Challenges facing the integrating of energy generation in greenhouses.

23 November 2016, Bram van Breugel

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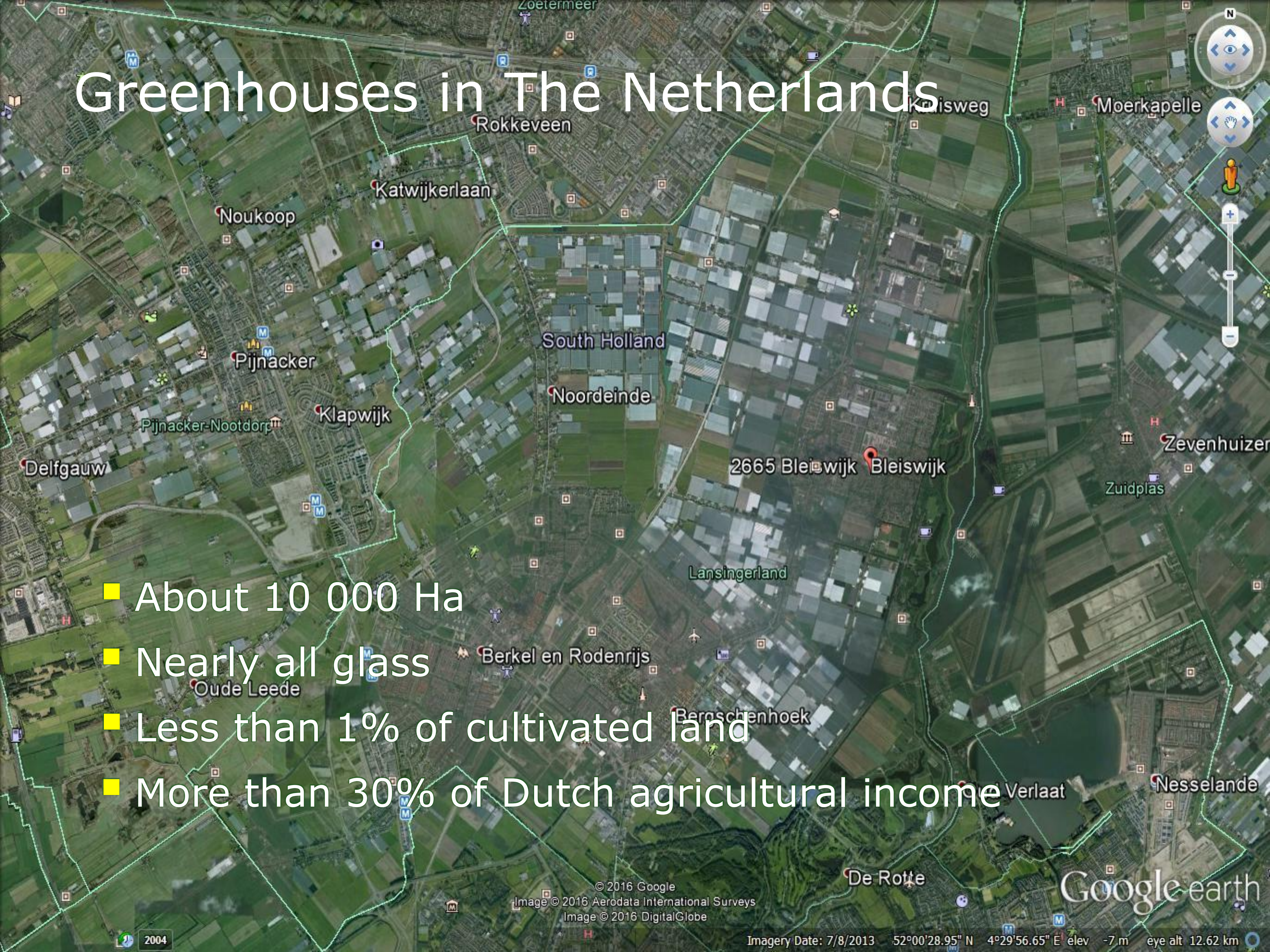
Overview

