GEMINI+

The GEMINI+ project paves the way for an early deployment of industrial nuclear cogeneration in Europe

A European H2020 project

Dominique Hittner, Grzegorz Wrochna, Christoph Pohl, John Lillington, Michael Fütterer, Wojtek Brudek, Chloé Chavardes

D

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n°755478

A new class of modular HTGR?

- Modular HTGRs (up to ~ 600 MWth) satisfy only partly the IAEA definition of SMR "designed to generate electric power up to 300 MW, whose components and systems can be shop fabricated and then transported as modules to the sites…"
  - Power OK
  - Shop fabrication limited due to the large size of components, price to pay for small power density (which is an asset for safety)

- Recently small HTGR designs (< 200 MWth) for different applications
  - 3 HTGR designs are under CNSC Vendor Design Reviews (VDR) for addressing the energy needs of remote isolated sites in the North of Canada
  - Industrial process heat appears to be a new market for nuclear energy and the needs of industrial sites rarely exceed 200 MWth, e.g.
    - UK-AMR competition
    - Polish government initiative
    - GEMINI+ design complying with the needs of Polish industry → 165 MWth

Will such small HTGRs be designed as smaller copies of the biggest modular HTGRs, or will their design take advantage of their small size?

CNSC VDRs

- All 10 are SMRs
- 6 of them < 100 MWe
- 3 of the 6 are HTGRs

Vendor	Name of design and cooling type	Approximate electrical capacity (MW electrical)	Applied for	Review start date	Status
Terrestrial Energy Inc.	IMSR Integral Molten Salt Reactor	200	Phase 1	April 2016	Phase 1 complete
			Phase 2	December 2018	Phase 2 assessment in progress
NuScale Power, LLC	NuScale Integral Pressurized Water Reactor	50	Phase 2*	Pending early 2019	Service agreement under development
Ultra Safe Nuclear Corporation / Global First Power	MMR-5 and MMR-10 High Temperature Gas	5-10	Phase 1	December 2016	Completion expected October 2018
			Phase 2	Pending late 2018	PHASE 2 Service Agreement in place – Project start pending
Westinghouse Electric Company, LLC	eVinci Micro Reactor Solid core and heat pipes	Various outputs up to 25 MWe	Phase 2*	Pending early 2019	Service agreement under development
LeadCold Nuclear Inc.	SEALER Molten Lead	3	Phase 1	January 2017	Phase 1 on hold at vendor's request
Advanced Reactor Concepts Ltd.	ARC-100 Liquid Sodium	100	Phase 1	Fall 2017	Assessment in progress
URENCO	U-Battery High-Temperature Gas	4	Phase 1	To be determined	Service agreement under development
Moltex Energy	Moltex Energy Stable Salt Reactor Molten Salt	300	Series Phase 1 and 2	December 2017	Phase 1 assessment in progress
SMR, LLC. (A Holtec International Company)	SMR-160 Pressurized Light Water	160	Phase 1	July 2018	Assessment in progress
StarCore Nuclear	StarCore Module High-Temperature Gas	10	Series Phase 1 and 2	To be determined	Service agreement under development

