Innovative technology for transition to a low-carbon greenhouse industry

A technology scan of the glasshouse industry in the Netherlands, for TomatoesNZ / Horticulture New Zealand in Wellington

By Elly Nederhoff, Crophouse Ltd., Tauranga
Elly@crophouse.co.nz

April 2021

Photo: www.kasalsenergiebron.nl/nieuws/nieuwe-reeks-projecten-gestart-voor-kas-als-energiebron

Photo: vanderhoeven.nl/products/modulair.html

Photo: vandebron.nl/energiebronnen

CONTENTS

TERMINOLOGY

- **'Greenhouse heating'** is a common term, but more accurate is '**greenhouse climate control',** 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.
- **Sustainable energy, renewable energy** are used here interchangeably
- **Carbon-free, carbon-neutral, low-carbon, fossil-free** 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.
- **WattHour (Wh)** is the common unit for electricity. Conversion to Joules is: 1 Wh = 3600 J.
- **CHP** = combined heat & power, or cogeneration, fed by natural gas
- **NLD** = The Netherlands
- **WUR** = Wageningen University & Research
- **HNT** = *'Het Nieuwe Telen' =* a new way of growing = a comprehensive new approach of growing

INTRODUCTION

This study, commissioned by TomatoesNZ / Horticulture New Zealand, aims to explore options for renewable energy sources and sustainable energy technology for greenhouse climate control. New technology is needed for the transition towards a more sustainable greenhouse industry and ultimately a carbon-neutral or fossil-free economy. This study will present some solutions that are being used or 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 demand depends on the location, climate, greenhouse, crop and other variables. The high energy use is/was justified by the incredibly high production, for instance tomatoes can produce 100 kg per m^2 per year, which is equal to 1,000 tons per hectare per year. This is 10 to 20 times more than the production of any field-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.

This study looks at the Netherlands (NLD), because 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 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 over a decade ago, e.g. one multiple hectares glasshouse was run virtually fossil-free in 2011. See Story 2 at the end. The main fuel for the Dutch greenhouse industry is still natural gas, that is/was mined 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 (but import from other European countries may be allowed after that). This decision corresponded perfectly with the European climate goal, and 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. Options include: **electricity from various renewable sources (to drive heatpumps), residual heat from factories or sustainable sources, geothermal heat, biomass**. Heat storage will be important: daily storage in a heat buffer and seasonal storage in underground water bubble (aquifer). Heat can come from a range of sources. Heatpumps will play a crucial role in retrieval of stored heat.

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. Therefore greenhouse operations are now forming ‘clusters’ with other large ones, and sometime also with other companies or large residential projects.

Table 1*. Some data on energy use & CO2 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*	

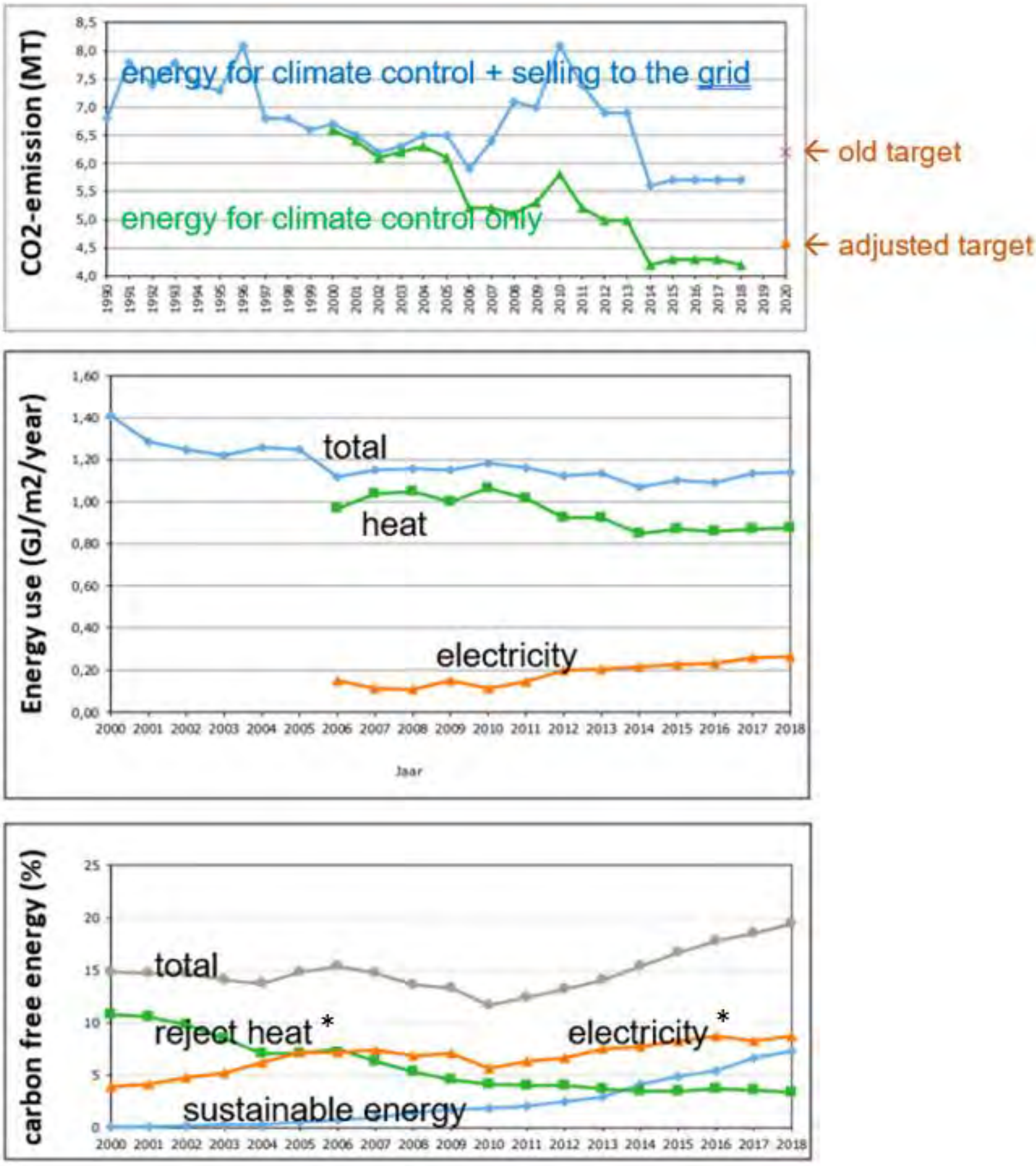
NOTES with the table above

- *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. Surplus heat from lighting can be 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: NZ: EECA Fact sheet. Indoor Cropping – Process Heat and Greenhouse Gas Emissions, 2016.
NLD: Energiemonitor van de Nederlandse glastuinbouw 2018. WUR, 2019.
pbl.nl/sites/default/files/downloads/pbl-2019-achtergronddocument-het-klimaatakkoord-effecten-en-aandachtspunten_3807.pdf

