2016 仿生論壇

農業系統的仿生設計

Biomimetic Design of Agriculture System

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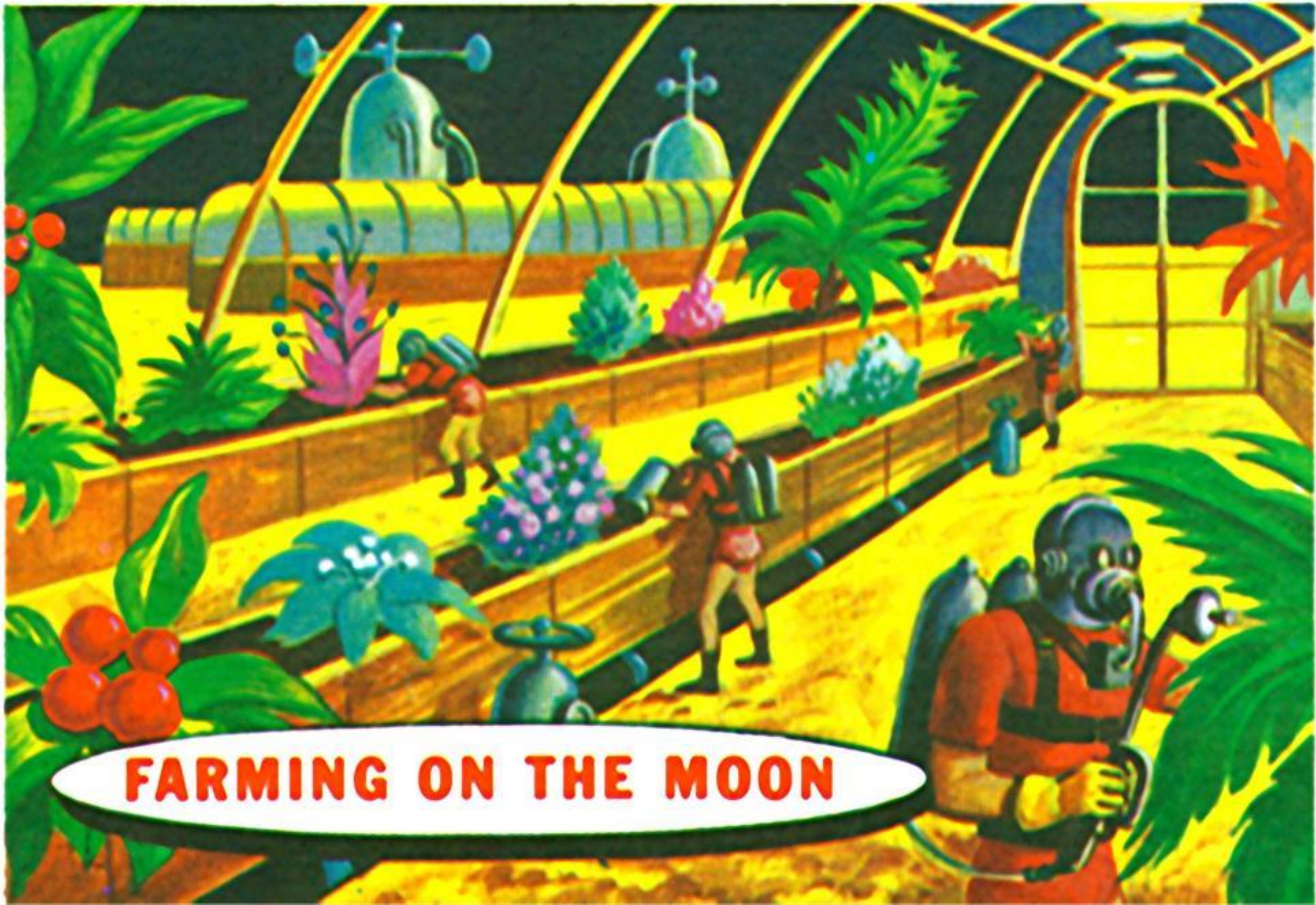
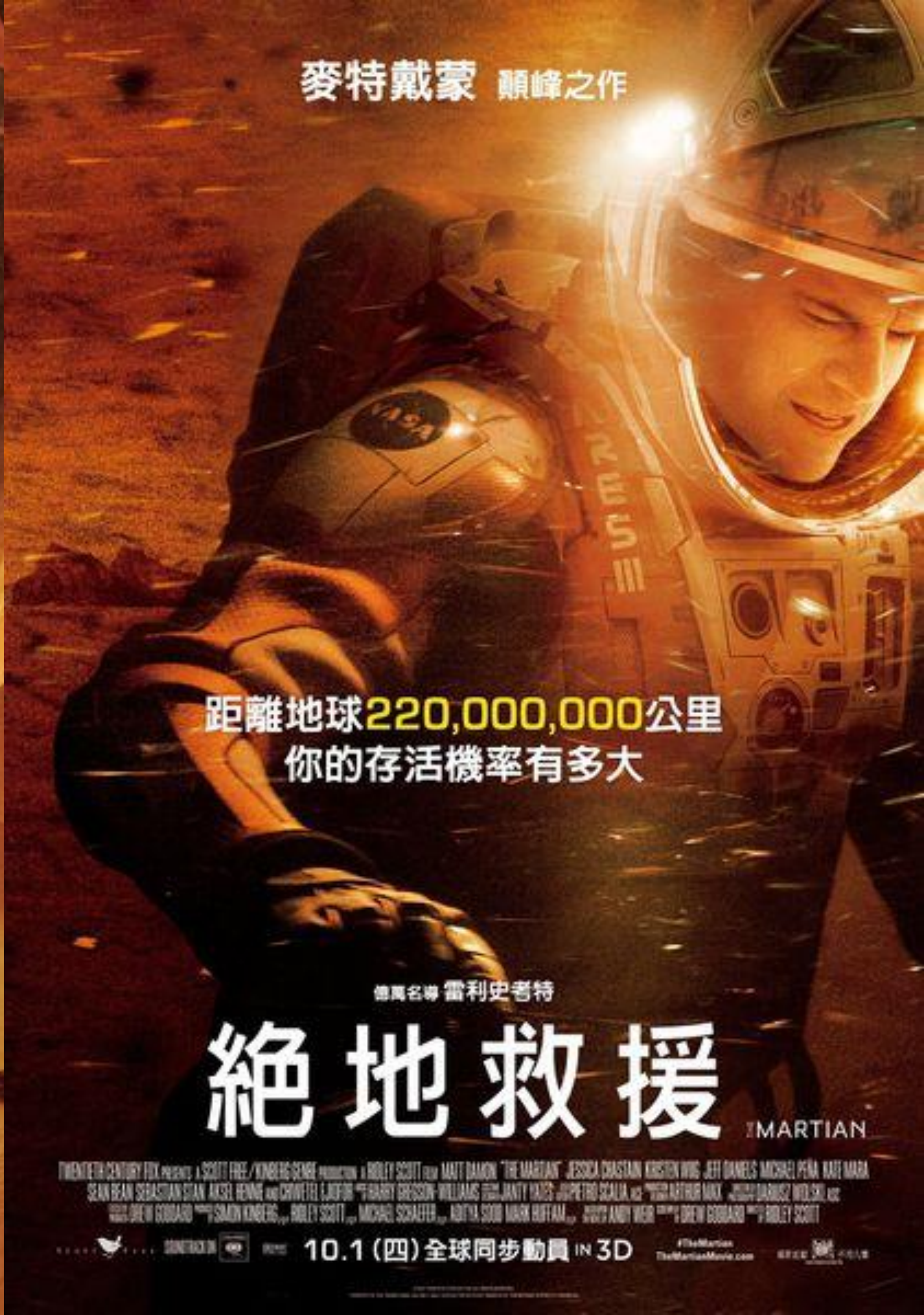
2016.12.10