GEMINI+

Notice

Advanced Modular Reactor (AMR) Feasibility and Development Project

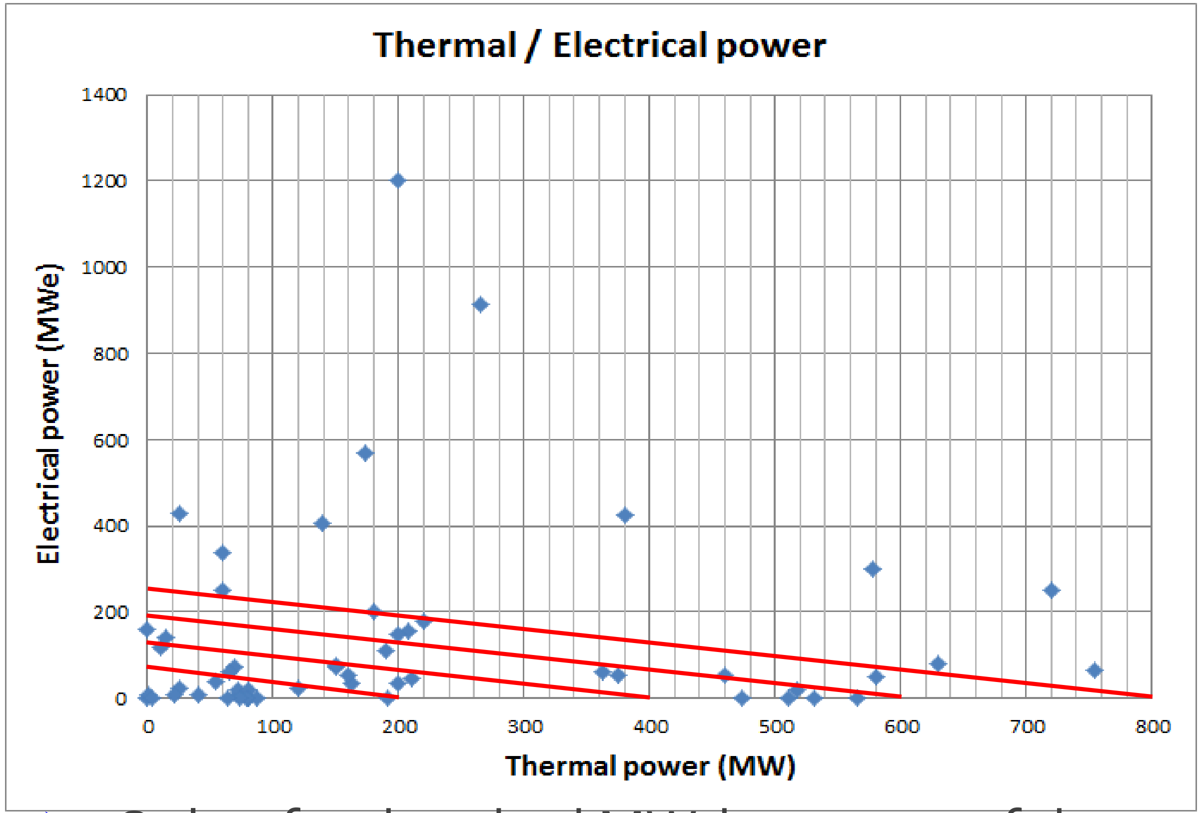
Details of the Advanced Modular Reactor Feasibility and Development Project.

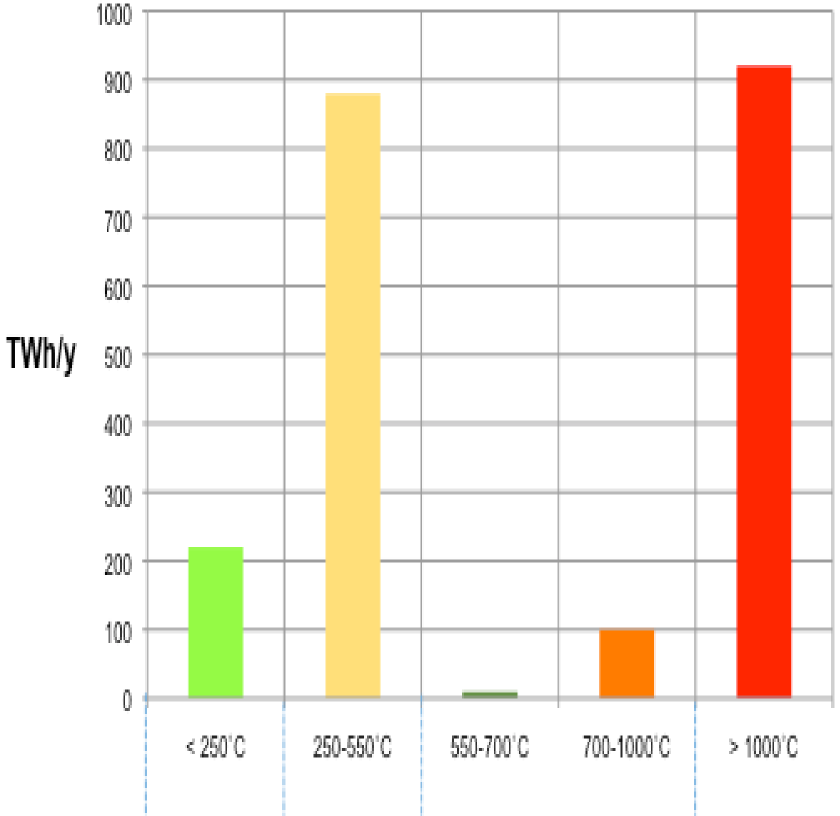
Published 5 September 2018
From: Department for Business, Energy & Industrial Strategy

