TECHNOLOGY FACTSHEET

GAS-FIRED CHP PLANT - ELECTRICITY PRODUCTION AND DISTRICT HEATING

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Sector	Built environment Other sectors
ETS / Non-ETS	ETS
Type of Technology	CHP
Description	Working of the Technology: A 'modern' natural gas-fired power plant can be a combined heat and power plant (CHP). In case of a combined cycle gas turbine/CCGT (Dutch: Stoom en Gasturbine/STEG) there is a gas turbine and steam turbine. In the first turbine, gas is expanded to drive the turbine. The second turbine, a steam turbine, is being driven by the residual heat of the gas turbine. Water is evaporated using heat from the waste heat recovery unit steam generator (heat exchanger) to produce high pressure steam which is expanded in a steam turbine to generate electricity using a generator. From the drain of a steam turbine, heat can be fed into a heat distribution network. Heat can be supplied to different sectors such as the built environment or industry. This factsheet focuses on a CHP plant that delivers heat to the built environment. A CHP plant without carbon capture and storage (CCS) is considered in this factsheet. Main components: Components of a gas-fired power plant for the production of electricity and district heating typically are an (inlet) air compressor, gas turbine and generator, heat recovery boiler, economiser/heat exchanger (i.e. feedwater heaters; commonly used as part of a heat recovery steam generator in a combined cycle power plant), steam turbine(s) and generator, condensor, cooling technique, and flue gas cleaning equipment. Energy production related aspects: The downside of utilizing heat for district heating is that the electrical efficiency of the CHP plant is lowered (loss of electricity production) (ECN, 2011). Loss of electricity production (GJe/GJth supplied) depends on the temperature of heat disconnection. Figures about losses are included in this factsheet. Besides CO2 emissions, a STEG also emits NOx (Ecofys, 2014). A power plant is equipped with flue gas cleaners to limit NOx emissions. The flue gas cleaner is included in the costs presented in this factsheet.
TRL level 2020	TRL 9 The technology is already being applied on a large-scale and can therefore be considered to be mature. A substantial amount of the installed capacity in the electricity sector in the Netherlands consists of gas-fired CHP (ECN, 2017b). Gas-fired CHP is one of the main heat sources for district heating in the Netherlands in 2015 (ECN, 2017a).

TECHNICAL DIMENSIONS

	Functional Unit		Value and Range								
Capacity	MWe		500								
			200			-			900		
			Current			2030			2050		
Potential	MWe	NL	-			-			-		
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Market share	%	Share of final heat demand	2			-			-		
			2	-	2	*Min*	-	*Max*	*Min*	-	*Max*

