R&D Plan 2015 ECN Solar Energy

- part of the TKI Solar Energy Program –

The future in 2014: large-scale use of solar energy in the urban environment. City of the Sun, Municipality of Heerhugowaard, NL (photo: Jan Tuijp).

Building block for all system types: the solar module. Here: ECN's Black Beauty (rear-contact technology for high yield and attractive looks)

Vision, mission and overall targets

Vision (ECN and TKI)

PV is major source of sustainable electricity in the Netherlands, in Europe and in the world. Dutch technology and industry play a key role in the global success of PV.

Mission (ECN as partner in TKI)

To develop world-class PV technology with and for the Dutch and international industry and to support its large-scale deployment.

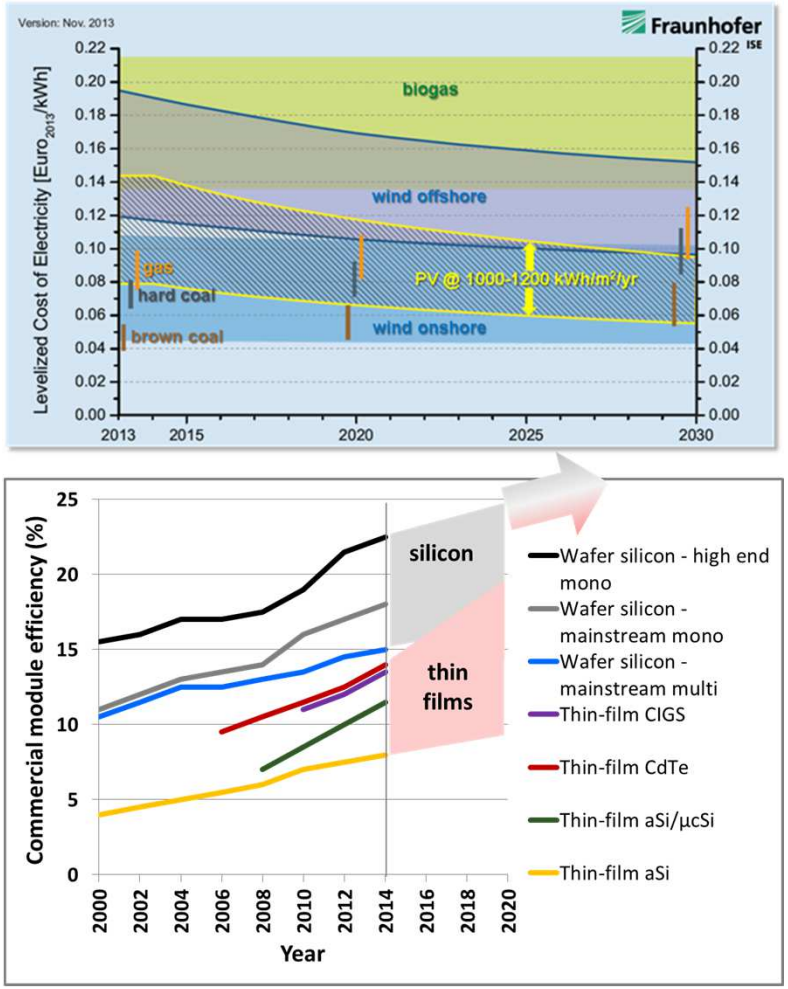
2020 (2030) targets (TKI with key contributions of ECN)

- Develop technologies to enable of 4-8 (10-20) GWp PV in the Netherlands by 2020 (2030);
  - generation costs <0.10 (0.05) €/kWh in 2020 (2030) for selected system types, including sustainable margins;
  - competitive solutions for integration in buildings, infrastructure and landscape.
- Strengthen the organization and position of the Dutch PV sector (all parts of supply chain):
  - 7,500 (15,000) jobs in 2020 (2030);
  - 2 (4) G€ turnover in 2020 (2030).

