HTR System Integration in Europe and South Africa

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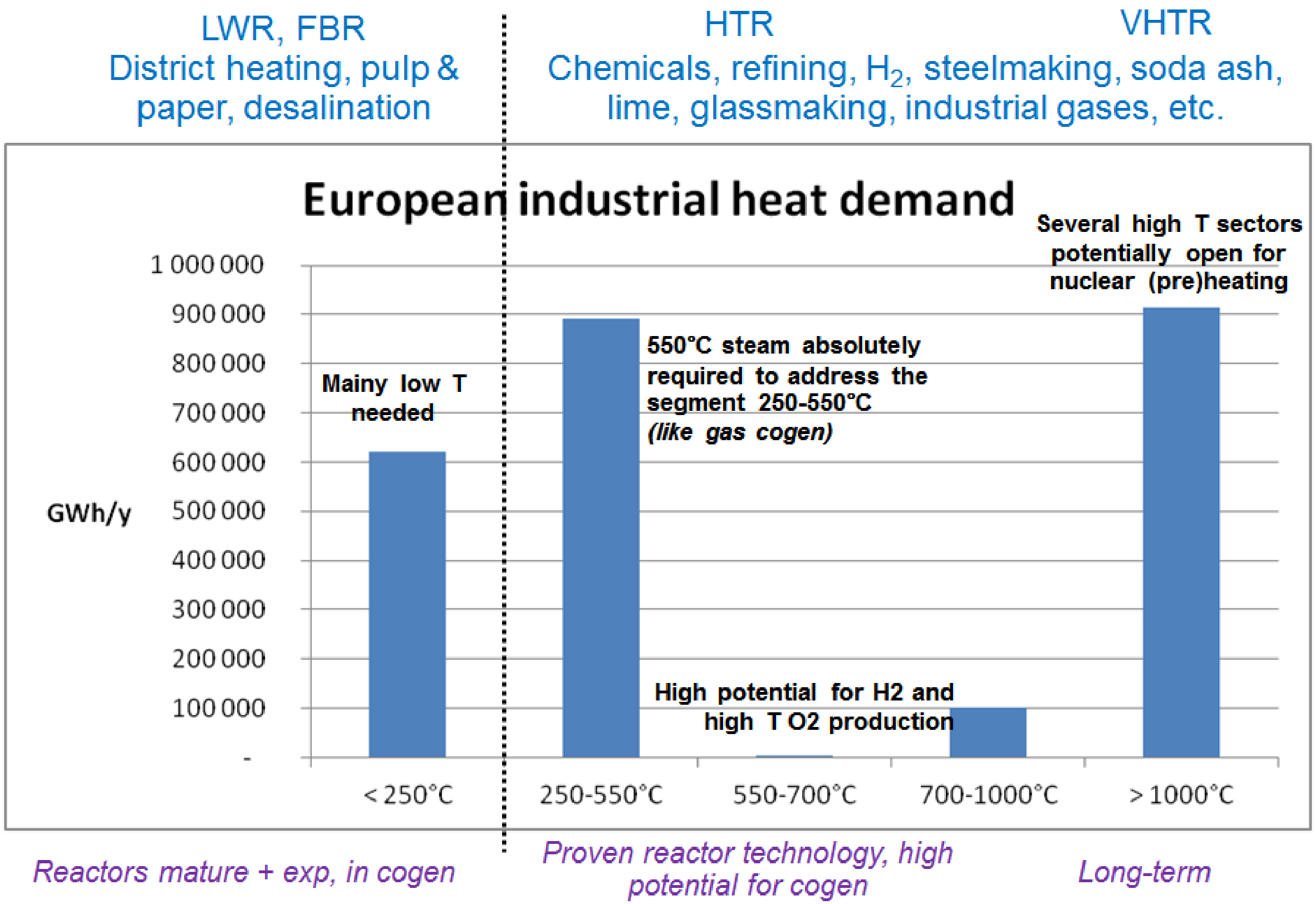
Archer
Advanced Reactor
for Cogeneration of
Heat & Electricity-R&D

Contents

Introduction: Electricity & Heat Market

Traditionally nuclear industry focuses on electricity market.

