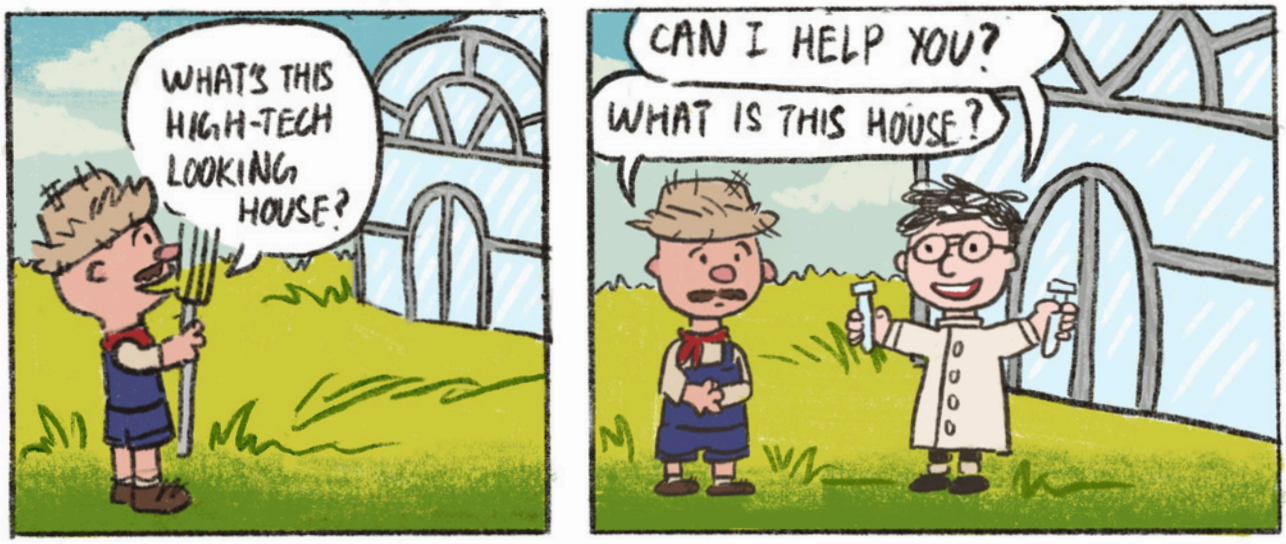
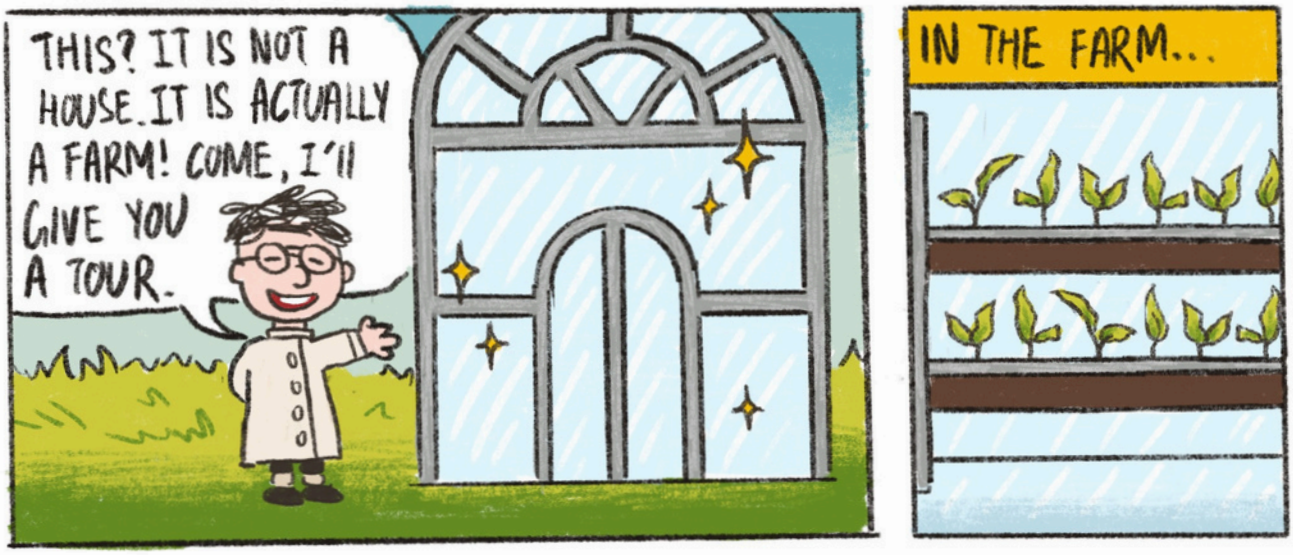
