Multicountry Observational Study Mission on Agricultural Innovation in Japan to Increase Productivity Organized by APO

Role of Plant Factory with Artificial Lighting (PFAL) for sustainable society

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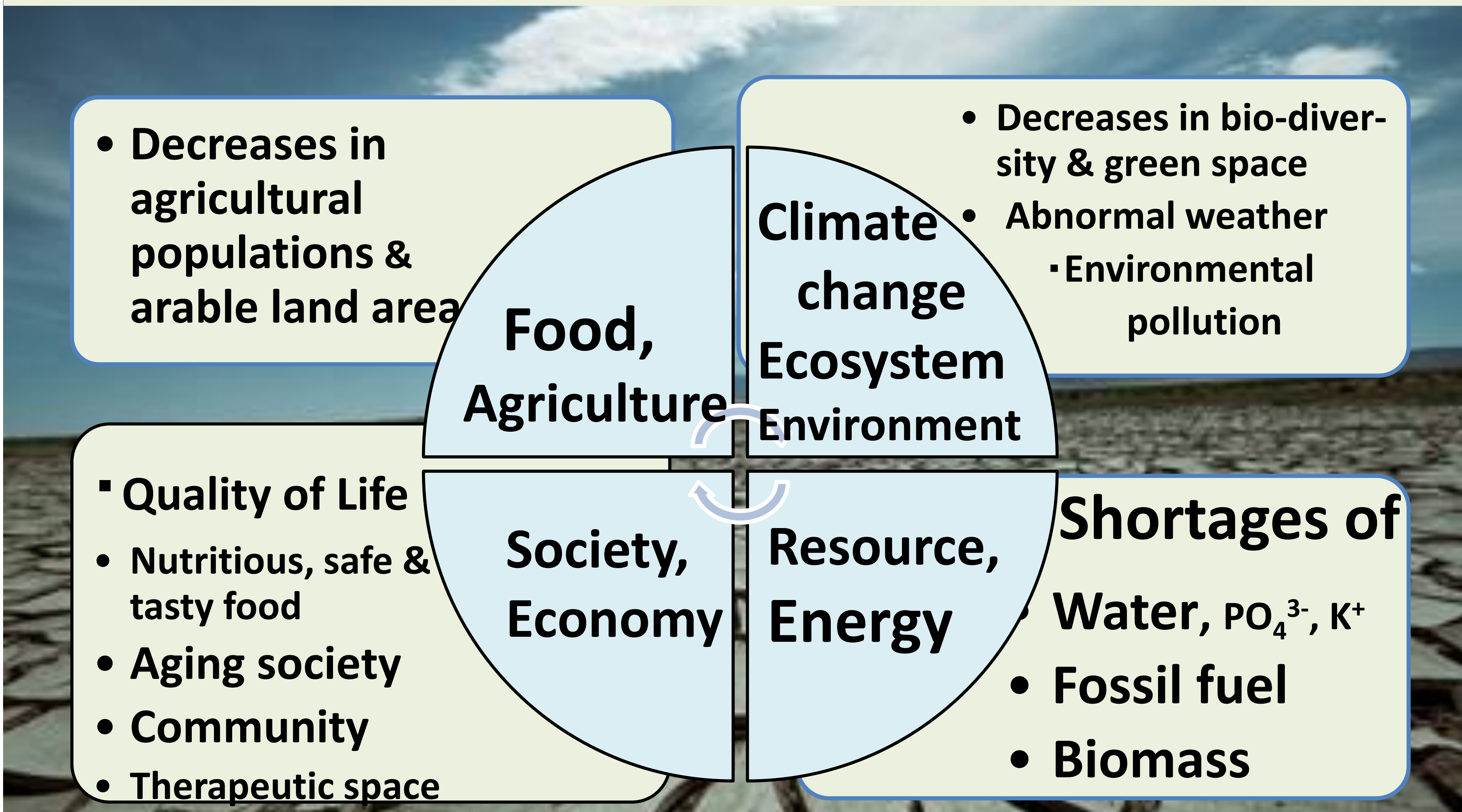
Contents

Four Inter-related global as well as local issues to be solved concurrently



Our Mission is:

to develop economically feasible plant production systems which achieve:

a maximum production of highest quality plants with minimum yield variation, using minimum amounts of resources, leading to highest resource use efficiencies, minimum costs and pollutant emission, for human welfare and global as well as local sustainability.

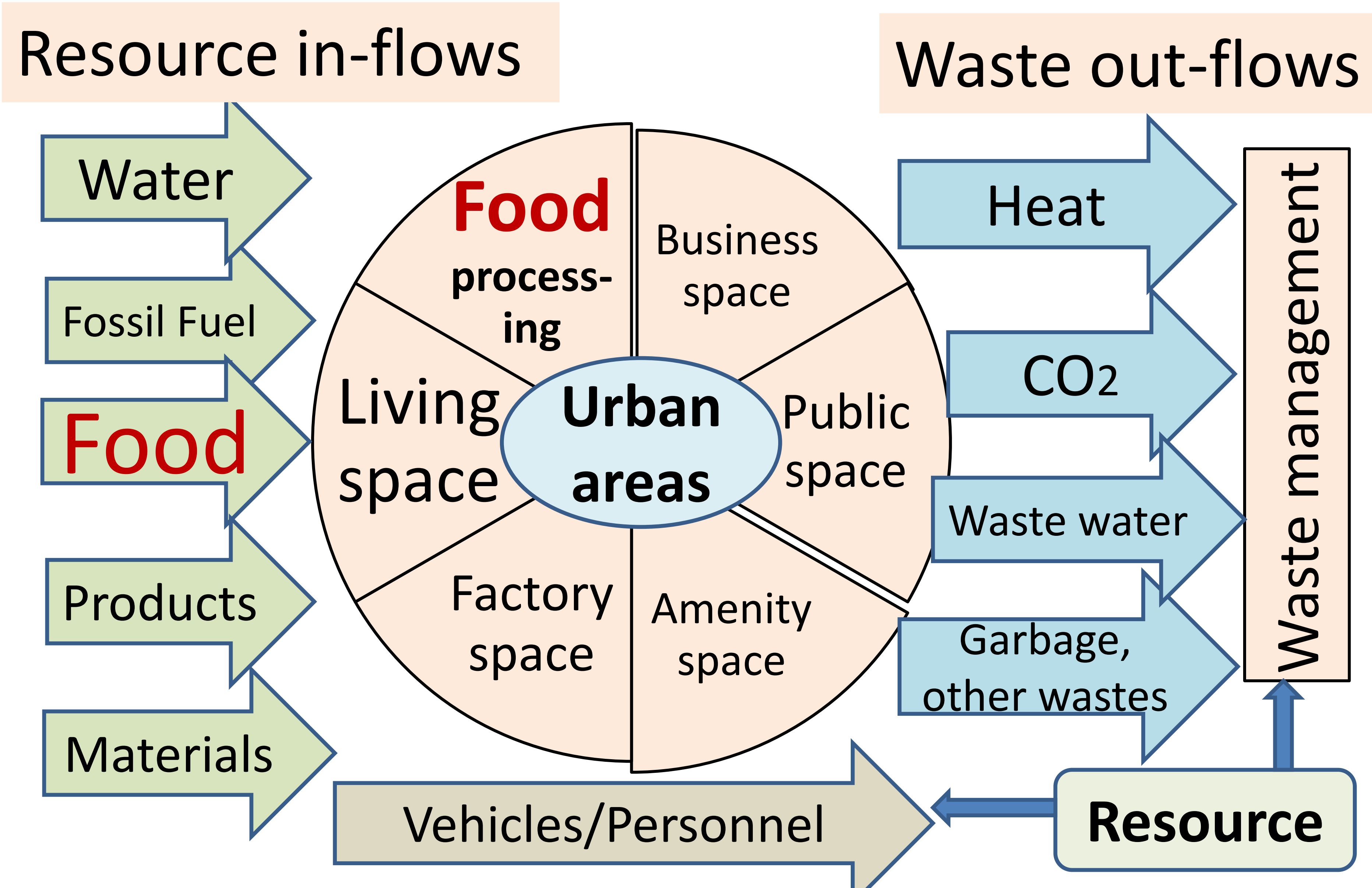
Why fresh foods in urban areas using PFALs?

- The population in urban areas will keep increasing, and will reach 70% of world population in 2050.
- The population in agricultural areas will keep decreasing, with aged farmers/growers.
- We need to produce and deliver foods with less water, less fossil fuel and less fertilizer.
- Also, we need to reduce the resources to process the foods after harvest, if fresh foods are tasty and good for our health, and environmentally friendly.

By producing fresh foods in urban areas:

- Much fossil fuels for the transportation and refrigeration are saved, with less traffic and less CO_2 emission. Traffic jams and acccidents are reduced.
- Job opportunities are created, and vacant spaces can be used. Local production for local consumption is achieved,
- Citizens can enjoy ‘fresh’ foods, and growing them.
- Wastes (waste water, garbage, CO_2 etc.) can be used as essential resources (water, fertilizer, CO_2, etc.) for plant production.
- Nighttime (surplus) electricity can be used for lighting and air conditioning.

Resource in-flows and waste out-flows in urban areas



Components of Urban agriculture

Urban Agriculture

- **Plant factory with artificial lighting (PFAL)**
- Greenhouse with/without supplemental artificial lighting (including rooftop one)
- Protected cultivation (mulched, netted screen, tunnel)
- Open fields (including roof top gardens)

Current status of PFALs

A PFAL with LEDs lighting, Mirai Co. Ltd.

Annual production capacity
2,500 lettuce heads/m^2
Sales: 2,500 US$/$m^2$

The PFAL with LEDs in Japan by Mirai Co. Ltd.

The largest PFAL in Japan built in 2006, producing 23,000 leaf greens daily

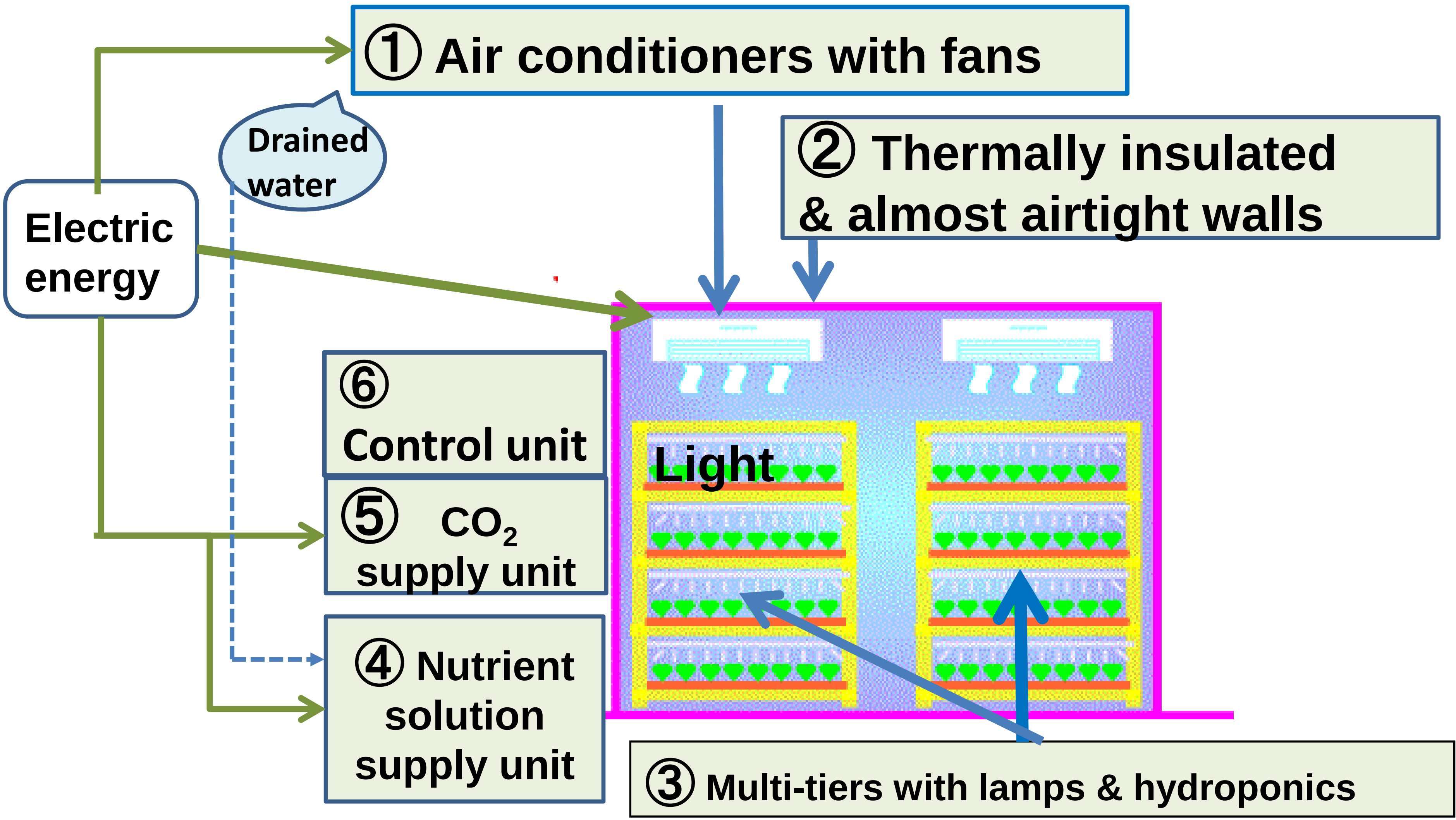
40 g/containe

80 g/bag

Spread Co. Ltd. Kyoto, Japan

Six main components of PFAL as CPPS

Initial cost: 3,000 US$/m^2 in Japan (50% for facilities)



