Industrial applications of high temperature reactors and the H2020 GEMINI+ project

SNETP Forum

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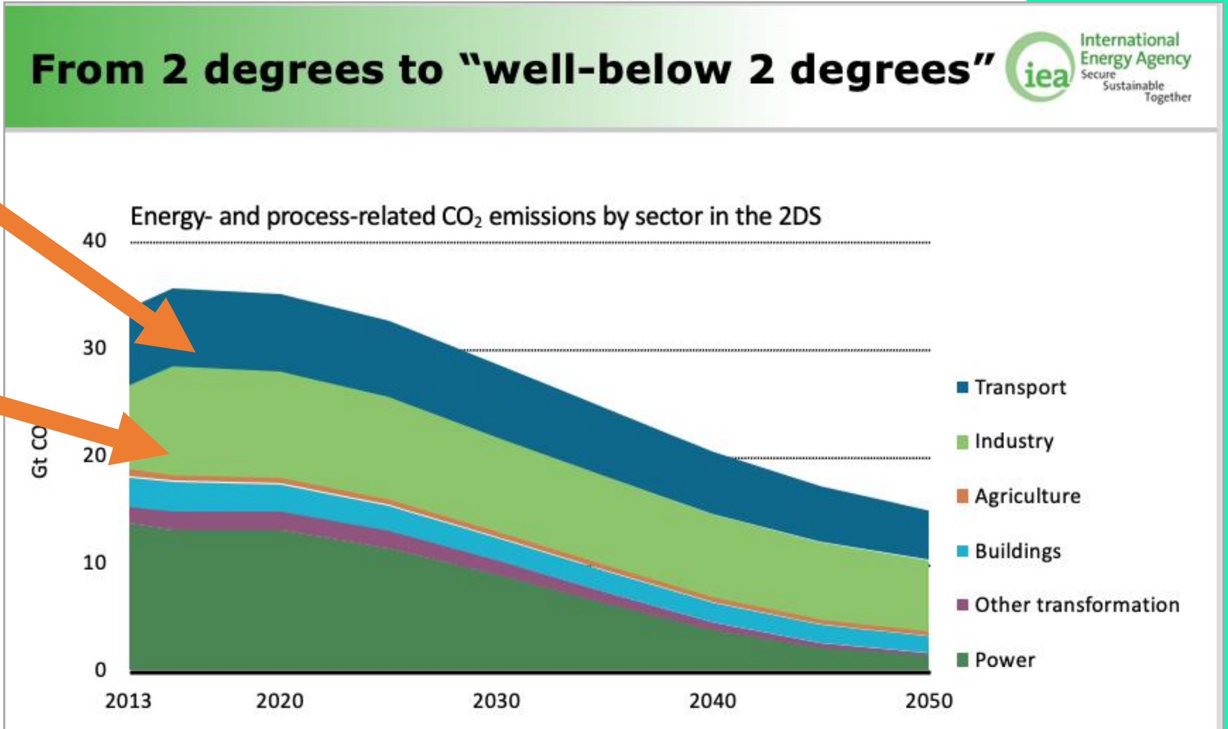
Industry is a major contributor to CO_2 emissions

