28 January 2019

HTGR for heat market
Plans in Poland

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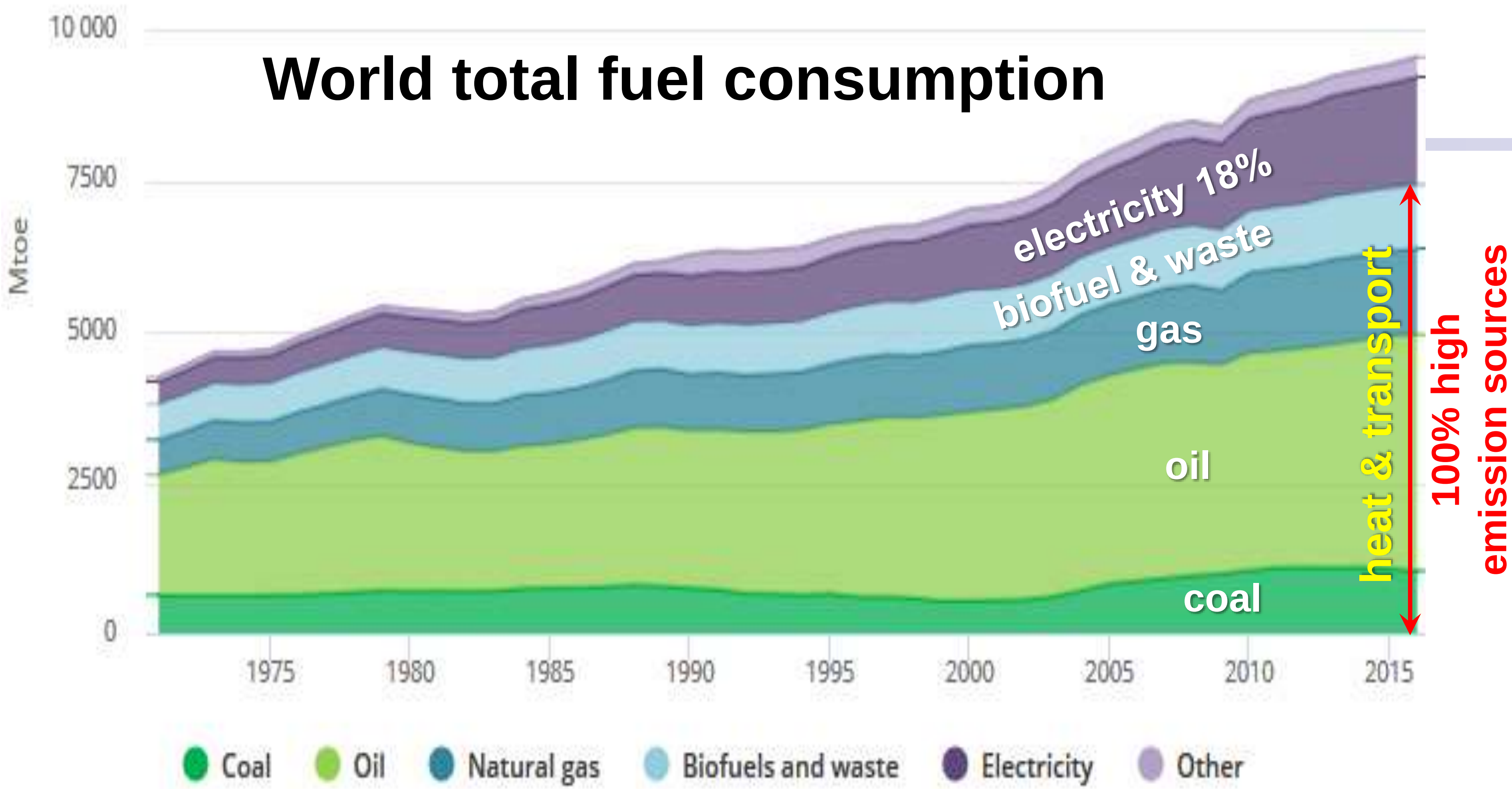
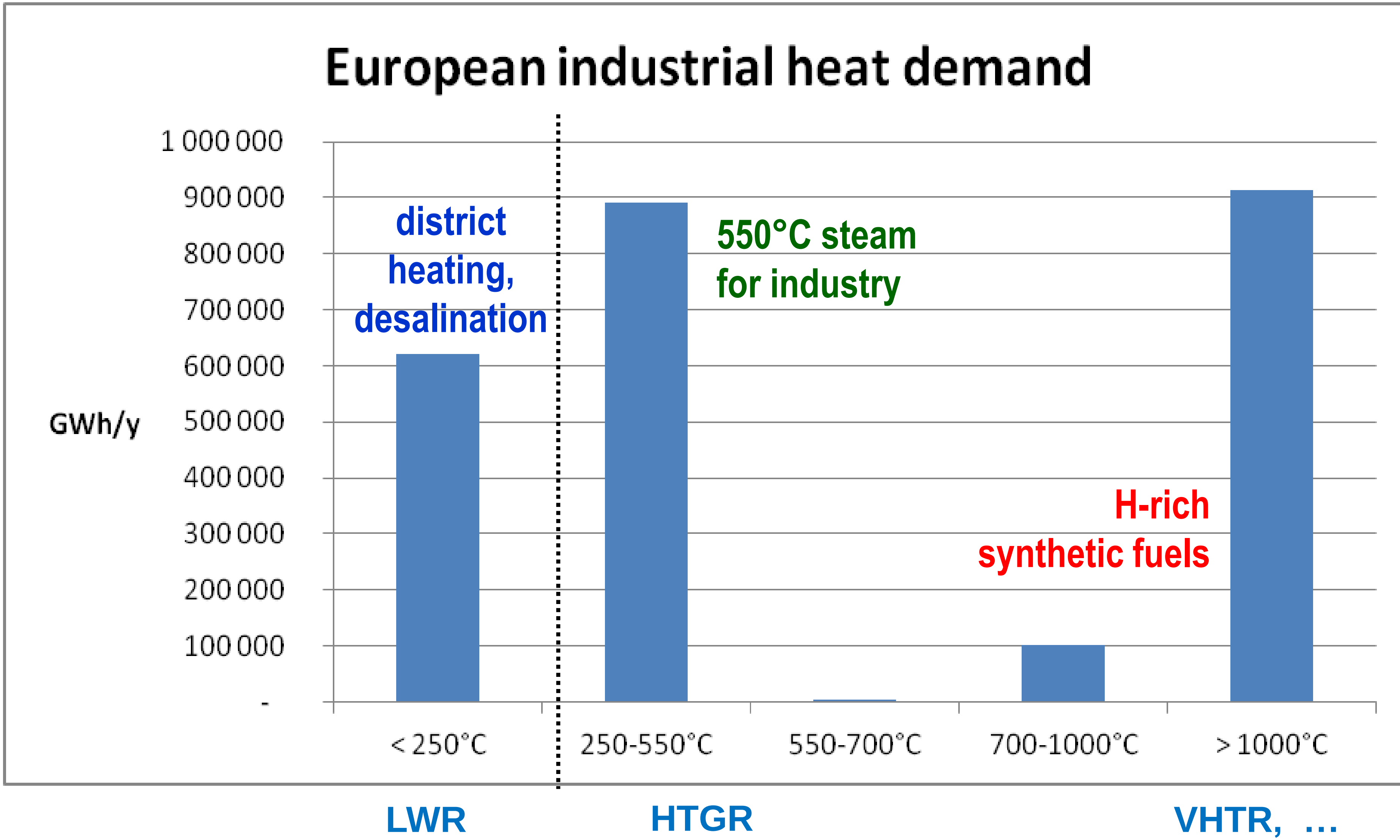
World total fuel consumption



