TECHNOLOGY FACTSHEET



v.2													
DIABATIC COMPRESSED	AIR ENERGY STORA	GE (CAES) F		-SCALE T	EMPORA	L ELECTRI	CITY STO	ORAGE					
Date of factsheet	20-2-2020												
Author	Sam Lamboo												
Sector	Electricity generation												
ETS / Non-ETS	Non-ETS												
Type of Technology Description	Storage												
Description	Compressed air energy storage (CAES) is based on storing electricity as compressed air. Compressed air is typically stored underground in suitable geological formations (salt, hard rock and porous rock or aquifer). Aboveground CAES is also a possibility, however investment costs in this case are higher.												
	This factsheet only considers underground CAES whereas air is expanded through a turbine to produce electricity. Diabatic CAES uses fuel (typically natural gas) to heat the expanding air (JRC ETRI, 2014). CAES is typically a large-scale, long-term storage option, and it is applied on the centralised grid.												
	As of 2017, there are two large diabatic CAES projects installed globally, the first one is a 290 MW plant in Germany, and the second one is a 110 MW plant in Alabama, the US (DNV KEMA 2013; IRENA, 2017).												
TRL level 2020	TRL 9 The two large existing projects v	vere already install	ed in 1978 (Gern	nany) and in 19	91 (Alabama) (E	NV KEMA, 201	3). More plant	ts are being prep	bared, such as a	plant in Larne,	Ireland (TNO,		
	2018).			-									
TECHNICAL DIMENSIONS	Functional Un	nit.					/alue and Ran	000					
Capacity	kWh	in.					3,000,000	-					
				580,000			-		3,000,000				
Potential	NL	GWh		Current 550			2030			2050			
			Min	-	Max	Min	_	Max	Min	-	Max		
Market share	Global utility scale electricity sto	orage %		0.30%		A -**	-		P. 47	-			
Capacity utlization factor	<u> </u>		Min	-	Max	Min	-	Max 1.00	Min	-	Max		
Full-load running hours per year								1.00					
Unit of Activity	PJ/year												
Technical lifetime (years) Progress ratio	 				30 years (IEA E	TSAP & IRENA, 2	2012), 40-55 y	/ears (JRC ETRI, 2	2014). Up to 200		NV KEMA, 2013 (JRC ETRI, 2014		
Hourly profile	No									N/A	UNC ET RI, 2014		
Explanation	Project specifications determine charge time is similar to discharg				-	-	-				Assuming		
		The potential estimated by TNO is 50% of the theoretical storage potential in onshore salt caverns in the Netherlands. These salt caverns can also be used for natural gas or hydrogen storage and may therefore not be completely available for CAES (TNO, 2018).											
	As of 2015, the global grid-connected CAES capacity is 440 MW (0.3%) and it is the largest installed utility scale storage after pumped hydro. Pumped hydro dominates the large-scale electricity storage market with over 140 GW installed capacity (99.1% of installed capacity) (IRENA, 2015). More projects are under development (TNO, 2018).												
	Reports on lifetime vary from 30) vears (IEA-ETSAP	& IRENA, 2012).	to 40-55 years (and to 20, 100	<i>(</i> , - - , , , ,						
			,,		JRC ETRI, 2014)	, and to 20-100	years (IRENA	, 2017).					
COSTS					JKC ETKI, 2014)	, and to 20-100	years (IRENA	, 2017).					
	2015		,, 		JKC ETKI, 2014)	, and to 20-100		, 2017).					