Use of hydrogen and electricity can reduce these emissions

Process heat + emissions of the processes

Increase of the use of hydrogen can reduce these emissions



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

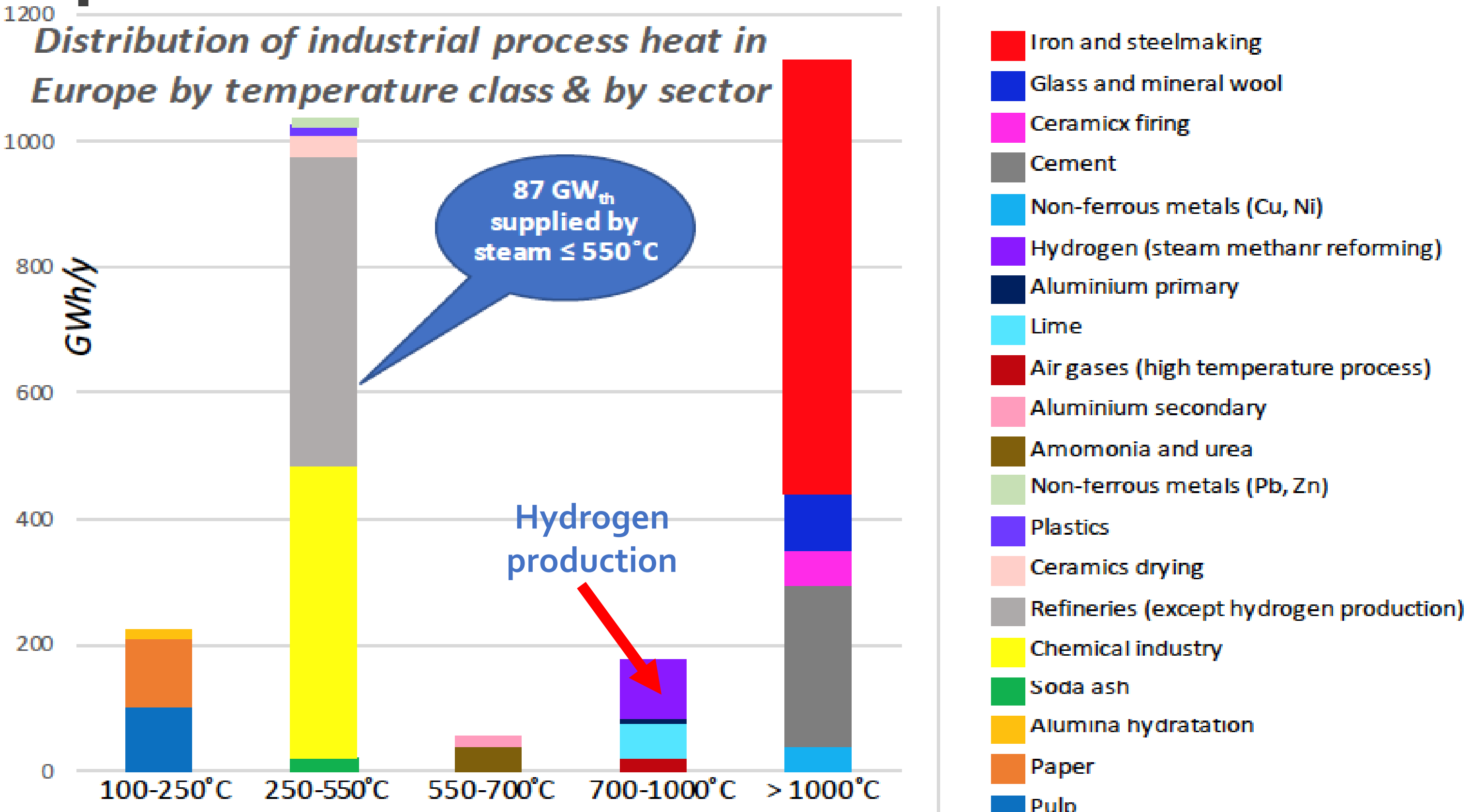
Source Energy Technology Perspectives, 2016

- **While many solutions are already implemented for decarbonising electricity generation (renewables, nuclear), no CO_2 free solution exists for industrial emissions.**
- **To have a real impact before 2050, any solution must be deployable very soon and therefore use sufficiently mature technologies**
- **H_2 can play a key role for reducing CO_2 emissions, but its production must be CO_2 free**

The GEMINI+ project

- Euratom project of H2020, 3,5 years, 26 partners (including non-European partn,ers, JAEA, KAERI, the NGNP Industry Alliance)
- Coordinated by NCBJ (Poland)
- Objective: to propose a nuclear contribution for reducing the CO_2 emissions of industry
    - ✓ To propose the main options of a design: modular HTGR chosen because of
        - Temperature range
        - Maturity of the technology
    - ✓ To propose the basis of a licensing framework (different type of reactor and different use of the reactor)
    - ✓ To study the feasibility of an early demonstration