BEIS is to invest up to £44 million in the Advanced Modular Reactor (AMR) Feasibility and Development (F&D) project. In this context Advanced Modular Reactor (AMRs) are defined as a broad group of advanced nuclear reactors. AMRs differ from conventional reactors, which use pressurised or boiling water for primary cooling. They aim to maximise the amount of off-site factory fabrication and can target:

- generating low cost electricity
- increased flexibility in delivering electricity to the grid
- increased functionality, such as the provision of heat output for domestic or industrial purposes, or facilitating the production of hydrogen
- alternative applications that may generate additional revenue or economic growth

The European market of industrial cogeneration





- Only a few hundred MWth on most of the industrial sites
- Most of the industrial processes require heat > 250˚C

✧ ***Not a niche market: ~ same size as electricity market***

Expected additional benefits for small power modular HTGRs

To take advantages of the expected assets of SMRs

- Modular manufacturing and construction
  - Integration of components into modules fully manufactured and commissioned in the workshop
  - Series effect in manufacturing
  - Time for site work (construction and commissioning) minimised
- Possible simplifications in the design
  - Small power HTGRs already benefit from the design simplifications of modular HTGRs (reduced number of systems and less safety classified components)
  - Possibility to find additional simplifications similar to those already considered for other SMRs
    e.g. in NUSCALE design
    - Already accepted by USNRC: The suppression of safety classified power sources
    - Still in discussion: absence of need for redundancy and diversity in the control rod system

The GEMINI+ project

- Context
  - ➢ The claim of the Polish government to develop an HTGR system for providing process steam to its industry
  - ➢ The Nuclear Cogeneration Industrial Initiative (NC2I) is grouping at European level nuclear industry and R&D organisations supporting application of nuclear energy for industrial process heat supply
  - ➢ International cooperation between NC2I, the US NGNP Industry Alliance, JAEA and KAERI

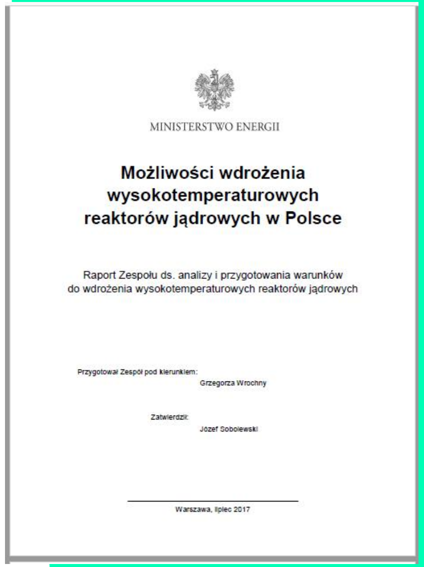
⟹The project GEMINI+, proposed by NC2I in Euratom H2020 programme, has been selected for funding

- ➢ 3 years, 27 partners from EU (industry, R&D, TSO), US, Japan & Korea


MINISTERSTWO ROZWOJU

STRATEGIA NA RZECZ ODPOWIEDZIALNEGO ROZWOJU *projekt do konsultacji społecznych*

WARSZAWA 2016


MINISTERSTWO ENERGII

Możliwości wdrożenia wysokotemperaturowych reaktorów jądrowych w Polsce

Raport Zespołu ds. analizy i przygotowania warunków do wdrożenia wysokotemperaturowych reaktorów jądrowych

Przygotował Zespół pod kierunkiem:
Grzegorza Wrochny

Zatwierdził:
Józef Sobolewski

Warszawa, lipiec 2017

Objectives of the GEMINI+ project

- Developing the design basis of a nuclear plant for process heat needs of Polish / European industry that can become competitive with fossil fuel-fired plants in the context of penalties on CO_2 emissions, thanks to:
  - Possible design simplifications due to small size
  - Use of modular manufacturing and construction techniques
  - Design standardisation in spite of versatile needs of industrial applications
- Proposing a licensing framework for such a nuclear system and its coupling with industrial process heat applications
- Preparing a full scale demonstration (nuclear + coupling with industrial processes) in Poland