Leafy vegetables/herbs currently produced commercialy in PFAL

Leaf lettuce   Frill lettuce   Green Mustard

Rocket (*Eruca sativa*)   Sweat Basil   Brassica rapa L. Japonica (mizuna)

Grow under low PPFD,
Short in height,
High price per weight,
High % of salable portion,
High planting density,
Added value for pesticide- free,

Price (Euro) per kg
Leaf lettuce 7
Basil 20
Coriander 35
Peppermint 60
spearmint 60

Low potassium leaf lettuce, rocket (*Eruca sativa*), watercress, parsley 30 Euro

Whole plants of root vegetables and medicinal plants are edible/salable when grown in PFALs

Turnip

Radish

Angelica acutiloba

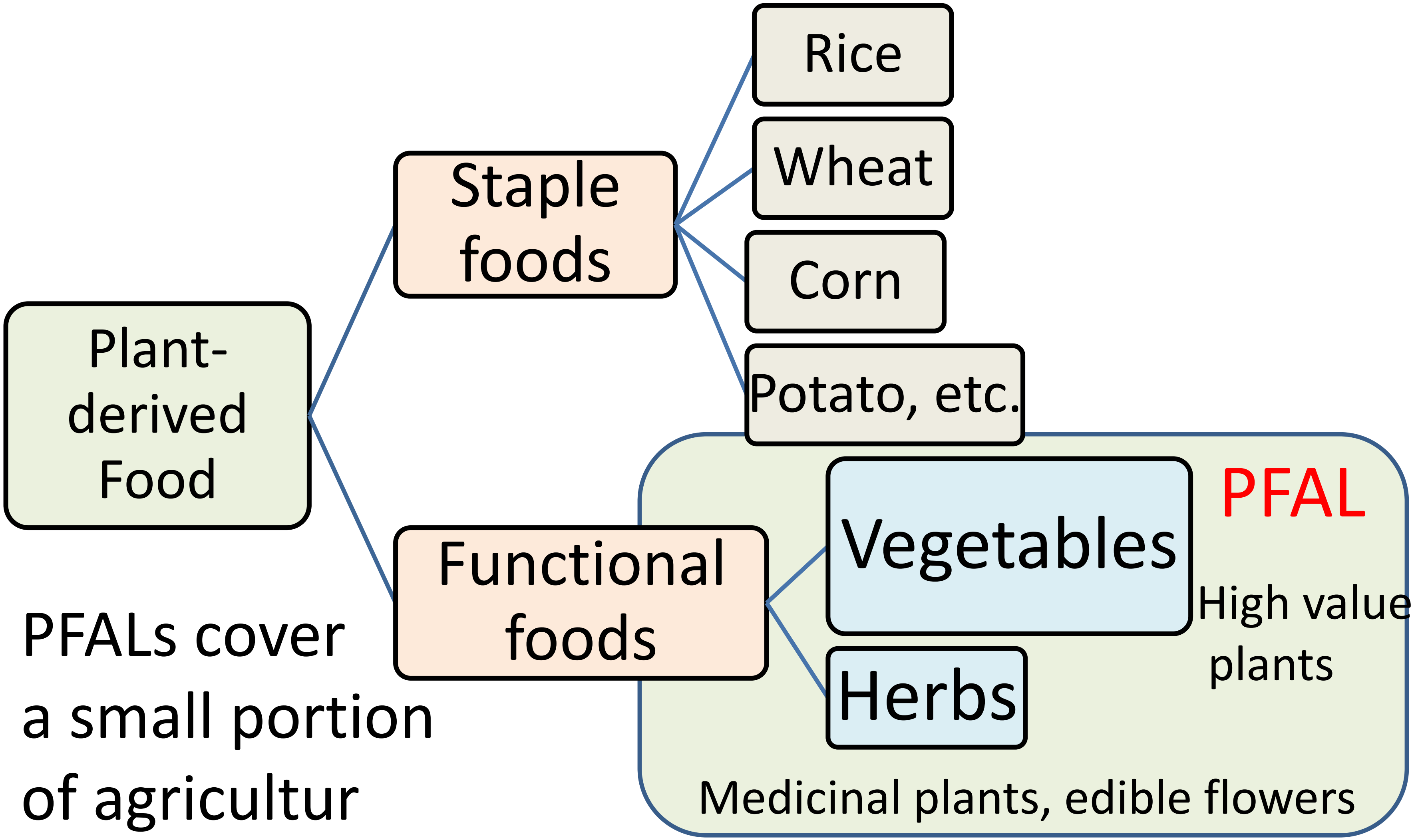
Panax ginseng

Carrot

Leaves, petioles and roots of Wasabi

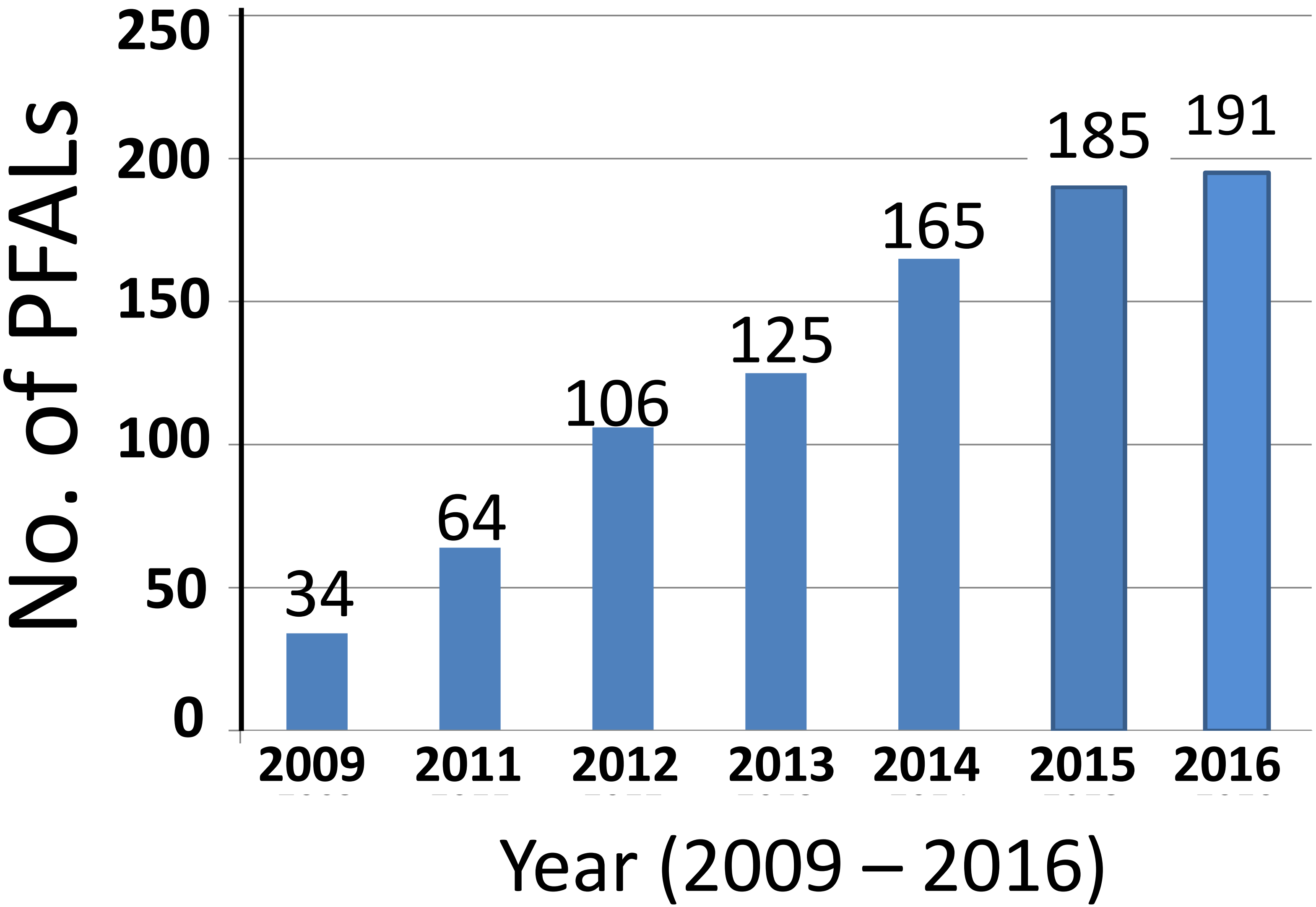
Both shoots with leaves and roots are edible, tasty and nutritious

Plants which suited to commercial production using PFAL



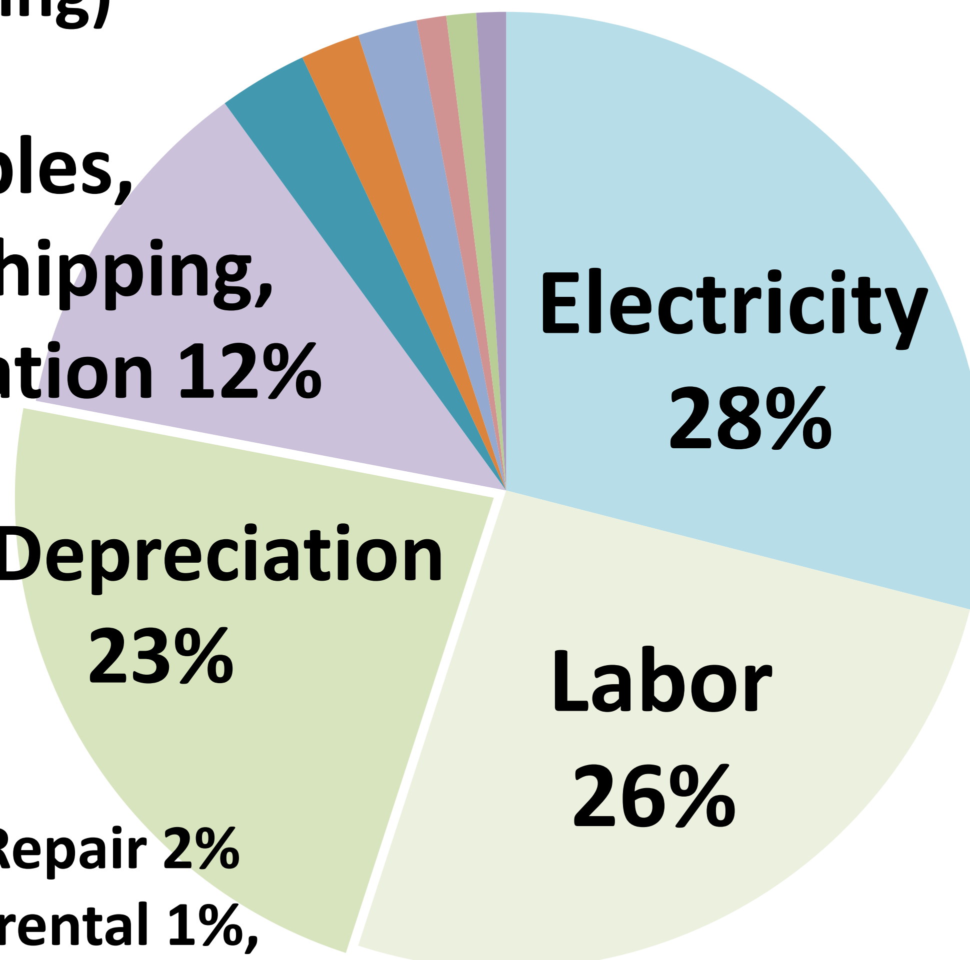
PFALs cover a small portion of agricultur