Topps Target Moon Trading Card #61, 1958


援救只在2亿2千5百万公里以外的太空
马特·达蒙
THE MARTIAN
火星救援
11月25日 星际拯救 刻不容缓
3D/中国巨幕 3D/IMAX 3D


麥特戴蒙 顛峰之作
距離地球220,000,000公里
你的存活機率有多大
雷利史考特
絶地救援
THE MARTIAN
10.1(四)全球同步動員 IN 3D

"I'm a botanist, damn it. I should be able to find a way to make this happen"
Mark Whitney, The Martian, pg. 12

"我是一個植物學家。該死！我應該要能找到方法來解決。"

Plant factories, and the technology developed to support space exploration, will be a part of sustainable food production systems of the future (*Image courtesy The Martian, 2015, 20th Century Fox, based on The Martian, 2011, Andy Weir*

NASA太空農業計畫

ALSS: Advanced Life Support System

BLSS: Bio-regenerative Life SS

CELSS: Controlled Ecological Life SS

*植物/動物/昆蟲/微生物都變成***工程元件**

可生產多少 Biomass (植物/動物性蛋白質)?

可產生/吸收多少氧氣?

可產生/吸收多少二氧化碳?

可產生/分解多少廢棄物?

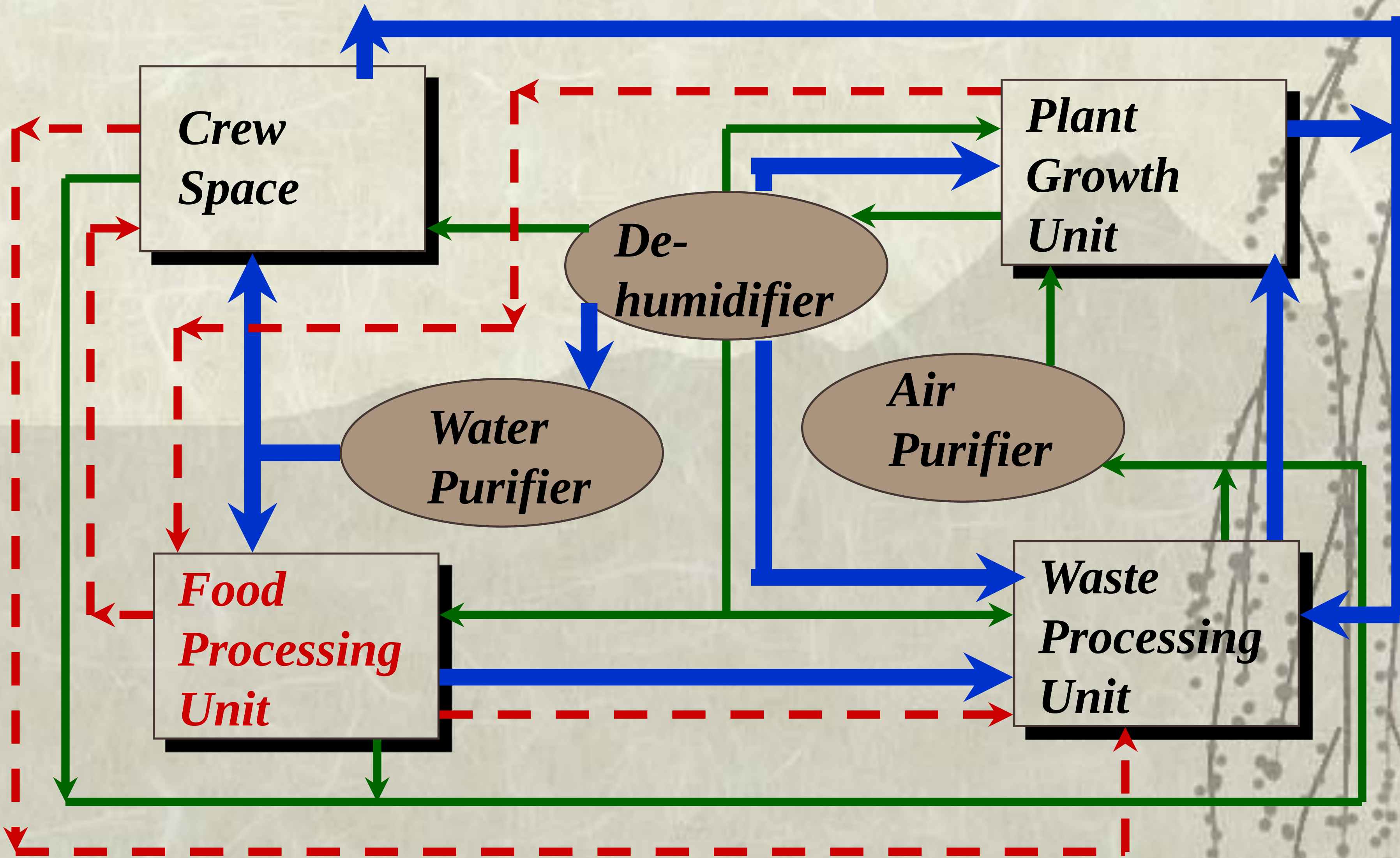
可產生/處理多少水/廢水?　都需要量化

ALSS, BLSS, CELSS
Biosphere II

- Work at KSC of NASA was to develop biological and technical approaches to enable total life support -
  - air revitalization,
  - water purification, and
  - food production - to occur.

