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D2.12 Report on Experience Feedback

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Summary

This deliverable presents the analysis of the feedback gathered from past experience on nuclear cogeneration. This feedback was collected via a questionnaire (deliverable D2.11) which was sent to stakeholders of existing or former nuclear cogeneration installations and complemented in some cases by face-to-face interviews.

The synthesis of the feedback follows the same structure as the questionnaire itself. It is divided into nine parts encompassing: Motivation and Initiative, Role of key players, Organizational structure, Technical aspects, Safety & licensing, Financial aspects, Timing, Public relations and General experience feedback.

Finally, we have used the feedback to distil Key Success Factors, lessons learned and remaining questions. Moreover, a SWOT analysis was prepared with the aim of providing guidance for the successful realization of new nuclear cogeneration projects.

Approval

Rev.	Date	First author	SP leader	Project Coordinator
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1 Introduction

The strategic objective of the NC2I-R project is to structure the European public and private R&D capabilities for delivering a nuclear cogeneration demonstrator fully meeting the market needs, in support to the European Nuclear Cogeneration Industrial Initiative (NC2I).

Following the earlier EUROPAIRS project and in close collaboration with the ongoing ARCHER project, national projects (e.g. Polish HTRPL, German SYNKOPE), non-EU HTR programs (US, China, Japan, South Korea, South Africa) and Generation IV International Forum, NC2I-R contributes to prepare a successful, low-risk and rapid European nuclear cogeneration demonstration for Europe's industry as an alternative energy source with high emission savings potential.

The objective of the first task of the WP2 of the NC2I-R project is to take stock of existing infrastructures and competences related to the use of nuclear cogeneration in the EU and beyond and to collect educated experience feedback from stakeholders involved in existing, closed, currently operating or planned nuclear cogeneration projects. For this purpose, this task has prepared a list of the most globally relevant nuclear cogeneration projects and has established (wherever possible) contacts at the right level to maximize chances for gathering complete and correct information. The questionnaire issued as deliverable D2.11 of this project was distributed to these contact persons and the returned questionnaires were analyzed. In several cases, interviews could be arranged which helped to better understand certain answers.

This report provides a synthesis and an analysis of the feedback gathered during these interviews; it had three main objectives:

1. Collect feedback from experience and projects related to nuclear cogeneration;
2. Learn from past experience to reduce risk for future projects;
3. Identify Key Success Factors (KSFs), i.e. a configuration of functions, activities or business practices, defined by the market and the customer and that are/were critical to the vendor and to the success of the project.

2 Methodology

2.1 Scope

This study supports the demonstration of nuclear cogeneration with HTR for the cogeneration of electricity and heat. However, there have been only few HTR demonstrators in the world. To obtain more feedback on nuclear cogeneration, the scope was enlarged to nuclear cogeneration involving other types of reactors as the heat source. Moreover, projects involving nuclear cogeneration which did not necessarily lead to a physical installation ("paper projects") were also included.

2.2 Organisation

After collection of a number of completed questionnaires, it was decided to focus face-to-face interviews on those projects with the highest relevance, and with relevant knowledge and expertise still available. Semi-structured interviews were used: an interview guide was sent to key stakeholders of the project to prepare for a face-to-face interview with those projects that seemed to be most relevant for NC2I-R. For each project, two NC2I-R representatives (from WP2 and WP3 – related to safety and licensing) were appointed to contact key stakeholders of the cogeneration installation. These face-to-face interviews enabled to elucidate valuable details not covered by the questionnaire.

2.3 Structure of the interview

The interview guide was composed of open and semi-open questions. The information requested was mainly qualitative but some questions required quantitative answers. The questions were organized in 9 categories, namely: Motivation and initiative, Key players, Organizational structure, Technical aspects, Safety and licensing, Financial aspects, Timing, Public relations and General experience feedback. However, these questions aimed in the first place at showing what type of information NC2I-R is interested in, and were not, in any kind, a limitation in the discussion. The interviewees were even encouraged to propose further discussion items.

2.4 Stakeholders interviewed

The people interviewed worked mainly for utilities operating the NPPs, but other stakeholders were met as well, e.g. industrial end-users. We have also aimed to obtain the views of other stakeholders and decision makers such as end-users, licensing authorities and politicians, but those were more difficult to approach, were often retired and could not give us a complete vision of the project (technical, financial, safety/licensing aspects, etc.) due to unavailability or loss of this information or due to protected intellectual property.

3 Projects screened

A total of 36 projects could be identified and contact persons be found using the international network of the NC2I-R consortium. 23 questionnaires were returned completed and a total of 10 interviews were conducted in different countries, mostly in Europe, but also in China and Japan. Despite several attempts through different channels, we were unsuccessful to collect information from Canada, Kazakhstan and Russia.

