ANTARES Application for Cogeneration

Oil Recovery from Bitumen and Upgrading

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Presentation Outline

- Introduction
- Description of main ANTARES features
- Positioning nuclear heat source for combined heat and power production
- Example : Bitumen recovery and upgrading
- conclusion

Introduction

- A fast evolving context:
  - Fossil fuels are becoming more expensive
  - Price volatility of conventional fuels is high
  - Environmental concerns are growing

  ➔ Incentives for:
  improved efficiency
  strict limitations or control of GreenHouse gases releases

  ➔ HTRs are a non GHG producing heat source able to deliver both power and heat in a significant temperature range

- ANTARES design with a combined cycle power production system is readily adapted to most combined heat and power applications.

Description of ANTARES Features

- The project started in 2003 based on an extensive legacy of experience with the German MODUL and the GT-MHR
- Presently in its conceptual design phase.
- Basic technical choices:
  - Prismatic type fuel
  - Annular core
  - Combined cycle power conversion system using mostly conventional components
  - The thermal power is 600 MW
- The design should be adaptable to combined heat and power configuration without any major redesign: have a standardized heat source as much as possible

The Case for Nuclear Combined Heat and Power (1/3)

- Nuclear power cost has a weak dependence on nuclear fuel cost
  - A doubling of uranium cost only increases power cost by 5%, therefore it is predictable and reasonably stable for the medium term
  - In contrast, fossil fuel power cost is very dependent on fuel cost
  - A doubling of natural gas price increases power cost by 75%. Therefore fossil fuel power cost is very sensitive to fuel cost and volatile. It is unpredictable on a medium term basis. (The Henry Hub natural gas price moved from 2.5 $/mmbtu in 2002 to over 13 $/mmbtu recently, it was 1$/mmbtu in 1978)
- For those applications that are big consumers of heat and power, power cost stability and predictability is essential on a medium term basis since an industrial basis is rarely established for less than 20 years

The Case for Nuclear Combined Heat and Power (2/3)

- To be cost effective, the nuclear heat source must be standardized but a process heat power requirement will probably never match the nuclear plant power. Combined heat and power design allows excess power to be distributed as electricity.
- Bulk process heat is used in large amount in some industries
- Combined heat and power production is very efficient, in some applications up to 80% of the heat source is used
- Combined heat and power is a commonly used technique in the conventional fossil fuel field
- In the present and probable future energy environment, the HTR used as a heat source to a combined heat and power application brings the well known efficiency advantage together with long term price stability and no greenhouse gases release

The Case for Nuclear Combined Heat and Power (3/3)

- Because of its capability to supply heat up to 800°C in the near term, maybe up to 1000°C in the longer term, the HTR concept is the only near term nuclear concept able to replace fossil fuel heat sources

- By design ANTARES is able to supply heat and power to a variety of applications with only minor adaptation

- Optimization of the plant configuration and performance is accomplished with a computer code named “THERMOPTIM” and a methodology developped at the Ecole des Mines of Paris. As a function of the heat needs, it helps identify where to get it from the power cycle to have the best overall electricity+heat performance.

Example of application: Bitumen recovery and upgrading

- We assume bitumen is recovered with the SAGD (Steam Assisted Gravity Drainage) process.
- If the heat source is a nuclear unit it should be able to provide steam to the field for 30 years at least. Steam must have a sufficient range, say up to 10 km from the steam generator
  - ➔ pressure at the source must be sufficient, about 100 bars.
- Steam can be dry or up to 20 % wet
- Steam to oil (SOR) of 2.5 to 3 are required
- A field producing 100000 barrels per day (bpd) needs about 120 Mwe for its operation, mostly for pumping
- When a field has been treated with steam for several months, steam injection interruption for up to a month does not affect production due to soil thermal inertia. Plant refueling can take place without losses.