GEMINI+

Main assumptions of GEMINI+ design

- To use as much as possible proven technologies to be able to develop a first generation of nuclear systems for industrial process heat supply ASAP
  - Reactor operating temperature ≤ ~ 750˚C
  - Heat exchange with steam to extract the heat from the reactor
- To look for innovation as long as
  - It can bring benefits in terms of cost or safety
  - It does not introduce additional risks and delays
- To endeavour to converge with design options of the NGNP reference design, as long as the requirements of European customers and regulators don’t make it impossible

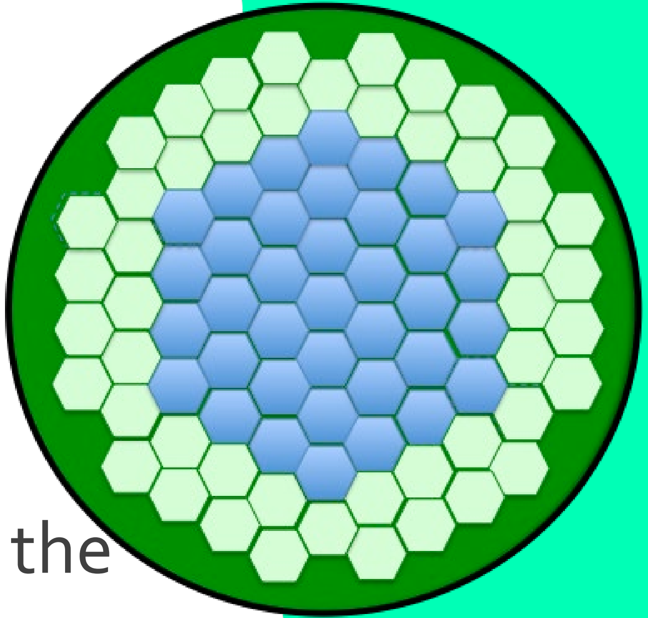
  ⇒ To be able to share development efforts and risks

First design options of GEMINI+ system: Core design

- Block type core ← *Higher power density (compactness)*
- TRISO fuel

} + *Common design with international partners*

- Cylindrical core design ← *compactness*
- Fully passive intrinsic safety: decay heat release from the core by making systematic use of intrinsic physical properties of the fuel and reactor:
  - Strongly negative temperature coefficient
  - Integrity of fuel (TRISO particles) up to > 1600˚C
  - Thermal conduction and radiative heat transfer from the fuel to the RPV
  - Large thermal inertia of the core
  - Chemical inertia of the coolant (He)



First design options of GEMINI+ system: Interface with end-users (1)

