The rise of nuclear technology 2.0

Tractebel's vision on Small Modular Reactors

Tractebel Business Line Nuclear | December 2020

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"[…] Clean-energy miracles don't just happen by chance."
- Bill Gates

Content

Executive Summary

Small Modular Reactors (SMRs) [1] have picked up a growing attention from the media in recent years. And rightly so, as such effervescence has last been observed 60 years ago, at the very birth of nuclear industry itself [2]. The USA, Canada, UK, France, Finland, Estonia, Poland, Czech republic and other Eastern countries have expressed a clear willingness to shape the future with SMRs. One question is on everyone's lips: are we witnessing the rise of nuclear technology 2.0?

For the last 3 years, Tractebel has been deep-diving into the promises of these advanced reactors, investing thousands of engineering hours in technical due diligence and market studies. Today we are pleased to officially unveil our vision for SMRs and the role that we, Tractebel, aspire to play within that future.

The decarbonization of the electricity mix is what has been drawing most of the attention in the energy transition debate. Yet it is merely the tip of the iceberg: according to IEA 2018’s numbers, out of more than 116,000 TWh of total final energy consumption, electricity constitutes only 20% [3]. In fact, the energy transition is about decarbonizing the whole economy i.e. (1) electricity, (2) heat and (3) transport. Given the technical limitations for total electrification, each of those sectors will require a specific energy vector to be economically sound: (1) electrons to power our devices, (2) steam to feed industrial processes and (3) molecules to cross continents. With renewables at the forefront, arduous challenges will arise from each of these three pathways. This is where Small Modular Reactors step in.

SMRs are not a single product; they are a business model that brings sensible answers to the crucial questions of the 21st century energy context. Namely, becoming an enabler of the zero-carbon transition :

- (1) through load-balancing capabilities and GWh-scale energy storage that foster the penetration of intermittent renewables;
- (2) through better size compatibility with market demand, alternative reactor coolant and higher operating temperature that enable district heating, water desalination & demineralization… And even delivery of process heat to the industry in a wide range of applications ;
- (3) through pink (nuclear-based) hydrogen production that may serve as (a) feedstock for steel and fertilizers production or (b) as intermediary to eMolecules synthetization (such as eKerozene) close to CO_2 deposits (such as those from the limestone industry).

Tractebel has accumulated more than half a century of nuclear experience, first as the architect engineer of the Belgian nuclear fleet, later as a respected engineering company involved in the most complex nuclear projects over the world. As a key player in cross-functional fields ranging from energy production, storage and transport, it is in our DNA to engineer integrated energy solutions with SMRs at their core.

The vibrant international race for Advanced Nuclear

At a glance

1. While current nuclear reactors were designed to meet the needs of the 20th century, SMRs are bringing sensible answers to the crucial questions of the 21st century: flexibility, deep decarbonization of the economy, investability, simple & inherent safety and even spent fuel (waste) burning options.
2. With more than 70 concepts addressing diverse market segments, SMRs are creating an effervescence within the nuclear industry not observed since its inception. As in the 1950s, individual technology's success will be conditioned by more than mere technical merits. Designs deemed promising also need to meet market appetite and industrial deliverability requirements.
3. Pilot SMR projects are on the verge of being materialized in leading countries. First SMRs will be online in 2021 in China and Russia, and western technologies will follow by 2027 in the US and Canada. With full market deployment expected within 10 years, now is the right time to move to integrate SMRs into the design of tomorrow’s energy ecosystem.

How did we reach those conclusions?

For the last 3 years, Tractebel has been deep-diving into the promises of Small Modular Reactors, conducting many technological watch and market studies. We have strived to address three of the most recurring concerns about SMRs in an effort to capture and validate the visible market enthusiasm.

Is all the excitement about SMRs just a mirage?

A nuclear renaissance has been talked about since the 2000s but has faced major roadblocks over the last decade: major construction delays and cost overruns in large nuclear projects; increase of public concern about nuclear safety in the wake of Fukushima accident; decrease of financial appetite for nuclear projects due to investments too big for private equity and long period before first return.

Yet in recent years, small modular reactors have been generating an effervescence within the nuclear industry that has not been observed since its inception in the 1950s. That effervescence has given birth to more than 70 SMR concepts that encompass a wide variety of technologies: from evolutionary designs, evolved from today’s water-cooled reactors, to promising next-generation nuclear reactors, the diversity of modular solutions covers power outputs ranging from 5 to 300 MW(e). If SMRs are not a single product, what sets them apart is their business model that brings sensible answers to the crucial questions of the 21st century, including aforementioned roadblocks:

The crucial questions

Expand role in zero-carbon transition?

SMRs support deep decarbonization strategies through built-in flexibility that complements intermittent renewables, better size compatibility with industrial market demand, or even alternative coolants that enable high temperature industrial steam and GWh-scale heat storage.

Foster nuclear investments?

By shifting from a scale economy logic driven by size increase to a mass production of standardized and simplified designs, SMRs are cutting the maximal exposure investors may face by orders of magnitude.

Recreate public trust in nuclear safety?

By relying on natural phenomena (rather than mechanical components) to passively cool down the reactor and to limit radiological risks to site boundary, SMRs aim at reaching safe state without human intervention and eliminating the need for evacuation of population even in the most adverse conditions.

Alleviate concern of nuclear waste?

Advanced fast-neutron SMRs will be able to cut down lifetime of nuclear waste by burning long-lived radioisotopes. They will reinforce the commitment to long-term waste solutions by enabling recycling of current spent fuel stockpile in a circular economy scheme.

With so many concepts, how to bet on a winning concept?

Tractebel developed a tool for assessing best-suited concept per individual user requirements, leveraging its in-depth knowledge of the most promising concepts. Our methodology consists of the following steps, as shown on Figure 1:

- **Exclusionary assessment:** Exclusion of designs not suited with the user requirements and criteria (example of exclusion criteria below).
- **Technology pre-assessment based on publicly available data:** Ranking of remaining designs through a high-level assessment of a set of Critical Success Factors that address technical merits, market appetite and industrial deliverability of each concept
- **Deep dive:** More in-depth analysis of leading candidates through engagement with vendors