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Bitumen Recovery results

Production	100000	bpd
SOR	2.5	
Steam quality	80%	
Steam Temperature at the generator	310	°C
Steam pressure at the Generator	100	bar
Steam flowrate	460	Kg/s
Thermal heat to steam	912	MWth
Number of HTR modules	2	
Electricity production	186	MWe
Net electricity export after SAGD consumption	66	MWe

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Bitumen upgrading

- The recovered bitumen is too viscous for long distance pumping
- It is not adequate for feedstock in refinery
- Therefore, it is upgraded meaning basically enriched with hydrogen
- H2 need is about 3.5 kg per barrel (depends somewhat on the bitumen)
- This is usually produced with steam reforming of natural gas but several problems are expected in the future:
  - Natural gas availability if many SAGD operations are running
  - Natural gas price impacts strongly H2 cost
  - Extensive CO2 production. Either CO2 sequestration is required (expensive and not necessarily practical) or a CO2 tax is levied in a country abiding by the Kyoto agreement
- From nuclear electricity, hydrogen can be produced today from conventional electrolysis of water (about 52 kwhe per kg) and in the future from advanced electrolysis (hoped for 34 kwhe per kg)

H2 supply

	Conventional Electrolysis	Advanced Electrolysis
H2 need for 100000 bpd	350 ton/day	350 ton/day
Need Electric power	773 Mwe	496 Mwe
Number of reactor modules	3	2
Available power for export	82 Mwe	74 Mwe

Total Heat and Electricity Needs for recovery and upgrading

Number of modules For 100000 bpd	With conventional electrolysis 5	With advanced electrolysis 4
Net electric power for export or other internal use	148 MWe	140 MWe
Total Nuclear Thermal Power	3000 MWTh – 1051 for SAGD – 1627 for H2 – 312 for Export	2400 MWTh – 1051 for SAGD – 1044 for H2 – 295 for Export
CO2 release avoidance	12 000 to 15000 tons/day (compared to natural gas use)	12 000 to 15000 tons/day (compared to natural gas use)

Sharing the unit output both for electricity and heat brings a very good level of redundancy ensuring high H2 availability, while steam production can be cut partially or totally, as mentionned before without impacting production

