2017 International Training Course on Value-added Controlled Environment Agriculture, Taipei, Taiwan

Q&A for Plant Factory with Artificial Lighting (PFAL)

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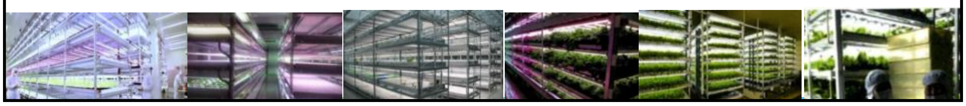


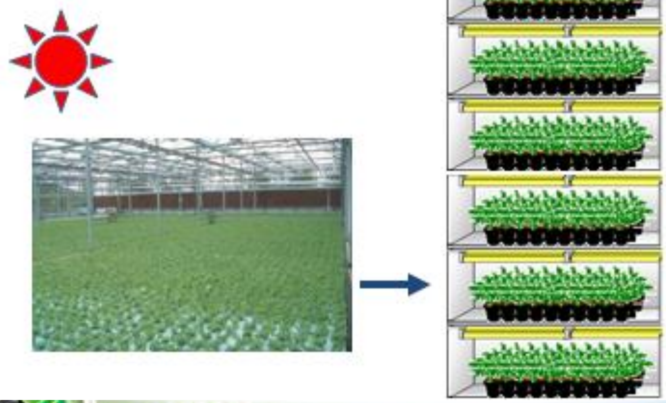
Terminology

- CEA: Controlled Environment Agriculture
- PF: Plant Factory
- PFAL: Plant Factory with Artificial Lighting
- Vertical Farm
- Urban Horticulture/Agriculture

Controlled Environment Agriculture (CEA)

Greenhouse: Plant Factory with sunlight and/or supplemental light

Plant Factory with Artificial Light (PFAL)



Vertical farm

We need CEA in the 21st century for sustainable food production

Background

1）Demands for fresh, clean, pesticide-free, and functional or nutritional leaf vegetables and their transplants have been increasing worldwide.

2) For delivering such high value produce to consumers living in hot or cold climate regions, with minimum consumption of fossil fuel and minimum emission of environmental pollutants,

We have 2 choices: Strategy A and Strategy B

CEA people take Strategy B

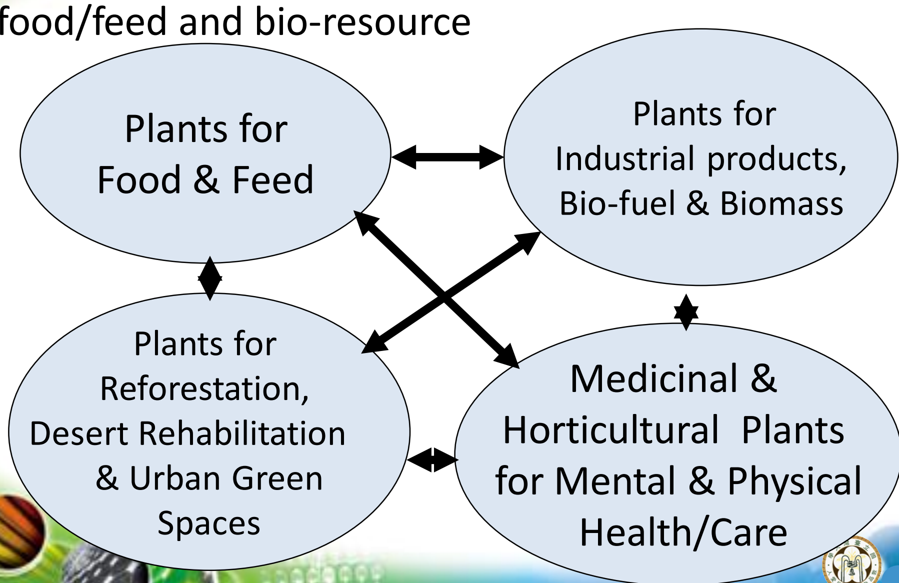
Strategy A

Produce the vegetables in a favorable climate region and transport them for a long distance to the consumers

