TECHNOLOGY SCAN

Innovative technology for transition to a low-carbon greenhouse industry

Climate control technology and alternative energy sources (other than natural gas) used in the glasshouse industry in the Netherlands

FOR: Tomatoes New Zealand & Vegetables New Zealand

BY: Elly Nederhoff, Crophouse Ltd., Tauranga
Elly@crophouse.co.nz

Version 3 - 9 July 2021

Photo: https://www.goedemorgenroos.nl/roos/nieuws/online-bijeenkomst-kennisagenda-aardwarmte/

CONTENTS

TERMINOLOGY

- **Carbon-free, carbon-neutral, low-carbon, fossil-free** are used here interchangeably.
- **CHP** = combined heat & power, or cogeneration, engine usually fed by natural gas
- **Calorific value** (lower value) of natural gas in the Netherlands is 31.65 MJ/m^3
- **Conversion**: 1 Watt =1 Joule/second
- **Conversion**: 1 kiloWatthour = 1000 x 1 J/s x 1 h x 3600 s/h = 3,600,000 Joule = 3.6 MJ
- **'Greenhouse heating':** '**greenhouse climate control'** is better, because energy is used for increasing the temperature, reducing the humidity, and (in case of natural gas) for elevating the CO2 concentration, and (in case of electricity) also for lighting.
- **HNT** = *'Het Nieuwe Telen' =* new way of growing = a comprehensive new approach to growing
- **kiloWattHour (kWh)** = common unit for amount of electricity used over a period of time.
- **kiloWatt =** the unit for power in one second (1 kW = 1000 Watt = 1000 Joule/second)
- **NLD** = The Netherlands
- **Sustainable energy** and **renewable energy** are used here interchangeably
- **Units**. For large amounts, prefixes are used such as: Kilo (K, 10^3), Mega (M, 10^6), Giga (G, 10^9), Tera (T, 10^{12}), Peta (P, 10^{15}). E.g. Kilo is 1,000. Peta is 1 followed by 15 zeros, etc.
- **WUR** = Wageningen University & Research

INTRODUCTION

This study was commissioned by Tomatoes NZ & Vegetables NZ. It explores innovative climate control and alternative energy sources for the transition towards a more sustainable low-carbon greenhouse industry in New Zealand. It presents several solutions that are being used and approaches that are being trialled overseas, in particular in the Netherlands.

Production of vegetables and other crops in greenhouses uses a lot of energy for the control of temperature and humidity (heating), as well as for CO2 enrichment and sometimes lighting. The energy use depends on the location, climate, greenhouse specifics, crop, temperature settings, and other variables. The high energy use is/was justified by the incredibly high production, for instance tomatoes in a modern glasshouse can(!) produce 100 kg per m^2 per year, or **1,000 tons per hectare per year,** although the average is about half that amount: **500 t/ha/y.** Compare this with some other crops (in tons per ha per year): wheat 8, lettuce 40, potatoes 50, bananas 60, sugar beet 80, sugar cane 120 t/ha/y (https://ourworldindata.org/crop-yields). So glasshouse tomato production is multiple times the production of any outdoor-grown crop.

The greenhouse industry worldwide is facing major challenges considering energy, as governments are calling for drastic reduction in the emission of CO2 and thus reduction in the use of fossil fuel, to combat climate change.

The reason to look particularly at the Netherlands (NLD) is that the Dutch greenhouse industry is one of the largest and most innovative in the world. It covers around 9,000 hectares of high-tech glasshouses (for vegetables, flowers and plants combined), and the production has a value of 6 billion Euros or nearly 10 billion NZ$ (April 2021). The greenhouse industry in NZ (and also Europe, UK, USA, Canada & many other countries) is largely based on the Dutch model regarding glasshouse structures, materials, technology, knowledge, etc.

GREENHOUSE INDUSTRY IN THE NETHERLANDS (NLD)

The greenhouse industry in NLD is in the middle of a radical energy transition. Some forerunners started the transition nearly two decades ago, e.g. in 2003, when grower company Themato constructed the **first 'closed greenhouse'**. In 2011, grower Duijvestijn started using **geothermal energy** and became virtually fossil-free in a multiple hectare glasshouse (see Story 2 at the end). Thermal screens are being used since the 1980's.

The main fuel for the Dutch greenhouse industry is still natural gas, that is/was extracted from the earth in the northern province of Groningen. The large-scale gas extraction caused local earthquakes, which prompted the Dutch government in 2019 to reduce the natural gas extraction immediately and to stop it completely by 2030. However, there is an 'escape', namely that import of natural gas may be allowed after that. The decision to stop natural gas extraction fitted perfectly with the European climate goal. It gave a strong impulse for faster transition to renewable energy.

Also in 2019, a Climate Agreement was signed by the Dutch government and industry partners, including the association for the Dutch greenhouse horticulture industry ('*Glastuinbouw Nederland*'). This greenhouse industry body, together with the government, set the goal to be fossil-free by 2040. So growers were given 2 decades to change to renewable energy sources. Over the years, the following energy sources have been identified as promising alternatives:

- electricity from various renewable sources (often used in combination with heatpumps)
- low-grade heat from a wide variety of sources (often in combination with heatpumps)
- high-grade heat from geothermal or industrial sources (optionally with heatpumps)
- biomass & biogas

Heatpumps play a crucial role in retrieval of stored heat, especially low-grade heat. They are part of the so called 'electrification of greenhouse heating'.

Heat storage will be important too: daily storage in a heat buffer and seasonal storage in the aquifer (underground water layer).

The investment costs of some new developments (e.g. geothermal) in NLD are astronomical, and can only be feasible on a very large scale and for a long life-span. Dutch glasshouse operations are already large-scale (many are tens of hectares), but that is still too small for the huge investments in geothermal. Therefore greenhouse operations are now forming 'clusters' with other large growers and other companies and often also a large number (thousand or more) homes.

***Table 1**. Some data on energy use & CO_2 emission in the greenhouse industry in NZ and NLD.*

	New Zealand 2016		the Netherlands 2016	
	Energy (PJ)	CO2 (KT)	Energy (PJ)	CO2 (KT)
natural gas	1.6	87	ca 80	
coal	1.2	116	0	
geothermal	0.4	0	4.3	
diesel	0.3	16	0	
electricity for grh control			6.8	
waste heat			3.7	
renewable energy			5.4 or 7.4	
TOTAL all fuels	3.4	221	101	4,300
Source:	*EECA Fact Sheet Indoor Cropping*		*WUR energie monitor*	
Area	256 ha in 2017 (all crops)		ca 9100 ha in 2016 (all crops)	
Source:	*Statistics NZ, Agr Prod Stats*		*WUR energie monitor*	

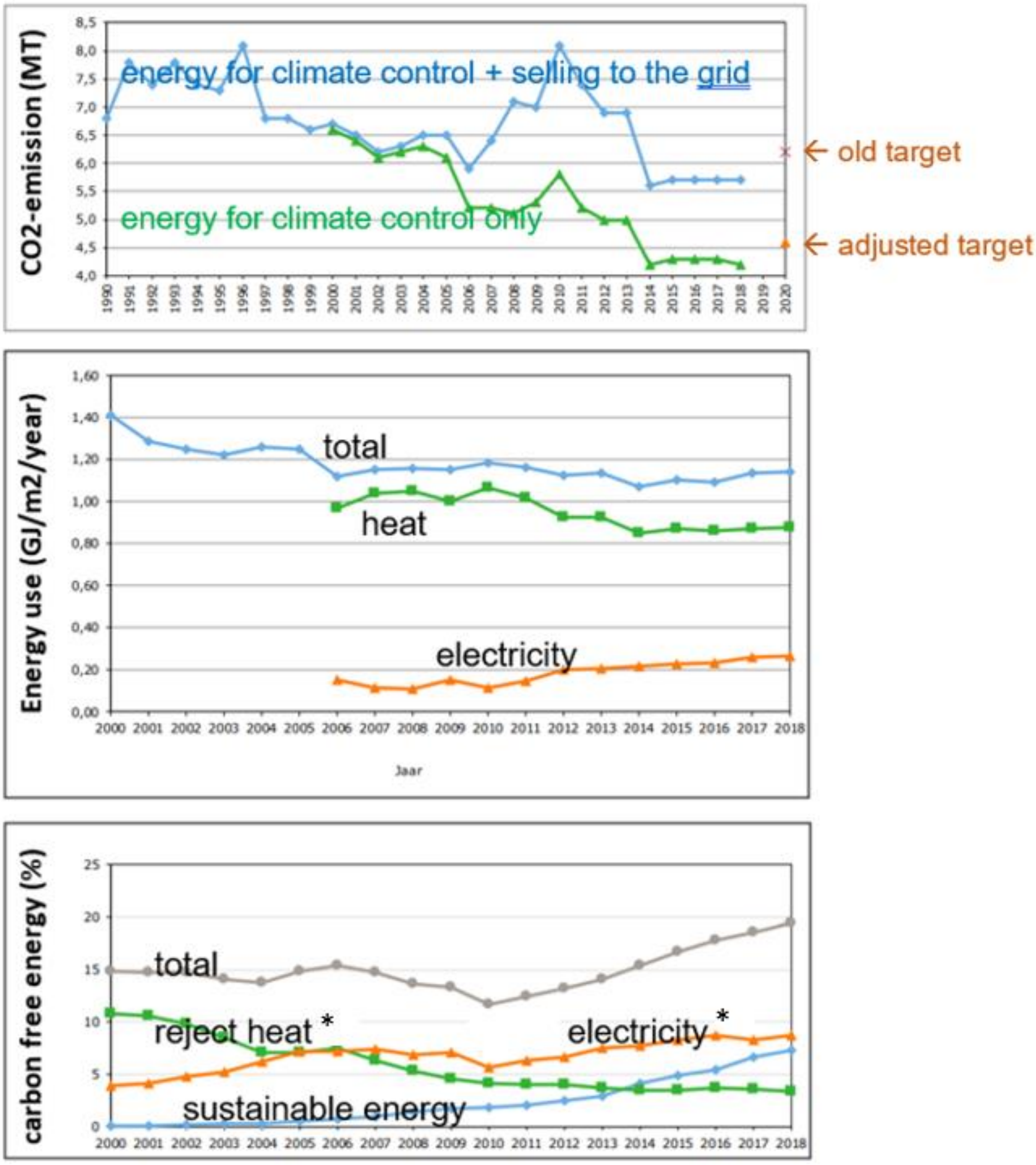
NOTES with the table above

- *No comparative data could be found of a more recent year.*
- *Some data are approximations only; different publications sometimes give different data.*
- *Energy flows can be complicated. Lighting (fuelled by electricity) produces heat that warms the greenhouse, with surplus heat from lighting captured and stored. Later the stored heat is retrieved and is fed into a heat pump that uses electricity, and then used for heating again.*
- *Often a considerable part of the electricity generated in a CHP (gas-fired combined heat & power) is sold to the grid. This overstates the natural gas consumption in a greenhouse. The number above (ca 80 PJ) is supposed to be natural gas use for glasshouse climate control only.*

Sources:
For NZ: EECA Fact sheet. Indoor Cropping – Process Heat & Greenhouse Gas Emissions, 2016.
For NLD: Energiemonitor van de Nederlandse glastuinbouw 2018. WUR, 2019.
Also: pbl.nl/sites/default/files/downloads/pbl-2019-achtergronddocument-het-klimaatakkoord-effecten-en-aandachtspunten_3807.pdf

***Fig. 1**. Trends in overall CO_2 emission, and energy use per m^2, and sustainable energy in greenhouse horticulture (vegetables & flowers) in the Netherlands.*

Source: Energiemonitor van Nederlandse Glastuinbouw. WUR. 2018.

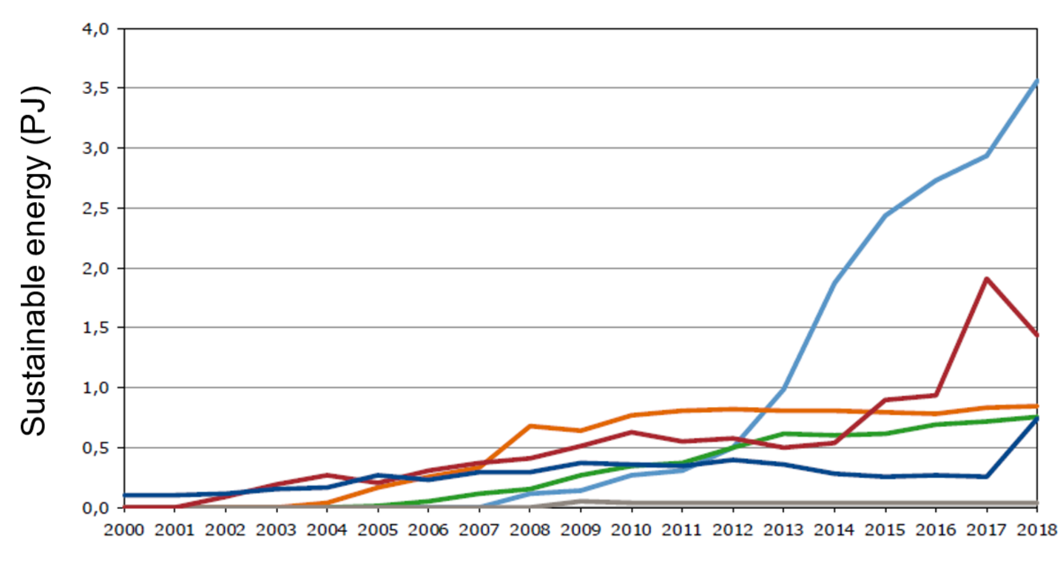


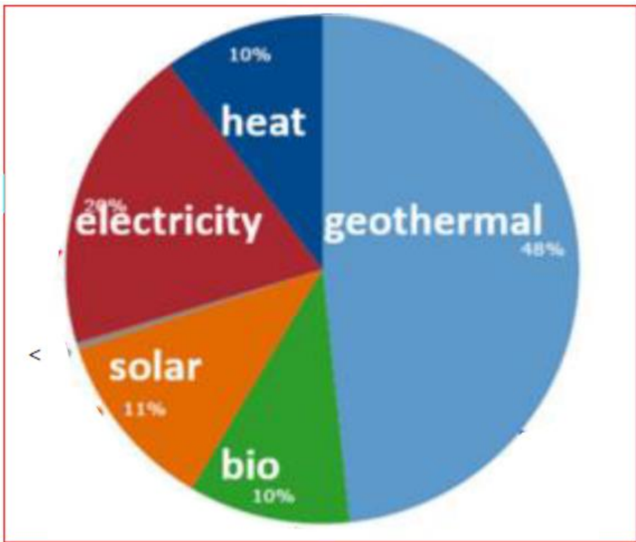
NOTES with the graphs above

- *The greenhouse area in NLD declined from 10,307 hectares in 2010 to 8,990 ha in 2018.*
- *In the middle graph, energy use is split into heat (green line) and electricity (orange line) from 2006 onwards. Note that electricity for lighting also produces heat.*
- *In the last graph, the green line represents reject heat from non-sustainable sources, while the orange line is electricity from non-sustainable sources.*
- *The blue line represents truly sustainable energy, consisting of 6 types: geo, bio, solar, sust. heat, sust. power and sust. gas. (sust. = sustainable or renewable). It is steady on the rise.*

Fig. 2. Sustainable energy sources in the Netherlands (2018): timeline, pie-chart and table

Source: Energiemonitor van de Nederlandse glastuinbouw 2018. WUR. 2018





Legend for graph & pie-chart

- geothermal heat
- biofuels
- solar
- sust. gas (purchased)
- sust. electr. (purchased)
- sustainable heat (purchased)

Sustainable energy	number	area (ha)	heat (PJ)	electricity (TWh)	total (PJ)	share (%)
geothermal	**81**	**741**	**3.6**	**-**	**3.6**	**48**
bio fuels	**41**	**194**	**0.7**	**<0.01**	**0.8**	**10**
* heat	35	150	0.5	-	0.5	6.7
* heat & electricity	6	45	0.2	<0.01	0.2	2.7
solar energy	**124**	**471**	**0.8**	**0.01**	**0.8**	**11**
* electricity	62	257	-	0.01	0	
* heat	62	214	0.8	-	0.8	10.8
purchasing sustainable energy			**1.5**	**0.4**	**3**	**40.5**
* electricity				* 0.4	** 1.4	18.9
* gas			<0.1	-	<0.1	<1
* heat	9	68	0.6	-	0.6	8.1
Total	**255**	**1474**	**5.9**	**0.42**	**7.4**	**100**

* *TWh = TerraWatthour. Terra = 10^{12}* ** *PJ = PetaJoule. Peta = 10^{15}*

WattHour converted to Joules: 1 Wh = 3600 J

Combining this, the conversion is: 0.4 TWh = 1.4 PJ

CLIMATE AGREEMENT WITH THE DUTCH GREENHOUSE INDUSTRY

Europe has the ambition to be climate-neutral in 2050 in the large majority of member states. In the Netherlands, the government and industry partners signed the 'National Climate Agreement' in 2019, and set out to reduce the greenhouse gas emissions by 49% in 2030 and by 95% in 2050 compared to 1990 levels (or more if other European countries do the same).