The number of PFALs in Japan by year



Initial & production costs by components

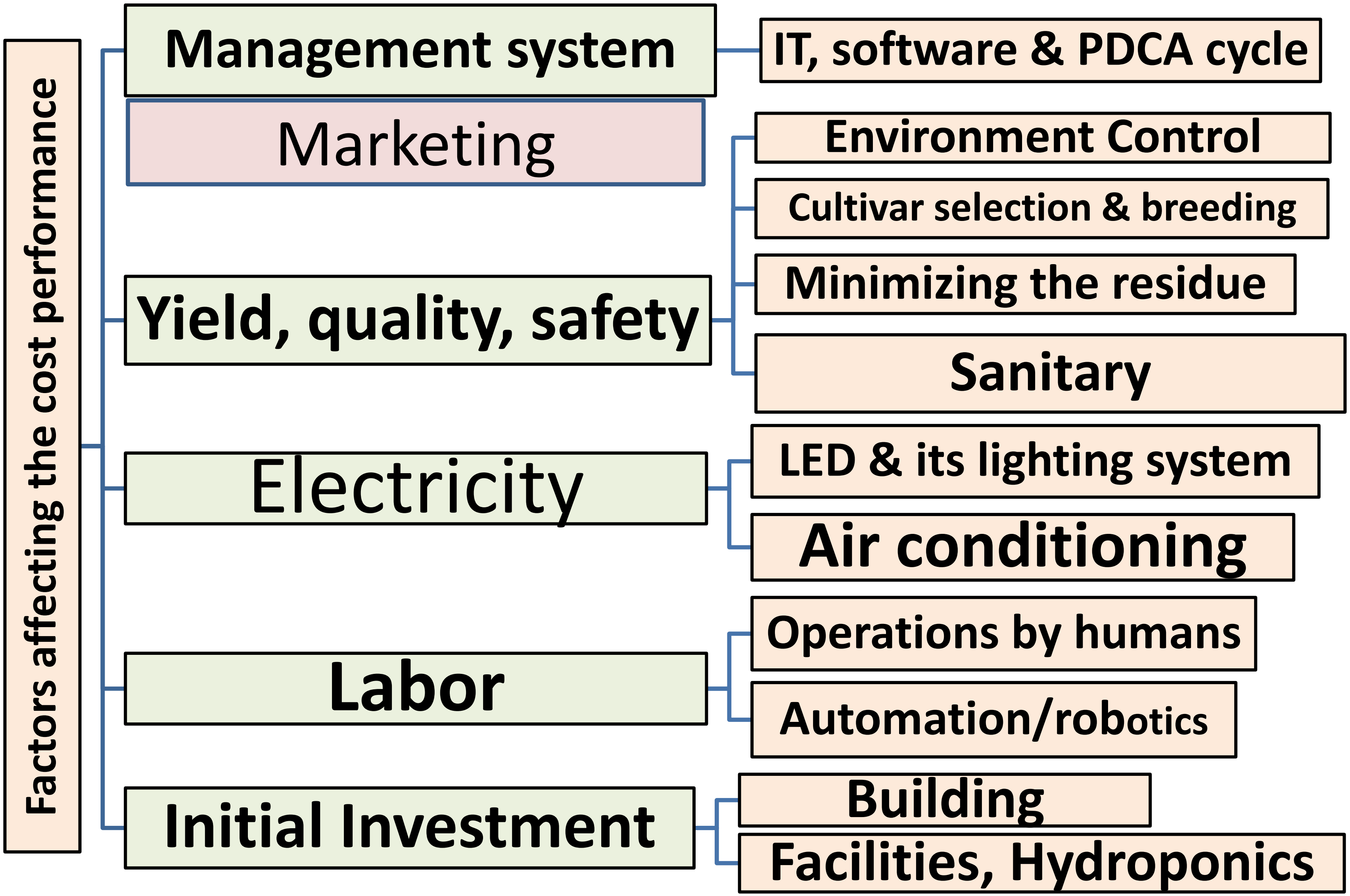
Initial cost: 3,000 US$/m^2 in Japan (50% for facilities, 50% for building)



Consumables 3%, Seeds 2%, Repair 2%
Supplies 1%, Water 1%, Land rental 1%,
Miscellaneous 1%, Land rental 1%

Ohyama (2015)

Factors affecting the cost performance of current PFALs



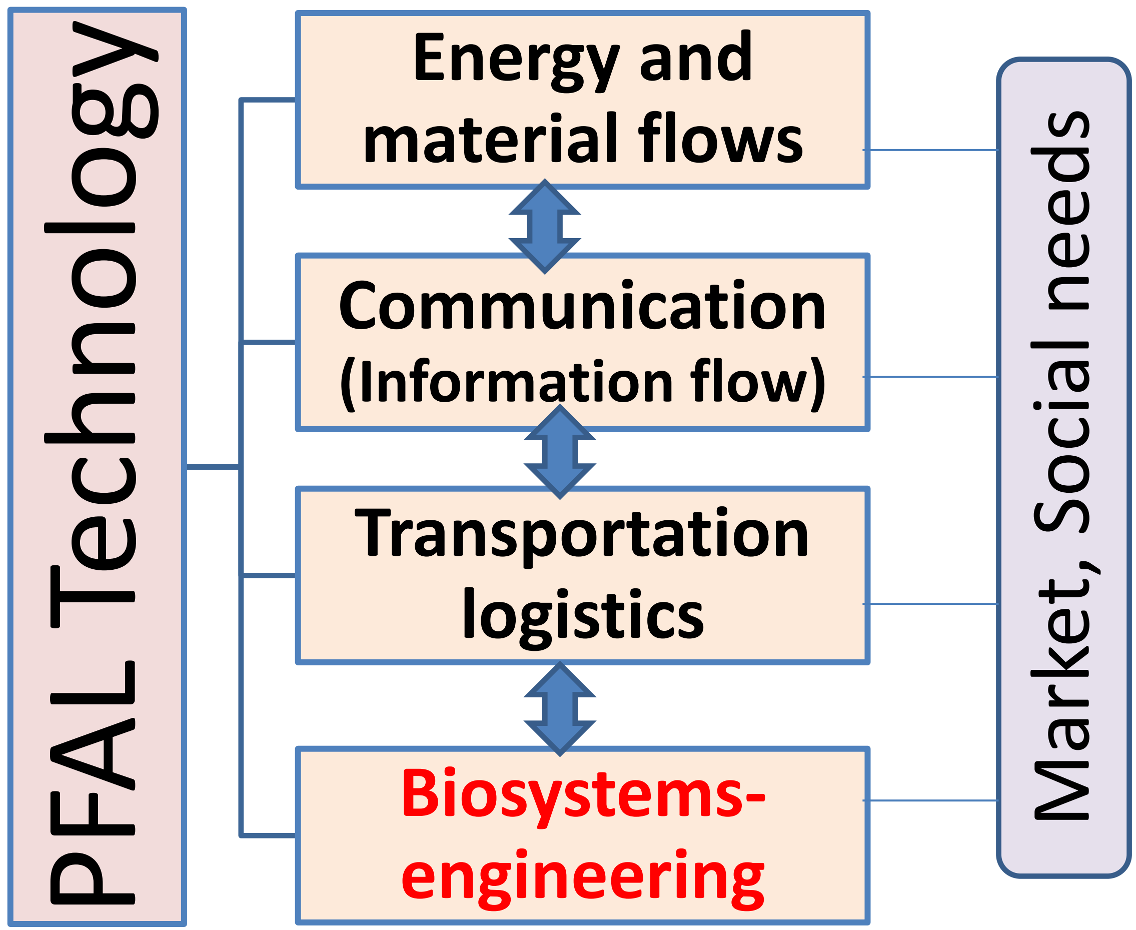
Is PFAL business profitable in Japan?

- **Currently, 30% of PFAKs only is making profits, 50% is break-even, and 20% is loosing money.**
- **It should be noted, however, the economic profitability will be much higher in 2020-2025 than in 2016.**

PFAL business can be profitable only when the PFAL is:

- Well designed,
- Operated by a well-educated, well-trained high-skill manager, with respect to managements of environment, workers and production process
- Almost all produce can be sold because of its quality and delivery as scheduled under reasonable marketing.

Components of PFAL Technology



Strength of PFALs (1)

Resource consumptions in the PFAL are reduced considerably, compared with those in the greenhouse

- Pesticide by 100% (clean room),
- Water by 95% (recycling),
- Land area by over 90% (multi-tiers, etc.),
- Fertilizer by 50% (no drainage),
- Labor hours by 50% (small area, etc.),
- Plant residue by 50% (Environ. Control)
- Variations of yield & quality by 50% (CPPS)

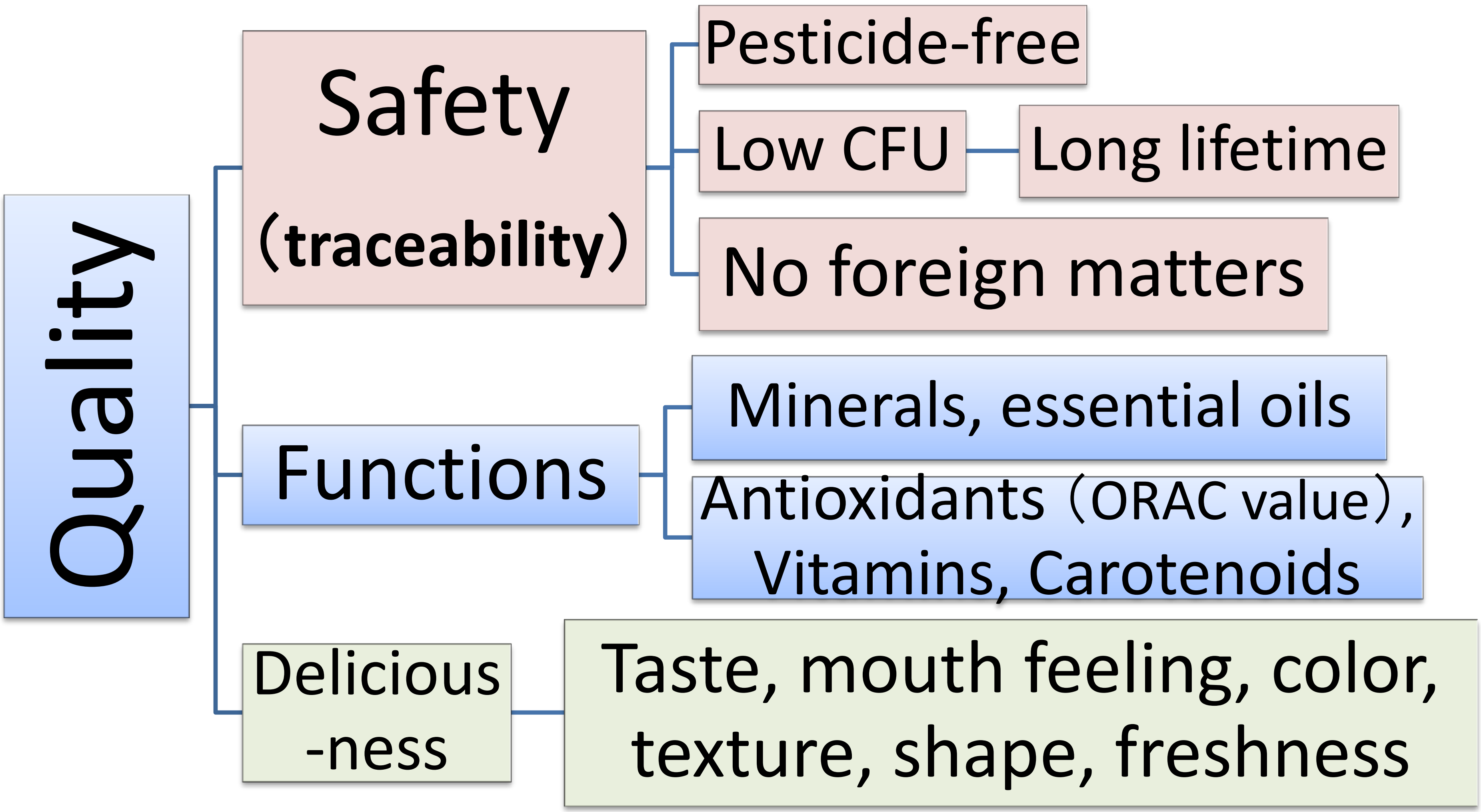
Strength of PFAL (2)

- Clean, so that no need to wash before eating fresh
- Longer duration of life due to very low population of microorganisms on leaves
- Plant growth & quality of produce are not affected by weather, soil fertility, pest insects.
- Comfortable working condition,
- Taste, nutrition, flavor & mouth feeling can be modified by environment control.
- Production cost of leaf vegetables can be competitive in price against imported ones
- Almost perfect traceability from seeding to harvesting.