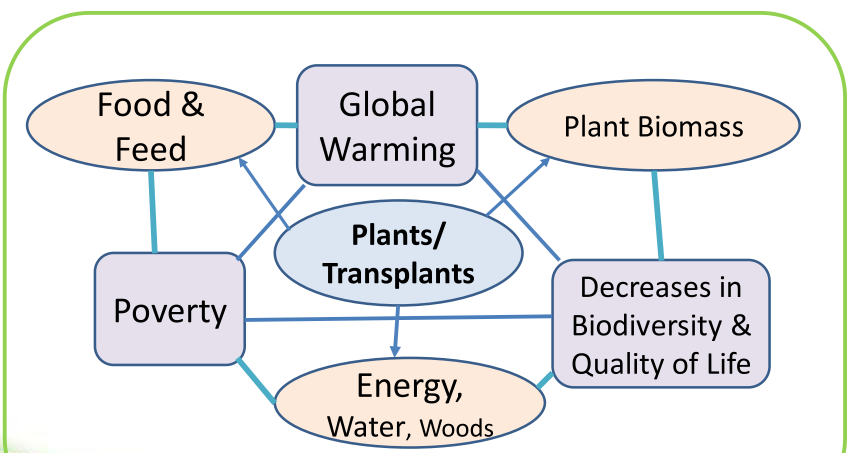
Strategy B

Produce them in a Controlled Environment

Billions of individual plants of various kinds are needed to solve 'glonacal' issues on environment, food/feed and bio-resource



Billions of plants/transplants are being required to solve "glonacal" issues on global warming, poverty and biodiversity



'Glonacal' diversity governance needs to be constructed.

Glonacal

Global

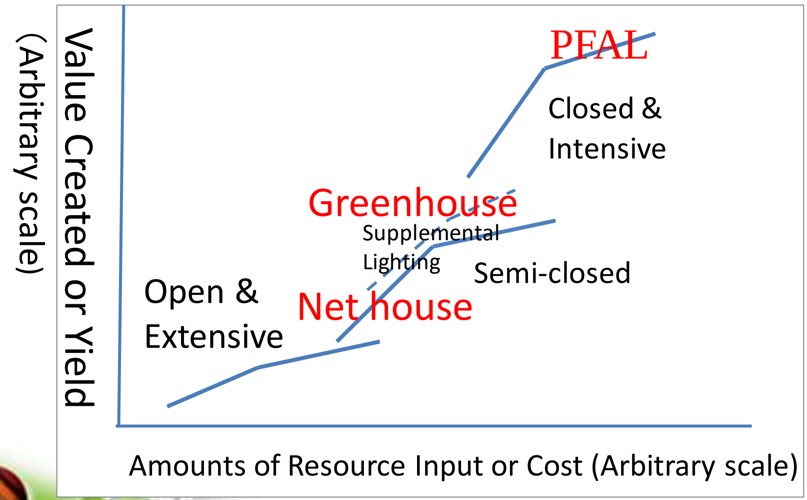
National

Local

Types of Plant Production Systems Classified by Controllability of Plant Environments

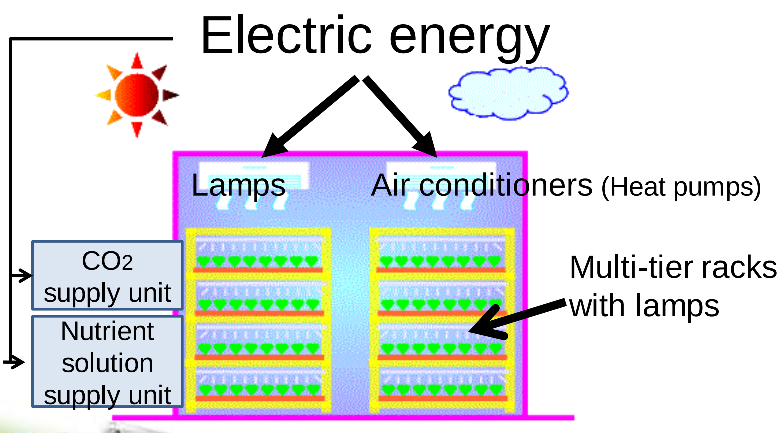
- Open and extensive plant production systems with solar light -Open fields-
- Semi-closed (or Semi-open) plant production systems with solar light with/without supplementary artificial light –Greenhouses-
- Closed and Intensive plant production systems with artificial light – Plant Factory with Artificial Lighting (PFAL)

Types of plant production system

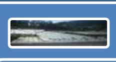


How can we grow high quality plants using minimum resource with minimum environmental pollution in a limited time, land area and labor?