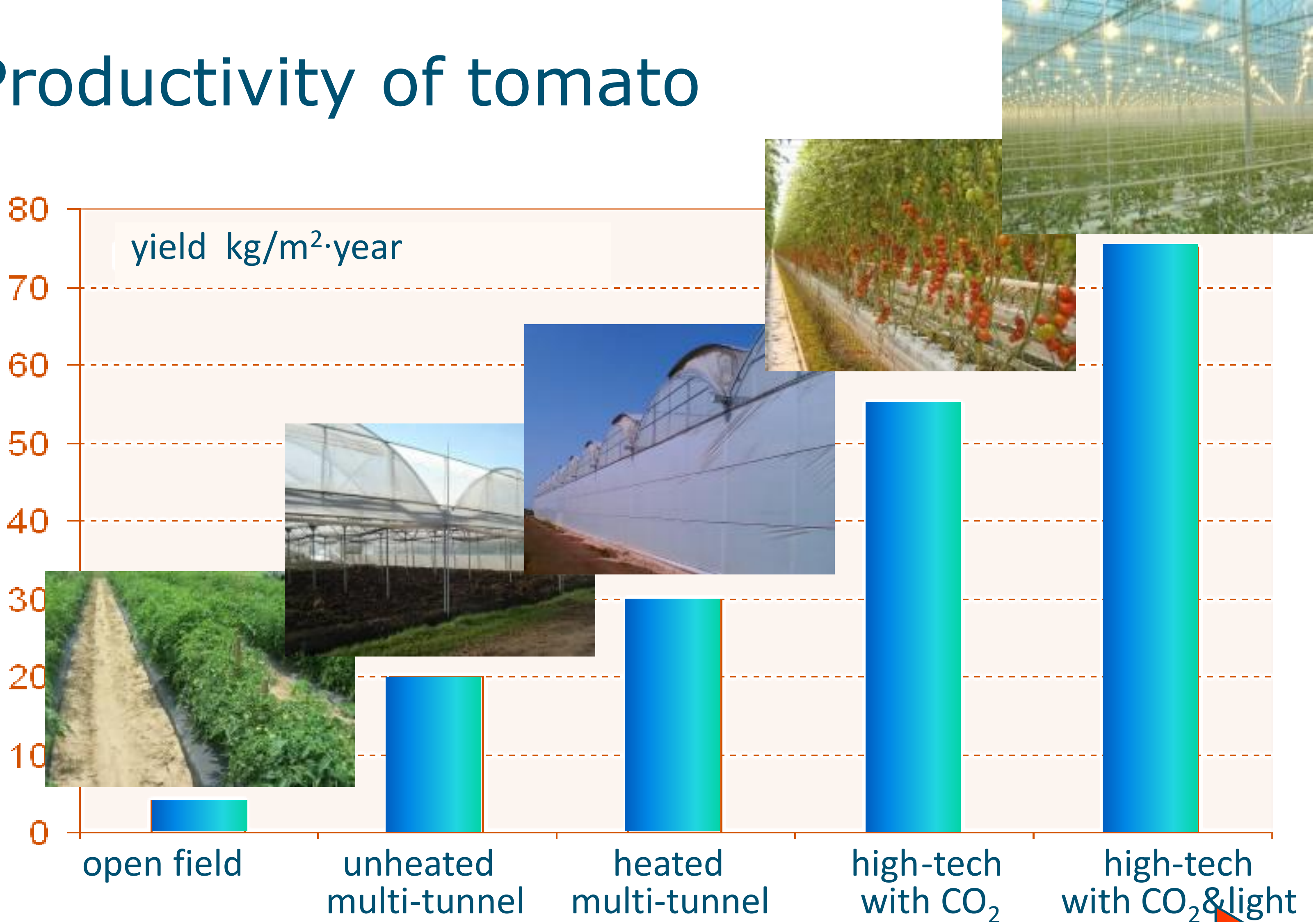
- Why we use greenhouses and how this interacts with energy use and current efforts in energy saving
- Crop - light interaction
- What is available for electricity generation
- Efforts in energy producing greenhouse design
- Future efforts

Greenhouses in The Netherlands

- About 10 000 Ha
- Nearly all glass
- Less than 1% of cultivated land
- More than 30% of Dutch agricultural income



Productivity of tomato



Control of production factors

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Developments in energy saving have been hugely successful.

