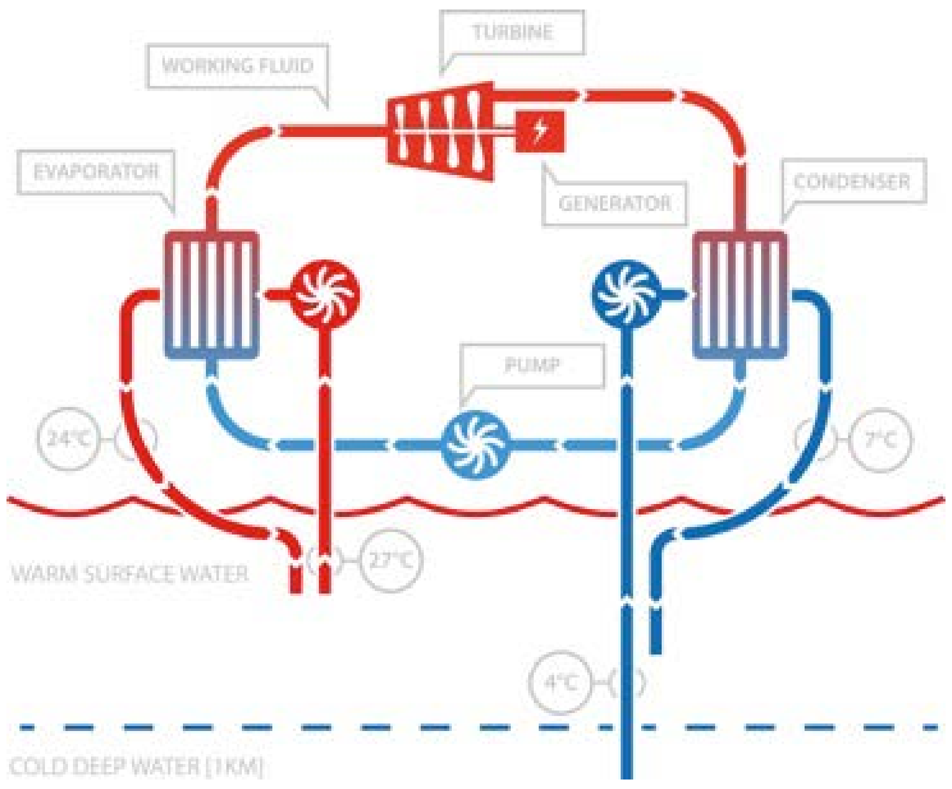
FACTSHEET ENERGY FROM WATER

TECHNOLOGY DESCRIPTION

Name technology	Ocean Thermal Energy Conversion (OTEC)
Date of factsheet	10-11-2020
Author	Ruud van den Brink and Sam Lamboo
Description	Ocean Energy Thermal Conversion uses temperature differences between warm surface water and cold deep ocean water to generate electricity. Warm surface water evaporates a working fluid, which drives a turbine to generate electricity, after which the working fluid is condensed again by the cold ocean water. OTEC exploits temperature differences of more than 20 °C, for which a sea-depth of approximately 1 km is required. The efficiency of an OTEC installation is low (7%), but this makes little difference because no costs are incurred for the energy source. Due to the relatively low temperature difference, large amounts of water (750 tons per second with a 100 MW installation) and large pumps are required - which is the main technical challenge. (IRENA, 2014) There are several variants of OTEC: closed-cycle, Kalina cycle (variant of closed-cycle), open-cycle and hybrid systems. Closed systems use ammonia or another working fluid to drive the turbine. Open systems use evaporated warm surface water to power a turbine, after which it is condensed using cold seawater. After condensation, fresh water remains that can be used. Open systems require a large surface area for evaporation, making open systems less scalable than closed systems. Closed systems can also work with smaller pipes, smaller turbine diameters and require less surface area for heat exchangers. The efficiency of closed systems is also higher than that of open systems. Closed systems are therefore cheaper than open systems. All types of installations can be on land, at sea and floating. With floating systems, the platform and connection to the grid are more expensive, but from a certain size of installation, seawater inlet pipes are cheaper to fix vertically under a floating platform than to extend to land. (IRENA, 2014; Allseas, 2020) These fact sheets focus on closed systems. It is assumed smaller systems (up to 3 MW) are land-based and that larger systems are floating installations.