However, in addition there is a huge heat market



Source: EUROPAIRS study on the European industrial heat market

Introduction: Energy & HTR

SET-Plan

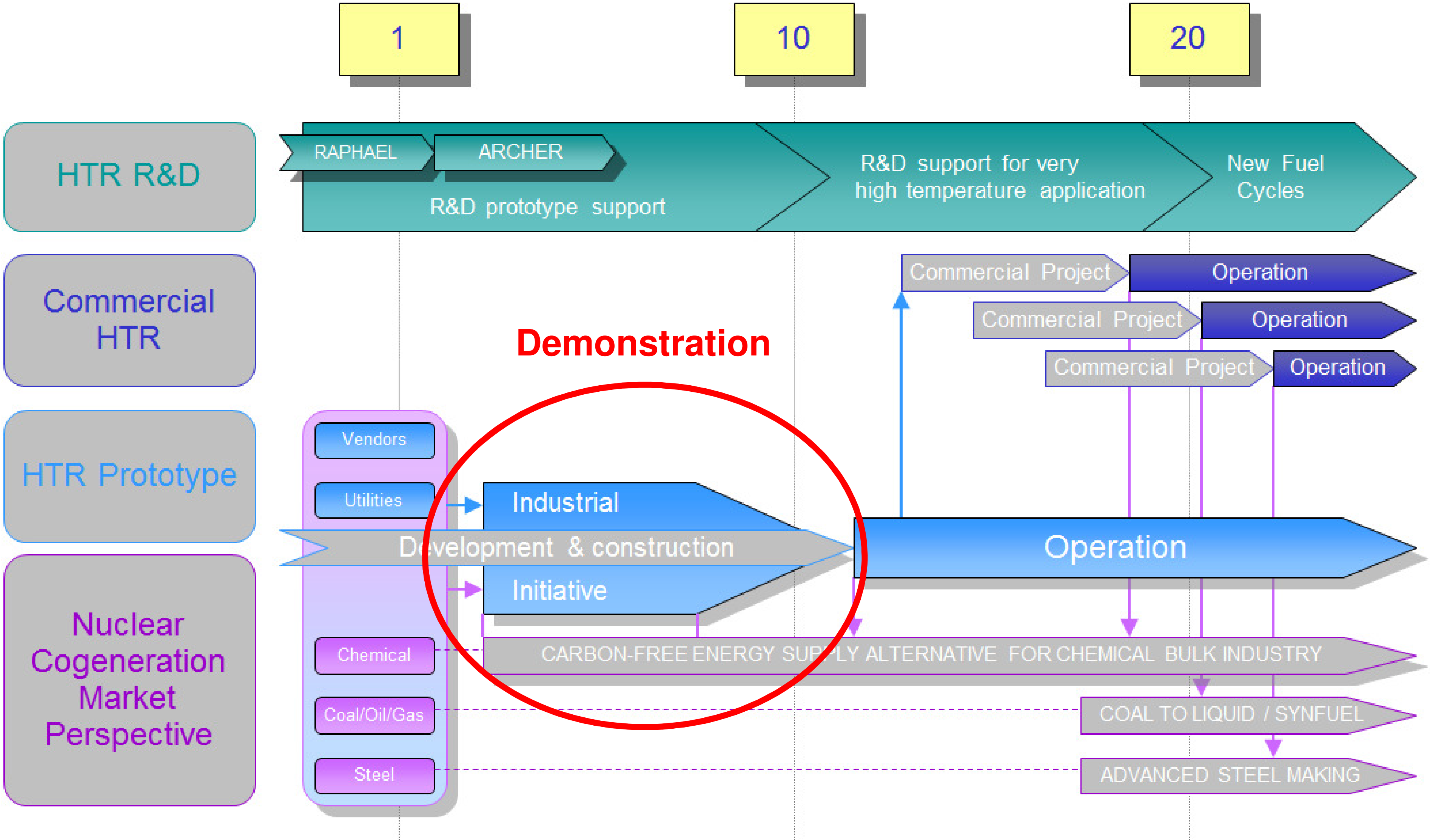
- **Goals for 2020**
  - *20% reduction in energy consumption*
  - *20% reduction in greenhouse gas emissions*
  - *20% reduction of renewable energy*
- **Goal for 2050**
  - *60-80% reduction in greenhouse gas emissions*
- **Industry needs affordable, reliable, clean (low CO_2) energy source**