Development:	Energy usage in m^3 gas per m^2 of greenhouse
Reference (NL in 1980)	**45**
Refined climate control and use of screens during night time	**29**
Regenerating heat during dehumidification combined with limited seasonal heat storage	**19***
Usage of double glass and heat exchangers to regenerate heat during ventilation	**10***

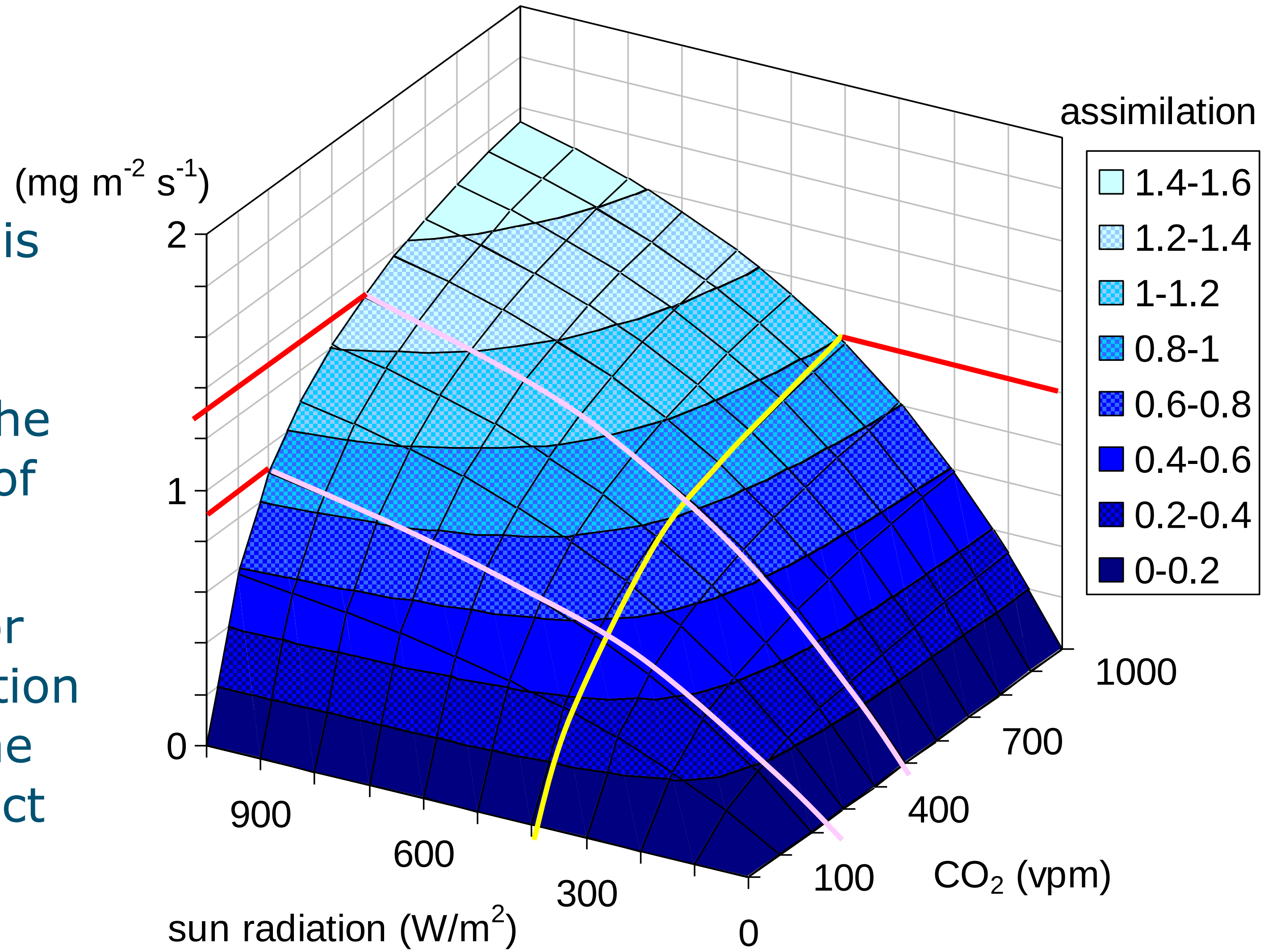
*m^3 gas equivalents in electricity, applying regenerative heating leads to overall energy saving but also a relative increase in electricity use

If just 4% of solar energy harvesting can be combined with the state of the art in energy saving, greenhouses could become energy neutral.

Concept of limiting factor

Example: Trend of photosynthesis

- The maximal photosynthesis that can be attained depends on the combination of light and CO_2
- A single factor limits production even when the other is perfect



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Light is the limiting factor in NL:

yield increase per % light increase

Crop	% Yield increase
Lettuce	0.8
Radish	1
Cucumber	0.7–1
Tomato	0.7–1
Rose	0.8–1
Chrysanthemum	0.6
Pointsettia	0.5–0.7
Ficus benjamina	0.6