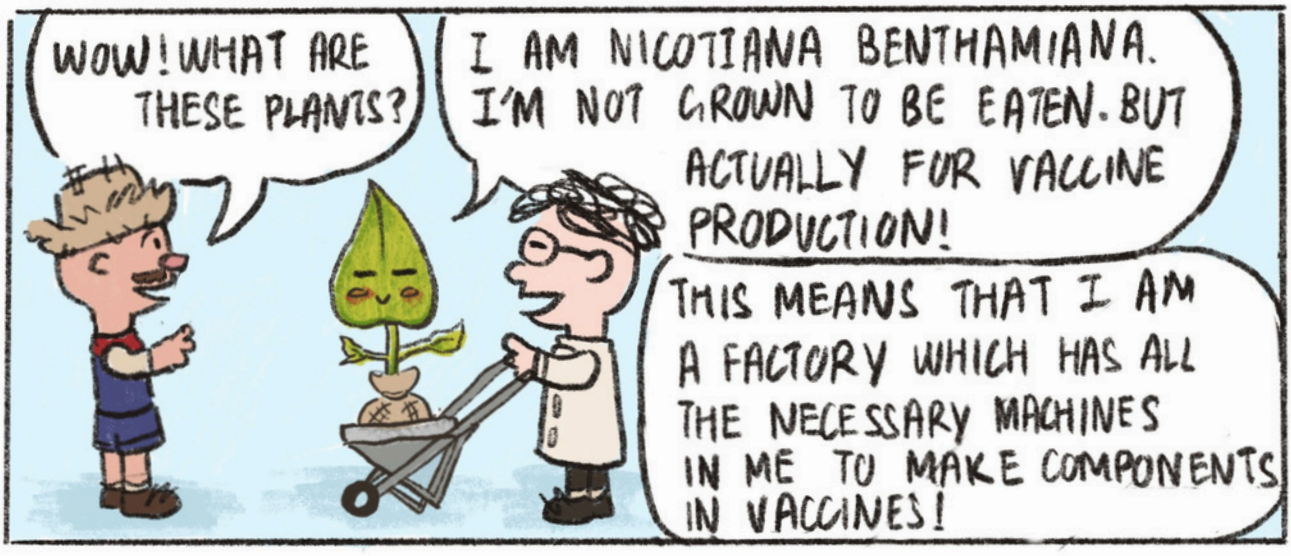
Farming with BIOCHEMISTRY

