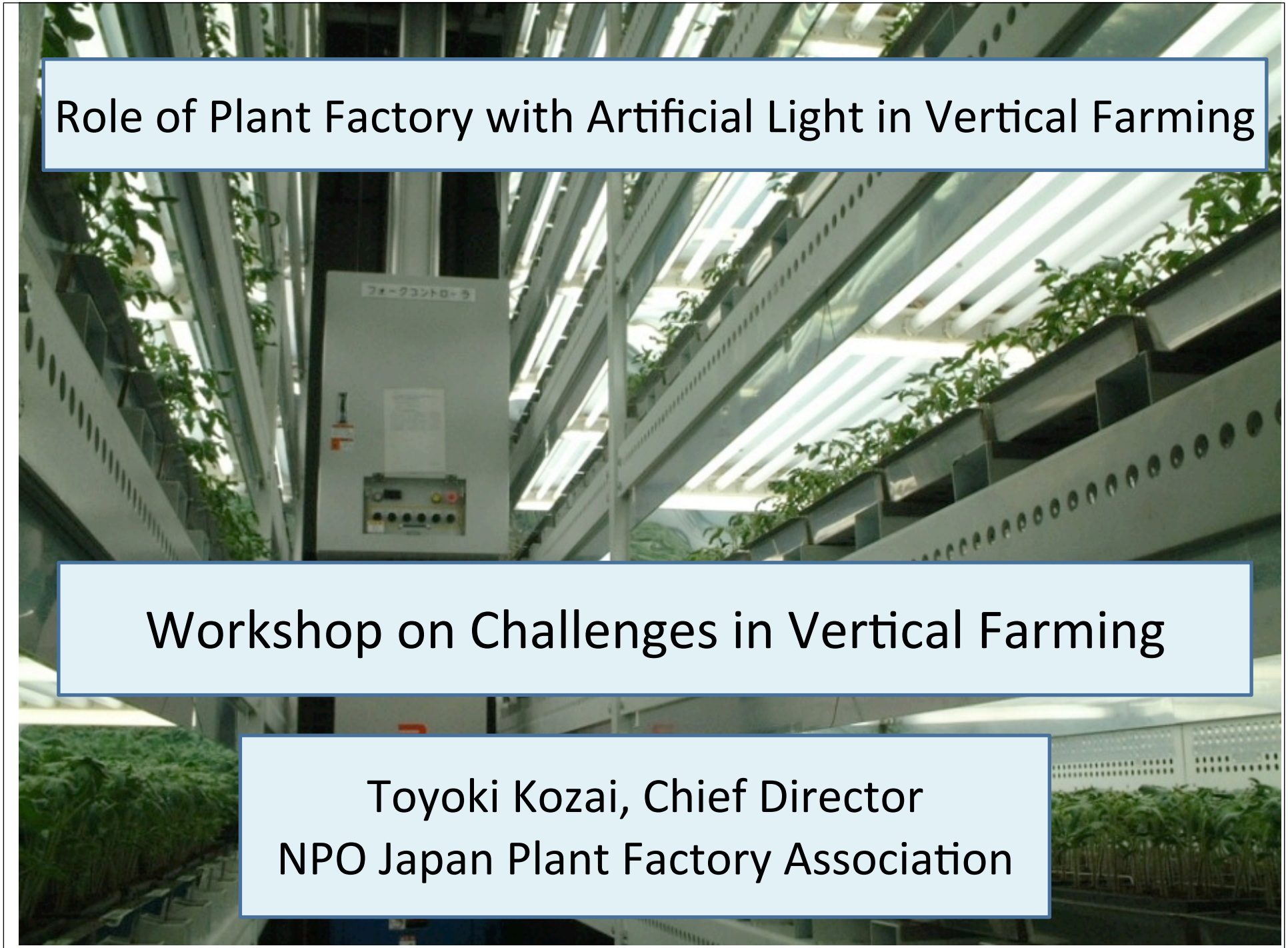


Role of Plant Factory with Artificial Light in Vertical Farming

Workshop on Challenges in Vertical Farming

Toyoki Kozai, Chief Director
NPO Japan Plant Factory Association

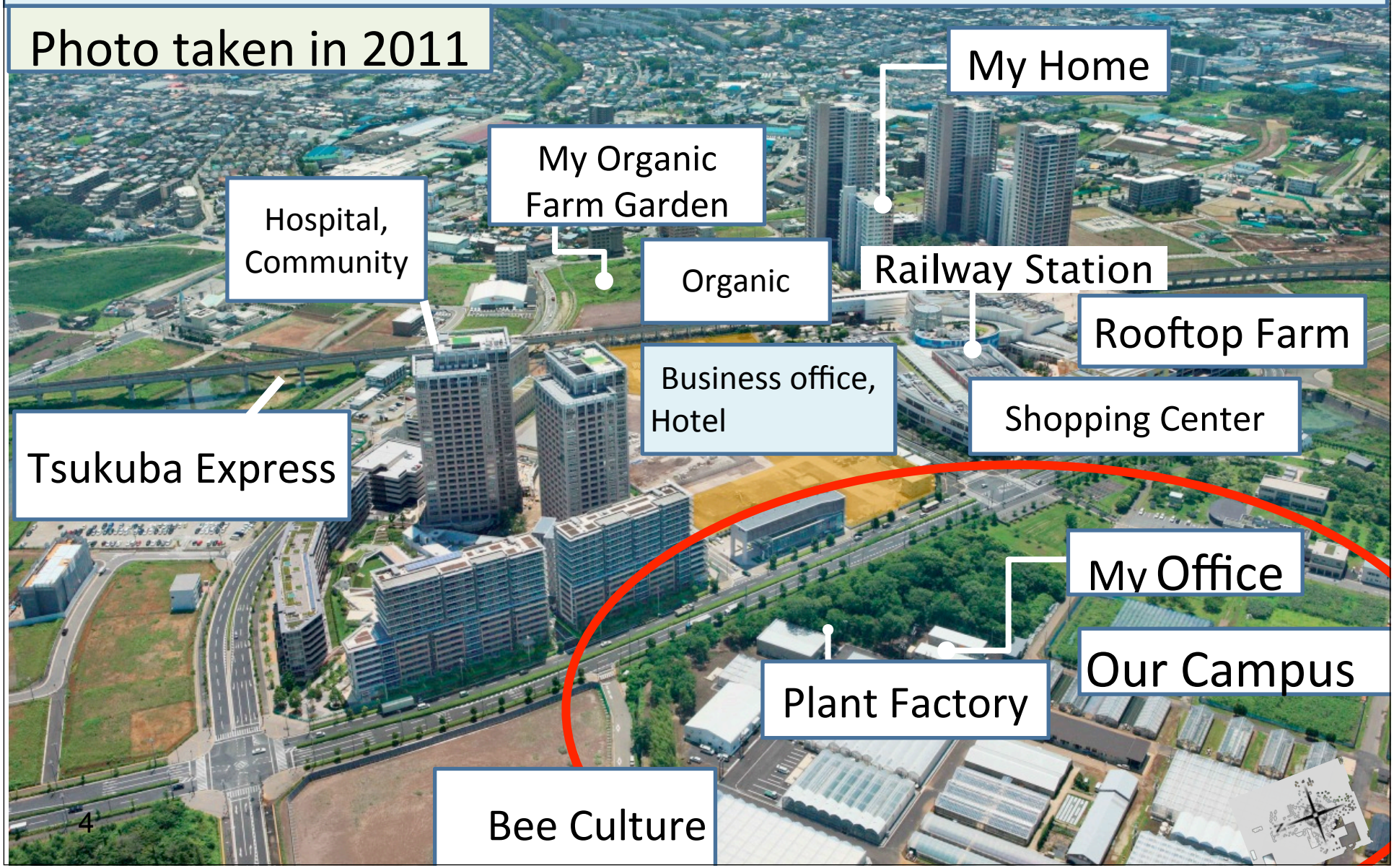
Contents

- Introduction
- Concepts of CPPS (closed plant Production system) and its application as PFAL (plant factory with artificial light)
- Concept of RUE (Resource-use efficiency)
- Resource saving characteristics of CPPS
- Online Estimation of RUE and Rate Variables
- Integrative Environment Control
- Ubiquitous and In-town PFAL
- Challenges in Vertical Farming