ECN's research in the Dutch, European and global context (1)

Global developments photovoltaic solar energy (PV)

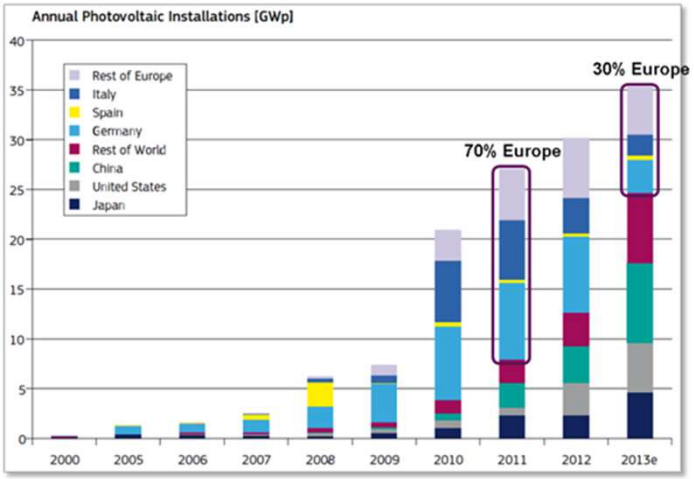
- Installed PV capacity was 140 gigawatt-peak (GWp) at the end of 2013.
- The contribution of PV to global electricity consumption will reach 1% in 2014.
- Europe's share in system installations has decreased from 70% in 2011 to 30% in 2013, illustrating slowing down of sales in Europe and acceleration in China, Japan, USA, India and other markets, see Figure on the next slide.
- Turn-key price levels below 1 €/watt-peak for large systems are seen in several parts of the world, corresponding to typical generation costs between 0.05 and 0.10 €/kWh, depending on the insolation level (1000~2000 kWh/m^2/year) and market maturity, see the Figure for the case of Germany, which is similar to the Netherlands.
- The upstream part of the industry sector (especially manufacturers of solar cells and modules) still suffers from the effects of production overcapacity, but the gap between capacity and demand is closing: demand for new capacity is expected to recover by 2016/2017. Dutch research and industry is positioning itself to be a supplier of advanced technology when that happens.
- With growth and broadening of markets, the demand for differentiated products increases: from "one size fits all" modules to application-specific solutions, such as Building-Integrated PV (BIPV) and desert PV.
- Wafer-silicon based modules continue to dominate the market (share of ≈90%), but sales of thin-film technologies grow in absolute terms.
- Efficiencies of commercial solar modules show a gradual, but robust increase, and range from 8% to 22% today. Mainstream thin-film and wafer-silicon technologies are typically between 12% and 17%.



ECN's research in the Dutch, European and global context (2)

European developments photovoltaic solar energy (PV)

- The big European markets of the past years (Germany and Italy) have decreased in 2013 as a result of modified incentives (see Figure), other markets (e.g. UK and the Netherlands) continue to grow but cannot yet compensate the loss.
- The PV solar energy sector lost part of its political support in several European countries and at EU level, especially because of the loss of most of its industry base. In spite of this, about half of the economic added value of new installations is still realized in Europe.
- In response to the previous point, several initiatives to regain a share in (high end) production of solar cells and modules have been developed, among which the German-French "xGW" initiative, also known as the "Solar Airbus Initiative".
- The European Commission is developing its "SET Plan Integrated Roadmap" (SET = Strategic Energy Technology), to support reaching the EU 2020 targets for CO_2 emission reduction, enhanced energy efficiency and increased share of renewable energy. This Roadmap provides input to set priorities in Horizon 2020 (H2020), the new framework program for research and innovation. PV is covered by the Integrated Roadmap, but shares its position with a wide ranges of other energy technologies.
- The European counterpart of the Dutch TKI Solar Energy (see next slide) is the Solar Europe Industry Initiative. Although it has been launched with great ambition a few years ago, its future in the H2020 era is uncertain. The most important parts of its content, however, have been included in the SET Plan Integrated Roadmap recently and will thus continue to provide input for programming.