Capacity utlization factor		0,80
Full-load running hours per year		7.000
Unit of Activity	PJe/year	12,6
Technical lifetime (years)		30
Progress ratio		-
Hourly profile	Yes	
Explanation	Typical Electric and Heat Capacity Of Gas-fired Power Plants The electrical capacity of most STEG plants in different OECD countries ranges between 280 and 900MWe (IEA, 2015). In the Netherlands the electrical capacity of STEG plants ranges between 200 and 900MWe (Ecofys, 2014). Here, 500 MWe is taken as an average. Full load hours per year for electricity production are case-dependent. It depends strongly on the position of these plants within the electricity market (ECN, 2017b). The increasing share of intermittent renewable electricity generation may decrease full load hours, because plants do not have to operate when there is sufficient production from renewable sources (ECN, 2019). Gas-fired CHP could then provide back-up capacity. From a general historical perspective, a gas-fired CHP plant used for district heating typically runs as base load plant for electricity production; 6.000 to 8.000 full load hours per year (ECN, 2010; Gasterra, 2008). In case of 7.000 full loads hours this translates to a capacity utilitization factor of 80%. Indeed, IEA (2010) indicates 75 to 85% as capacity utilization factor for a CCGT CHP (IEA ETSAP, 2010). A CHP plant with a capacity of 500 MWe and 7.000 full load hours produces 12,6 PJe per year. Full load hours for heat delivery are not the same. Indeed, heat demand peaks in winter and in other seasons there is a (much) lower heat demand. Heat is available when the plant produces electricity, but due to limited overlap with the heat demand only 30 to 45% of the available heat can be supplied per year (ECN, 2011). For example, consider a large scale district heating network that supplies about 1 PJth per year, as average for the Netherlands (ECN, 2017a). About 25% heat losses can be assumed in a heat network (ECN, 2017a). This means the heat source needs to produce about 1,3 PJth per year. Assuming 4.500 full load hours (Energy Matters, 2012), the needed thermal output capacity for district heating is 82MWth. A minimum heat disconnection capacity for district heating is 10MWth (Ecofys, 2014). Heat Supply by Gas-fired Power Plants In The Netherlands About 4% of the final heat demand in the built environment (463 PJ in 2015 based on ECN, 2017a) in the Netherlands is supplied with district heating in 2015 (ECN, 2017a). In 2015, 67% of final heat demand of large scale heat networks (18 PJ) is supplied by (natural gas and coal fired) CHP plants, this figure is also including small gas-fired CHP units (ECN, 2017a). Excluding heat supplied by coal-fired CHP (2,7 PJ in 2015 based on ECN, 2017a), this results in a share of about 2% for gas-fired CHP plants in the final heat demand of the built environment. This share is expected to decrease as the share of sustainable heat goes up. Technical Lifetime Gas-fired Power Plants ETRI indicates a technical lifetime of 30 years for a CCGT CHP (ETRI, 2014). ECN indicates a technical lifetime of 30 years for a gas-fired CHP (ECN, 2011). IEA (2010) indicates a technical lifetime of 25 years for a CCGT CHP (IEA ETSAP, 2010).	

COSTS

Year of Euro	2015								
	Euro per Functional Unit	Current			2030			2050	
Investment costs	mln. € / MWe	1,01			1,00			0,98	
		0,87	-	1,22	0,85	-	1,19	0,83	-	1,16
Other costs per year	mln. € / MWe	-			-			-	
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Fixed operational costs per year (excl. fuel costs)	mln. € / MWe	0,05			0,05			0,05	
		-	-	0,06	0,04	-	0,06	0,04	-	0,06
Variable costs per year	mln. € / MWe	0,03			0,03			0,03	
		0,02	-	0,03	0,03	-	0,03	0,03	-	0,03

Costs explanation

Overview:
The ETRI (2014), Energy Matters (2012), IEA ETSAP (2010) and PBL (2017) and ECN (2011) reports provide information on gas-fired CHP' investment costs/capital expense (CAPEX), fixed operational costs (FOM), and variable operational costs (VOM). Costs are described for different capacity levels expressed per unit of capacity.

Costs explanation per source:
• ETRI (2014) indicates the CAPEX of a CCGT advanced CHP (ETRI, 2014). ETRI indicates a CAPEX of 870-1210 €/kWe for the plant in 2020, a CAPEX of 850-1180 €/kWe for the plant in 2030 and a CAPEX of 830-1150 €/kWe for the plant in 2050. The FOM costs per year in 2020, 2030 and 2050 amount to 5,2% of the CAPEX, namely 3,9% for FOM and 1,3% for FOM refurbishment (ETRI, 2014). The VOM costs per year in 2020, 2030 and 2050 amount to 4 €/MWh (ETRI, 2014) and these are converted to €/MWe assuming 7.000 full load hours per year. In the CAPEX the following cost components are included (ETRI, 2014): Civil and structural costs, Major equipment costs, Electrical and I&C supply and installation, Project indirect costs, Development costs and Interconnection costs. Costs not included are: Balance of plant costs and Insurance costs (ETRI, 2014).