TRL LEVEL

	2020	2030	2050
TRL	5-7	9	9
Explanation	There are prototypes and demonstration projects in the order of 100 kW operational, where tests are being done (ETIP Ocean, 2019; Allseas, 2020). In 2019, tests were carried out with a 600 kW system in South Korea, which is expected to be operational in 2020 or 2021 (Allseas, 2020; Petterson and Kim, 2020). Allseas expects to be able to realize a pre-commercial demonstration project on Bonaire in 2023 (Allseas, 2020). Commercial projects can then follow before 2030. Large-scale systems (order size 100 MW) still face a number of technical challenges such as construction of large cold water pipes, biofouling, corrosion, frequency instability in the generator and aggressive degassing of cold seawater in condensers (IRENA, 2014).		



Closed OTEC system (Source: Bluerise and Topsector Water, 2014).

CURRENT INSTALLED CAPACITY AND ANNUAL ELECTRICITY PRODUCTION IN THE NETHERLANDS

Installed capacity	-
Annual electricity production	-
Explanation	-

POSSIBLE LOCATIONS IN THE NETHERLANDS

Locations	Due to the required temperature differences and depth only possible in the Dutch Antilles. The theoretical potential is greater than the electricity demand on the islands, thus the largest potentials lie in Aruba, Curaçao and St. Maarten, where the demand for electricity is higher than on Bonaire, St. Eustatius and Saba.
Explanation	In the Netherlands we could think of possible spin-offs, such as supplying cooling based on deep seawater for specific applications such as data centers. Sea Water Air Conditioning (SWAC) is already being applied on a commercial scale in some places in Europe (ETIP, 2019). Generating electricity from low-grade residual heat (40-50 degrees Celsius steam) may also be interesting. Bluerise (2018) has calculated the business case for the Frisia salt plant in Harlingen, which is positive if subsidy schemes for innovative projects can be used, such as the Energy Investment Deduction (EIA) or the Demonstration Energy Innovation (DEI).

POTENTIAL IN THE NETHERLANDS

		2030					2050				
	Unit	Main source	Source 2	Source 3	Source 4	Source 5	Main source	Source 2	Source 3	Source 4	Source 5
Energy potential (technical)											
	Unit	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
Energy potential (economic)		0	2				5.6				
	PJ/year	*Ecofys 2017*	*Allseas 202*	*Source*	*Source*	*Source*	*Allseas 2020*	*Source*	*Source*	*Source*	*Source*
Mitigation potential											
	Unit	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*

Explanation	Up to 2030 the market potential (economic potential that is expected to be realized) is estimated by Ecofys (2017) at 0 PJ/year. Allseas estimates the economically feasible potential in 2030 at 0.57 TWh/year (2 PJ/year) and 1.55 TWh/year in 2050 (5.6 PJ/year) in 2050. The largest share at the larger islands, where the demand for electricity is also higher: in 2030 10 MW in Curaçao and 30 MW in both Aruba and Sint Maarten. In 2050 60 MW on all three islands. 3 MW is foreseen for Bonaire in 2030, expanded to 13 MW in 2050. On Saba and St. Eustatius 2 MW in 2050. The potentials have been calculated by Allseas on the basis of 90% availability. (Allseas, 2020)