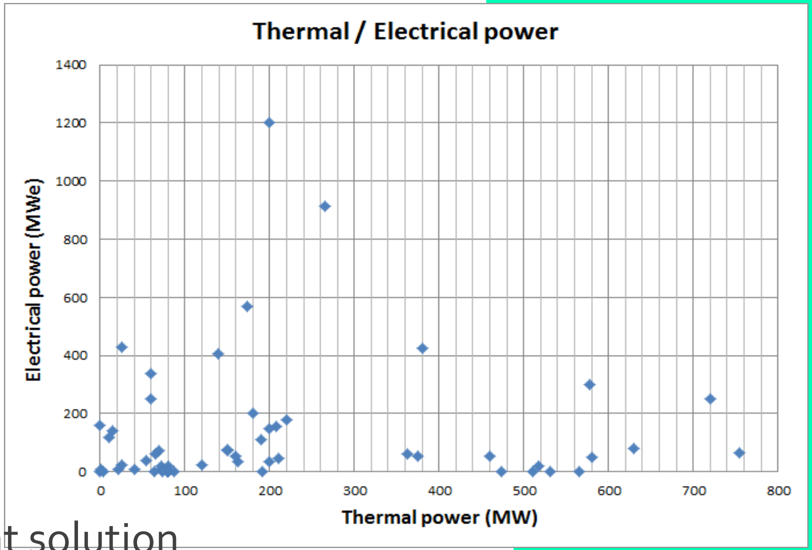
The European market of industrial process heat



From "Market study on energy usage in European heat intensive industries" EUROPAIRS Euratom project FP7

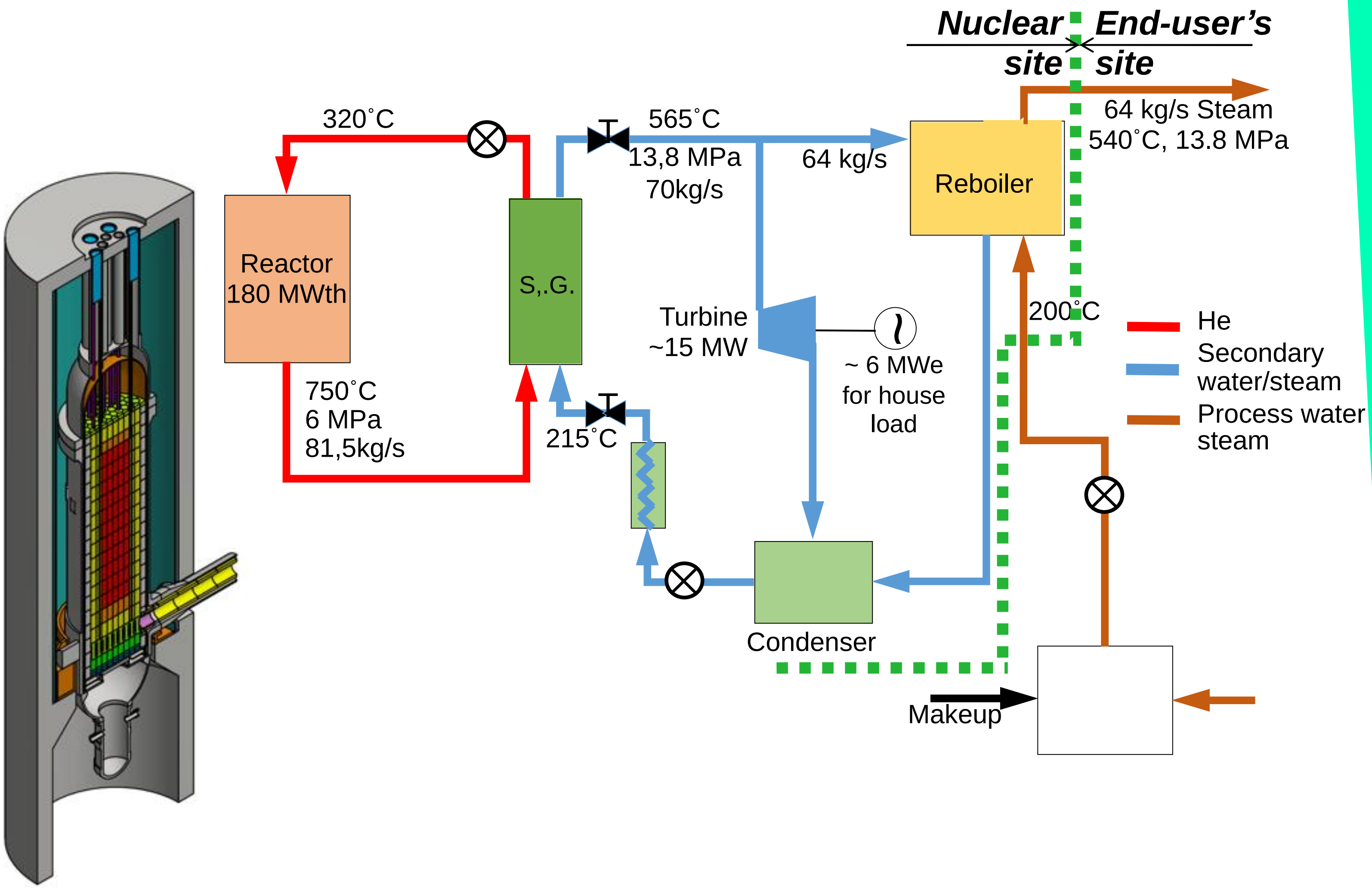
⇒ **First target: chemical and petrochemical sites with steam networks already in place**