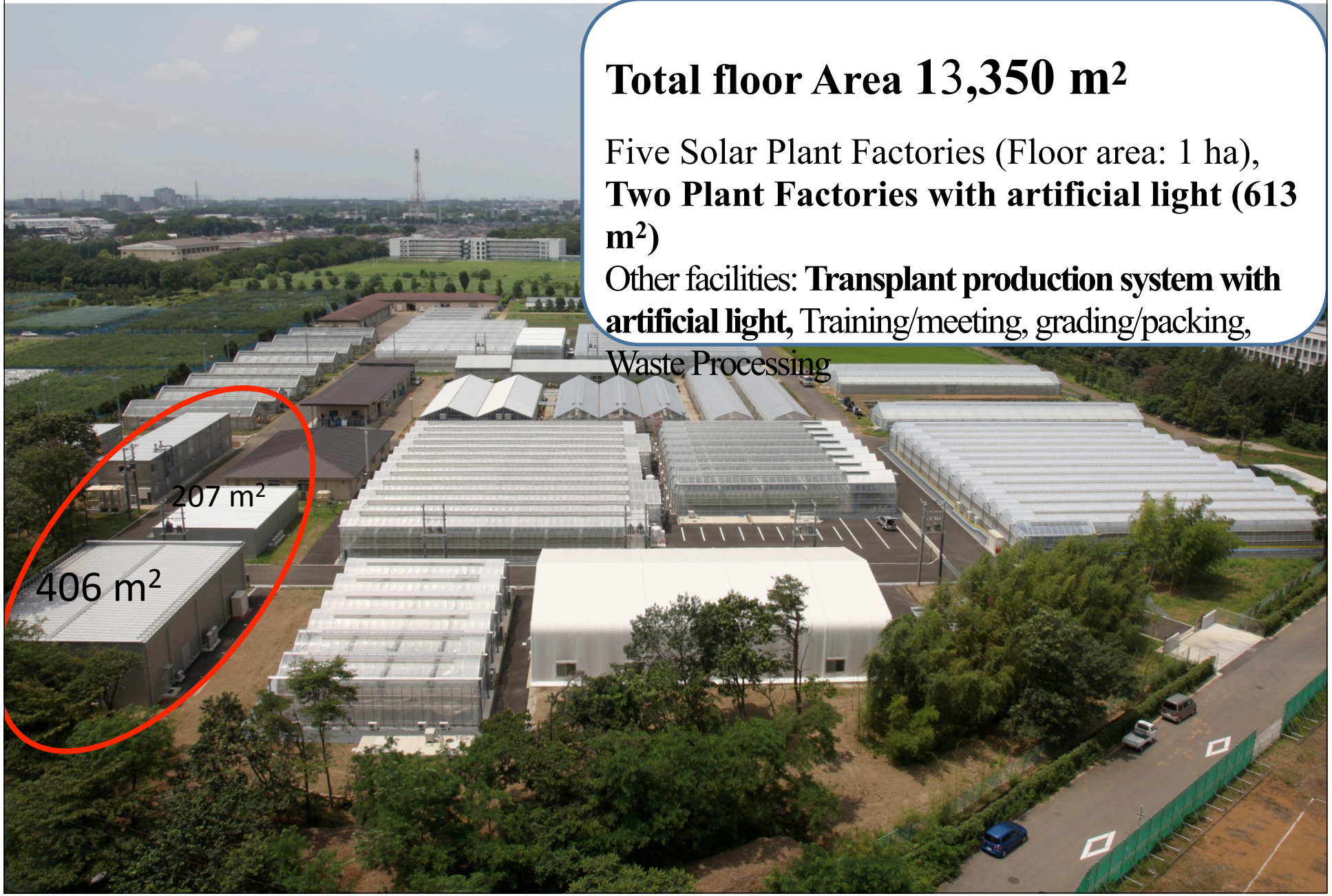
Center for Environment, Health & Field Sciences of Chiba University was established in 2004 with Missions of :

- Sustainability Science with special reference to Food, Health and Environment
- Development of Urban Horticulture Science and Technology to contribute to Society
- People-centered Civic Science and Contribution to Sustainable Town Management and Planning
- Production of Horticultural, Medicinal and Amenity plants under Controlled Environments, and the Interactions between plants and People

A ‘Smart City with Agricultural Life’, located 40 minutes from central Tokyo



Plant Factory Project Area of Chiba University



Total floor Area 13,350 m²

Five Solar Plant Factories (Floor area: 1 ha),
Two Plant Factories with artificial light (613 m²)
Other facilities: **Transplant production system with artificial light,** Training/meeting, grading/packing, Waste Processing

PFAL for growing crisp head lettuce plants

Wago Inc. Total floor area: 207 m^2 (Pilot size for R & D)

Plant Factory with artificial light (PFAL) at Kashiwa-no-ha Campus of Chiba University

Mirai, Co. Ltd. group

PFAL at Kashiwa-no-ha-Campus

Floor area for cultivation: 356 m^2, 10 tiers, 10 rows

Iceberg lettuce

ca. 3,000 heads/d

One M heads/y

8.4 heads/m^2/d

2,800 heads/m^2/y

Annual productivity of leafy greens per unit land area is over 100-fold, compared with that of field-grown leafy greens

- 10-fold by the use of 10-tier cultivation shelves
- Decrease in culture period by half through optimal environmental control
- Number of days per year usable for culture is doubled by year-round production
- Planting density is doubled
- Production value increases around 1.5 times because of improved yield rate and high quality resulting from no pest damage and weather disasters.

Annual productivity: 120-fold (= 10 x 2 x 2x2 x

Leaf lettuce plants grown in a PFAL are on sale at a supermarket. On the plastic bag, it says “No pesticide. Clean enough to eat it as flesh salad without washing.”

QP Corp.


Sumita Yasai Koboh

Plants suitable for production in PFAL are:

those which grow fast at relatively low light intensity and at high planting density and almost all part of plant is edible or salable at a high price. Then, electricity cost/salable plant weight is low.