COSTS

		2020					2030					2050				
	Unit	Main Source	Source 2	Source 3	Source 4	Source 5	Main Source	Source 2	Source 3	Source 4	Source 5	Main Source	Source 2	Source 3	Source 4	Source 5
Capex		12300					10500	4400	13000			2300				
	€/kW	*Bluerise en To*	*Source*	*Source*	*Source*	*Source*	*Vega 2010*	*IRENA 201*	*IRENA 201*	*Source*	*Source*	*IRENA 2014*	*Source*	*Source*	*Source*	*Source*
Fixed Opex		480					420	175	525			90				
	€/kW/year	*Bluerise en To*	*Source*	*Source*	*Source*	*Source*	*Calculation ba*	*IRENA 201*	*IRENA 201*	*Source*	*Source*	*IRENA 2014*	*Source*	*Source*	*Source*	*Source*
Variable Opex																
	Unit	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
Grid connection																
	Unit	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*	*Source*
LCOE		0.19					0.16	0.08	0.25			0.04				
	€/kWh	*Bluerise en To*	*Source*	*Source*	*Source*	*Source*	*Vega 2010*	*IRENA 201*	*IRENA 201*	*Source*	*Source*	*IRENA 2014*	*Source*	*Source*	*Source*	*Source*

Explanation	Costs in 2020 are based on a feasibility study for a floating offshore 10 MW installation (Bluerise and Topsector Water, 2014). Of the investment costs, 63% is for heat exchangers, the offshore platform and the seawater pipes. Other equipment is 17% of the investment costs and 20% of the investment costs are for transport, installation and commissioning. Fixed annual costs consist of 49% O&M (3% of investment costs for rotating equipment and 2% for non-rotating equipment, on average about 2.5% of equipment investment costs), 32% insurance (1-1.5% of investment costs) and 19% other facilities, administration and management. The LCOE is calculated on the basis of financing costs (WACC) of 8%, life of 30 years and 95% availability. IEA-OES (2015) calculates for a 10 MW installation with comparable costs: $ 15,000 / kW investment costs and $ 480 / kW / year operating costs. However, IEA-OES (2015) estimate a higher LCOE at $ 0.35 / kWh. For 2030, cost estimates of installations of 35 MW (main source), 100 MW (bottom of bandwidth) and 10 MW (top of bandwidth) have been used. Fixed O&M costs are calculated as 4% of the investment costs based on Bluerise and Top Sector Water (2014). IRENA (2014) estimates the O&M costs to be lower: between 1.4% and 2.7% of CAPEX. The LCOEs are calculated based on a WACC of 8%, a lifespan of 30 years and 95% availability. IEA-OES (2015) estimates the costs for a 100 MW commercial installation higher with a Capex of $ 7,000-13,000 / kW, operating costs of $ 340-620 / kW / year and LCOE of $ 0.15-0.28 / kWh.