HTR can meet these goals

- **HTR Demonstrator 2025**
- **Commercial deployment from 2030**
- **CO_2 reduction from 2040**

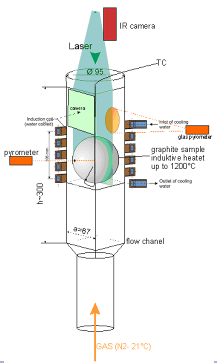
No other options in SET plan take <u>process industry</u> into account

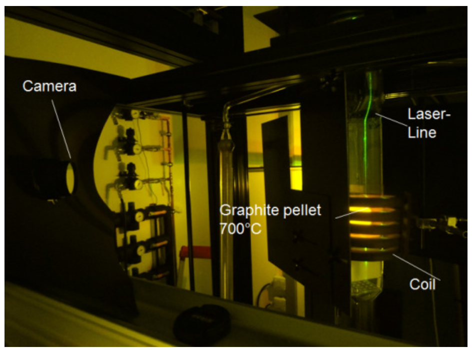
Introduction: HTR Roadmap

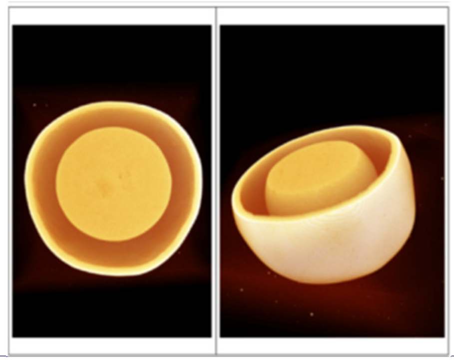


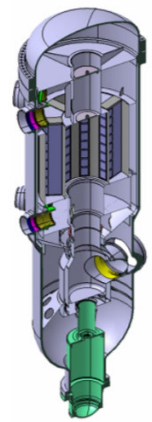
Introduction: ARCHER

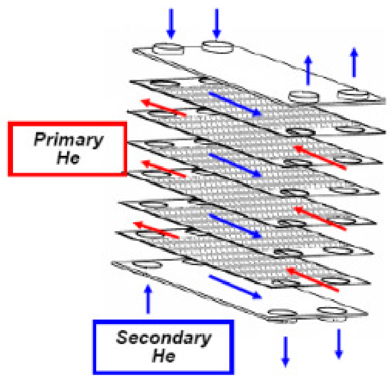
- **The project ensures the HTR knowledge base in Europe is maintained and expanded**
- **ARCHER directs the existing knowledge base towards a demonstrator project via:**
  - *Link to end users/coupling*
  - *Licensing & Safety*
  - *Fuel performance and licensing*
  - *Grapite & steels to be adopted*
  - *Steam generator & heat exchanger*
  - *Dissemination of HTR knowledge and experience to a new generation*
  - *International contact (GIF) and (public) communication*











Introduction: ARCHER System Integration

- Identify and solve issues that come up when a multitude of systems and components are combined with the objective of safe and economic operation whilst meeting end user needs

- Establishment of a design schematic of a nuclear cogeneration system connected to industrial processes

- Assessment of a coupled system
  - Gap analysis
  - SWOT analysis

- System code integration
  - requirements for integration, development and qualification/validation

Reference HTR System for Analyses

Not a precise, specific design, only main characteristics

Some characteristics as Steam Generator Outlet temperature can be adjusted to match the required process

Reference HTR	Value
Thermal Power	2x260 MWth
Electric Power	127 MWe
Process Heat Power	400 t/hr
Availability	90%
Primary System Pressure	70 bar
Number of Pebbles	317500
Steam Generator Inlet	700°C
Steam Generator Outlet	250°C
Helium Mass Flow	111 kg/s