Estimated relative annual productivity of PFAL by its components, compared with those in the open field.

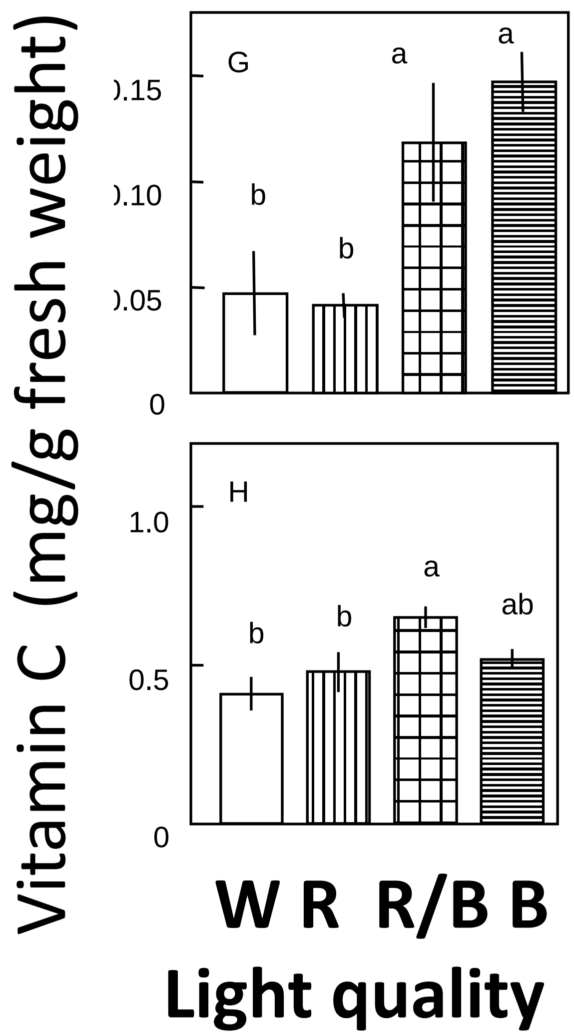
No.	Magnification by PFAL compared with the open fields	Component Factor	Multiplied Factor
1	15-fold by use of 10 tiers	15	15
2	2-fold by shortening the culture period by means of optimal environment control	2	30
3	2-fold by transplanting seedlings one day after harvest all year round assuring no time loss	2-3	60-90
4	1.5-fold by increased planting density per cultivation area	1.5	90-135
5	1.5-fold per cropping by no damage due to abnormal weather & outbreak of pest insects	1.5	**135-202**
6	1.3-fold sales price due to improved quality and less loss of produce after harvest	1.3	175-263

Research on quality of vegetables has been conducted intensively from different aspects



Vitamin C (L-ascorbic acid) in leaves as affected by light quality (white, red, red/blue and blue)

(Ohashi-Kaneko, 2015)

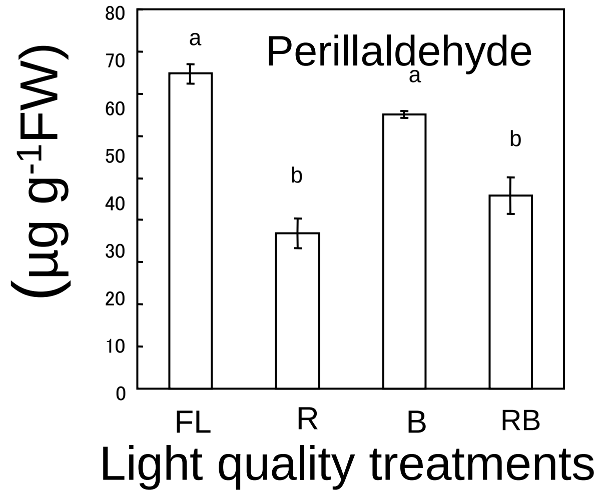


Lettuce

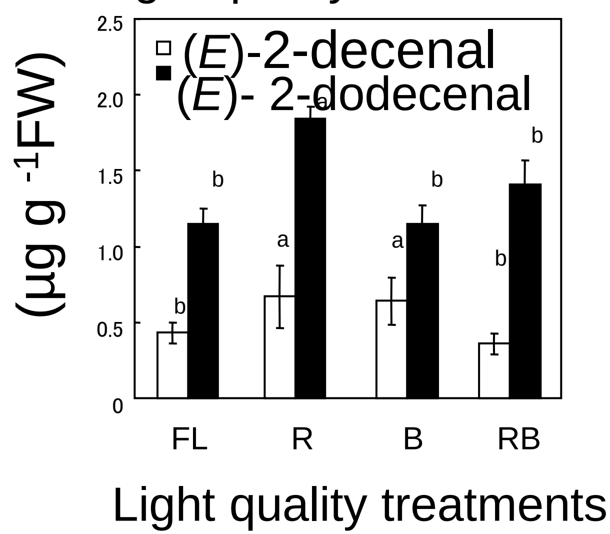
Spinach

Essential oil concentration in herbs (Perilla and Coriander) as affected by light quality (Ohashi-Kaneko, 2015)

Perilla



Coriander

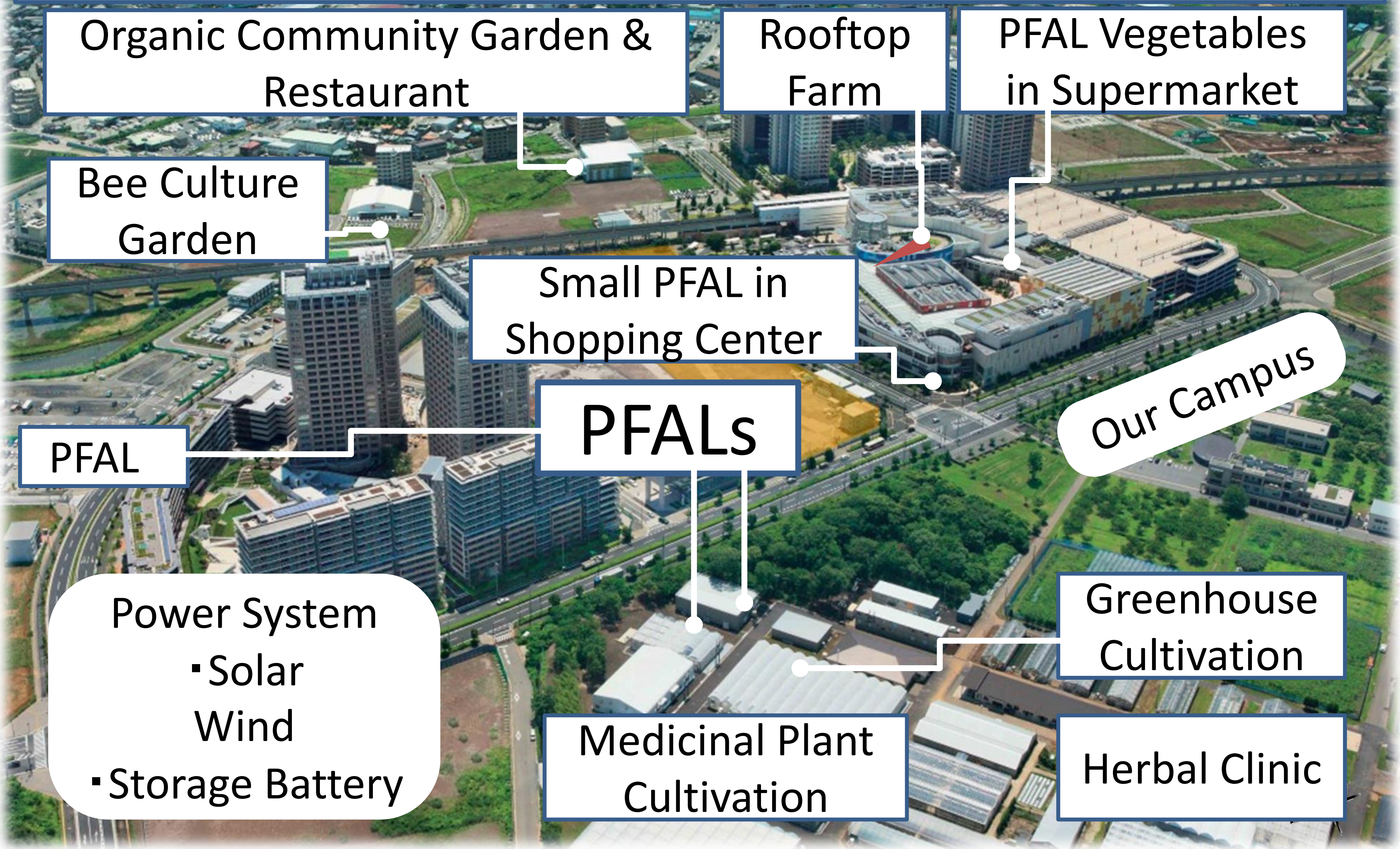


An ongoing social experiment in Kashiwa-no-ha
smart city with urban agriculture,
in corporation with Chiba University and
Japan Plant Factory Association

Towards changes in life style and
social infrastructure
for sustainable societies

