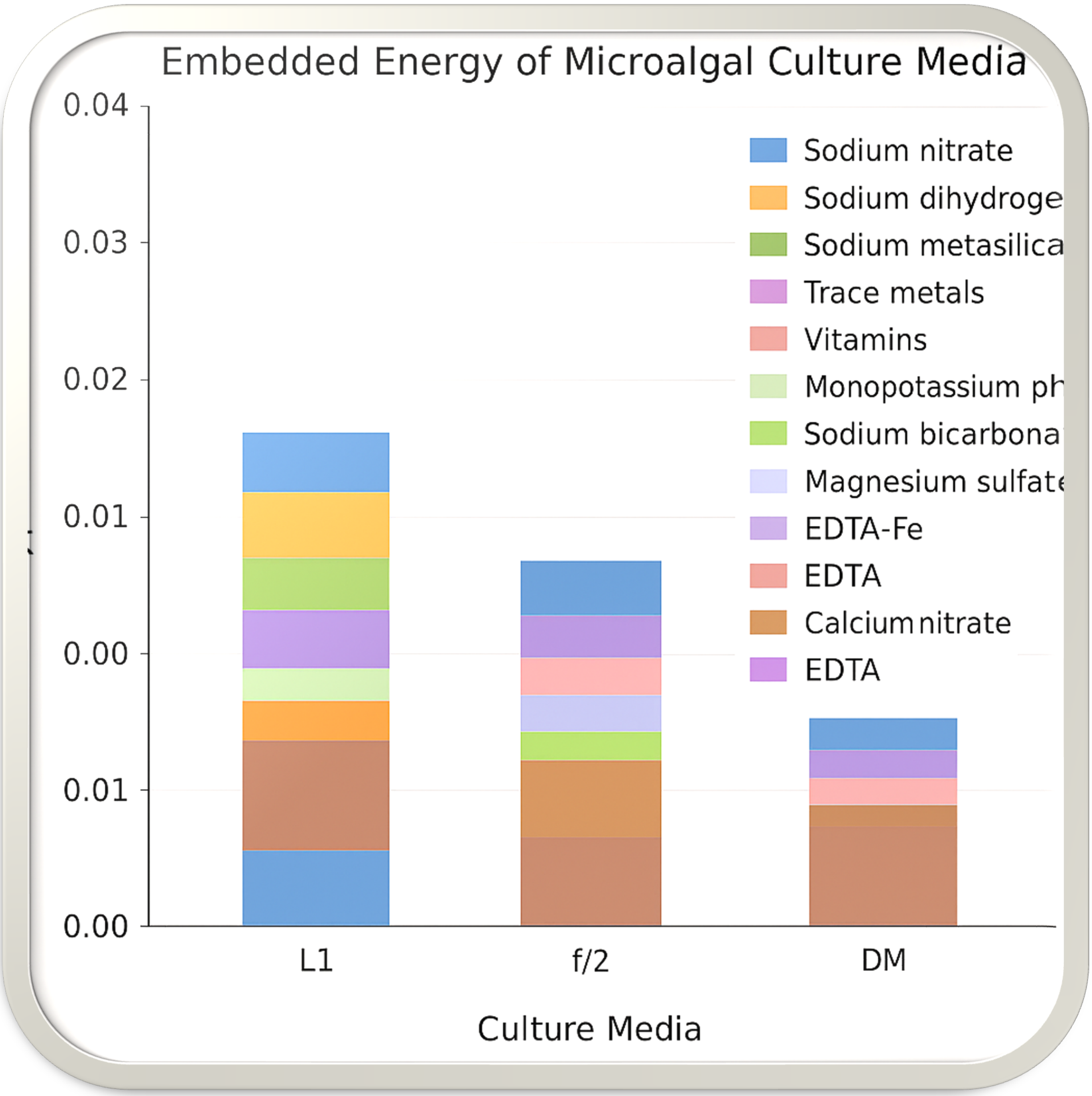
Embedded Energy of Common Microalgal Culture Media (L1, f/2, and DM)

Microalgal culture media contain various chemical nutrients whose production carries a “hidden” energy cost. Here we evaluate the embodied (life-cycle) energy per liter of three widely used media – **L1**, **f/2**, and **DM** – focusing on industrial-scale preparation of their constituents. We break down the energy by each component of each medium, and compare total embedded energy per liter for the three media. (Note: We exclude variable preparation energy like sterilization or heating, and assume marine media use natural seawater as the base, while DM uses deionized water.)