Source: Marcelis et al., 2006

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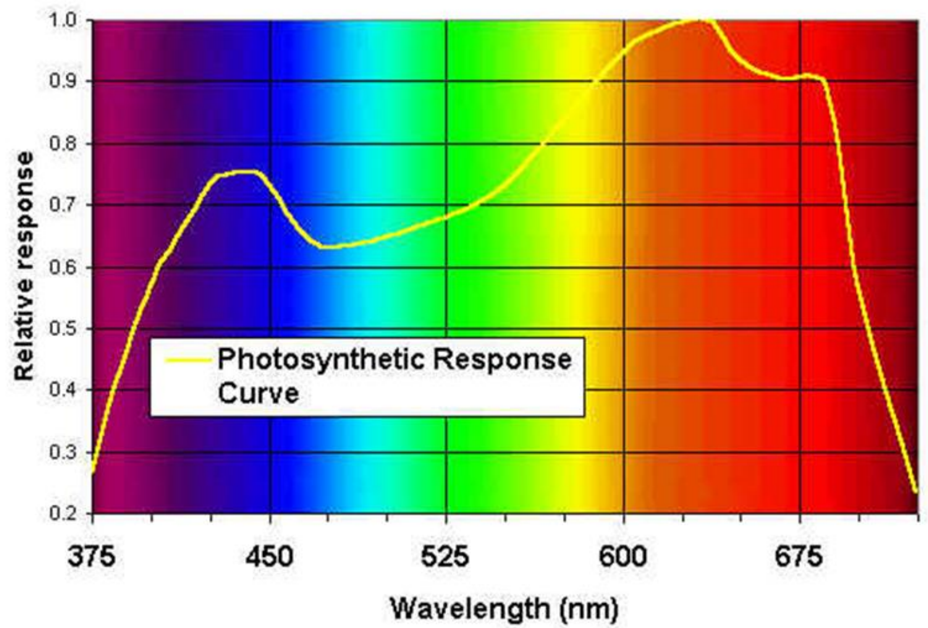
Solar radiation split out to functionality

UV	300-400 nm	morphogenesis
PAR	400-700 nm	photosynthesis, morphogensis
FR	700-800 nm	morphogenesis
NIR	800-2500 nm	*increasing greenhouse temperature*
FIR	2.5-100 µm	*heat radiation*

- Photosynthetic active region ≠ Chlorophyll absorption



Shade-tolerant pot plants

Local excess light should be avoided to prevent leaf damage and maintain quality.

Measures:

- Heavy screening, inside or outside of greenhouse
- Application of chalk on greenhouse cover to reflect incoming irradiance
- Results in low daily light integrals (4-7 mol m^{-2} d^{-1})
- Options to use the excess light?

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Horticultural crops

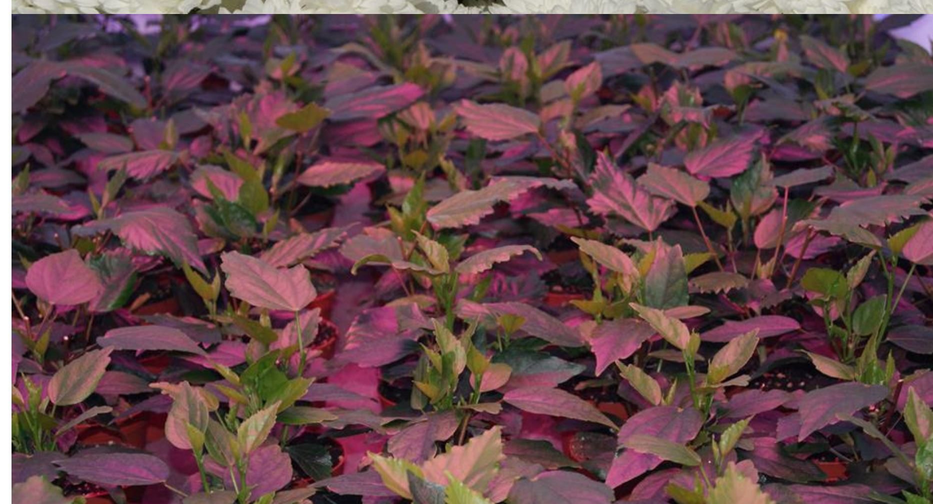
Vegetables [4750 ha]

- 1750 ha tomato
- 1200 ha pepper
- 550 ha cucumber

Cut flowers [1880 ha]

- 390 ha chrysanthemum
- 280 ha rose
- 160 ha gerbera

Potted plants [1300 ha]



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Demands on a solar energy harvesting greenhouse cover

- Highly PAR-transparent greenhouse cover needs to be maintained
- Good thermal insulation
- Which excess energy to use?
    - Not heat (is inefficient)
    - Not PAR (as far as possible)
    - NIR (although it may increase heating requirement)
    - Direct light (in some cases)
    - UV (in most cases)

The easy and available 'solution'

- Could be useful in places where sunlight is very abundant, not in northern latitudes.
- Even in southern latitudes using non transparent solar cells on greenhouses leads to less effective greenhouses combined with sub optimal use of solar panels

NIR recollection at Wageningen UR Greenhouse Horticulture...