***Fig. 1**. Trends in overall CO2 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.

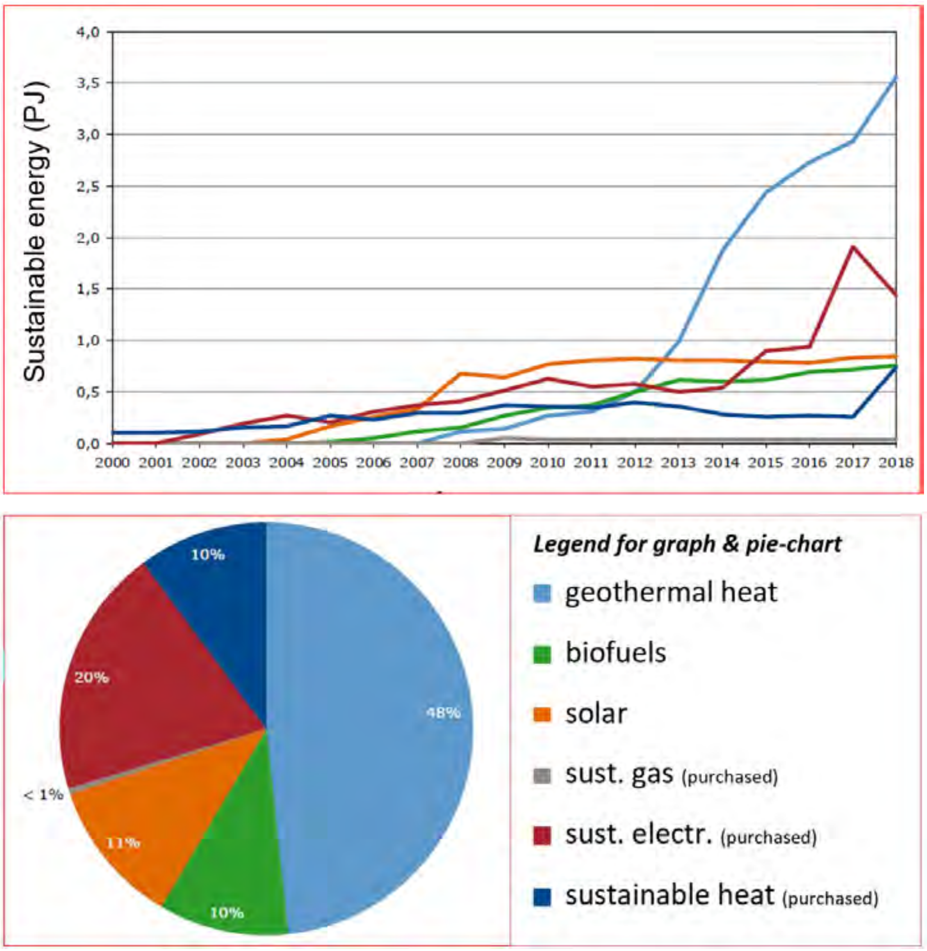


NOTES with the graphs above

- *The greenhouse area in NLD declined from 10,307 hectares in 2010 to 8,990 ha in 2018.*
- *In the middle graph, from 2006 onwards, energy use is split into heat (green line) and electricity (orange line). Note that electricity for lighting also produces heat.*
- *In the last graph, the blue line is truly sustainable energy. The green line and brown lines (*) are reject heat and electricity from non-sustainable sources. Sustainable energy consists of 6 energy sources: geo, bio, solar, and sustainable heat, power and gas.*

Fig. 2. Sustainable energy sources, and pie-chart for data in the Netherlands in 2018.

Source (both): Energiemonitor van de Nederlandse glastuinbouw 2018. WUR. 2018



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			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

* *Units used in the blue table above.*

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

WattHour can be converted to Joules: 1 Wh = 3600 J

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

THE DUTCH CLIMATE AGREEMENT

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. The industry has set the goal to be climate-neutral by 2040. Whether this will happen depends on developments in other fields such as geothermal energy, residual heat, sustainable electricity and carbon capture and supply.

Already 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. It is paid by the government, who in turn raises the funds via a levy and/or tax on natural gas (EB & ODE). These government funds also provide subsidies for geothermal and bio-energy projects.

During the energy transition (roughly from 2010 to 2030 or 2040), the aim is to use an optimal combination of various technologies and energy sources. The remaining natural gas fed CHPs and boilers will gradually be replaced by low-carbon energy sources such as geothermal energy, residual heat & biomass, and purchased green electricity (generated off site).

Geothermal will be very important in the Netherlands. In 2019 there were 17 geothermal projects. At least 35 successful new geothermal projects must be realised 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 (heat pumps, thermal storage, power to heat, pump energy, geothermal energy) 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.

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.

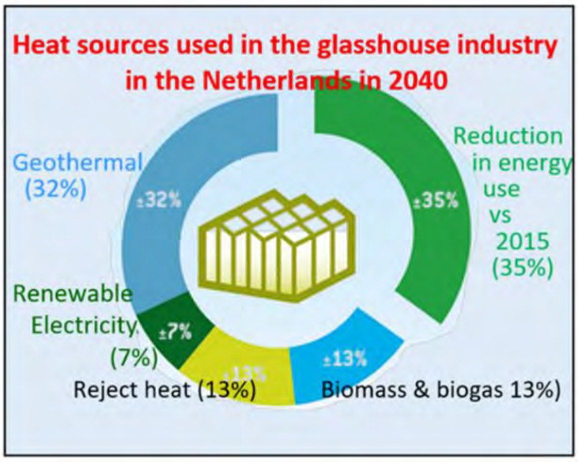


Fig. 3. *Target for energy sources by 2040 →*
Source: Samen werken aan een Verantwoorde Glastuinbouw: Energie. Glastuinbouw Nederland

SUMMARY OF INNOVATIVE DEVELOPMENTS
IN ENERGY IN GLASSHOUSES IN THE NETHERLANDS

1. The greenhouse industry in the Netherlands (NLD) is in an energy transition since 2010 and will be at least until 2030.

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 faded out. Combined Heat & Power installations (CHP or co-generation) fuelled by natural gas were/are still very common, but will gradually come to an end.