Industrial requirements



- Flexibility
  - ✓ Power
  - ✓ Sharing heat/electricity
  - ✓ Load following
- Cost competitiveness with gas
  - ✓ Making use of the scale effect is not the right solution
  - ✓ Standardisation: challenge for compatibility with flexibility
  - ✓ Use of modular manufacturing and construction techniques
- No mutual perturbation in operation of the nuclear plant and the industrial site
  - ✓ Safety aspects
    - No radiocontamination of industrial facilities, workers and products
    - To impact of nuclear regulations on the industrial site
    - No impact of industrial accidents on the safety of the nuclear plant
  - ✓ High availability of the nuclear plant
  - ✓ No modification of the industrial infrastructure: in particular use of existing steam network ⇒ "plug-in" solution

The design basis of GEMINI+, a proposed solution

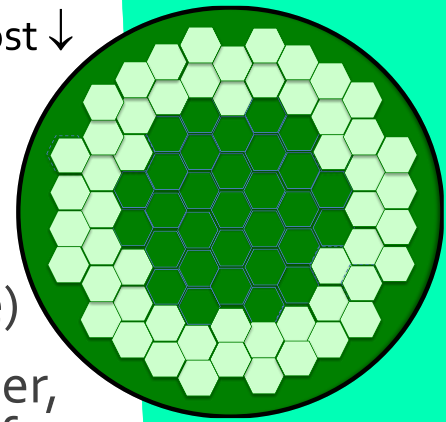


G+ solution for industrial cogeneration

- Block type fuel design with cylindrical core
  - ⇒ More compact
- Small power: 165 MW_{th} delivered to the customer (reactor power 180 MW_{th})

⇒ • Modular manufacturing & construction facilitated ⇒ cost ↓
• Transportable by road

  - ⇒ Flexibility to adapt to variable industry needs ⇒ market ↑
- Uses mature technology (< 800°C, secondary steam cycle)
- No electricity supplied by the nuclear plant to the customer, only steam, provided to the steam distribution network. If electricity needed, generation on the industrial site, using part of the steam of the steam network
  - ⇒ Standardised plug-in solution
  - ⇒ Use of non-nuclear industrial turbogenerator ⇒ cost ↓
- Reactor and industrial steam network separated by an intermediate water/steam circuit
  - ⇒ No radio-contamination of the industrial site