Producer　　*Decomposer*　　*Consumer*

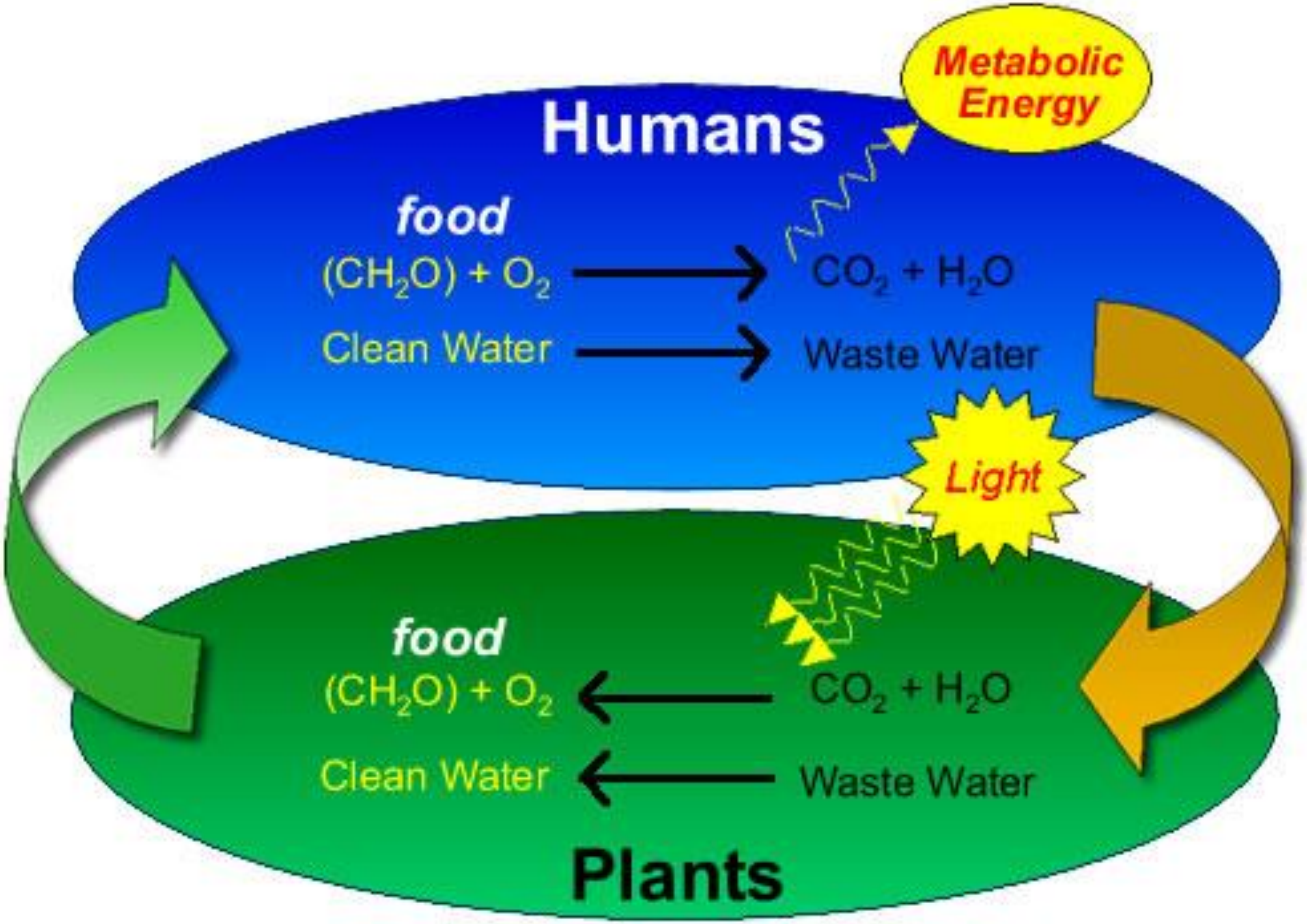
系統內的生產者、消費者、分解者必需時時維持平衡



A Schematic ALSS

(After M.M. Averner, 1989)

Bioregenerative Life Support



Human Life Support Requirements for Long Duration Space Missions

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%

TOTAL 31.0 kg

Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)

TOTAL 31.0 kg

Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

Biomass Production Chamber (BPC)
Breadboard Scale Ground Testing

Circa 1990

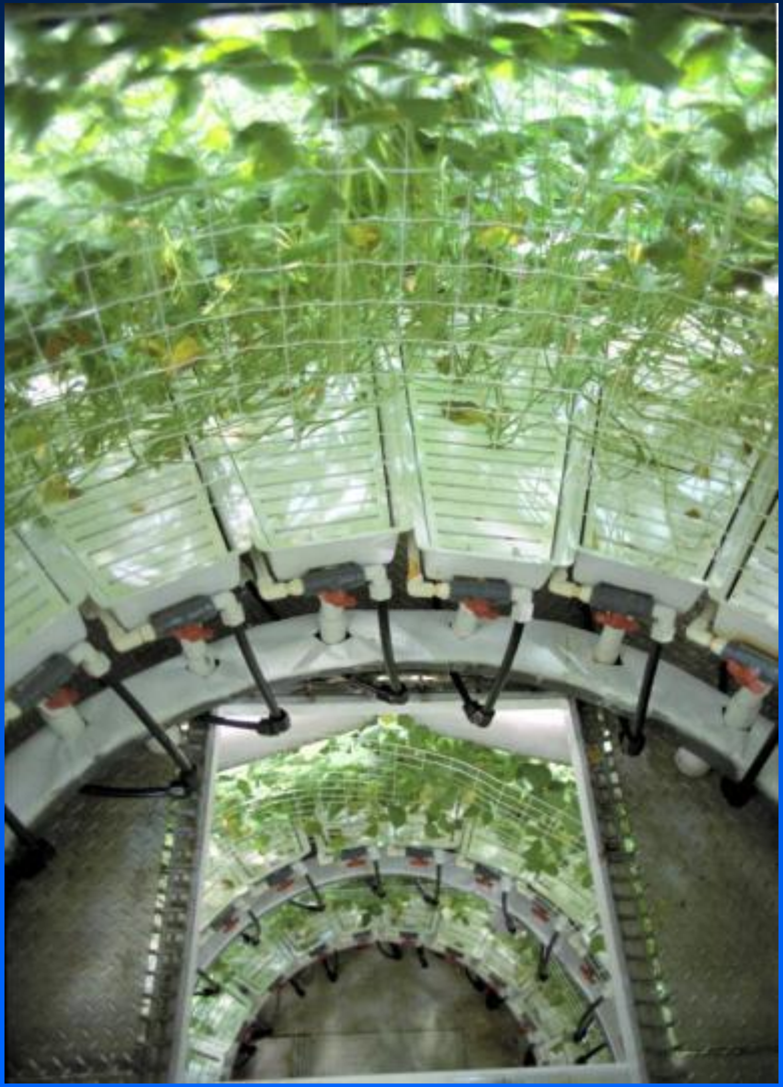
Cylindrical chamber (7.5 M x 3.7 M) with internal volume of ~113 m^3.

Four crop growing areas with ~ 5 M^2 growing area (20 M^2 total).

Recycling of water between Nutrient delivery system (NDS) and humidity control system (HCS).

Leakage of ~ 5-10% per day allowed tracking of CO_2, water, and VOC usage/accumulation.