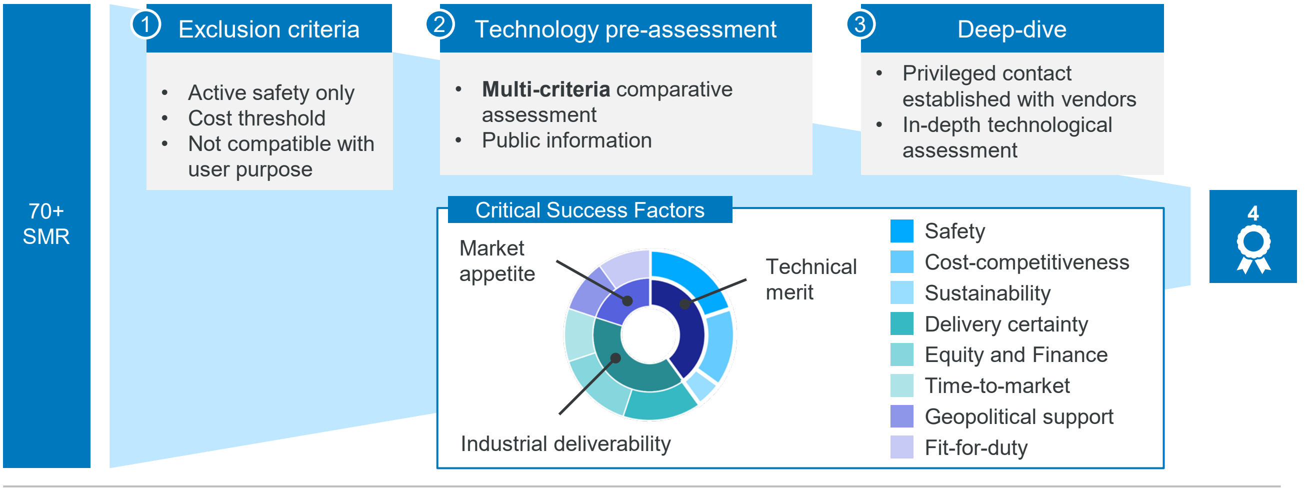


Figure 1 – SMR down-selection methodology [5]

Application of this process has led us to develop excellent knowledge of promising concepts. Several types of technologies retain our interest: mature market initiator light-water SMR technologies; as well as low-maturity but game-changing technologies such as molten salt SMR have been our main area of focus. A close eye is also kept on high-temperature gas-cooled reactors, close to demonstration, and with far-reaching industrial applications, as well as on lead fast reactors that can close the fuel cycle, and with leading Belgian expertise. Sample of promising technologies are displayed on Figure 2.

Is product delivery compatible with industries' decarbonization timeline?

The nuclear industry is on the verge of launching SMR pilot projects in many parts of the world. US and Canada are accelerating their SMR development like China and Russia:

Leading Countries

- United States **:** the US pressurized-water SMR NuScale has recently become the first-ever SMR to receive design approval from the US safety authority; the boiling water SMR design by GE Hitachi is also in advanced stages of licensing. Through US DOE Advanced Reactor Demonstration Program (ARDP), advanced SMR technologies are being pushed to reach demonstration by the end of the decade.

- Canada **:** Canada is pursuing three tracks of SMR development in parallel: a micro-reactor demonstration for remote communities by 2026, an on-grid SMR to be built by Ontario Power Generation by 2028, and very promising fast-spectrum technologies such as molten salt reactor to be demonstrated by the mid 2030s on the site of New Brunswick Power.

- Russia **:** the first marine-based Russian SMR has been operational since May 2020; a construction project has been launched for a land-based SMR;

- China : the pilot high-temperature gas-cooled SMR is built and in commissioning phase, with full commercial operation expected in 2021. Several versatile SMRs with combined heat and power uses are expected to be launched by the mid-2020s;

And this is merely the tip of the iceberg: several other countries have already notified their intention to pursue SMRs: UK, Argentina, Estonia, Finland, Poland, Czechia; and even countries that previously had or still have bans on nuclear new builds such as the Netherlands and Australia are now reconsidering their position.

Several indicators are there to prove it: SMRs are not just scientific ideas on a sheet of paper anymore. The dynamics has overwhelmingly switched from a planned conception mode led by public research centers to start-up-like development driven by entrepreneurs backed by private investors; so that vibrant ecosystems are being nurtured in most of the G20 countries.

Furthermore, we may expect SMRs to leverage recently regained know-how of lifetime expansion and large new build reactor program to streamline their delivery process.

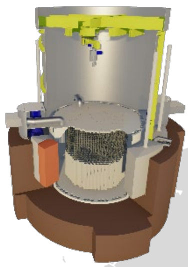
All in all, full market deployment, which may be expected within 8 to 12 years from now, is just around the corner, if national policies are in place to support it. An alternative that is deeply needed in the huge endeavor of combating climate change.

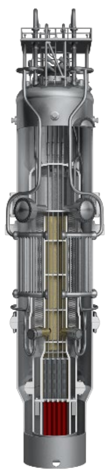
IMSR (Terrestrial) – TRL4
Thermal molten salt reactor. Under licensing for construction in Canada & US

Image source: Terrestrial Energy

SSR-W (Moltex) – TRL3
Fast molten salt reactor. Under design for construction at NBP Point Lepreau site in Canada

Image source: Moltex Energy



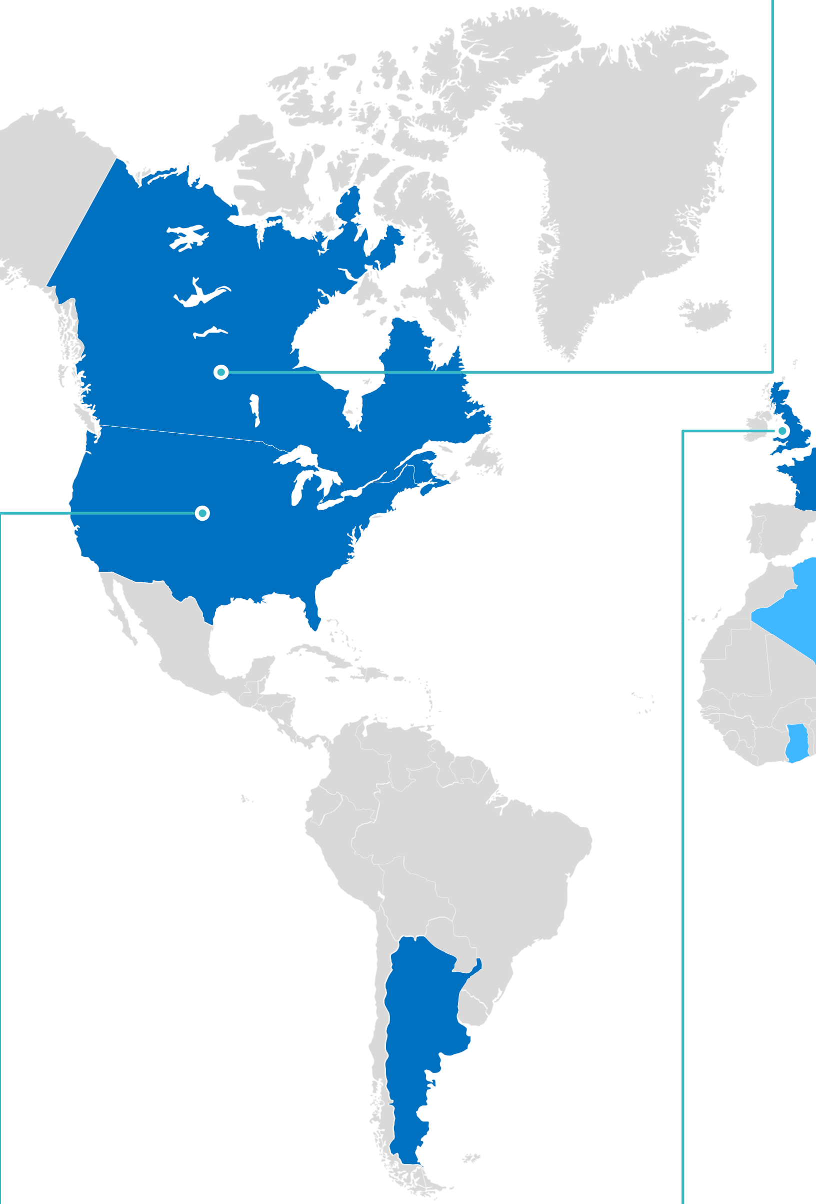


NuScale (Fluor) – TRL6
Multi-module Pressurized Water Reactor. Under licensing by US-NRC for demonstration at Idaho National Lab site by 2027