Prospects for demonstration in Poland

- Governmental interest for HTGR replacing localcoal and imported natural gas for heat supply to industry
  - ✓ Strategy for Responsible Development (2017):
    "preparation for the construction of the first HTR supplying technological heat for industrial installation"
  - ✓ The Ministry of Development introduced HTGR in the list of National Smart Specialisations (2019)
  - ✓ The new version of the National Energy Programme (PEP 2040) includes the HTGR development
- A programme of development of a small experimental reactor (EUTHER) on NCBJ site for demonstration of the technology presently under preparation
- Partnership with the Nuclear Cogeneration Initiative (NC2I) in the frame of the GEMINI+ project, which aligned its design work on the needs of Polish industry
  - ⇒ GEMINI+ design option is the base on which the Polish demonstration project will start its design work

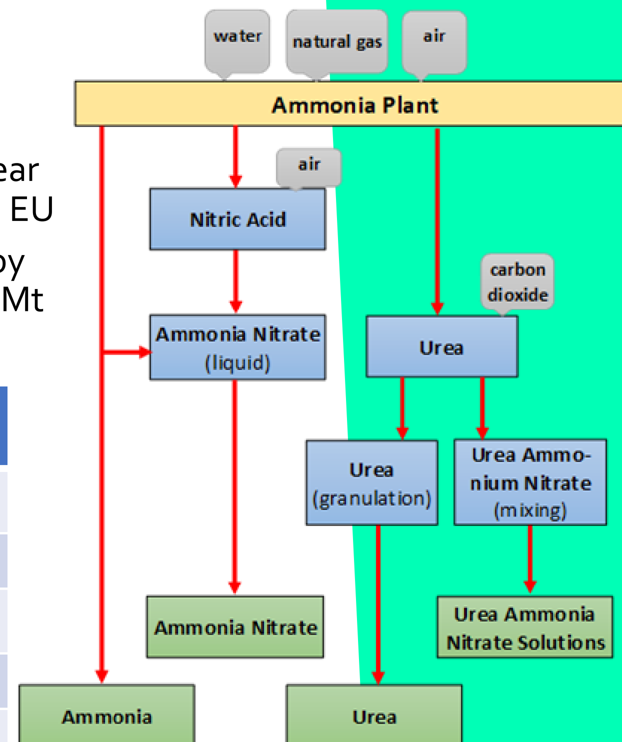
Next step: "plug-in" industrial deployment

- Substitute HTGR plants to fossil fuel-fired boilers or cogeneration plants feeding existing steam networks on chemical sites with no change in the industrial infrastructure
- The implementation can be evolutive
  - ✓ e.g. fertiliser production
    - 1/3 heat production emitted by NG burning
    - 2/3 the process itself

1st step: replace NG burning by nuclear heat: 8 Mt CO_2 emission saved in the EU

2nd step: + replace NG as feedstock by CO_2 free H_2 produced by nuclear: 24 Mt CO_2 emission saved in the EU

Type of product, chemical formula	Reaction	Process parameters		Net energy efficiency (average with BAT**) [GJ/t of product]	Heat demand [% of total energy]
		T [°C]	p [MPa]		
Ammonia (Am), NH_3	Haber-Bosch process $N_2 + 3H_2 \rightarrow 2NH_3$	(350 – 500)*	(10 – 25)*	~37 / 29 [10]	90
Urea (U), $CO(NH_2)_2$	$2NH_3 + CO_2 \rightarrow NH_2COONH_4 \rightarrow H_2O + NH_2CONH_2$	190	14 - 17	3.7 /3.2 [11]	9
Ammonium nitrate (AN), NH_4NO_3	$HNO_3 + NH_3 \rightarrow NH_4NO_3$	100 - 180	~0.4	0.5 / 0 [12]	1
Urea ammonium nitrate (UAN)	mixing (U + AN)	ambient	0.1	0.04 / 0 [11]	~0
Nitric acid (NA), HNO_3	Ostwald Process (not stoichiometric here) $NH_3+O_2 \rightarrow NO_x(N_2O)+H_2O \rightarrow NO+O_2 \rightarrow NO_2+H_2O \rightarrow HNO_3 + NO$	~230	1	-2.3 / -3.1 [13]	exothermic reaction