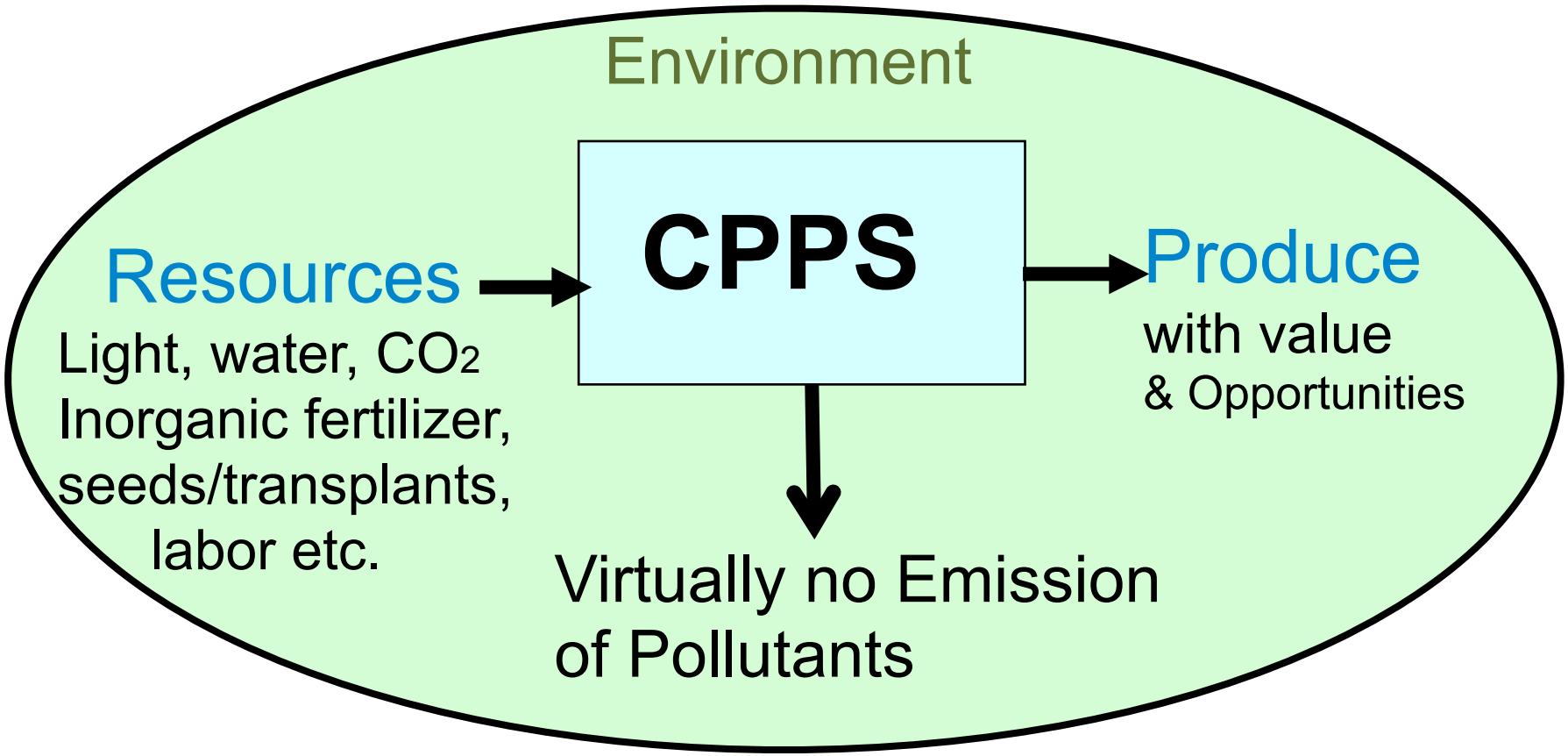
- Transplants or seedlings of all kinds
- Leafy vegetables, herbs, root crops, herbaceous medicinal and aromatic plants with short height
- Short-height plants with high added value/functional plants (Japanese horse radish, miniature rose and

Generally, plants for staple food to intake calories (rice, wheat, potatoes, etc.) are not suitable for production in PFAL.

Definitions and Examples of Numerical Data

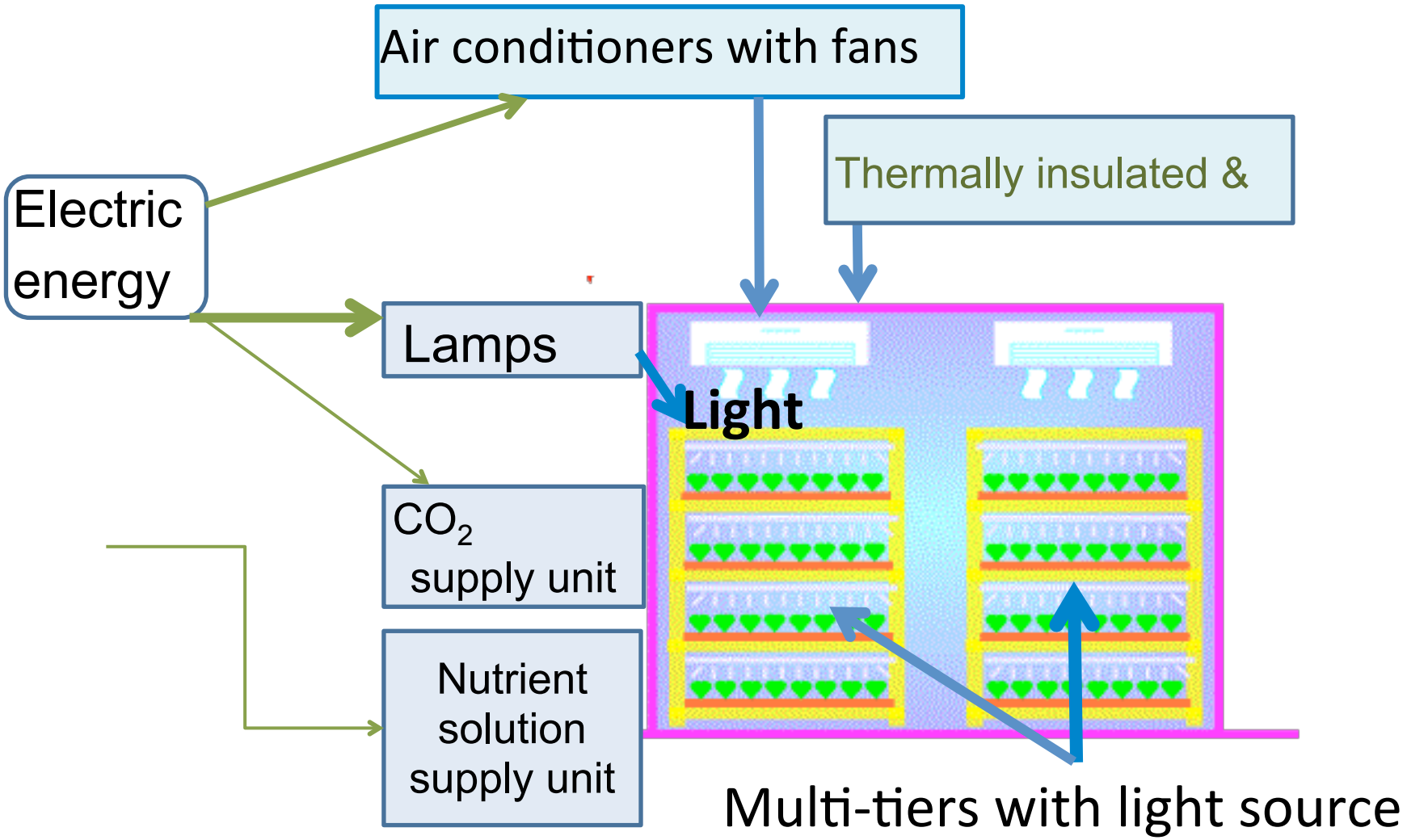
- CPPS (closed plant production system)
- PFAL (plant factory with Artificial light)
- RUE (resource-use efficiency)
  - WUE (Water use efficiency)
  - CUE (CO_2 use efficiency)
  - LUE (light energy use efficiency)
  - EUE (electric energy use efficiency)

Concept of CPPS (Closed Plant Production system)



Almost all resource inputs are converted into high quality produce. Then, resource consumption is minimized, and no environmental pollutants are emitted to the outside, resulting in maximum resource-use efficiencies and minimum costs.

Components of CPPS (Closed Plant Production System with artificial light)



Most components are mass-produced at low costs and are suitable for re-use after their life.