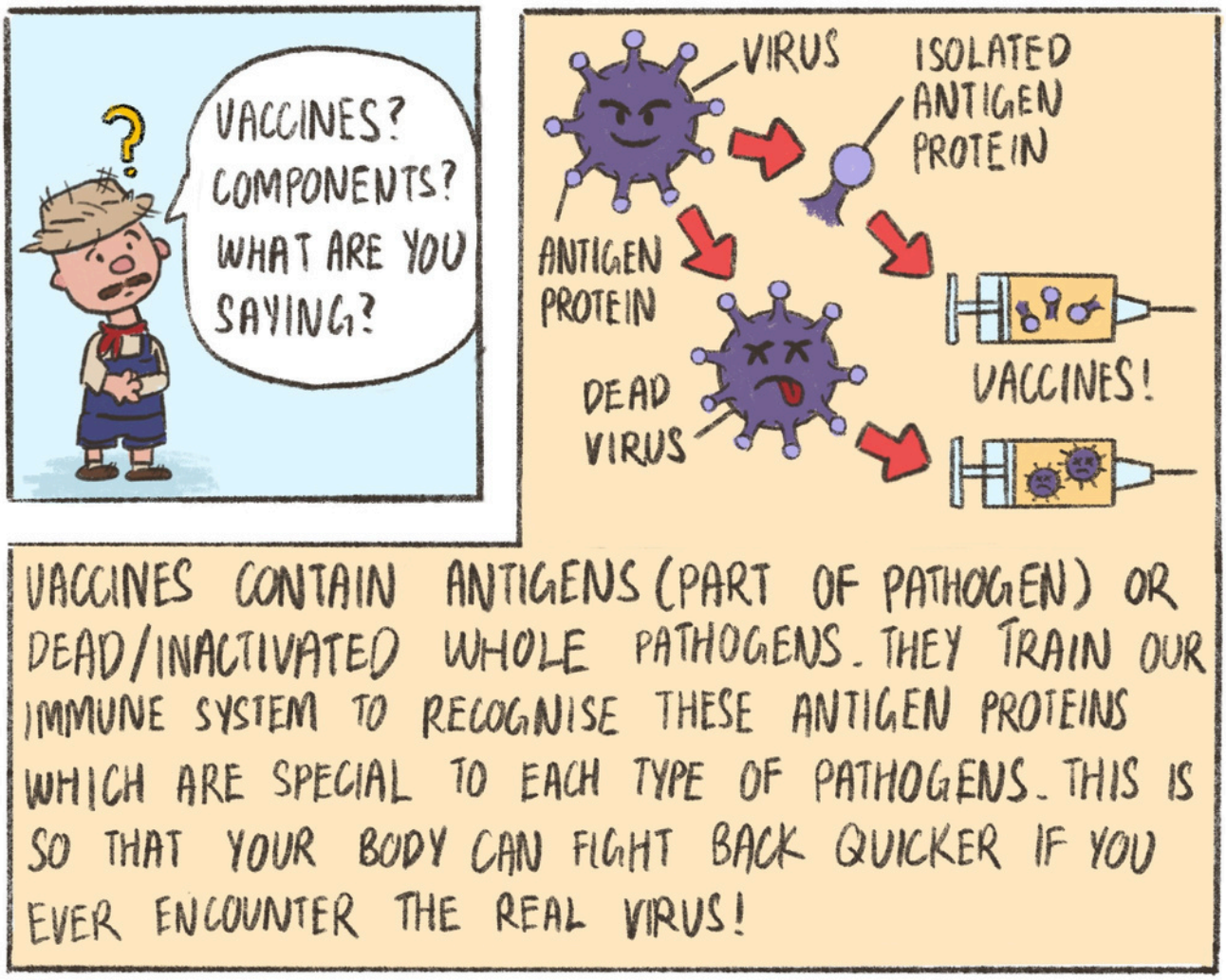
CREATING A GREENER FUTURE!