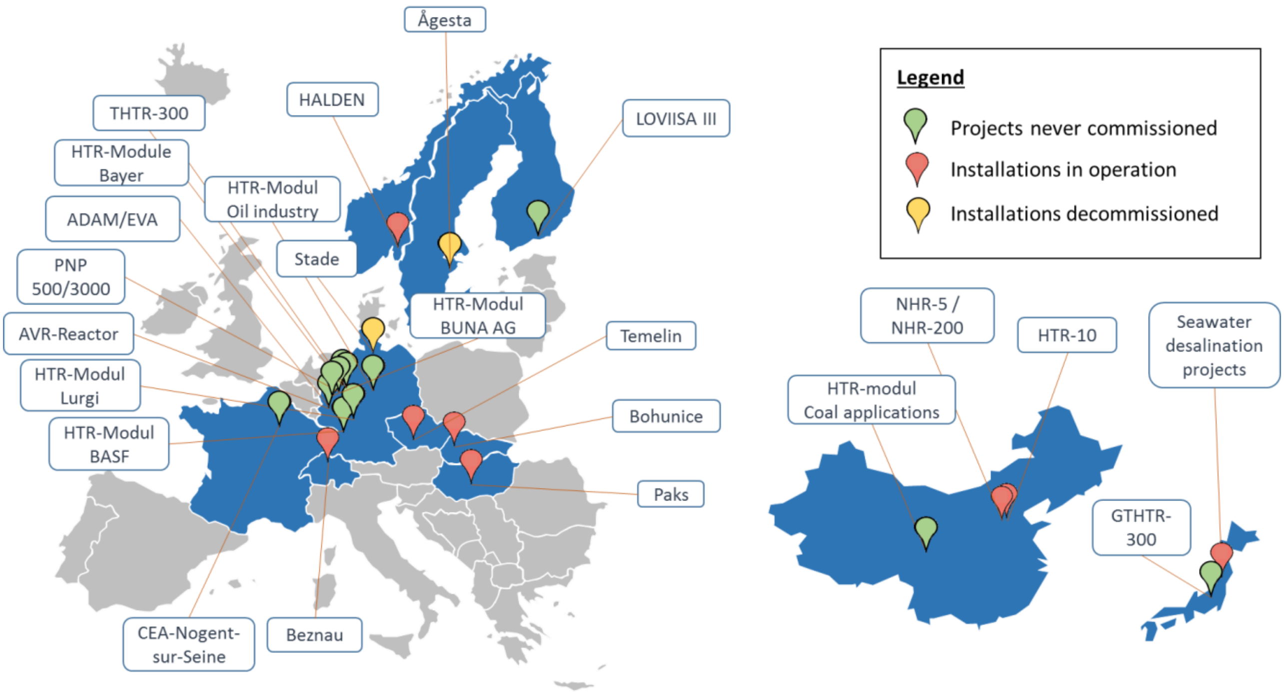

Figure 1: Nuclear cogeneration projects/installations which returned questionnaire

The 23 projects from where feedback was received are listed in the table below:

Project	Country	Description	Status
1. Beznau NPP	Switzerland	Production of electricity and district heat using a PWR	In operation
2. Stade NPP	Germany	Production of electricity and process steam for salt refining between 1984 and 2003 using a PWR	Decommissioned
3. AVR	Germany	R&D on a modification of the existing AVR (HTR) for process heat applications, particularly in the chemical and coal sector.	Study
4. THTR-300	Germany	Originally planned to demonstrate HTR for coal gasification, then used for electricity generation instead (gasification would require > 850°C on the process side instead of the 750°C He outlet temperature).	Study
5. PNP 500/3000	Germany	Both the medium-size PR-500 and the large-size PNP-3000 were process heat reactor concepts (e.g. for H_2 production via steam methane reforming) developed within the PNP project (1970s and 1980s, phased out in beginning of the 1990s after shutdown of THTR).	Study
6. ADAM/EVA	Germany	Conversion of methane to syngas using nuclear energy to be then used for transport and/or storage; in this program, several important components were tested and developed.	Study
7. BASF-Ludwigshafen	Germany	Project to produce process heat and electricity with an HTR-Modul Reactor for Chemical Company BASF in Ludwigshafen	Study
8. BUNA AG East Germany	Germany	Project to produce process heat and electricity with an HTR-Modul Reactor for Chemical Company BUNA AG and Leuna-Werke in former East Germany	Study
9. Oil Refinery Hannover	Germany	Project to produce process heat and electricity with an HTR-Modul Reactor for oil industry	Study
10. LURGI Frankfurt	Germany	Project to produce process heat and electricity with an HTR-Modul Reactor for Chemical Company LURGI AG Frankfurt	Study
11. BAYER-Leverkusen/ HOECHST AG Frankfurt	Germany	Project to produce process heat and electricity with an HTR-Modul Reactor for the Chemical Companies BAYER in Leverkusen and HOECHST AG in Frankfurt (today Marl Hüls)	Study

Project	Country	Description	Status
12. CEA – Nogent-sur-Seine and other sites	France	Study conducted to investigate the benefits of a modification of the Nogent-sur-Seine power plant (addition of a cogeneration system, e.g. for district heating)	Study
13. Halden	Norway	Test reactor providing steam to a paper mill	In operation
14. Loviisa 3	Finland	Plans for cogeneration of district heat to Helsinki metropolitan area	Study
15. Ågesta	Sweden	Production of district heat for the suburb of Stockholm for 10 years using a FOAK PHWR	Decommissione d
16. Bohunice NPP	Slovakia	Production of electricity and heat for district heating using a PWR	In operation
17. Paks	Hungary	Production of electricity and heat for district heating for the town of Paks using a PWR	In operation
18. Temelin	Czech Republic	Production of electricity and heat for district heating using a PWR	In operation
19. Ohi 1-4 Takahama 3-4	Japan	Several plants produce electricity and heat for seawater desalination	In operation
20. GTHTR-300	Japan	Production of electricity and heat for the production of hydrogen and process heat applications	Study
21. several sites	China	Project to produce process heat and electricity with an HTR-Modul reactor for coal liquefaction	Planned
22. HTR-10	China	Production of district heat for INET campus using an HTR	In operation
23. NHR-5 / NHR-200	China	Production of heat for the demonstration of nuclear district heating	In operation

Table 1: Projects for which feedback was received; projects interviewed are marked in blue

4 Synthesis of Feedback

The synthesis of the feedback is presented here according to the structure of the questionnaire which was also used to interview the contact persons of the nuclear cogeneration projects. It includes 9 sections. The present document gathers feedback for 8 of the 9 sections, the Safety and licensing part being described in another specific deliverable (D3.11).