CPPS with total floor area of 500 m^2 developed in 2000 at Chiba University, Japan

- **Seven tiers with**
- **Fluorescent lamps**
- **Automatic plug-tray transportation system**
- **Automatic precision irrigation system**
- **Distributed intelligent control system**
- **Total floor area: 500 m^2**

Sterilized area
Transfer room
Production rooms
Non-sterilized area
Cleaning room
Preparation room
Control room

A basic unit of CPPS with a floor area of 16 m^2 (3.5 by 3.6 m) for production of transplants was developed at Chiba University in 2004, and was commercialized in 2005. About 280 units of CPPS are in use at more than 120 locations in Japan this year, just for transplant production only.

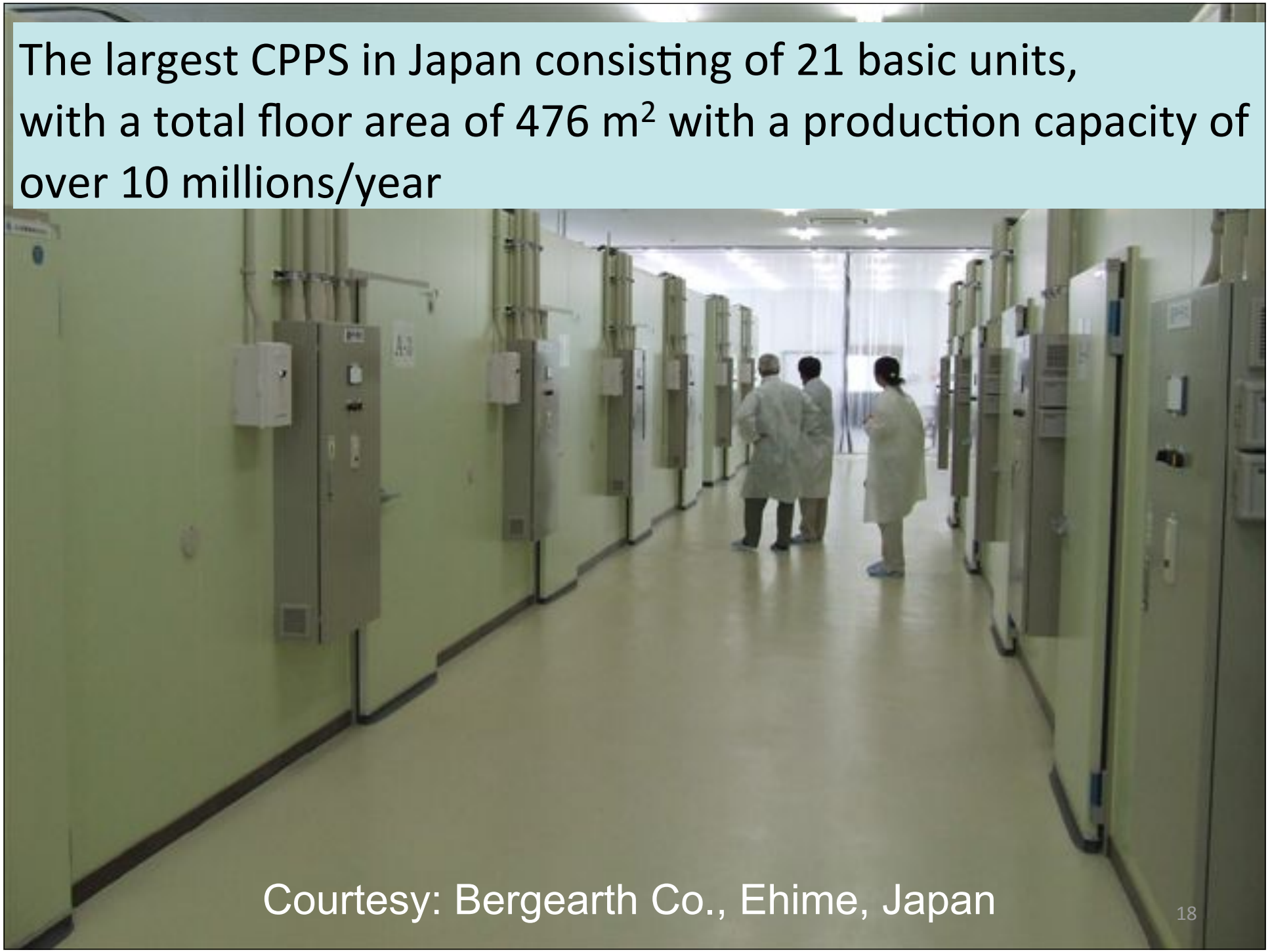
Mitsubishi Chemicals Inc.

Four layers, 2 rows, holding 96 plug trays

A CPPS consisting of 4 basic units holding 384 plug trays

Production Capacity: 250,000 plants/month, 3 million plants /year

The largest CPPS in Japan consisting of 21 basic units,
with a total floor area of 476 m^2 with a production capacity of over 10 millions/year



Courtesy: Bergearth Co., Ehime, Japan

PFAL with concept of CPPS can realize concurrently:

- Highest yield, quality and value creation, as scheduled all the year
- Highest resource use efficiency bringing about minimum resource consumption, minimum emission of pollutants, and lowest costs
- Provide Comfort working environment for humans
- Provide Profit-making business, job opportunities & high quality of life

Definition of resource-use efficiency （**RUE**)

$$RUE = \frac{\text{Amount of resource fixed/held in produce}}{\text{Amount of Resource Input}}$$

1) Water-use efficiency (WUE)

Water held in plants/Irrigated water

2) CO_2-use efficiency (CUE)

CO_2 fixed in plants/CO_2 supplied

3) Light energy-use efficiency (LUE)

Chemical energy fixed in plants/Light energy supplied

4) (Inorganic) fertilizer use efficiency (FUE)

Fertilizers absorbed/Fertilizer supplied

5) Electric Energy use efficiency

Chemical energy fixed in plants/Light energy supplied)

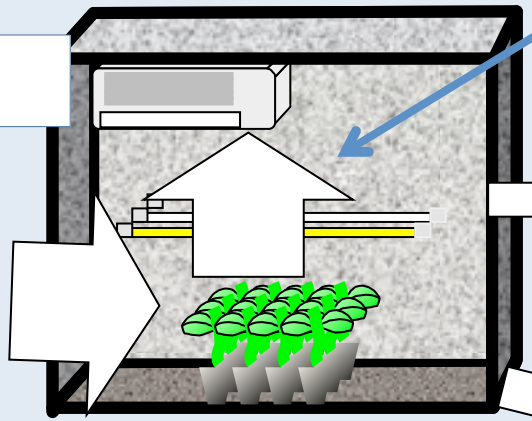
Water use efficiency (CUE)