Concept of a PFAL



PFAL is a mean of minimizing the resource/energy consumption of the whole process from growers to consumers.



Construction

Growers

Production
- Preparation, Cultivation
- Harvesting

Distributors
Brokers

Postharvest
- Processing, Packing
- Transportation

Consumers

Sales and Cooking
- Sales at shops, Cooking & consumption
- Recycling & Residue processing

Growing leafy vegetables, transplants and medicinal plants (herbs) in PFAL is feasible, because:

1) They are 15-30 cm tall, so that multi-tiers with lamps can be employed.
2) Their quality (nutritional components, color, texture, taste, etc.) and growth can be improved considerably by environmental control.
3) They grow well at low light intensity of ca. 250 $\mu mol\ m^{-2}\ {}^{s}s^{-1}$ PPF.
4) Very high traceability and liability

On the other hand, the greenhouse and open field are not ideal for all-year-round production of leafy plants under harsh climates, because,

- Solar light intensity is often too low and too high.
- Temp., RH, and CO2 conc. are considerably affected by solar radiation, and it is difficult to optimize them.
- It is also difficult to control air current speed, light quality, light period, etc. which affect the plant growth and development significantly.
- Working environment for human is often unfavorable.

In leaf vegetable production using the PFAL, loss of produce and water consumption after harvest, for example, can be minimized, because the produce is hygienic and contamination-free.

- Little physical damage
- Little microbial damage
- Thus, little consumption of water for washing/cleaning
- Little labor for removing damaged leaves.

Can PFAL make us richer, smarter, greener, healthier, and happier?

Open field

< 3 kg/m^2/year

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Semi-closed: Greenhouse

69 kg/m^2/year

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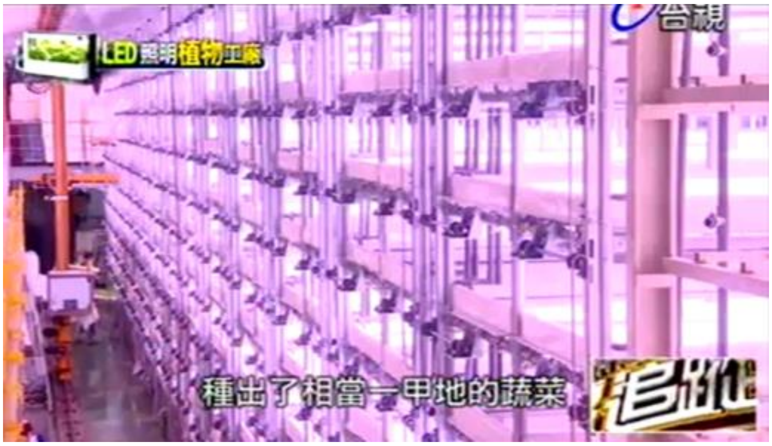
Closed: PFAL

4 layers > 100 $kg/m^2/year$

Closed: PFAL

7 layers > 200 $kg/m^2/year$

Closed: PFAL



10 layers $\quad > 300\ kg/m^2/year$

More than 100 times compare with open field production

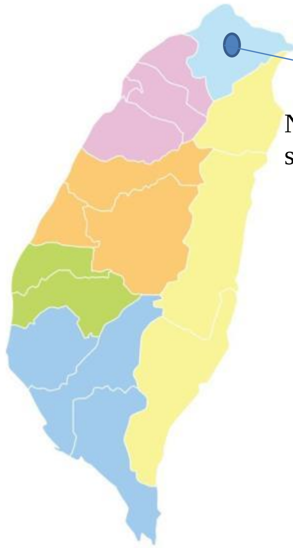
More than 100 times means…

Same amount of floor area →
100 times of yield/value

Same amount of yield →
99% of floor area can be saved
Paid for only 1% of land
Labor cost can also be saved

A brief history of PFAL in Taiwan (1/3)