4.1 Motivation and initiative

First, we aimed to identify what motivated the nuclear cogeneration project. Five main reasons could be found to trigger the installation of nuclear cogeneration:

1. **Security of supply**: after the oil crisis of 1973, numerous projects on nuclear cogeneration were conducted to find an alternative to crude oil. Today again, the concerns about security of supply pushes several countries with limited primary energy sources (mainly gas or coal) to develop nuclear cogeneration for the production of heat and electricity.
2. **Conducting R&D on industrial nuclear cogeneration**: several projects were conducted in view of demonstrating the technology required for nuclear cogeneration in industry (AVR in Germany, Halden in Norway), or were triggered by the technical interest of the vendor (HTR-10 in China).
3. **Reducing carbon and other emissions**: several projects see in nuclear cogeneration a way to reduce CO_2 emissions (Loviisa 3 in Finland, Beznau in Switzerland) and the associated pollution (Temelin in Czech Republic) caused by the use of fossil fuels.
4. **Economic benefit**: for countries which do not have fossil fuel resources on their territory, the nuclear energy to produce both heat and electricity can be an economic solution (Bohunice in Slovakia).
5. **Increasing the efficiency of the NPP**: by producing both heat and electricity, the efficiency of a NPP can increase from 32 up to more than 70%.

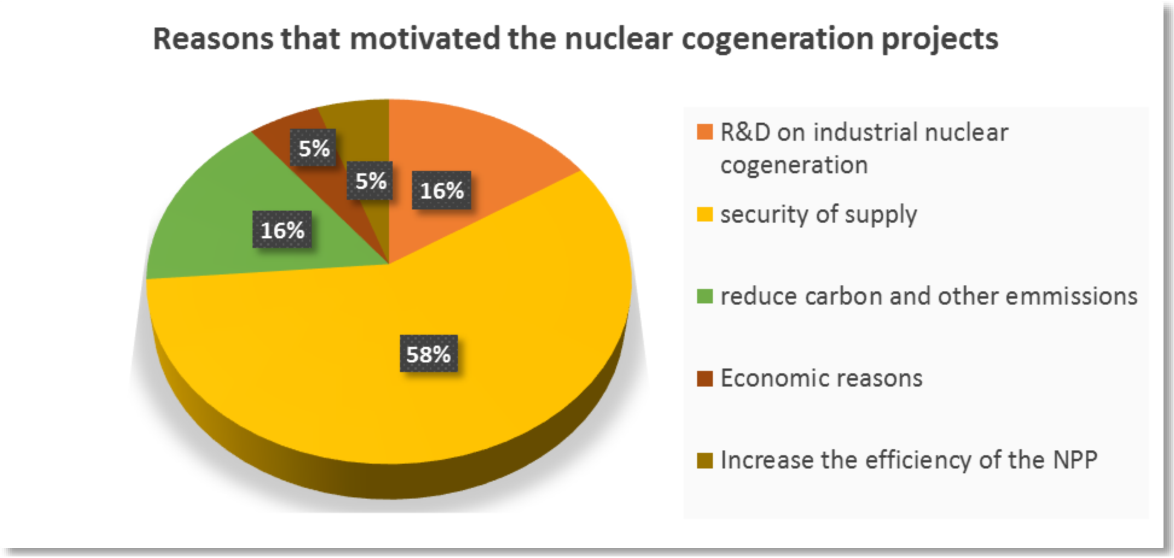

Figure 2: Reasons that motivated nuclear cogeneration projects

In the case of water desalination in Japan, cogeneration was used to produce clean water for in-house power plant consumption because water from a nearby river was too scarce.

The influence of political support was found necessary but not sufficient on its own. Most of the projects which were supported by political representatives were commissioned. The 2 projects that were not commissioned and yet benefited from political support were the PNP 500/3000 and the THTR-300 which received some funding to conduct R&D but never reached nuclear cogeneration capability (the THTR-300 produced electricity but not heat).

Conversely, none of the projects which were not supported by the political government led to the construction of a reactor/nuclear cogeneration installation. Indeed, The Loviisa 3 project, aiming at providing heat for the Helsinki area was presented to the city of Helsinki which did not commit at this stage (uncertainty of the power plant construction); the project was not pursued. Several German studies supported by industrial companies (chemical, oil, coal, etc.) were essentially economically motivated, they did not benefit from political support and were not built. On the contrary, these German projects had to face opposition, mainly from ecologists.

The other projects were quite well accepted and did not have to face opposition, except the Ågesta project in Sweden, for which the local community was first against the implantation of the NPP. However, after years of operation, the local community changed its mind and ultimately turned against the closure of that NPP.

4.2 Key players

Each nuclear cogeneration project is different but the following stakeholders, or at least some of them provided feedback:

4. manufacturer of the plant;
5. operator;
6. utility;
7. end-user (industry, municipality);
8. plant owner;
9. political representatives at different levels.

Additionally, international organizations can be stakeholders for specific R&D projects. For example, the OECD participates in the Halden project in Norway via the OECD-Halden Reactor Project (OECD-HRP), specifically under the umbrella of the NEA. While the Halden reactor is mainly used for irradiation testing of materials and fuel it also produces process steam for the neighboring paper mill. The OECD financed a part of this demonstration programme.

In most cases approved in the past, the opinion of the public was heard through the decision of the administrative bodies of the local governments. The licensing included the procurement of a construction permit delivered by a nuclear licensing authority. More recently, public inquiries have become a standard part of the approval process.