The association for the Dutch greenhouse horticulture industry ('*Glastuinbouw Nederland'*) is a partner in the Climate Agreement. This industry body has set the goal for a climate-neutral greenhouse industry by 2040. Whether this will happen depends on progress in other fields such as geothermal energy, residual heat, sustainable electricity, electricity transport, as well as carbon capture and supply.

Back in 2005, the industry body started an action programme 'the greenhouse as a source of energy' ('*kas als energiebron'*) to stimulate the energy transition. This programme assists the industry by funding in-depth innovative research and knowledge transfer. The funds come from the government, who in turn raises the money via a levy and/or tax on natural gas (called EB & ODE). These government funds also provide subsidies for instance for geothermal and bio-energy projects.

During the energy transition (from 2005 or 2010 to 2030 or 2040), the aim is to use an optimal combination of various technologies and energy sources. Natural gas fed CHPs and boilers will remain for some time, but be replaced gradually by low-carbon energy sources such as geothermal energy, green electricity (generated off site), residual heat and biomass.

Geothermal will be very important in the Netherlands. In 2019 there were 17 geothermal projects. The goal is to realise at least 35 successful new geothermal projects by 2030.

Green electricity will be used a lot, not only for lighting, but more and more for heating too. This 'electrification' of the heat supply cannot happen too fast, though, because the electricity transport & distribution net cannot yet cope with huge quantities of electricity. Hence CHPs and boilers will be allowed for some time. Electrification will involve heat pumps and the use of low-grade heat, as well as storage and retrieval of heat, power to heat, pump energy, and more.

Growers play a major role in shaping the future. Their decisions set the direction for decades to come. Since heatpumps will be an essential part in most solutions, many growers are starting to invest in that technology. These are heatpumps especially developed for greenhouses that control the temperature and humidity.

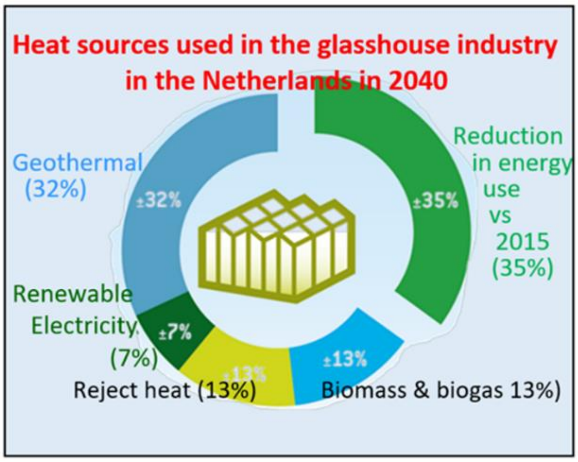


Fig. 3. *Target for energy sources by 2040* →
Source: Samen werken aan een Verantwoorde Glastuinbouw: Energie. Glastuinbouw Nederland

OVERVIEW OF INNOVATIONS RE. ENERGY
IN THE DUTCH GLASSHOUSE INDUSTRY

1. The greenhouse industry in the Netherlands (NLD) is in an energy transition that started in about 2005 or 2010 and will continue until at least 2030 or 2040.

2. Government and industry partners signed a Climate Agreement in 2019. The industry aims to be climate-neutral by 2040 and completely sustainable and economically viable by 2050.
   Sources: Glastuinbouw Nederland. Visie_Energie_2019. Also: Klimaatakkoord 2019 (pbl.nl/sites/default/files/downloads/pbl-2019-achtergronddocument-het-klimaatakkoord-effecten-en-aandachtspunten_3807.pdf)

3. Natural gas will be gradually phased out. Combined Heat & Power installations (CHP or co-generation) fuelled by natural gas are still very common and will be useful in this decade, but no new CHP's should be installed anymore.

4. Drastic energy saving is the first and cheapest step towards fossil-free greenhouse control. Energy-saving measures are now adopted and implemented at full speed, such as:
   - the use of insulating screens (2 or even 3, one of them also shade-screen in summer)
   - better understanding of control of air humidity and choosing higher setpoints
   - better understanding of temperature control and smarter choice of setpoints
   - new technology for humidity control, e.g. fans, air treatment units
   - optimised use of CO2 enrichment
   - creating an even climate (without cold spots)
   - smarter venting for preventing loss of heat (in winter) or CO2 (in summer)
   - advanced plant management: new approaches for growing are being taught and adopted, such as HNT (new way of growing), Plant Empowerment, semi-closed glasshouses.

5. Guidelines for 2030 for the glasshouse industry as a whole are:
   - Electricity: 38 PetaJoule (PJ). Up from 6.8 PJ in 2016.
   - Geothermal energy: 14.9 PJ. Up from 4.3 PJ in 2016.
   - Biomass in boilers and CHPs: 5.2 - 5.5 PJ. Was minimal in 2016.

   Source: Klimaatakkoord 2019.

6. The demand for electricity from the glasshouse industry will increase dramatically, and will put huge pressure on the distribution net. CHP will be permitted a bit longer to maintain localised electricity production to mitigate (or delay) the distribution problem. CHP should be used especially during peak demand (e.g. cold nights) and as an emergency heating system.

7. 'Clusters' are being formed, consisting of several large-scale greenhouses, often combined with other energy users such as offices, small industries and/or hundreds/thousands of suburban dwellings. A cluster forms a financial consortium that can afford the high investments for instance in geothermal energy.

8. Heat distribution networks have been constructed and new ones are planned, each covering many square kilometres. Each network receives high-grade heat from an industry or geothermal bore. The network distributes it to a 'cluster'.

9. Instead of joining a cluster, a grower can opt to have a 'sustainable independent glasshouse', that is not connected to a heat net, but has its own heat supply. These independent glasshouses will most likely be heated by electricity with the use of heat pumps, or by biogas, green gas, or biomass burned in a boiler. This is relatively affordable for medium-scale greenhouses.

10. Carbon dioxide (CO2) enrichment is considered essential for good plant growth and production. In many regions in NLD with glasshouses, a large underground pipe network distributes affordable horticultural-grade CO2 gas from industrial sources. New pipe networks will be completed by 2030. Growers not connected to a CO2 network, will have buy CO2 delivered by road tankers.

11. Artificial lighting (with HPS lamps and increasingly LED) is common practice in tomatoes (and flowers). They will use 'green electricity' (renewable electricity) produced off-site. Climate control in lighted greenhouses is often 'all electric'. The residual heat from lighting (even if it is LED) is utilized for heating, supplemented with heat from other renewable sources.


12. Geothermal heating is reality in many large glasshouse NLD, with around 17 geothermal sources in operation. Hot water of 70-100 °C is retrieved from 1.5 to 2.5 km deep. Due to the enormous investments, geothermal heating usually supplies a cluster. The plan is to build at least two geothermal systems each year until there are 65 to 80 in 2040.

13. Biomass has been trialled by several large-scale greenhouse growers in NLD in the last decade. An issue is to have CO2 suitable for CO2 enrichment – it seems to be possible to adequately purify flue gases. However, not enough woody biomass is available, or distances and thus transport costs were excessive. This made it an unfeasible and unsustainable option for large-scale growers, at least in the Netherlands. The use of other types of biomass is still being investigated. A target has been set to use 5.2 PJ per year of biomass by 2030.

14. '*Electrification of heating*' or '*all electric climate control'*, entails using electricity, heatpump(s), and heat from a range of possible sources. Climate control without natural gas was first realised on a large commercial scale in 2013 (Koppert Cress, see in Appendix).

15. 'High-grade heat' (with a temperature of e.g. 80 – 100 °C) from geothermal bores and industries is becoming a major energy source for very large glasshouses, and/or clusters.

16. 'Low-grade heat' (often below 30 °C) from external or internal sources is becoming very important.

17. Internal sources of low-grade heat can be for instance:
    - the greenhouse itself in sunny periods, with heat being 'harvested' and stored
    - latent heat (energy in the form of moisture in the air) can be recovered by dehumidifiers
    - artificial lighting in the greenhouse (even if it is LED lighting)
    - solar heat collected in another solar collector system
    - heat produced by an onsite cool store
    - aquifer (underground water bubble), with warmth injected and retrieved seasonally

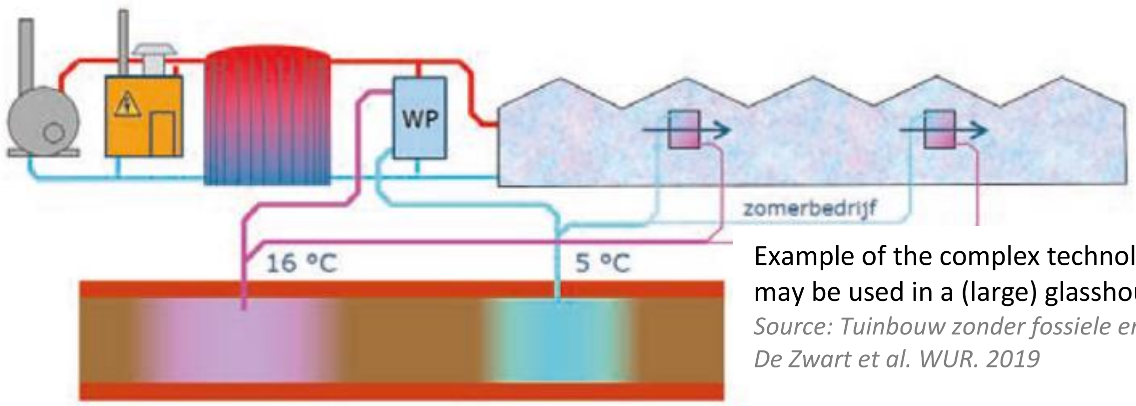
18. External sources of low-grade heat can be for instance:
    - industry or data centre (residual heat, waste heat or reject heat)
    - water treatment plant, waste processing plant
    - 'surface water' (canals, ponds): heatpumps extract low-grade heat from lukewarm water
    - aquifer (underground water bubble), 'external' source if grower doesn't inject warmth

19. The aquifer is used for seasonal warm/cold storage to provide low-grade heating in winter, as well as cooling in summer. [Note this is not geothermal heat]. A 'doublet' consists of two pipes that are drilled up to ca 300 meter deep. One is the cold well (or bore) and the other the warm well (or bore). Each well has an extraction pump and infiltration pump.

20. The low-grade heat from the warm well in the aquifer is usually fed into a heatpump, either water-to-air or water-to-water. Warm air is spread through the greenhouse via large plastic perforated air tubes laying under the gullies. Or warm-water flows through the heating pipes.

21. If the water temperature in the heating system is lukewarm (say under 30 °C) instead of hot (say over 80 °C) it is necessary to use more heating pipes per m^2 or to use heating bodies with a greater surface area than the traditional 51 mm pipes.

Fig. *Examples of air distribution via sleeves or (on right) free outflow* *Source: left KUBO, right Certhon*



Example of the complex technology that may be used in a (large) glasshouse.
Source: Tuinbouw zonder fossiele energie. De Zwart et al. WUR. 2019

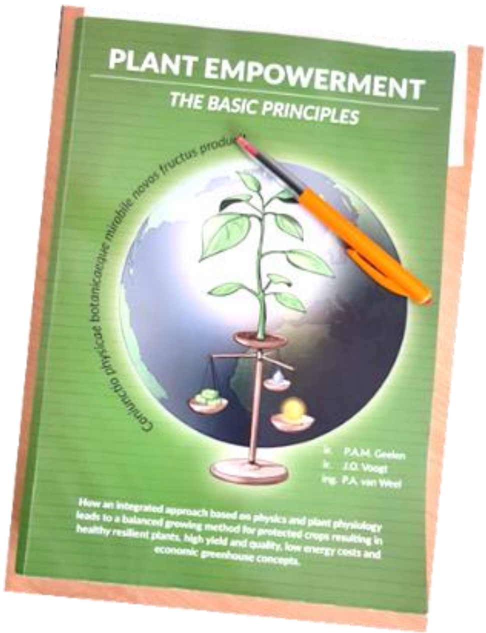
PART 2 - ENERGY SAVING METHODS

'THE NEW WAY OF GROWING' and 'PLANT EMPOWERMENT'

INTRO

A very important part of the energy transition is reducing the energy use. That is not really the scope of this report, so here is only a short summary of actions that growers can take.

In the Netherlands, the greenhouse industry has chosen an overall approach called 'The new way of growing' (in Dutch 'Het Nieuwe Telen', HNT). A variation is called 'Plant Empowerment', which is described in a large book (over 300 pages A4 size). →



'The new way of growing' comprises new insights of how to control the greenhouse climate and how to grow the plants in an energy efficient way, and secondly it works with additional technology (requiring investments) to reduce the energy demand even further. Different HNT 'recipes' were developed for different crops.

This new approach was developed by researchers of WUR in NLD after the first closed greenhouses were built by growers and tested by researchers (from 2003 onwards). (Semi-)closed greenhouses required a new approach of climate control based on mechanical ventilation.

The first to implement this new approach was cucumber grower Dion van Mullekom, of Multigrow BV in Grashoek (NLD) in 2013. He fitted a second energy-saving screen and an air dehumidification and heat recovery system. He learned to use the energy screen for more hours than what was normal practice at the time, and how to prevent or overcome humidity problems. This and other new knowledge enabled him to improve his cultivation strategy and reduce the energy demand by 25%, without any adverse effects on growing conditions and production.

In 2016, more than 350 growers, or 1800 hectares, were putting HNT in practice. They are applying it to their own specific crop, at their own tempo, with or without investment. By optimally control of the temperature, humidity, CO2, lighting and screening, they achieve considerable energy savings. Up to 30% energy saving is possible even without investment.