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)
   - new technology for humidity control, e.g. with outside air, vertical venting through screen
   - better understanding of control of air humidity (and temperature)
   - 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, sometimes with other energy users such as offices, small industries and/or hundreds 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 many greenhouses or 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, most likely from electricity with heat pumps, or from biogas, green gas, or biomass burned in a boiler. This is relatively affordable for medium-scale greenhouses.

10. Carbon dioxide (CO_2) 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 CO_2 gas from industrial sources. New pipe networks will be completed by 2030. Growers not connected to a CO_2 network, will have to pay for CO_2 delivery by road tankers.

11. Artificial lighting (with HPS lamps and increasingly with LED) is common practice in tomatoes (and flowers). The energy source will be renewable electricity or 'green electricity'. 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 on many places in NLD, with around 17 geothermal sources in operation. Hot water of 70-100 ^{o}C is retrieved from 1.5 to 2.5 km deep. Due to the enormous investment costs, 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. Problems with CO_2 enrichment can sometimes be overcome by purification of the flue gases. But not enough woody biomass is available, or distances and thus transport costs were excessive. This made it an unfeasible and unsustainable option for 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 pa of biomass by 2030.

14. 'Electrification of heating' or 'all electric' climate control, entails using electricity, heatpump(s), and a heat source, but no natural gas. It was first realised on a large commercial scale in 2013. A range of possible heat sources is being used. (See article about Koppert Cress)

15. 'High-grade heat' from geothermal bores and industries is becoming a major energy source.

16. Also important is 'low-grade heat' from external or internal sources. Internal sources e.g.:
    - the greenhouse itself in sunny periods, with heat being 'harvested' and stored
    - condensation of moisture in the air (= latent heat), using dehumidifiers and heatpumps
    - the artificial lighting in the greenhouse (even if it is LED lighting)
    - solar heat collected in another solar collector system
    - cool store onsite
    - aquifer (underground water bubble), with warmth injected and retrieved seasonally

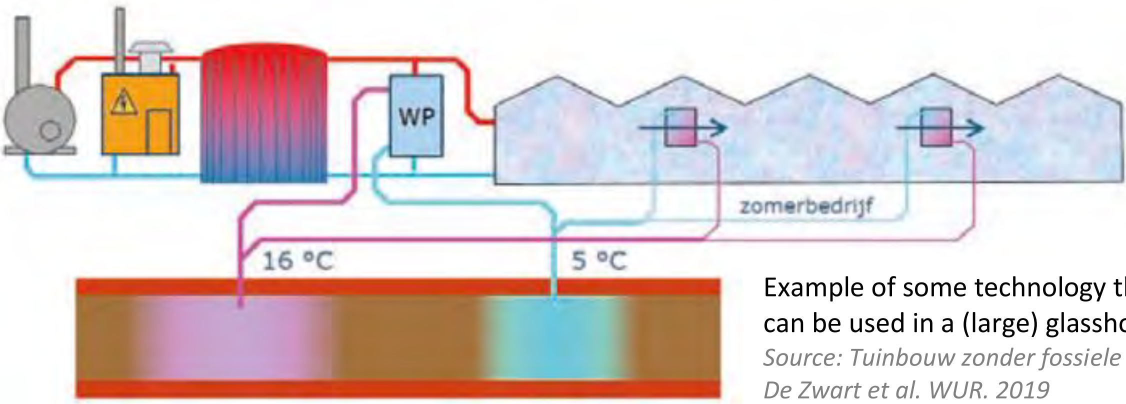
17. External sources of low-grade heat can be for instances:
    - industries or data centres (residual, waste or reject heat)
    - water treatment plants, waste plants
    - 'surface water' (canals, ponds): heatpumps extract low-grade heat from lukewarm water
    - aquifer (underground warm water bubble, 'external' if grower does not inject warmth)

18. The aquifer (groundwater) 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: a cold and a warm well (or bore). Each well has an extraction pump and infiltration pump. (The terminology varies: well or bore, warm or hot).

19. 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.

20. If the water temperature is lukewarm (say 30 °C) instead of hot (say 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*



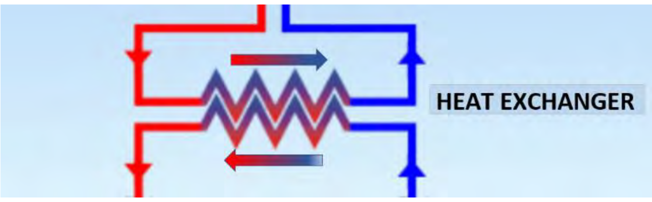
Example of some technology that can be used in a (large) glasshouse.
Source: Tuinbouw zonder fossiele energie. De Zwart et al. WUR. 2019

TECHNOLOGY

HEAT EXCHANGER AND HEAT PUMP

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 condenser(s), dehumidifier(s), buffer(s) and underground heat storage. Often a range of technologies is used in one glasshouse. See for instance an article about Koppert Cress (some pages further).
Here is first an explanation about the difference between a heatpump and a 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). See Fig …. here →.



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. A heatpump (e.g. a fridge) requires electricity to compress the refrigerant liquid, which is the core of the heatpump action. The electric energy (expressed in Watt) that is consumed is only one-third to one-fifth of the heat that is pumped up into that room (also expressed in Watt). So 3 to 5 times more heat energy is gained compared to electric energy used. This factor of 3 or 5 is the COP (= Coefficient of Performance, or efficiency).
See schematic drawing here →

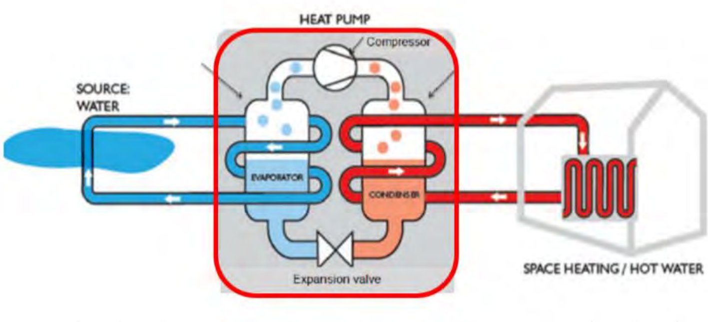


Fig. .. *Heat pump from Certhon (https://www.certhon.com/nl/greenhouse-solutions/ innovaties/energiebesparing-tuinbouw)*

POSSIBLE HEAT SOURCES AND HEAT STORAGE OPTIONS

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

1) High-grade (= high-temperature) heat, e.g. geothermal heat or industrial waste heat. This can be used directly, without or with a heatpump, and 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