A smart city with urban agriculture

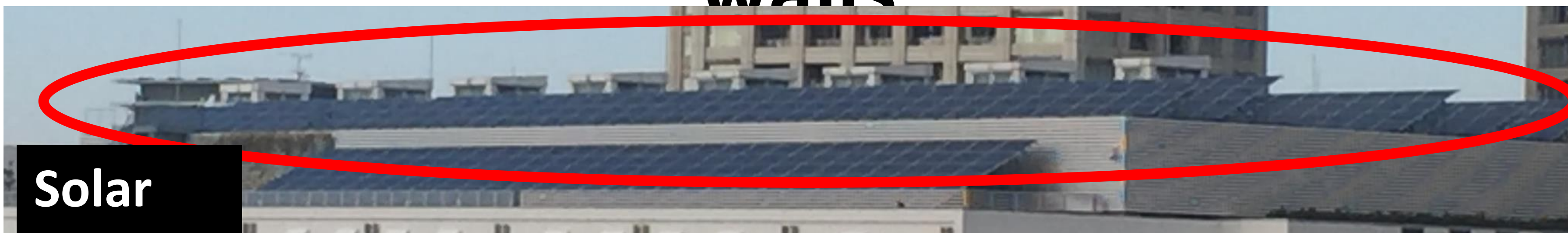
Kashiwa-no-ha, the suburb of Tokyo

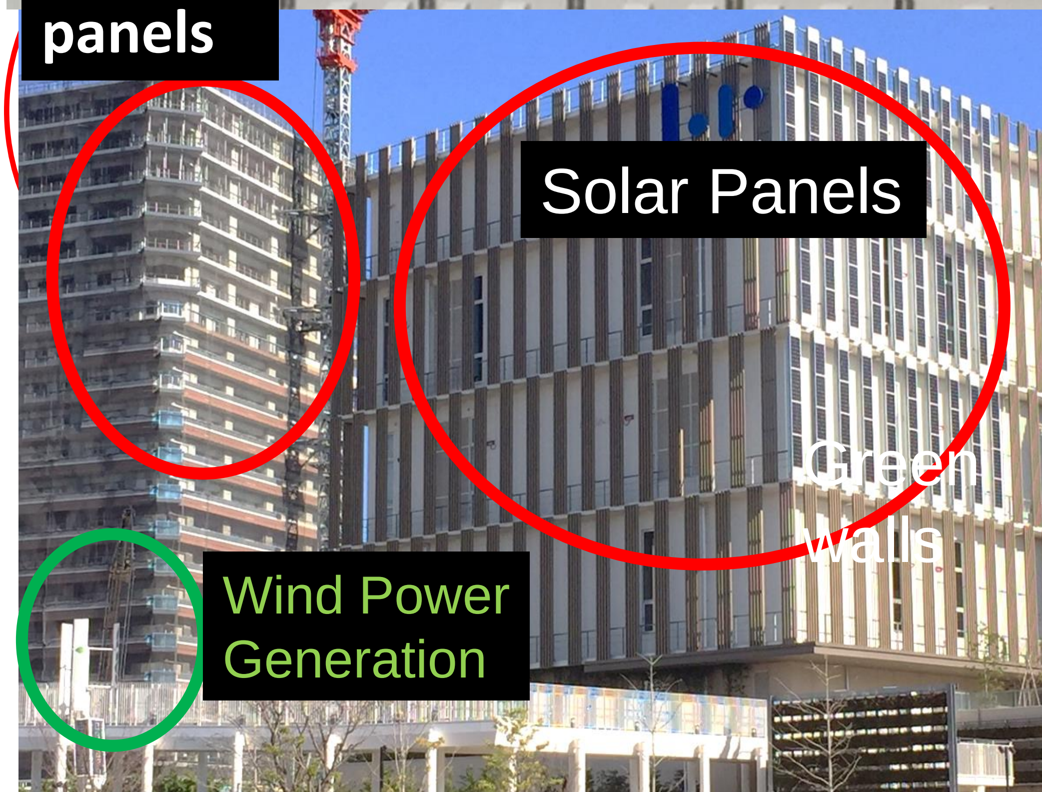


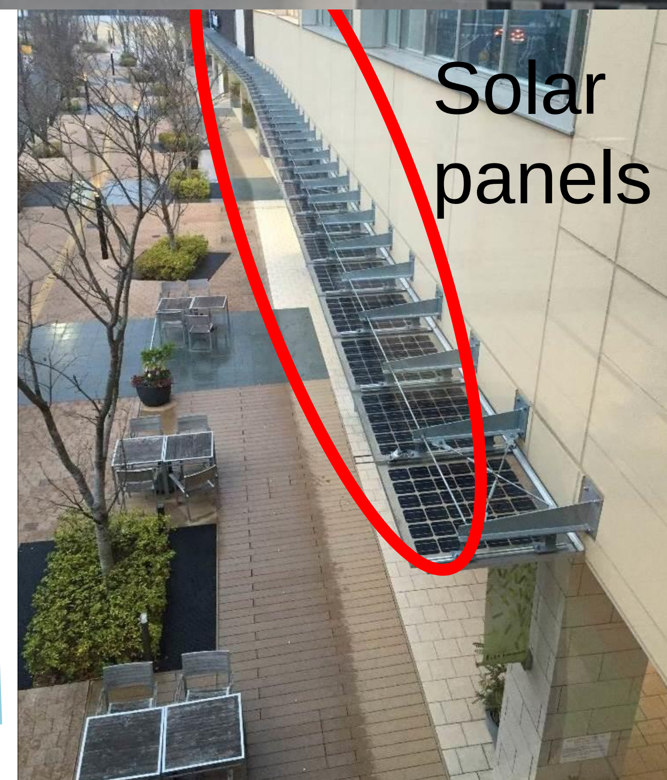
Smart city with urban agriculture

- Rooftop farm, organic city farm, organic restaurant
- Mini PFALs at the shopping center, food shop, café restaurant, hotel restaurant,
- PFALs of Mirai, Japan Dome house and Wago
- Household PFAL
- Greenhouses at Chiba Univ.,
- Solar panel & wind power generation, Batteries
- Oriental medicine clinic, acupuncture clinic, herb garden
- Honey bee house

Smart Building with solar panels, wind power generation, and green walls







PFALs in Kashiwa-no-ha town of different sizes for different purposes

10,000 heads/d

3,000 heads/d

700 heads/d

CPPS for Seedling Production

Hotel Restaurant

Home-use

Since 2014
1,400 m^2
11-14 layers
10,000 heads/day

MIRAI

都市に豊かさと潤いを
三井不動産



PFAL at Chiba University built in 2010.

Floor area of culture room: 338 m^2, 10 tiers, 9 rows

Operated by Mirai Co. Inc.

Leaf lettuce

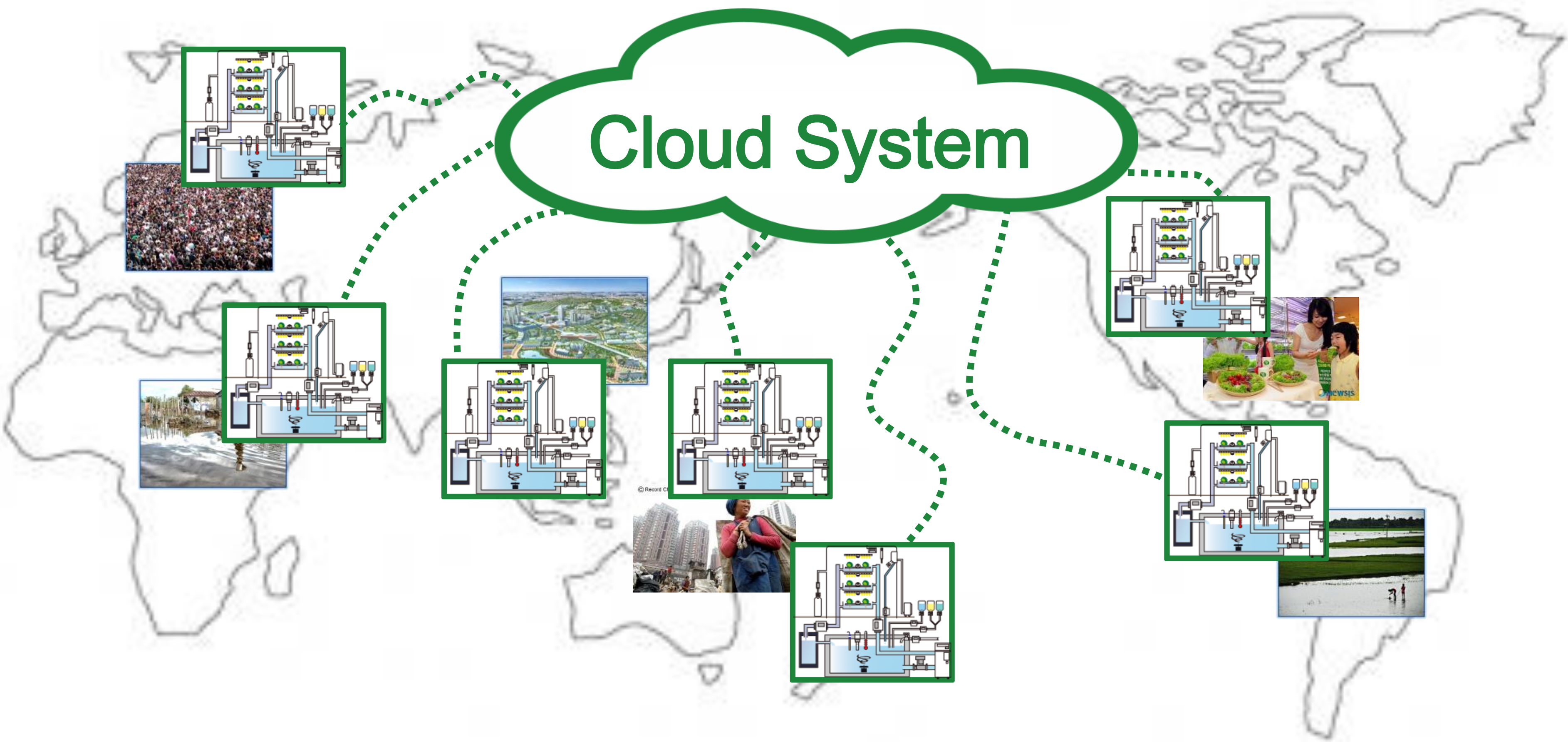
3,000 heads/day
One M heads/y

2,800 heads/m^2/y

Leaf lettuce grown in PFAL at Chiba Univ. produced by Mirai Co. Ltd. for sale at a supermarket

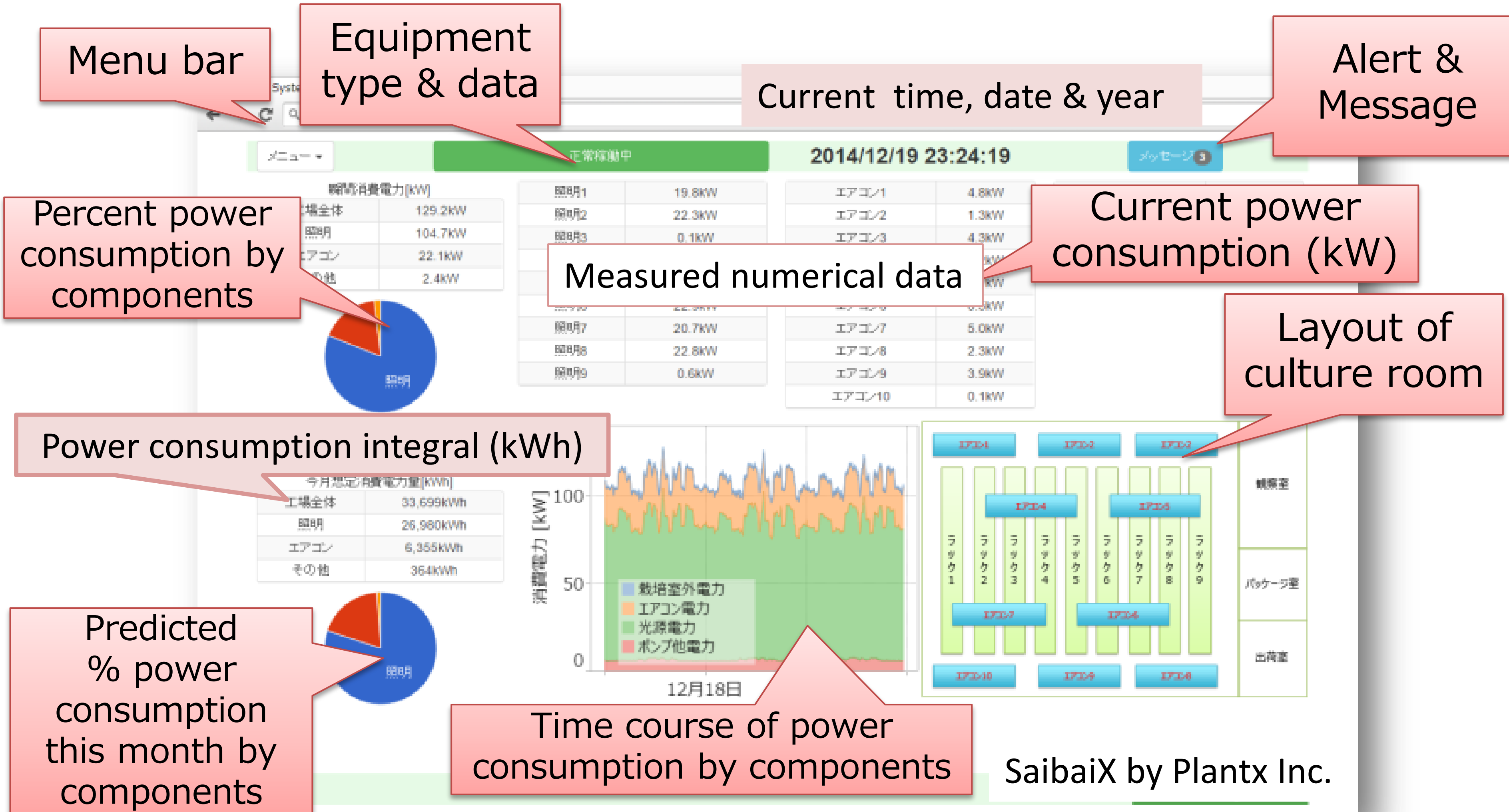
Romaine lettuce 1.4 Euro/bag (70-80 g)

PFAL technology based on 'Cloud Computing'



By the courtesy of PLANTX

Visualized daily report of power consumptions by components on the computer display screen for the PFAL manager as a daily report



SaibaiX by Plantx Inc.