The 'New Way of Growing' and similar approaches is far-stretching, can be complicated, and often tailor-made recipe for a particular crop. Growers take classes and attend training sessions over several days, and follow on in work groups.

Source: Kas als Energiebron. Saving energy and sustainable energy in greenhouse horticulture
Source: www.rijksoverheid.nl/onderwerpen/klimaatverandering/documenten/rapporten/2019/06/28/klimaatakkoord

NOTE: WINTER CONDITIONS. The description below is for the **colder conditions (winter and parts of spring and autumn).** Summer is important too for energy, but then for cooling and CO2 enrichment. Of course the geographic location is important too: energy saving investments will be much more feasible in the South Island than in mild Northern areas.

INVESTMENTS

Heat supply, recovery, storage

By far the major investment is for a new heating systems and/or alternative fuel, as will be discussed at length in the following chapters.

Mechanical ventilation and Air Treatment Units (ATUs).

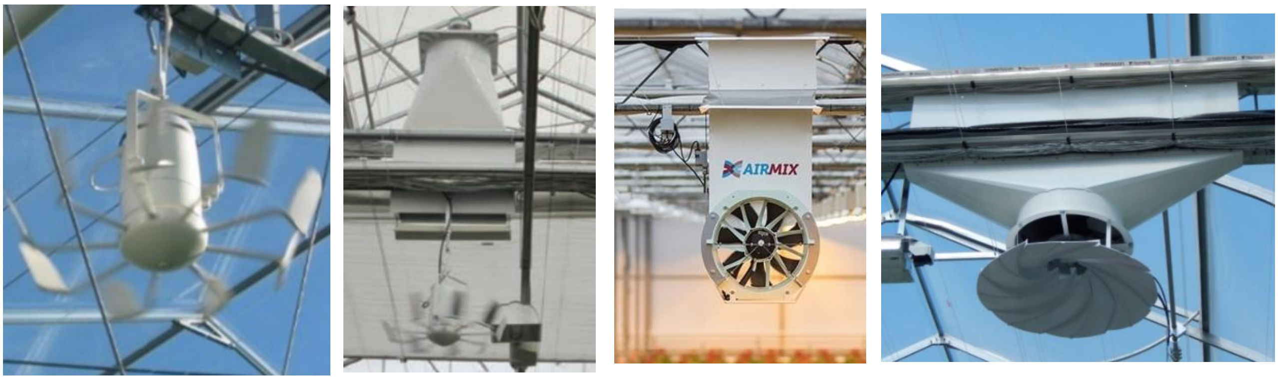
Instead of climate control by opening vents and firing the heater, the new approach is to use air treatment units (ATUs) that 'treat the air' and spread that throughout the greenhouse.

Semi-closed greenhouse

A glasshouse with mechanical ventilation can be 'semi-closed' meaning it has far less roof vents. This makes it far more critical to master the climate control. See details in a separate chapter.

Fans (horizontal, vertical, and/or through the screen)

Much energy is used for preventing too high air humidity. Humidity can be particularly high under a screen, and even more if plants transpiration is stimulated by lighting. One solution is moving the humid air to the compartment above the screen. Special fans have been developed that have made the high-air-humidity problem very manageable. Fans are also used for making the climate more uniform (to avoid condensation on the plants), and also for stimulating plant transpiration.



Left: Nivolator. groentennieuws.nl/article/95824/verticaal-ventileren-hogere-opbrengst-en-lager-energieverbruik/
Second: Nivolator under a screen.
Third: Airmix. www.vanderendegroep.nl/nl/nieuws/artikel-groei-verticaal-ventileren-vereistkennisuitwisseling
Right: vertical circulation system. nivola.nl/landing/verticaal-circulatiesysteem/

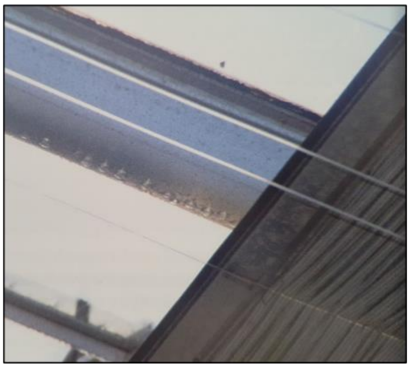
Thermal screens

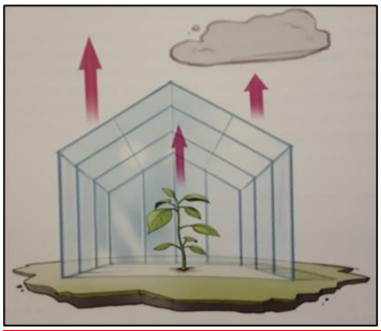
Thermal screens are useful when outside temperature is below say 12 ^{o}C. A screen greatly reduces heat emission from the plant head, so keeps the plants warmer. This has major (positive) effects on plant development and health. A screen also keeps the heat in the plant compartment. However, also the air humidity builds up very quickly under a screen. The old method was to open the screen on a gap so moisture could rise and condense against the roof. This sacrifices energy. Nowadays, greenhouse air is pushed in a controlled way through the screen, to let moisture condense against the cold roof. Or Air Treatment Units take care of humidity problem.

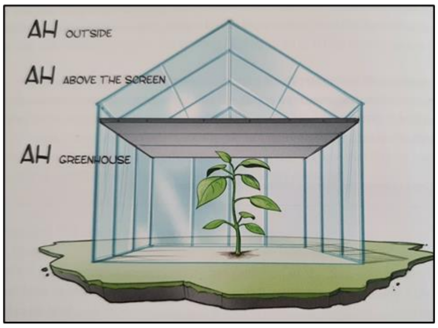
In the Netherlands, a thermal screen is standard equipment, and the discussion is about adding a second screen. Screens can be retrofitted but it is much easier to do in a new built.

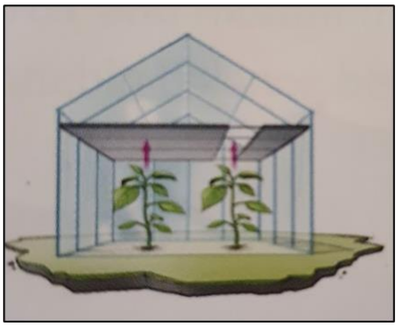
A cost/benefit analysis is more likely to be positive for cold climates such as in the S.I, than in the warmer regions of the N.I. In a cold climate, a screen can be used many more hours and can save much more energy than in a mild climate. Screen control has greatly improved over the years.

IMAGES SCREENS









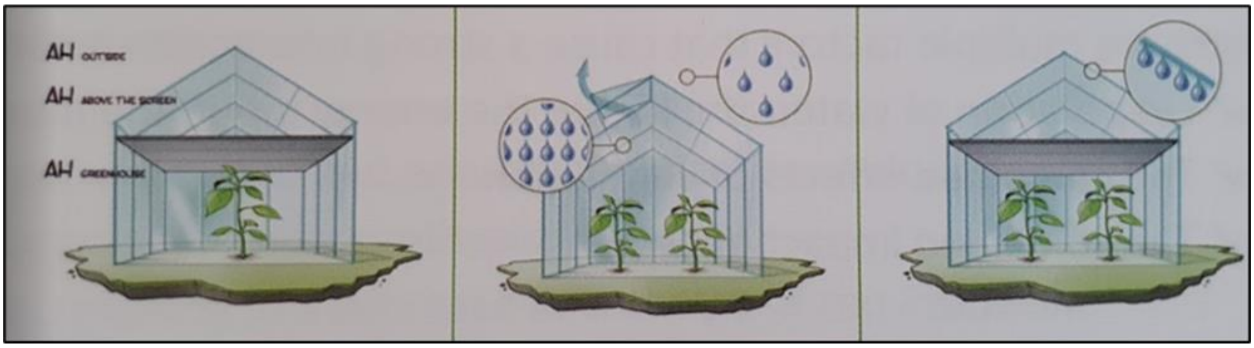


Fig *screen situations depicted. Source of the drawings: book Plant Empowerment*

Sensors
On top of the many sensors that are being used already, some new measurements are now incorporated in the control, e.g.:
- leaf temperature sensor or thermographic camera
- pyrgeometer, to measure heat loss emission from the plant heads
- PAR meter (photosynthetic active radiation)
- optionally a stomata meter

Investments to make the greenhouse more uniform

It is now well understood that a uniform climate is important for energy efficiency. Growers tweak the heating pipe lay-out, ventilation, screen etc., to repair 'cold spots' where condensation often occurs.

CONTROL ACTIONS

Improved temperature control

Energy is saved by aiming for lower temperature without losing performance. Temperature determines plant shape, vegetative/generative balance, production and performance in future months (e.g. tomato plants have to perform 11 months). Temperature is chosen depending on plant variety, crop stage, time of the day or night, light level, weather and weather predictions, and more.

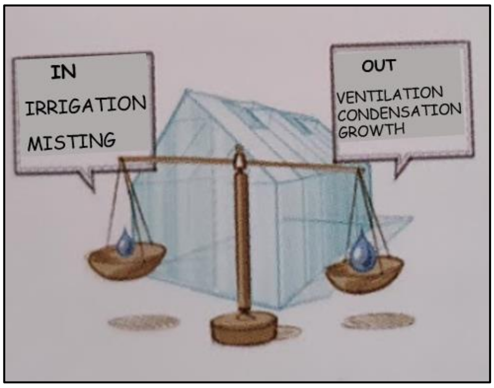
Smart humidity control.

In mild climates (as the NZ climate mostly is), a major part of the energy is used is for humidity control. One objective is to keep the plants dry to avoid fungal plant diseases (mould, rot) and another is to keep transpiration going. Growers use a large safety margin to avoid condensation (that would lead to diseases) and therefore aim at a low Relative Humidity (RH of 80% or so). Growers are learning to work with absolute humidity (instead of RH) and with dewpoint (for avoiding condensation). This saves an enormous amount of energy.

CO2 enrichment

This can use a lot of energy, especially when there is a lot of air exchange (ventilation). The CO2 control is under consideration.

Balances



In the 'New Way of growing' and 'Plant Empowerment' the computer calculates six balances:

- energy balance (for plants and greenhouse)
- water balance (for plants and greenhouse)
- carbon (CO2) balance (for plants and greenhouse)

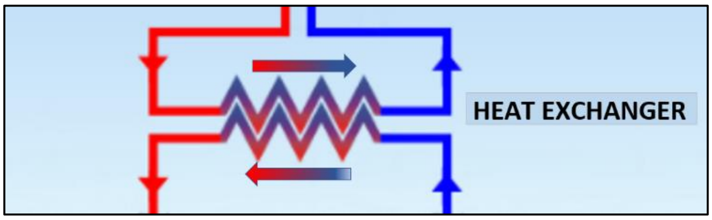
Measurements describe the current conditions (temperature, humidity, CO2, light, air movement, condensation, heat emission, stomata opening, water uptake, etc). The specialized computer program can calculate how much energy is needed to change those conditions.

PART 3 - TECHNOLOGY

The future sustainable greenhouse will require a lot of technology. Two basic pieces of machinery are the heat exchanger and the heatpump. Both can take the form of one large machine, or many small ones in one greenhouse. In addition there can be heater(s), cooler(s), condenser(s), dehumidifier(s), foggers/misters, screens, heat storage (aboveground and underground). Often a range of technologies is used in one glasshouse. See for instance an article about Koppert Cress (at the end). First an explanation about the difference between heatpump and heat exchanger.

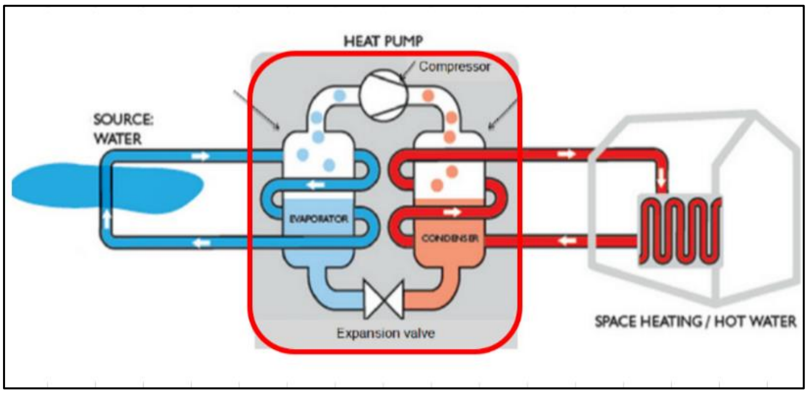
HEAT EXCHANGER

A heat exchanger enables passive transfer of heat from a warmer medium to a colder medium. In principle it is a system where two pipes come in close contact with each other. Each pipe has water (or air) flowing through it, but in opposite direction. Where the pipes touch, the hot medium cools down and the colder medium warms up due to passive heat transfer. The transfer can go from water to water, or from water to air, or from air to water, or from air to air (and of course other fluids or gases). Schematic drawing here →.



A heatpump does not use electricity, although electric pumps are used to maintain the flow. Heatpumps are often used for high-grade (= high-temperature) heat sources, e.g. geothermal or industrial heat.

HEAT PUMP



A heatpump actively 'pumps' heat **from a colder medium to a warmer medium**. A fridge is an example of a heatpump. Both contain an evaporator, a condenser and a working fluid called a refrigerant. While the inside of a fridge is colder than the room it is in, the refrigerant can still extract heat out of that fridge and make it even colder. The fridge releases the heat at the back, and thus actively warms up that room.

See schematic drawing above ↑. A heatpump (e.g. a fridge) requires electricity to compress the refrigerant liquid, which is the core of the heatpump action. The Coefficient of Performance (COP) is 3 to 5, in other words, the efficiency is 300 to 500%. The amount of heat (expressed in Watt) that is pumped into the room is 3 to 5 times the amount of electric energy consumed (also expressed in Watt).

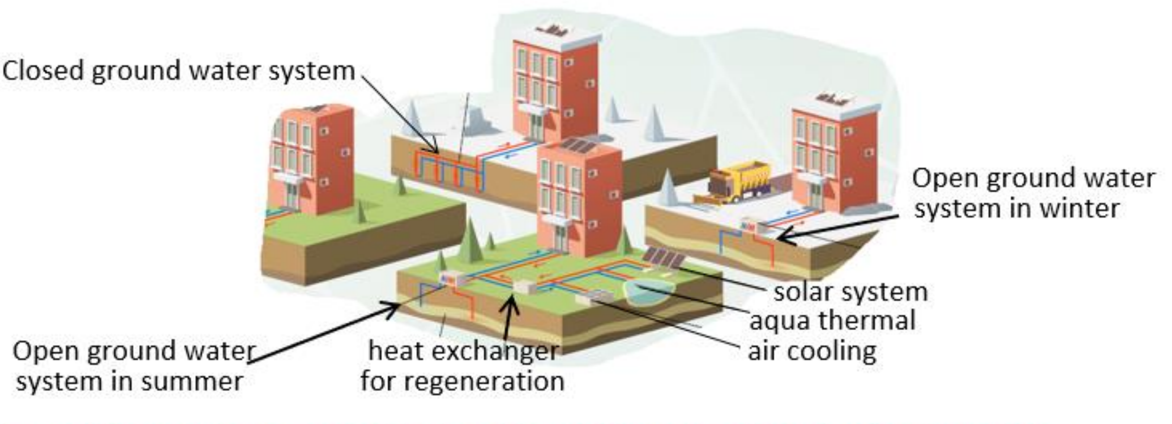
With the use of a heatpump, and availability of a lukewarm or warm heat source, growers are able to 'create' heat. The newly created heat can be supplied to others who need heat/energy. This is the principle behind the concept of a heat-producing (or energy-producing) greenhouse.