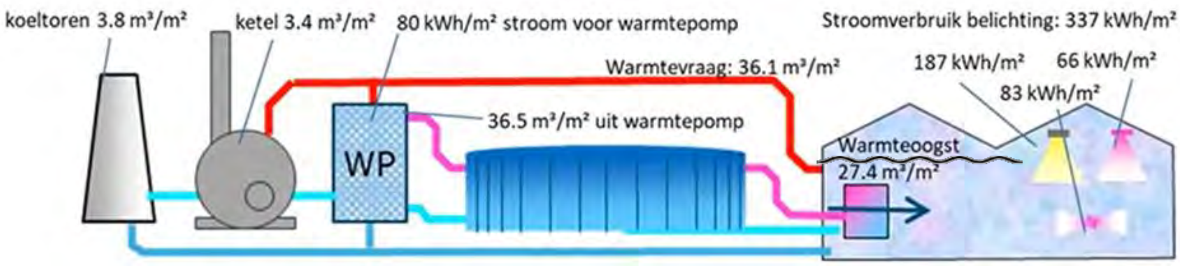
5) Low-grade heat can be used in various ways:
   - directly pumped into the heating system
   - fed into a heatpump so the heat is added to lukewarm water to increase its temperature
   - stored in a 24-hour buffer and used that night
   - added to the warm well in the aquifer

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 amount 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. *Overwhelming amount of technology? 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



SEMI-CLO SED, FULLY-CONTROLLED GREENHOUSE

Several greenhouse builders have developed a version of a semi-closed greenhouse. These greenhouses have a very advanced climate control system, that includes cooling, heating, humidifying and dehumidifying. In some greenhouse brands, the air treatment happens either **in air treatment units**, while in other greenhouse brands, the air treatment happens in a **compartment (a narrow corridor) along a wall** over the full length or width of the greenhouse. Inside the air treatment units or inside the corridor, air streams from inside and outside are treated and then mixed. From there the conditioned air is blown into the greenhouse, often via perforated sleeves laying under the gullies, or sometimes by large open pipes with a strong fan.

As the air is perfectly 'conditioned', the roof vents don't need to be opened to let heat out (in summer) or to reduce humidity (in all seasons). Quite often they have smaller or viewer vents in the roof than normal, and they are used sparingly. Hence such greenhouses are called semi-closed. Some greenhouses have no roof vents at all, making them closed greenhouses. Because the air exchange in (semi-)closed greenhouses is controlled and much lower than in normal greenhouses, it costs less CO2 to maintain a high CO2 concentration. Here follow some examples.

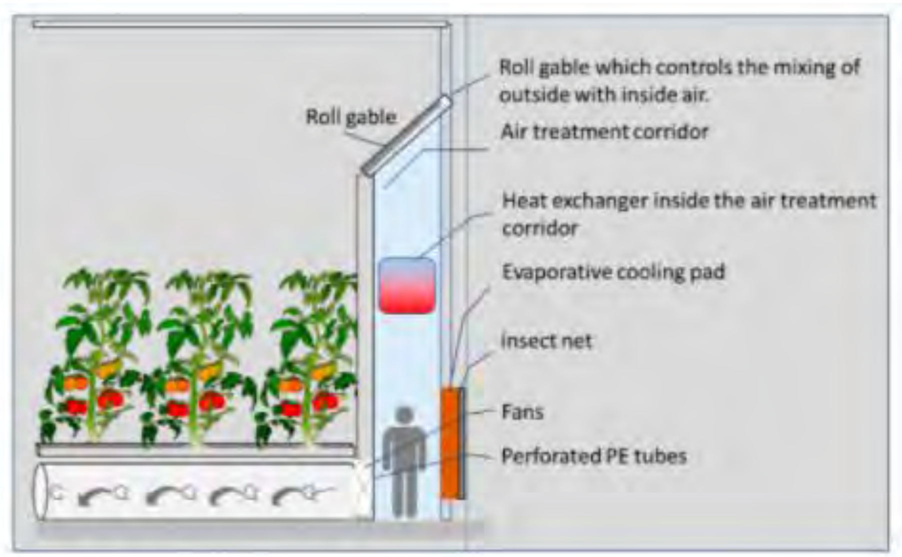


Fig. Schematic drawing of a semi-closed greenhouse with air treatment corridor and air distribution sleeves. Source: Sapounas et al. Design, Control, Performance Aspects of Semi-Closed Greenhouses. Agronomy 2020, 10(11), 1739

Semi-close greenhouse with corridor

Ultra-Clima greenhouse from KUBO was the first of this type. Nowadays there are many, e.g. the SuprimAir concept of Certhon. Important components are:

1. Perforated sleeves under the gullies that distribute the conditioned air
2. A narrow corridor (compartment) along a wall where the air streams (from inside and outside) are treated and mixed. The conditioned air is pushed from here into the sleeves.
3. A long window in the corridor can be opened to let fresh air into the corridor.
4. Heating in this corridor can increase and/or dry the air.
5. A 'wet pad' in this wall can give **adiabatic cooling** (i.e. in summer, warm 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 reduce need for opening roof vents (in summer), makes it a semi-closed greenhouse.
8. It is easier and cheaper to maintain a high CO2 level.
9. The principles of 'The new cultivation' (*Het Nieuw Telen*) have been applied in the control.

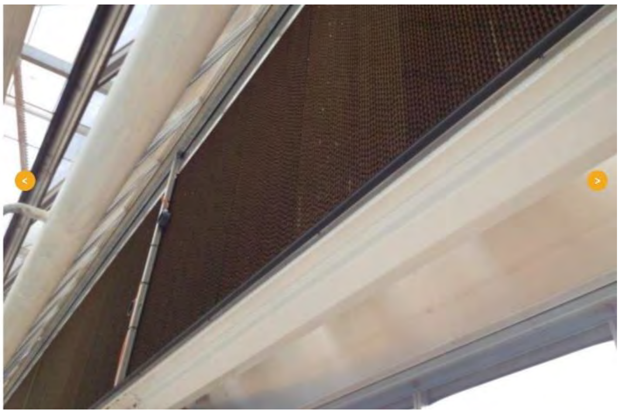


Fig. *Interior of the air treatment corridor of an Ultra-Clima greenhouse from KUBO (NLD). Outside air can enter from the top and mixed with greenhouse air. The conditioned air is sucked into the grey boxes. Each grey box is an entrance to a sleeve. This is at D'Vine Ripe in South Australia.* *Source: 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