- **Reducing to zero emission from electricity production would solve only 1/6 of the problem**
- **Industry needs high temperature heat (>500°C)**
- **Synthetic H-rich fuels for electric cars with fuel cells is the future of transport (>700°C heat needed to produce them)**

Heat demand for different temperatures



Source: EUROPAIRS study on the European industrial heat market

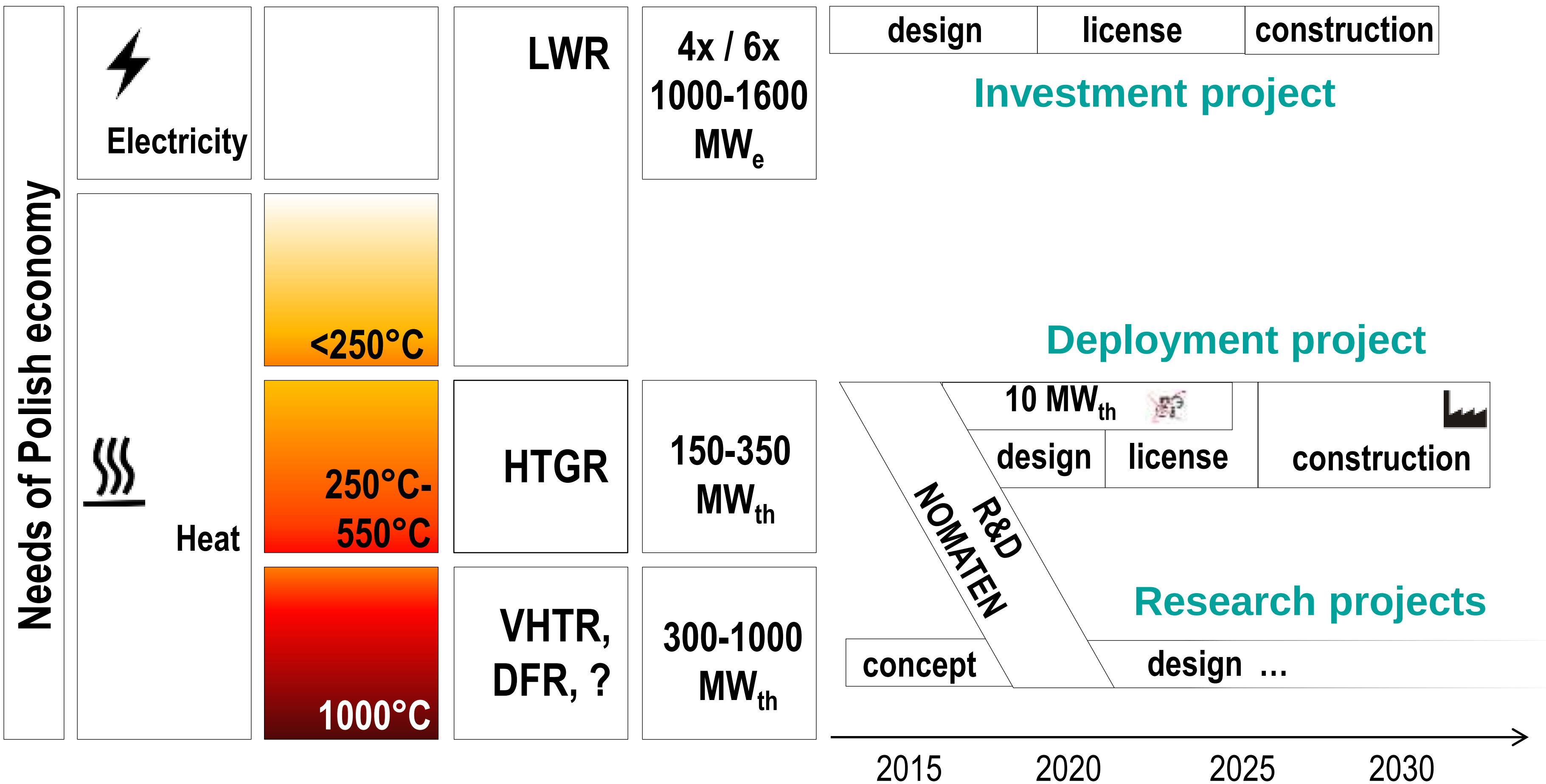
HTGR for Poland

- **13 largest chemical plants have installed today 6500MW of heat at T=400-550°C**
- **They use 200 TJ / year, equivalent to burning of >5 mln t of natural gas or oil**
- **165 MW_{th} reactor size fits all the needs**
- **Estimated market by 2050 PL: 10-20, EU:100-200, world:1000-2000**

Plant	boilers	MW
ZE PKN Orlen S.A.Płock	8	2140
Arcelor Mittal Poland S.A.	8	1273
Zakłady Azotowe "Puławy" S.A.	5	850
Zakłady Azotowe ANWIL SA	3	580
Zakłady Chemiczne "Police" S.A.	8	566
Energetyka Dwory	5	538
International Paper - Kwidzyn	5	538
Grupa LOTOS S.A. Gdańsk	4	518
ZAK S.A. Kędzierzyn	6	474
Zakl. Azotowe w Tarnowie Moscicach S.A.	4	430
MICHELIN POLSKA S.A.	9	384
PCC Rokita SA	7	368
MONDI ŚWIECIE S.A.	3	313

- **Possible replacement of 200 MW_e cogeneration units in future**
- **Increasing interest in T=500-1000°C for H_2 production**

Nuclear Roadmap of Poland



HTGR's are not to replace LWR's! They address different market niche.