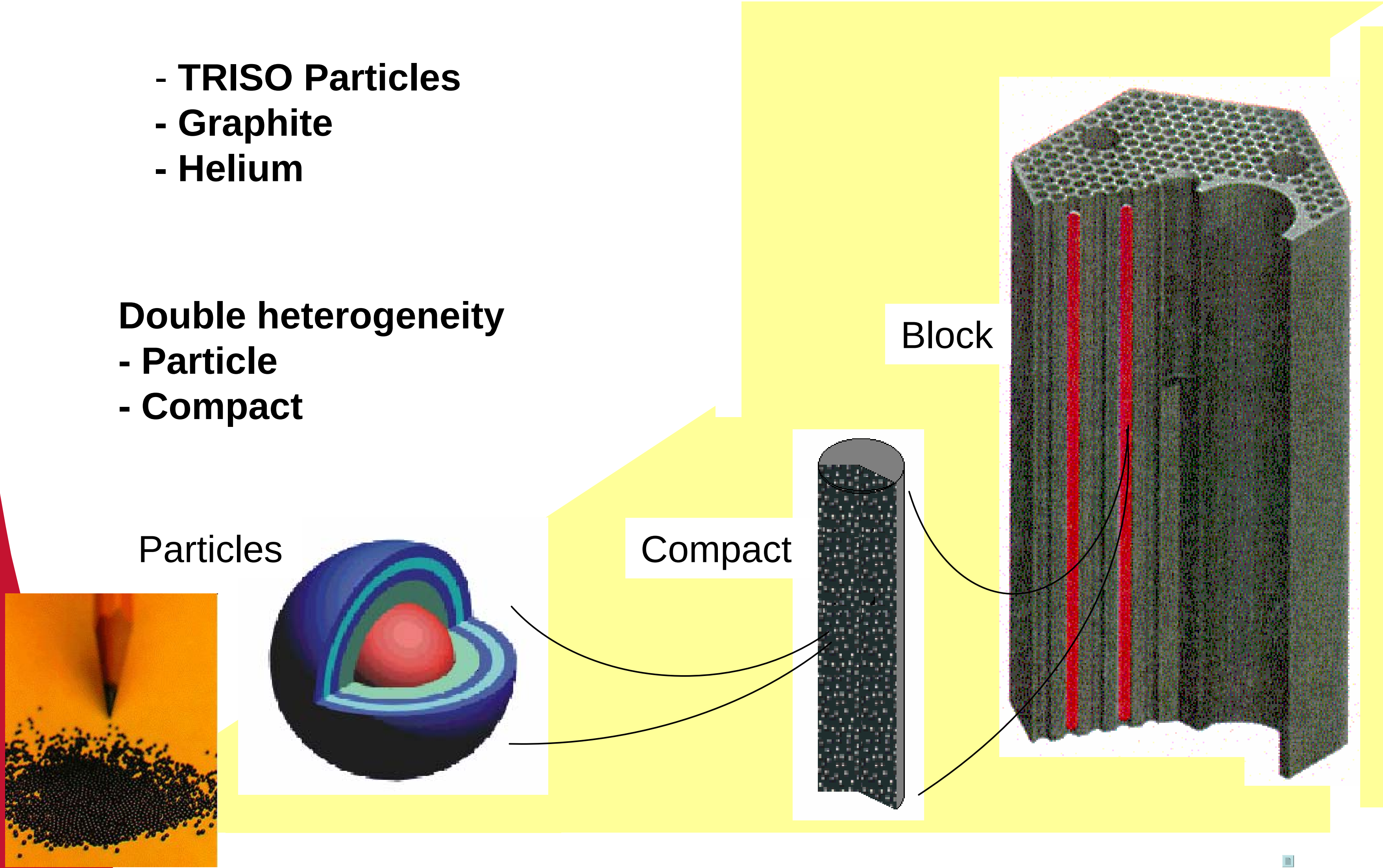
Conclusions

- Nuclear combined heat and power production becomes more and more attractive in the context of volatile fossil fuel prices
- Such combined production has a very high efficiency, over 80% depending on usage
- There is no greenhouse gases releases
- ANTARES is, by design, ready for such combined production without any modification of the nuclear heat source.
- Many industrial applications could potentially benefit from this concept
- Bitumen recovery and upgrading illustrates such a good match