Four Vertically Stacked Shelves
(5 m^2 each)



View Looking Down (Soybeans)

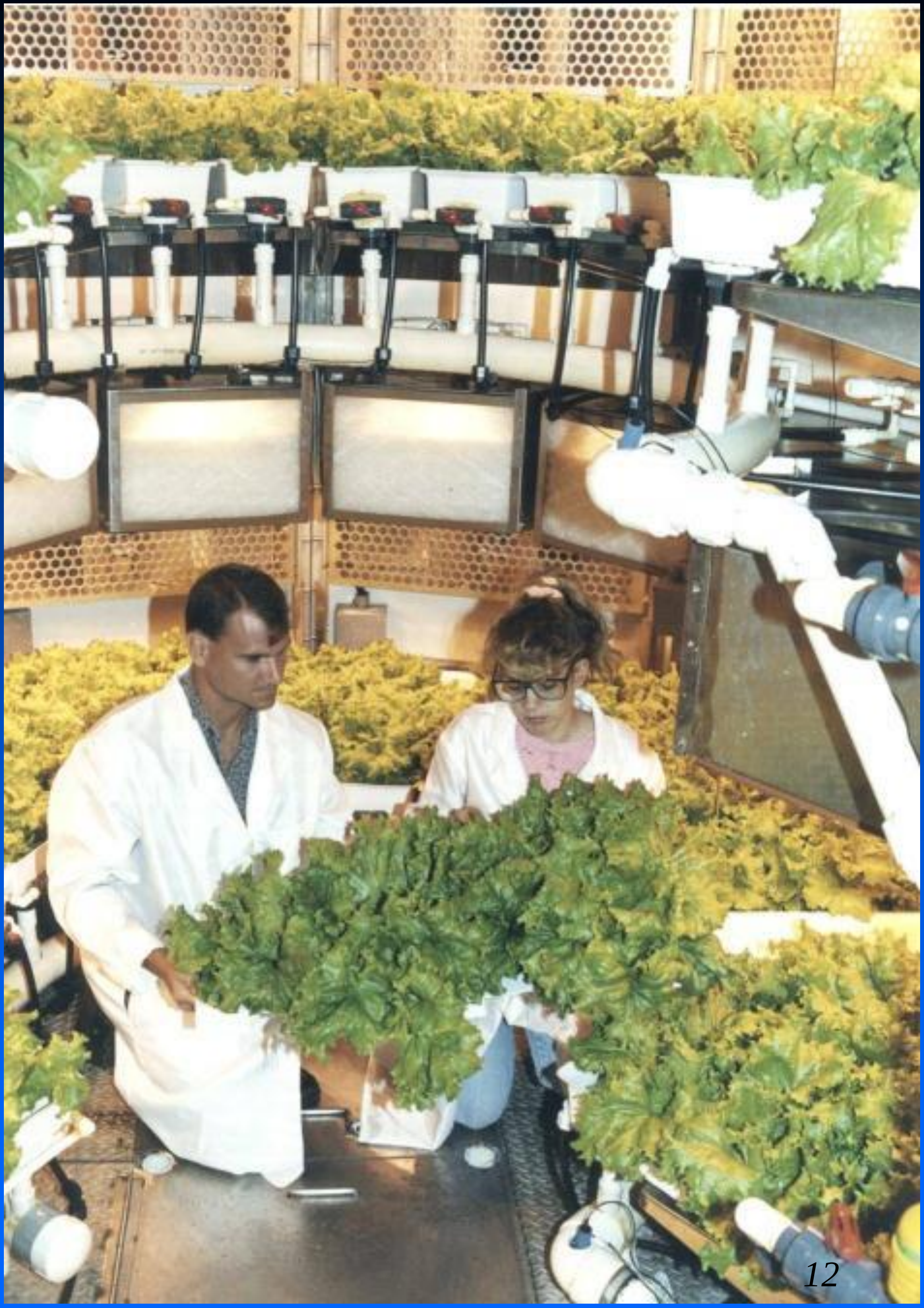
View Looking Up (Wheat)

Lettuce

(Lactuca sativa)
cv. Waldmann's Green

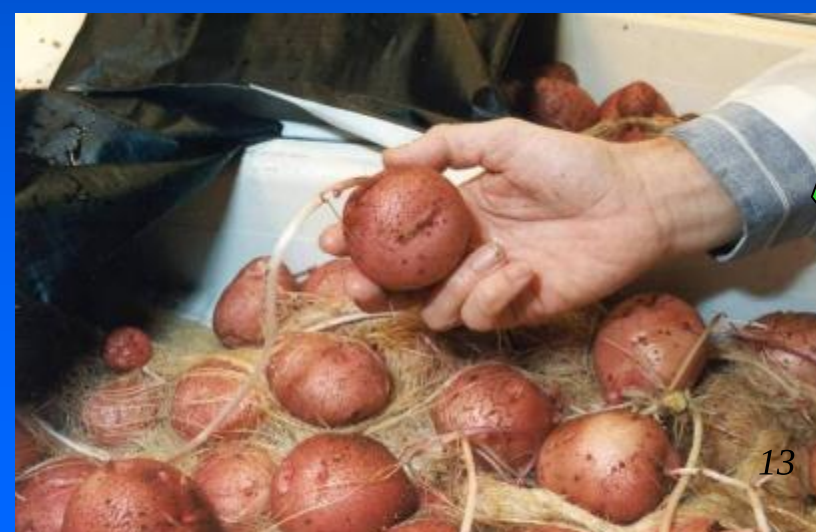
Typical Growth Cycle
28 days

Exceeded all commercial yield models



Potato

(Solanum tuberosum)
cvs. Norland and Denali



Typical Growing Cycle
90 – 105 days
2X world record field yields in
2/3 the time

Tomato

(Lycopersicon esculentum)
cv. Riemann Philipp

Typical Growth Cycle
90-100 days
Achieved over 50% harvest index on dry mass basis

Crop Species Tested:

- Biomass Production Chamber (BPC)
  - Wheat (*Triticum aestivum*)
  - Soybean (*Glycine max*)
  - Lettuce (*Lactuca sativa*)
  - Potato (*Solanum tuberosum*)
  - Tomato (*Lycopersicon esculentum*)
  - Radish (*Raphanus sativus*)

- Small growth chambers:
  - Same as BPC
  - Sweetpotato (*Ipomea batatas*)
  - Peanut (*Arachis hypogaea*)
  - Beet (*Beta vulgaris*)
  - Spinach (*Spinacea oleracea*)
  - Bean (*Phaseolus vulgaris*)
  - Rice (*Oryza sativa*)
  - Strawberry (*Fragaria ananassa*
  - Pepper (*Capsicum annuum*)
  - Green Onion (*Allium fistulosum*)
  - Carrot (*Daucus carota*)

Estimated Area Required to Support Biological Life Support from Crops

- Clean Water
  - **5-10 m^2** (plant transpiration combined with pre-processing (e.g. Total organic carbon reduction and nitrification)
- Oxygen production and CO_2 removal
  - **20m^2** (assumes photosynthetic assimilation quotient and human respiratory quotient =1)
- Food (2500 kcal $crew^{-1}$ day^{-1})
  - **40-50m^2** (assumes a harvest index of 50%)

THESE VALUES DEPEND ON LIGHT PROVIDED AND VAPOR PRESSURE DEFICITY (HUMIDITY)

Space Agriculture is Continues to Push Boundaries of Technology and Science

SyNRGE NanoCube experiments developed into investigate effects on microgravity on plant/microbe interactions for commercial applications

VEGGIE hardware testing by NASA has demonstrated capabilities to grown food and ornamentals for crew in ISS

Bioregenerative life support systems designed for space colony's on Mars are providing technology to achieve sustainable food production on Earth.

農業系統的發展

- 露天栽培 → 簡易設施栽培 → 環控設施栽培 → 植物工廠

- 開放式 → 半開放/半密閉 → 密閉式

***Goal**: improve human life*

***Method**: Develop **a system** that used least amount of resource, least impact on environment and produce mass amount of high quality plants.*

Is there any plant production system capable of producing mass amount of high quality products in the shortest time, use the least amount of resource (land, water, labor, energy, etc.), and has the least amount of impact on environment

有沒有一種**作物生產系統**，
使用
最少的資源（土地、水、人力與能源等），
對環境的影響小，
而能夠
在最短的時間內
栽培出高品質的農產品?