HTGR deployment in Poland

Government on 14 February 2017 published
„Strategy for responsible development".
- the governmental plan for Polish economy grow

List of energy actions contains:

- **Preparation of HTR deployment for industrial heat production in cogeneration, using industrial & scientific potential of Poland.**
- **Support for Polish R&D on materials for gen. IV reactors.**

„National Smart Specializations" is a list of areas with priority to EU funds. Recent update (Dec. 2018) contains:

- **„Design and implementation of high temperature nuclear reactor technology for production of industrial heat"**
- **„Production of process heat for industry and cogeneration using high temperature nuclear reactors".**

Draft of „Energy Policy of Poland till 2040" (Nov. 2018) mentions HTGR as a potential heat sorce for industry.

HTGR deployment in Poland

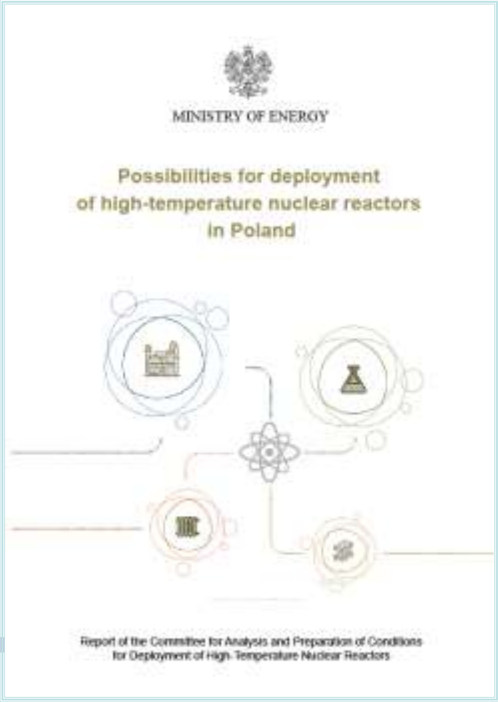
Minister of Energy in July 2016 appointed
„Committee for deployment of high temperature reactors".

Chairman: G.Wrochna

Members from:

- **Nuclear R&D: NCBJ**
- **Engineering: Energoprojekt, Prochem**
- **End-users: Azoty, Orlen, Enea, Tauron, KGHM**

Associates: PAA (regulator), NCBR (R&D funding agency), PKO BP (bank)



Report published January 2018: tiny.cc/htr-pl

Minister of Energy has given a green light to proceede with implementation of the conclusions.