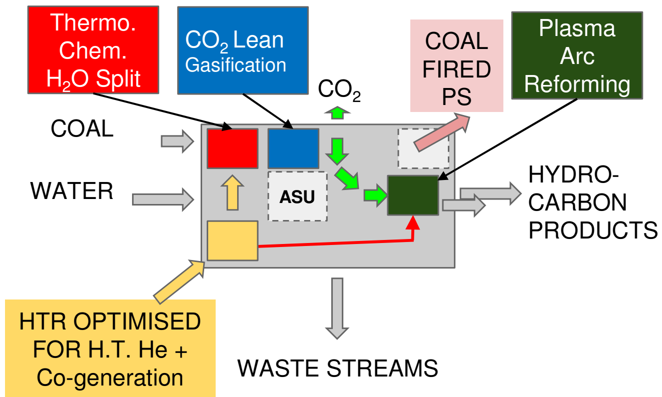
Process Heat Application for Analyses: European Case

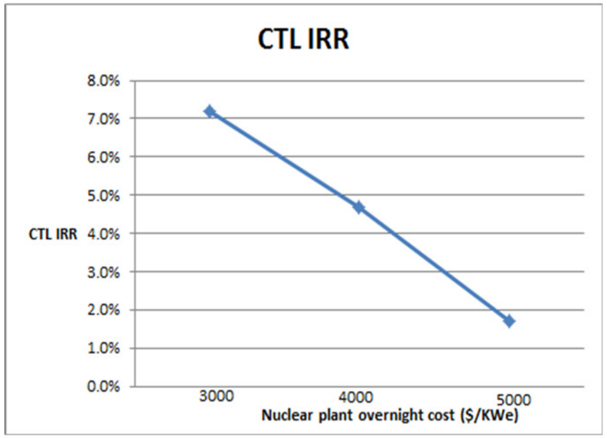
Fictive but realistic case representative for a large chemical plant:

- **Steam required at 3 pressure levels**
  - **high pressure: ~30 bar, 260°C**
  - **medium pressure: ~16 bar, 220°C**
  - **low pressure: ~ 4 bar, 200°C**
- **Steam generated in dedicated power and steam station:**
  ~130 bar, 540°C
- **Steam is frequently in direct contact with end-product**
- **No condensate return**
- **Steam consumption is seasonal (higher in winter)**
- **Stable steam conditions required for safe and reliable operation**

Process Heat Application for Analyses: South African Case

- **Demonstrate economic and technical viability of coupling a European HTR to the SASOL coal to liquid process to reduce the carbon footprint**
  - Validation of economic model to existing situation at SASOL
  - Study refers to typical RSA situation with cheap coal
  - Key Performance Indicator: Internal Rate of Return > 6%
  - Conclusion:
    - serious economic challenges (target HTR construction price at IRR = 6% lower than 3400$/kWe)
    - additionally: safety and licensing challenges of construction and operation of NPP near industrial site
- **Separate presentation from P. Stoker at HTR2014!**