20 ft. container with thermally insulated walls



National Taiwan University supported by NSF, Taiwan

First PF_AL related research 1993

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Lots of stress

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If the plant can talk,

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SOP based CEA

Much less in risk / stress

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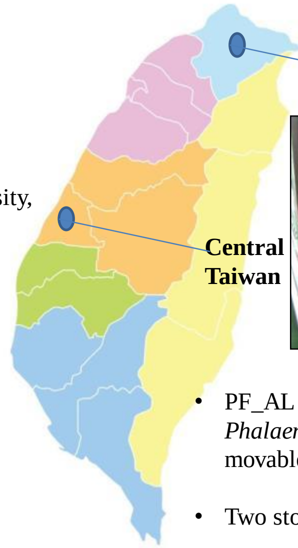
A brief history of PFAL in Taiwan (2/3)

1996
LED related
research

Pulse light with adjustable intensity, duty ratio, frequency

Patents:
2001 Taiwan
2001 China
2002 US

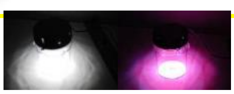


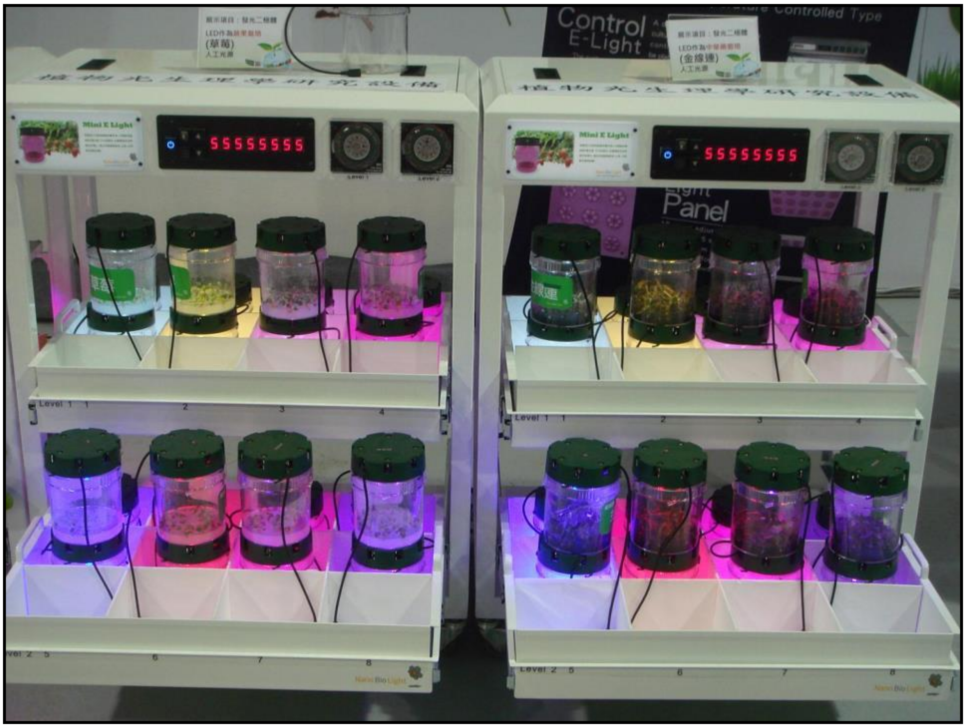
- PF_AL for tissue culture and for *Phalaenopsis* seedling production with movable light was developed in 2001.
- Two stories building with 7 layers each.