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

Dehumidified by air conditioners while cooling

2000 kg for re-use

Evapotranspired 2058 kg



Increase in plants and substrate: 42 kg

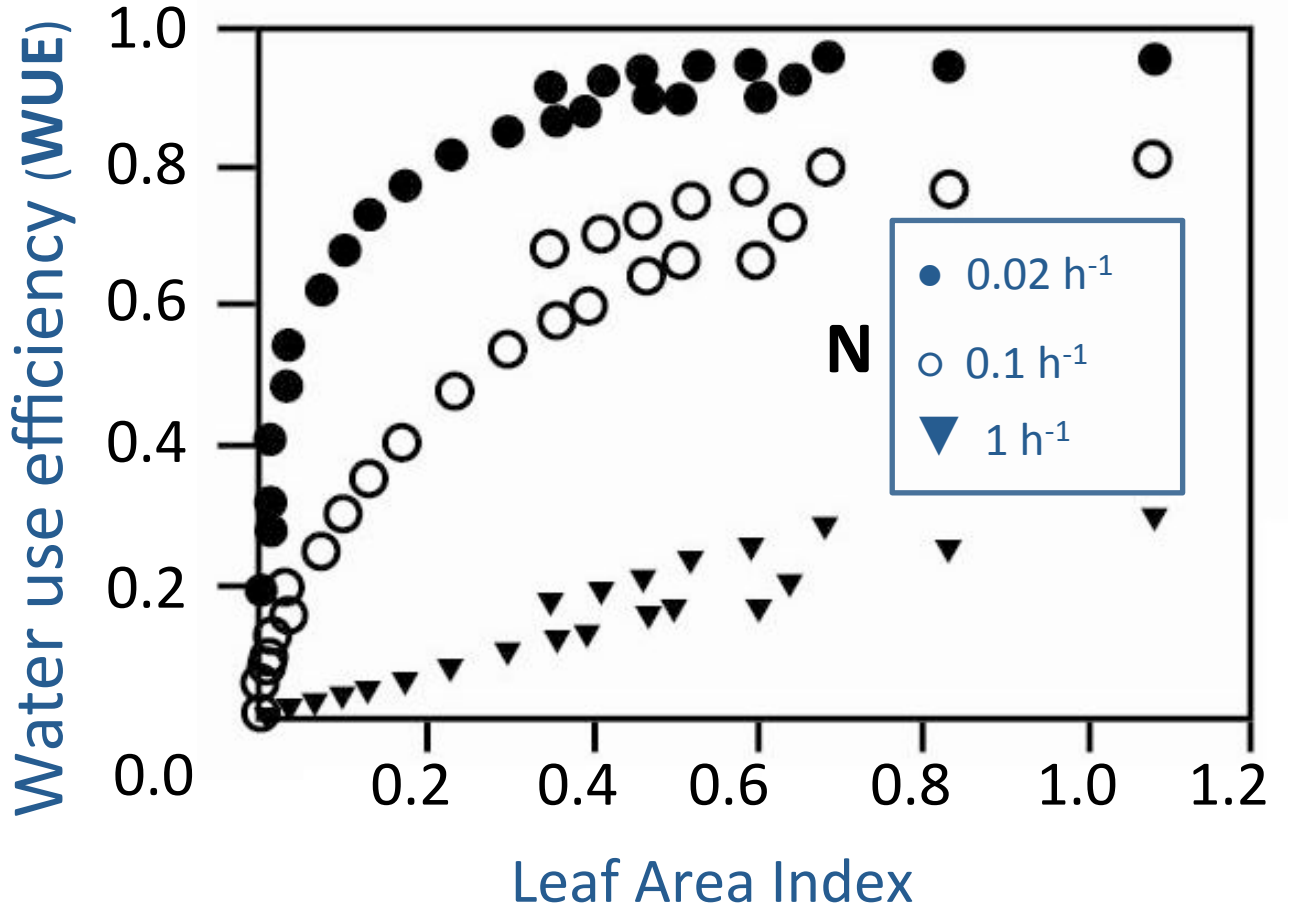
Irrigated: 2100 kg

Ventilated: 58 kg

If dehumidified water is not used, the efficiency is 0.02 (=(2100 -58 - 2000)/2100=42/2100) ⇒ the water needed for irrigation in the CPPS is 1/48 (=2/97) of that in a greenhouse.

Ohyama et al. (2002).

WUE of the CPPS is improved with increasing LAI (leaf area index) and N (number of air exchanges per hour)



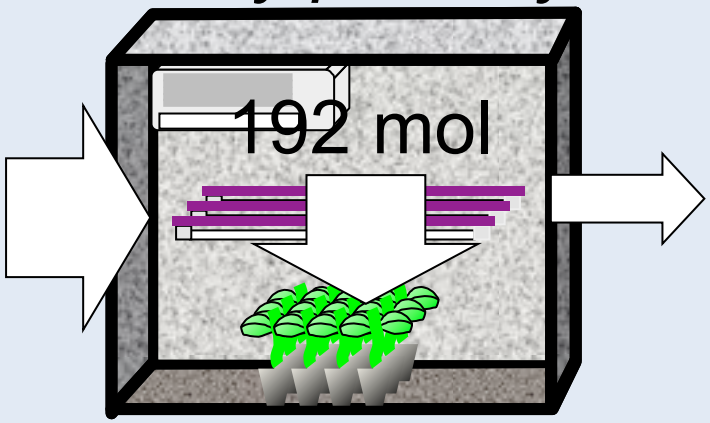
Water vapor density inside and outside the CPPS was assumed to be 16 and 6 g m^{-3}, respectively. All values indicate simulated values (Yokoi et al., 2005).

CO_2 use efficiency (CUE) $= \frac{CO_2 \text{ Fixed}}{CO_2 \text{ supplied}}$

$= 192/221 = (221-29)/221 = 0.87$

Fixed by photosynthesis:

Supplied:
221 mol

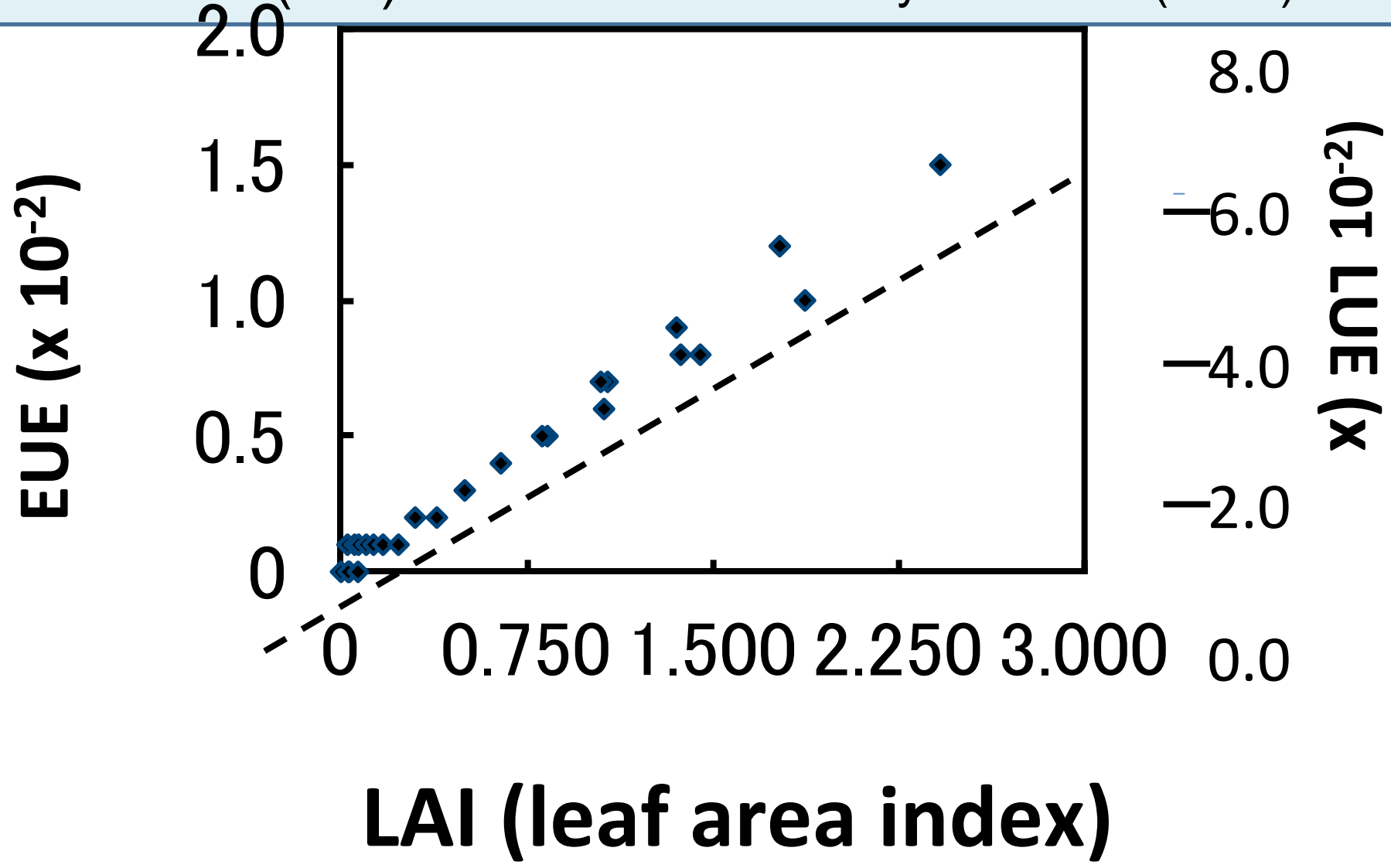


Ventilated: 29 mol

Number of air changes
$= 0.01\ h^{-1}$

Ohyama et al. (2005)