- Spectral filter which focus and reflects NIR
- CPV collector for producing electricity

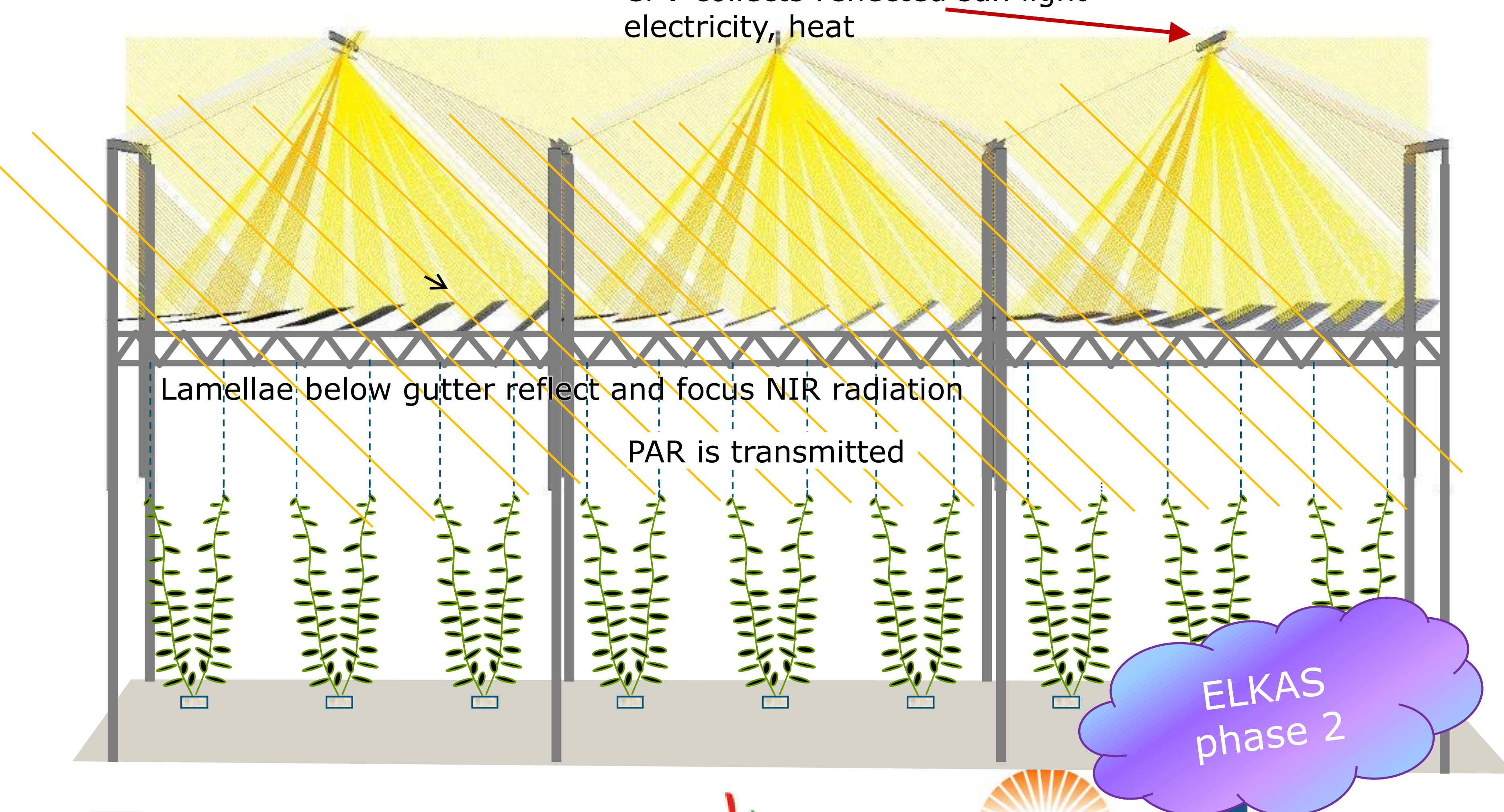
ELKAS
phase 1

Productschap Tuinbouw
Voor een bloeiende zaak

Kas als Energiebron

Ministerie van Economische Zaken, Landbouw en Innovatie

NIR recollection at Wageningen UR Greenhouse Horticulture...