Engineering systems in Biology
Engineering Bio-systems

- 環控農業 Controlled Environment Agriculture
  - 植物工廠 Plant Factory
    1. Thermally insulated wall / roof / floor
    2. Artificial light
    3. Multi-layer bench
    4. Water/Nutrient recirculating
    5. Aero & Root Environmental control
    6. Automation

Controlled Environment Agriculture (CEA)

Plant Factory 植物工廠
Vertical FARM 垂直農場

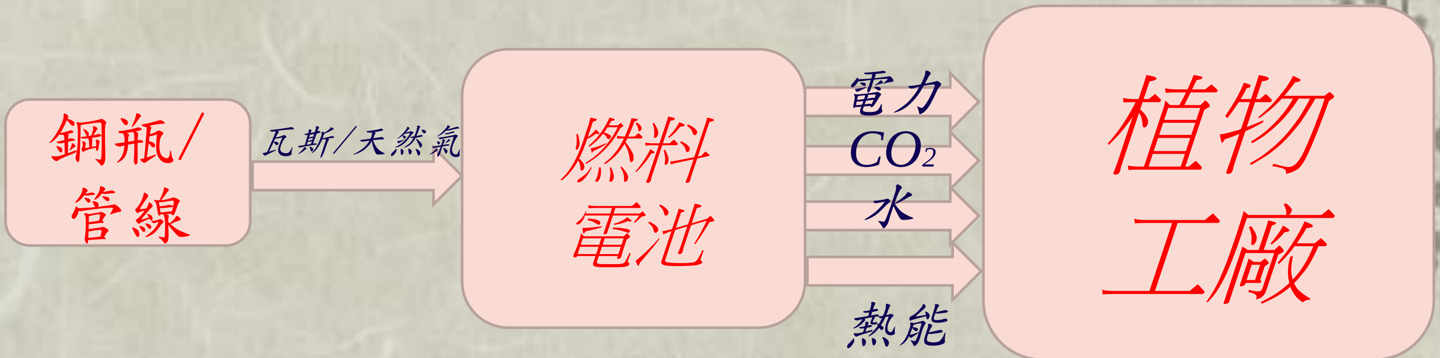
SOLUTIONS FOR WORLDWIDE CHALLENGES AHEAD

Controlled Environment Horticulture (CEH)

Advanced Plant Factory
進階的植物工廠

Technology policy: Applying renewable energy

以搭配植物工廠的使用而言，所有的再生能源，如太陽能、風力、水力、潮汐、溫差發電等都不如燃料電池，特別是固態氧化物燃料電池；系統輸入只需瓦斯，系統產出是 電力、CO_2 、水、熱能



Advanced Plant Factory
進階的複合式植物工廠

- Technology policy: resource sharing

- 氮源共享：魚菜共生
- 碳源共享：菇類栽培場 + 植物工廠
- 能源共享：一般冷藏庫 + 植物工廠
- 雙源共享：農產品冷藏庫 + 植物工廠（碳/能源）
- 三源共享：農產品冷藏庫 + 魚菜共生