Image source: Moltex Energy

BWX-300 (GE-Hitachi) – TRL6
SMR version of the large scale ESBWR, already licensed by the US-NRC

Image source: GE-Hitachi Energy



Canada

[6]	First SMR in Darlington by OPG by 2028
[7]	Government invest massively in SMRs
[8]	10 SMRs under Canadian pre-licensing

United States of America

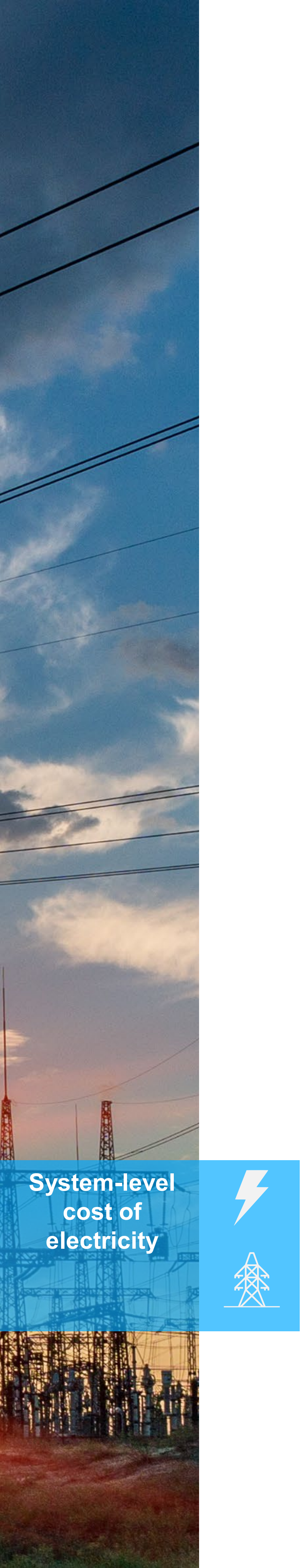
[9]	US DOE invests >3B$ in R&D over 7 years
[10]	NuScale first SMR to be licensed in the US
[11]	Export nuclear finance ban lifted

United Kingdom

[12]	UK invests 525m£ in SMRs
[13]	Rolls Royce plans 16 SMRs for UK
[14]	Westinghouse LFR* in AMR** phase 2

*Lead-cooled Fast Reactor | **Advanced Modular Reactor

Figure 2 – World overview of key SMR development [5]



Beyond baseload electricity production

At a glance

1. Leading SMRs are expected to reach LCOE comprised between 40 and 65 €/MWh [24]. Their economic competitiveness is even better than production cost suggests. To minimize transmission and storage system cost, low electricity prices in the 2050 zero-carbon electricity market will require low-carbon dispatchable energy : SMRs are the most favorable option in Europe.

2. With intermittent renewable energies at the center of the energy transition, SMR flexibility capabilities are their main economic driver and lead to penetration rate of at least 25% even in countries with high potential for cheap renewables [25].

3. Delivery cost overrun for demonstration of the low maturity disruptive technologies is not a business case killer because first units bring substantial economies to the overall system cost. Yet, it is imperative from an investability standpoint that SMRs deliver pilot projects on time and on budget.

How did we reach those conclusions?

Tractebel conducted a joint market simulation study with ENGIE Impact, combining technological knowledge of SMR cost structure and market knowledge of the European Power grid.

Comparing the full picture of electricity costs

Our methodology uses a power market model that solves the following optimization problem: starting from the energy mix we have today, what kind of assets should be invested in to minimize the overall system cost function while simultaneously achieving CO2 emissions reductions target and ensuring security of supply across a whole year with a granularity of one hour.

The use of an overall system cost function enables a more integrated view of the electricity market economy as it accounts for both:

- Plant-level cost i.e., all costs of electricity generation assessed over the lifetime of the asset;

- Grid-level cost i.e., costs related to transmission, distribution and storage of electricity. Their inclusion more accurately reflects cross-border transmission line and significant storage investments, that are induced by ensuring security of supply in a grid driven by intermittent producers.

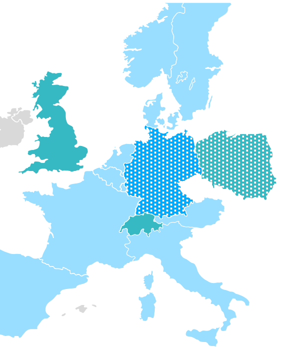
The results provide a more accurate basis of comparison than the traditional LCOE methodology which only compares plant-level production costs.

This power market model was used to make a complete trajectory study between 2030 and 2050 to get a full picture of the transition to a zero-carbon electricity market.

A European case study

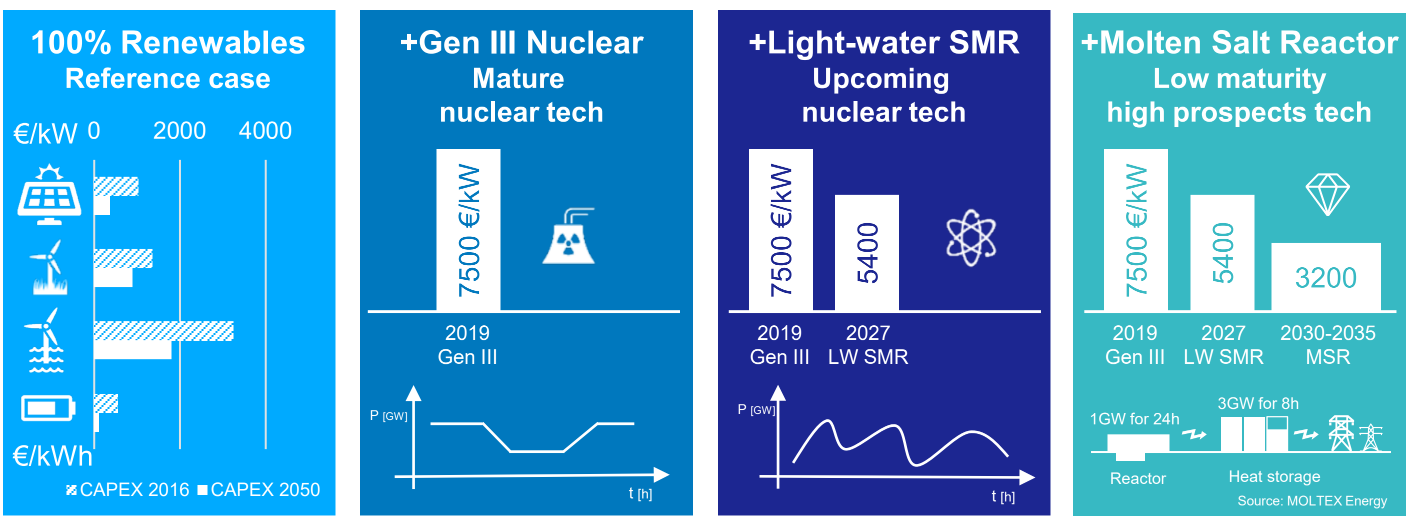
The analysis was performed on the Western European Power grid. New nuclear energy was only considered from the perspective of countries, where new build is deemed possible and with profiles somewhat indicative of other regions: UK (for its wind potential); Poland (for its elevated carbon footprint); and Switzerland (for its hydro resources).