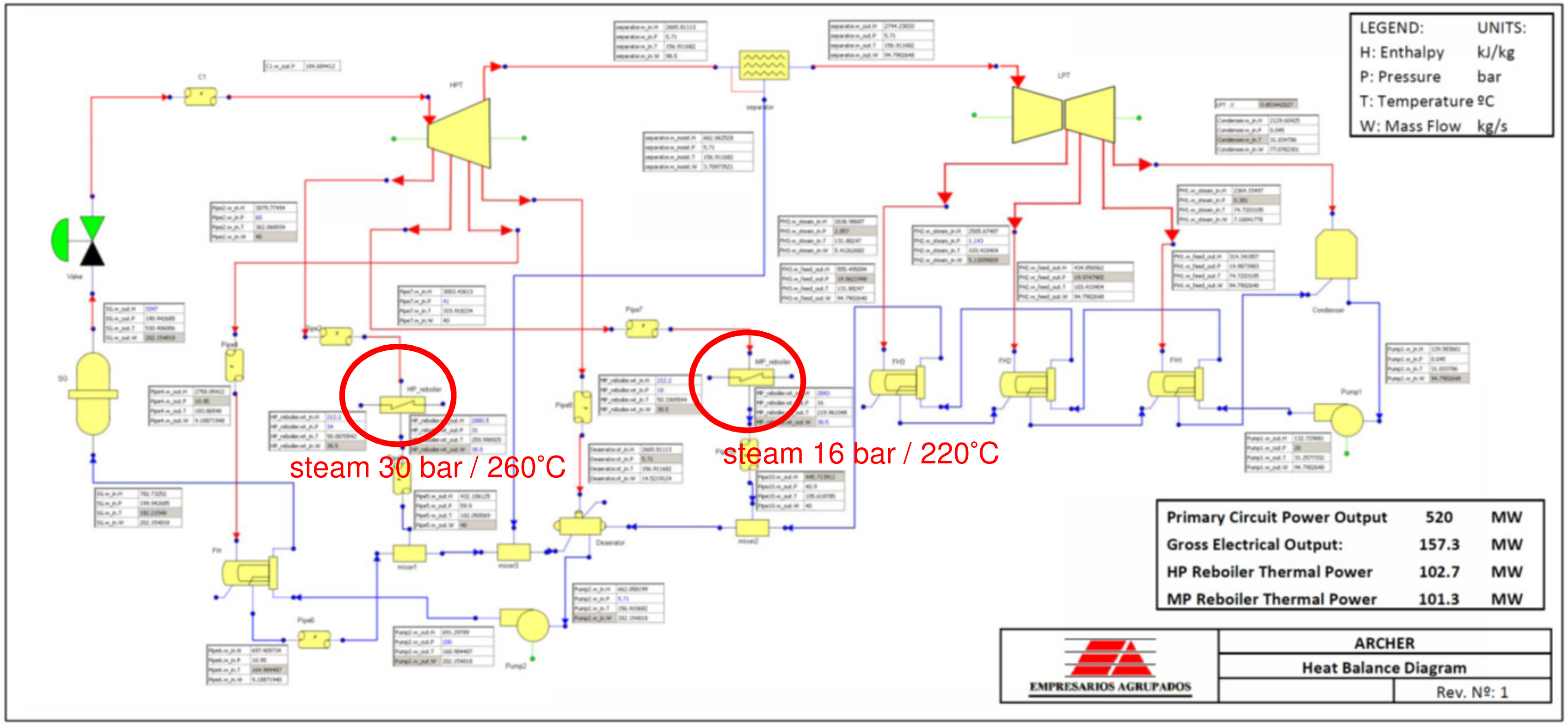
Coupling Options

- **Indirect steam cycle**
  - **Allows $T_{sec} < 550$°C before material issues appear**
  - **Corresponds to existing heat marker demand**
  - **Nuclear heat source not used to full potential**
- **Indirect gas cycle**
  - **If $T_{sec} > 550$°C is required**
  - **IHX acts as separating barrier between nuclear island and application**
  - **Can be combined with bottoming cycle for steam generation**
  - **Economical viability is to be considered**
- **Direct helium cycle with a Brayton topping cycle for electricity generation and steam generator as bottoming application**
  - **Minimize leakage and tritium permeation**

Design Schematics

ARCHER reference HTR plant coupled to the ARCHER reference secondary system. Main conclusions:

- **Nuclear heat source should be close to end-user which will complicate licensing process**
- **Economic viability is main challenge**



Key Indicators (HTR vs. CCGT)

KPI (Plant Characteristics)	Result
Power Level Thermal	Similar
Availability	Similar
Design Lifetime	Similar
Time to Market	10 years for HTR
Construction Duration	HTR ~2x longer
Space Requirements	Similar

KPI (Environmental)	Result
GHG emission	Nuclear ~70x less
Conventional Waste	Nuclear ~4x less
Chemical Waste	Nuclear ~1.5x less
Radioactive Waste	Nuclear ~500 more
External cost	Nuclear ~5x less

KPI (Safety)	Result
Worker Injuries	Similar
Evacuees	Assuming no off-site evacuees for HTR 10 per GWyr for CCGT
Fatalities+injured	Nuclear and gas similar
Licensability	easy for CCGT difficult for HTR

KPI (Economics)	Unit
Construction costs	HTR ~9x more
O&M costs	HTR ~3x more
Fuel (cycle) costs	HTR ~8x less
Decommissioning	~650 €/kWe for HTR ~0 for CCGT
Generation costs	Similar at discount rate of 10%

Technology Gap Analysis (1/2)