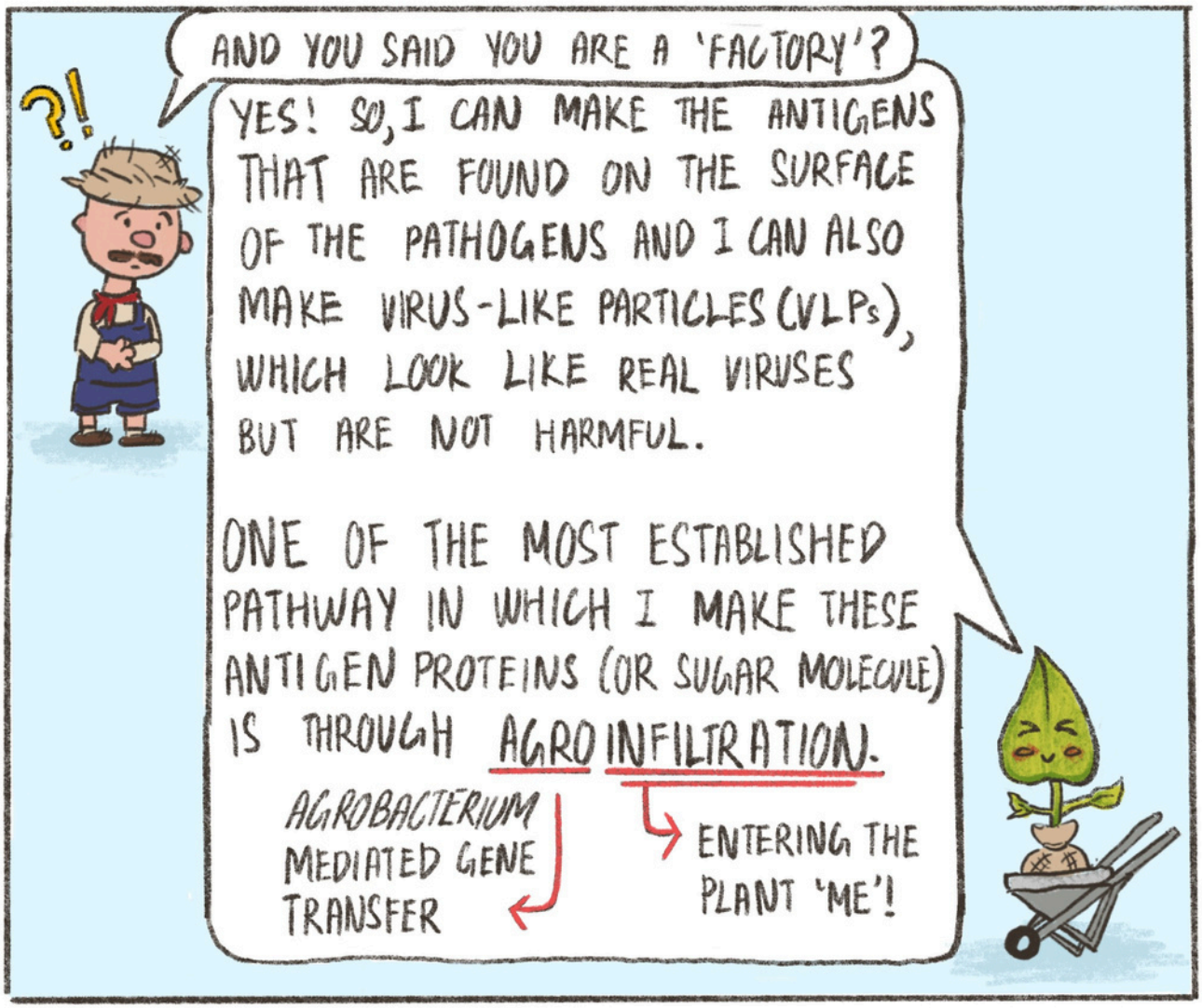
by Hao Yin Bon





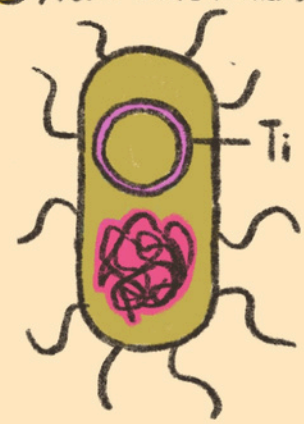



VACCINES? COMPONENTS? WHAT ARE YOU SAYING?
VIRUS
ISOLATED ANTIGEN PROTEIN
ANTIGEN PROTEIN
DEAD VIRUS
VACCINES!
VACCINES CONTAIN ANTIGENS (PART OF PATHOGEN) OR DEAD/INACTIVATED WHOLE PATHOGENS. THEY TRAIN OUR IMMUNE SYSTEM TO RECOGNISE THESE ANTIGEN PROTEINS WHICH ARE SPECIAL TO EACH TYPE OF PATHOGENS. THIS IS SO THAT YOUR BODY CAN FIGHT BACK QUICKER IF YOU EVER ENCOUNTER THE REAL VIRUS!