• Energy Matters (2012) indicates investment costs of a STEG with capacity of 120MWe (Energy Matters, 2012). Energy Matters indicates an investment of 1.050 euros/kWe. CAPEX ncludes Civil and structural costs, Major equipment costs including heat disconnection costs. Fixed operational costs are zero (Energy Matters, 2012). Variable costs per year are 2,52 Million Euros per year (Energy Matters, 2012). This plant is used for electricity production and disctrict heating.

• According to the IEA (2010) the investment cost of CCGT CHP plant (including indirect costs or IDC) is in the range of $1100 to $1800/kWe , which is 10-45% higher than the cost of a power plant, depending on the capacity of the plant (IEA ETSAP, 2010). Typical investment costs amount to $1300/kWe (inc. IDC). The O&M costs, which are given as the total of fixed and variable, are in the range of $40/kWe to $60/kWe per year (typically $50/kWe). According to the IEA (2010) projection, incremental improvements and technology learning may lead to investment cost of $1200/kWe by 2020 and $1100/kWe by 2030 (IEA ETSAP, 2010).

When a CHP plant supplies heat to a heat network for the first time, there are additional investment costs for heat disconnection:
• PBL (2017) indicates an investment of 150-175 euros2017/kWth,output (PBL, 2017). The costs consist of the investment/CAPEX for heat disconnection (Dutch: 'kosten warmteuitkoppeling'). The fixed operational costs per year are 5% of the investment.
• ECN (2011) indicates an investment of 300 euros2011/kWth,output (ECN, 2011). The costs indicated consist of the investment/CAPEX for heat disconnection (Dutch: 'kosten warmteuitkoppeling').

ENERGY IN- AND OUTPUTS										
	Energy carrier	**Unit**	**Current**			**2030**			**2050**	
Energy carriers (per unit of main output)	*Main output:* Electricity	PJ			-1,00			-1,00		-1,00
			-1,00	-	-1,00	-1,00	-	-1,00	-1,00 -	-1,00
	Natural gas	PJ			2,00			2,00		2,00
			2,00	-	2,33	2,00	-	2,33	2,00 -	2,33
	Heat	PJ			-0,80			-0,80		-0,80
			-0,98	-	-0,74	-0,98	-	-0,68	-0,98 -	-0,68
		PJ			-			-		-
			Min	-	*Max*	*Min*	-	*Max*	*Min* -	*Max*

Energy in- and Outputs explanation

Overview:
The electrical efficiency of existing combined cycle gas turbines in different OECD countries ranges between 39% and 61% (IEA, 2015). Depending on capacity of the plant, generally lower efficiencies are found for smaller units and higher efficiencies for larger units (Gasterra, 2008).
The electrical efficiency of a CHP plant can only improve marginally due to further technical optimizations. The maximum possible efficiency of any heat engine is defined as the Carnot efficiency, which is not obtainable in practice.
According to ETRI (2014) current combined cycle power plants used for cogeneration have a typical electrical efficiency of 59% at peak electrical load and a thermal efficiency of 46% at peak thermal load (ETRI, 2014). Peak load efficiency means the efficiency if the plant maximizes one of its outputs. In case of CHP, a higher heat output lowers the electricity output and vice versa.

Ratios (used to determine min.-max. range in table above):
• ECN (2011) indicates a 57% electrical efficiency and (possible) thermal efficiency of 40% for a gas-fired CHP plant used for electricity production and district heating (ECN, 2011). Disconnecting 0,4GJth at 120 °C per GJ natural gas input results in a decrease of electricicity production from 0,57GJe to 0,5GJe (ECN, 2011). For 2020, 2030 and 2050 the same values are assumed.

• Energy Matters (2012) indicates a 42% thermal efficiency and a 43% electrical efficiency for a gas-fired combined cycle CHP used for large scale district heating (Energy Matters, 2012). For 2020, 2030 and 2050 the same values are assumed.