ME, IChTJ & NCBJ obtained 16 mln PLN for preparatory project GOSPOSTRATEG-HTR

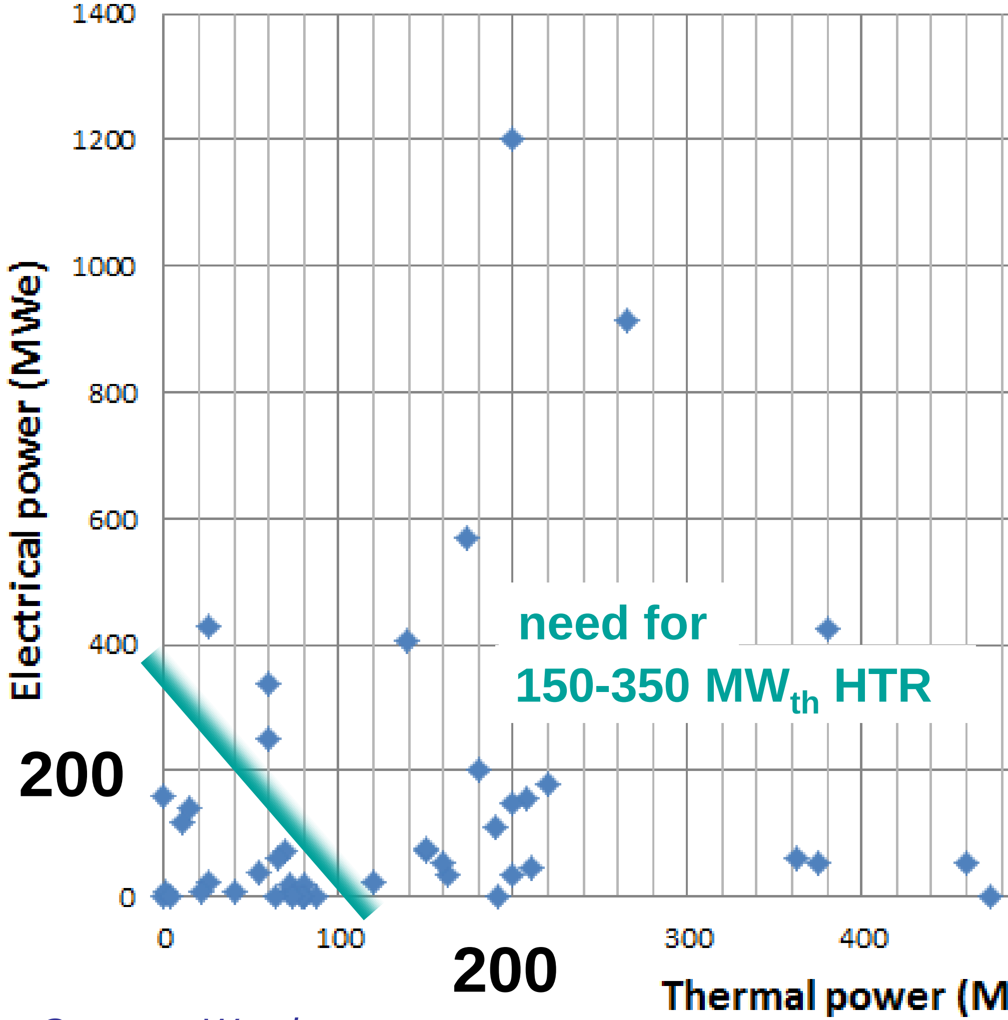
Conclusions of the HTR Committee

In agreement with other international studies:

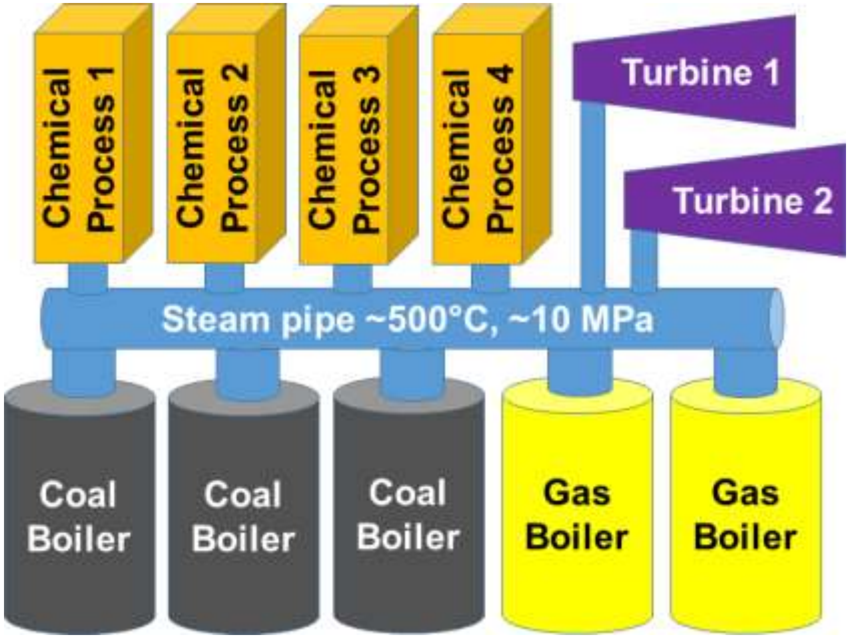
- **SNETP - Sustainable Nuclear Energy Technology Platform „Deployment Strategy", 2015, www.snetp.eu/publications**
- **OECD Nuclear Enery Agency „Nuclear Innovations 2050", www.oecd-nea.org/ndd/ni2050**
- **IAEA - International Atomic Energy Agency "Industrial Applications of Nuclear Energy", IAEA Nuclear Energy Series No. NP-T-4.3, 2017.**
- **UK gov. (BEIS): "Small Modular Reactors: Techno-Economic Assessment", 2017 www.gov.uk/government/publications/small-modular-reactors-techno-economic-assessment**