Japan Dome House, Inc., Kashiwa

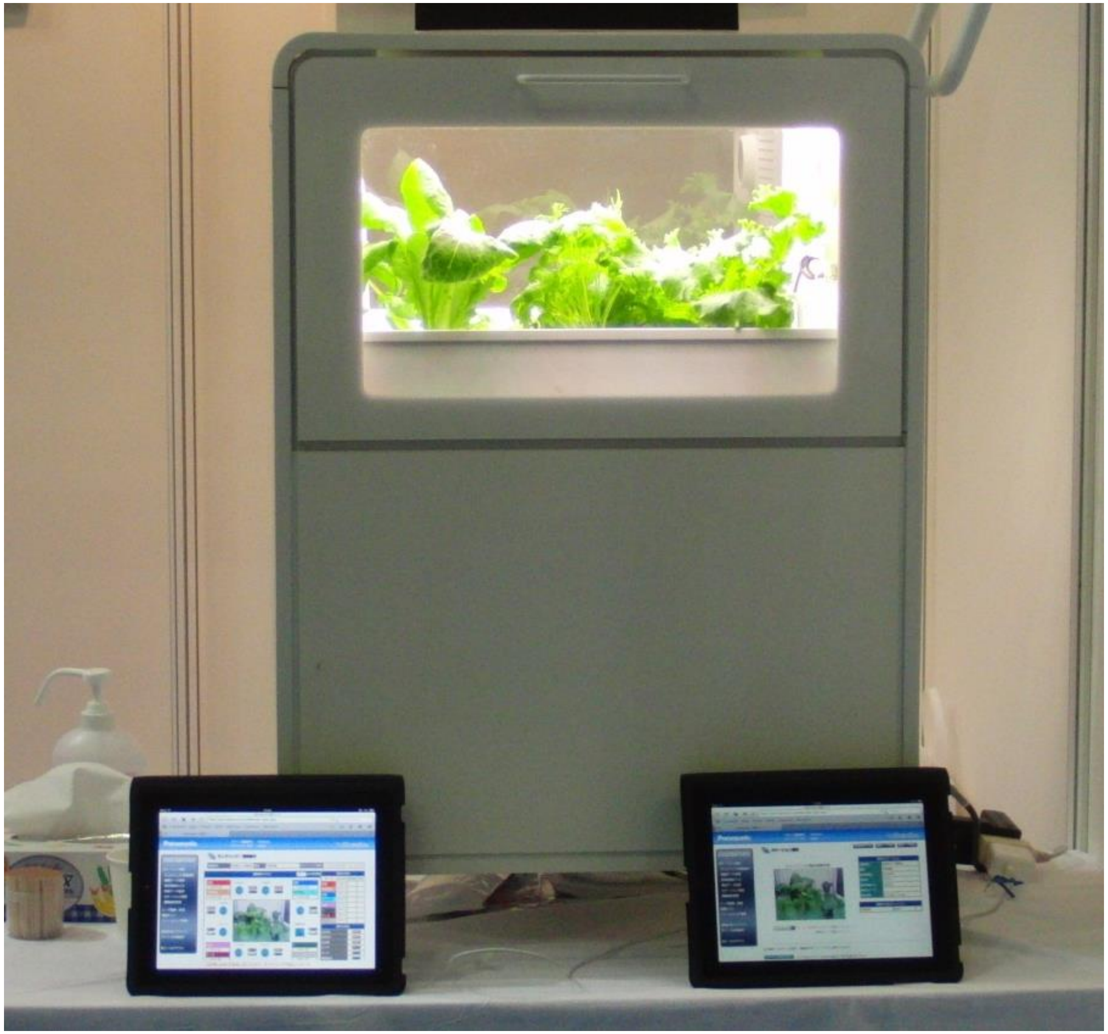
Inside View of PFAL, Japan Dome House, Kashiwa

A CPPS (closed plant production system) for production of transplants with a floor area of 16 m^2. In 2014, about 300 units of CPPS are in use at 130 different locations in Japan.

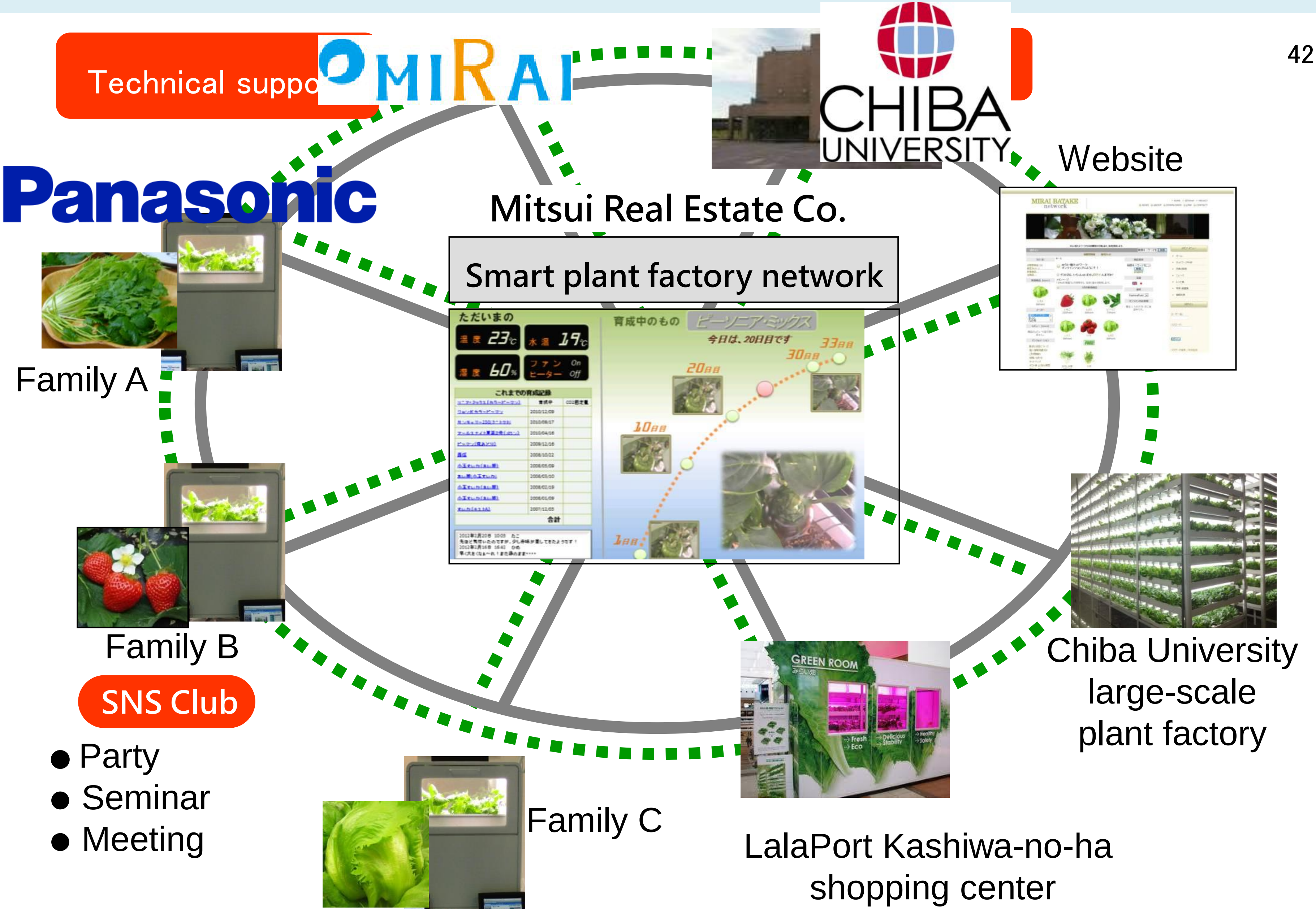
Mitsubishi Chemicals Inc.

Four layers, 2 rows, holding 96 plug trays

A household plant factory connected with Internet for SNS by Panasonic Inc.



Household PFAL network for SNS via Internet



http://www.miraibatake.ne

Bookshelf-type PFAL at coffee shop in Kashiwa, Chiba

Café Restaurants Agora

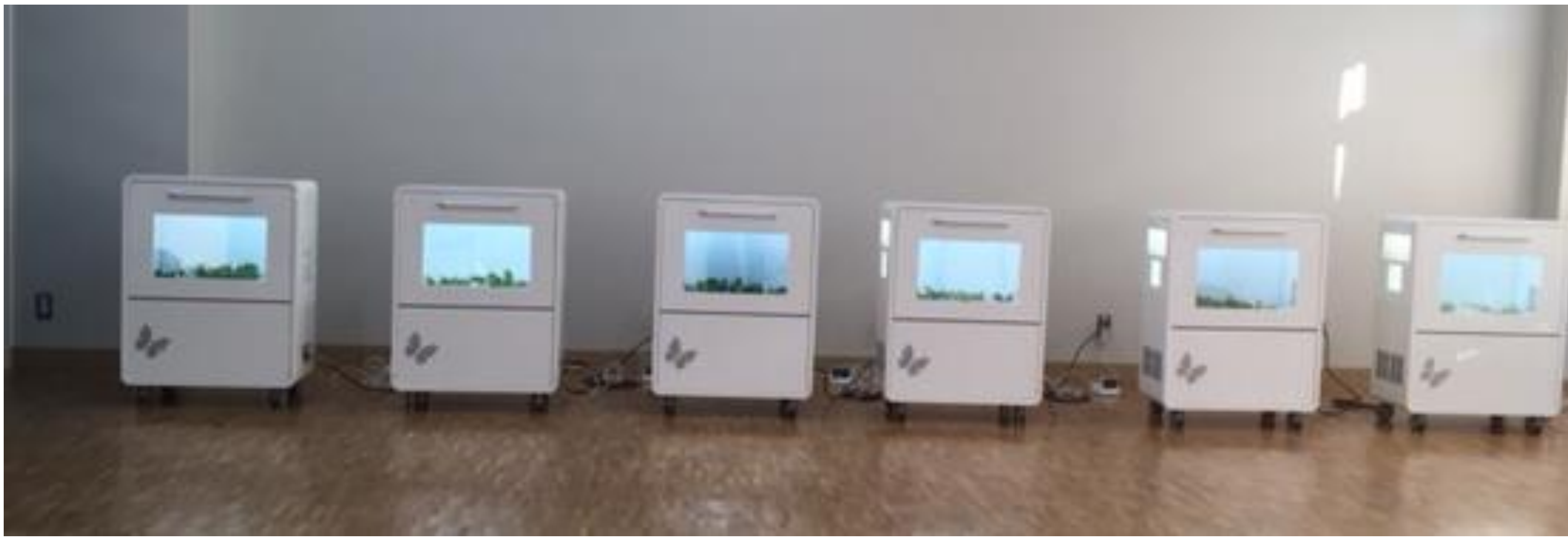
Further applications with support of Japan Plant Factory Association and Chiba University

PFAL connected with mushroom factory operated by ‘Japan Dome House’ in Fukushima Pref., Japan

Medicinal Mushroom Factory

In the lobby of Sakakibara Memorial Hospital

Small PFALs for educational/self-learning purposes, connected each other via Internet with cloud computing system