Fig. .. *Heat pump from Certhon (https://www.certhon.com/nl/greenhouse-solutions/ innovaties/energiebesparing-tuinbouw)*

Fig. …. *Heat pump extracts heat from a lukewarm source, e.g. greenhouse air (26 °C), or water in canal (16 °C) and transfers it to warmer water (e.g. 30 °C).*

WARM & COLD STORAGE IN THE AQUIFER (GROUNDWATER)

this is not geothermal heat



Source: Stichting Warmtenetwerk/Dutch New Energy Research (2020). Nationaal Warmtenet Trendrapport 2021: Bodemenergie

Description

- Note that this is not geothermal heat, but rather 'summer heat' stored in ground water.
- A greenhouse (or even large residential or office building) has a system on the property consisting of two bore holes: a warm and a cold well (bore), up to 300 meter deep.
- When heat is needed, (luke)warm water is pumped up from the warm water well.
- A heatpump with high efficiency (high COP) extracts the heat and delivers it to the user.
- The source water loses it heat and thus becomes cold, and pumped down into the cold well.
- This cold water will stay stored in the ground until it is needed for cooling (half a year later).
- Vice-versa: when cold is needed, cold water is pumped up and used for cooling. Thesource water warms up and is pumped back into the ground, but now in the warm well.
- The warm well is ca 20-30 ^{o}C; much lower than standard hot-water-pipe heating (60- 85 ^{o}C).
- Therefore a larger heat surface is needed, e.g. more pipes, wider pipes or pipes with fins.
- Optionally a heat pump can be used to create water of a higher temperature.
- For small projects (1 house) a 'closed loop' system can be used, containing glycol as coolant.

Regeneration

Over the course of a year, often more heat than cold is taken out. The difference in demand for warmth and cold causes an unbalance. This balance can be restored by 'regeneration': warm water (sometimes upgraded by a heat pump) is pumped down in the warm well. (Regeneration of the cold well is not common)

Advantages

- Heating with stored heat has a high efficiency and is cheap. Same for the cooling.
- It does not use fossil fuel, only electricity, which should be generated sustainably.
- The ground in the Netherlands is very suitable for warm & cold storage in most places.

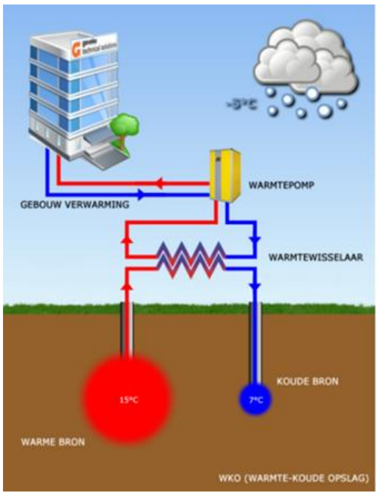


Fig. … a heat pump (yellow block) boosts the temperature of the water flowing through the heating system

Disadvantages

- Small risk of unwanted mixing of different groundwater layers.
- With 'closed loop' systems (using glycol as coolant) there is a small risk of leakage of glycol.

Conditions

- Permit required.
- Criteria: suitability of ground, no drinking water catchment, distance to other systems, etc.

Data for warm/cold storage in the Netherlands for 2020 (not greenhouse related):

- Number of heat networks connected: 188
- Number of dwellings connected: 21,000
- Amount of heat supplied in 2020: 0.8 PetaJoule
- Average life span: 25-35 years
- Average earn back time: 5-20 years
- Investment costs: €500 – €1,500 per kiloWatt
- Operational costs: €4 – €12 per kW per year

Source: Stichting Warmtenetwerk (details in first picture)

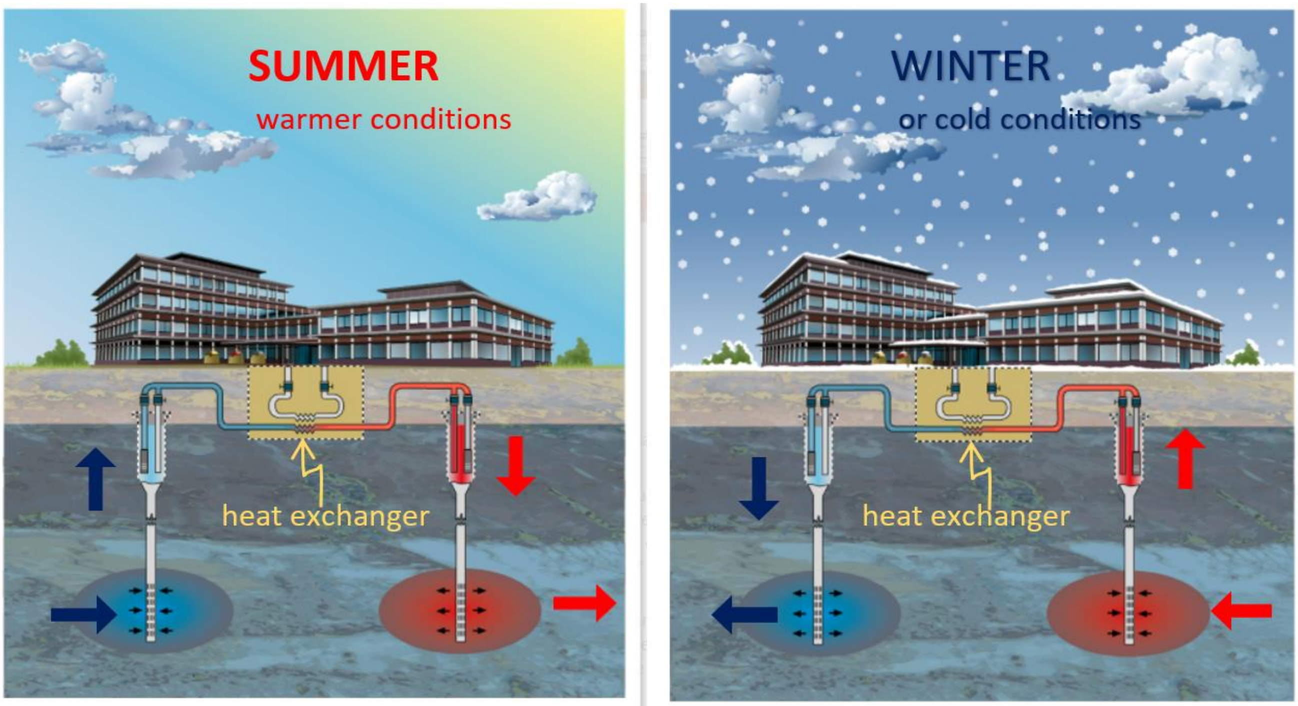
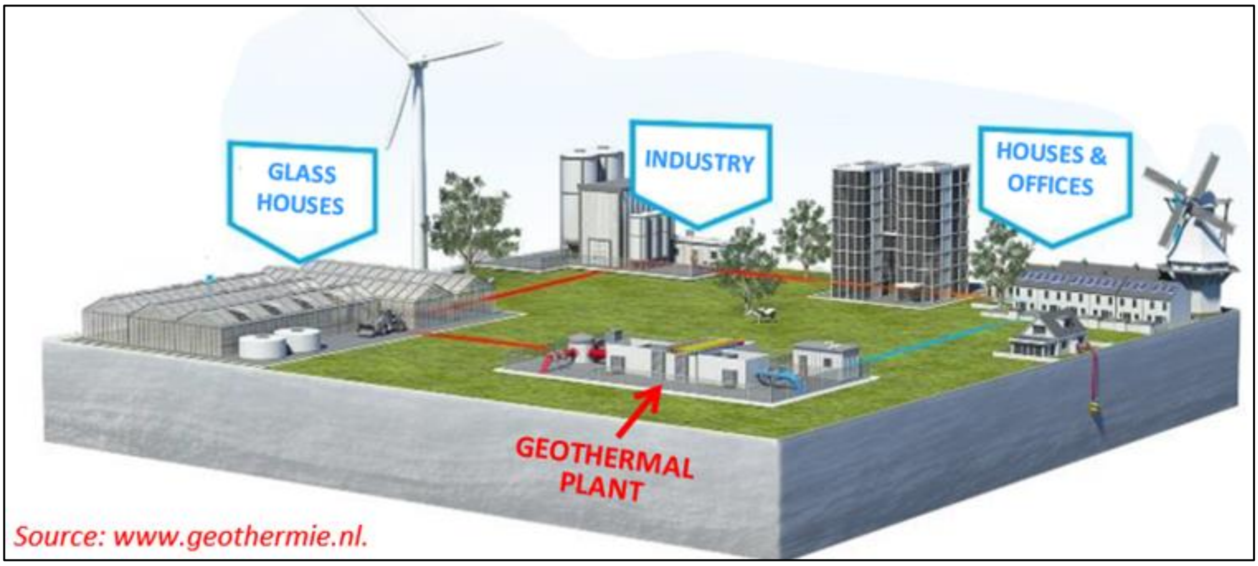
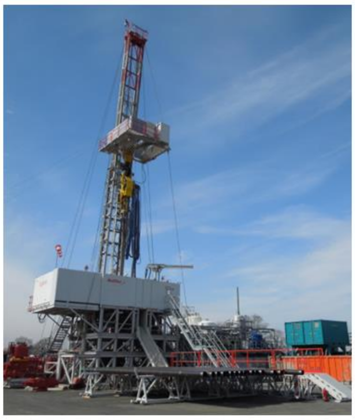


Fig … *Heat storage (regeneration) in summer and heat retrieval in winter.*

'CLUSTER' or NETWORK



Geothermal energy is incredibly expensive in the Netherlands, and not affordable for a single grower, not even a large corporate. Hence a consortium or a 'cluster' is formed, sometimes a public-private partnership to create the financial base to operate a network. A cluster can consist of some very large glasshouses + heavy industries + commercial buildings + many homes. One network can cover a huge area (e.g. the Westland cluster is 90 square kilometers). It contains a pipe network for heat and another network for CO2. The heat is often high-grade (say 80-90 ºC), either from an industry or a geothermal source, or both. Heat exchanger(s) transfer heat from the network to water in receiving heating system. Heatpumps can be used as well. The Dutch government supports & subsidizes most clusters, partly funded by levy on natural gas.



INDEPENDENT SUSTAINABLE GLASSHOUSE (NOT IN A CLUSTER)

Small and medium-size glasshouses can normally not take part in a cluster. So they stay independent, with their own heat and CO_2 supply. For example:
1: sustainable electricity + heat pumps + low-grade heat + heat storage + CO_2 by road tanker
2: biogas, green gas or biomass burned in a boiler (or CHP?) - CO_2 availability is often a problem.

Independent sustainable glasshouses can use biogas and/or biomass. Very large glasshouse complexes are not using bio-fuels, simply because there is not enough of it. Independent sustainable glasshouses can have a complex technology setup, consisting of a range of devices. They can qualify for government subsidy as well.

SEMI-CLOSED, FULLY-CONTROLLED GLASSHOUSE

Several greenhouse builders have developed a version of a semi-closed greenhouse. These have a very advanced climate control system, that can include cooling, heating, humidifying and dehumidifying. As the air is perfectly 'conditioned', no vent opening is needed to let heat out (in summer) or to let humidity out (in all seasons). Such greenhouses can have smaller or fewer vents in the roof than normal, and vents are used sparingly. Hence the name semi-closed greenhouses. The occasional greenhouse that is built with no roof vents at all, is called a closed greenhouse. Because in (semi-)closed greenhouses the air exchange is controlled and much lower than in normal greenhouses, it costs less CO2 to maintain a high CO2 concentration.

In some greenhouse brands, the air treatment happens **in air treatment units**, while in other greenhouse brands, the air treatment happens **in an air treatment corridor** (a narrow compartment along a wall) over the full length or width of the greenhouse. Air treatment that occurs inside the air treatment units or inside the corridor can be: greenhouse air and fresh outside air are mixed, temperature and/or humidity are adjusted. The treated air is blown into the greenhouse, often via perforated sleeves laying under the gullies, or sometimes it is blown out by large open pipes over the plant heads.

Here follow some examples.

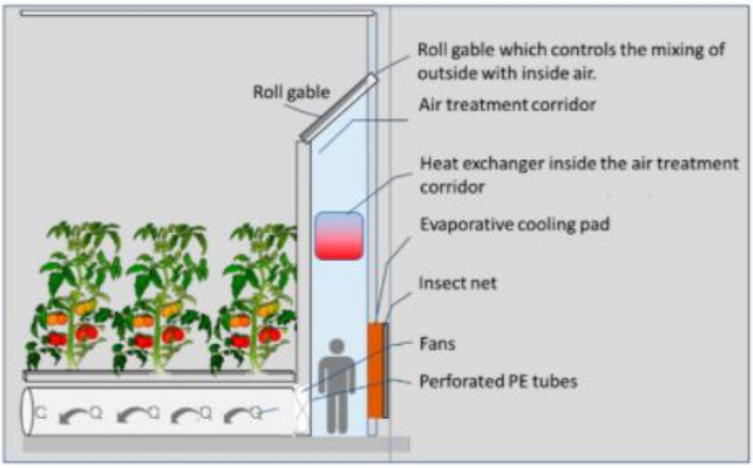


Fig. *Schematic drawing of a semi-closed greenhouse with an air treatment corridor and air distribution sleeves. This one contains an evaporative colling pad.*
Source: Sapounas et al. Design, Control, Performance Aspects of Semi-Closed Greenhouses. Agronomy 2020, 10(11), 1739

Semi-close greenhouse with a corridor

The Ultra-Clima glasshouse from KUBO was the first of this type. Nowadays there are more, e.g. Ultra-Clima of Enerdes and SuprimAir concept of Certhon, and more. Important components:

1. There is a long narrow corridor (compartment, 2 m wide) along a wall of the glasshouse.
2. A long window in the corridor can let a controlled amount of fresh air enter the corridor.
3. Two air streams (inside air and outside air) are mixed.
4. Heating in this corridor can increase the temperature and/or reduce the humidity.
5. A 'wet pad' in this wall can give adiabatic cooling (i.e. in summer, warm dry outside air is drawn through the wet pad, and made wetter and cooler).
6. Advanced software makes that the required conditions are created.
7. The treated / conditioned air is pushed into perforated sleeves and spread in the glasshouse
8. The reduce need for opening roof vents (in summer), makes it a semi-closed greenhouse.
9. It is easier and cheaper to maintain a high CO2 level.
10. The principles of 'The new cultivation' (*Het Nieuw Telen*) are often applied in the control.