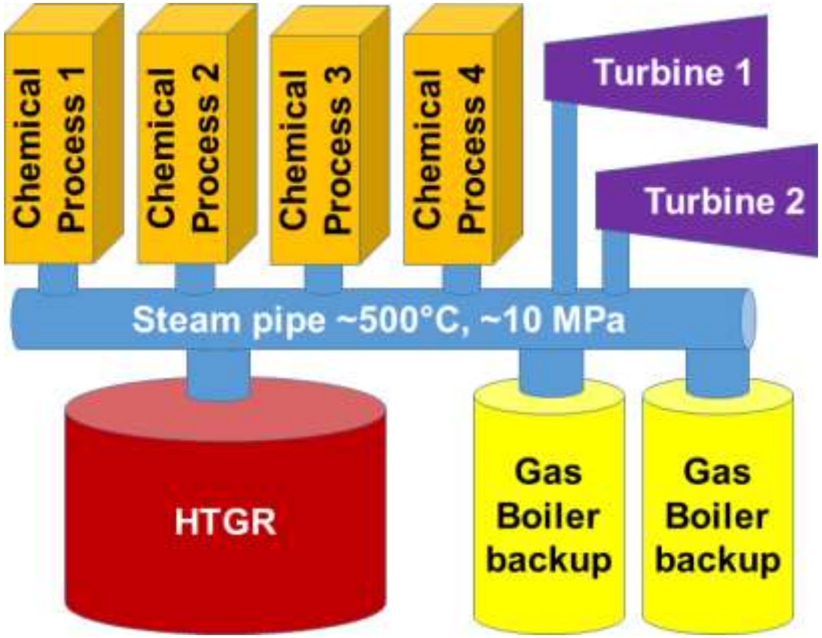
End-user needs

- Sample of >130 sites in Europe
- Mostly chemical industries



Feedback from industry





- **Several sites use ~500°C steam networks**
- **Need to exchange old boilers with HTGR**
- **Electric island already there**
- **HTGR parameters matching standard boilers:**

540°C, 13.4 MPa, 165 MW_{th}*, 230 t/h

***) +10% for internal use**

Cost estimate

1$ ≈ 3.5 PLN
1€ ≈ 4.2 PLN

- **The cost of design and general license: ~ 500 million PLN**
  - **It virtually does not depend on the reactor power**
- **The construction cost was calculated by scaling the costs of larger models down to 165 MW$_{th}$:**

Oryginal power [MW$_{th}$]	**600**	**2×250**	**350**	**165**
Type	prismatic block			pebbles
Cost 165 MW$_{th}$ [M PLN]	2566	1995	1519	1358

- **The cost of HTGR of a block type should be 5-10% lower than the HTGR of a pebbled type**
- **Reducing the power may enable breaking technological barriers and result in lower cost,**
  - **e.g. a tank made entirely in a steel mill by rolling**
- **A middle option, close to PLN 2000 million, was adopted for economic analyzes**
  - **The dispersion of PLN 600 million is a measure of the uncertainty of estimation**
- **The construction cost includes 10% of the design cost**

Coal, gas & HTGR economy

Coal & gas boilers compared to HTGR 165 MW_{th},
230 t/h of steam 540°C, 13.8 MPa.
Current fuel prices. 30/60 years boiler/HTGR lifetime.
For HTGR: 15 idle days/year, 80% of power used.
Design cost covered by the first 10 HTGR's.

1$ ≈ 3.7 PLN
1€ ≈ 4.2 PLN
F-NPV: financial
E-NPV: economic

	Steam cost LCOE M PLN /GJ				**F-NPV** M PLN		**E-NPV** M PLN	
Discount rate	8%		4%		8%	4%	8%	4%
CO_2 emission cost /t	20€	50€	20€	50€	50€		50€	
Coal boiler OP-230	27	37	25	35	158	619	-91	-119
Gas boiler OG-230	37	43	36	42	20	144	4	98
HTGR 165 MW	55	55	36	36	-268	538	-268	538

Cost of steam from HTGR could be comparable to that from coal/gas
Largest uncertainties:
discount rate, CO_2 emission cost, coal & gas price & availability.

Why HTGR not used widely?