Composition of L1, f/2, and DM Media

L1 Medium (Marine): An enriched seawater medium derived from f/2 by adding extra trace metals . Per liter, L1 adds: 75 mg sodium nitrate (NaNO3), 5 mg sodium dihydrogen phosphate (NaH2PO4·H2O), 30 mg sodium metasilicate (Na2SiO3·9H2O), 1 mL of a trace-metal solution, and 0.5 mL of a vitamin solution . The trace-metal solution contributes ~4.36 mg disodium EDTA (Na2EDTA·2H2O), 3.15 mg ferric chloride (FeCl3·6H2O), and minute amounts (micrograms per liter) of MnCl2·4H2O, ZnSO4·7H2O, CoCl2·6H2O, CuSO4·5H2O, Na2MoO4·2H2O, plus the unique additions of H2SeO3, NiSO4·6H2O, Na3VO4, and K2CrO4 (each on the order of 1–2 mg/L in the trace stock, i.e. ~0.001–0.002 mg/L in the final medium) . Vitamins added per liter are ~0.1 mg thiamine (B_1), 0.0005 mg biotin (B_7), and 0.0005 mg cyanocobalamin (B_{12}) .

f/2 Medium (Marine): The classic Guillard's f/2 is a half-strength enriched seawater medium . Per liter it contains 75 mg NaNO3, 5.0–5.65 mg NaH2PO4·H2O, and (if culturing diatoms) 30 mg Na2SiO3·9H2O . It includes 1 mL of trace metals solution providing 4.36 mg Na2EDTA·2H2O, 3.15 mg FeCl3·6H2O, 0.18 mg MnCl2·4H2O, 0.022 mg ZnSO4·7H2O, 0.01 mg CoCl2·6H2O, 0.01 mg CuSO4·5H2O, and 0.006 mg Na2MoO4·2H2O . (Notably, f/2 lacks the Ni, Se, V, Cr found in L1.) A 1 mL vitamin solution is typically added, supplying ~0.1 mg thiamine and 0.0005 mg each of biotin and B_{12} (some protocols use 0.5 mL, as in L1, with the same total vitamin amounts).

DM Medium (Freshwater Diatom Medium): A comprehensive freshwater medium (after Beakes et al. 1988) for diatoms . Unlike L1 and f/2 (which rely on seawater for base salts), DM must provide essential macro-ions. Per liter, DM includes ~20 mg calcium nitrate tetrahydrate (Ca(NO3)2·4H2O), 12.4 mg potassium dihydrogen phosphate (KH2PO4), 25 mg magnesium sulfate heptahydrate (MgSO4·7H2O), 15.9 mg sodium bicarbonate (NaHCO3), and 30 mg sodium metasilicate (Na2SiO3·9H2O) . Its trace solution provides 4.5 mg of chelated iron mix (0.45 g FeNaEDTA + 0.45 g Na2EDTA per 200 mL stock , yielding ~2.25 mg each of Fe-EDTA and free EDTA per liter medium), plus ~2.48 mg H3BO3, 1.39 mg MnCl2·4H2O, and 1.0 mg ammonium molybdate ((NH4)6Mo7O24·4H2O) per liter . Vitamins in DM are added at ~0.04 mg/L each for thiamine, biotin, and B_{12} (the stock contains 8 mg of each in 200 mL) .

Embodied Energy by Medium and Component

Industrial production of each chemical involves raw material extraction and processing, consuming energy that is "embodied" in the product. Table 1 summarizes typical life-cycle energy requirements for key compounds (in MJ per kg of compound produced):

- **Sodium nitrate ($NaNO_3$):** ~9.4 MJ/kg .
- **Calcium nitrate ($Ca(NO_3)_2 \cdot xH_2O$):** similar order (we assume ~10 MJ/kg, as it is produced via neutralizing nitric acid with limestone or ammonia-derived nitrate).
- **Phosphate salts:** Monosodium phosphate ~8.6 MJ/kg ; monopotassium phosphate is comparable (on the order of 8–9 MJ/kg, derived from phosphoric acid neutralization).

- **Magnesium sulfate:** A relatively low-energy salt (often a mining or simple reaction product); on the order of a few MJ/kg (for estimation, ~5 MJ/kg).
- **Sodium bicarbonate:** Produced via the Solvay process or mining of soda ash; roughly ~5 MJ/kg (low to moderate energy intensity).
- **Sodium silicate (water glass):** ~4–5 MJ/kg for furnace process production (silica sand fused with soda ash at high temperature).
- **EDTA (ethylenediaminetetraacetic acid) and Fe–EDTA chelates:** Being complex organic chemicals, EDTA has a high production energy (tens of MJ per kg) due to multi-step synthesis. We assume ~30–60 MJ/kg range (exact LCI depends on production route).
- **Trace metal salts ($FeCl_3$, $MnCl_2$, etc.):** Inorganic chemicals often in the range of a few to ~15 MJ/kg (e.g. manufacturing FeCl