Photos air treatment corridor

Fig. *Interior of the air treatment corridor of an Ultra-Clima greenhouse from KUBO (NLD). Outside air can enter from the top and mixed with greenhouse air. The conditioned air is sucked into the grey boxes and then pushed into a sleeve. This is at D'Vine Ripe in South Australia.*
Source: www.aabnl.nl/en/project/68/ultra-clima-kas-voor-dvine-ripe.htm

Fig. *The air distribution sleeves in the Ultra-Clima greenhouse from KUBO, at D'Vine Ripe in South Australia.*
Source: www.aabnl.nl/en/project/68/ultra-clima-kas-voor-dvine-ripe.htm

Fig. *The SuprimAir greenhouse made by Certhon. Left: the roundish shape is a long window to let air into the corridor. Below that is a wet pad. Heating is also included.*
Right: the sleeves under the gutters. *Source: https://www.certhon.com/*

Semi-close greenhouse with air treatment units outside

In other glasshouse brands, there are individual air treatment units installed outside the glasshouse along the wall. One unit can serve one row (one gully), or several. They (can) contain a fan, heater, heat exchanger, etc. These units assist in using less ventilation through the roof vents, and are often used in semi-closed greenhouses.

Examples of small air treatment units outside the glasshouse along a wall. *Source: www.itbclimate.com/product/green-vent/*

Air treatment units made by Technokas. Left the first model in 2009; right the current models.
https://technokas.nl/tag/het-nieuwe-telen/

Treated air is pumped through sleeves that are under the plants, or is released above the plants.

PART 4 – ENERGY & HEAT STORAGE

Overview

Heat exchangers and heat pumps work with various sources of energy. Here is an overview.

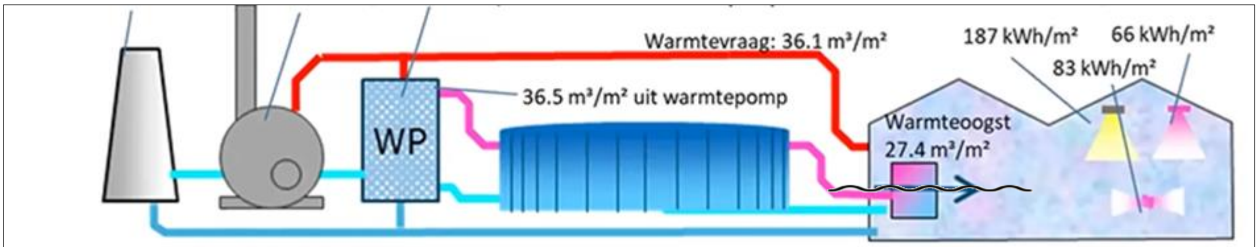
1) High-grade (= high-temperature) heat is usually geo-thermal heat or industrial waste heat. This can be used directly, and does not need a heatpump. It can also be stored. Due to economy of scale, often a cluster of greenhouses is connected to a high-grade heat source.
2) Low-grade (= low-temperature) heat can come from:
   - an external source
   - internal sources
   - a buffer (daily storage)
   - warm/cold underground storage (seasonal storage)
3) External source of low-grade heat can be:
   - industrial site (factory, data centre, cool store, waste processor, waste water treatment)
   - surface water (a canal or pond that has warmed up in summer)
   - (aquifer, but usually heat is injected by grower for storage, so is not an external source)
4) Internal source of low-grade heat can be:
   - hot air from the greenhouse in sunny conditions (by a heat-pump)
   - humidity (= latent heat) from the greenhouse, that releases heat by condensation
   - lamps or LED units (some LEDs are water-cooled, so heat can easily be harvested)
   - aquifer, after heat was injected and stored for a period of weeks or months
5) Low-grade heat can be used in various ways:
   - directly pumped into the heating system
   - fed into a heatpump so the heat is added to lukewarm water to increase its temperature
   - stored in a 24-hour buffer and used that night
   - added to the warm well in the aquifer

Peaks and emergencies

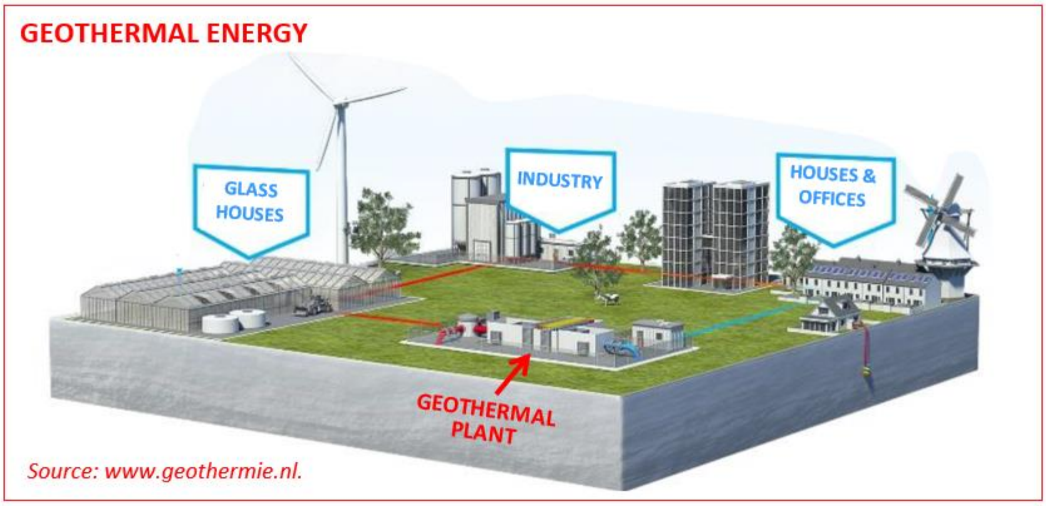
In the energy transition period (roughly 2010-2030), the goal is not yet to achieve 100% coverage by renewable energy, but to achieve economical coverage. Small amounts of fossil energy can still be used, especially for peaks in heat demand. The fossil fuel is combusted in a boiler, and many growers like to keep a boiler available for emergency situations. Also a CHP is still allowed for peaks and as an emergency kit.

Fig. *Illustration of the complexity. Here only 3.4 m^3 natural gas was used per m^2 (ca 10% of standard energy use), while the production was standard (capsicum 31 kg/m^2).*

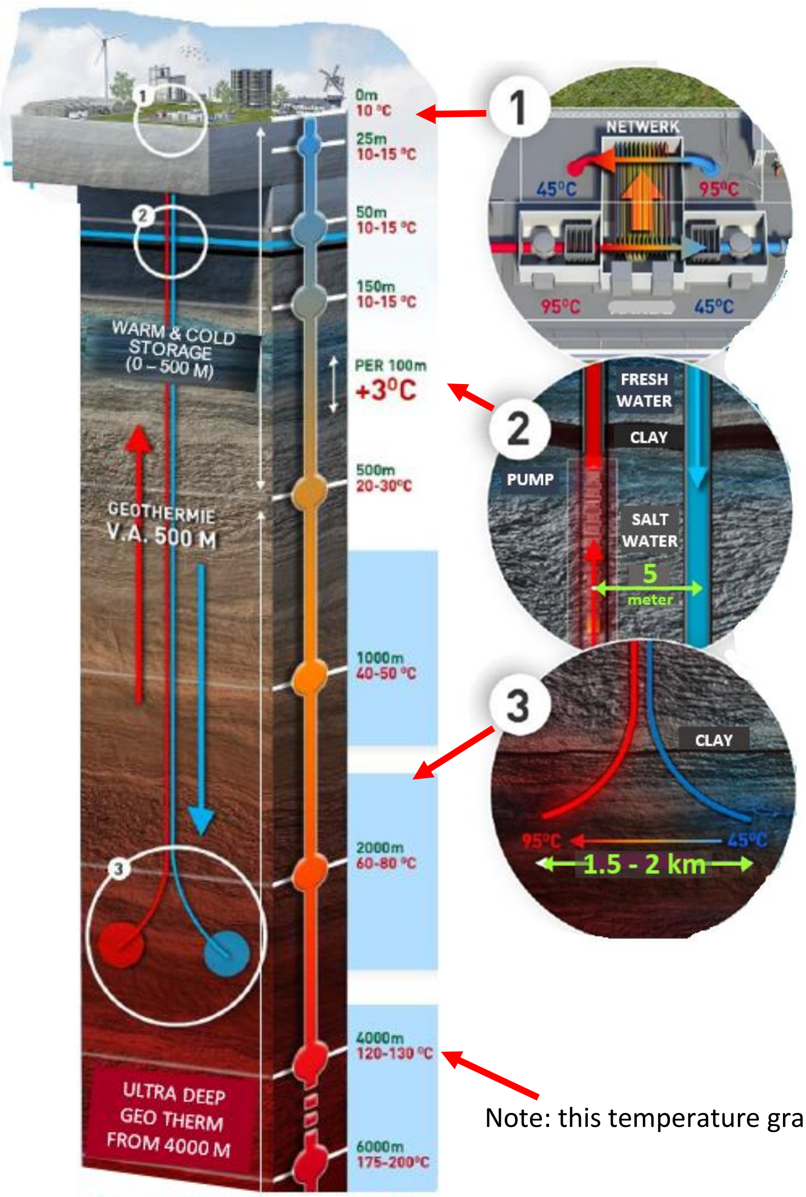
Source: Delphy Improvement Centre in Bleiswijk (NLD), Het Nieuwe Telen Paprika 2.0. Project nr. 20047



GEOTHERMAL ENERGY



Source: www.geothermie.nl.



Source: www.geothermie.nl.

Note: this temperature gradient is in the ground <u>in the Netherlands.</u>

DESCRIPTION

① A huge heat exchanger located in the geothermal plant receives hot water that is pumped up from deep down. In the heat exchanger, heat is transferred from the source water to the water of the heating system (without mixing the different water streams!). The then-colder source water is pumped back to the underground via the cold water pipe.

② Two pipes are drilled circa 5 meters apart. One is the production pipe (for hot water coming up) and the other is the injection pipe (for cold water going down). Inside the hot water pipe hangs a pump that pumps water up from a depth of circa 1.5 to 2.5 kilometer, where the water temperature is 70 – 100 °C.

③ The inlet of the hot pipe and outlet of the cold pipe are deep down, and are spaced out about 1500 – 2000 meter. The two water bubbles may gradually flow and mix. Cold water may warm up due to the geothermal energy at that depth.

GEOTHERMAL ENERGY (CONTINUE)

Advantages

- Independence of season and weather
- Durable, sustainable, renewable
- Low CO2 emission
- Reliable

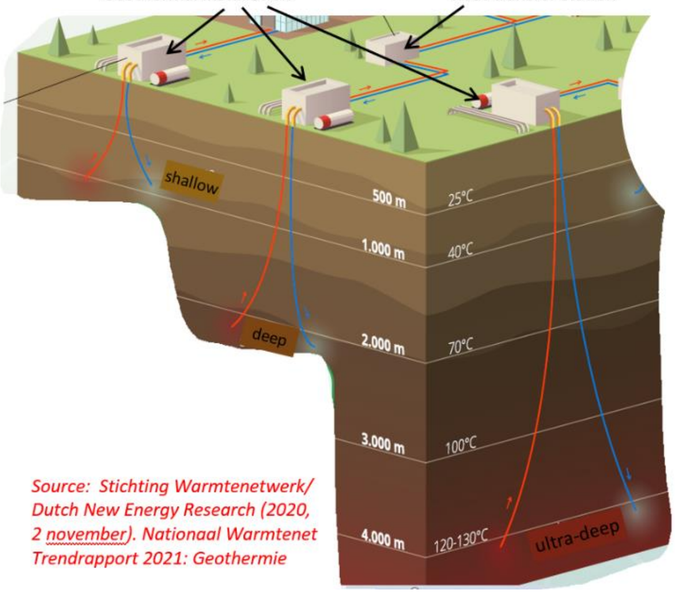
Disadvantages

- Very high investment costs
- Small risks of: ▪ gas while drilling,
  ▪ radioactive particles,
  ▪ water layers mixing, ▪ seismic activity

Conditions (in the Netherlands)

- Permits needed.
- Space needed for drilling (0.5 to 1 ha).
- Ground and water layers must be suitable.
- Geological conditions must be safe.
- Minimum scale 500 dwellings for deep geothermal, and 4,000 dwellings for ultra-deep geothermal.

Temperature profile underground in the Netherlands



Source: Stichting Warmtenetwerk/ Dutch New Energy Research (2020, 2 november). Nationaal Warmtenet Trendrapport 2021: Geothermie

Data for Geothermal energy in the Netherlands for 2020 (not greenhouse related):

- Number of heat networks connected: 24
- Number of dwellings connected: 1,000
- Amount of heat supplied in 2020: 5.6 PetaJoule
- Average life span: 30-40 years
- Average earn back time: 15 years
- Investment costs: €850 – €2,500 per kiloWatt
- Operational costs: €100 – €200 per kW per year

Source: Stichting Warmtenetwerk (see in picture)

- Number of greenhouses with geothermal in 2018: 81
- Greenhouse area with geothermal heating in 2018: 741 ha
- Geothermal energy used in greenhouse industry in 2018: 3.6 PJ

Source: Energie monitor. Van de Velden et al., WUR, 2018

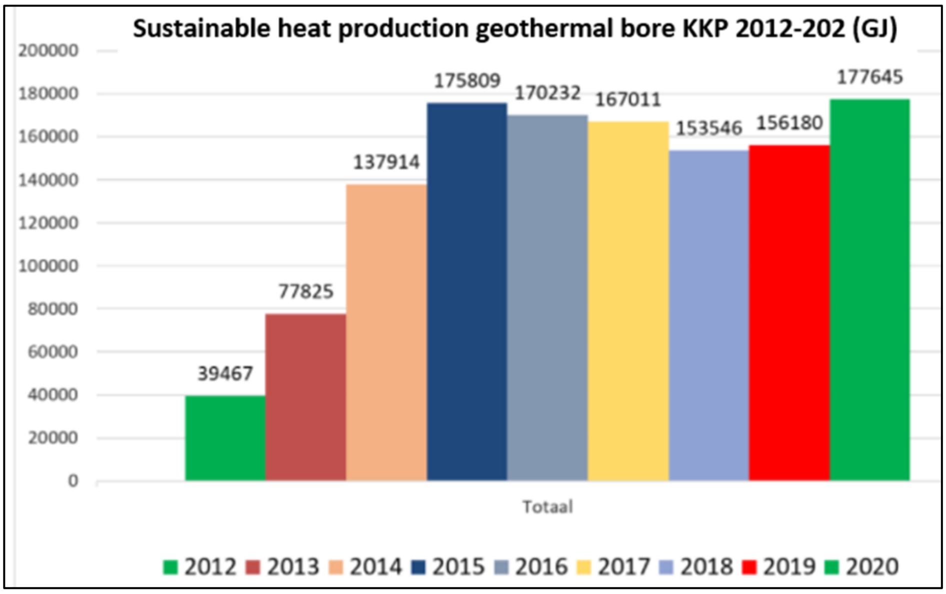
https://www.kasalsenergiebron.nl/content/docs/Over ons/Folder_Kas_als_Energiebron_in_English.pdf

Geothermie at Ammerlaan, The Great Innovator, potplant grower Source: https://www.ammerlaan-tgi.nl/

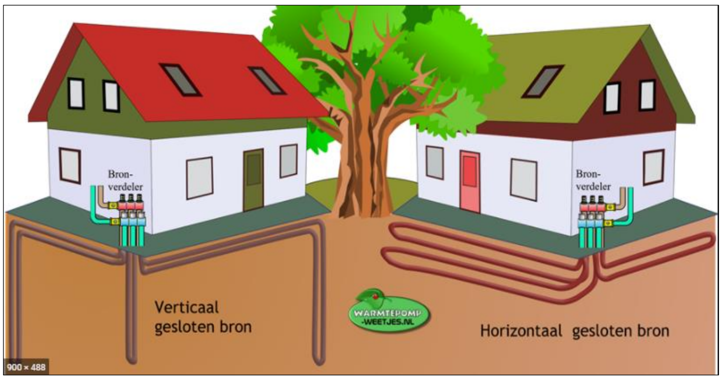
Here are some numbers about two geothermal projects.