4.3 Organisational structure

Most of the projects from which feedback was received did not create a consortium for operating the NPP/nuclear cogeneration installation because of different reasons:

The financial size of the project was relatively small and the energy producer/utility could handle the project inside its operational budget.

No specific consortium was created but the reactor was built in cooperation between several industries such as the manufacturer or the utility (Ågesta)

The project was developed within a joint programme under the umbrella of NEA (Halden, Norway).

The project was partly and initially financed and commissioned by the Soviet Union (Paks in Hungary and Bohunice in Slovakia).

In the case of Temelin in Czech Republic, no specific consortium was set up, but 2 heat-supplier companies were created. The CEZ group, whose main shareholder is the Czech Republic, owns a large part of these companies.

The German and Finnish projects considered setting-up a consortium including the NPP manufacturer the utility and the end user of the electricity/steam (industry or local municipality).

Most of the projects did not interact with similar projects elsewhere. For those which exchanged information, the dissemination mainly dealt with safety information and technical information on district heating. The IAEA, in particular, has collected a wealth of relevant documents concerning nuclear cogeneration for district heat and other non-electric applications [1], [2], [3].

4.4 Technical aspects

In most of the projects, the cogeneration installation was included in the original design and did not require a revamp/upgrade of the NPP.

The great majority of the commissioned projects did not encounter unexpected difficulties. However, the NPP Ågesta in Sweden had to face problems related to the FOAK character of the heat source. Paks in Hungary had technical problems related to the conventional heat transport system.

All projects require back-up power to cover O&M outages. Fossil fuel boilers are used for back-up, and the backup capacity is minimized by planning outages during summer when no domestic heating is required.

4.5 Financial aspects

As a first remark it must be said that it turned out to be very difficult to obtain reliable financial information on the nuclear projects. As a matter of fact, most of the information was either confidential or not known to the persons who filled in the questionnaires or were interviewed.

Obviously, the capital expenditure (CAPEX) for a nuclear cogeneration project highly depends on the type of reactor, its power capacity and the electricity/heat fraction. The CAPEX ranges from a few dozens of million € for a capacity of several 100 MW to more than 1,000 million € for the Loviisa 3 project, using a reactor with a planned electric capacity between 1,200 MWe and 1,700 MWe and a thermal capacity between 2,800 MWth and 4,600 MWth.

The investment was either made by the government (Halden in Norway, Paks in Hungary), or absorbed within a utility budget - most of the time owned partly by the government - (Slovenske Elektrarne for Bohunice in Slovakia, Refuna AG for Beznau in Switzerland; Refuna is an 80-20 public-private partnership).

The operational expenditure (OPEX) was generally difficult to estimate for those interviewed, so there is little usable feedback on this particular aspect. Some of the information is also business confidential and could not be reported. However, the general feedback which was expressed is that the CAPEX/OPEX of the cogeneration infrastructure (pipelines, heat exchanger stations, etc.) is negligible compared to the CAPEX/OPEX of the NPP and that it is also negligible compared to the dominant fuel costs of a fossil-fired cogeneration plant. CAPEX and OPEX for the required fossil backup capacity are generally low because of short duty cycles. However, this statement is little precise and depends amongst others on the distance between heat source and end-users, customer density, the presence of existing heat networks or cogeneration facilities, geographical characteristics (heat bridges, pumping power), weather and climate conditions, seasonal activities, or evolution of demand:

improved home insulation, development of competitive technologies such as heat pumps, woodchips or geothermal heat, creation or disappearance of large single customers such as greenhouses or public swimming pools etc. (Generally, the CAPEX can be written off more quickly in cold countries with high demand and a long heating season.) Many of these considerations are valid for low-temperature heat for which alternative sources are increasingly available on the market. High temperature cogeneration of process heat with industry as the main customer is likely to be less affected by competing energy sources.

Just like for CAPEX/OPEX, it was difficult to obtain the levelized cost of energy (LCOE) since it is constantly evolving. Even for one specific NPP the LCOE can depend on the specifics of the end-user situation, the energy distributor and the energy producer as well as on contractual terms, market, inflation etc. The Loviisa 3 project in Finland, estimated that the energy produced by the NPP would have been 7 €/ MWh cheaper than in a biofuel-fired scenario and 18-26 €/MWh cheaper than in a scenario where the primary fuel was coal, a statement which depends on the cost assumptions made for biofuel and coal. For Paks in Hungary, the initial levelized cost of delivered electricity was (11 HUF_{1985}/kWh) in 1985, at today's exchange rate equivalent to 0.0358 $€_{2013}$/kWh, a little useful value 30 years later. The initial levelized cost of delivered heat was 2.9 €/GJ (894 HUF/GJ). More recent dependable data is not available to us.

However, one can estimate that generation cost of low temperature heat tapped from turbines is at least 3 times cheaper than the bus bar cost of sold electricity, assuming a 33% power conversion efficiency. A different approach was used in the case of Beznau/Refuna where, similarly to many natural gas delivery contracts, the price of heat was coupled to the price of fuel oil, which is the displaced energy form, and the delivered heat was not taxed. This scheme enables to share risks related to energy price evolution: when oil prices increase, it comes to an advantage for Refuna, when they decrease, it is beneficial for the customer. However, when the customer is not a small private entity but an energy-intensive industry, predictability and stability of the energy price become quintessential, which is a strong point for nuclear cogeneration. This is because nuclear energy is little dependent on variable fuel costs and can thus deliver energy at stable prices for long periods of time. Therefore, in an industrial context, the indexation of the heat cost on the price of a highly volatile commodity does not seem to be an attractive approach as it would prevent the customer from benefiting from one of the major advantages of nuclear energy over other energy sources.