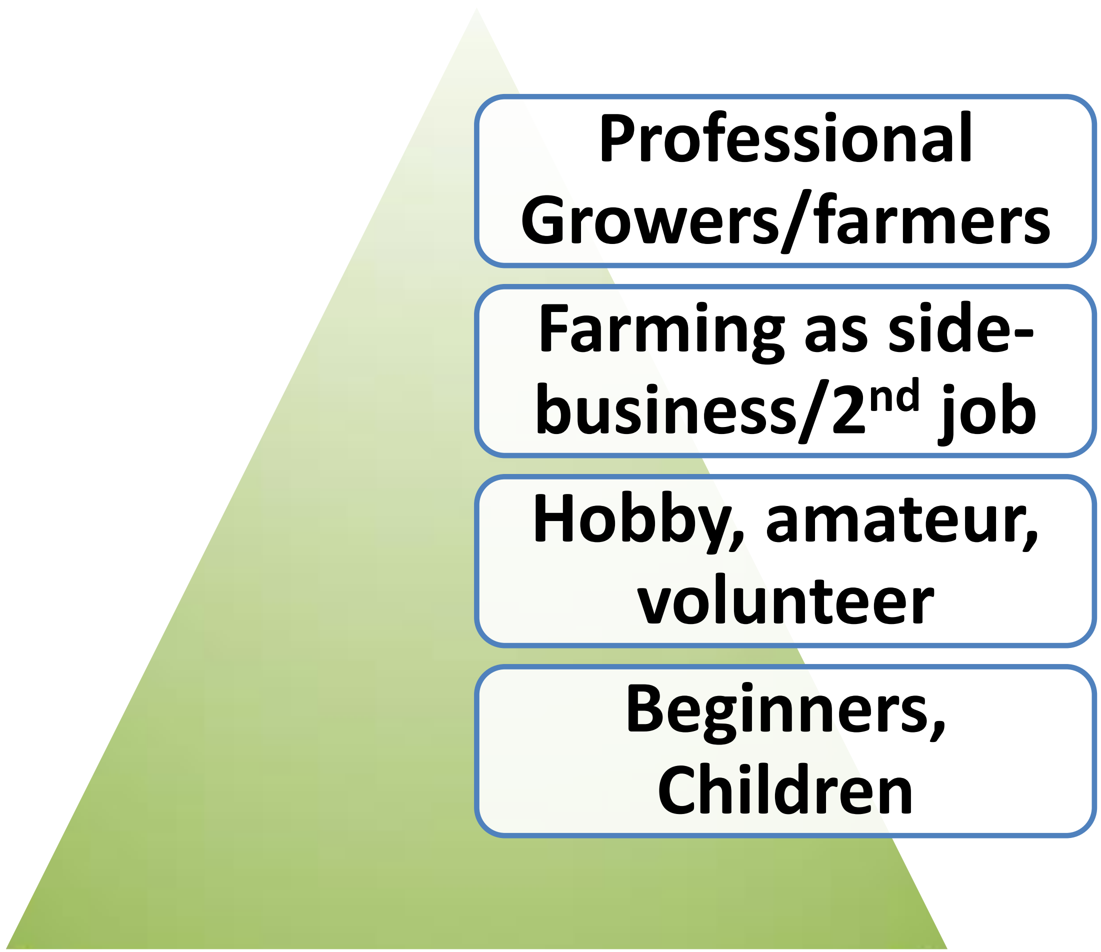
Iri’hune Junior High School, Urayasu city, Chiba, Japan (Panasonic)

Plant factory for next generation

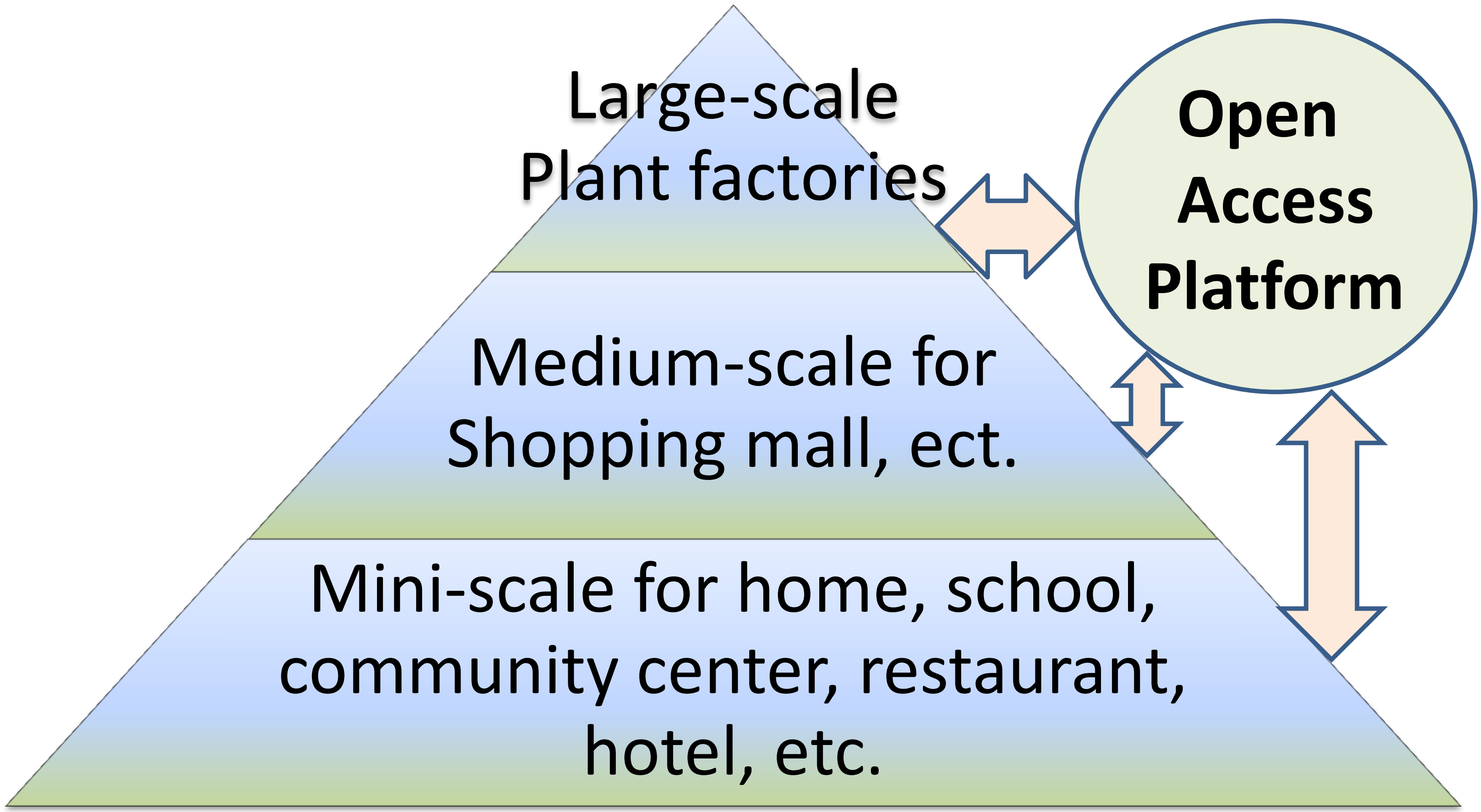
PFALs for Next Generation (1)

- **Multi-layer, ubiquitous PFALs**
- **PFALs integrated with other biological systems**
- **Autonomous PFALs with use of natural energy in local, and/or agricultural areas**
- **Breeding specifically for PFALs with molecular biology**
- **LCA (life cycle assessment)**
- **Integrative bionic sustainable smart city**