• IEA ETSAP (2010) indicates an electrical efficiency of 42-47% for a natural gas-fired combined cycle CHP and a thermal efficiency (steam) of 33-38% (IEA ETSAP, 2010). The 2020 projection is an electrical efficiency of 44-48% (46%) and a thermal efficiency of 32-36% (34%). The 2030 projection is an electrical efficiency of 46-49% (47,5%) and a thermal efficiency of 31-34% (32,5%) (IEA ETSAP, 2010). For 2050 the same efficiencies as 2030 are assumed.

Other ratios:
• ETRI (2014) presents energy efficiencies of a CCGT advanced CHP (ETRI, 2014). Efficiencies at peak thermal load or peak electrical load are given in the report, which means that the plant maximizes either its heat or electricity output. In 2020, the max. thermal efficiency is 46% and the max. electrical efficiency is 59% (ETRI, 2014). In 2030, the max. thermal efficiency is 47% and the max. electrical efficiency is 61% (ETRI, 2014). In 2050, the max. thermal efficiency is 49% and the max. electrical efficiency is 63% (ETRI, 2014). The ETRI report does not give (max.) heat efficiency when (max.) electrical efficiency is given and vice versa.

MATERIAL FLOWS (OPTIONAL)											
	Material	**Unit**	**Current**			**2030**			**2050**		
Material flows					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Material flows explanation											

EMISSIONS (Non-fuel/energy-related emissions or emissions reductions (e.g. CCS)											
	Substance	**Unit**	**Current**			**2030**			**2050**		
Emissions					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
					-			-			-
			Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
Emissions explanation	Most of the NOx emissions are prevented due to the flue gas cleaner.										

OTHER										
Parameter	**Unit**	**Current**			**2030**			**2050**		
Loss of electricity production per unit of heat supplied	GJe/GJth			0,18			0,18			0,18
		0,09	-	0,18	0,09	-	0,18	0,09	-	0,18
Water consumption	liters/kWh			0,01			0,01			0,01
		0,01	-	0,01	0,01	-	0,01	0,01	-	0,01
				-			-			-
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*
				-			-			-
		Min	-	*Max*	*Min*	-	*Max*	*Min*	-	*Max*

Explanation

• Downside of utilizing heat for district heating is that the electrical efficiency of the CHP plant is lowered (loss of electricity production). For each GJth of drain heat supplied to a district heating network there is 0,18 GJe loss of electricity production (ECN, 2011). The higher the temperature of the heat, the higher the losses. ECN (2011) indicates a loss of 0,18 GJe/GJth for drain heat at 120 °C and a loss of 0,09 GJe/GJth at 80 °C (ECN, 2011).

• According to ETRI the water withdrawal is equal to 0,01 liters per kWhe and water consumption (i.e. water which is not returned to the water system) is 0,01 liters per kWhe (ETRI, 2014).

REFERENCES AND SOURCES

Ecofys (2014). Warmteladder. Available at: https://www.ecofys.com/files/files/ecofys-2014-warmteladder.pdf

IEA (2015). Projected Costs of Generating Electricity 2015 Edition

ETRI (2014). Carlsson J, Energy Technology Reference Indicator projections for 2010-2050, 2014 Edition, EUR 26950 EN, Publications Office of the European Union, Luxembourg, 2014, ISBN 978-92-79-44403-6, doi: 10.2790/057687, JRC92496
https://setis.ec.europa.eu/related-jrc-activities/jrc-setis-reports/etri-2014

IEA ETSAP (2010). Combined Heat and Power - Technology Factsheet

Gasterra (2008). Warmte en Kracht: WarmteKrachtKoppeling: een overzicht en leidraad

PBL (2017). Functioneel ontwerp VESTA 3.0.

ECN (2011) Restwarmtebenutting, potentielen, besparing, alternatieven

ECN (2010). Kolencentrales Eemshaven Dwingende redenen openbaar belang Antwoorden op vragen van het Ministerie van EL&I.

ECN (2017a). Monitoring Warmte 2015

ECN (2017b). Nationale Energieverkenning 2017

ECN (2019). Monitoring Warmte 2017