Caps with various spectrums were developed

Essential 8 for Tissue culture

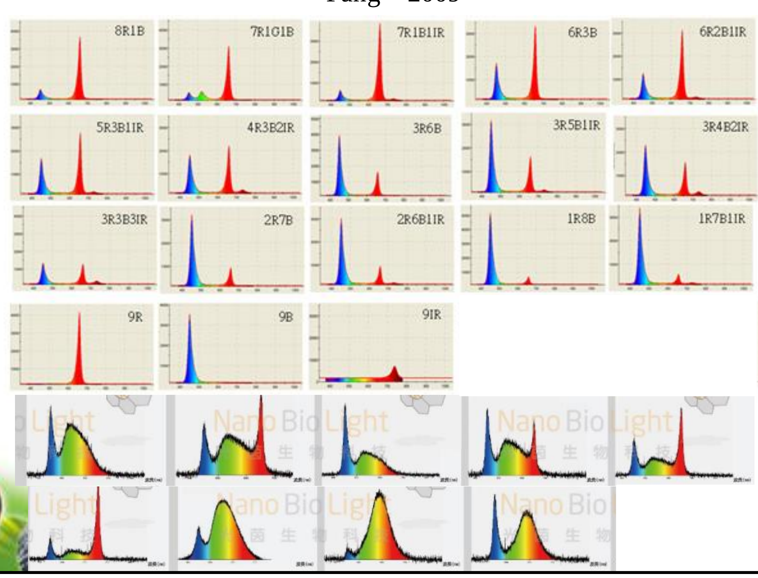
Fang，2008

	B 401~500nm	G 501~600nm	R 601~700nm	IR 701~800nm
CW (5500 K)	26 %	46	26	2
WW (2700 K)	10	45	41	4
8R1B	13		87	
7R1G1B	13	7	80	
3R3B3IR	46		42	12
6R			100	
6B	100			
6IR				100



Totally 27 spectrums of caps and tubes were developed for TC and PF applications

Fang，2009

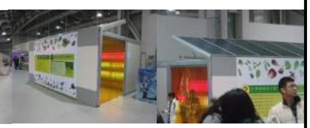


A brief history of PFAL in Taiwan (3/3)

Public attention of PFAL for the first time :

2010 Taipei Floral Expo

- booth of PF: **8 m x 50 m**
- duration: **one month, 8:00~21:00**



How does the PFAL industry established in Taiwan?

Promotion of PFAL in Taiwan (step 1/5)

Starts

- Fundamental research (1992.2 till now)
- An experimental pilot plant factory was setup in NTU (2011.1.1)
- Up to now, more than 2800 visitors

Wind + solar power assisted: 13 kW



Renovated from a discarded roof-top greenhouse

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Promotion (step 2/5)

Books published

2010 Fang	2011 Kozai	2011 Takatsuji	2012 Kozai	2013 Fang

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Promotion (step 3/5)

- 30 hours workshop: started 2011, twice per year, more than 600 people were trained (Fundamentals & Tour)
- 16 hours workshop: started 2016, four times per year, more than 200 people were trained (Design & operational)
- From various Industrial/Business/Agriculture sectors

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Promotion (step 4/5)

Partners and Interested Parties

- ❑ Research and educational institutions
- ❑ Governments
- ❑ Real estate developers and builders
- ❑ Construction companies
- ❑ HVAC industry
- ❑ Electronics industry
- ❑ Supermarkets
- ❑ Restaurants
- ❑ Institutional food services (hospitals, schools, etc.)
- ❑ Consumers
- ❑ Media
- ❑ Etc.

NGOs

TPFIDA

CPFA

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Promotion (step 5/5)

International Forums and Exhibitions

- ❑ Taipei International Floral Expo in 2010
- ❑ Plant Factory Exhibitions were held annually from 2014
- ❑ International Forums were held annually
  - ❑ 2015 on plant factory
  - ❑ 2016 for Advanced Protected Horticulture
  - ❑ 2017 for Value-Added Plant Production in PFAL