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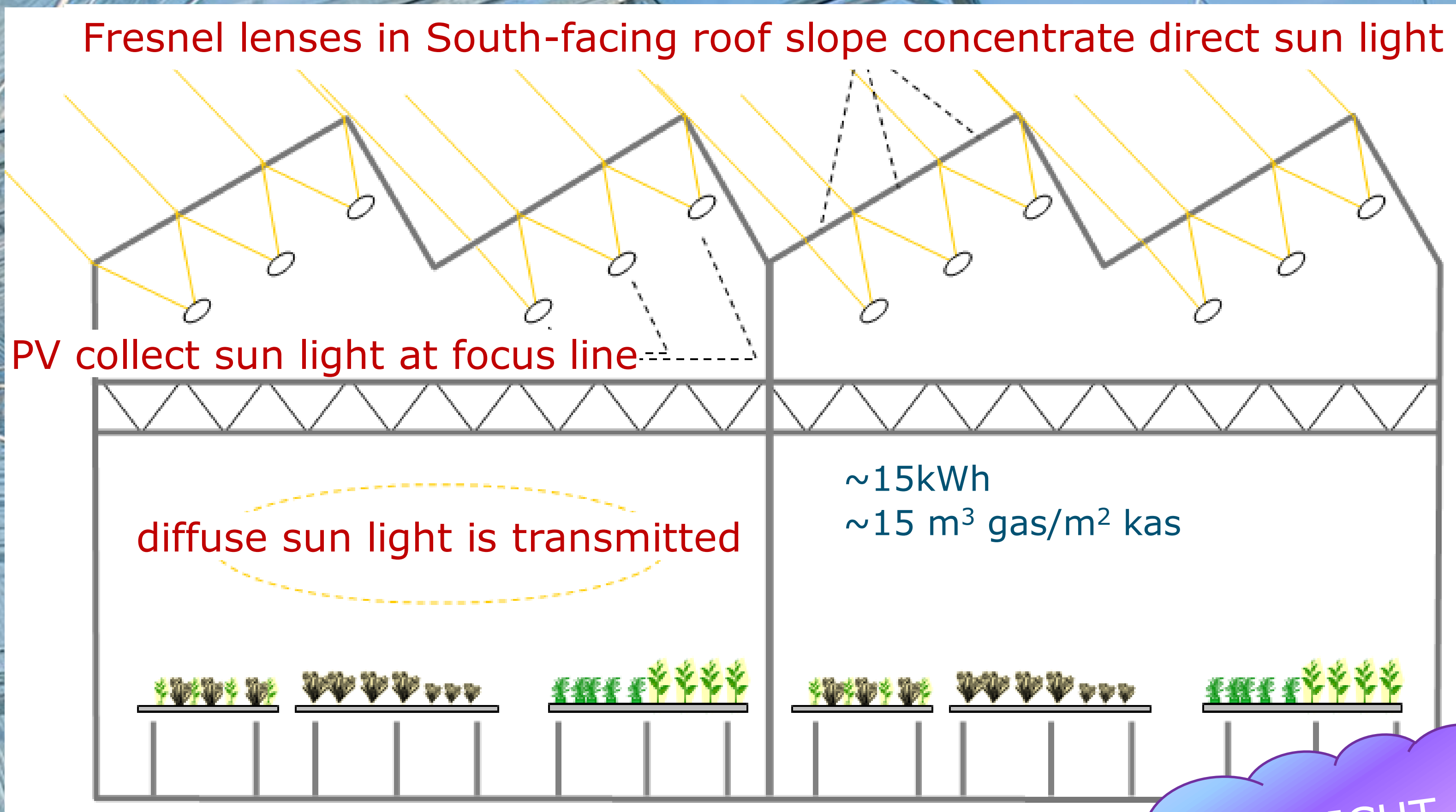
Recollection of direct light