For most of the projects which were operated, the sale of heat is viable, if electricity and occasionally also system services (grid stabilization, load following) are sold at the same time. Several projects mention that the viability of heat sales must be viewed in a more general context considering other options such as oil or gas and the benefits need to be assessed on the basis of a multi-criteria analysis. The nuclear option is often the best solution considering the production price and the other benefits offered by the NPP (quality of air, security of supply, etc.).

4.6 Timing

From the first idea of cogeneration project to the commissioning, the process includes the following steps which, however, could not be detailed in duration and compared to obtain a reliable estimate for the duration of each phase:

- Design;
- Licensing;
- Construction;
- Operational tests.

On average, the whole process until start of operation requires between 5 and 10 years for a NOAK-reactor, as shown in the following figure.

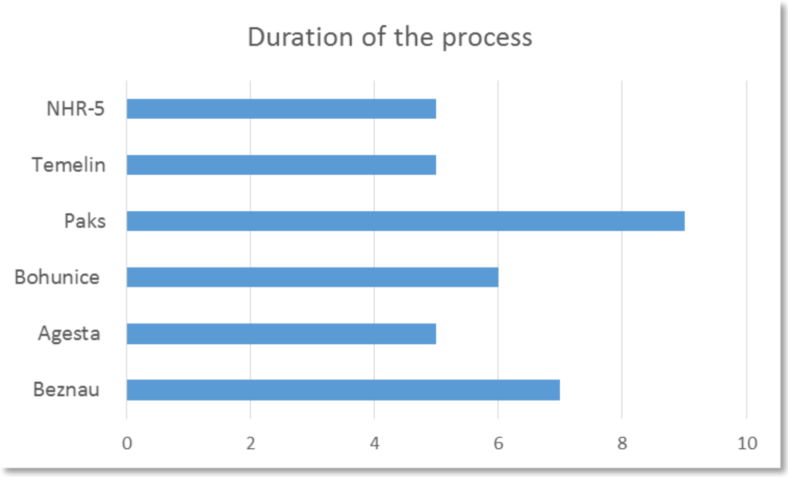

Figure 3: Time span to operation

It must be noted that the whole process for the Paks NPP in Hungary took 14 years due to a 5 year-interruption, which was taken into account in the figure. Moreover, if the cogeneration project is an upgrade project after the startup of the NPP (already existing NPP), the whole process might be shorter and can be estimated at less than 5 years. Apart from the Paks NPP, none of the projects mentioned delays in the execution of the process.

The planned lifetime of the nuclear cogeneration installation depends on the NPP lifetime, typically between 50 to 60 years. However, large industrial installations including process heat end-users usually have shorter lifecycles, typically half of that of the NPP, so that a single NPP could serve two generations of industrial end-users. Regarding the GTHTR in Japan, the planned lifetime of the NPP is 40 years while the planned lifetime of the hydrogen production facility is only 10 years (due to corrosion). This aspect must be taken into account during the elaboration of the Business Plan (while the Hydrogen facility is refurbished, the NPP is supposed to continue producing electricity).

Concerning seawater desalination, the Japanese experience at the Ohi NPP shows that Reverse Osmosis seems to be less robust and have a shorter service life than Multi Stage Flash or Multiple Effect Distillation.

This means that the type of end-user and the chosen end-user technology can exert a significant impact on the lifetime performance and economy of a nuclear cogeneration system.

4.7 Public relations/involvement

For the great majority of projects, the relations with the public go through political communication actions. Indeed, **some efforts were made towards political representatives but not directly towards the general public.** The reason for this appears to be that managers of a nuclear cogeneration project usually consider that the opinion of the general public is expressed by their political representatives during the licensing process.

There is one noticeable exception which is the Beznau NPP in Switzerland where there was and is a strong tradition of local political involvement. Here, the local public and decision makers were and still are involved in decisions related to the use of nuclear energy for district heating. It has to be noted that in Europe today a public hearing is mandatory before such a new project can be started.

Several projects made explicit communication efforts towards the general public and one project released **information in the local press**. The Beznau NPP organizes open days and communicates with neighboring communities including anti-nuclear activists. The Bohunice NPP also organizes **“open days”** once a year during which residents can visit the NPP with a cultural program, special activities for children, etc… Tours are organized for pupils and students of Slovak schools several times a year (according to their interest) or on request. Moreover, the utility Slovenské elektrarne a.s. regularly prepares actions to promote NPP operation. The result is a very positive public opinion of residents around Bohunice V2 NPP. However, this positive effect cannot be attributed exclusively to these PR efforts, because in many cases the neighboring population of a NPP has already a positive attitude, also because the NPP is a significant employer.

The feedback received from the questionnaires reveals that there is further potential to improve the image of nuclear cogeneration in the public. After the Fukushima Dai-ichi accident, most utilities and vendors rather stayed beneath the radar of the press and public opinion instead of explaining to the public the benefits of nuclear energy and why those would justify any remaining risk. The examples of the Bohunice and Beznau NPP show that, by getting people involved in a nuclear project, the project is generally well accepted by the local population. This local population became then a convincing ambassador for the nuclear project who could help develop other nuclear cogeneration projects.

Efforts on communication actions were also conducted regarding the HTTR and GTHTR projects in Japan to make the general public aware about the safety-related advantages of HTR. Thanks to press articles and in organized discussions with public (e.g. in Oarai town and in a public hearing on the occasion of the HTR 2012 conference in Tokyo), these advantages seem to be generally acknowledged and have in the meantime led to continued financial support for further development, which was confirmed during the HTR 2014 conference in Weihai, China.

4.8 General experience feedback

First of all, all the projects interviewed which actually led to an operational cogeneration installation recognized that the project was **successful technically**. The financial success of these projects is, however less generalized as shown in the following figure.