(*) Poland was modelled based on surrogate data from Germany. Market potential results are shown for PL, but system impacts are measured with a modified DE



In order to get a better grasp on the potential of nuclear energy in a grid driven by intermittent producers, scenarios are compared to a reference case study, focused on renewables and which does not allow new coal or nuclear power station. Three scenarios gradually introduce nuclear technology options from most to least mature (from Gen III nuclear reactors to Molten Salt Reactor).

Assumptions were voluntarily chosen optimistic for renewables but kept comfortable margins on SMR technologies: while CAPEX above 5000/kW were used for light-water SMRs, latest estimations tend to indicate that promising designs could go below 4000€/kW and get closer to offshore wind capital cost.



Economic prospects of SMRs are beyond doubt

In a snapshot, comparing nuclear scenarios to the 100% renewables scenario (Figure 5) lead to the following observations in the zero-carbon electricity market of 2050:

- Under current cost assumptions, generation III nuclear reactors show prospects mostly in regions where geography is less favorable to renewables such as Poland;
- Thanks to higher flexibility, light water SMRs reach at least 25% of the total generation in each country where their potential was assessed and display excellent complementarity with renewables. It goes as far as reaching 65% for a country like Poland. With the SMR option, Switzerland becomes a net exporter of about 15% of its generation, compensating for intermittency in neighboring countries;
- At target CAPEX around 3000€/kW, Molten Salt Reactors would become by far the cheapest energy source. It is to be noted that given their GWh scale energy storage and great load balancing capabilities, they remain competitive solutions even above 7000€/kW.

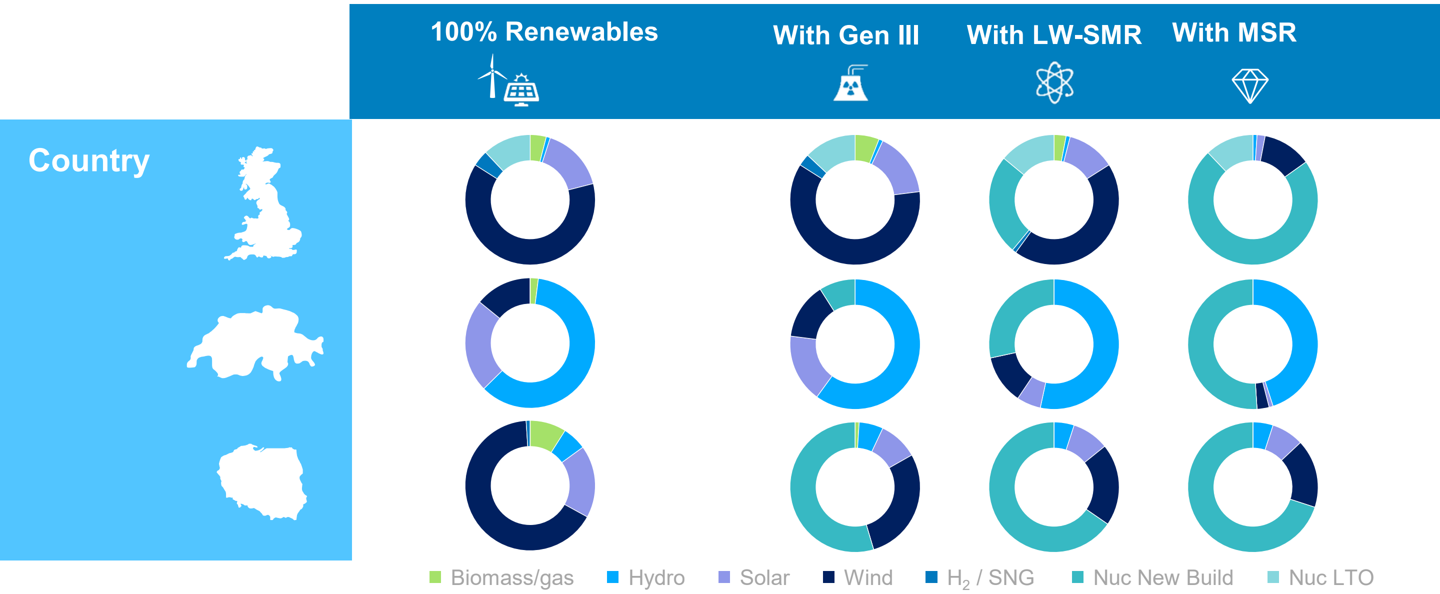
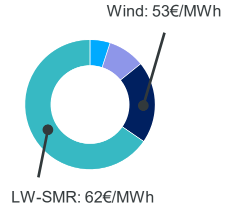


Figure 5 – Power Market Model - Snapshot of results for 2050 [24]

If SMRs have yet to prove claimed competitiveness through actual construction, cost overrun on a first-of-a-kind would not necessarily equate to failed demonstration projects. A sensitivity analysis showed that even above 7000€/kW, appreciable installed capacity is still derived by our economic optimization model, as the first low-carbon dispatchable units bring substantial economies to the overall system cost. One imperative however remains: proving to investors that SMRs and licensable and have incorporated lessons learned from Generation III new builds and i.e. can be built on time and on budget.

Zoom on Poland 2050 case study – Light Water SMR scenario

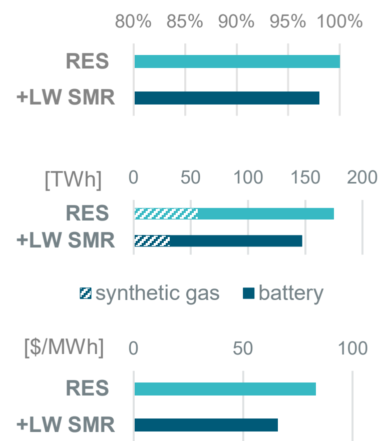


Furthermore, the model perfectly illustrates why Levelized Cost Of Electricity comparison is far from giving the whole story. An in-depth analysis of the case of Poland shows that wind energy at cheaper LCOE (53€/MWh) than light water SMRs (62€/MWh) would get a lower share of the energy mix. The explanation lies in the fact that:

Compared to 100% renewable scenario, light water SMRs minimize the generation cost at grid-level for the whole configuration thanks to its dispatchable nature;

Total storage capacity decrease by ~16% on the whole European configuration with light-water SMRs only implemented in the 3 case study countries;

As a result, projected electricity prices decrease by >20% in Poland thanks to SMRs despite their higher LCOE.