AND YOU SAID YOU ARE A 'FACTORY'?
YES! SO, I CAN MAKE THE ANTIGENS THAT ARE FOUND ON THE SURFACE OF THE PATHOGENS AND I CAN ALSO MAKE VIRUS-LIKE PARTICLES (VLPs), WHICH LOOK LIKE REAL VIRUSES BUT ARE NOT HARMFUL.
ONE OF THE MOST ESTABLISHED PATHWAY IN WHICH I MAKE THESE ANTIGEN PROTEINS (OR SUGAR MOLECULE) IS THROUGH AGROINFILTRATION.
AGROBACTERIUM MEDIATED GENE TRANSFER
ENTERING THE PLANT 'ME'!

FIRSTLY, THE SCIENTIST CHANGES THE DNA OF A SPECIES BACTERIA CALLED *AGROBACTERIUM TUMEFACIENS* TO INCLUDE THE GENE ENCODING FOR THE ANTIGEN. (Laere et al., 2016)

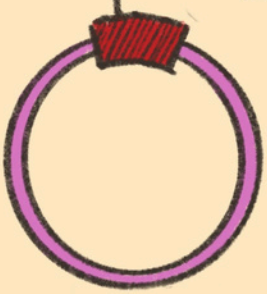
1 *AGROBACTERIUM TUMEFACIENS*



TAKEN OUT

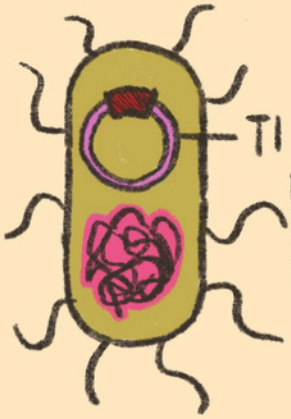
2 Ti PLASMID

T-DNA (GENE OF INTEREST) INSERTED



THIS RECOMBINANT BACTERIA, WHICH MEANS BACTERIA THAT HAVE BEEN GENETICALLY CHANGED IN THE LAB, IS THEN GROWN TO MILLIONS IN POPULATION.

3 Ti-PLASMID REINTRODUCED



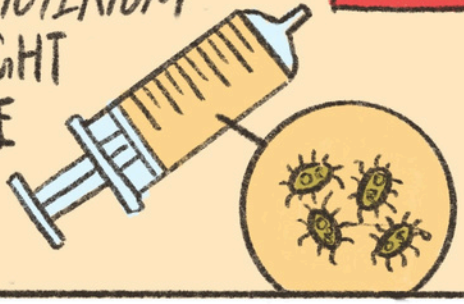
REPLICATION

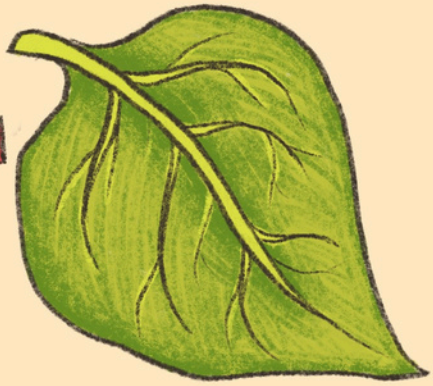
4 *AGROBACTERIA* REPLICATION



THEY ARE THEN 'FORCED' INTO THE PLANT (ME!) THROUGH GAPS IN MY LEAF ('STOMATA').