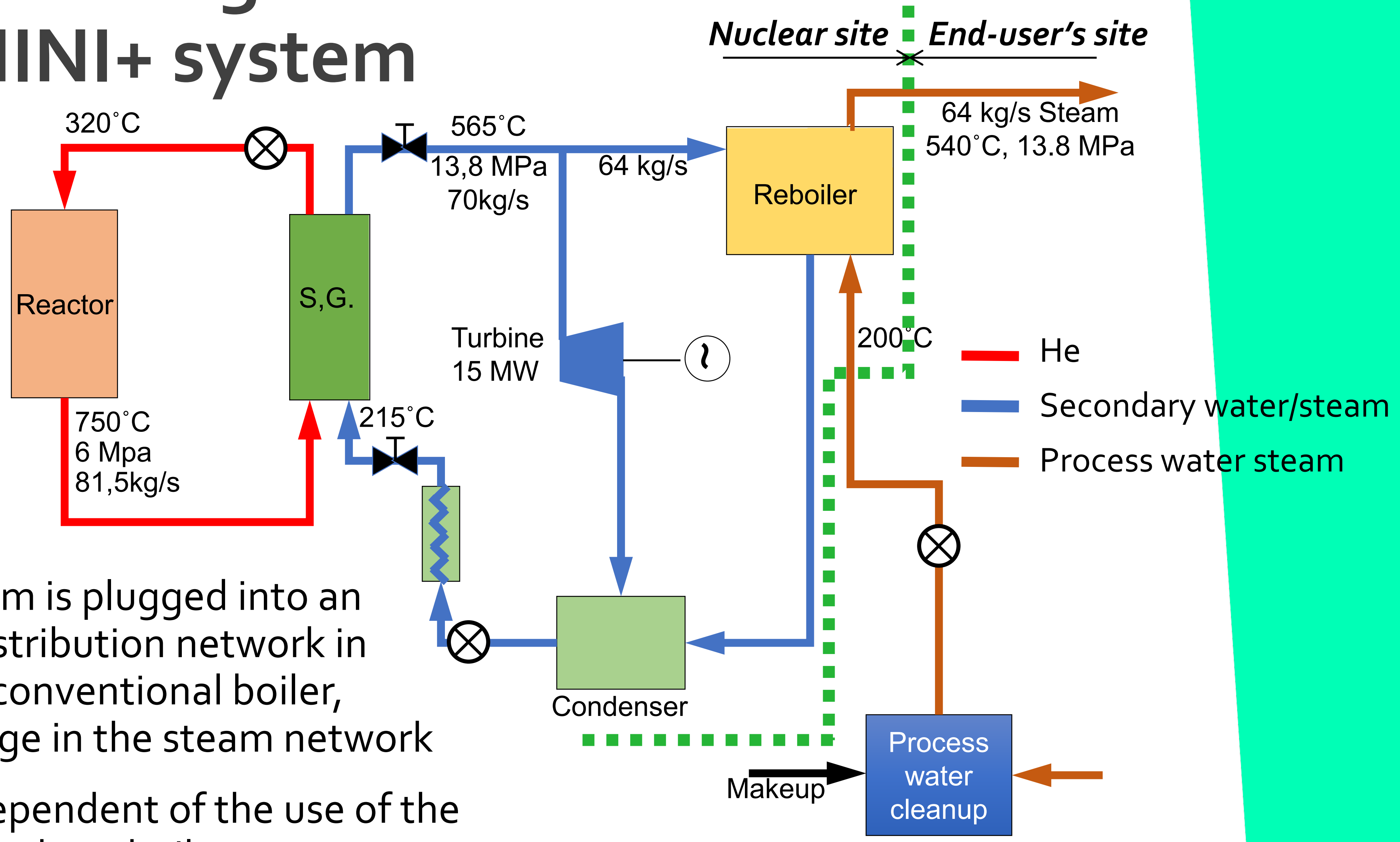
- The first market targeted is the market of sites equipped with existing steam distribution networks => interface designed for connecting with such steam distribution network
- The GEMINI+ system operates as a boiler, providing only steam to end-users, no electricity. If end users need electricity, they can use <u>on their site</u> part of the steam supply to drive a turbo-generator (often already existing on end-users' sites)
  - A possible turbo-generator (as well as all the steam distribution network) is outside of the fence of the nuclear plant and is not subject to nuclear licensing
  - The characteristics of the steam output required by Polish industry are 64 kg/s steam, 540°C, 13.8 Mpa → 165 MWth

First design options of GEMINI+ system: Interface with end-users (2)

- To avoid risks of radio-contamination of end users' facilities, the reactor steam generator cannot directly supply its steam to the steam distribution network
  - ⇒ Intermediate secondary circuit with water / steam heat carrier
  - ⇒ A steam generator is the interface with the primary circuit and a reboiler is the interface with the steam distribution network
- No electricity generation in the secondary circuit, except for house load of the nuclear plant, which, for availability reasons, should be kept independently of possible fast variations of load on the application site
  - ⇒ A small turbo-generator of ~ 15 MWth supplies power for house load
  - ⇒ Safety classification is not required for this turbo-generator, as no power is required to maintain the reactor in safe conditions

⇒Standard secondary system, independently of applications

General configuration of GEMINI+ system



- The nuclear system is plugged into an existing steam distribution network in substitution to a conventional boiler, without any change in the steam network
- The design is independent of the use of the steam supplied by the reboiler

Potential for innovations (1)

- Advanced high temperature instrumentation to
  - Minimise margins du to uncertainties => improve performance
  - Maximise the benefit of the demonstration for future commercial plants (optimisation, licensing)
- Advanced materials for limited applications (control rod cladding, reactor internals, reactor vessel support…) for design simplification, improved lifetime, safety benefit…
- Integration of GEMINI+ systems in an electric grid with a large fraction of variable renewables for stabilizing the grid, thanks to its thermal inertia and its potential for polygeneration, while keeping the reactors operating at full power.