ECN's research in the Dutch, European and global context (3)

Dutch developments photovoltaic solar energy (PV)

- Cumulative installations doubled for the second year in a row in 2013, to 720 MWp. The contribution of PV to the total Dutch electricity consumption is still modest at slightly over 0.5%, but grows rapidly.
- The TKI Solar Energy target for the contribution in 2020 is 4-8 GWp (depending on the applicable market incentives), corresponding to 3-6% of the total electricity consumption.
- TKI Solar Energy research, of which ECN Solar Energy research is part, supports the National Energy Agreement and its targets for 2020 and 2023. In this Agreement, the 4 GWp target has been adopted.
- The contribution of PV may grow to 10-15% in 2030 and to several tens of percents in the longer term. A recent study of the potential of PV in the Netherlands, carried out by DNV GL (formerly KEMA) and PBL shows that area is not a limiting factor if roofs and other available surfaces are used efficiently. Integration into the grid requires adequate measures to be taken in time, but does not have to be limiting either.
- Dutch industry and research play an important global role in PV manufacturing technology (as supplier of equipment, processes and materials; the "upstream" part of the PV supply chain), with an estimated 50% of all solar modules produced worldwide containing some form of Dutch technology. However, competition is strong and increasing and rapid innovation is crucial to maintain or increase market share.
- With the growth of the PV market in the Netherlands, the number of companies active in the "downstream" part of the PV supply chain (product development, installation, etc.) increases rapidly. The TKI Solar Energy targets innovations in this part through its joint program with the TKI EnerGO, "solar energy in the built environment" (ZEGO), also see next slide.

TKI Solar Energy targets Energy & Economy

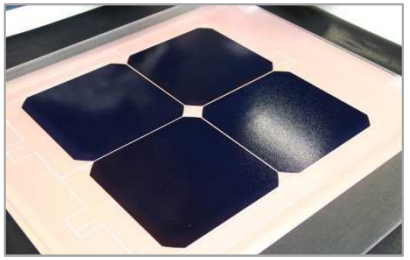
		Achievements	Targets		Potential
Indicator	Unit	in 2012	2020	2030	2050
Energy production	PJe*)	1,0	12 (9-23)	60	230
Installed capacity	GWp	0,35	4 (3-8)	20	80
Energy savings**)	PJ	1,4	14 (11-28)	58	155
CO2-savings	Mt CO_2-eq***)	0,17	2 (1,5-4)	10	38
Total turnover	G€	*0,5*	2	4	7,5
Export	G€	*0,1*	1	3	5
Employment	FTE	*2500*	7500	15000	28000

Roof-integrated PV system in Sint Pancras, NL
(house & photo Ivo Opstelten)

Selected highlights ECN research and development 2014

Wafer-silicon PV technologies

- Proof of concept of high-performance rear-contact, rear-junction Interdigitated Back Contact (IBC “Mercury”) technology with simplified processing. All-black appearance, module efficiency potential well above 20%, unique module technology for flexible design (see picture).
- Production of bifacially operating cells and modules using Dutch (ECN & Tempress) “n-Pasha” technology started in newly built Mission Solar Energy factory in San Antonio, Texas, USA.



Thin-film PV technologies

- Demonstration of all inkjet printed organic solar cells. Essential input technology for very high throughput roll-to-roll manufacturing of flexible solar modules with potential for partial transparency, various colors and freedom of shape (see picture).

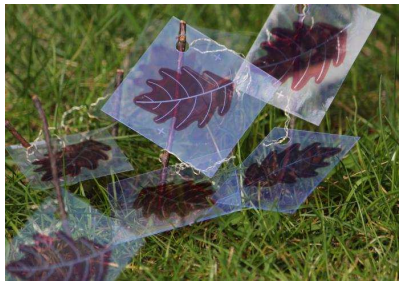
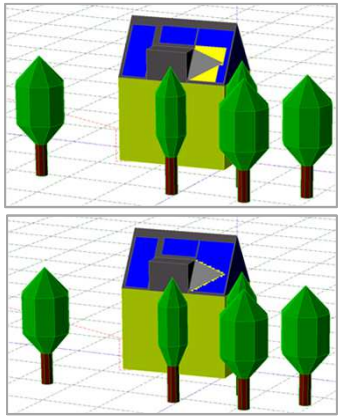


Photo: Solliance

PV Applications

- Proof-of-principle and working prototype of shade-tolerant “high-voltage” module for use under non-ideal irradiation conditions. Performance close-to-linear under a range of relevant partial shading conditions, i.e. on average 2x better than standard designs.
  The pictures on the right show the actual shadowing condition (left) as well as the electricity yield of the the system for standard modules (upper right) and “high-voltage” modules (lower right). Blue parts operate as normal, gray (shaded) and yellow (not shaded, but influenced by shading of nearby areas) parts are inactive.