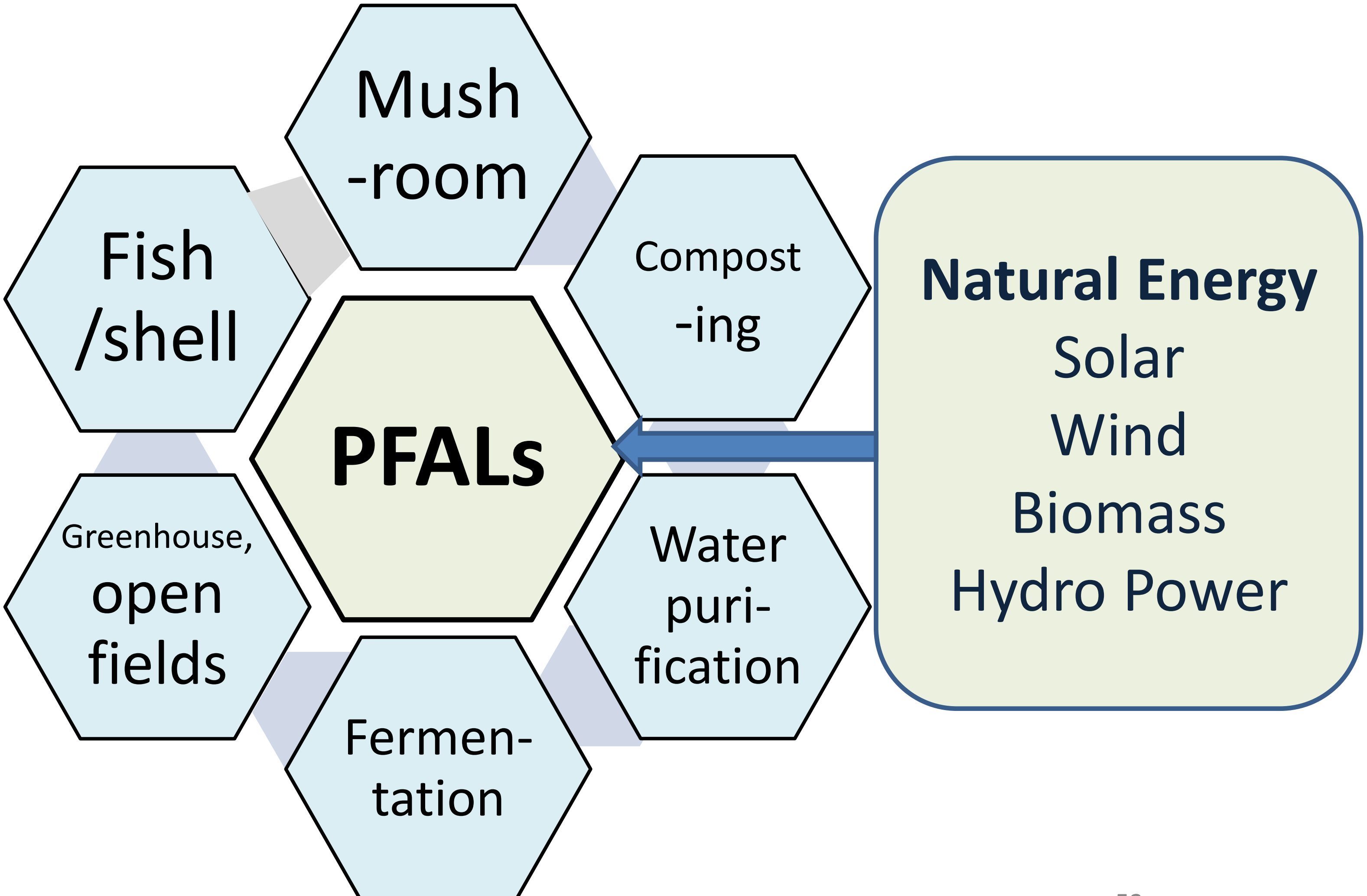
Multi-layer PFAL users



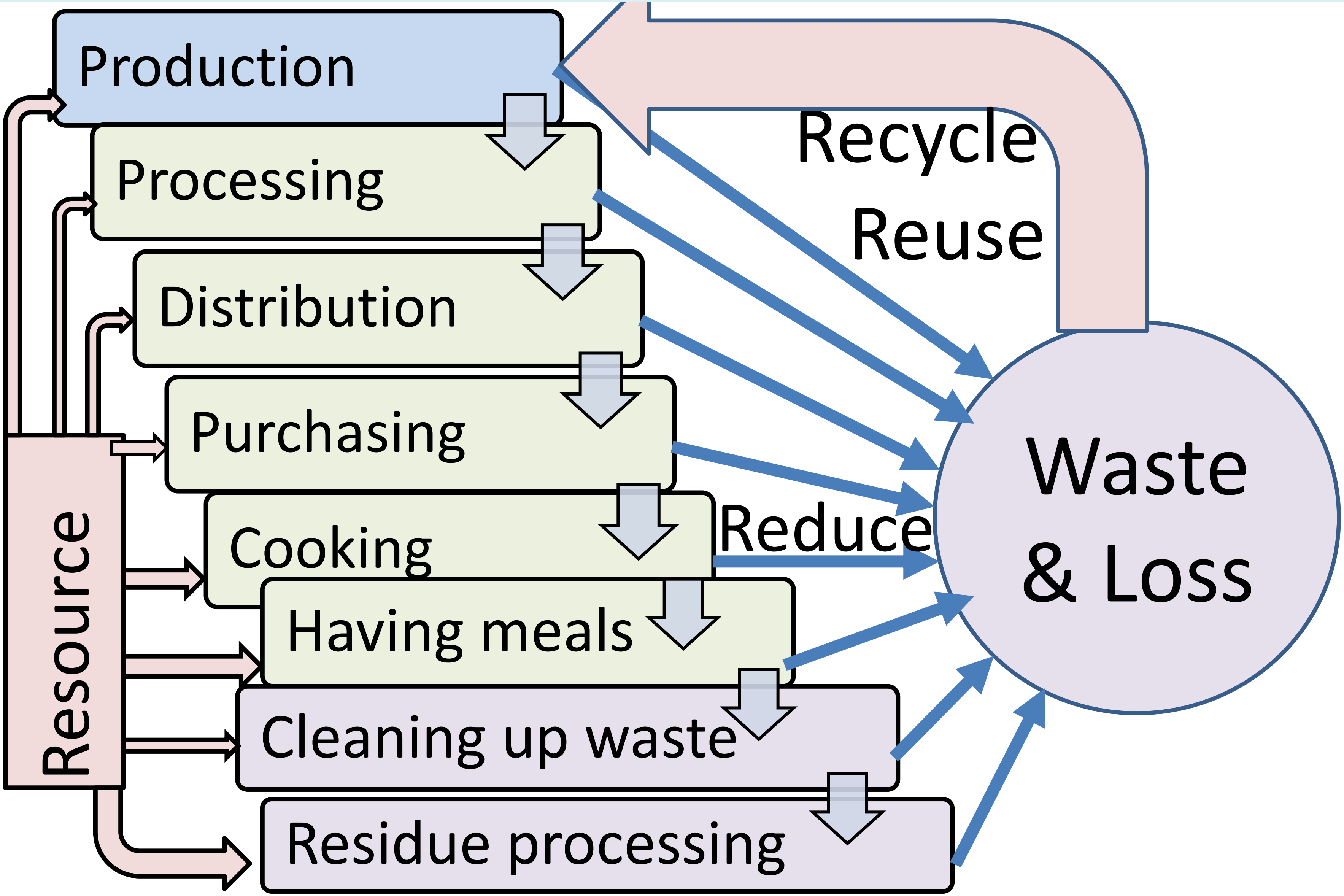
Distributed (Ubiquitous) network of PFALs



PLALS integrated with other biological systems for sustainable fresh food production in urban areas



Resource inputs and reduce, reuse & recycling of wastes, and minimizing losses in a food chain



Conclusion (1)

The PFAL will bring about high productivity with minimum resource and emission of environmental pollutants, and will become a key component in urban agriculture to solve the food, environment & social tri-lemma issues in urban areas.

Conclusion (2)

We are just at the entrance of PFAL technology. PFAL networks will grow by being integrated with other biological systems towards sustainable societies.

Improvements of PFALs

How can we overcome the weakness of PFAL

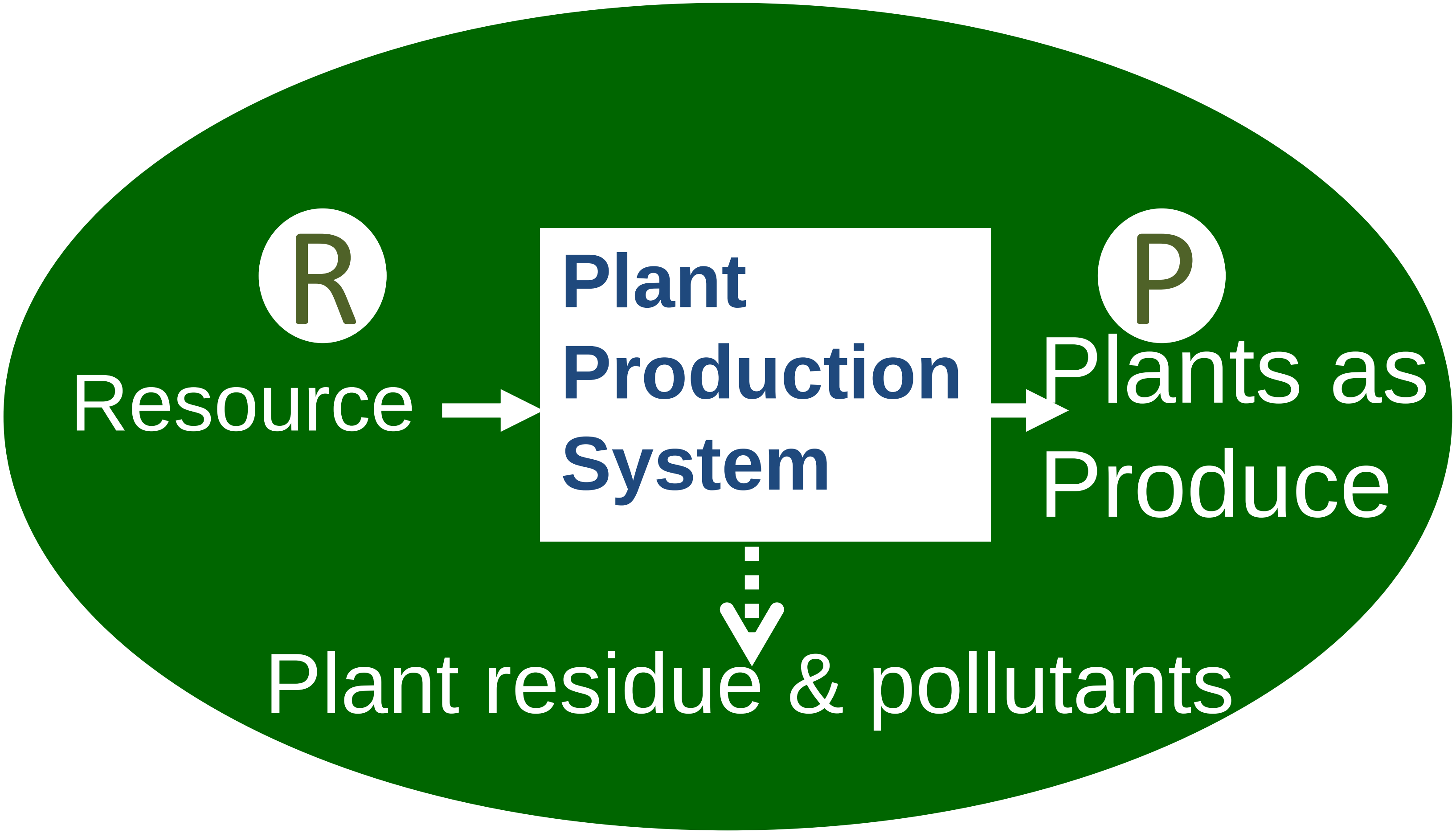
- High initial (building and facilities) costs
  - Improve the cultivation system and its components
- Environmental control & its visualization and analysis
  - Reduce electricity cost
  - Increase the plant growth rate
  - Increase the economic value of produce
  - Increase salable or edible portions of plants
- Human operations
  - Automation and improvements of production process
  - Computer software development, IT, AI and IoT
  - Human resource development
- Marketing, market creation, new life style creasiton

Methodology for improving resource use efficiency and cost performance in PFALs

- **resource use efficiency (RUE)**
- **cost performance (CP)**
    - economic value per weight
    - salable portion of plants

Resource Use Efficiency (RUE) = P/R

Higher the RUE, higher the economic feasibility & sustainability



Resources: water, CO_2, fertilizer, light energy, seeds, labor etc.

Key indices (RUE and CP) and concept (CPPS)

- **RUE (Resource Use Efficiency)**

  Resource fixed by produce/Resource supplied

- **CP (Cost Performance)**

  Economic value produced/cost of resource

- **CV (Coefficient of variation)**

  Standard variation of production /Its average

- **CPPS (Closed Plant Production System)**

  PFAL is Perfect CPPS when RUE=1

Breakdown of RUE

1) Water use efficiency (WUE)
2) CO_2 use efficiency (CUE)
3) Light energy use efficiency (LUE)
4) Electric energy use efficiency (EUE)
5) Fertilizer use efficiency (FUE)
6) Seed/transplant use efficiency (SUE)
7) Coefficient of performance of heat pumps (COP)

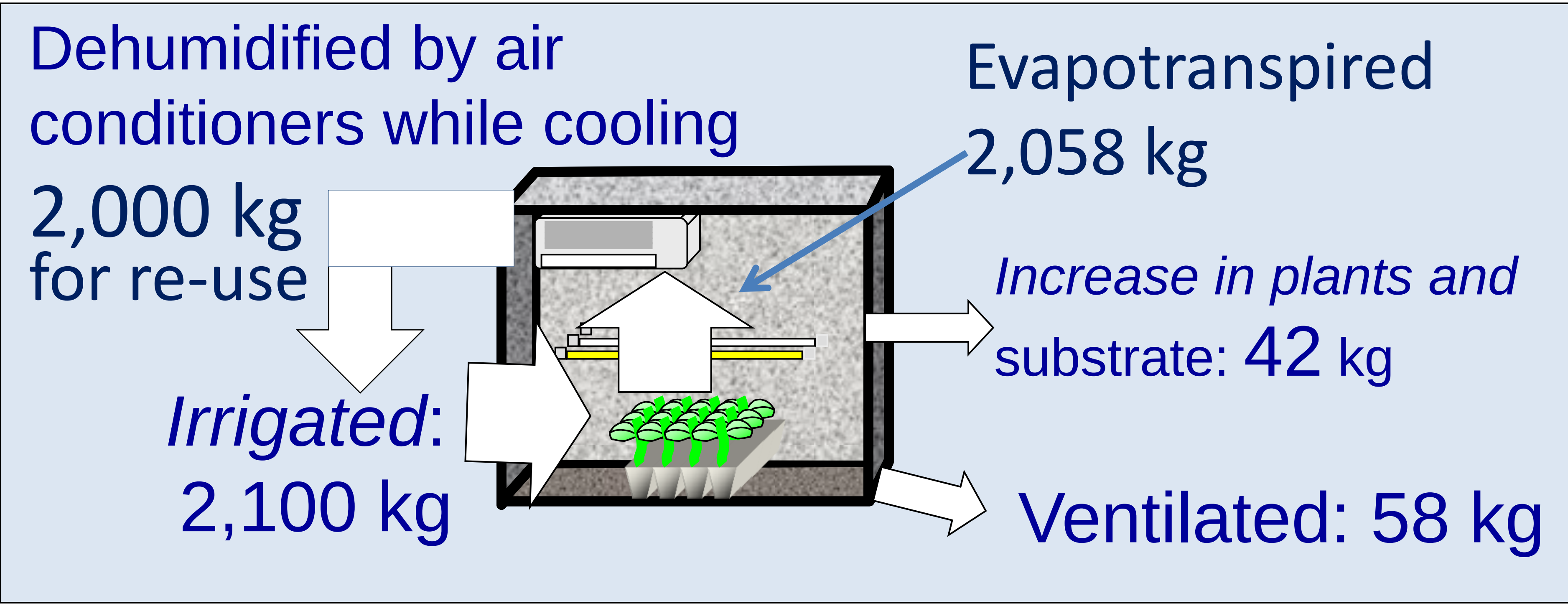
WUE, CUE and LUE are significantly greater in PFAL than in the greenhouse

Use Efficiency	PFAL	Greenhouse
WUE (water)	0.96	0.02-0.03
CUE (CO_2)	0.88	0.4-0.6
LUE (light energy)	0.027	0.017
EUE (electricity)	0.007	----------

Ohyama et al. (2002; 2005; 2006); Yokoi et al. (2005)

Water use efficiency (WUE)

$$\frac{\text{Irrigated} - \text{Ventilated}}{\text{Irrigated}} = \frac{2100 - 58}{2100} = 0.97$$



If dehumidified water is not used, the WUE is 0.02 (=(2100 -58 - 2000)/2100 ⇒ the water needed for irrigation in the CPPS is 1/48 (=2/97) of that in the greenhouse.

Ohyama et al. (2002).

Light Energy Use Efficiency(LUE) can be more than doubled in PFAL

Electric Energy — 100%

Heat energy about 70%

Photosynthetically active radiation (PAR) — about 30%

PAR received by crop leaves

Heat Energy about 29%

PAR fixed by plants as chemical energy — lower than 1%

Current PFAL consumes much electricity for lighting and cooling

Light source, lighting and culture systems, and new cultivar (by breeding) need to be newly developed. High value crops needed.