	Cost estimates of a large (> 100 MW) offshore installation have been used for 2050, because it is expected that systems of such size can only be realized then. Costs of smaller systems (10-100 MW) are expected to be comparable to the indicated costs for 2030, with a possible further decrease due to learning effects. The LCOE is calculated based on a WACC of 8%, life of 30 years and 95% availability. In addition to the size of the system, costs depend on the design (open or closed system) and production of by-products such as fresh water or cold (IRENA, 2014).
ENERGY PROFILE	
Energy profile	Base load techology with a capacity factor of 90-95% (IRENA, 2014).
Explanation	The availability of warm and cold sea water does not fluctuate in such a way that it will disrupt electricity production.
EXPORT POTENTIAL	
Export potential	Globally, the potential is estimated between 3-30 TW or 300 exajoules (EJ) per year (Nihous, 2005; Nihous, 2007; Rajagopalan & Nihous, 2013; IRENA, 2014). Allseas also sees potential in the provision of services or parts for OTEC systems (Allseas, 2020).
Explanation	Interesting tropical regions are: Caribbean, Pacific islands, India, west and southeast coast of the American continent, and Africa (especially Mozambique, Comoros, Reúnion and Mauritius) (IRENA, 2014). Even before projected cost reductions can be realized, OTEC can be interesting for islands where the reference price for electricity is determined by diesel generators and is above 0.30 € / kWh (IRENA, 2014).
POSSIBLE NON-ENERGETIC SIDE EFFECTS	
Ecological effects	Lems-de Jong (2017) conducted research into ocean currents around Curaçao, the influence on the performance of an OTEC plant and the influence of an OTEC plant on water temperature. It was concluded that intake of cold and hot water, even for a 100 MW system, does not affect average temperature, because it concerns a very small amount of water compared to the volume of water that flows past the island. The discharged water does have a different temperature and density than the water taken in and the outlet of water must therefore be placed at a suitable height to prevent impact on the environment. Much is still unknown about the ecological effects of OTEC, which requires additional (local) research. Among other things, we must take into account the effects on the coast, impingement and entrainment of marine life and the effects on water quality due to the discharged water (effluent), which may differ in temperature or have a higher content of nutrients or other substances such as biocide residue, metals, sediment and working fluid (e.g. ammonia in case of leaks) than the environment in which the effluent ends up (IRENA, 2014; Bluerise and Topsector Water, 2014; Deltares, 2020).
Multiple use	Can be combined with cooling function (air-conditioning, district cooling, agricultural greenhouse cooling) (IRENA, 2014). Feasibility of supplying cooling depends on the number of customers. With many stakeholders involved, implementation is less straightforward (Allseas, 2020). Fresh water can also be produced as a by-product. In open systems this is done by evaporating seawater, but this will be on a small scale due to the challenges of scaling-up open systems. With all OTEC systems it is possible to use the cold seawater to condense water vapor from the air. OTEC systems can also be coupled to a desalination (reverse osmosis) system to produce fresh water, possibly at a cost 2-5 times lower than large-scale seawater desalination plants. (IRENA, 2014; Allseas, 2020)
Social and landscape effects	An advantage of floating systems compared to systems on land is less land use (IRENA, 2014).
Material use/circularity	Most of the material for an OTEC installation is needed for the seawater inlet pipes and heat exchangers. Multiple materials can be suitable for seawater inlet pipes, such as concrete, steel, composite and polyethylene (HDPE), so that life span, material use and possibilities at the end of use can be taken into account. Heat exchangers are usually made of titanium, of which relatively little is available in the desired thicknesses. Allseas is investigating the possibilities of using plastics as material for the heat exchangers. (Bluerise and Top Sector Water, 2014; Allseas, 2020).
SOURCES	
1	IRENA (2014) - Ocean Thermal Energy Conversion: Technology brief.
2	ETIP Ocean (2019) - Powering homes today, powering nations tomorrow: Policy solutions to deliver ocean energy industrial roll-out
3	Petterson en Kim (2020) - Can ocean thermal energy conversion and seawater utilisation assist small island developing states? A case study of Kiribati, Pacific Islands Region.
4	Ocean Energy Europe (OEE) (2020) - https://www.oceanenergy-europe.eu/ocean-energy/otec/, visited 15 July 2020.
5	Ecofys (2017) - Overige hernieuwbare energie in Nederland. Een potentieel studie (in Dutch).
5	Allseas (2020) - Interview on 16 July 2020 and written response to draft factsheet (in Dutch).
6	Bluerise (2018) - OTEC systeemintegratie voor restwarmte conversie bij Frisia Zout in Harlingen, https://projecten.topsectorenergie.nl/projecten/otec-systeemintegratie-voor-restwarmte-conversie-bij-frisia-zout-in-harlingen-00028986 (in Dutch).
7	Vega (2010) - Economics of Ocean Thermal Energy Conversion: An update
8	Muralidharan (2012) - Assessment of Ocean Thermal Energy Conversion
9	Nihous (2005) - An order-of-magnitude estimate of Ocean Thermal Energy Conversion resources
10	Nihous (2007) - A preliminary assessment of Ocean Thermal Energy Conversion resources
11	Rajagopalan & Nihous (2013) - Estimates of global Ocean Thermal Energy Conversion resources using an ocean thermal circulation model.
12	Deltares (2020) - Interview on 3 July 2020 and written response to draft factsheet.
13	Lems-de Jong (2017) - Ocean current patterns and variability around Curaçao for Ocean Thermal Energy Conversion.