Year of Euro	Euro per Function			Current	JKC ETKI, 2014)		2030	, 2017).		2050 26			
Year of Euro Investment costs	Euro per Functiona € / kWh		2		50	31		, 2017). 40	26	2050 26 –	26		
Year of Euro Investment costs	Euro per Function		2	Current 35 - -	50	31	2030 31 -	40		26	_		
Year of Euro Investment costs Other costs per year	Euro per Functiona € / kWh			Current 35 –			2030 31		26 Min	26	26 <i>Max</i>		
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	2015										
	Euro per Functional U	Init	Current			2030			2050		
Investment costs	€ / kWh		35			31			26		
			2	-	50	31	-	40	26	-	26
Other costs per year	€ / kWh			-			-			-	
			Min	_	Max	Min	-	Max	Min	_	Max
Fixed operational costs per year	€ / kWh			0.46			0.40			0.34	
(excl. fuel costs)			0.46	-	1.01	0.40	_	0.80	0.34	-	0.34
	€ / MWh			1.21			1.21			1.21	
Variable costs per year	- ,		1.21	_	30.00	1.21	_	30.00	1.21	_	1.21
Costs explanation	discharge times and the energy/pow The sources used have been chosen complete set of data, including CAP investment costs from other source JCH JU McKinsey (2015), and 2009 f The main FOM costs calculated usin 2030 and 2050. Other FOM costs ar assuming a standard storage capaci VOM costs are only provided for 20 related O&M costs that vary with el	n because they a PEX and FOM/VO es vary from 2 €/ for Chen et al. (2 ng the JRC ETRI (2 re from FCH JU N ity of 15 hours (2 013 by JRC ETRI (2	re recent public M estimates up KWh to 500 €/k 009). 2014) assumptic Ackinsey (2015) 200MW/3000M 2014) and it is a	ations and inclu to 2050. Detail Wh. Data point on that they rep that states FON Wh system - JR ssumed the the	Ide projections s of the cost est s for the curren resent 1.3% of i A costs as 15 €/I C ETRI, 2014). y remain the sa	up to (at least) imates are not, t year (2020) di investment cost <w 2013<br="" in="" year="">me in 2020, 203</w>	2030. JRC ETRI , or only shortly ffer per source ts. It is assume 3 and 12 €/kW	(2014) is used a , elaborated in : 2020 for JRC E d that FOM cost /year in 2030. T	as primary source these reports, a TRI (2014), 2010 ts remain 1.3% o hese have beer	ce because it h and estimation 6 for IRENA (20 of investment n calculated to	s of 017), 2013 for costs in 2020, M€/GWh/year
ENERGY IN- AND OUTPUTS	Energy carrier	Unit		Current			2030			2050	
	Main output:	РJ		-1.00			-	•		-	
	Electricity		-1.00	-	-1.00	Min	-	Max	Min	-	
	Electricity	PJ		0.77			_				Max
Energy carriers (per unit of main output)			0 77		1		r	1		-	Max
- in the state of			0.77	-	0.77	Min	-	Мах	Min	-	Max Max
incigy carriers (per anne of main output)	Natural gas	PI	0.77	- 1.13	0.77	Min	-	Max	Min	- - -	1
	Natural gas	PJ	1.13		0.77	Min Min	- - -	Max Max	Min Min	- - - -	1
	Natural gas			1.13			-			- - - -	Max
	Natural gas	PJ PJ		1.13			-			- - - - -	Max
Energy in- and Outputs explanation	The required amounts of electricity due to the addition of heat from the	PJ and natural gas e combustion of	1.13 Min are stated to ob	1.13 - - - otain 1 PJ of ele	1.13 Max ctrical output -	Min Min based on Huang	- - - g et al (2017). M	Max Max Note that the ou	Min Min utput of electric	ity is higher th	Max Max Max an the input
Energy in- and Outputs explanation	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob	1.13 – – – otain 1 PJ of ele tal efficiency is	1.13 Max ctrical output -	Min Min based on Huang	- - - g et al (2017). N h is at the high	Max Max Note that the ou	Min Min utput of electric	ity is higher the rted by DNV KE	Max Max Max an the input
	The required amounts of electricity due to the addition of heat from the	PJ and natural gas e combustion of	1.13 Min are stated to ob	1.13 - - - otain 1 PJ of ele	1.13 Max ctrical output -	Min Min based on Huang	- - - g et al (2017). M	Max Max Note that the ou	Min Min utput of electric	ity is higher th	Max Max Max an the input
Energy in- and Outputs explanation	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To	1.13 - - otain 1 PJ of ele tal efficiency is Current -	1.13 Max ctrical output - 53% in this conf	Min Min based on Huanş iguration, whicl	- - - g et al (2017). N h is at the high 2030 -	Max Max Note that the ou end of the 42-5	Min Min utput of electric 54% range repor	ity is higher the rted by DNV KE 2050 -	Max Max Max an the input MA (2013).
Energy in- and Outputs explanation	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob	1.13 – – – Dtain 1 PJ of ele tal efficiency is Current	1.13 Max ctrical output -	Min Min based on Huang	- - - g et al (2017). N h is at the high 2030	Max Max Note that the ou	Min Min utput of electric	ity is higher the rted by DNV KE	Max Max Max an the input
Energy in- and Outputs explanation EMISSIONS (Non-fuel/energy-related em	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To Min	1.13 - - otain 1 PJ of ele tal efficiency is Current - - -	1.13 <i>Max</i> ctrical output - 1 53% in this conf <i>Max</i>	Min Min based on Huang iguration, whicl Min	- - - g et al (2017). N h is at the high 2030 - - -	Max Max Note that the ou end of the 42-5	Min Min utput of electric 54% range repor	ity is higher the rted by DNV KE 2050 - - - -	Max Max Max an the input MA (2013).
Energy in- and Outputs explanation EMISSIONS (Non-fuel/energy-related em	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To	1.13 - - btain 1 PJ of ele tal efficiency is Current - -	1.13 Max ctrical output - 53% in this conf	Min Min based on Huanş iguration, whicl	- - - g et al (2017). N h is at the high 2030 - -	Max Max Note that the ou end of the 42-5	Min Min utput of electric 54% range repor	ity is higher the rted by DNV KE 2050 -	Max Max Max an the input MA (2013).