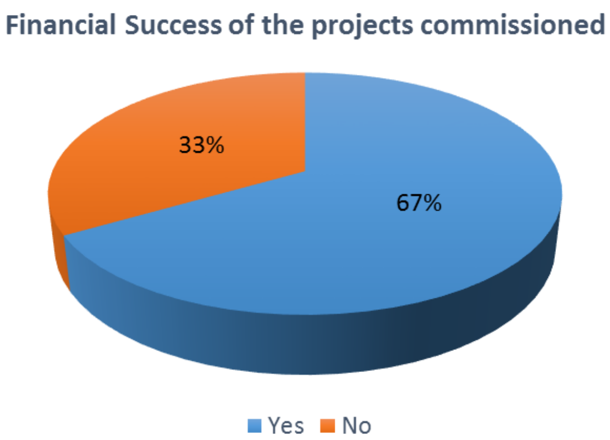

Figure 4: Financial success of the projects commissioned

The “No” to the question – “Was the project a financial success?” can be explained by the significant initial investment. For instance, the Ågesta reactor was a First Of A Kind Pressurized Heavy Water Reactor (FOAK PHWR) which had suffered from significant teething problems. The original budget was estimated at 35 million SEK whereas the final cost was around 200 million SEK. As a result, the Ågesta NPP only made profit during its last year of operation (due to the oil crisis at the time 1973-1974).

Another example of a financially little successful project is the Beznau NPP in Switzerland where the operator of the heat network (Refuna, an 80-20 public-private partnership) required several times financial support. One of the reasons for this was that the planned infrastructure for the heat distribution was not optimal for the low population density in the rural vicinity of the NPP (needs and requirements of the final customer poorly known) and due to gradually declining demand owing to improved home insulation, warmer winters and competing energy sources such as geothermal or woodchip heating.

Moreover, the Halden interview revealed that while the production and sale of steam to the neighboring paper mill (no electricity produced) creates a significant part of revenue, it is not sufficient to cover the operational cost of the reactor. The OECD Halden reactor runs large R&D programmes and, like for most research reactors, extra income has become increasingly important to cover the operational cost of the reactor.

Several interviews pointed at **the success of the cogeneration plant with regard to environmental aspects** (Halden, Stade, Temelin, Paks, Bohunice, Beznau). Indeed, nuclear cogeneration substitutes fossil energy sources and thus cuts CO_2 emissions. For example, in the Beznau case, it was estimated that the small nuclear cogeneration part of the plant alone substituted 336,000 tonnes of fuel oil in 30 years, corresponding to the avoidance of 1 million tonnes of CO_2. Other benefits include the avoidance of other pollutants, local smog, truck traffic, noise, all arguments that significantly enhance the quality of life.

Most persons interviewed would change only little if they were to consider a new nuclear cogeneration project. Ågesta would avoid the risk related to a FOAK and rather use a conventional LWR instead of a PHWR.

The Halden project would likely **include the production of electricity** to make the project more economically viable, although in Norway this may be a risky approach in a country with abundant hydropower.

Another feedback common to several projects is that they have initially targeted a rather small customer basis whereas in reality the market is larger. Bohunice and Paks would **extend the district heating infrastructure** to other communities. Temelin would not change anything but has already planned to extend the distribution of heat to another town.

In the context of European energy policies supporting larger fractions of variable renewables in the electricity mix, it can be noted that already the large thermal inertia of low temperature applications such as district heating enable a NPP to perform load following thus contributing to compensate for a part of the variability of most renewable energies. This type of grid service represents an increasing value and the obtained revenue can contribute to counter-finance the heat application.

5 Synthesis of Feedback

5.1 Lessons learned

Based on the feedback gathered during this study, several good practices have become obvious which would support future nuclear cogeneration projects to become a success:

➢ **SOCIETAL ASPECTS**

- **Ensure political support**: organize communication and promotional actions to convince the current government of the legitimacy and societal value of the project; ensure consistency with the government's strategy, energy, environmental, social, industrial and market policy.
- **Gain public support:** gaining public support and avoiding opposition is essential to get the required political support. Possible actions include local communication on information about the project, the benefits, the technology, etc. A new project should not wait for the start of the public inquiry mandatory today, but should pro-actively prepare the grounds for a well-informed debate early on.

➢ **FINANCIAL ASPECTS**

- **Elaborate a convincing Business Model**: the financing of a cogeneration project can be problematic, the investors need to see how the project will generate money in a given time span and become profitable. Different business models can be considered (production of electricity and heat for district heating and/or industries, with one or several utilities, incorporation of grid services, etc.). Prepare for externally motivated project obstacles, e.g. a "German style" nuclear phase-out or unforeseen taxation (e.g. tax on nuclear fuel).
- **Avoid budget overruns:** In Ågesta, budget overruns occurred due to technical difficulties because the heat source was a prototype; In Beznau, financial problems of the heat distribution company Refuna occurred because of rather low end-user density with decreasing demand. This could have been compensated for by a larger heat distribution network (increased customer base), but anti-nuclear movements hinder this approach.

➢ **TECHNICAL ASPECTS**

- **Take advice from IAEA or other projects on nuclear cogeneration:** from a technical point of view, other similar projects or IAEA documents can provide useful technical documents.
- **Think big enough:** The size of a district heating network should not be chosen too small. Several projects mentioned that if they could change something today, they would extend the initial district heating plans to additional locations/towns in the vicinity of the NPP (Bohunice in Slovakia). Paks in Hungary and Temelin in Czech Republic have planned to expand their heat distribution system to additional communities.