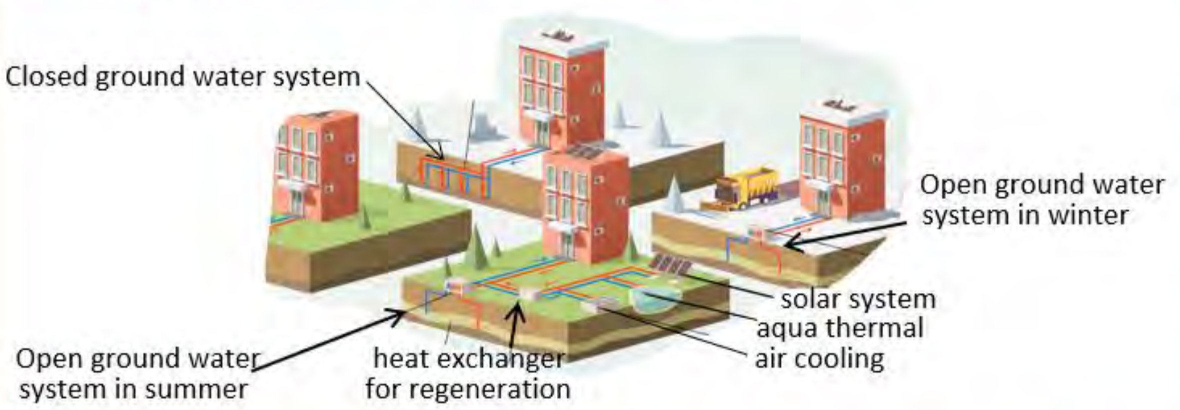
Fig. *The SuprimAir greenhouse made by Certhon. Left: the long window that can let air come into the corridor. It includes a wet pad and heating. Right: the sleeves under the gutters.*

Examples of small air treatment units. They (can) contain a fan, heater, heat exchanger. These units are not necessarily used in semi-closed greenhouses, but they assist in using less ventilation through the roof vents. *Source: www.itbclimate.com/product/green-vent/*

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

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 large greenhouse (or even a house) 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, 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 is now cooled down, and then 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. The then warmed-up in water is pumped back into the ground, but now in the warm well.
- The warm well is only ca 20-30 °C; not as hot as hot-water-pipe heating used to be (80 oC).
- 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

- Due to different warm and cold demand, the temperature in the ground often gets imbalanced. Over the course of a year, often more heat than cold is taken out.
- The balance can be restored by 'regeneration'. Then warmth is obtained from any available source, and supplied to 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.

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.

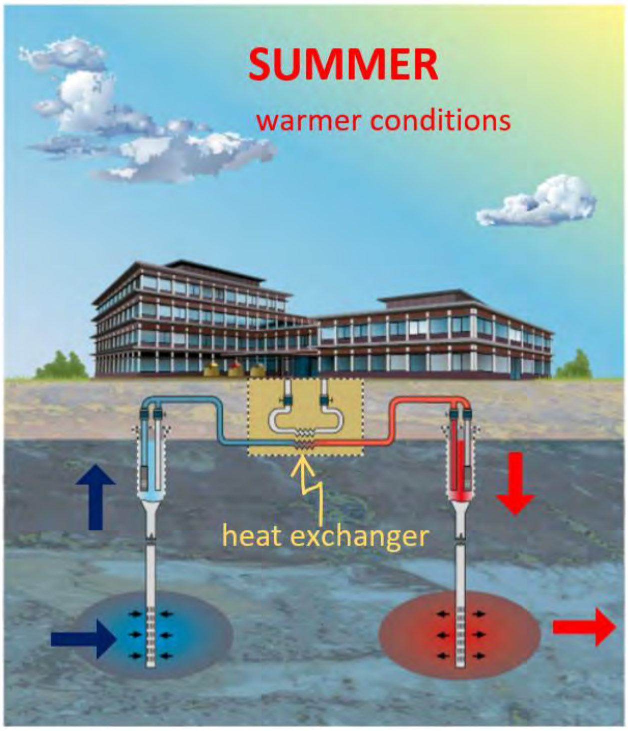
Conditions

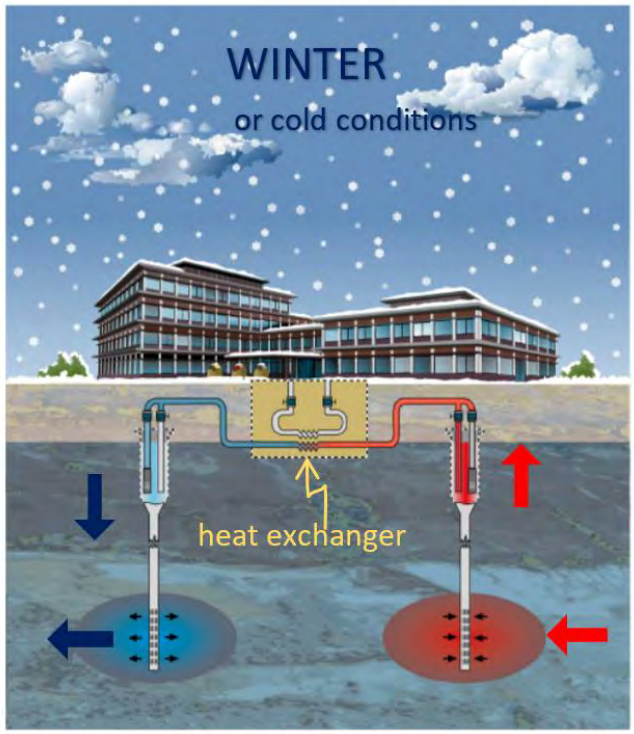
- Permit required.
- Criteria: suitability of ground, no drinking water catchment, distance to other systems, etc.

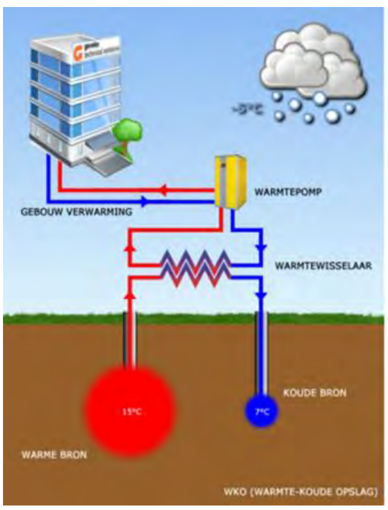
Data for warm/cold storage in the Netherlands for 2020 (not greenhouse related):

- 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)