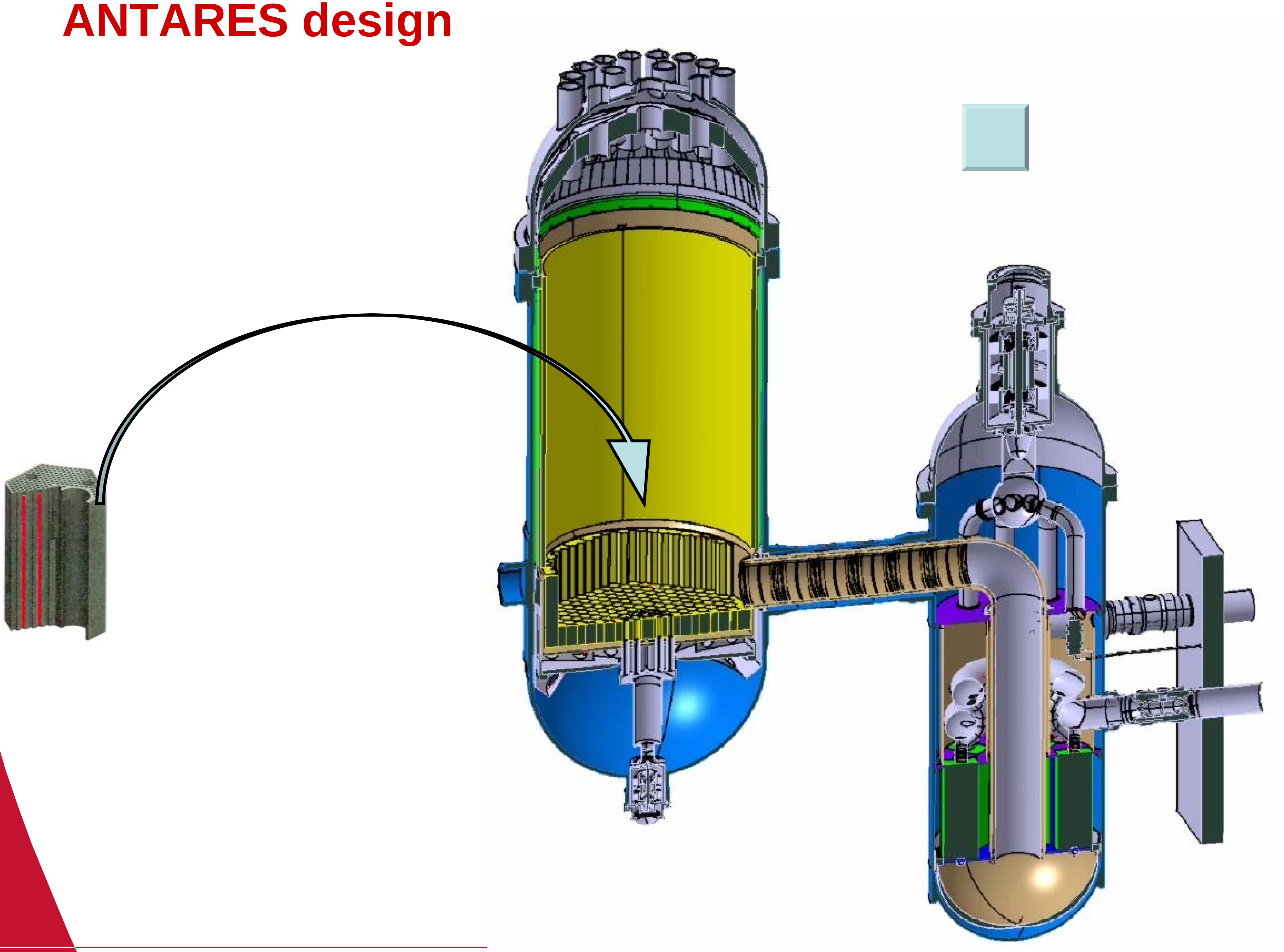
A Specific Fuel Design

- TRISO Particles
- Graphite
- Helium

Double heterogeneity
- **Particle**
- **Compact**



ANTARES design



Realizing Benefits of Modular HTRs Involves Development and Risk

- Advanced modular HTRs promise significant benefits
  - Passive safety
  - High temperature for process heat and efficient power generation
  - Incremental deployment
- Key development areas
  - Fuel
  - Materials
  - Reactor technology
  - Power generating system
- This development entails risk for each project phase
  - R&D may overrun cost/schedule
  - Selected design approaches may not be feasible
  - Completed facility may not perform as planned

Minimizing these risks is a priority for AREVA's HTR design approach

Genesis of the AREVA HTR Concept

Modular prismatic HTR (e.g., GT-MHR reactor)
- Economical heat source
- Enhanced passive safety