Example 1, Ammerlaan, The Green Innovator, in Pijnacker, NLD).

- It produces 600 m3 water per hour of high temperature
- saves 25,000 tons of CO_2 per year
- 6.5 ha (own) + 24 other growers
- 75 ha glasshouses total
- 543 homes
- swimming pool + sport hall + High school



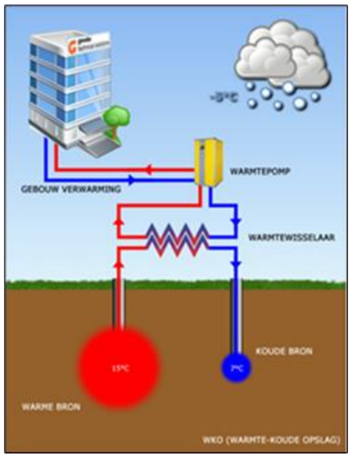
RECAP: THREE DISTINCT SYSTEMS USING 'THE GROUND'



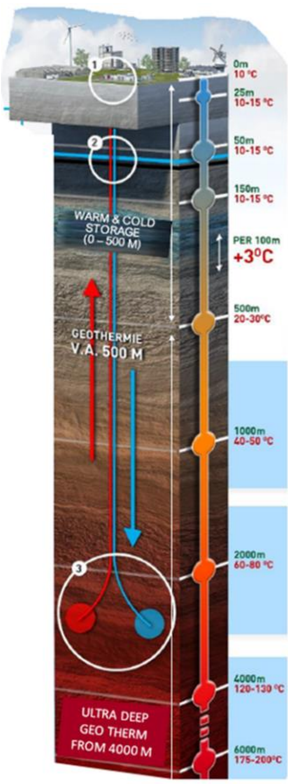
[1] EARTH / WATER HEAT PUMP
(not discussed yet)

- Most used for homes, not glasshouses
- Shallow (2 meter), horizontal
- Water temperature 7 – 15 °C year-round
- Or deeper (100 meter), vertical, 10 °C
- Summer: directly used for cooling
- Winter: heat pump → 35 - 45 °C
- Tubes filled with 'brine'
- Tubes in contact with the ground

[2] WARM & COLD STORAGE IN THE AQUIFER
(discussed some 10 pages back)



- Water temp:
  - cold well (bore) ca 10 °C;
  - warm well (bore) ca 30 °C
- Depth: 200 – 300 meter
- Summer heat stored underground
- Small-scale
- much simpler than geothermal



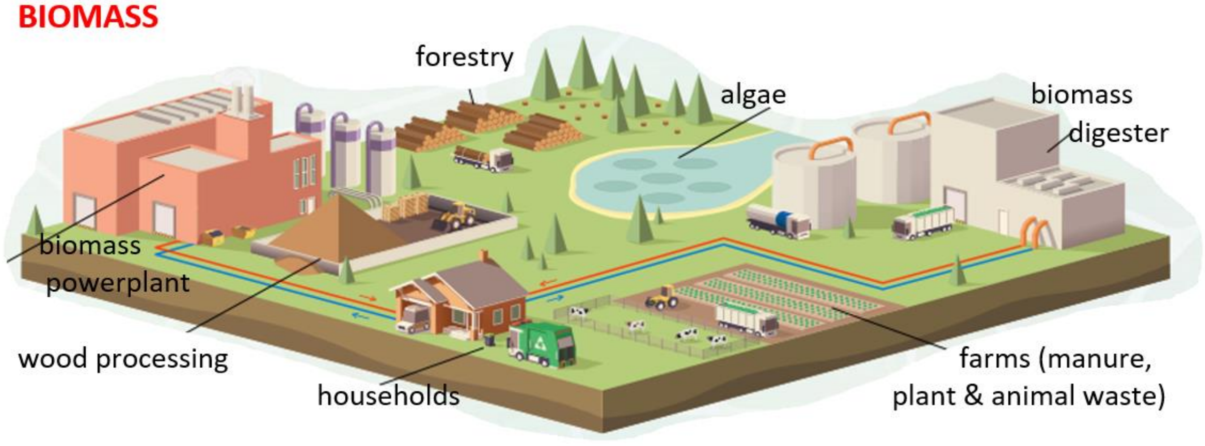
Source: www.geothermie.nl.

[3] GEOTHERMAL
(discussed some 3 pages back)

- Deep: 3 – 4 kilometer (in NLD)
- Hot: 80 – 90 °C
- Extremely expensive
- Large scale, network
- Glasshouses + homes

BIOMASS

Source: Stichting Warmtenetwerk (details in picture)



source: Stichting Warmtenetwerk/Dutch New Energy Research (2020). Nationaal Warmtenet Trendrapport 2021: Biomass.

Description

- Biomass is organic material from animal, plant or algae origin, in solid or liquid form.
- Energy can be extracted from biomass by burning it in a biomass power plant.
- Biomass can be converting via fermentation or gasification into biogas or syngas.
- Biomass & biogas can be used in a boiler or a co-generator (Combined Heat & Power, CHP).

Carbon cycle

- CO2 is absorbed from the air during the growth phase.
- CO2 is emitted during combustion, fermentation or gasification.
- This is considered a CO2 neutral cycle.
- However, transport of biomass emits CO2, so needs to be minimal.
- Biomass for heat supply must meet sustainability criteria.
- Whether biomass can be used for CO2 enrichment depends on several factors.

Advantages

- Biomass is suitable as a base load, peak or backup source.
- Heat production from biomass is a proven technique.
- Heat from biomass is high-grade (high-temperature), so little adaptation needed to existing heating system.

Left: one example: a medium-size biomass installation in IJsselmuiden (NLD). Waste from landscaping is burned and supplies heat to 37 ha of glass. Built in 2019. Heat production in 2020 was 182,500 GJ, equivalent to 5.8 Million m^3 natural gas. The same region also has a geothermal plant, and of course a heating network.

Source:https://www.destentor.nl/kampen/bouw-regionaal-warmtenet-koekoekspolder-stap-dichterbij~ad3211ff/

Disadvantages

- Biomass power stations emit nitrogen and particulate (although limited amounts).
- Availability of biomass depends on supply and demand and can be uncertain long-term.
- The sustainability (durability) of different types of biomass can be questionable.

Conditions (in the Netherlands)

- Biomass plants must meet strict emission standards.
- Biomass must be produced and obtained in a sustainable manner.
- Minimum scale recommended: 500 to 1,000 homes for a woody biomass plant.

Data for biomass from the Netherlands for 2020 (not greenhouse related):

- Number of heat networks connected: 41
- Number of dwellings connected: 70,000
- Amount of heat supplied in 2020: 3.6 PetaJoule
- Average life span: 25 years
- Average earn back time: 5-10 years
- Investment costs: €500 – 2,500 per kiloWatt
- Operational costs: €30 – 120 per kW per year

BIOGAS and GREEN GAS

Biogas is released during the fermentation/composting or gasification of biomass. It does not necessarily have the same quality as natural gas. Large scale gasification is very expensive.

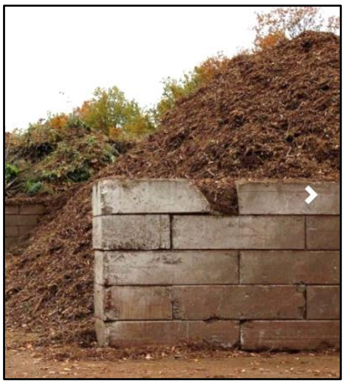
Green gas is biogas that has been upgraded to the quality of natural gas.

Biogas is now mostly produced from green waste (vegetable, fruit and waste from the food industry). It is also produced by water treatment plants and by installations for digestion or fermentation of manure. The supply grows only very slowly (in the Netherlands). Suppliers now have the ambition to grow to 70 PJ green gas in 2030.

Green gas can be fed into the infrastructure for natural gas. It can also be used for hybrid heatpumps or for assisting boilers in a warm water network. Green gas is intended more for residential use. The company AgroEnergy has agreements with several green gas producers. They offer various technical options and various reimbursements schemes for buying green gas, and on the other hand for selling green gas. Instead of selling the green gas for use in a local CHP or boiler, they prefer to feed it into the natural gas network, from where growers can purchase it for use in their CHP or boiler. AgroEnergy issues a certificate (Garantie van Oorsprong, Guarantee of Origin) with their products.

A biomass composting facility producing methane

A small company has built a composting facility in 2005 in Sittard (NLD) for processing green waste (garden and food waste). Composting produces methane, which is a 25 stronger 'greenhouse gas' in terms of global warming, than carbon dioxide. The main intention was to put this methane gas to a good use. Currently the company produces biogas (green gas?), as well as heat that is used for heating 1100 homes in the area, and electricity that is sold to power company Vandebron. See photos here below.



Source: vandebron.nl/energiebronnen/bron/f8b110b4-0ce2-47b1-95ce-a57c011e41d0

SOLAR ENERGY

Solar energy is obviously very important for greenhouses. It comes in different forms:

1. Solar heat is trapped in a greenhouse, which is a solar collector.
2. Surplus warmth can be extracted from a greenhouse
3. Warmth can be harvested from Photothermic cells (PT)
4. Electricity can be generated by Photovoltaic cells (PV)

(2) This is related to cooling, which is common practice in some ornamental crops that need low temperatures. Heat is extracted from the greenhouse air or the growing medium using a heatpump. While the heat pump cools the matter (water, air, soil, growing medium) on one side, it heats up the matter on the other side. The heat produced can be utilised or can be stored either in aboveground buffers (day storage) or in underground aquifers (seasonal storage).

(4) The number of greenhouses with Photovoltaic cells is increasing. PV cells are the main method of producing sustainable electricity in the greenhouse industry. But the percentage of solar in the total amount of sustainable energy is minimal.

SOLAR PANELS ON A GREENHOUSE

Source: Haalbaarheid transparante zonnepanelen. van Staalduinen. InnoAgro. 2019

Solar panels on the ground are effective, but are not desirable where ground space is a premium, as in NLD. Solar panels on a shed or packhouse are beneficial in two ways: they generate energy and at the same time keep the workspace cool, so no money is spent on a shade screen.

Fig … *Solar panels (SanSolar from Certhon). https://www.certhon.com/nl/greenhouse-solutions/innovaties/energiebesparing-tuinbouw*

The idea of solar panels on a greenhouse roof is tempting, because that opens up a vast area. There are greenhouses with photovoltaic cells (PVs) installed on (parts of) the roof. The advantage (power generation) must be weighed against the disadvantage of uncontrolled year-round light loss. Even 'standard' solar panels are sometimes installed on a greenhouse roof. They are efficiency and relatively cheap, so the price per kWh is low. Another disadvantage they have, on top of blocking the day light), is that they are heavy, so the greenhouse structure must be enforced. Different types of PVs and different fixing systems all have their own pros and cons.

Flexible (bendable) solar panels

These panels are flexible in material and in applicability, lightweight, can be ordered to size, can easily be retrofitted, can be glued on the greenhouse roof and other surfaces (heat storage tanks, sandwich panels, etc).

The price of a kWh of power produced is surprisingly favourable. The economic feasibility depends on site-specific variables such as the orientation of the greenhouse, roof system, glass size, accessibility, crops, lighting, electricity need, electricity price, savings on heating and/or cooling costs, subsidies and tax opportunities, and life span of the greenhouse.

The feasibility can be assessed by calculating the LCOE (levelized cost of energy), which gives the cost price of a kWh of electricity over the life of the installation. These prices can then be compared with the price of electricity from a CHP or from the grid. In most cases, the flexible panels are not yet feasible, but they are an interesting technique for the near future.

Dye sensitized Solar Cells (e.g. Brite Solar)

The technique is still under development, and unproven but promising. These dye-sensitized solar cells (e.g. of Brite Solar) use an innovative way to print solar cells on glass (Teckwin). The solar panels have a transparency of 70% and a high thermal insulation value. They can be made to size and with the thickness of standard glass. They are good for retrofitting in existing greenhouses. As the PV layer is located between two glass layers, a roof cleaner can be used without any problems (unless also a coating is applied on the outside). PV glass is strong compared to safety glass. Replacing a broken solar panel is equivalent to replacing a standard greenhouse window. The performance of these panels at higher temperatures (e.g. high in the glasshouse) is not known. The light transmission can be different for different wavelengths. The spectrum under the panels is not known yet, but may be important.

Cadmium Telluride (CdTe) solar panels or thin film solar.

These solar panels look like tinted glass. They have a light transmission of only 20%, a low efficiency and a poor perform under higher temperature. Hence, they cannot compete with alternatives. Also Info: www.sanko-solar.nl/nl Sirius solar.

Glass panel with crystalline solar cells (mono or poly)

Nearly-fully transparent panels are relatively expensive per m² and have a lower yield per m², so are not competitive. Semi-transparent crystalline solar panels can be an option. The PV cell itself is not transparent, but the PV cells are mounted between transparent glass layers, so a semi-transparent panel is created. They can be beneficial depending on the crop, location, etc. This technique is offered by various greenhouse builders and has been widely applied, e.g. at Zuidkoop in De Lier, and many more outside NLD (e.g. in Germany, France and Canada).

There are monocrystalline, polycrystalline and amorphous solar panels. All are made from silicon, which is available in abundance and is a very durable element. There are differences between them, but we leave that for now.

Hortisolar panels in Italy, solar roof, 2MW.

Hortisolar in Zevenbergen (NLD), 390 kWp.

Source: /www.hortisolar.nl/portfolio

Crystalline solar panels are custom-made, and made to order, made to size, and be made with a certain light transmission, obviously related to the number of PV cells per m^2. The maximum light transmission is 65%. The top glass layer has a coating that makes the light slightly diffuse. The bottom layer can (optionally) be made of synthetic to be lighter and cheaper.

The product complies with all NEN and ISO rules, and is insurable and affordable. Their technical lifespan is 25 years plus. These panels are most suitable for new construction, because then the additional weight is accounted for. Retrofitting involves changing the windows, or the whole roof.

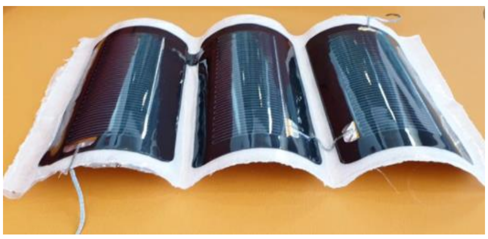
The thermal insulation value of these solar panels is slightly higher than that of standard glass, so snow melts a little slower. At hight temperatures, the performance is reduced. Mono-crystalline cells perform better at higher temperatures than poly-crystalline or thin-film panels. In the near future, a particular type of mono-crystalline cells will enter the market that perform well with a wider light spectrum and with diffused light.

A greenhouse roof cleaner can drive over PV glass without a problem, but no brushes should be used on panels that have a coating.

The costs of the panels depend on the number of cells per window and the glass size. Mounting costs are only marginally higher than mounting normal glass. Standard rods can be used.