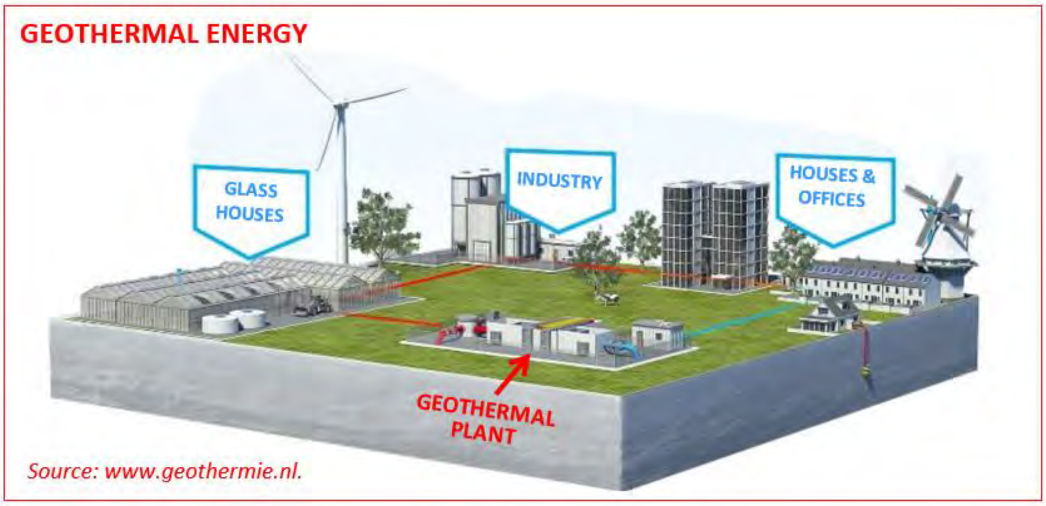




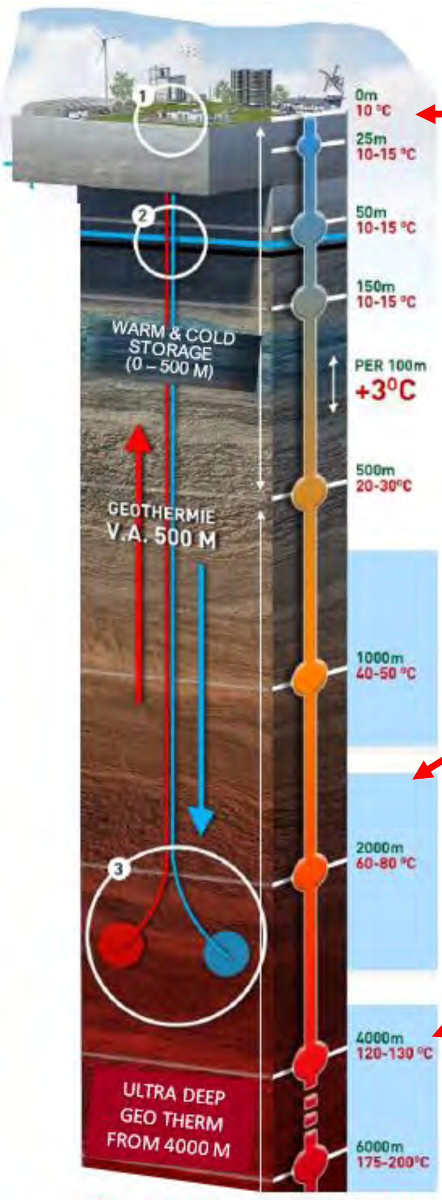
The figures above show heat storage (regeneration) in summer and heat retrieval.

The figure at the left shows that a heat pump (yellow block) can be part of the technology. This will boost the temperature of the water flowing through the heating systems.

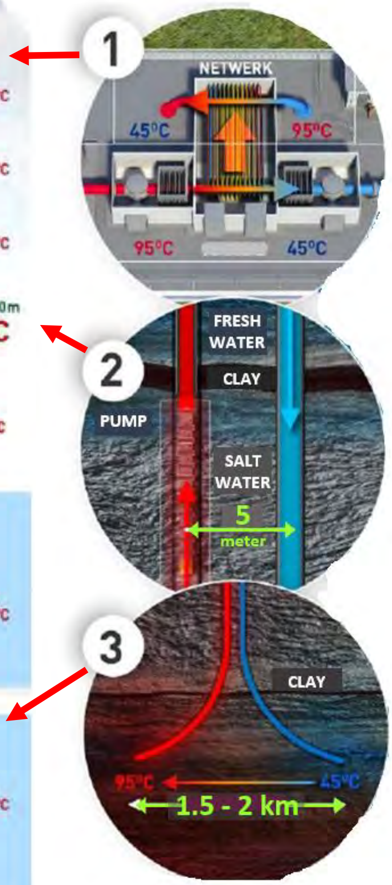
GEOTHERMAL ENERGY



Source: www.geothermie.nl.



Source: www.geothermie.nl.



DESCRIPTION

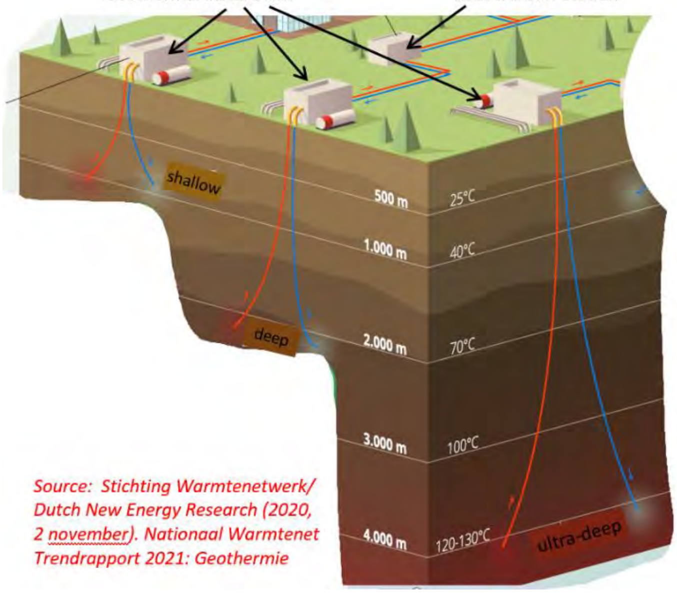
① A huge heat exchanger located in the geothermal plant receives hot water that is pumped up from deep down. In the heat exchanger, heat is transferred from the source water to the water of the heating system (without mixing of different water streams!). The then-cold source water is pumped back to the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

Note: temperature gradient in the ground in the Netherlands.

Geothermal energy (continue)



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

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.