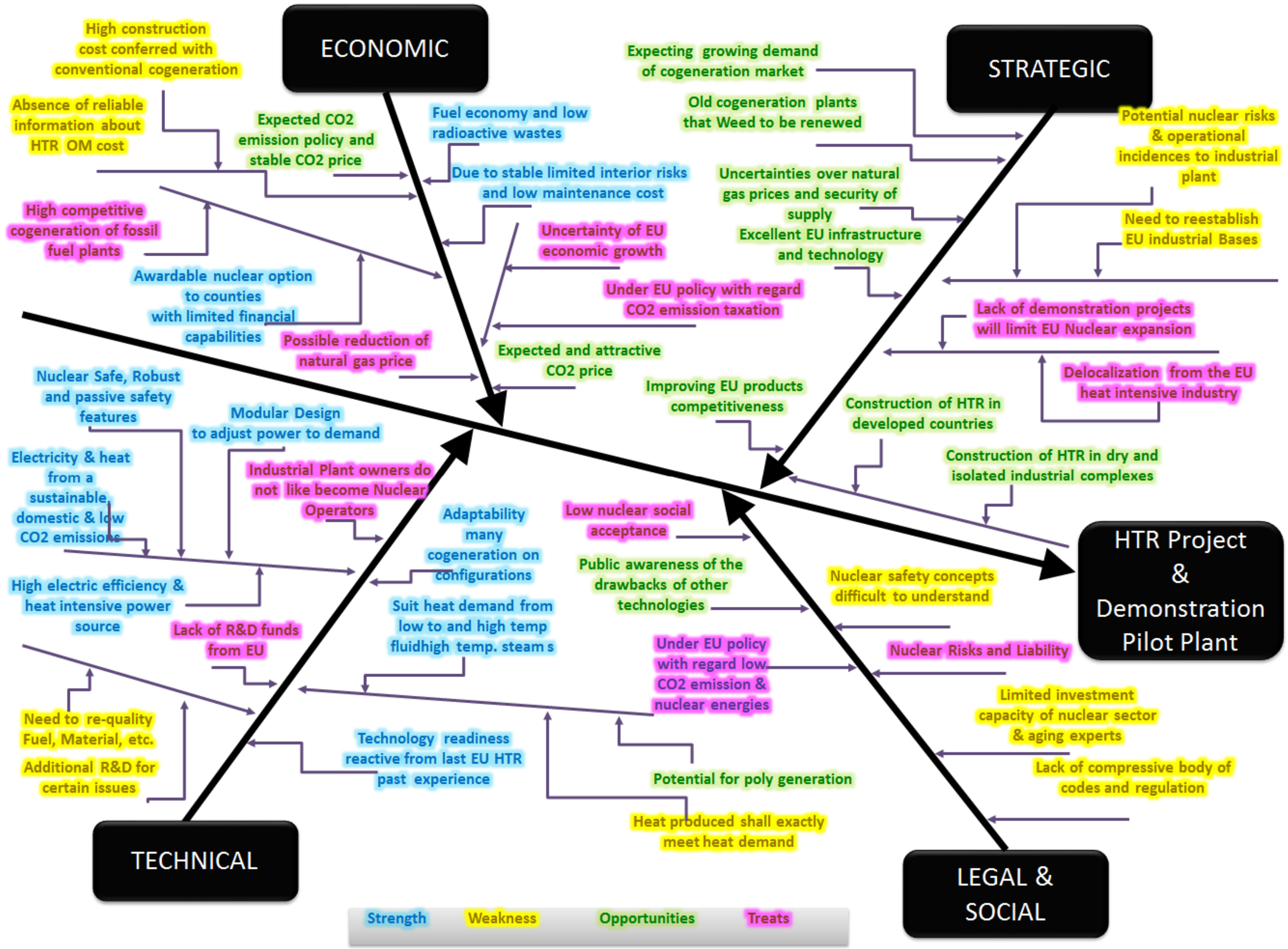
Based on industrial experience from THTR