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2013 Industrial MAP

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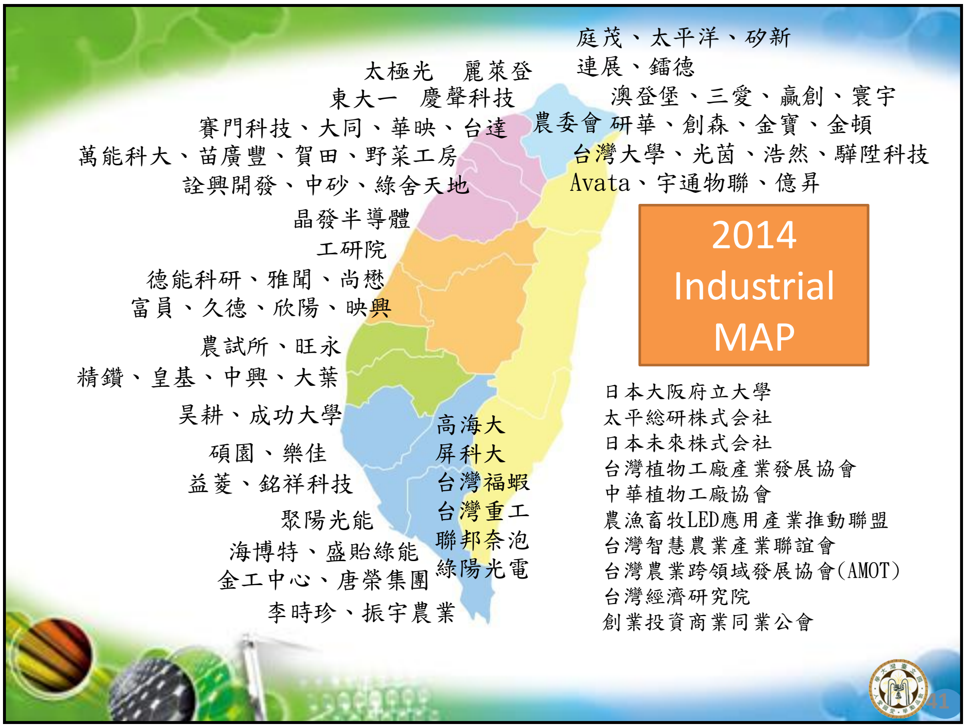
庭茂、太平洋、矽新
連展、鐳德
太極光　麗萊登
東大一　慶聲科技
澳登堡、三愛、贏創、寰宇
賽門科技、大同、華映、台達
農委會 研華、創森、金寶、金頓
萬能科大、苗廣豐、賀田、野菜工房
台灣大學、光茵、浩然、驊陞科技
詮興開發、中砂、綠舍天地
Avata、宇通物聯、億昇
晶發半導體
工研院
2014 Industrial MAP
德能科研、雅聞、尚懋
富員、久德、欣陽、映興
農試所、旺永
精鑽、皇基、中興、大葉
日本大阪府立大學
太平総研株式会社
日本未來株式会社
台灣植物工廠產業發展協會
中華植物工廠協會
農漁畜牧LED應用產業推動聯盟
台灣智慧農業產業聯誼會
台灣農業跨領域發展協會(AMOT)
台灣經濟研究院
創業投資商業同業公會
昊耕、成功大學
碩園、樂佳
益菱、銘祥科技
聚陽光能
海博特、盛貽綠能
金工中心、唐榮集團
李時珍、振宇農業
高海大
屏科大
台灣福蝦
台灣重工
聯邦奈泡
綠陽光電
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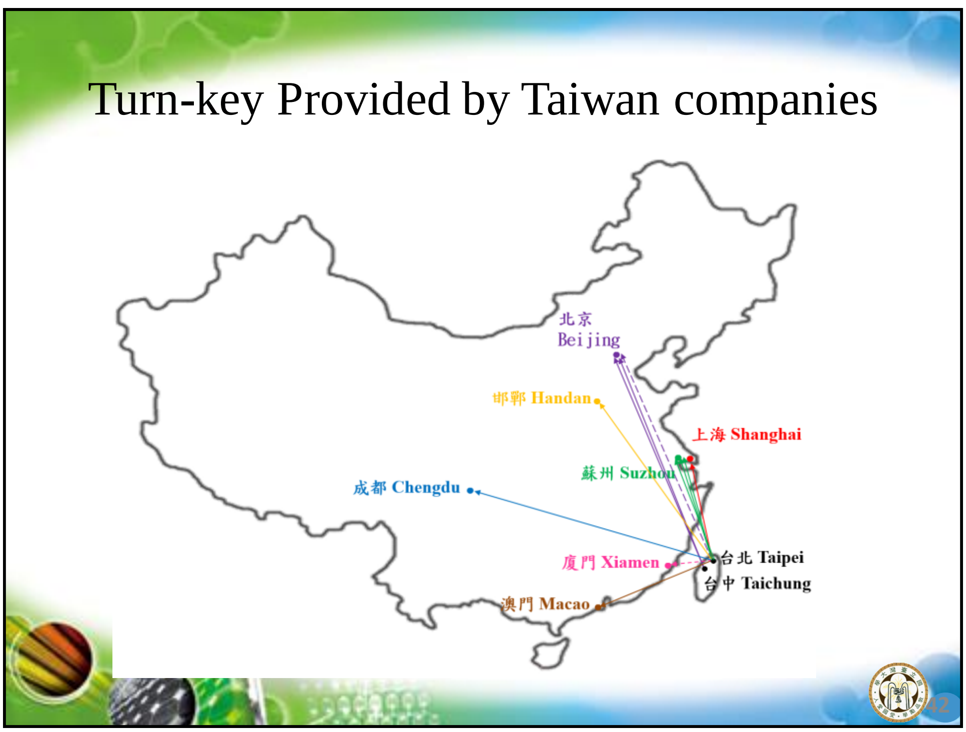
Turn-key Provided by Taiwan companies
北京 Beijing
邯鄲 Handan
上海 Shanghai
蘇州 Suzhou
成都 Chengdu
台北 Taipei
台中 Taichung
廈門 Xiamen
澳門 Macao
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Electricity bills must be high?