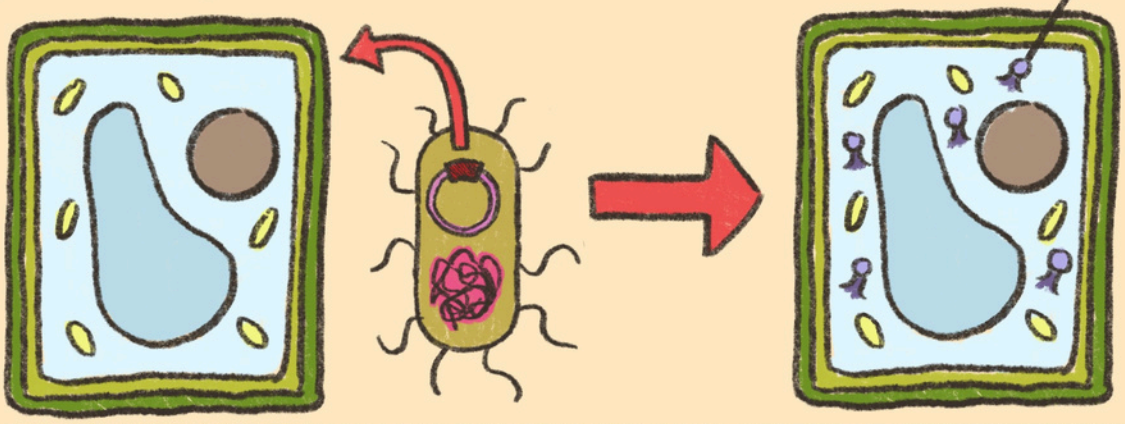
5 *AGROBACTERIUM* OVERNIGHT CULTURE





THE GENE ENCODING THE ANTIGEN THEN ENTERS MY CELLS AND USING MY MACHINERIES (SUCH AS RNA POLYMERASE II), I CAN EXPRESS THIS ANTIGEN! AS THE GENE IS NOT INTEGRATED TO MY PLANT GENOME, THIS PROCESS IS CALLED TRANSIENT GENE EXPRESSION.

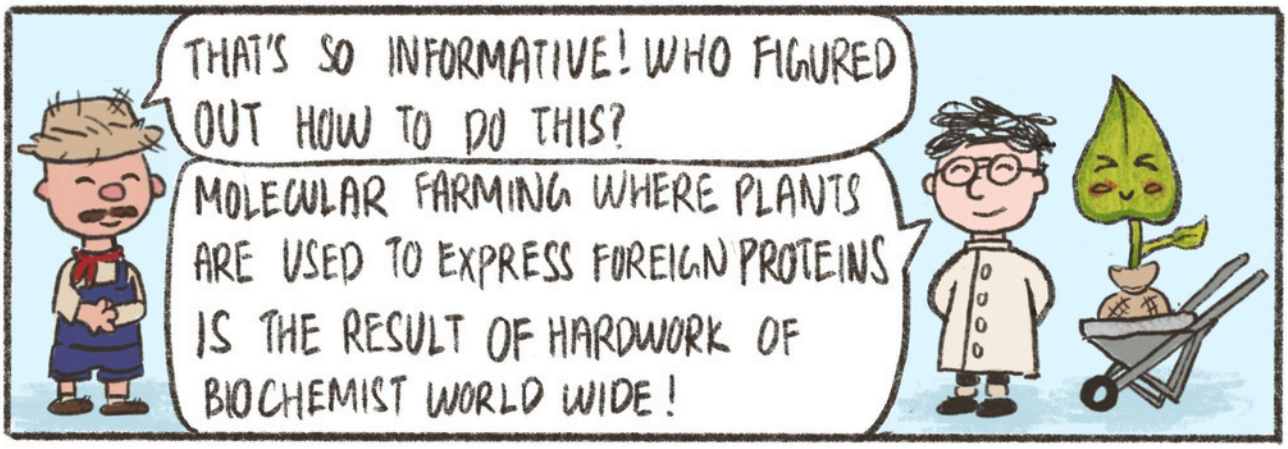
6 TRASFER OF T-DNA TO PLANT CELL



MY LEAVES ARE THEN HARVESTED, BLENDED, AND CENTRIFUGED. THIS PLANT 'JUICE' UNDERGOES A PURIFICATION STEP USING CHROMATOGRAPHY TO ISOLATE THE ANTIGEN FOR THE VACCINE!