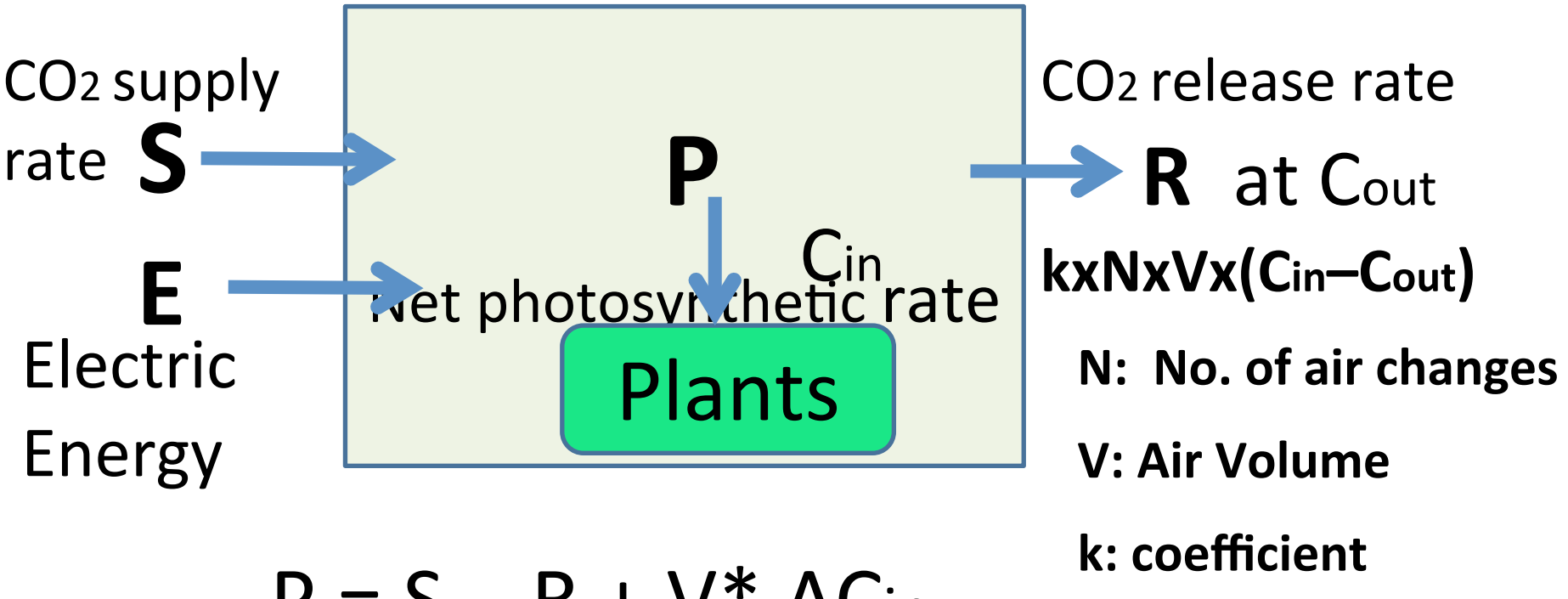
Electric energy use efficiency (EUE) and light energy use efficiency (LUE) increases with increase in leaf area index (LAI) Ohyama et al. (2006)



Methods for improving EUE

- Use LED with a higher electric-light energy conversion factor
- Use the light source with optimal light quality, photoperiod and intensity
- Place the light source close to leaves
- Keep the direction of lighting to leaves only
- Use light reflectors with good design
- Keep Leaf Area Index (LAI) at around 3 by spacing
- Keep the light source temperature at optimal to get a maximum light energy output
- Control the environment to maximize the net photosynthetic rate under a given lighting condition
- Increase a portion of usable part of plants by environmental control and cultivation system
- Leveling the daily electricity consumption for lighting

Online Estimation of hourly net photosynthetic rates (P) under CO_2 enrichment, based on analysis of dynamic CO_2 balance, and of hourly CUE & EUE