室內魚菜共生　　　　養魚/蝦工廠

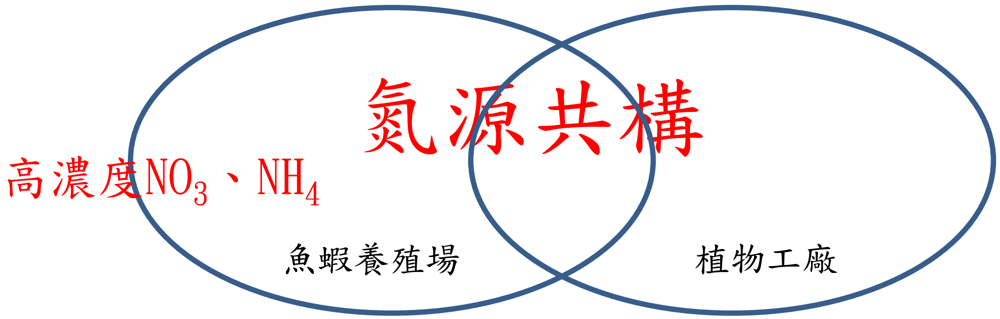
魚蝦是很好的動物性蛋白質來源/飼料轉化率高於禽畜類

超集約、節水、低風險

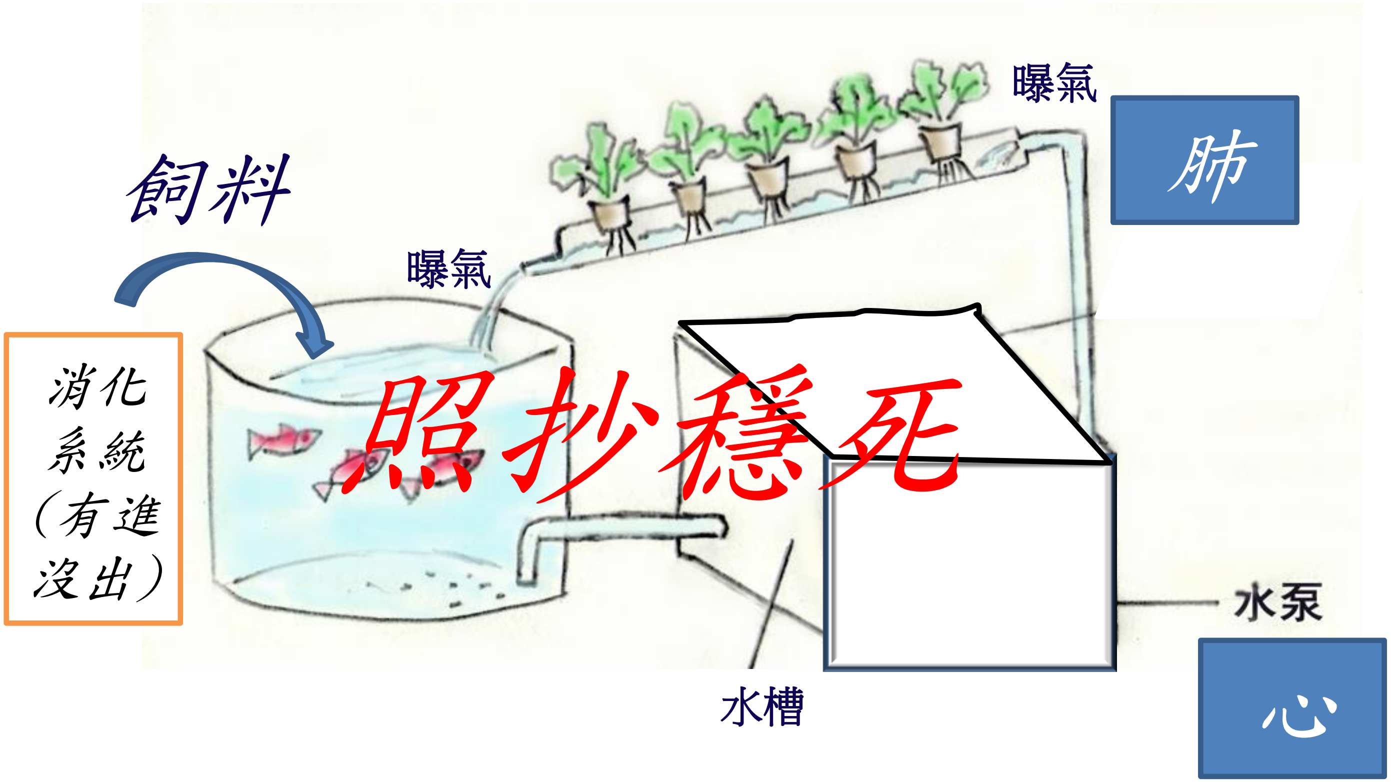
環境控制下的生態農業

- 轉廢為寶
  - 養魚/蝦工廠的廢水含高濃度銨氮廢棄物

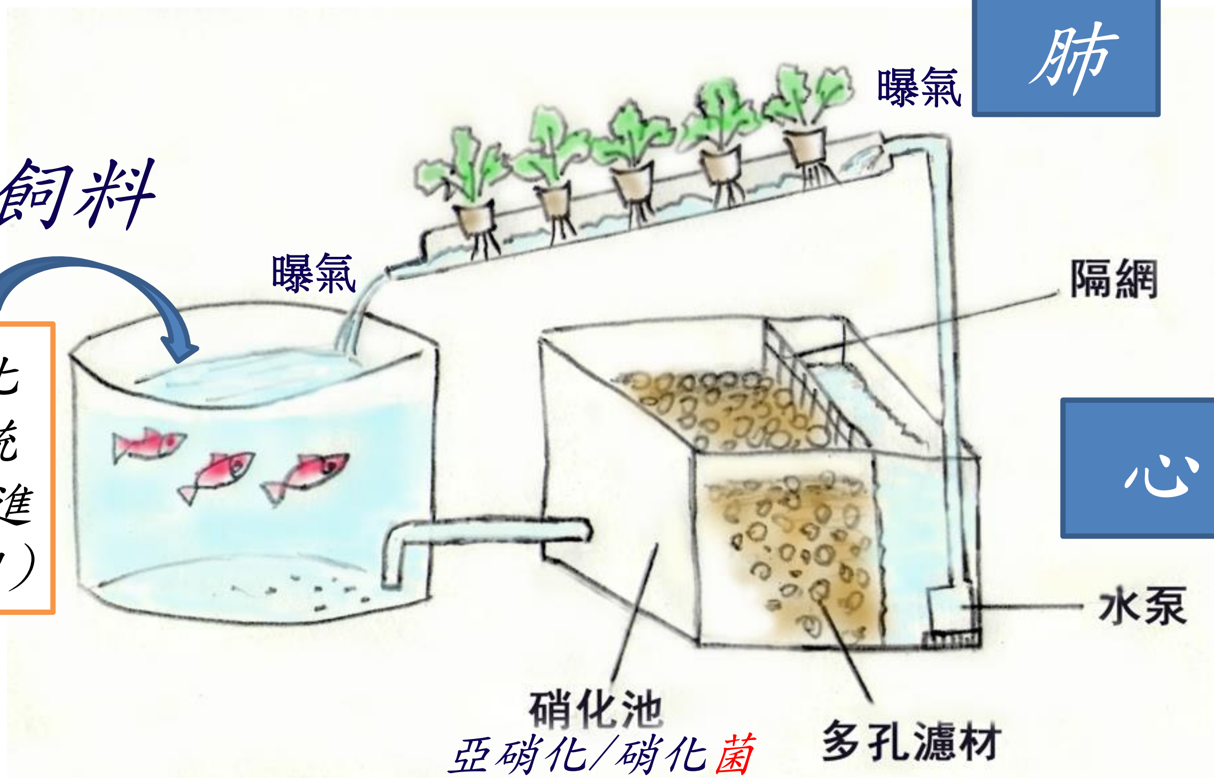
可做為植物營養來源 （氮源）



魚菜共生　養/氧一體的循環



魚菜共生 vs. 人體五臟



飼料

消化系統（有進沒出）

肺

心

肝

脾

腎

少了

排泄系統

神經系統

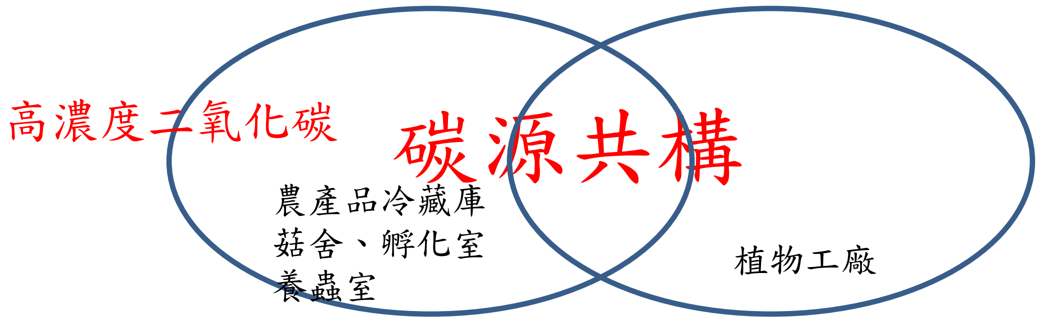
+ 蛋白除沫器
+ 蚯蚓
+ IoT

菇舍/孵化室/養蟲室

環境控制下的生態農業

- 轉廢為寶
  - **農產品冷藏庫、菇舍、孵化室、養蟲室**等均會產生 CO_2

    可做為植物光合作用的原料（碳源）

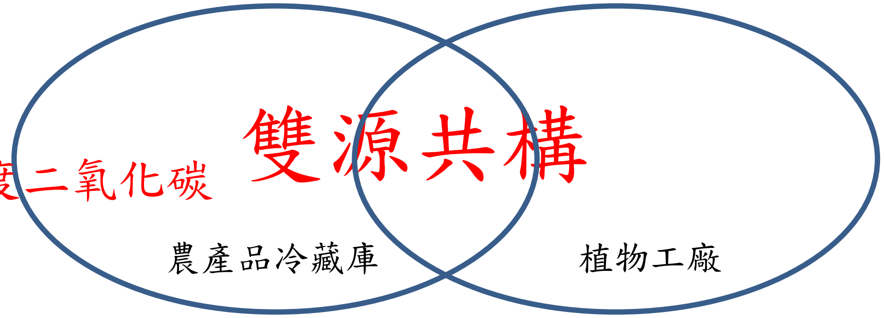


環境控制下的生態農業

- 轉廢為寶
  - 農產品冷藏庫定期排放的廢氣通常仍在 10 度C 以下

    可做為植物工廠低溫來源 （能源）
  - 農產品冷藏庫會產生 CO_2

    可做為植物光合作用的原料（碳源）



三源共構的環境控制下的生態農業

- 轉廢為寶
  - 農產品冷藏庫定期排放的廢氣通常仍在 10 度C 以下
    可做為植物工廠低溫來源 （能源）
  - 農產品冷藏庫、菇舍、孵化室、養蟲室等均會產生 CO_2
    可做為植物光合作用的原料（碳源）
  - 養魚工廠的廢水含高濃度銨氮成分
    可做為植物營養來源 （氮源）