Potential for innovations (2)

- Innovation in industrial processes for adapting them to the temperature range accessible with HTGR:
  - Hydrogen production with GEMINI+ system might be essential for penetration in the industrial market, as many industries that don't need only process heat but also hydrogen, expect a global offer
  - For hydrogen production and other possible applications in the range 550-650°C, an evolution of the coupling between the reactor and the applications might be necessary

Conclusion

- The main challenge for SMRs is to beat the scale effect and find ways to reach competitiveness
- For taking up this challenge, SMR designers endeavour to rely on
  - Simplification
  - Standardization
  - Flexibility
  - Systematic use of modular manufacturing and construction techniques
- GEMINI+ is following such an approach with a small modular HTGR meant at addressing the very versatile process heat needs of industry.

Thank you

Get in touch for more information!

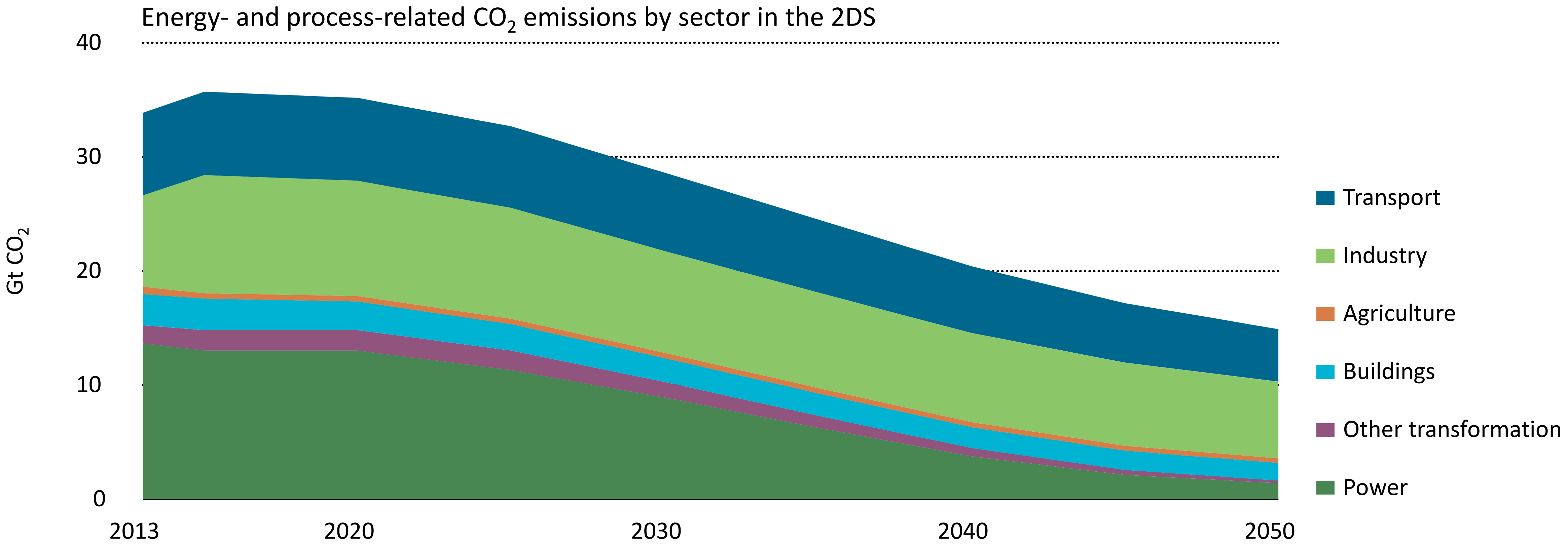
More information on the GEMINI+ website: **www.gemini-initiative.com**

Project coordinator: Grzegorz Wrochna, NCBJ
Contact us: contact@gemini-initiative.eu

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n°755478

GEMINI+

From 2 degrees to "well-below 2 degrees"



Industry and transport accounted for 45% of direct CO2 emissions in 2013, but they are responsible for 75% of the remaining emissions in the 2DS in 2050.

Source: Energy Technology Perspectives, 2016