Component	Technology Gap (red = subject in EU R&D Program)
RPV	-
SG & HEX	- deposition of graphite dust - steam generator inspection - tube sheet design and behaviour
Core structure	- qualification of new graphite - minimization of bypass flows
Blowers	- bearings (magnetic vs. oil lubrication) - orientation (horizontal vs. vertical)
Fuel handling	- recycling vs. once through - performance at elevated temperatures
Reactivity control	- diverse shutdown systems - testing and qualification of in-core control rods (if needed)
Helium purification	- review and possible update to current regulatory standards
Core design	- development and validation of integral HTR modelling package

Technology Gap Analysis (2/2)

Component	Technology Gap (red = embedded in EU R&D Program)
Graphite dust	- fuel element performance - filters - flushing effect - development of separation concept - development of simulation tools (formation, activation, transport, deposition, remobilization) - preventation of formation
Air & water ingress	- development and validation of simulation tools
Hot gas duct	- determination of thermal stratification loads (if any)
Regulatory framework	- collection and analysis of regulatory requirements and industrial standards
Economical framework	- comparison of economics of scale, simplification, replication - design optimization with respect to economic aspects
Supply chain	- re-establishment of the (European) supply chain

SWOT Analysis (1/3)



SWOT Analysis (2/3)

Strengths	Weaknesses
- Robust passive safety systems - Proven experience - Fuel economy - Waste stability - Modularization potential - High Efficiency - Low carbon source of energy - Reliability of heat supply	- Existing knowledge and experience retiring - Requalification of fuel, materials, components - Need to re-establish industrial basis - High relative construction costs - Nuclear risks affecting industrial plant - No up-to-date European licensing framework - Communication of nuclear safety concepts to public
- Large potential heat market - Volatility of prices for natural resources - CO_2 emission reduction policies - European nuclear industry - Potential for cogeneration - Public awareness of drawbacks of all energy sources - End-of-life for existing cogeneration plants	- Unstable public and political support - Existing reference technologies - Economic uncertainties for end-users - Process heat users do not wish to be nuclear operator - Restrictive nuclear policies - Co-location with industrial sites complicates licensing - Competition with other resources promoted by EU incentives
Opportunities	**Threats**

SWOT Analysis (3/3)

SWOT Summary

- **Large market forms opportunity for low CO_2 emission HTR technology.**
- **European knowledge and experience base was strengthened.**
- **Energy from an HTR is affordable, reliable (i.e. security of supply and safe), and clean (low carbon)**
  → compliant with EU energy policy goals.
- **HTR can deliver heat in a wide range of pressure and temperature.**
- **HTR fits very well in small grids. Many heat intensive industrial complexes are located in such areas.**
- **Nuclear safety concepts are difficult to explain to the public at large. Nuclear risks and liabilities are hindering deployment.**
- **EU member states make individual energy technology choices.**
- **A consistent and up-to-date regulatory framework is lacking.**

Integration of Analysis Tools (1/2)

Code inventory containing data:

- **Initial purpose (LWR, FBR, HTR,…)**
- **General features**
- **HTR specific code development needs**
- **Limitations**
- **Key contact person**
- **Couplings**
- **Validation status**
- **References**
- **Input/output structure**
- **…**

Integration of Analysis Tools (2/2)

- **Overview of HTR codes in EU and RSA**
- **Many legacy codes with long development history**
- **Various ways of data storage and transport**
- **Heterogeneous infrastructure and codes**

ACCORD	DORT-TD/ THERMIX-DIREKT	GOTHIC	RELAP5-3D	TAC-NC	VSOP
ASTEC-V2	DYN3D	MANTA	RELAP5/ MOD3.2 & 3.3	THYDE-HTGR	WIMS
ATHLET	FLOWNET	MELCOR	SCDAP/RELAP /ATHENA	TINTE	ZIRKUS
CATHARE	FPRC	MGT	SIM-ADS	TORT-TD/ ATTICA3D	
CONTAIN	FRESCO-PANAMA	MGT-3D	SPECTRA	TRAC/AAA	
CRYSTAL	GAMMA	PANTHER MIX	STACY	TRAC-M	

- **Different codes are needed to simulate different aspects. However, input data is shared and many aspects are coupled.**
- **Final aim is to arrive at integral HTR simulation platform such as the HTR Code Package (HCP) under development at FZJ (S. Kasselmann et al. (2014) in NED)**