SMRs and renewables are synergetic means to get to zero-carbon

Overall, it can be concluded that flexible nuclear energy could accelerate the deployment of renewables since it will alleviate the need for big infrastructural transformations in storage and transmission. This is what makes SMRs the perfect partner for renewables.

European Heat Market

At a glance

1. The heat market potential for SMR is real and represent **100+** compatible sites in Europe.
2. The petrochemical clusters are the most promising sector followed by district heating, paper production and steel making.
3. Early adopters' countries are not systematically countries with the largest absolute co-generation potential. Nevertheless, Poland, England & Finland stand out globally on both appetite for demonstration and overall market potential.

How did we reach those conclusion?

The market study have been performed in two phases: first a top-down sectorial analysis and then a bottom-up geographical characterization.

Top-down sectorial analysis

The sectorial analysis has been performed through literature review, namely from:

- The End-Users Requirements fOr Process heat Application with Innovative nuclear Reactor for Sustainable energy Supply (EUROPAIRS) report written by LGI and approved by Tractebel [26];
- The Best Available Techniques (BAT) Reference Document for the relevant Industries, written by JRC [27] to [36].

The industrial sectors have been mapped against a set of relevant indicators, namely:

- Maximal process temperature that informs about the range of SMR technologies (i.e. coolant type) compatible with the application;
- Coupling easiness that qualitatively advises about the engineering effort needed to integrate an SMR with such industry;
- Market size that helps nuancing investment requirement for pilot demonstration with reachable economic potential;
- Plants size that briefs on the relevance of installing at least one SMR for co-generation next to the industrial facility.

Figure 6 maps the result and highlights the industrial sectors for which pilot projects are to be prioritized.

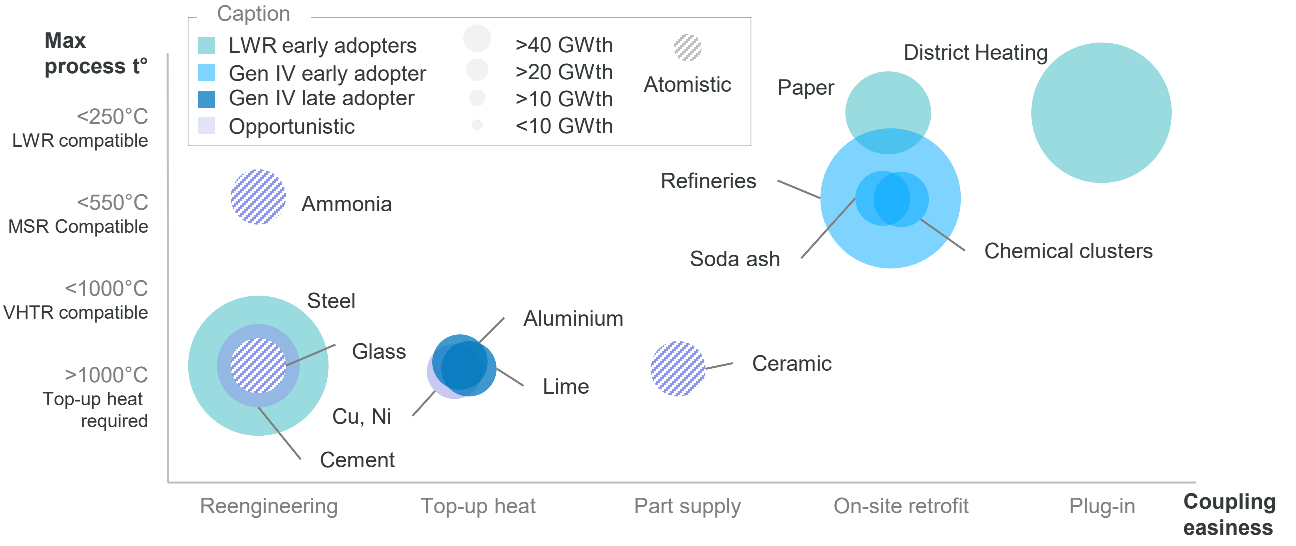


Figure 6 – Industrial sectors affinity with SMR-based co-generation [37]

A pre-feasibility study is on-going in a Nordic country for district heating application with SMR. This study will demonstrate potential of SMR for this important energy intensive sector. Such pre-feasibility should be carried out as well for other sectors.

Bottom-up geographical characterization

The country-by-country analysis of the suitable industrial sites followed two steps:

1. The country dynamic characterization through macro indicators such as:

Country indicators

- Nuclear industry maturity that enlightens on the strategic interest and ability of the domestic workforce to carry a demonstration project by itself;
- Nuclear appetite which is indicative of the political receptivity to nuclear new build projects given the ambient momentum around nuclear energy within the country.
- Co-generation potential that measures the market size deemed unlockable through investment in local business development activities (incl. geographical expansion);
- Carbon footprint which gauges the pressure of resorting to bold and disruptive solution to decarbonize the country's entire economy.

Once aggregated, those indicators give a high-level view about the ecosystem in which pilot projects could emerge and materialize.

2. The individual site attractiveness evaluation using indicators such as:

Site indicators

- Heat demand which is representative of the capability of carrying pilot project.
- Available infrastructure that would help de-risk the project such as: water access, existing district heating network, retrofittable fossil assets…

Information has been sourced by using open-source Geographical Information System such as Peta4, CoalTracker, IndustryAbout and others. More than 100 compatible sites have been identified and characterized in Europe only.

Figure 7 captures the aggregated results of both geographical analyses and synthetizes the market potential we foresee.