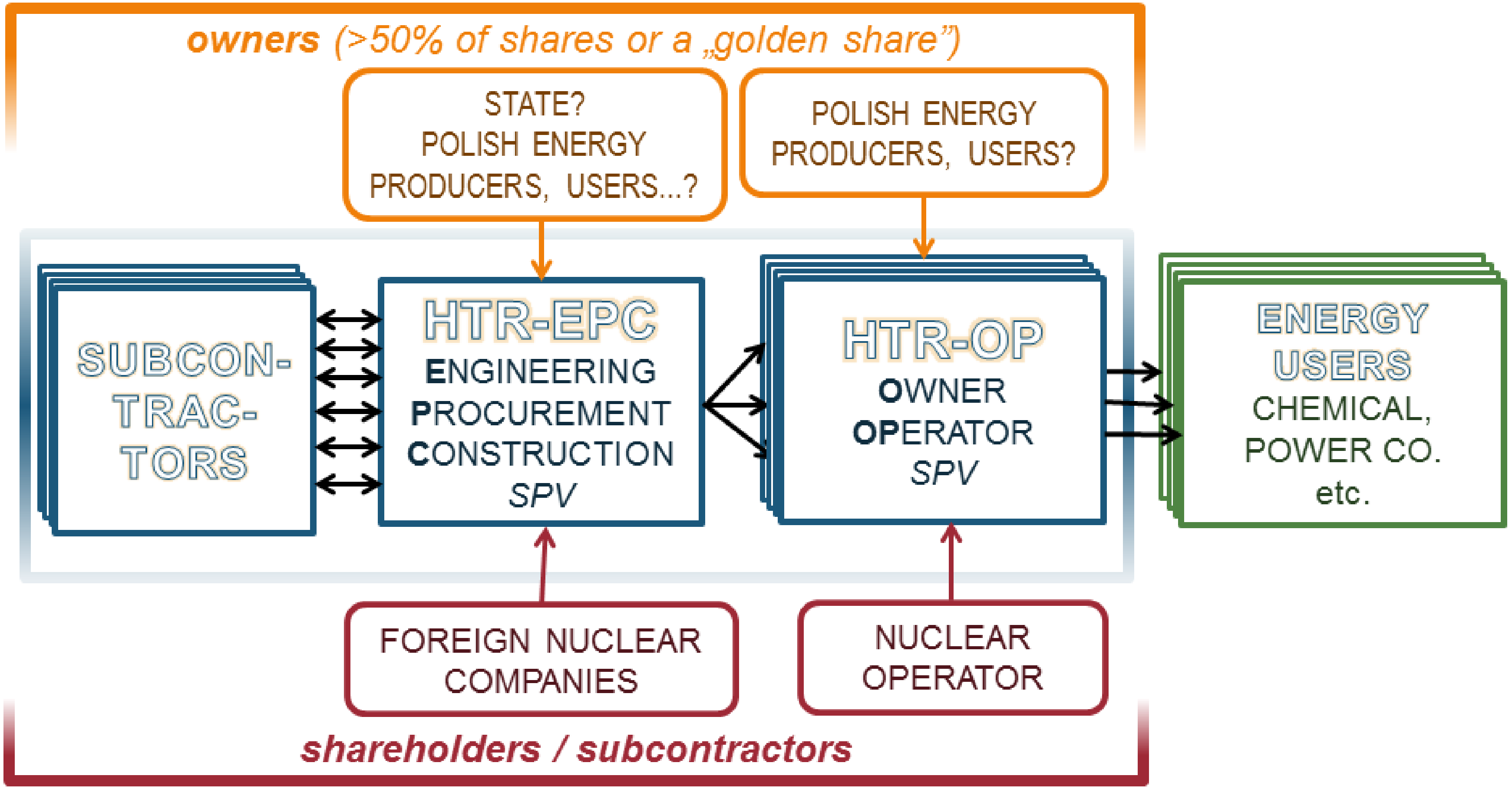
- **Traditional business model:**
  - **Big contract between big Vendor and big Utility**
  - **Vendor could be sure to find a buyer sooner or later**
  - **Utility was not afraid to order a reactor similar to others already in use**

- **Such approach for HTGR created „chicken and egg" dead loop**
  - **No vendor can afford detailed design before having an order**
  - **No user (e.g. chemical company) will order a reactor not even designed**
  - **Too high level of risk on both sides (vendor and user) is the barrier**

- **Solution: let's users become the vendor**
  - **reactor designed by SPV own by users**

HTR business model

Large nuclear vendors not interested to take lead in HTR project
A new company should be established in Poland
Foreign expertise should be involved by hiring, contracts and shares



A user point of view

- **Power and chemical companies use today coal- and gas-fires boilers to produce heat**
  - **In 2030-2050 most of them will need to be replaced**

- **Replaced with what? What will be less expensive and less risky?**
  - **Coal and gas**
    - **Large uncertainty on fuel price and cost of CO_2 emission (20-75€/t)**
    - **Risk of finishing domestic coal resources**
    - **Risk of gas supply from a single source**
  - **Nuclear HTGR**
    - **Technological risk – no design ready to buy**
    - **Uncertainty of „overnight" reactor cost** (2,0±0,6 MPLN / 165 MW_{th})
    - **Strong dependence of profitability on cost of money (discount rate)**