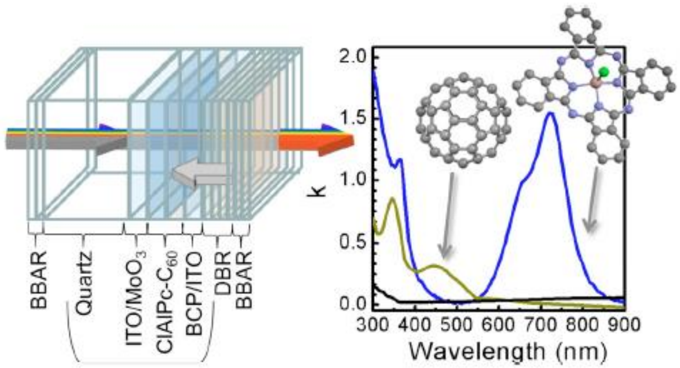
DAGLICHT KAS

Results so far

- Si-pv laminate ➔ takes away to much PAR light
- ELKAS 1 ➔ did manage to generate electricity for a short time but nowhere near commercial feasibility
- ELKAS 2 ➔ only heat production was proved succesfull
- Fresnell Greenhouse ➔ produced ~15 kWh/m^2 per year and useful heat equivalent to ~15 m^3gas/m^2greenhouse. This design is currently used by a commercial grower but only the thermal energy capture is implemented.

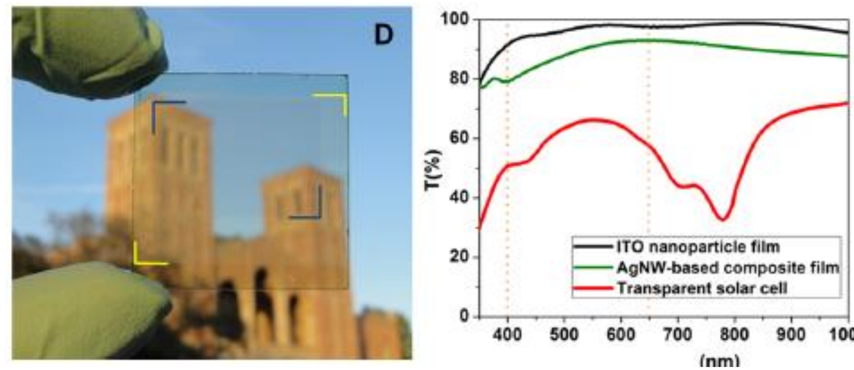
Future option: wait for transparent PV cells?

65% transmission



Source: Richard R. Lunt and Vladimir Bulovic. 2011. Transparent, near-infrared organic photovoltaic solar cells for window and energy-scavenging applications. APPLIED PHYSICS LETTERS **98**, 113305 2011

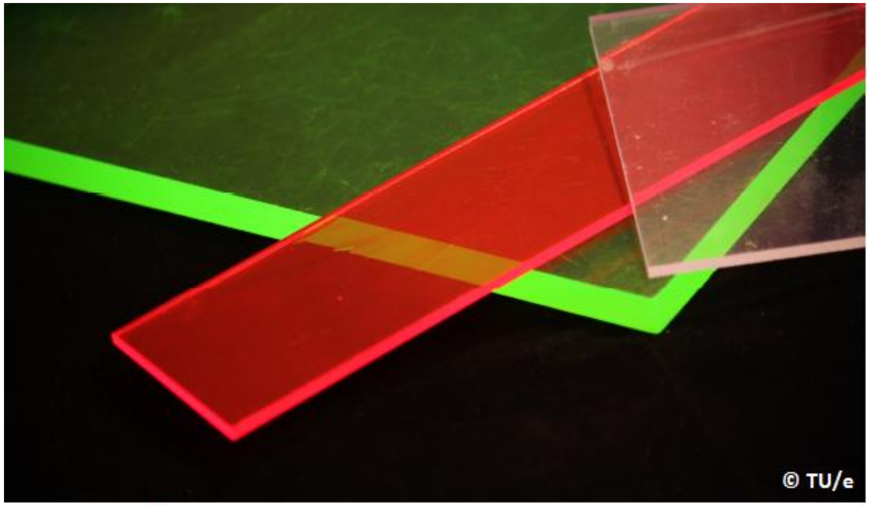
66% transmission

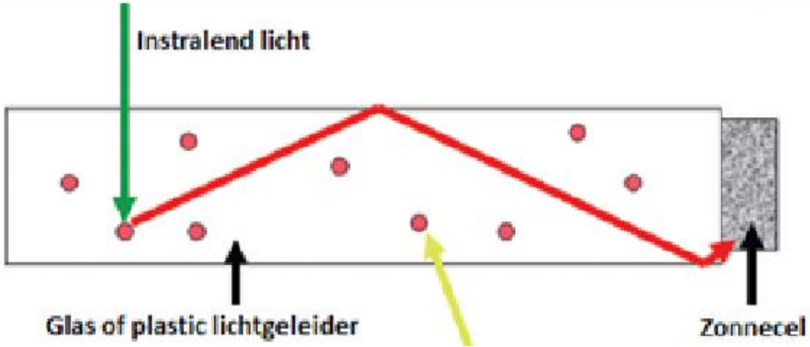


Source: Chun-Chao Chen, Letian Dou,Rui Zhu, Choong-Heui Chung, Tze-Bin Song, Yue Bing Zheng, Steve Hawks, Gang Li, Paul S. Weiss, and Yang Yang. 2012 Visibly transparent polymer solar cells produced by solution processing. ACS Nano VOL. 6 ’ NO. 8 ’ 7185–7190 ’ 2012