5.2 Key Success Factors

After analyzing the different feedback gathered for several nuclear cogeneration projects, regardless whether operational or successful, several criteria appear to be crucial for the success of a nuclear cogeneration project:

- **Government/public support**: the government is often one of the first investors of the project either directly by providing funds or through state-owned companies such as utilities or manufacturers. Moreover, government support allows sharing the risk associated with an innovative application (reduction of development risk, financial risk and commercial risk) and leveraging investments. Public support is important since it can influence the government support and the opinion and decisions of local representatives about the nuclear project. Moreover, a strong opposition from the local population might dissuade potential investors from financing the project.
- **Technical knowledge**: This KSF is of course crucial for the success of the project but does not appear as a real issue for most of the projects interviewed. Indeed, cogeneration technology is now well known, established, and relatively well documented in IAEA Tecdocs (e.g. [1], [2], [3]). The Temelin experience shows that an engineering company with no experience in the nuclear sector but knowledge in connecting district heating to conventional plants can manage to connect a NPP to its final end-users. The technical knowledge can be an issue when the NPP includes a FOAK reactor or other innovations and involves as a result potential unexpected technical difficulties leading to delays, budget overruns, and outages.
- **Financing solutions**: One major difficulty when building a nuclear project is to mobilize funds to finance it. Indeed, the initial investment is significant, certainly compared to other sources of energy. In investor circles, power generation has an image of low profitability due to the subsidized growth of variable renewable electricity generation. Nuclear cogeneration, however, is different as it does not compete with renewable electricity but, on the opposite, could even contribute to iron out the supply-demand mismatch caused by renewables. Government support can lower the risk of other investors. The benefit for the government lies then in the achievement of typical policy objectives such as security of energy supply, emission reduction, industrial strategy, job creation and others. The financial resources relevant to technology development and prototype building are reviewed in the deliverable D1.23 *“Map and analysis of financial resources of interest to NC2I”*. These financial resources include among others Structural funds, the European Regional Development Fund (ERDF) and European Investment Bank (EIB) products.
- **Need for articulated incentives**: The rationale for a new and different type of energy (carbon-free, more economical, secured supply) is very important for the development of new nuclear cogeneration projects. Policy makers, industry, end users need strong incentives to change their well-established practices. Even considering a completely operating system, with no technical or financial risk, the energy produced and distributed by a nuclear cogeneration system must first be recognized as advantageous by all involved stakeholders thus requiring stakeholder-specific multi-criteria assessments.

5.3 SWOT

A SWOT is a tool which helps identify the most relevant Strengths – Weaknesses – Opportunities – Threats of a project so as to assist decision makers in taking action required to make a project successful or, conversely, to stop it. The SWOT is a way to represent all those positive and negative elements that may affect any new proposed actions/projects for a company.

The SWOT table below summarizes some generic characteristics of various nuclear cogeneration projects, but not for specific nuclear reactor types or applications. It results from the interviews with different kinds of projects and studies using various types of reactors (PWR, PHWR, HTR) for a range of applications (district heating, paper mills, R&D, etc.).

Also, as the screened projects cover several decades, what was a problem at a given point in time may no longer be a problem today or, vice versa, new and different difficulties may have appeared in the meantime. Therefore, while the table may be incomplete and may also contain an element of subjectivity of the interviewers and interviewees, it does mirror issues which repeatedly surfaced during this investigation.

Strengths	**Weaknesses**
- Technical success, no major problems identified; - Nuclear cogeneration can be the most economical solution compared to other heat sources; - Reduced heat pollution to the environment; - Suitability for arid regions (air cooling); - Improved resource utilization; - Flexibility between production of heat and electricity (daily, seasonally) which increases the overall efficiency of the NPP and makes it suitable to stabilize energy systems with large fractions of variable renewables; - Compatible with required high power densities in urban agglomerations and industry sites; - Does not emit CO_2 and provides clean air compared to fossil fuels; - Enhances energy security; - Maintains competitiveness of local industries with all secondary effects on employment, tax income, strategic independence etc.; - CAPEX/OPEX for reactor modifications and cogeneration infrastructure (pipelines, heat exchanger stations, etc.) are relatively low/negligible compared to the CAPEX/OPEX of the NPP; - Lifetime comparable to reactor lifetime; - High satisfaction both on the producer and on the end-user side; - No reports on negative effects of "nuclear origin" of heat;	- Relatively high CAPEX/OPEX for NPP with growing uncertainty; - Decommissioning of the NPP is perceived as financially risky although decommissioning costs are covered by a reserve which an NPP has to build from its revenue (included in the Business Plan); - In some cases, nuclear cogeneration projects are not financially successful due to an underestimation of the initial investment or overestimation of demand; - Seasonal variations of demand/income have to be factored into the Business Plan; - Long term strategic energy infrastructure investments do not comply with fast Return On Investment requirements from today's investors; - Weakening support for climate change mitigation policies; - Relevant regulation framework for nuclear cogeneration plants is yet to be built;
Opportunities	**Threats**
- European policies to reduce carbon emissions and pollution, to enhance security of energy supply, and to promote competitiveness; - Positive feedback and global support of population (end-users) due to low heat prices; - Nuclear in energy markets other than pure electricity can be an attractive option for countries with poor energy resources; - Good option for energy source diversification (security of supply); - Renewal of existing nuclear reactor fleet in the next decades; - Renewal of industrial sites in the next decades;	- Nuclear cogeneration requires political support and initial sovereign investment; - Governments and investors are currently still more inclined to follow short investment cycles instead of long-term strategic infrastructure development; - Bad image of nuclear in the general public due to past accidents; - Highly competitive cogeneration from fossil fuel plants; - Possible reduction in natural gas prices over longer periods of time; - Development of competing carbon-free solutions (carbon capture and storage, geothermal etc.) to improve current production systems of electricity and heat; - Diminishing needs (especially for district heating) due to improved insulation and alternative energies;