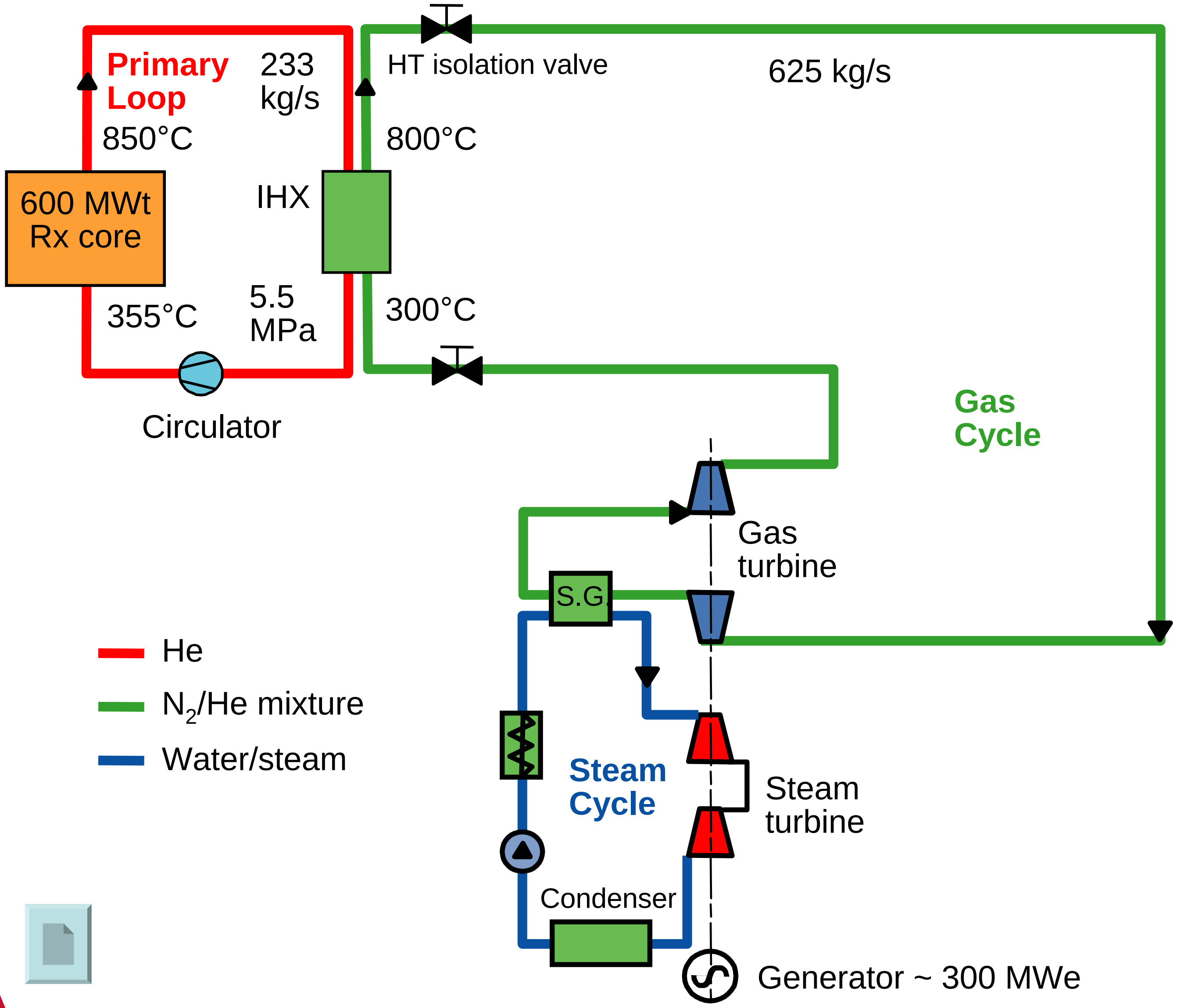
Indirect cycle configuration
- Simplifies nuclear heat source
- Provides versatility

CCGT generating systems (e.g., natural gas-fired)
- Very high efficiency
- Reliable operation
- High fuel costs