Transplant production

- The amount of electricity required for a single tomato or eggplant transplant, for example, is 400kJ, which includes lighting and cooling, which costs around \1 in Japan or 0.9 US cent.
- Since the overall production cost of tomato transplants in Japan is around \50 or 45 US cent, electricity accounts for just a fraction of that.

Transplant production

- Installing six 40-W fluorescent tubes (1.2 m long) in parallel 40 cm above the tier, we get a PPFD (photosynthetic photon flux density) of 350 μmol/m^2/s at the plant community level, which is high enough for growing about 1,000 tomato transplants. For providing the PPFD of 350 μmol/m^2/s for 16 hours/day during 11 days, which is enough for tomato transplant production, electric energy of 53.8 kWh (6 x 40 x 16 h/d x 10 d = 38,400 Wh =38.40 kWh) is consumed.
- At present, fluorescent tubes are replaced by 20-W LED, the same PPFD can be reached and elec. Fee can be cut down by half.

- In addition, about 8 kWh of electric energy is consumed for cooling. The total of about 37 kWh of electric energy costs about \900 (\ 24/kWh) in Japan or about 10 US $, being about \ 0.9 per transplant.
- Since the electricity consumption is proportional to a product of light intensity, illuminated area and time integral of illumination, the electricity cost per plant increases with decreasing planting density and with increasing the number of days for production.

Leafy Green Production

- Using florescent lamps, one degree of energy can produce 100 g of lettuce
- Using LED with proper spectrum, 150 g of lettuce can be reached per degree of energy consumption.
- Recent target is to reach 200 g_FW/degree

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But surely natural light is free?

- A natural light greenhouse requires equipment which is not needed with a closed system, such as shading cloth, thermal screens, ventilation equipment and insect screens.
- A natural light greenhouse also incurs heating and agricultural chemical expenses.
- Accordingly, while natural light itself may be free, the greenhouse environment control and management are not.

Is the electricity for cooling not expensive?

- Since closed plant production systems use heat insulating walls, the heat to be expelled by cooling is only the heat generated by the lighting.
- If electric heat pumps (specifically, air conditioners) having the annual average coefficient of performance (COP) of 5 is used, the electric power used for cooling will be one-fifth of the electric power used for lighting and cooling. ("COP" is the ratio of the electric heat pumps' cooling capacity to the electric power consumption)
- In practice, since the heat pumps installed in the closed system with no ventilation will cool inside even when the outside air temperature is lower than room temperature, the annual average COP for the Tokyo region will be around 8.
- A breakdown of the electric power consumed by one closed system as an example is given in Table 5.

Why are there no heating costs?

- If lighting is provided at night, the heat generated by the lighting makes any additional heating unnecessary, even during winter in colder districts where minimum air temperature outside is below around -5 degrees centigrade.
- If anything, cooling will be required, and exhaust heat generated at the condenser outside the closed system as a result of cooling can be used for heating and drying purposes in adjacent facilities.
- Plant growth is hardly affected whether lighting is on at night or during the day.

Will production costs other than electricity not be expensive?

- Since the percentage of marketable produce grown in the closed system is increased by approximately twenty percent, the cost of consumables such as seeds and culture media will be reduced by around seventeen percent.
- Since no water is discharged that might contain fertilizer, and also for the reasons given above, fertilizer expenses are reduced by one-third.
- There are basically no agricultural chemical expenses
- Labor costs are reduced by about thirty percent because of the smaller working floor area; and irrigation water usage is around 1/15

Is it possible to obtain healthy plants and transplants in an artificial environment?