Context

ECN Solar Energy research program in the TKI Solar Energy program

ECN PMC's and TKI Program Lines

- ECN Solar Energy's research programme is part of the research program of the TKI Solar Energy (including the joint programme of the TKI Solar Energy and the TKI EnerGO: ZEGO – solar energy in the built environment).

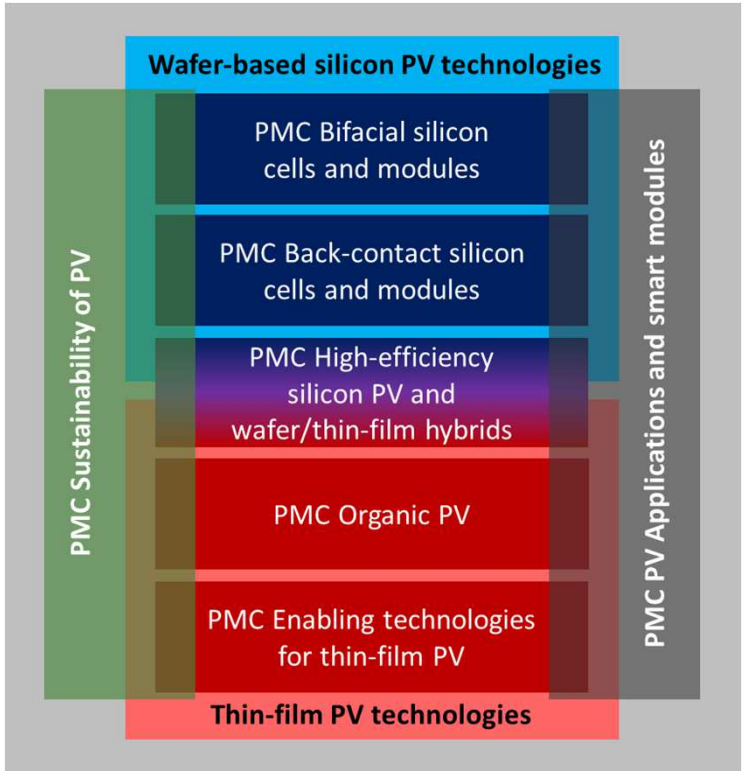
- **ECN's research** is divided into **Product-Market Combinations (PMCs)**, i.e. blocks of projects all addressing a specific technology field (also see figure on the right),

- The **TKI program**, in turn, is divided into **two Program Lines** (each with **five underlying Programs**). All ECN PMC's fall within these lines. Individual PMC's fall in one or more Programs.

  TKI Program Line 1: Generation (Wafer-silicon technologies, Thin-film Technologies and Hybrid Technologies)**:**
  - ECN PMC Bifacial silicon cell and module technologies;
  - ECN PMC Back-contact silicon cell and module technologies;
  - ECN PMC High-efficiency silicon PV and wafer / thin-film hybrids;
  - ECN PMC Organic photovoltaics;
  - ECN PMC Enabling technologies for thin-film PV.

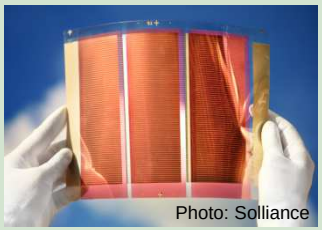
  TKI Program Line 2: Integration (Electrical and Physical)**:**
  - ECN PMC PV Applications and smart modules;
  - ECN PMC Sustainability of PV.

