NPHyCo
Nuclear Powered Hydrogen Cogeneration

"Requirements that need to be fulfilled by the NPP to allow H2 cogeneration"

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Explanatory Note

This spreadsheet contains requirements or parameters that are necessary, favourable or of other importance to the hydrogen cogeneration via coupling of a hydrogen production plant HPP to a nuclear power plant NPP.

This spreadsheet focuses on the requirements and aspects regarding the needed modification in a NPP to realize hydrogen co-generation.
There is a similar spreadsheet focussing on the requirements and needs of a HPP to allow the cogeneration. This is given with Deliverable D2.3.

The requirements to be met by a NPP to allow (or favour) the co-generation of hydrogen with nuclear power in a coupled NPP are highly dependent on the possibilities and limitations of a specific NPP. This are dependencies resulting not only from the NPP type but as well from various other local specificities. Thus a listing and detailled description of respective modifications cannot be given in general.

To give some idea on the requirements that need to be met though this spreadsheet gives respective information on the basis of specific sites as an example. With respect to the level of integration an onsite scenario was used as this resembles the most modifications.

As NPHyCo had some specific interest in VVERs reactor types and due to the good connection of the consortium partner ESG with the Ukranian operator Energoatom it was possible to gain enough site related information use the Ukranian NPPs in Rivne and in Khmelnitzky as examples.

This was not possible for other sites of existing european NPPs unfortunately. But the gained insight is transferable for other NPPs of the same type and to some extend for other NPP types as well. Actually many modifications depend much more on local conditions than on reactor type.

The requirements are categorized in the following classes:

T for technical requirements
C for commercial requirements
L for licencing requirements
O for other requirements

All this requirements/parameters listed were taken into account in the subsequent workpackages e.g. WP3 (economical roadmap), WP4 (Licensing roadmap) and especially in the decision matrix elaborated in WP5 (implementation roadmap)

List of Abbreviations

HPP	Hydrogen Production Plant
NPP	Nuclear Power Plant
OPEX	Operational Expenditures
CAPEX	Capital Expenditures
LCOH	Levelized Cost of Hydrogen
HTSE	High Temperature Steam Electrolysis
SOEC	Solid Oxide Electrolysis Cell
LTE	Low Temperature Electrolysis
PEM	Proton Exchange Membrane
AEL	Alkaline Electrolysis

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					Rivne (VVER440 and VVER100)	Khmelnitzky (VVER1000)
Classification	Number	Designation of Requirement	Relevance of Requirement	Significance S1: very significant; S2: significant; S3: less signifcant	Specification of reqiurement as for example Rivne	Specification of reqiurement as for example Khmelnitzky or Temelin
		Demineralized Water Connection	Demineralized water is the only input material for the electrolytical production of hydrogen. It is available in all nuclear power plants as they have an own need for demin. water anyway. But rarely the the available quality is sufficient for direct use and needs an additional make-up step.	very significant		
T	001	Tie-In Point	defines length of piping	significant	1200 m	1200 m
T	002	Available Quality (conductivity)	defines the extent of additional water make-up	significant	≥ 0.3 µS/cm	≥ 0.3 µS/cm
T	003	Available Amount	sole input material for the hydrogen production, availability is a pre-requisite	very significant	0-165 m3/h	0-165 m3/h
T	004	kind of piping	defines cost of piping	less significant	stainless steel, DN50	stainless steel, DN50
C	005	Cost of connection	contributes to CAPEX (the cost estimation considers demi water, cooling water and wastewater, there is not independent estimation for demi water modification)	significant	2.755.000 €	2.755.000 €
C	006	Cost of the supplied demineralized water	contributes to OPEX	significant	2,2 €/m3	2,2 €/m3
C	007	Cost of tap-water supply	in case demin. water is not available in the needed extend it has to be produced from tap water with a cleanest water unit (mostly reverse osmosis)	less significant	0,55 €/m3	0,55€/m3
		Steam Connection - only for SOEC	In Case of HTSE in addition to electricity a seconed source of energy supply is used. Steam from the NPP supports the pre-heating and evaporation of the feed water. Usually about 25% of the needed energy may be supplied in form of steam. Steam is available in all NPPs in principal as it is produced to feed the turbines.	very significant for SOEC	not available in example case	not available in example case
T	008	Tie-In Point (= length of piping)	defines length of piping	less significant		
T	009	Pressure	any pressure level that allows to overcome the pressure drop of the piping	less significant		
T	010	Temperature	any temperature above 150°C is usable for pre-heating of the feedwater	less significant		
T	011	Available amount	usually 25% of the overall energy input comes from the steam, but more or less is feasible; contributes to the overall efficiency and thus to OPEX	significant		
T	012	kind of piping (DN, insulation, …)	defines cost of piping	less significant		
C	013	Cost of connection	contributes to CAPEX	less significant		
C	014	Cost of the supplied steam	contributes to OPEX	less significant		
		Cooling Water Connection (for stack cooling) - only for AEL and PEM	With LTE systems a significant part of the inputenegy is not used for splitting water but is dissipated in form of heat. as the electolyzer cells degrade quicker with higher temperatures it is necessary to cool the stacks and remove this excess heat. In an NPP this may be done via the exisiting cooling systems given the installed capacity can coever the additional need.	significant		
T	015	Available Amount	if no cooling water is available a stand-alone system with final transfer of the excess het to ambient air is necessary	significant	2x 900 m3/h	2x 900 m3/h
T	016	Temperature Difference In-Out	It is asumed that cooling water with a deltaT of 10K is available to remove heat from th electrolyzer stacks	low significance	<30 C	<30 C
T	017	Tie-In Point (= length of piping)	defines cost of piping	significant	400 m	500 m
T	018	kind of piping (DN, insulation, …)	defines cost of piping	low significance		
C	020	Cost of supplied cooling water	contributes to OPEX	significant	0,029 €/m3	0,029 €/m3
		Chilled Water Connection	first step of hydrogen purification = cooling below dewpoint to condensate water in hydrogengasstream, for this operation chilled water is needed	significant	Not available	Not available
T	021	Available Amount	chilled water is probably not available in many NPPs, in this case a chilled water unit needs to be added to the HPP	less significant	not available in example case	not available in example case
T	022	Tie-In Point (= length of piping)	defines cost of piping	less significant	not available in example case	not available in example case