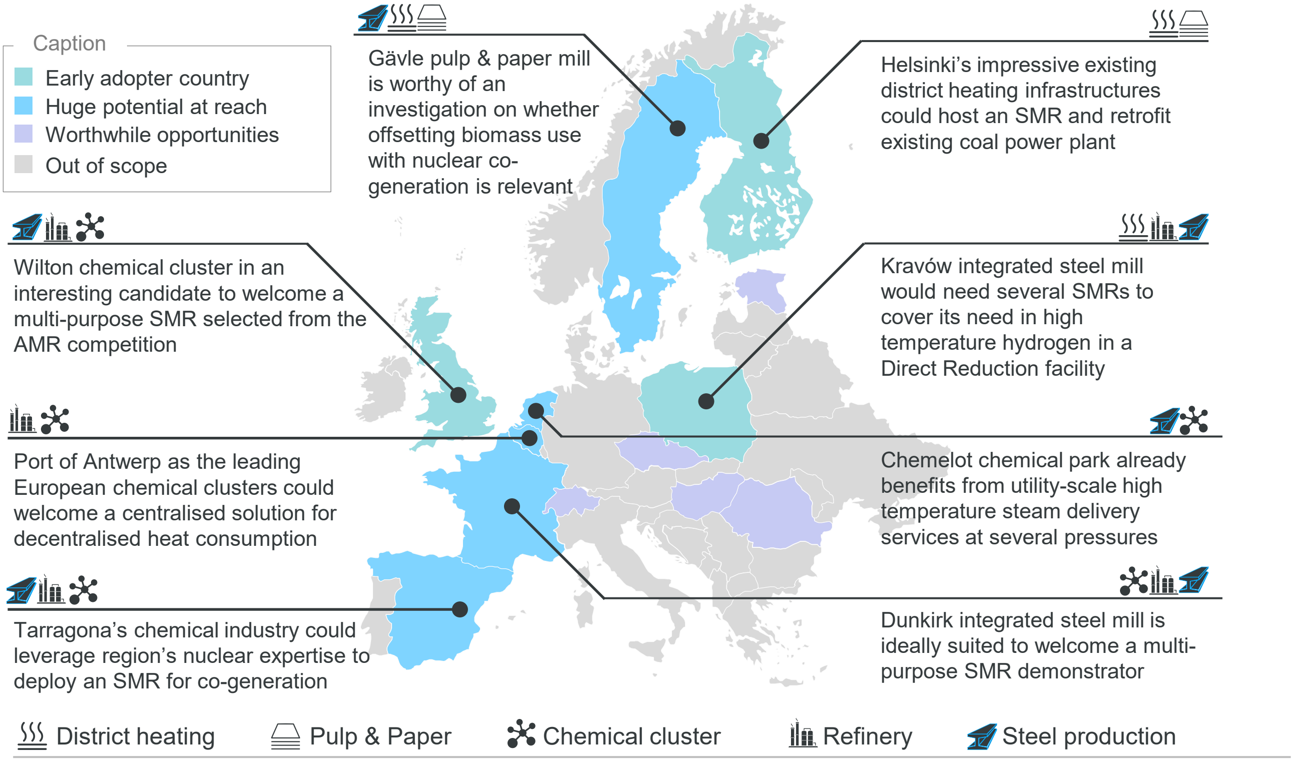


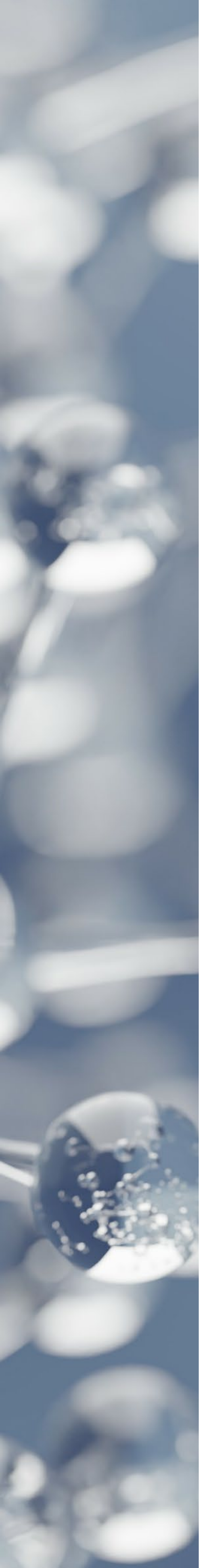
Figure 7 – European heat global market potential with illustrative examples of the diverse opportunities [37]

Countries

We see the following trends driving the emerging momentum:

- United Kingdom: its domestic supply chain and captive market strategically position UK to become the European SMR hub. The political willingness is there.
- Poland: political leadership and the pressure of a deeply carbonated captive market render Poland a long-term partner for the deployment of SMR for co-generation.
- Finland: Political boldness regarding carbon neutrality ambition sets Finland the ideal early adopter of LW-SMR co-generation.
- Netherlands: Its cutting-edge R&D on advanced reactors and domestic chemical clusters place it as a fertile environment for early adoption of Molten-Salt reactors.
- Belgium*: With an existing nuclear site inside the leading European oil and chemical cluster, Belgium has an unparalleled advantage to become a world leader of advanced nuclear application.
- France: European leader of nuclear with 56 reactors in operation, France is working on EPR and SMR. Its captive market could welcome a fleet-size of its domestically developed SMR & demonstrate its exportability.
- Spain* : An alliance of industrials in need of decarbonized heat could renew interest in nuclear new build that has declined in light of the PV revolution.
- Sweden*: An alliance of industrials in need of decarbonized heat could renew interest in nuclear new build that dropped with renewables momentum.

* Change in national policy is a prerequisite



Low-carbon Hydrogen for eMolecules

At a glance

1. As transport needs energy-dense vector, CO_2 becomes a resource to combine with hydrogen to synthesize eMolecules (eMethane, eKerozene…). Hence, the geographical matching of CO_2 deposits (e.g. limestone industries) with abundant decarbonized energy assets such as SMRs reveals game changing opportunities.
2. A short-term solution to source demineralized water (DW) is to mutualize idled infrastructure when deploying SMR on existing nuclear sites. At medium term, feeding demineralized steam to high temperature electrolyser will set the new thermodynamic standard since half of electrolysis enthalpy comes from water evaporation.
3. From a safety standpoint, there is no technical showstopper to co-localize an electrolysis facility of up to 1 GW in the direct vicinity of a nuclear power plant. Proximity being crucial for process integration.

How did we reach such conclusions?

Among all, two studies stand out, both market and technology wise.

A shift in the hydrogen landscape's dynamics

Presently, hydrogen is used as a feedstock in the ammonia and refinery industry where IEA reports a total demand of about 70 Mt in 2018 [38].

When screening the technologies available to decarbonize the long-distance transport (aviation and navy) none match the energy density of liquid hydrocarbon –by a factor 25 for current electric batteries [39]. Hence, a shifting strategy looms where carbon neutrality is reached by off-setting downstream CO_2 emissions through the upstream process i.e. by draining CO_2 from other emitters [40].

It is the century-old Fischer-Tropsch process that helps recreating the needed hydrocarbon chains (e.g. kerozene). In this Power-to-Liquid path, CO_2 becomes a resource when combined with water and energy to produce synthetic fuel (or eMolecule) unlocking a theoretical market one order of magnitude larger: about 15Mt and 1PWh just for Europe's aviation and navy transport [41] to [43].

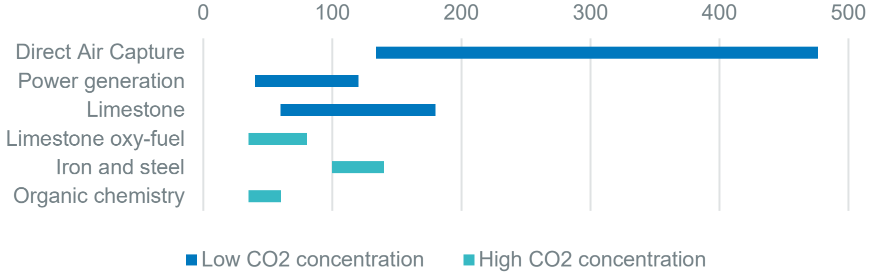


Figure 8 – CO_2 capture cost per sector [44] to [46]

With CO_2 becoming an asset rather than a burden, arise the question of access to ressources. Figure 9 illustrates the relative competitiveness of sourcing pathways. This paper agues that when renewable energy fields are not available close to CO_2 reservoirs then Small Modular Reactors may match the energy needs to ensure eFuel competitivity.

Large scale supply of demineralized water

With PWh of conventional fuel to offset with eMolecules, sourcing demineralized water may become an attention point. A first investigation established the superiority of ultra filtration (Reverso Osmosis (RO)), an electricity-based process over its thermal counterpart, the Multiple-Effect Distillation (MED).