永續運作的先決條件

- 不論是雙源或三源共構，越多源（元）越容易維持穩態

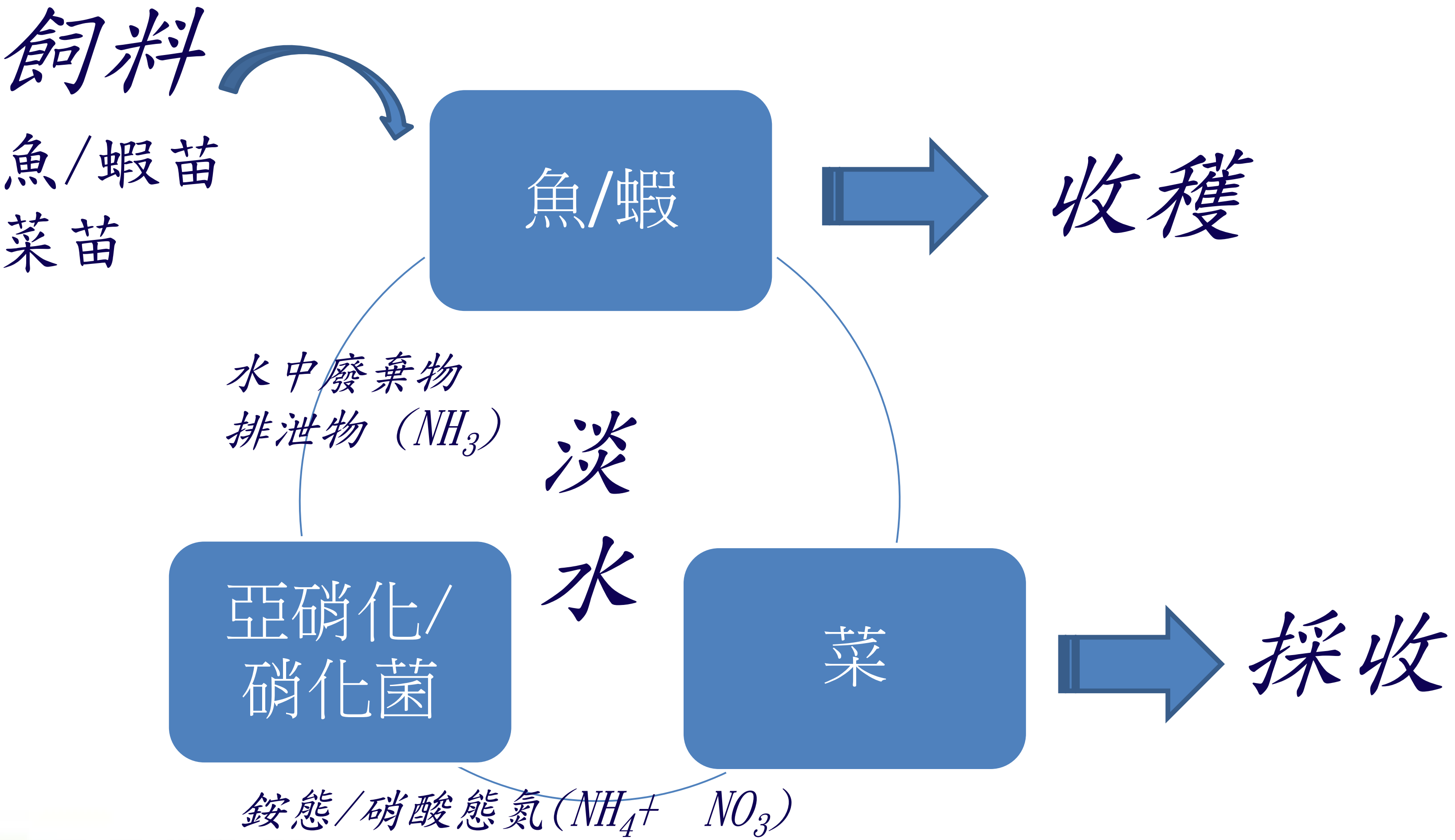
  生物多樣性的重要

- 要能永續運作的先決條件是必須
  - 所有資源能夠循環利用
  - 所有的參與者要能共榮，都是利益共同體

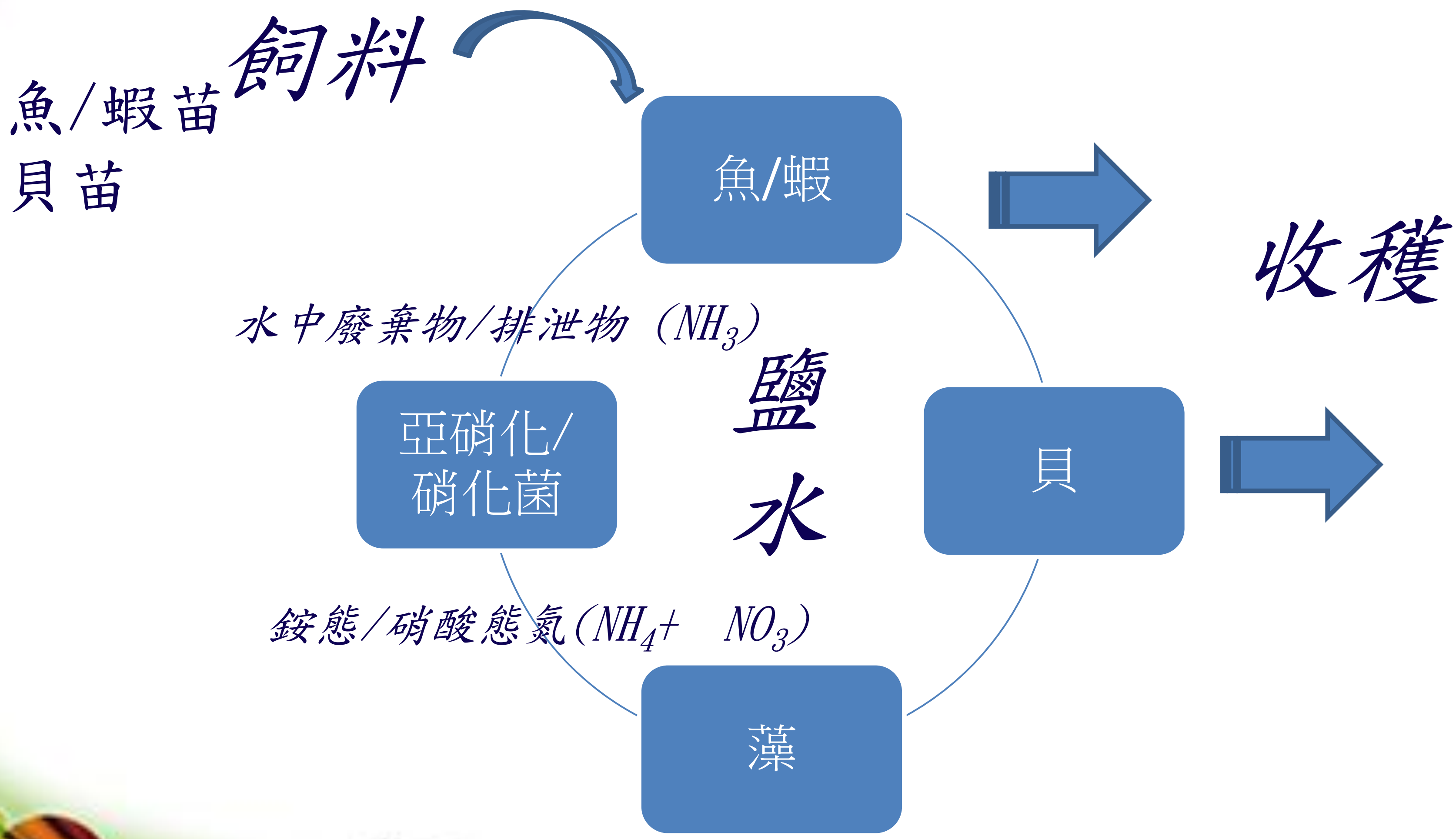
  多贏、共榮

- 由生態中學習
  - 生產者、消費者、分解者 都要全程能夠穩定發展

魚蝦菜共生穩態養殖（三輪傳動）



魚蝦藻貝共生穩態養殖（四輪傳動）



不論是 三輪或四輪傳動

輪胎大小都需要一模一樣

任一者太大或太小或

任一者有時大有時小

都無法維持長期的穩態

Producer
生產者

Decomposer
分解者

Consumer
消費者

全年維持穩態的一設計例

- 由系統設計開始
- 假設蝦類養殖需要 16 週
  - 需要 16 個小蝦至成蝦的養殖槽
  - 各槽養各週的蝦
  - 每週固定收穫一個足齡大蝦槽
  - 每週固定加入一個幼齡小蝦槽
  - 還需 養藻槽、養牡蠣槽

  - 蝦/貝總在養數量、蝦類飼料總投入量
    總廢水量、總銨氮濃度、亞硝化/硝化菌總量
    藻類總產量、蝦/貝總收穫量

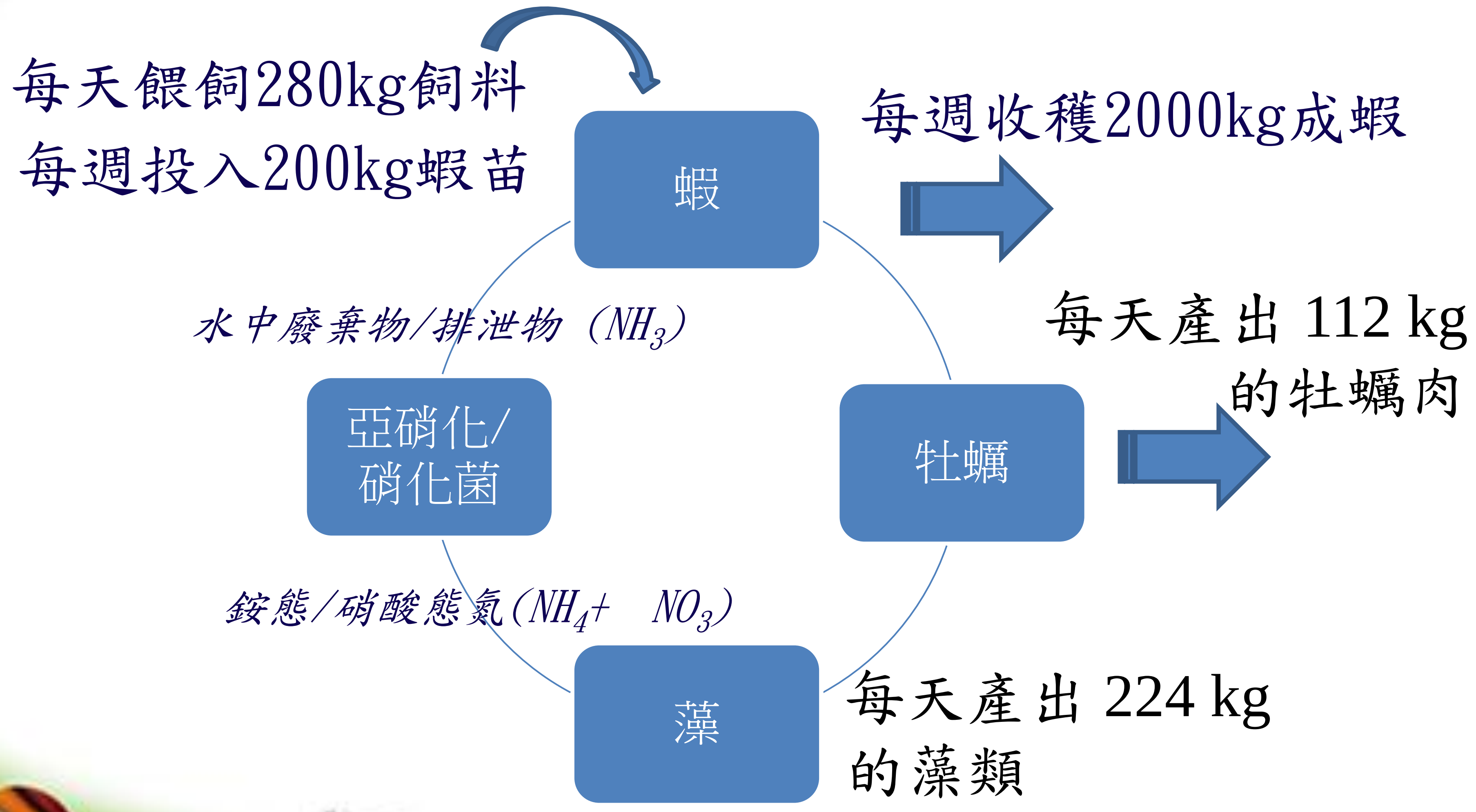
    總工時、每日工作量 **均為固定**

循環水養蝦、養藻與養牡蠣

Table 1
Estimated system production

Tank number	Number of shrimp	Average shrimp weight (g)	Shrimp biomass (kg)	Daily shrimp feed (kg)	Daily algae production (kg)
1	100 000	2	200	3	2.4
2	98 524	4	348	5	4
3	97 070	5	492	7	5.6
4	95 637	7	631	9	7.2
5	94 225	8	766	11	8.8
6	92 835	10	897	13	10.4
7	91 464	11	1024	15	12
8	90 114	13	1147	17	13.6
9	88 784	14	1266	19	15.2
10	87 474	16	1382	21	16.8
11	86 183	17	1494	22	17.6
12	84 911	19	1602	24	19.2
13	83 657	20	1706	26	20.8
14	82 423	22	1807	27	21.6
15	81 206	23	1905	29	23.2
16	80 007	25	2000	30	24
Sub-Total			18 668	280	224

魚蝦藻貝共生穩態養殖（四輪傳動）



穩態量產

- 必須不受天候影響
- 必須不靠天吃飯
- 必須在一個環境可控制的室內

- 不論是菜田種菜、水田養魚養蝦，能穩態量產，都有機會致富

富

Questions?