7 HARVESTING AND PURIFICATION





WHY NOT MAKE VACCINES THE TRADITIONAL WAY?

TRADITIONAL VACCINE MANUFACTURING SUCH AS CELL CULTURE USES BIOREACTORS WHICH REQUIRES A LOT OF ENERGY. PLANT-DERIVED VACCINES BYPASS THIS COMPLETELY AS THEY ONLY NEED SUNLIGHT OR LED LIGHT TO GROW WHICH LOWERS ENERGY DEMAND AND GREENHOUSE GAS EMISSION.

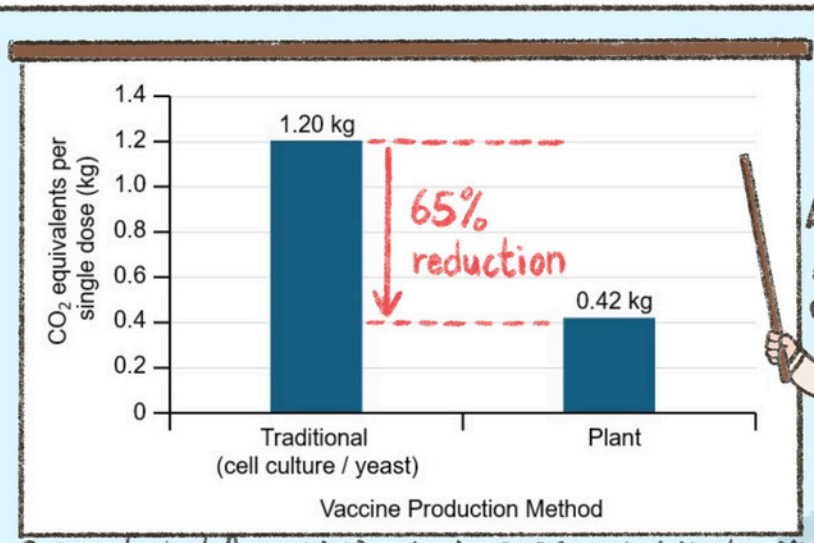
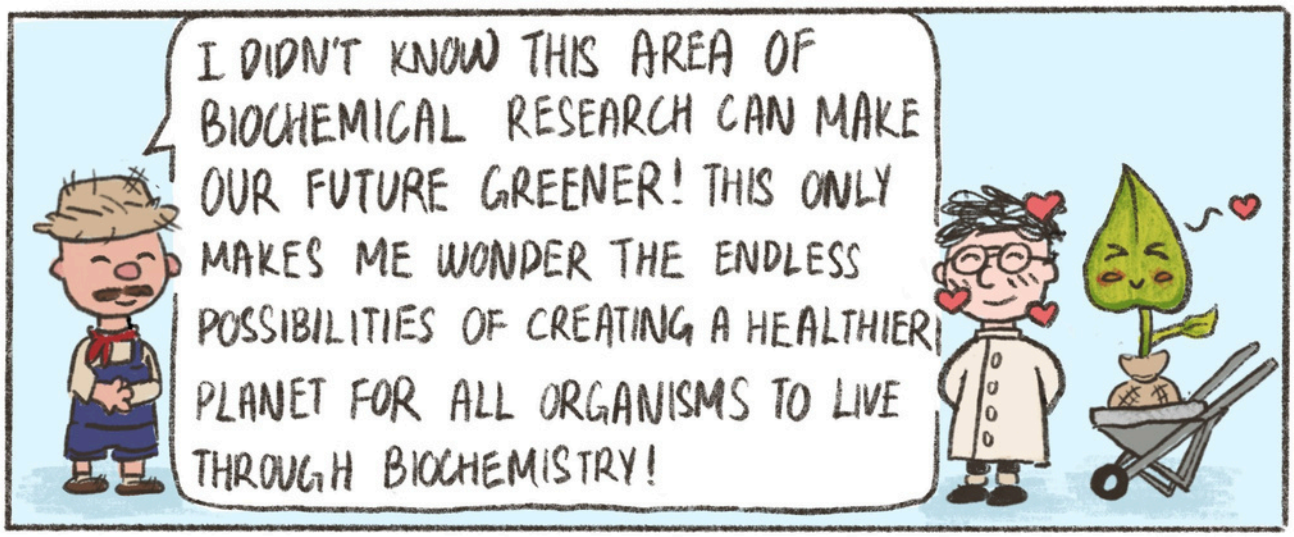