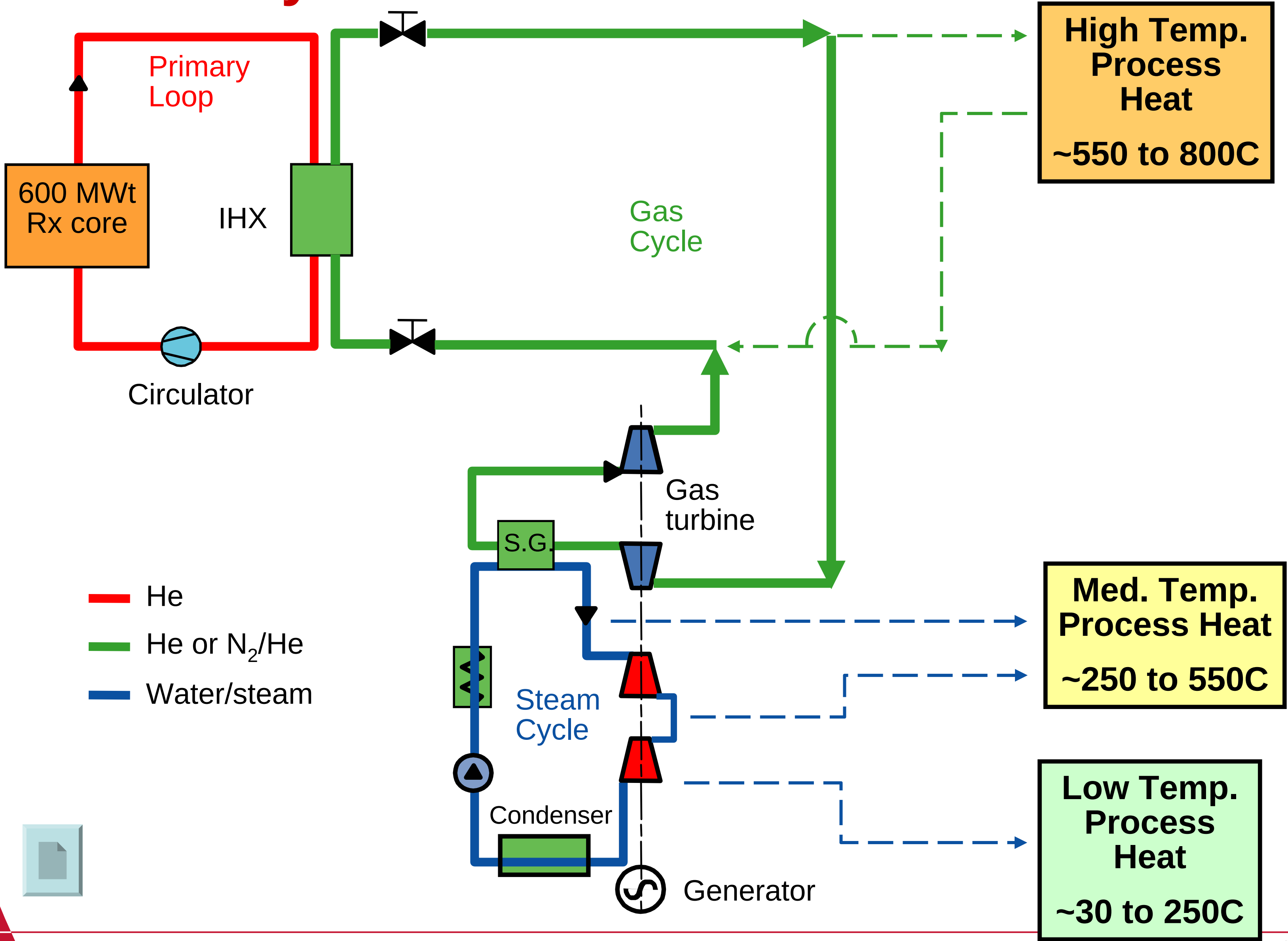
Need for non-emitting high temperature process heat (e.g., for H_2 production)
- Scarcity and price of oil
- Environmental impact of carbon-based fuels

AREVA HTR Concept
- Flexible heat source
- Passive safety
- Economical power
- Non-emitting process heat