Future option: could Luminescent Solar concentrators be compatible with greenhouses?

- Extremely selective spectral response
- Concentrates direct and diffuse light
- No solar tracking needed
- Mostly inexpensive materials



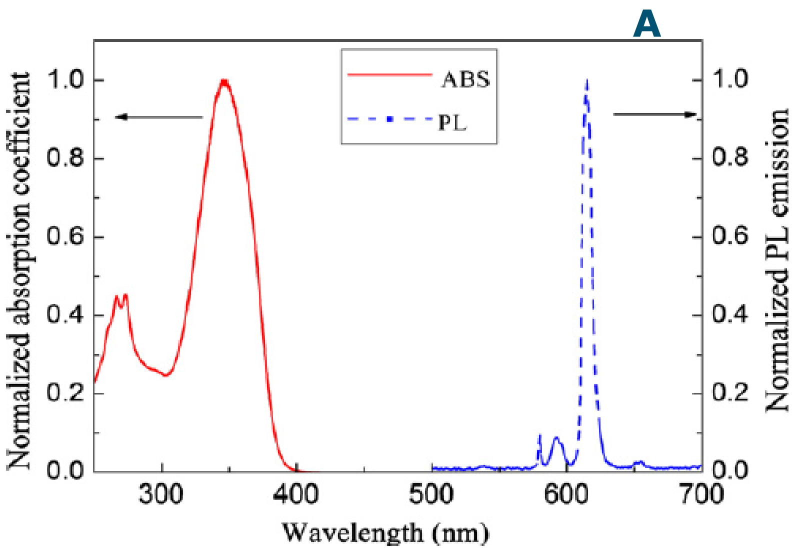


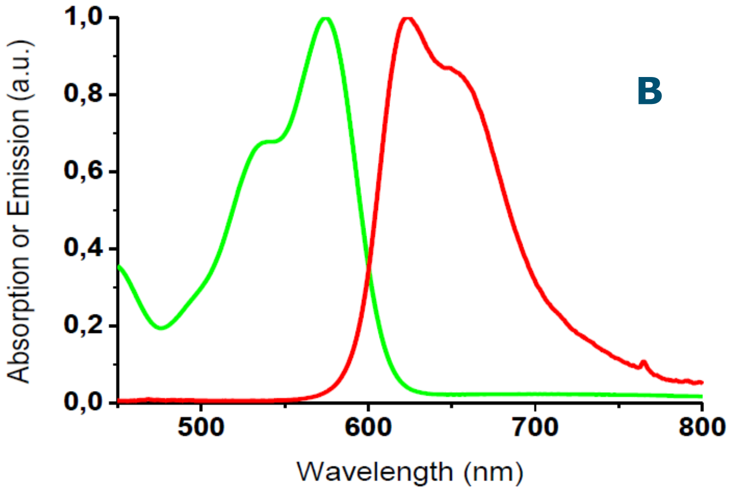
2 varieties of LSC that could fit in greenhouse systems

1. Utilise UV for electricity generation
   - Limited potential due to limited available energy in UV range

2. Apply fluorescent coating in removable form during summer months

(3). NIR LSCs could be very useful but are currently unfeasible because no suitable dyes are available





A: Tongxin Wang, J. Z. (2011). Luminescent solar concentrator employing rare earth complex with zero self-absorption loss. *Solar Energy*, 2571–2579
B: Paul P. C. Verbunt, S. T.-W. (2012). Increased efficiency of luminescent solar concentrators after application of organic wavelength selective mirrors. *OPTICS EXPRESS*, 655-668

Conclusions

- Dutch greenhouses receive more energy from the sun than they need.
- Large amounts of fossil energy is currently needed to operate greenhouses due to a timing mismatch in solar energy supply and energy demand
- Generating solar energy in greenhouses could make sense, but only if:
    - it does not compete with crop production
    - not to much costs are involved

Thank you for your attention!

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Questions?

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