Energy in- and Outputs explanation EMISSIONS (Non-fuel/energy-related em	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To Min Min	1.13 - - otain 1 PJ of ele tal efficiency is Current - - -	1.13 Max ctrical output - 1 53% in this conf Max Max	Min Min based on Huang iguration, which Min Min	- - - g et al (2017). N h is at the high 2030 - - -	Max Max Note that the ou end of the 42-5 Max Max	Min Min utput of electric 54% range repor 54% min Min	ity is higher the rted by DNV KE 2050 - - - -	Max Max Max an the input Max Max
Energy in- and Outputs explanation EMISSIONS (Non-fuel/energy-related em	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To Min	1.13 - - - - - - - - - - - - -	1.13 <i>Max</i> ctrical output - 1 53% in this conf <i>Max</i>	Min Min based on Huang iguration, whicl Min	- - - g et al (2017). N h is at the high 2030 - - - - -	Max Max Note that the ou end of the 42-5	Min Min utput of electric 54% range repor	ity is higher the rted by DNV KE 2050 - - - -	Max Max Max an the input MA (2013).
Energy in- and Outputs explanation	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To Min Min	1.13 - - - otain 1 PJ of ele tal efficiency is Current - - - - -	1.13 Max ctrical output - 1 53% in this conf Max Max	Min Min based on Huang iguration, which Min Min	- - - g et al (2017). N h is at the high 2030 - - - - - -	Max Max Note that the ou end of the 42-5 Max Max	Min Min utput of electric 54% range repor 54% min Min	ity is higher the rted by DNV KE 2050 - - - -	Max Max Max an the input Max Max
Energy in- and Outputs explanation EMISSIONS (Non-fuel/energy-related em	The required amounts of electricity due to the addition of heat from the nissions or emissions reductions (e.g.	PJ and natural gas e combustion of CCCS)	1.13 Min are stated to ob natural gas. To Min Min	1.13 - - - otain 1 PJ of ele tal efficiency is Current - - - - -	1.13 Max ctrical output - 1 53% in this conf Max Max	Min Min based on Huang iguration, which Min Min	- - - g et al (2017). N h is at the high 2030 - - - - - -	Max Max Note that the ou end of the 42-5 Max Max	Min Min utput of electric 54% range repor 54% min Min	ity is higher the rted by DNV KE 2050 - - - -	Max Max Max an the input Max Max

OTHER											
Parameter	Unit		Current			2030			2050		
Depth of discharge	9/		N/A			-					
	70	-	-	-	Min	-	Мах	Min	-	Max	
Charge time	Hours		26		-			-			
		26	_	26	Min	-	Max	Min	-	Max	
Discharge time	Hours		15			-			-		
		2	_	26	Min	-	Max	Min	_	Max	
Self discharge	% / month		-			-			-		
Self discharge		-	-	-	Min	_	Max	Min	-	Max	
REFERENCES AND SOURCES	and Larne (IE)) with varying specifications (Hur time depend, amongst other things, on cavern					•		/ 1 - /			
	forence Indianters (FTRI) projections for 2010 2050						t.		-		
e. e.	referice indicators (FTRD projections for 2010-2050						τ.		-		
	ference Indicators (ETRI) projections for 2010-2050 sis Power to Gas (deliverable 1: Technology review)						τ.				
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Luo et al. (2015). Overview of cu	sis Power to Gas (deliverable 1: Technology review)	gies and the applic	ation potential	in power syste	·		t.				
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Luo et al. (2015). Overview of cu TNO 2018. Ondergrondse Opslag	sis Power to Gas (deliverable 1: Technology review) costs rrent development in electrical energy storage technolo in Nederland: Technische Verkenning ectricity Storage: a technology roadmap for REmap 2030		ation potential	in power syste	·		t.				
Luo et al. (2015). Overview of cu TNO 2018. Ondergrondse Opslag IRENA 2015. Renewables and Ele IEA-ETSAP & IRENA 2012. Electric	sis Power to Gas (deliverable 1: Technology review) costs rrent development in electrical energy storage technolo in Nederland: Technische Verkenning ectricity Storage: a technology roadmap for REmap 2030		ation potential	in power syste	·		t.				
Luo et al. (2015). Overview of cu TNO 2018. Ondergrondse Opslag IRENA 2015. Renewables and Ele IEA-ETSAP & IRENA 2012. Electric FCH JU McKinsey (2015). Comme	sis Power to Gas (deliverable 1: Technology review) costs rrent development in electrical energy storage technolo in Nederland: Technische Verkenning ectricity Storage: a technology roadmap for REmap 2030 city storage technology brief		ation potential	in power syste	·		t.				