Suppliers

Several greenhouse builders have PV glass in their portfolio: www.hortisolar.eu; www.bomgroup.nl; www.gakon.nl; www.technokas.nl; www.vanderhoeven.nl; www.debetsschalke.com; www.reytecinnovationprojects.nl; www.horconex.nl



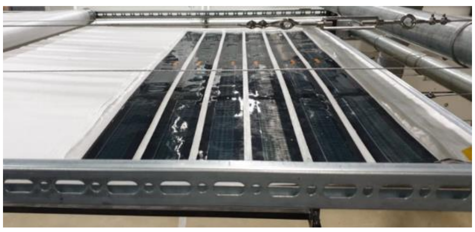


Fig. *Researchers at WUR are looking at integrating solar cells in energy screens*

Source: https://www.kasalsenergiebron.nl/nieuws/schermen-met-flexibele-zonnecellen-is-uitdagend-project/

GREEN ELECTRICITY (GREEN POWER)

Green electricity is produced cleanly and sustainably, in NLD mostly by wind, and less by sun, hydro and biomass. Green power makes up about 20% of the total electricity consumption in NLD. Some power companies generate and sell their own green power, while others buy from small suppliers and sell to (small) customers. (e.g. Vandebron/Essent, AgroEnergy, Energiedirect, and more).

There are hundreds of producers/suppliers, varying from enthusiastic individuals with one small wind turbine, to corporates operating huge wind farms or solar parks. Many are farmers or other landowners, others have wind turbines in the North Sea. There are several technical options and price structures for supply to the grid, depending on the volume.

Fig. *Some suppliers of green electricity, Mum & Dad investors.* Source: vandebron.nl/energiebronnen





Consumers entering a contract can opt for power from either wind, sun, hydro or biomass. Some power companies (e.g. with Vandebron) allow customers to opt for a particular supplier too. Consumers get a Guarantee of Origin ('*Garantie van Oorsprong', GvO*) with the energy products they buy. The GvO certificates are issued by a certificating organisation while the process is overseen by the Authority for Consumer & Market.

Interestingly, the green power goes through the same cables as the 'standard' power, and at the same time. The green power company injects a certain amount of green power into the network, and their consumers buy that amount.

AgroEnergy is working on sustainable energy for greenhouse horticulture and are keen to cooperate with growers. Several power companies also buy and sell green gas.

Photos: vandebron.nl/energiebronnen

Suppliers

Here follows a fairly complete list of power companies supplying green electricity in the Netherlands, in order of sustainability, with the greenest suppliers first: Pure Energie, Vrijopnaam, Energie VanOns, Om-nieuwe energie, Powerpeers, HVC Energie, Energy Zero, EasyEnergy, Vandebron, Greenchoice, Eneco, ENGIE, Budget Energie, NLE, Essent, EnergieDirect, Neosmart, Vattenfall (NUON), Clean Energy, Oxxio, Delta, Innova Energie, Woonenergie, Fenor, United Consumers, Nieuw Hollands Energiebedrijf, Servicehouse, MAIN Energie.

Carbon intensity of electricity

The carbon intensity of electricity refers to the number of grams of carbon dioxide (CO2) that it takes to make one unit of electricity. The unit is gram CO2 per kWh. Electricity generated in coal power stations have a very high carbon intensity, because a lot of carbon dioxide (CO2) is produced as part of the power generation process. Electricity from hydro and solar has a very low carbon intensity. The lower the carbon intensity, the greener the electricity.

Source: https://www.nationalgrideso.com/electricity-explained/carbon-intensity-explained

'ELECTRIFICATION' OF GREENHOUSE HEATING

Glasshouse will rely more and more on electricity for their control, which is called electrification of heating. The electricity does not enter a heating system, but a heatpump. The heatpump uses sustainable heat as input. So the system is:

Heat pump(s) + green electricity + sustainable heat

Options are:

- Own heat sources, such as warm greenhouse air, condensation energy, heat from lighting, excess heat from own cool store. This is mostly low-grade heat (25 - 30 ^{o}C).
- External heat source: canal water, nearby industry, milk factory, water treatment plant
- Lukewarm water from the aquifer (often heat was pumped into the aquifer in summer)

Technology required:

- heat pump(s) to increase the temperature
- Overnight storage in heat buffer
- Seasonal storage in ground water (aquifer)

Fig. *Green electricity is used for lighting, and the excess energy contributes to heating either directly or after being stored*

Source: Pylot by Kubo . www.pylot.nl/nl

HYDROGEN (green and blue)

Source: www.government.nl/ministries/ministry-of-economic-affairs-and-climate-policy/documents/publications/ 2020/04/06/government-strategy-on-hydrogen.
And: www.government.nl/documents/publications/2020/04/06/government-strategy-on-hydrogen
And: technologystudent.com/energy1/hydrocycle1.html

Hydrogen (H2) is a very powerful and clean fuel. Under normal pressure it is a gas, but when compressed it becomes a liquid. It is produced in an electrolyser by splitting water (H2O) into oxygen (O2) and hydrogen (H2). When hydrogen is combusted in a fuel cell to produce energy, it releases only water. The clean cycle does not necessarily produce carbon dioxide or other by-products.

Hydrogen is odourless, tasteless, colourless and non-toxic. It has a high energy content by weight, nearly three times that of gasoline. Hydrogen is not a *primary* energy source such as natural gas, coal, biomass or wind, but it is called an 'energy carrier' that can transfer and store energy. However, in everyday language it is called a fuel.

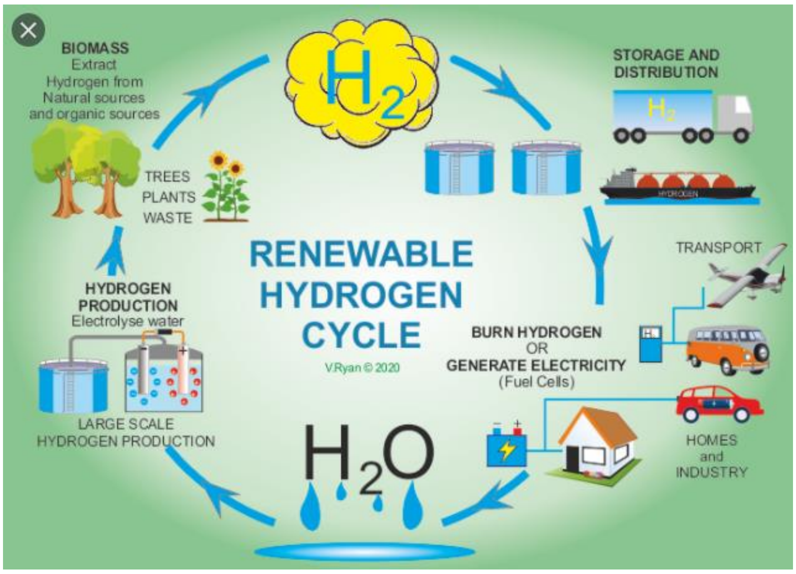


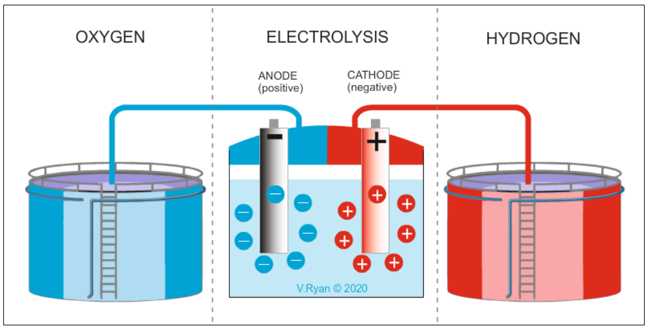
Fig. *The water - hydrogen cycle. At the left an electrolyzer and also an indication of hydrogen extraction from biomass.*

Below: an electrolyser splits water (H2O) in hydrogen (H2) and oxygen (O2). Two platinum / iridium electrodes are charged, one positive and one negative.

Source: https://technologystudent.com/ energy1/hydrocycle1.html

Hydrogen does not exist naturally and must be produced. There are various methods, and the resulting product gets a name with a colour:

- Brown hydrogen is produced from natural gas (or coal gasification), with a lot of CO2 released
- Grey hydrogen is produced by Steam Methane Reforming (SMR) of natural gas
- Blue hydrogen is basically grey hydrogen, but with carbon dioxide (largely) captured.
- Green hydrogen can be produced from water by electrolysis using (renewable) electricity. See figure.



- Green hydrogen (2). Alternatively hydrogen can be produced from biogenic fuels. It's green hydrogen if the fuels are produced sustainably.

Green hydrogen is much more expensive than grey. Blue is expected to stay cheaper. Green hydrogen can become cheaper by 2030 by scaling up production from MegaWatt to GigaWatt.
Source: https://technologystudent.com/ energy1/hydrocycle1.html

Advantages of hydrogen

1. Hydrogen can be stored as liquid gas. This makes it possible to transport by tankers.
2. Hydrogen fuel cells are efficient, operating at an efficiency of 80%. [Compare this with generating electricity by burning fossil fuel in a power station: efficiency is 35%, plus ca 10% is lost in transport].
3. The emissions from hydrogen fuel cells, are non-polluting.
4. Fuel cells have a wide range of applications: vehicles, houses and businesses.
5. Cars powered by fuel cells are much more energy efficient than cars on petrol.
6. Moving to a hydrogen economy reduces pollution, environmental damage, global warming.

Disadvantages of hydrogen

1. Sustainable hydrogen production needs sustainable electricity for electrolysis.
2. Fuel cells are expensive. Cost will fall due to increased demand and scale of production.
3. Hydrogen is harder to store (as a gas or a liquid) than other fuels, making it more expensive.
4. When fuels cells operate outside a specific temperature range, they are less efficient.
5. Huge investments in infrastructure needed, for hydrogen (gas & liquid) storage & transport.

Fig. *Source: www.fool.com/investing/2020/07/31/1-energy-company-to-watch-in-hydrogen-fuel.aspx*

Hydrogen is not new. It has been produced commercially in NLD since the early 1900s, and was used as town gas until the 1960s. Currently, a very small amount of hydrogen is already mixed with natural gas and transported through existing gas pipelines.

A consortium in Denmark has built the first-of-its kind hydrogen production facility and started producing in 2018. The system is a 1.2 MegaWatt proton exchange membrane (PEM) electrolyser. It is powered by electricity from wind turbines, thus wind energy is converted to hydrogen. Hydrogen is produced when electricity prices are low, which is typically when wind energy is abundant. The hydrogen can be stored or transported easily to customers.
So far it has produced 120 tons of hydrogen, enabling 24/7 delivery of hydrogen to an industrial customer. The electrolyser is highly dynamic and flexible in terms of power fluctuations. Therefore it was able to balance the electricity grid to better utilize renewable energy sources. This facility can supply a fleet of more than 1,000 fuel cell electric vehicles. Denmark is on the cutting edge of clean power. In 2019, 47% of electricity consumed in Denmark came from wind power. *Source: https://www.3blmedia.com/News/Cummins-PEM-Electrolyzer-Will-Supply-Hydrogen-Denmark-Europe-Demonstrating-Strong-Hydrogen*

Fig. *The Cummins PEM Electrolyser in Denmark, Europe.* *Source: https://www.3blmedia.com/News/Cummins-PEM-Electrolyzer-Will-Supply-Hydrogen-Denmark-Europe-Demonstrating-Strong-Hydrogen*

Many European countries are expecting that an extensive international hydrogen market will emerge, and they want to play a role in it. Dutch companies are planning for production especially of green hydrogen, primarily from electrolysis using sustainable electricity, and secondly based on biogenic feedstocks, provided they have been produced sustainably. Thirdly there will also be a place for blue hydrogen as long as it does not impede the growth of green hydrogen.

In the Netherlands, the collective plans for 2025 add up to a total electrolysis capacity of over 800 MW (0.8 GW) plus production of 15 kilotonnes of green hydrogen from biogenic fuels. For 2030, the plan is to have 3-4 GW electrolysers capacity established. There is a need for a hydrogen infrastructure, including transport and storage. Potentially the infrastructure that is/was used for natural gas can be used for hydrogen, after modification.

Production of hydrogen can be an excellent method of storing a temporary surplus of electricity. For instance, when there is an overproduction of electricity from solar panels or wind turbines, when supply exceeds demand, wind turbines are stopped. Also, there is a need for electricity storage. Batteries have their limits. A possible solution is to produce hydrogen in an electrolyser that is driven by the surplus electricity. Hydrogen can be the end product of an offshore generator park, because transport of hydrogen may be more efficient (due to less losses) than transport of electricity via a long cable. Ultimately hydrogen can be used as a substitute for diesel in heavier tractors and machinery. A disadvantage can be that hydrogen production requires a lot of energy. However, that should not be counted as a disadvantage in situations where the hydrogen is made only from surplus solar or wind energy.

Hydrogen compression requires a lot of energy as well. There is no need to highly pressurise the hydrogen if it is to be used close to where it is produced. In contrast, pressurising is needed if it is to be used as fuel in vehicles, or if it needs to be transported. A lot of energy can be packed in a small volume.
There are still a lot of questions around hydrogen use, both technical and economic. The government is stimulating research. The Dutch university for agriculture, WUR, is studying hydrogen production and use in agricultural situations on a practical scale. They use a hydrogen-fuelled fork-lift as a test and demonstration object.

OTHER INNOVATIONS

'DAYLIGHT GREENHOUSE' COLLECTS HEAT USING LENSES

The 'Daylight greenhouse' contains a futuristic piece of technology, developed by WUR and commercial partners, and now built by Technokas. The innovation is that lenses are incorporated in double glazed roof. The lenses concentrate incoming sunlight onto black tubes that are filled with water. The other innovation is that the pipes move automatically so they are always in the beam of the concentrated sunlight. The heat generated in the pipes is transferred to heat collectors, via a heat exchanger. This heat is stored and used for heating purposes later. The light inside the greenhouse is more diffuse (milder) than in a traditional glasshouse. This is excellent for shade-loving crops such as certain ornamentals. The result is better growth, increased yield, improved quality and greatly reduced energy need. The Daylight glasshouse can provide approximately 75% of its own heat need, and thus reduce the external energy need to a quarter of its standard energy need. The first prototype built by WUR was 500 m2. The first commercial daylight glasshouse was built in 2014 and is 4000 m2. The same grower then built a 5 ha (50,000 m2) daylight glasshouse in 2018. The grower is Ter Laak Orchids in Wateringen

***Fig**. a black pipe filled with water receive a concentrated bundle of sunlight*

Sources: (https://technokas.nl/smart-greenhouses/kassenbouw/daglichtkas/

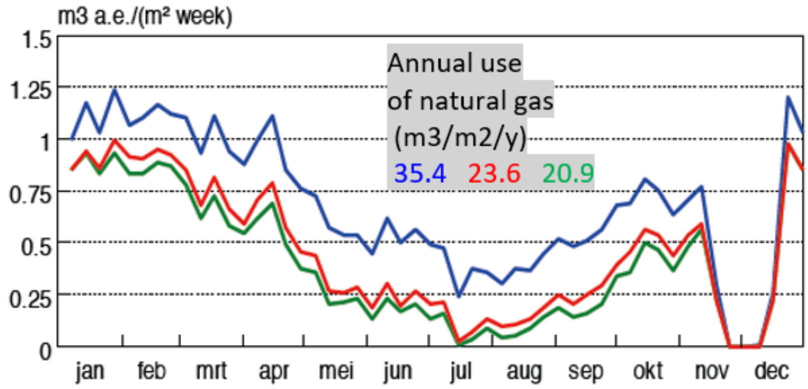
And there is much much more …..