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C	023	Cost of supplied chilled water	contributes to OPEX	less significant	not available in example case	not available in example case
C	024	Cost of chilled water connection	contributes to CAPEX	less significant	not available in example case	not available in example case
		Electrical connection	the supply of electricity is the minimal requirement for co-generation.	very significant		
T	025	Available Amount	needs to supply the HPP, defines the operational mode, number of operational hours etc	very significant	45 MW	45 MW
T	026	Voltage Level	defines eventually needed transformers	less significant	110 kV	110 kV
T	027	Tie-In Point = length of cabling	defnes length of cabling	less significant	2800 m (onsite scenario)	500 m (onsite)
T	028	Kind of Cabling	defines cost of cabling	less significant		
C	029	Cost of electrical connection (Eur)	contributes to CAPEX	less significant	3.680.000 €	3.680.000 €
C	030	Cost of electricity (EUR/kWhod)	contributes to OPEX and is of utmost importance for the LCOH- Ukraine data year 2021	very significant	0,026	0,026
		Area / Location for the HPP	A suitabable location onsite of the NPP area or in te vicinity is the pre-requisite for the onsite and offsite integration scenarios.	very significant		
T	031	Site plan for the NPP - Suitable location available ? Where is the location compared to sensitive structures?	Suitability of the location is defined by the footprint of the HPP, safety aspects and other. The most relevant are indicated below.	very significant	Two different potential locations were given by operator to allow investigation of NPHyco. This was the basis for the distinct entries in this spreadsheet	Two different potential locations were given by operator to allow investigation of NPHyco. This was the basis for the distinct entries in this spreadsheet
T	032	minimal distance from HPP to specific areas of the NPP	D2.2 investigated the impacts especially with respect to safety in worst case scenarios as explosion. As the hydrogen production asks for short distances to minimize connection cost, the explosion risk is asking for larger distances to especially sensitive structures or safety related equipment Thus it is important to incvestigate both the sensitive structures of the NPP and the risk coming from the different parts of the HPP. Eventually some parts need to be separated and installed in differen positions /production and storage) and/or additional mitigation measures have to be taken t minize the risk to acceptable levels.	very significant	The structural fragility criterion of 10 kPa for Rivne NPP structures was exceeded for the worst-case vapour cloud explosion at the electrolyser facility, and a pressure vessel burst in the 30 kg buffer tank. In addition, missile impact from the physical explosion in the buffer tank has a potential flying range of 564 m. No missile impact criterion has been provided for the NPP.	Analogous to Rivne NPP but adapted to the critical safety distances.
T	033	Hazard zones of the NPP	Roughly there are the parts of the HPP with little additional risk to the NPP such as Demin.water make-up unit, chiller-unit, cooling water structures. Then there are the hydrogen containing parts of the electrolyzer system that bear the risk of explosion. Depending on the specific risk minimizing and mitigation measures the equipment and subsystem are to be categorized according to explosion protection regulations (ATEX). But the hydrogen content of the electrolyzer is actually limited. The zone with highest amount of hydrogen is by nature of their function necessarily the storage tanks.	very significant	The following applies to the HPP in a container solution analysed in D2.2A. The MV trafo and container electrical unit would pose a fire hazard from an ignition source (e.g., spark or electric arc). The electrolyser stack container, and the gas processing area would be both characterized as ATEX Gas Zone 1. Since the 30 MWel HPP would be arranged into three identical 10 MW modules, physical barriers such as blast walls are advised in between modules to prevent domino effects under the worst-case accident scenario.	