ECN Solar Energy program structure with PMC interactions



ECN Solar Energy R&D Plan 2015

TKI Solar Energy Program Line 1: Generation

TKI Program Line / Program	Main targets 2015	Contribution of ECN to 2015 targets
Program Line 1: PV technologies for (manufacturing of) innovative PV cells and modules	**Overall targets 2020:** • PV module cost: <0,35 €/Wp, enabling turn-key system prices <0,8-1,0 €/Wp (incl. margins) → generation costs of solar electricity (Levelized Cost of Electricity ; LCoE) in the Netherlands <0,08-0,10 €/kWh; • (thus contributing to) acceleration of PV deployment in the Netherlands : >4 GWp in 2020, >8 GWp in 2023; • (and contributing to) 7500 jobs in Dutch PV sector.	  Photo: Solliance
Program 1.1 (TRL 3-6)*): Wafer-based silicon PV-technologies	Efficiency increase and cost reduction of wafer-based silicon cells and modules, further improvement of sustainability profile.	Research of cells and modules with a high efficiency and a high electricity yield, especially new rear-contact (MWT *(left picture)* and IBC) and bifacially operating technologies. Explore options for recycling and design-for-sustainability as well as biobased materials for encapsulation.
Program 1.2 (TRL 2-6): Thin-film PV-technologies	Efficiency increase and cost reduction of (especially) thin-film CIGS/CZTS en OPV (cells and) modules, further improvement of sustainability profile; enabling new applications.	Application-driven research of organic solar cells and modules *(right picture)*, especially using atmospheric processes, and research CIGS/CZTS based thin-film PV, especially through the topics described in 1.3.
Program 1.3 (TRL 1-6): New, hybrid and generically applicable PV-technologies	Proof of concept of PV cells and modules with a very high energy conversion efficiency (>25%), proof of feasibility of new processes and techniques for cell or module manufacturing or measurement.	Development of technologies for advanced light management, back-end interconnection of cells into modules and encapsulation for thin-film PV, development of optimized rear-contact (IBC) silicon bottom cells and wide-bandgap absorbers for top cells of high-efficiency hybrid tandem concepts.
Program 1.4 (TRL 6-8): Application development and demonstration of Dutch PV-technologies	Development and demonstration of PV elements for special applications and demonstration of new PV technologies.	(See also 1.1) Development and field tests of bifacially operating, light-weight and/or flexible, desert-proof, and (partial-)shade-tolerant modules.
Program 1.5 (TRL 6-9): Infrastructure for Dutch innovations in PV cells and modules	Strengthening and extension of the Dutch PV research, development and demonstration infrastructure (incl. Silicon Competence Centre and Solliance).	(Helping) the establishment of the research infrastructure in the Silicon Competence Centre, contributing to strengthening of the Solliance infrastructure.

*)**TRL = Technology Readiness Level (see http://en.wikipedia.org/wiki/Technology_readiness_level for details)**

ECN Solar Energy R&D Plan 2015

TKI Solar Energy Program Line 1: Generation

Selected projects contributing to the 2015 targets

- **NL TKI Solar Energy**

  - Silicon Competence Centre 2 (partners: Tempress, Eurotron, Levitech, DSM, Roth & Rau BV, Solar Electricity Development, Univ. Utrecht en ECN) – Network for developing and sharing knowledge and technology for wafer-silicon based PV using a joint infrastructure.
  - NChanted (partners: Tempress, Levitech, ASM, Meco, Roth & Rau BV, TU Eindhoven, ECN) – Development of processes and equipment for cost-effective, high-efficiency (towards 22%) n-type front junction cells and modules, starting from the 20%-efficient n-Pasha cell.
  - Pamplona (partners: Eurotron, Tempress, Levitech, Meco, ECN) – Development and demonstration of low-cost, high-throughput process technology for several cell and module manufacturing technologies with objectives: reducing materials consumption and optimizing cell and module integration and efficiency.
  - IBChampion (partners: Levitech, Tempress, ASM, Roth & Rau BV, TU Eindhoven, TU Delft, ECN) – Develop a cost-effective rear-junction, rear-contact (IBC) cell and module technology with cell efficiencies between 22-23%, to support Dutch equipment manufacturers in the global market of photovoltaics.
  - FANTASTIC (partners: CCM, Smit Ovens, IBSPE, Roth & Rau BV, TNO, ECN) – Development of back-end (i.e. applied after deposition of the light-absorbing layers) interconnect technology for use in (especially, but not only) thin-film CIGS module manufacturing.
  - DESIRE (Partners: Roth & Rau BV, Smit Ovens, TNO, TU Eindhoven, ECN) – Develop and demonstrate cadmium free production of cost-effective and efficient CIGS and CZTS thin-film solar cells by combining two recently developed deposition techniques.

- **EU FP7 and H2020**

  – MUJULIMA (partners: TNO, imec, TU Eindhoven, WUP, CEA, PCAS, Disasolar, NEN, ECN) – Development of high performance commercially competitive materials with excellent stabilities for cost-effective production of double and triple junction organic PV, for improved light management and for enhanced outdoor stability, to achieve high module efficiencies (>15%) and long lifetime (>10 years).