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

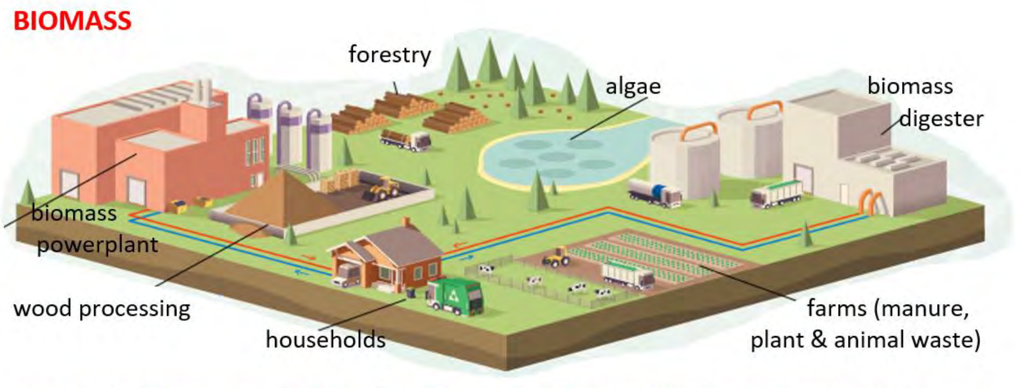
Source: Stichting Warmtenetwerk (see in picture)

• Number of greenhouses with geothermal in 2018:	81
• Greenhouse area 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/Overons/Folder_Kas_als_Energiebron_in_English.pdf

BIOMASS



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 by burning 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 makes it a CO2 neutral cycle.
- However, transport of biomass emits CO2.
- 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 - little adaptation needed to existing heating system.

Disadvantages

- Biomass power stations emit nitrogen and particulate (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

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

Source: Stichting Warmtenetwerk (see in picture)

BIOGAS and GREEN GAS

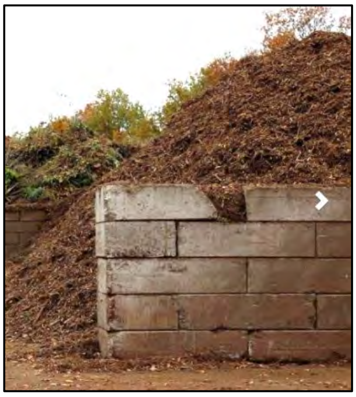
Biogas is released during the fermentation/composting or gasification of biomass. It does not necessarily have the same quality as natural gas.
Green gas is biogas that has been upgraded to the quality of natural gas.

Biogas is now mostly produced from green waste (vegetable, fruit and waste from the food industry). It is also produced by water treatment installations and manure digestion or fermentation plants. The supply grows only very slowly. 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 and also for supplying green gas. Instead of selling the green gas for use in a local CHP or boiler, they feed the green gas into the natural gas network. Growers can purchase green gas for use in their CHP or boiler. AgroEnergy issues a certificate (Garantie van Oorsprong, Guarantee of Origin) with their products. Large scale gasification is very expensive.

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 gas to a good use. Currently the company produces bio gas (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 important for greenhouses, and 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. Electricity can be generated by Photovoltaic cells (PV)
4. Warmth can be harvested from Photothermic cells (PT)

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

(3) 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 needs to be 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. On top of blocking the day light, they have the disadvantage of being 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)

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 to greenhouses, 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. There are differences between them, but they all capture energy from the sun and turn it into electricity and all are made from silicon, which is available in abundance and is a very durable element.

Hortisolar panels in Italy, solar roof, 2MW.

Source: /www.hortisolar.nl/portfolio

Hortisolar in Zevenbergen (NLD), 390 kWp.

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 taken into account. Retrofitting involves changing the windows, or the whole roof, etc.

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, 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 as they can damage the 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 and standard rods can be used.

Suppliers

The following greenhouse builders apparently have PV glass in their portfolio. Many show videos of a range of new technologies: www.hortisolar.eu ; www.bomgroup.nl; www.gakon.nl; www.technokas.nl; www.vanderhoeven.nl; www.debetsschalke.com; www.reytecinnovationprojects.nl; www.horconex.nl

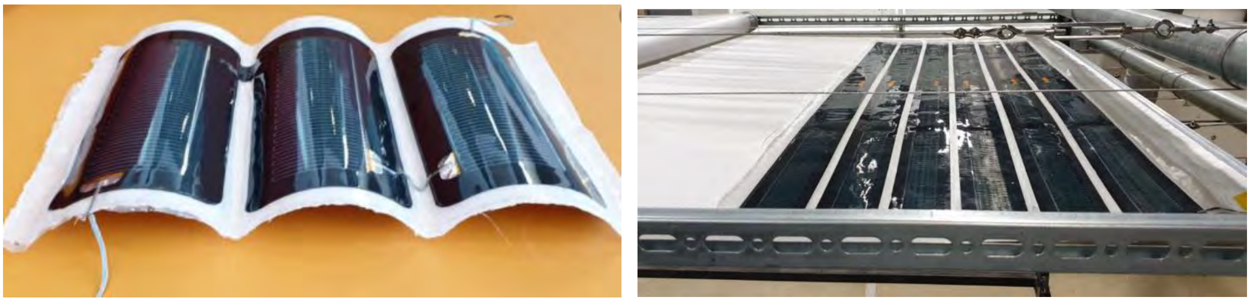


Fig. *Researchers at WUR are looking at integrating solar cells in energy screens*
Source: https://www.kasalsenergiebron.nl/nieuws/schermen-met-flexibele-zonnecellen-is-uitdagend-project/

GREEN ELECTRICITY (GREEN POWER)

Green electricity is produced cleanly and sustainably, in NLD mostly by wind, 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 (e.g. Vandebron/Essent, AgroEnergy, Energiedirect, and more) buy from various suppliers and sell to many customers. 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.* Source: vandebron.nl/energiebronnen

Consumers entering a contract can opt for power from either wind, sun, hydro or biomass, and with some power companies (e.g. with Vandebron) they can also opt to get power from a particular source.
Consumers get a Guarantee of Origin (‘*Garantie van Oorsprong’, GvO*) with their energy products. The GvO certificates are issued by a certificating organisation while the process is overseen by the Authority for Consumer & Market.
The green power goes through the same network 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.

Source: 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.

***Fig**. Green electricity is being used for lighting, and the energy contributes to heating*
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 combusted in a fuel cell it produces only water. This is a perfectly clean cycle that does not produce any carbon dioxide or other problem 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.