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T	034	Sensitive structures of the NPP	All NPP have a protection system against external hazards (fire, seism, APC, explosion pressure waves, missiles). The NPP structures are designed accordingly. Co-generation is possible when the existing design features are safe inoigh to cover as well the additional risks of the NPP and storage. Eventually there is a need for additional measures.	very significant	If the HPP is located in the centre of the proposed onsite integration location, additional 44 m are gained to critical NPP structures with respect to the site boundaries. Under such circumstances, and based on the adopted conservative conditions in the safety calculations, only the 30 kg buffer tank would need to be placed underground or outside the NPP perimeter to eliminate the risk of missile impact upon hypothetical vessel burst. Further calculations with plant specific data need to be performed to determine whether additional mitigation measures are required to comply with the 10 kPa criterion.	Analogous to Rivne NPP but adapted to the critical safety distances.
T	035	Available area for construction and commissioning	There needs to be enough room for the HPP and the soil characteristics must be such as to allow the erection.	significant	Yes	Yes
		Other requirements originating from the site-specific NPP regulations				
L	036	Safety Assessment	HPP and NPP need safety assesment of their own. A coupled plant needs to cover additional aspects as identified in the impact analysis (see D2.2). The exisiting NPP safety files need to be updated incorporatig the risks from the addiiional system.	very significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
T	037	Seismic Requirements	the HPP does not have the same requirements as the NPP as there is no risk of release of radioactivity; but an own categorization with respect to explosin risk needs to done, similar as for NPP the seismic requirements are depending on the 'to be expected earthquake in an area'. this differs per location.	low significance	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
T	038	Allowed noise levels	main source of noise is the compressor, mitigation measures can be designed acc. to needs	less significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
L	039	Check if HPP off-site complies with applicable land-use plan		significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
L	040	Environmental Impact analysis for HPP + possible coupled systems		significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
L	041	Check if HPP complies with NPP license restrictions for 'activities' onsite		very significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
L	042	Regulatory requirements for Building Facilities on NPP site		significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
T	043	Civil routing for piping above ground and underground	For pressure loss calculations and piping dimensions, support constructions	significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
T	044	Civil routing for cable trays above ground	For estimation of support constructions	significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.
T	045	Specification of roads modifications	in case trailer transport of hydrogen needs to be enabled	significant	such detailled work can only be performed in the design phase of plant execution.	such detailled work can only be performed in the design phase of plant execution.

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		Nitrogen Connection = probably not possible or irrelevant, but should be listed to be complete	Nitrogen is used for the purging the hydrogen from the HPP system in emergency cases or in maintenance. Nitrogen supply is available in general in NPPs. But needed amount is so low, that a set of bottles may be more usefull than a piping connection.	low significance		
T	046	Nitrogen supply available Y/N?		less significant	Y	Y
T	047	quality of nitrogen		less significant	purity of nitrogen is 99.6 - 99.9%	city: 135 nm^3/h; pressure: 0.7 kg/cm2 Purity: 99
T	048	Tie-In Point	defines length of piping	less significant	Nitrogen-oxigen station	Nitrogen-oxigen station
T	049	length of piping, kind of piping	contributes to CAPEX	less significant	500 m	500 m
C	050	cost of connection	contributes to CAPEX	less significant		
C	051	cost of supplied nitrogen	contributes to OPEX	less significant		
		Pressurized Air Connection	As a means of explosion protection many valves of the HPP are pneumatically actuated. Thus presurized air is needed. Press. ir is available in general in NPPs, but may need to be upgraded.	low significance		
T	052	Air supply available Y/N?			Y	
T	053	quality of compressed air		less significant	Quality grade 8 · solid particles, no more than 12.5 mg/m^3; –water in liquid form, 0.5 to 5 g/m3 -Capacity: 200 m3/min -Maximum working pressure: 8 bar	Quality grade 8 · solid particles, no more than 12.5 mg/m^3; –water in liquid form, 0.5 to 5 g/m3 -Capacity: 25 m3/min -Maximum working pressure: 10 bar
T	054	Tie-In Point	defines length of piping	less significant	Compressor station	Compressor station
T	055	length of piping, kind of piping	contributes to CAPEX	less significant	500 m	250 m
C	056	cost of connection	contributes to CAPEX - same cost as providing independen air compress station	less significant	60.000 €	60.000 €
C	057	cost of supplid press. air	contributes to OPEX	less significant		
		Waste Water Connection	Mainly the demi. water make-up and the process circuit cleaning produce some waste water that can be connected to the waste water system of the NPP.	less significant		
T	058	In order to be able to connect to the NPP waste water system (with water make-up unit), what are the pre-conditions of the NPP?		less significant	Reconstruction needed	Reconstruction needed
T	059	Quality of waste water that can be accepted	defines whether additional steps for waste water treatment are necessary	less significant	Y	Y
T	060	Amount of waste water that can be accepted	defines whether additional or alternative ways of waste water disposal are needed, for a 30MW scale approx. $2m^3/h$ of waste water are to be removed	significant	Y	Y
C	061	cost of connection	contributes to CAPEX	less significant	1.480.000 €	1.480.000 €
C	062	cost of supplied waste water capacity	contributes to OPEX	less significant	2,54 €/m3	2,54 €/m3