Then, with account for timing of electrolyser technology deployment, two strategies took shape during deepened investigations:

1. When looking at existing nuclear plants, it appears that demineralization systems hold substantial idle capacity due to fitful needs during normal operation. The Figure 10 sums our findings:

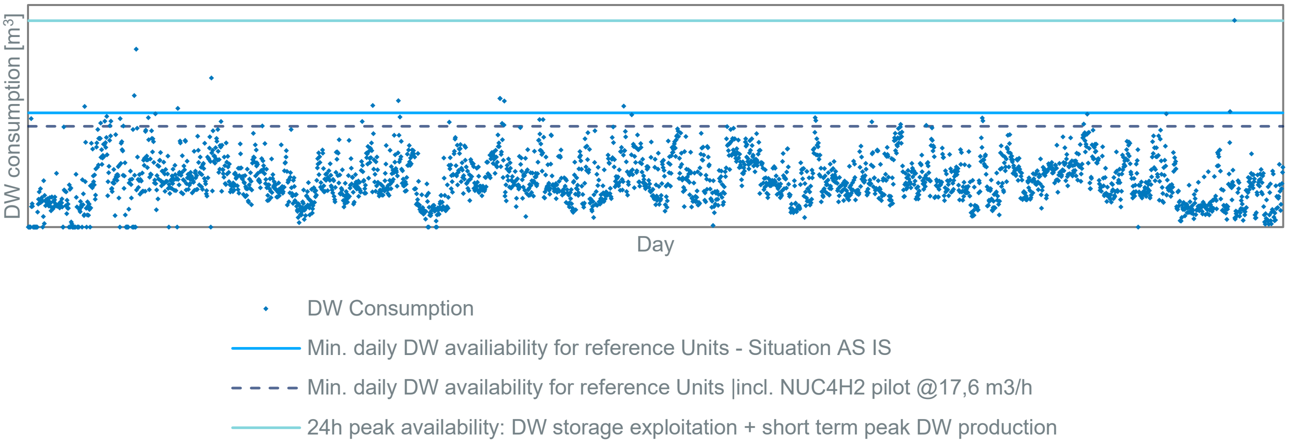


Figure 10 – Illustration of DW requirement of 100MW electrolysis facility with idle capacity of reference plant [47]

Knowledge of assets' constraints allowed us to design a fit-for-purpose by-pass and storage system compatible with operation of both the plant and the H_2 facility. Operators willing to deploy SMR on their site would benefit from such mutualization of infrastructure.

2. From a thermodynamic standpoint, about half the enthalpy involved in the hydrolysis process is used to change water from liquid to vapor phase. The other half helps splitting the chemical bond between hydrogen and oxygen. Hence, the solution we advocate for is an extraction of (demineralized) steam at ≈5 bars and 150°C. For a generic 60MWe SMR to supply directly to high-temperature electrolyser: two modules would be needed to supply the 100MW electrolysis plant both in electricity (50MWe) and steam (8.8 t/h) [48].

While we monitor the technological breakthrough necessary to deploy such electrolyser at commercial scale, we focus on ensuring system integration with physical proximity. It is where we tackled the safety considerations.

Ensuring safety

We anticipate an increased integration between power plant and eFuel facility: for electricity and steam supply. Therefore, design of both infrastructures must consider potential incidents. Our calculation ensures sufficient separation distances between the electrolysis facility and the nuclear reactor, in order to prevent any unacceptable effect.

Flammability and explosivity of hydrogen require a specific expertise and a thorough safety approach. Hence, a consequence modelling has been performed on a standardized 100MW H_2 facility [49], scaled up to 1GW, to study:

1. The effects of a jet fire in case of an ignited leak on a high-pressure hydrogen pipeline – different irradiation thresholds to be considered for different types of exposures (6,4 kW/m², 8 kW/m², 32 kW/m² or 44 kW/m²):

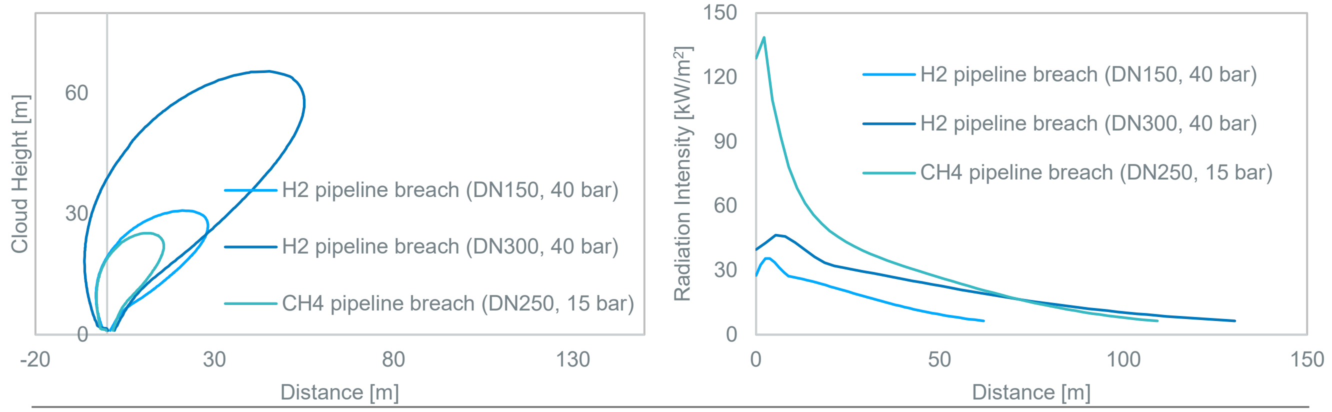


Figure 11 – H_2 & CH_4 safety analysis: could dispersion (left) and irradiance (right) for weather D48 type [50]

2. The effects of an explosion of a H_2 cloud within a confined space in the electrolysis and compression facility – different overpressure thresholds to be considered for different types of exposures (50 mbar or 160 mbar). Figure XX display results for the 160 mbar threshold:

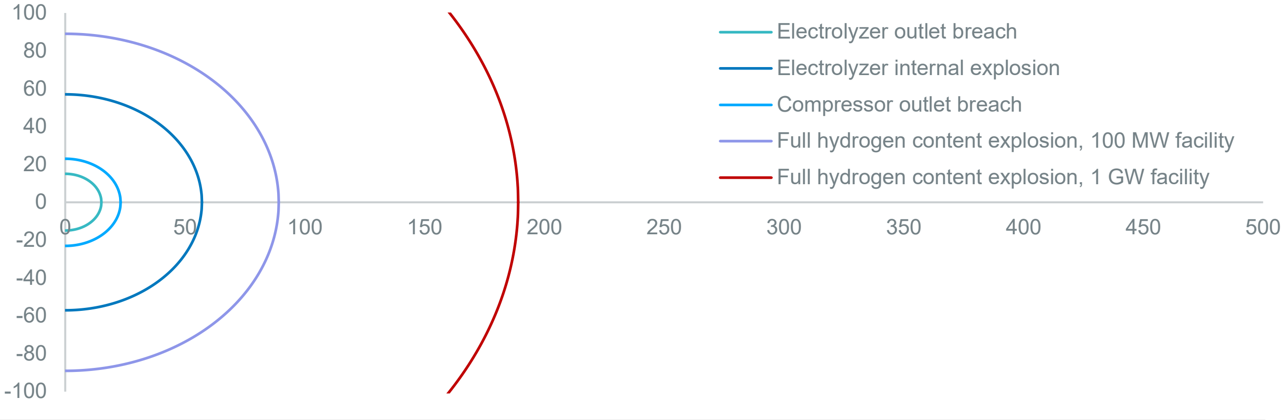
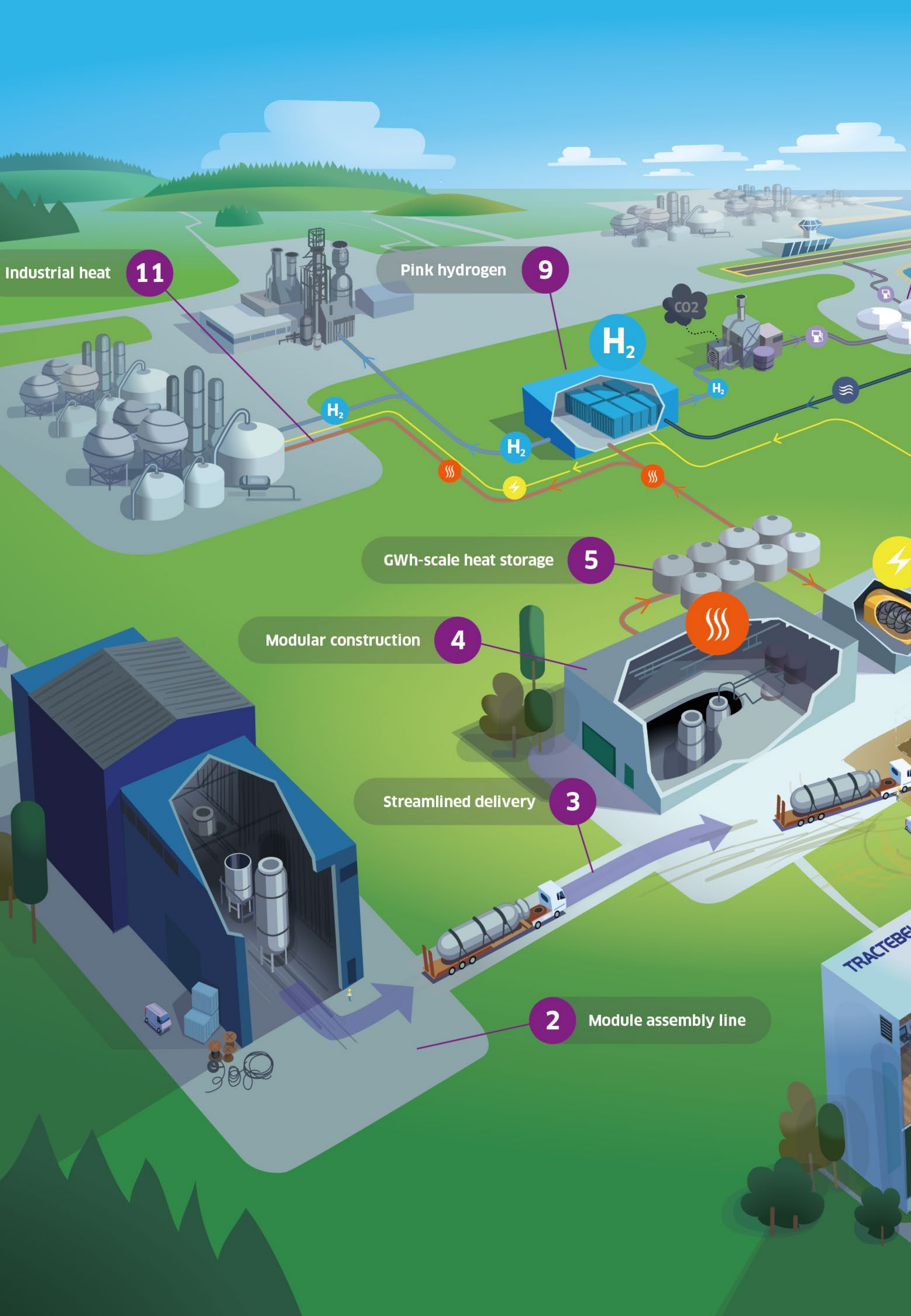


Figure 12 – H_2 safety analysis: reach for 160 mbar overpressure following explosion of accumulated H_2 [50]

The subsequent exclusion zones (about few hundreds meters) are compatible with our experience in heat and electricity transport solution. Hence, we argue that **eFuel Giga-factories** could be built in hubs where SMR are sited next to CO_2 reservoirs.



Industrial heat
11
Pink hydrogen
9
CO2
H_2
GWh-scale heat storage
5
Modular construction
4
Streamlined delivery
3
Module assembly line
2
TRACTEBEL

Tractebel's vision of tomorrow's multi-energy vectors ecosystems

Conclusion

The nuclear track record has been tarnished by the complications on the recent large scale new build projects. Cost overrun and schedule deviation, while abundantly fueled by stringent regulatory framework, also emerged from the inherent complexity of such objects. As a result, private investments have dried, leaving maintained only the projects carried by countries willing to perpetuate their domestic developments. Yet those projects are not enough to set a new course to the energy transition.

Similar testimony is to be found within the aviation industry, where flexible and lower scale planes with decentralized hubs are now the new standard. Likewise, the nuclear industry is defining its “new normal” with **simplified**, **standardized** and **smaller** modular reactors. Nevertheless, innovative designs will require enabling licensing frameworks to prevail.

Today what the SMR industry needs is a vision that will allow to reap the economic benefits of serial production by sparking a general momentum.

One imperative however remains: proving to investors that SMRs have incorporated lessons learned from Generation III new builds and can be built on time and on budget.

With built-in flexibility, SMRs can act both as the backbone of energy system and as the catalyst that will accelerate the deployment of renewables; the common goal being the phase-out of carbonated solution at an affordable cost. In a sense, renewables and nuclear: **just married**.

In fact, hardly any zero-carbon technologies economically meet the double criteria of: (1) **dispatchability**, imposed by downstream industrial processes (incl. electrolysis) and (2) geographical **independence**, allowing plants to be located next to existing industrial hubs. Hence, our vision is that SMRs will be at the core of integrated multi-energy vectors (steam, electrons and hydrogen) ecosystems.

A capable industrial landscape cannot simply be decreed, it must be built and nurtured over the years. In the meantime, extending the lifetime of existing nuclear reactors -by far the cheapest low-carbon alternative of all energy sources [51], is the ideal solution to maintain the current expertise.

For these reasons, Tractebel has placed at the core of its nuclear ambition to demonstrate the value of SMRs through real-world industrial projects. As an experienced and recognized actor in all the segments composing the complex energy system of tomorrow (industry, hydrogen, nuclear, renewables, grid and water), Tractebel considers itself ideally placed to become the system integrator of SMRs into their future landscape. To do so, we look forward to pilot project opportunities with interested parties around the world.

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