  – High-efficiency wafer-silicon / thin-film hybrid technologies (H2020 acquisition).

ECN Solar Energy R&D Plan 2015

TKI Solar Energy Program Line 2: Integration (& cross-cutting subjects)

TKI Program Line / Program	Main targets 2015	Contribution of ECN to targets 2015
Program Line 2: ZEGO (jointly with TKI EnerGO) – Solar energy in the built environment	**Overall targets 2020 (PV- en PV-thermal (PVT) parts):** • Turn-key system prices <0,8-1,0 €/Wp (incl. margins) → generation costs of solar electricity (Levelized Cost of Electricity ; LCoE) in the Netherlands <0,08-0,10 €/kWh; • unlocking the potential of PV in buildings and physical infrastructure by making optimized system solutions available (w.r.t. aesthetics, electricity yield, etc.); • (thus contributing to) acceleration of PV deployment in the Netherlands : >4 GWp in 2020, >8 GWp in 2023; • (and contributing to) 7500 jobs in Dutch PV sector.	 
Program 2.1 (TRL 3-8) : Components and services for optimization of solar energy system output.	Increasing the specific electricity yield (kWh/Wp) of PV systems operating under non-ideal conditions (such as they frequently occur in practice), thereby lowering the actual generation costs of electricity.	Development and testing of PV elements with modified (especially electrical) build-up or additional functionality for optimized electricity yield *(see pictures: prototype shade-tolerant mini-module (left) and testing under partial shading conditions (right).*
Program 2.2 (TRL 4-8): Multifunctional building elements with solar energy (electricity and/or thermal) generation functionality.	Facilitate and broaden the application of PV and PVT technologies by combining functions in building elements.	Development and testing of PV elements with modified (especially mechanical and optical) build-up for application in building components.
Program 2.3 (TRL 4-8): Energetic integration of solar energy with (smart) grids and storage systems.	Optimize the value of solar electricity by enabling very large scale use through integration into the energy system of a building or at a higher level.	Participate in projects where PV technology (PV components) is adapted for the purpose of system integration.
Program 2.4 (6-8): Demonstration of aesthetic integration of solar energy in infrastructure objects.	Foster large-scale deployment of solar energy with continued public support by realizing appealing and well-operating examples in the physical infrastructure.	Support demonstration projects initiated by market parties, in particular by evaluation and monitoring.
Program 2.5 (6-8): Demonstration of aesthetic integration of solar energy in buildings (and building elements).	Foster large-scale deployment of solar energy with continued public support by realizing appealing and well-operating examples in buildings.	Support demonstration projects initiated by market parties, in particular by evaluation and monitoring.

TKI Solar Energy Program Line 2: Integration (& cross-cutting subjects)

Selected projects contributing to the 2015 targets

- **NL TKI Solar Energy**

  - Module Level Power Management (partners: Femtogrid, Heliox, Mastervolt, Proxenergy, SolNed, Hogeschool van Amsterdam, SEAC, TNO, ECN) – Comparison and characterization of (systems with) power optimizers, micro-inverters and string inverters under shadow conditions.

  - LiRoB (partners: TULiPPS Solar, DSM, Yparex, Kiwa, SolNed, Sabic, Resin, SCX, Oskomera, SEAC, TNO, Chematronics, ECN) – Development of a new lightweight BIPV (Building Integrated PV) system for pitched roofs. The PV laminate is frameless and glued on to a back construction, creating a flexible, structural roofing element.

  - BAIBA (ECN) – Definition of requirements and enablers for BIPV and bifacial PV technology.

- **EU FP7**

  – PV GUM (Imperbell, Nolax, HyET Solar (see picture), DNV GL, Meyer, Guilbert Express, Eurinnov, B-Energ, ECN) - Development of low -cost flexible thin-film silicon PV modules integrated with roofing membrane.

  – SOPHIA (20 partners from Europe) – Strengthening and deployment of a European PV research infrastructure.

  – CHEETAH (34 partners from Europe) – Development of new concepts and technologies with reduced costs of materials and increased module performance, fostering long-term European cooperation in the PV R&D sector, accelerating implementation of innovative technologies in the PV industry.

HyET Solar thin-film silicon solar foil

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