Changing the user's point of view

- **Division of the project into 2 phases (design + construction) delays the investment decision by 5 years**
  - Uncertainty on fuel prices and CO_2 cost largely reduced
  - Design is known and construction cost much better predicted
- **Designing controlled by the users ensures:**
  - fulfilling the user requirements
  - trust of the users in the design
- **Cofinancing by several users ensures:**
  - cost sharing and possibility of using R&D funds
- **Cofinancing by public money ensures:**
  - reduction of the users expenses
  - decisive security for managers

HTGR programme

1$ ≈ 3.7 PLN
1€ ≈ 4.2 PLN

Designing Experimental HTGR
150 M PLN
50% from state?
~6 MPLN/year/partner

Construction of Experimental HTGR
600 M PLN
100% from EU?
(EU structural funds)

2019 **2021** **2024** **2026** **2032**

Designing Commercial HTGR
500 M PLN
50% from state?
~12 M PLN/year/partner

OPEX (B+R)

Construction of Commercial HTGR
2000 M PLN
100% end-user
(UE/PL suport for long term loan)

CAPEX (investment)

Investment decisions

4 industrial partners assumed

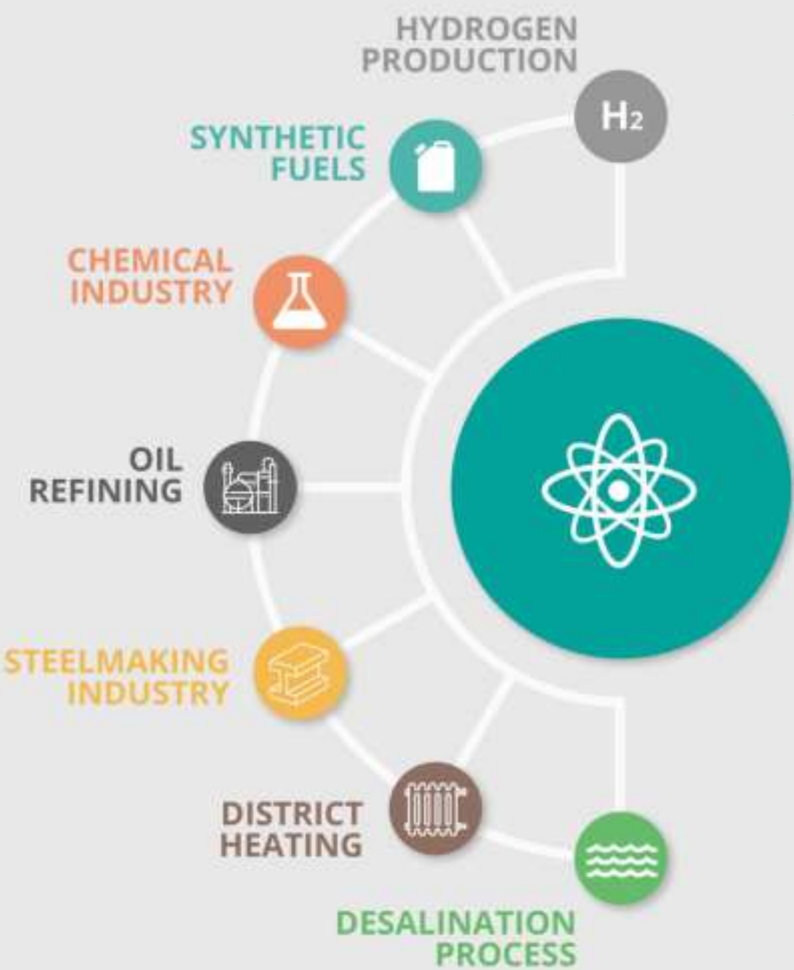
Additional challenges

- **Breaking economy of the scale**
  - **cogeneration** (~100% use of energy)
  - **large market** (PL: 10-20, EU: 100-200, world >1000)
  - **SMR: factory fabrication** (not construction at a site)
- **Universality**
  - **Same design for different applications**
    - steam for chemical factory
    - cogeneration: turbines + disctrict heating
    - ???
  - **Separation from the user installations**
    - no influence of user installations on the reactor

These challenges are addressed by the Gemini+ project

Nuclear Cogeneration Industrial Initiative

- Part of Sustainalbe Nuclear Energy Technology Platform



www.nc2i.eu

NC2I
Nuclear Cogeneration Industrial Initiative

Mission:

Contribute to clean & competitive energy beyond electricity by facilitating deployment of nuclear cogeneration plants

GEMINI - partnership of EU NC2I with US NGNP Industrial Alliance

GEMINI+

Euratom project: 4 M€/3y
Winner of Euratom SMR competition
26 partners from EU, Japan, Korea & US