Table 2: SWOT Matrix

5.4 Remaining questions

Despite the wealth of information gathered through the returned questionnaires and the persons interviewed, there are still points that clearly require further investigation, in particular:

- **Investors:** As most of the considered projects were at least partly funded by public money, it was impossible to distil a common methodology for attracting private investors for a new nuclear cogeneration project. How to convince them? How to share risks? Although there is a generic difficulty of bringing innovation into the market, specific difficulties of nuclear energy are the high required capital, the long lead times and the slow return on investment. More generally: long-term strategic energy infrastructure investments seem to be little compatible with today's financial market expectations. Those are often based on unrealistic targets which still originate from the internet bubble era but which are de facto impossible to achieve in Europe today in times of low interest rates, low growth, risk of deflation and strained public budgets. Paradoxically, most large investment companies are actually having the problem that they need to invest whereas the current market conditions leave them only few options to achieve the expected profitability. Due to the subsidies for renewable energies, electricity generation has become little profitable in several EU countries. Specifically for nuclear energy, the risk perceived by investors is also high, especially in the light of the delays encountered by the current EPR constructions in Finland and France. Unfortunately, the success stories from Chinese NPP construction (on time and on budget) weigh little in this debate. Another investment risk is linked to the volatility of public opinion and national policy orientations related to the use of nuclear power.
- **Licensing:** From the feedback received, the impression is created that licensing was no particular issue. However, we recall that the German THTR reactor has suffered significant delays due to changing licensing requirements. As licensing has a significant impact on cost and overall success of a nuclear project, this question certainly deserves renewed attention (cf. WP3). In Europe, licensing is the responsibility of national regulators with partly different rules and requirements which make it difficult to design a standardized nuclear cogeneration facility which could be licensed in any country. Common safety standards and licensing frameworks, at least at EU level, would be a decisive step forward.
- **Boundary conditions:** A majority of the projects which were actually operated appear to be successful but most of them then had no successor projects. If they were successful, why were no other similar projects planned (Hungary, Slovakia)? Many of these projects were started in times when decisions for large infrastructure investments were made by centralistic authoritarian governments. Today, it requires strong economic and strategic pressure (such as the effect of the oil crises in the 1970s on France) to trigger national governments to start a new nuclear development program. Recent examples for nuclear newcomers are the United Arab Emirates, Turkey or Poland. Moreover, new rules on competition (opening of the electricity market, separation of generation and transmission/distribution) have led to smaller utilities with less critical mass, reduced government influence, stronger shareholder expectations, etc. These conditions are little favorable for the construction of heavy, complex and long projects. Exceptions are possible though, e.g. when governments contribute to de-risk a nuclear construction program (UK), when they start a new nuclear project as part of a national industrial development policy (F) or when a vendor company itself or a purpose-built consortium can ensure a large part of the required upfront investment (e.g. proposed Rosenergatom investment in Paks 3).

6 Conclusion

Although the performance of this task has taken significantly longer than expected, a wealth of information could be collected from past, present and planned nuclear cogeneration projects in a significant number of countries. 36 projects could be identified and were contacted, thereof 23 returned the questionnaire and 8 interviews were conducted. To our knowledge, this was the first time that nuclear cogeneration projects could be screened with such a broad array of questions also covering non-technical aspects. Although more time and effort were required than anticipated for establishing the right contacts and for arranging meetings, the collected return was significantly better than expected, both in terms of quantity and quality. The analysis was performed together with WP3.

Difficulties were encountered mainly to obtain dependable quantitative financial information. The vast majority of the applications concerned district heating, steam for the paper & pulp and the chemical industry, as well as seawater desalination (Japan). All those projects which were actually built and operated were technically successful and have led to high end-user satisfaction.

Some key success factors and open questions could be identified from the returned questionnaires and a SWOT table was completed. In particular new economic, market and political boundary conditions will require a strong effort of de-risking on all fronts (technical, financial, licensing, public opinion, energy policy…) because all involved stakeholders prefer business-as-usual and many investors still have (unrealistically?) high profitability expectations. Political support appears to be fundamental for success.

It is therefore recommended that for preparation of an HTR demonstration the SNETP/Nuclear Cogeneration Industrial Initiative uses the information from this report and addresses these key success factors in the roadmap (D4.51 Roadmapping towards demonstrator).

7 References

[1] Advanced Applications of Water Cooled Nuclear Power Plants, IAEA TECDOC 1584, July 2007.

[2] Advances in Nuclear Power Process Heat Applications, IAEA TECDOC 1682, May 2012.

[3] Industrial Applications of Nuclear Energy, IAEA TECDOC, draft May 2014, under review.

8 Acronyms and definitions

Acronym	Definition
AVR	Arbeitsgemeinschaft VersuchsReaktor *(German)*
BWR	Boiling Water Reactor
CAPEX	Capital Expenditure
EC DG RTD	European Commission – Directorate General for Research and Innovation
European Investment Bank	EIB
European Regional Development Fund	ERDF
FOAK	First Of A Kind
HTR	High Temperature Reactor
KSF	Key Success Factor
LCOE	Levelized Cost Of Energy/Electricity
NOAK	N^{th} Of A Kind
NPP	Nuclear Power Plant
OPEX	Operational Expenditure
PHWR	Pressurized Heavy Water Reactor
PNP	Prototype Nuclear Process Heat Project
PWR	Pressurized Water Reactor
SWOT	Strengths – Weaknesses – Opportunities - Threats
THTR	Thorium High-Temperature Reactor