Part 5 - ENERGY IN NUMBERS

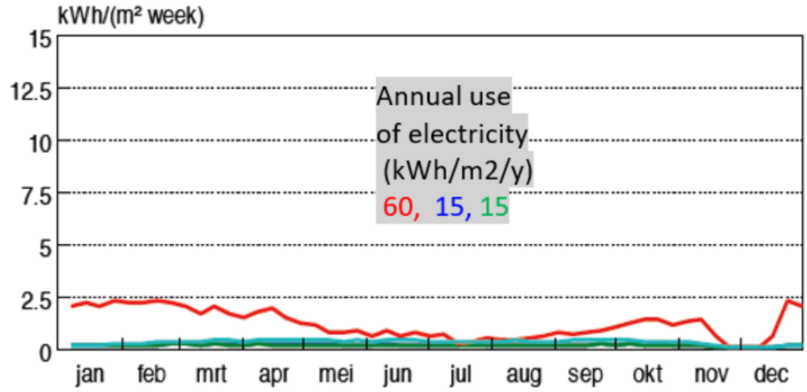
Some data about effect of energy saving measures.

Fig. *Amounts of natural gas, electricity and CO2 used in three different glasshouses for tomatoes in the Netherlands.* ***Blue line = reference*****,** ***Green line = energy saving glasshouse*** ***See details under the graphs.*** *Source: Feije de Zwart et al. Report WPR-853, WUR*

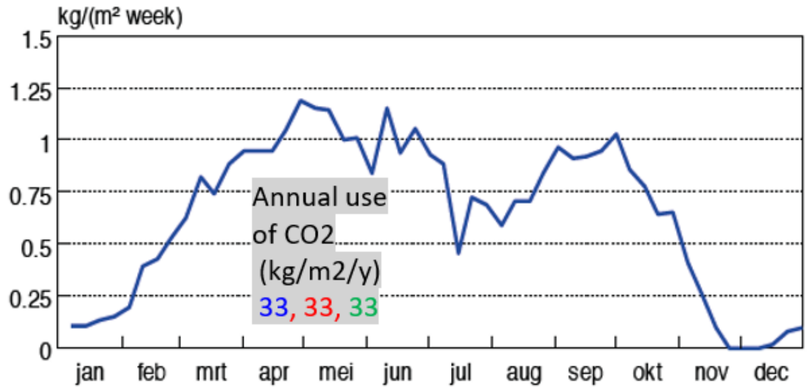
[a] Natural gas use in m3/m2/week.



[b] Electricity use in kWh/m2/wk



[c] CO2 use in kg/m2/week



BLUE: Reference glasshouse, modern Venlo, CHP on natural gas, single energy screen closed if outside below 15 ºC. Planting 15 Dec, finish mid-November. Standard temperature control. Minimum pipe of 40 ºC in dull weather only. Humidity control: 82% (day) and 85% (night). Dehumidifying by intake of fresh outside air with fans. CHP of 350 kW(electric) per ha.

GREEN: Energy saving glasshouse: differences with reference greenhouse: less minimum pipe, slightly higher humidity, double screen, and a dehumidifier that captures 75% of the heat that normally escapes. **RED: Energy saving glasshouse (2):** same as green, but with cooling block for dehumidifying

Many more examples available ………….

PART 6 - CONCLUDING REMARKS

The energy situation at present is highly uncertain, confusing and terrifying. Things will change, but who knows in what direction. Some technologies and approaches have proven to be effective in the Netherlands, and can be explored in NZ. Here are some points:

1. Determine a temperature regime that is economically optimal
2. Improve humidity control, including using a leaf temperature sensor
3. Do a cost/benefit analysis to see if a screen is feasible for your conditions, or

   at what energy price it will be feasible. Once a screen is in place, learn how to use it best
4. Explore new approaches, such as 'The new way of growing' or 'Plant Empowerment' that encompass some new technology, extra sensors, and a deeper look on plants & climate.
5. Find out if it is possible to get affordable electricity from a sustainable source
6. Find out about availability of biofuels (biomass, biogas, green gas) at reasonable distance
7. Consider heat pump(s) for retrieving heat from low-grade sources
8. Investigate how to collect, recoup and store heat, including latent heat from greenhouse
9. Find a way to store heat (even lukewarm), ideally seasonal storage (underground)
10. Large greenhouses: investigate high-grade source, including geothermal heat
11. And consider forming a cluster with other users of high-grade heat
12. See how hydrogen production develops in NZ

NZ is not unique or alone in this. The whole world must go through this energy transition.

Some good things will come out of this.

APPENDIX [1] PIONEER FOSSIL-FREE GLASSHOUSE, KOPPERT CRESS

This chapter is a reworked version of an article in a specialised magazine about heatpumps.

Source: https://www.vakbladwarmtepompen.nl/bronnen/artikel/2020/12/kwekerij-koppert-cress-innovatief-met-warmte-uit-sloot-en-middentemperatuuropslag-1016562

Introduction

Koppert Cress grows microgreens in a glasshouse complex of 5 hectares, spread over 7 greenhouses, located in Monster in the Netherlands. They also own 5 ha on other locations and employ 200 people in total. The owner is Rob Baan, and the Innovative project leader is Bart van Meurs. In 2010, Rob Baan set out to make Koppert Cress a sustainable company, with the lowest possible fossil footprint.

The glasshouse complex was expanding and had to increase the heating capacity. At the time it was common practice to install a Combined Heat & Power installation (CHP or co-generator) fuelled by natural gas. Instead, they installed a huge heatpump running on 'green electricity', which is purchased sustainably generated electricity. Currently there are two large heatpumps for heating and cooling of the 5 ha greenhouse complex with heating capacity 1,780 and 1,260 kiloWatt.
The heatpumps are fed with heat from a 'hot well', being an underground heat storage in the aquifer, in this case at a depth of 150 to 170 meters. In summer, cold water is pumped up from a 'cold well' at the same depth.

The hot well has a medium-high temperature, with a permitted maximum of 40 ^{o}C instead of the standard 25 ^{o}C. In an annual cycle, the hot well is replenished with heat from various sources:

(1) residual heat from the heatpump when it is cooling the glasshouse;

(2) heat coming from the LED lighting;

(3) reject heat released by the cooling installation of the cool stores;

(4) heat gained from a canal warmed up by the sun; and

(5) heat from solar collectors.

Heat from (2) and (3) is only pumped into the hot well when it is not needed for direct greenhouse heating.

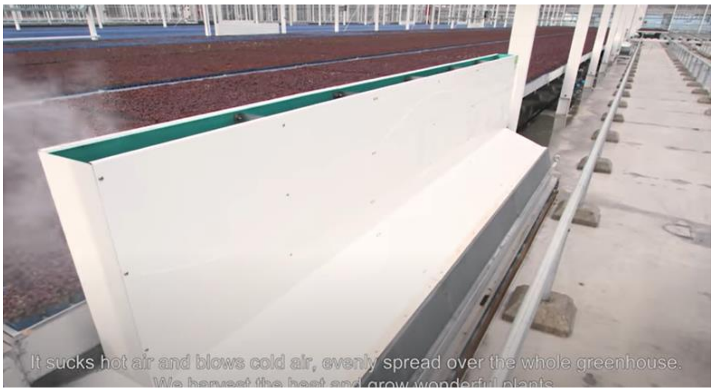
It is all sorted out in the technical room, where all installations and the two heat exchangers are set up. 'Energy management is a puzzle with many pieces', says project leader Van Meurs. The principle of the energy management at Koppert Cress is: 'what you have, you store, and what you lack, you get from the sources'. Below are more details about the various pieces of the puzzle.

Greenhouse climate control

Growing microgreens requires a climate that is uniform throughout the greenhouse, and fairly equal throughout the day and the seasons. This is achieved by a combination of underfloor heating/cooling (which is a slow system) and air heating/cooling (which responds fast). Both are fed by heat or cold from underground sources.
High air humidity is a concern especially in the autumn due to possible mould development. The easiest method to reduce the humidity is by opening windows, but that costs energy. Therefore they opt for dehumidification by air handling units. These units cool the air to the dew point to cause condensation, then remove the condensation water, and then reheat the air to the desired temperature.

Inside the glasshouses the heat (or cold) is spread via the air. In fact there are two different methods. Initially, they installed air handling units on the side of the greenhouse that drew air from the greenhouse, then treated the air in the units, and then blew it into large plastic perforated sleeves or tubes that were laying under the tables over the entire width of the greenhouse.

Later they changed to so-called JSK coolers from Certhon that are installed throughout the greenhouse. Each JSK unit has a fan and heat exchanger and receives cold water. The air is sucked in from above the table, then cooled down, and then freely blown out below the table. Heat is 'harvested' during this process. The JSK can also run the other way and can also be fed warm water. Koppert Cress switched to the JSK coolers because they are easier to install than the hoses. See photo →



Warm and cold storage in the aquifer

There are four cold wells at the front and four hot wells at the back of the greenhouses. The hot wells are medium-temperature storage, meaning they can be 40 ˚C instead of 25 ˚C, which is normally the permitted maximum temperature. The higher water temperature is an advantage, because water of 40 ˚C contains more energy than water of 25 ˚C, so more heat is stored, and less volume needs to be pumped. Medium-temperature storage is still in an experimental phase and applied only at a few greenhouse companies on a special permit. It is being assessed what happens to the microbiological life in the underground where the sources are located - so far nothing special has been observed.

Replenishing the warm well

Initially, more heat was taken out in winter than was pumped back in summer, so the warm and cold sources became unbalanced. The cold bubble got bigger and the heat bubble became too small. In order to continue heating in a sustainable manner, they had to pump more heat down (in summer or any other moment). Now various sources of heat are employed to replenish and maintain the underground hot well:

① 'Residual heat' coming out of the back of the heatpump (when the heatpump is cooling the greenhouse) is transferred to the hot well.

② Heat coming from the LED lighting in the greenhouses is primarily used to heat the greenhouse directly, but if that is not necessary, this heat is pumped into the underground hot well. [Note: LED lamps are more efficient than traditionally lamps, but still 50 percent of the energy is converted into heat. This is released from the back of the LED units. In water-cooled LED lights, the heat is absorbed by cooling water that flows passed through a line].

③ Heat released by the cooling installations of the cool stores can be sent to the underground hot well, but only when the heat is not needed for the greenhouses.

④ Heat gained from a canal (or ditch) behind the greenhouse, after the water is warmed up by the sun (see below). This is called aquathermy

⑤ Heat produced by solar collectors on the roofs of the buildings (not on the greenhouses). The collectors are plastic mats meant as heat collectors for swimming pools, with a total surface of 2,000 m2. They make a significant contribution to the heat demand.

Heat from a canal or ditch

Point ④ requires some explanation. In summer, the sun warms up the water in the nearby water canals to about 23 ˚C to 26 ˚C. This is 'free heat' that can be harvested and added to the hot well. (In the winter the canal is cold and not needed). Here is how it works. In summer, water of 6 oC is pumped up from the underground cold well, and used for cooling the greenhouse. This raises the temperature of the water from 6˚C to about 16 ºC. Instead of pumping this water directly into the hot well, it is first enriched with heat from the warmer canal water (23-26 ºC). In a dedicated heat exchanger, the water is warmed up from 16 ºC to perhaps 20 ºC, and is then pumped back into the hot well. The contribution of energy from the canal water is estimated at 15 % of the greenhouse heat demand in a year.

Technical data of the heatpumps

The two heatpumps at Kopper Cress are from Carrier. The first, installed in 2011, is a 23XRV4242 heatpump with heating capacity of 1,780 kW. The refrigerant is R134a. A special feature of this heatpump is the tri-rotor screw compressor (see picture). This compressor is fully speed-controlled and has a high efficiency.

The second heatpump, installed in 2016, is a 30XWHP1162, with heating capacity 1,260kW, and also R134a refrigerant. This machine has two refrigerant circuits with a twin rotor screw compressor on each circuit. Capacity regulation takes place via a regulating slide per compressor.

Evaluation

Koppert Cress aimed to be fossil-free, and the new goal is to minimize the electricity use. It is quite a puzzle to make sure that the various heat sources, the underground stores and the heatpumps work together properly.

Van Meurs hopes that medium-temperature storage will become a standard. He thinks it will be useful for greenhouses in the first place, but secondly also for buildings and homes. It is already put into practice for houses next to the nursery, where the underground stores are the heat source for the heatpumps.

Van Meurs also sees potential for aquathermy, which means harvesting low-grade heat from the canal (ditch) water. Already 15 % of their heat demand comes from the ditch - it's an underestimated technique. Calculations for a bedding plant nursery came out fine: the fixed costs are higher, but the variable costs are down. That actually applies to all the techniques applied here, says Van Meurs.

The question is if the total costs are lower with the fossil-free option than if a CHP (co-generator) had been chosen at the time. Van Meurs thinks it is, but he adds that cost savings were only secondary, and that sustainable production was the most important reason for Koppert Cress.

APPENDIX [2]: PIONEER GEOTHERMAL: DUIJVESTIJN TOMATEN

Sorce: https://www.nieuweoogst.nl/nieuws/2020/12/09/techniek-loodst-tomatenbedrijf-naar-circulair?fbclid=IwAR0A6P2ctcPSZYw_CdV4DEJZ6wujMNUAoATMteS2vGBdeYMhZ4jtSkMNpEY

Duijvestijn Tomaten in Pijnacker (NLD) was one of the first greenhouse companies to use geothermal energy (in 2011). Now in 2021, they cover almost 25 hectares glasshouses and have around 130 employees. They expect to produce 17 to 18 million kilos of tomatoes annually. The company has its own research department, and it collaborates with (amongst others): WUR, Stichting Innovatie Glastuinbouw Nederland, and Fresh Farma / vertical farming project. Shareholders are the four Duijvestijn brothers and general manager Ad van Adrichem, who is responsible for the day-to-day management.

Photo below: Duijvestijn has their own Innovation Centre. In the red circle is the sidewall of the ID-greenhouse. Source: https://duijvestijntomaten.nl/innovaties/#id-kas

In 2011, Duijvestijn Tomaten was one of the first nurseries to use geothermal energy for heating and therefore use virtually no fossil fuel. This saved 6 to 7 million cubic meters of natural gas per year. Also in many other fields they took sustainability to a new level. In 2012, they launched the first biobased packaging made from tomato stalks. In 2013, a geothermal oven became operational for drying surplus tomatoes (in summer) to produce dried tomatoes. In 2014 they built a high-tech glasshouse for circular cultivation, called the ID-greenhouse. →

This totally new construction allows more light in, and has a huge insulation value. This allows using low-grade heat, and thus saving 60% on energy costs. The production is higher than in a standard greenhouse thanks to higher light levels.

In 2020, Duijvestijn built a new 10 hectare glasshouse with the latest technology, including:

- geothermal energy
- underground heat storage
- buffer tank for storing (geothermal) energy
- new screen (co-developed) that allows ventilation and provides shade in summer
- Airmix system, allows venting under a closed energy screen
- hybrid lighting (50% LED units and 50% SON-T lamps)
- reverse osmosis

Photo left: installation for underground heat storage at Duijvestijn Tomaten (©Trees Borkus Henskens)

Photos below: construction of storage tank for geothermal heat at Duijvestijn Tomaten in 2020.