$$P = S - R + V^* \Delta C_{in}$$

$$CUE=P/S=(1-R+NxVx(Cin-Cout))/S$$

$$EUE = P/E$$

Daily changes in net photosynthetic rate in PFAL

No. of operating lamps

Net photosynthetic Rate

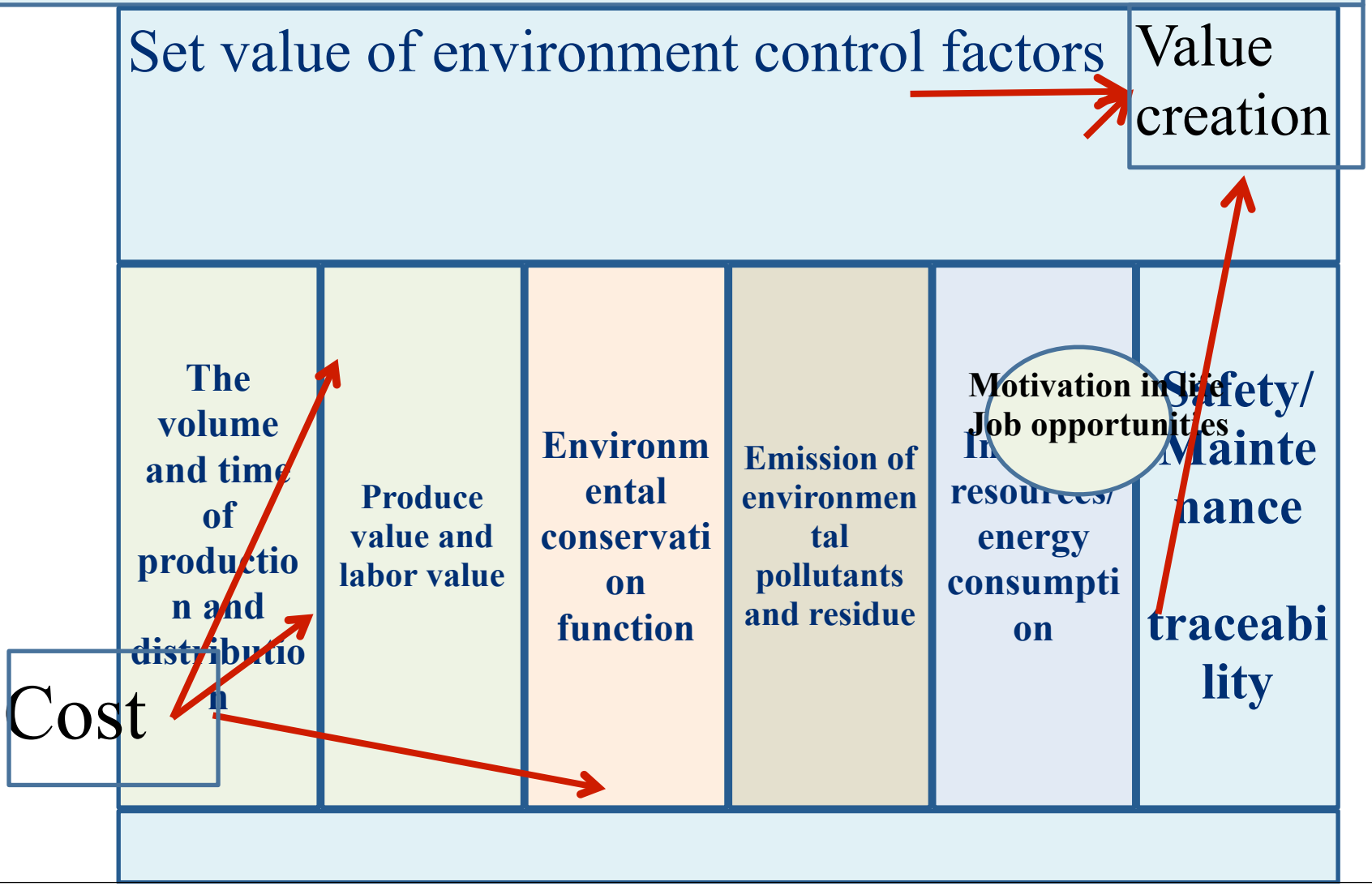
Li et al., 2012

Integrative environment control system (IECS)

Advanced PFAL is a CPPS equipped with an IECS for producing a maximum amount of high quality plants at highest cost performance, free from influence of weather conditions, on a year-round and scheduled basis, with joy of labor and contribution to society. IECS consist of distributed intelligent controllers networked with a core Integrative Control System.

Increased cost performance by integrated environment control

$$\frac{\text{Value created}}{\text{Cost of resources, safety, environmental conservation}}$$



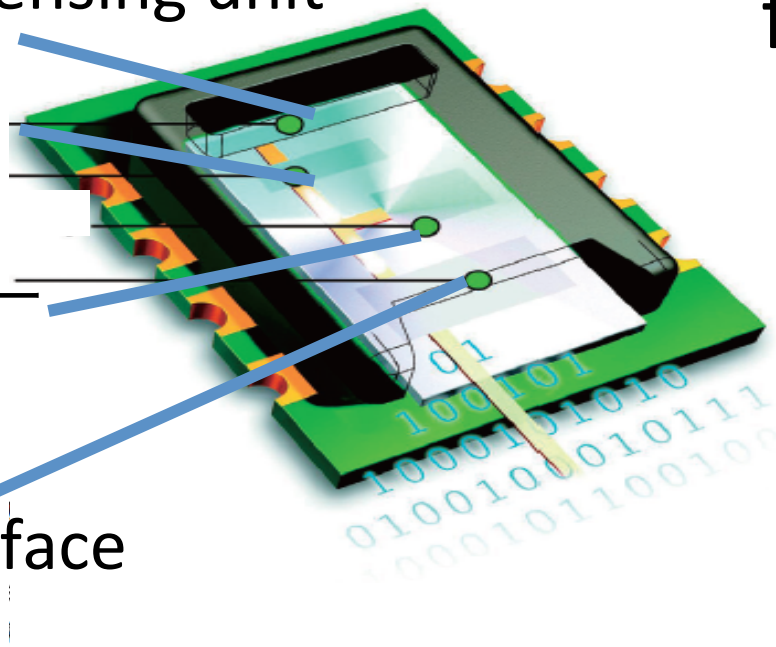
Temp. & relative humidity sensor with linearized digital output

Temp. & RH sensing unit

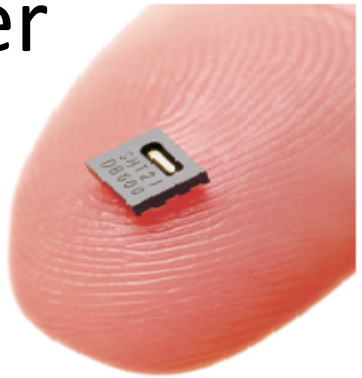
AD convertor

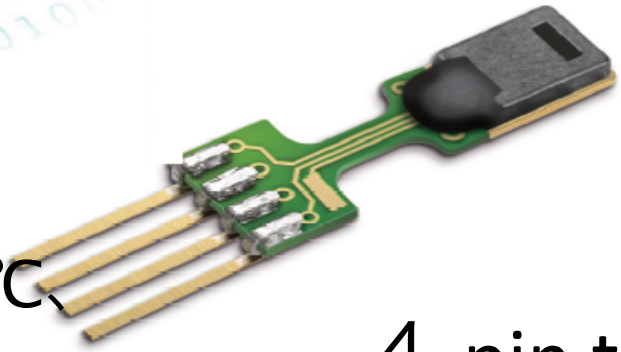
検定用メモリー

Digital Interface



Sensor on the finger





4 pin type

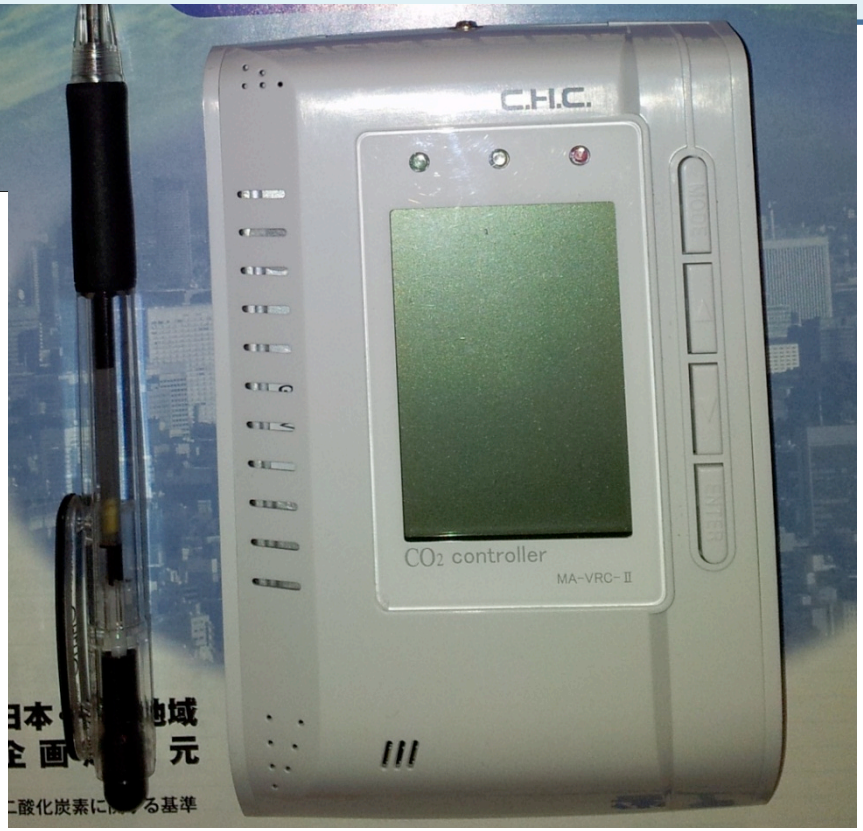
Response time: 8 s. Temp. Precision: 0.4℃、

RH accuracy: 2%。

From Sensirion catalog

CO_2 conc., Temp. and RH monitor (Left) and CO_2 conc. Controller (Right)

13.7 cm



Left：CO_2 Temp, RH Monitor（Model：Marbel 001, Marbel 063）），Price: 200 US$

Size： 137 mm wide, 96 mm long, 27 mm thick

Right： CO_2 conc. controller、Model：MA-VRC） （Price：350 US$ and 500 US$）

Size： 85 mm wide, 130 mm high, 27 mm thick

Ubiquitous In-town PFAL

Mitsui Real Estate, Panasonic, Mirai Co. Ltd. and Chiba Univ.