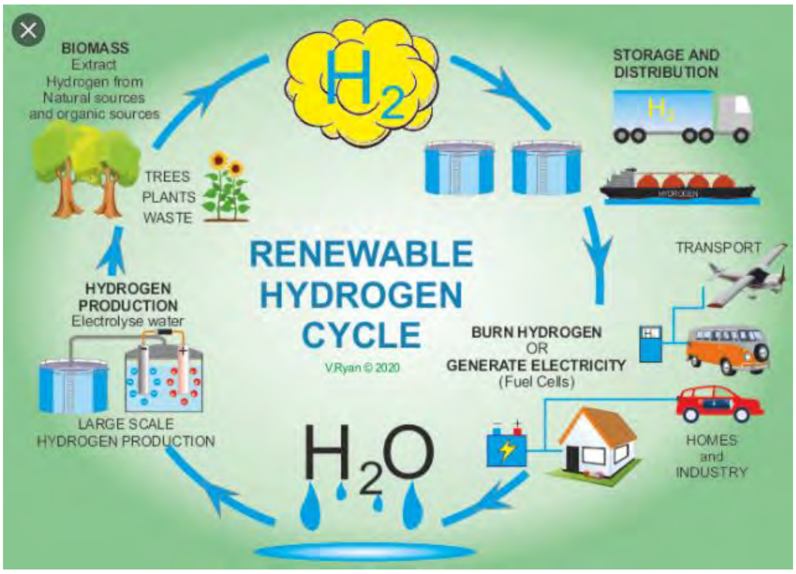


Fig. *The water - hydrogen cycle. At the left an electrolyzer and also an indication of hydrogen extraction from biomass.*

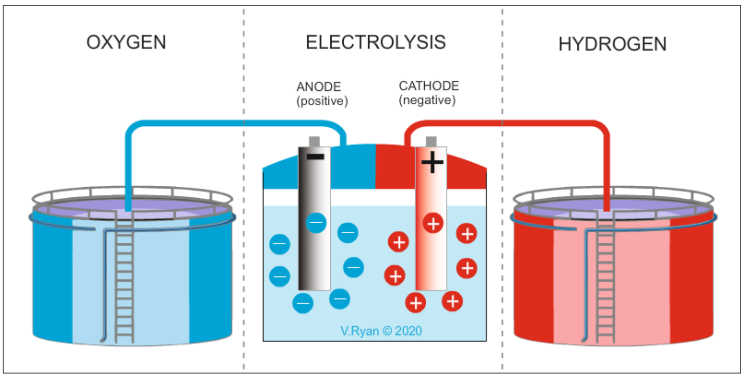
Below: an electrolyser splits water (H2O) in hydrogen (H2) and oxygen (O2). Two platinum / iridium electrodes are charged, one positive and one negative.

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 lots of CO2 released.
- Grey hydrogen is produced by Steam Methane Reforming (SMR) of natural gas.
- Blue hydrogen is basically grey hydrogen, but with the carbon dioxide (largely) captured.
- Green hydrogen is produced by way of electrolysis using (renewable) electricity. See figure →
- Green hydrogen can also be produced from biogenic fuels if those are produced sustainably.

Currently green hydrogen is much more expensive than grey. Blue is expected to stay cheaper. Green hydrogen can become cheaper by 2030 by rapidly scaling up production from MW to GW.



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%. [Generating electricity by burning fossil fuels at a power station, is only 35% efficient, 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. Hydrogen is harder to store (as a gas or a liquid) than other fuels, making it more expensive.
2. When fuels cells operate outside a specific temperature range, they are less efficient.
3. Huge investments in infrastructure needed, for hydrogen (gas & liquid) storage & transport.
4. Sustainable hydrogen production needs sustainable electricity for electrolysis.
5. Fuel cells are expensive. Cost will fall due to increased demand and scale of production.

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.

Recently, 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) electrolyzer. It is powered by electricity from wind turbines, converting wind energy to hydrogen and oxygen. 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 electrolyzer 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 is capable of supplying 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 Electrolyzer 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.

The collective plans for 2025 add up to a total electrolysis capacity of over 800 MW (0.9 GW) plus production of 15 kilotonnes of green hydrogen from biogenic fuels in NLD. For 2030, the plan is to have 3-4 GW capacity of electrolysers 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 <u>overproduction of electricity</u> from solar generators or wind turbines, when supply exceeds demand, wind turbines are stopped. 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 <u>surplus</u> solar or wind energy.

<u>Hydrogen compression</u> 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. The good thing is that 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. In agriculture, WUR university in NLD is studying hydrogen production and use in agricultural situations on a practical scale. They are using a hydrogen-fuelled fork-lift as a test and demonstration project.

OTHER INNOVATIONS

NEW WAY OF GROWING (HNT)

The 'New Way of Growing' (Het Nieuwe Telen, HNT) was developed between 2008 and now by researchers of WUR in NLD. It comprises of new technology that helps saving energy and new insights of how to control the greenhouse climate and how to grow the plants. There are different HNT 'recipes' for different crops.
In 2013 one grower was the first to implement the 'New Way of Growing'. 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 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. (This was cucumber grower Dion van Mullekom, of Multigrow BV in Grashoek).
Source: www.rijksoverheid.nl/onderwerpen/klimaatverandering/documenten/rapporten/2019/06/28/klimaatakkoord

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 dosage, lighting and screening, they achieve considerable energy savings. Up to 30% energy saving is possible even without investment.
Source: Kas als Energiebron. Saving energy and sustainable energy in greenhouse horticulture

There are other, similar approaches, such as plant empowerment and also cultivation methods for growing in semi-closed greenhouses.

VERTICAL VENTILATION, AND VENTILATION THROUGH A SCREEN

Much energy is used for preventing too high air humidity, especially under a screen, and especially if plants are stimulated by lighting to evaporate water. Research a decade ago focused on new ways to overcome high humidity. One solution is moving the humid air to the compartment above the screen. Special ventilations have been developed since then, and have made the high air humidity problem very manageable.



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/

‘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/

USE OF SOPHISTICATED SENSORS

***Fig.** Intensive use of sensors.* *Source: photo taken from Pylot by Kubo www.pylot.nl/nl*

CLUSTER & HEATING NETWORK

This a plan for a heating network covering the Westland region (90 square kilometers) between Rotterdam and The Hague, plus parts of adjacent regions. A partnership has been set up called Warmtesysteem Westland (Westland Heating System), that is supported by greenhouse horticultural businesses, the municipality of Westland, Port of Rotterdam, Gasunie and others. The Dutch government will subsidise it. Existing and new geothermal energy sources and local heating sources are systematically connected to a heat distribution network. Subsequently the residual heating systems of the 'heat users' will be connected. Heat users will include greenhouses, companies in the Port of Rotterdam and the built environment in Westland and Midden Delfland. The use of geothermal heat and heat generated by the port will be optimised in a market system, to provide the entire region with a reliable and affordable low-carbon heating supply. The system will enable carbon emissions reduction of over 1 Mt per year.

And much more ………………….

STORY 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.

STORY 2: PIONEER IN 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.