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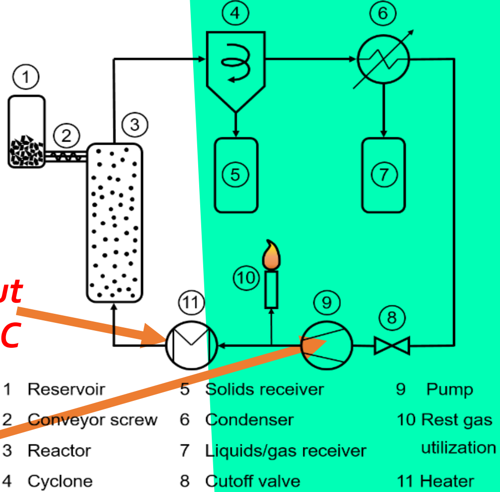
Longer-term: widening the market

- Pre-heating of very high temperature processes
- Evolution of existing very high temperature processes
  - ✓ e.g. steam-methane reforming with continuous extraction of H_2 through a membrane: it can have the same efficiency at 600°C than in a conventional reformer at 950°C, proven at the level of pilot plant
- New processes
  - ✓ e.g. Plastics Recycling with Polymer Cracking Process
  - ✓ CO_2 free hydrogen production
- VHTR



Polymeethyl-Methacrylate (PMMA) recycling

- Production emits 3.7-4.8 kg CO2 per kg of PMMA
  ➔ PMMA recycling saves much CO2

➔1 GEMINI+ reactor could process 120 t/h PMMA waste.

➔Triple the currently recycled PMMA waste in the EU

➔Save 3-4 Mt CO_2/yr compared to virgin PMMA

CO_2 free hydrogen production

Process	Required T_{max} at process	Efficiency	Remarks
Low T alkaline electrolysis	N/A	32%	And even 28% if electricity produced by LWR
Copper-chlorine thermochemical process	530˚C	43%	Needs heat + electricity Plug-in possible
High T Steam Electrolysis	650-850˚C	50%	Needs heat + electricity
Suphur-iodine thermochemical process	800-900˚C	35-50%	Needs heat
Steam-Methane Reforming	950˚C	65%	Still 7,3t CO_2/t H_2, even with heat provided by HTGR

- Use of GEMINI+ reactor is feasible with possibly different techniques for additional heat-up techniques beyond 550°C

⇒Objective for a GEMINI+ follow-up project: assess GEMINI+ reactor coupling with different H_2 production processes

- ✓ Technical feasibility
- ✓ Safety
- ✓ Economic competitiveness

GEMINI+

Conclusion

- HTGR provides a unique opportunity to get CO_2 free massive process heat supply. The GEMINI+ system proposes a solution to implement this opportunity, while
  - ✓ Complying with the flexibility expected by industry
  - ✓ Being competitive with natural gas
- This solution is sufficiently mature to be deployed early enough to provide a contribution to the Green Deal
- First a “plug-in” deployment, using existing industrial infrastructures is considered, but the technology has a large potential for extending to a much wider market
- In particular, with HTGR, massive CO_2 free hydrogen production is possible, providing a major contribution to decarbonisation of industry and transport, in addition to CO_2 free process heat supply.
- Cooperation with process heat user industries is necessary to optimise the matching of the nuclear heat source with its industrial applications

Thank you

Get in touch for more information!

All of the reports of the project will be available for download on the GEMINI+ website: **www.gemini-initiative.com**

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