- University
- School
- Shopping center
- Hospital
- Home
- Restaurant
- Hotel
- Parking lot
- Office
- Community center
- Store

Small refrigerator-size and table-size PFAL for home use displayed at P-Square showroom in Kashiwa-no-ha Campus of Chiba University

A PFAL or CPPS is a leaning tool of science with joy and excitement by means of visualization and experience of interactions among food production-environment-resource.

Resources input

- Electric consumption of lumps, air conditioners, pumps, fans
- Light energy input
- Water consumption
- Fertilizer supply
- CO_2 application
- Working hours

Output of PFAL

- Growth rate (leaf area, etc.)
- Increased dry matter
- Net photosynthesis rate (CO_2 absorption rate)
- Transpiration rate
- Water supply rate
- Absorption rate of fertilizer
- CO_2 leakage, water vapor

PFAL at the lobby of a hospital in Tokyo

Vegetables are grown by the clients and served to the

Photo taken at Sakakibara Memorial hospital on September 8, 2012

‘Urban Farm’ inside Office Building of Pasona Inc. in Tokyo

Indoor Rose garden

Meeting Room

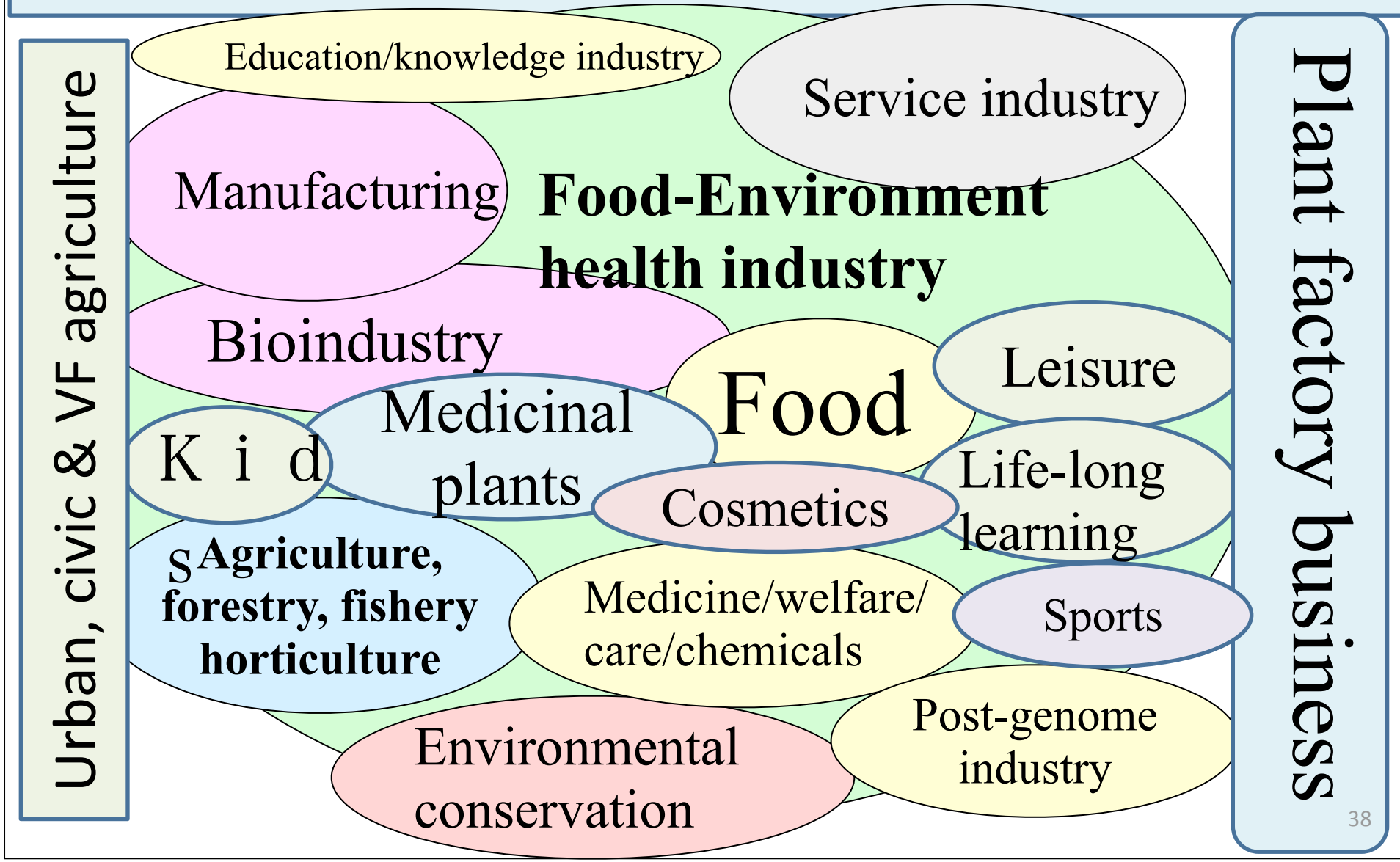
In front of Restroom Door

At Cafeteria

Preparation/packing working area within PFAL. The worker in the right foreground is on the wheelchair. People with physical/mental disabilities can work light duty safely.

Cosmo Plant Inc. in Iwamizawa City, Hokkaido (Photo credit: Mr. Toru Maruo)

Realization of sustainable low carbon/welfare society requires evolving and developing food-environment-health eco-industry with PFAL



Challenges in Vertical Farming

- Life Cycle Assessment (LCA)

- Simulators of Vertical Faming
- Distributed, intelligent & integrative network system
- New Industry incorporating Environment, Agriculture / Food, IT, Health(Medical) Industries
- Optimization of space allotments in cities

Acknowledgement

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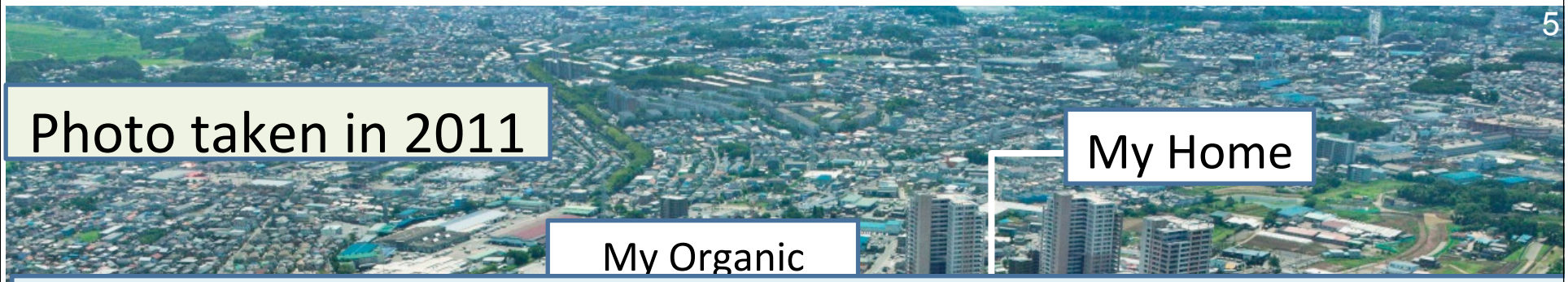
- Texus A&M Univ.: G. Niu
- Pasona Inc. S. Itami



Thank for your listening!

Looking forward to seeing you again in our town with PFAL in VF