- Over the past twenty years the light output per watt of fluorescent tubes has roughly doubled, allowing enough light intensity (around 350μmol/m^2/s or higher) to grow transplants and leafy vegetables.
- With outdoor and greenhouse cultivation on the other hand, light intensity will be too low in the morning and evening or when it is cloudy or raining, and during the day in some fine weather it may be too high.
- Controlling humidity and air current velocity is difficult in greenhouse cultivation, which is also susceptible to disease and pest damage, leading often to unhealthy plants.
- In addition, plants in the closed system are not damaged by insect pests, strong wind, hail, snow, etc.

Will transplants raised under artificial light grow well in fields under natural light and in greenhouses?

- Transplants raised with high light intensity under artificial light, favorable humidity and favorable air current velocity are more resistant to environmental stress and demonstrate better growth after transplanting than those raised in greenhouses.
- It is possible, moreover, to acclimatize the transplants by changing their closed system environment a few days prior to transplanting so that it matches their transplanting environment.
- Transplants raised under natural light which are exposed to cloudy weather or to rain, high humidity or windless conditions are often more vulnerable to environmental stress and grow poorly after transplanting.

Are lamplight wavelengths not unsuitable for photosynthesis?

- The wavelength range of natural light is 300 ~ 3000 nm, while the wavelengths effective for photosynthesis are 350 ~ 750 nm.
- The rest of solar energy with the wavelength range of natural light is 750 ~ 3000 nm, which accounts for about 50% of total solar energy, simply raises the air temperature and increases the cooling load.
- Since fluorescent lighting generates only the range of wavelengths that work for photosynthesis (that is, 350 ~ 750nm), it is a more energy-efficient source of light for growing plants than solar light.

What is nutritional content in plants ?

- Nutritional content can be broadly grouped as (1) starch, sugars, protein and fats, which can be expressed in calories or heat with a unit of joule, and (2) vitamins, polysaccharides, iron, calcium and other substances, whose function cannot be measured in calories.
- The latter group includes both organic and inorganic substances. Rational use is made of closed system production for functional food plants, which contain the latter group of nutrients, and ornamental plants which size are small.

Will nutritional content levels not be low?

- The nutritional and medicinal content yield of functional food plants is greatly influenced by environment.
- In that regard, the environmental control function of closed systems can be put to good use in the production of these plants.
- This environmental control can be used to raise levels of nutritional and medicinal content significantly above those of plants cultivated outdoors or in greenhouses.
- With greenhouse cultivation, on the other hand, levels of nutritional content will fluctuate in response to the varying strength of solar radiation and to the impact of changes in internal temperature and humidity which result from that..

Will PFAL not produce foods such as rice or soybeans?

- Yields of cereals and legumes (pulses) are heavily dependent on the integrated value of the given light energy (which is light intensity x area x cultivation period).
- PFALs are not suitable for the cultivation of food plants whose commercial values are heavily dependent on the calories contained in them.
- PFALs with the physical limitation of their multi-tier racks will also not be suitable for producing those plants which only generate produce if they grow higher than about 50 cm.

Do these systems really generate no disposables or waste product, and thus resource saving?

- With transplant production, the input trays and culture media will become a constituent part of the produce. The majority of input fertilizer, water and CO_2 will be converted into the basic structural elements of the plant bodies, and thus into marketable produce.
- Any remaining water and CO_2 will be recycled within the system. Seeds will be developed into seedlings for sale as principal commercial products. Some light energy will be fixed as chemical energy in the plant bodies.
- The remainder will be expelled externally in the form of heat by the heat pumps at comparatively high temperatures, to become a heat source for drying, hot water and heating purposes.
- In the end almost no wastes will be produced. In the case of leafy vegetable production, the roots and outer leaves will become a source of compost.

Why aren’t these systems more common today?

- We need efforts to encourage many people to have a good understanding of the nature and characteristics of closed systems.
- Because , people often misunderstand these systems because they draw lessons only from examples of past and present failures.
- For these systems to become more widespread it will require experts in cultivation who have familiarized themselves with the features of closed systems, but the people with that knowledge are in short supply.

What do you think of the food mileage?

Using the PFAL, plants can be produced anywhere (e.g., rooftop, basement, shaded place, waste land) closest to the consumers, resulting in ‘local production for local consumption’ or the minimum food mileage (distance between production and consumption sites times weight of produce).