FIGURE 1. (left) PLANT BASED PRODUCTION DRAMATICALLY LOWERS THE CARBON FOOTPRINT OF HPV VACCINES.

Data adapted from Wolfe et al., 2026 and plotted in Microsoft Excel.

NOT ONLY THAT, TRADITIONAL MRNA VACCINE REQUIRE ULTRA-COLD FREEZERS AND REFRIGERATION DURING TRANSPORT WHICH GENERATES AN EXTRA 0.01 TO 0.2 KG OF CO_2 PER DOSE. OPPOSITELY, PLANT-DERIVED VACCINES ARE SUPER STABLE AT ROOM TEMPERATURE – SO NO EMISSIONS FROM COLD-CHAIN LOGISTICS! (Kurzweil et al., 2021)

LAST BUT NOT LEAST, TRADITIONAL MANUFACTURING OFTEN NEEDS ANIMAL DERIVED COMPONENTS SUCH AS FETAL BOVINE SERUM, WHICH REQUIRES CATTLES TO BE RAISED THEN SLAUGHTERED. ON THE OTHER HAND, I DO NOT LEAVE A HUGE CARBON FOOTPRINT AS I ALSO PRODUCE OXYGEN DURING PHOTOSYNTHESIS.



Relating to United Nation's 17 Sustainability Development Goals (UN SDGs)



Molecular farming replaces energy-heavy steel infrastructure with greenhouses and hydroponics, which are **much cheaper and faster** to build in developing countries.



Unlike traditional cell culture systems, which generate substantial amounts of non-biodegradable hazardous plastic waste, plants function as **completely biodegradable** bioreactors, **minimising industrial waste**.



Living plants remove carbon dioxide from the atmosphere, acting as a **temporary carbon sink**. A more thermal-stable final product eliminates the need for traditional cold-chain transportation, reducing energy consumption that aligns with a **low-carbon circular economy**.



Molecular farming **eliminates the footprint** of animal husbandry, which is intensive in cell culture derived vaccines. Growing plants in hydroponics reduces land use and **preserves wildlife habitats**.

Further reading:

Kurzweil, P., Müller, A. & Wahler, S. (2021) The Ecological Footprint of COVID-19 mRNA Vaccines: Estimating Greenhouse Gas Emissions in Germany. International Journal of Environmental Research and Public Health. 18 (14), 7425. doi:10.3390/ijerph18147425.

Laere, E., Ling, A.P.K., Wong, Y.P., Koh, R.Y., Mohd Lila, M.A. & Hussein, S. (2016) Plant-Based Vaccines: Production and Challenges. Journal of Botany. 2016 (1), 4928637. doi:10.1155/2016/4928637.

Wolfe, A., Demand, J., Mistilis, J.J. & Diesburg, S. (2026) Assessing the Cradle-to-Gate Environmental Burden of Human Papillomavirus Vaccine Manufacturing using Life Cycle Assessment Methodology. ChemRxiv. 2026 (0106). doi:10.26434/chemrxiv-2025-4pwf9-v2.

Note: Sustainable Development Goal icons used for informational purposes. Sourced from the United Nations Department of Global Communications.