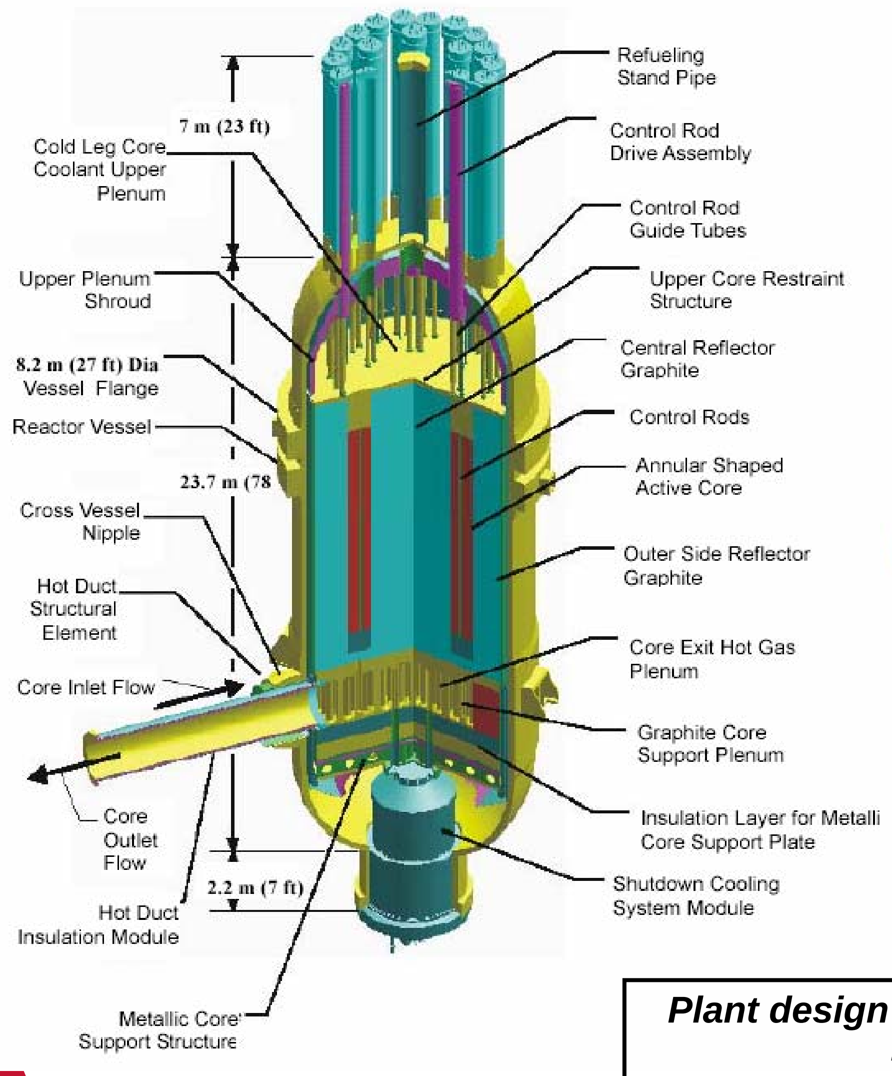
AREVA Commercial HTR
Combined Cycle Electric Power Generation

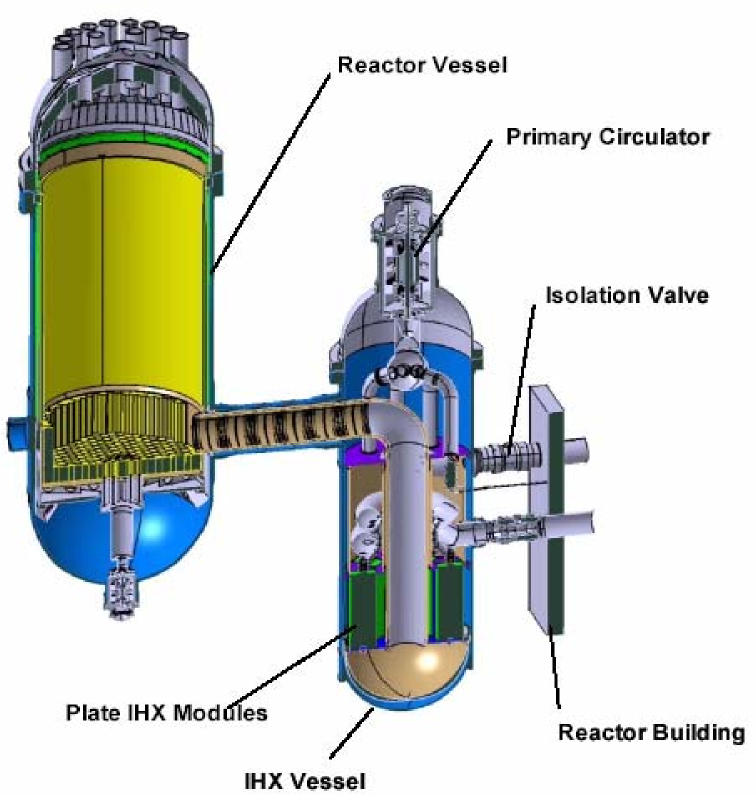


AREVA HTR Concept Can Also Serve Variety of Process Heat Markets



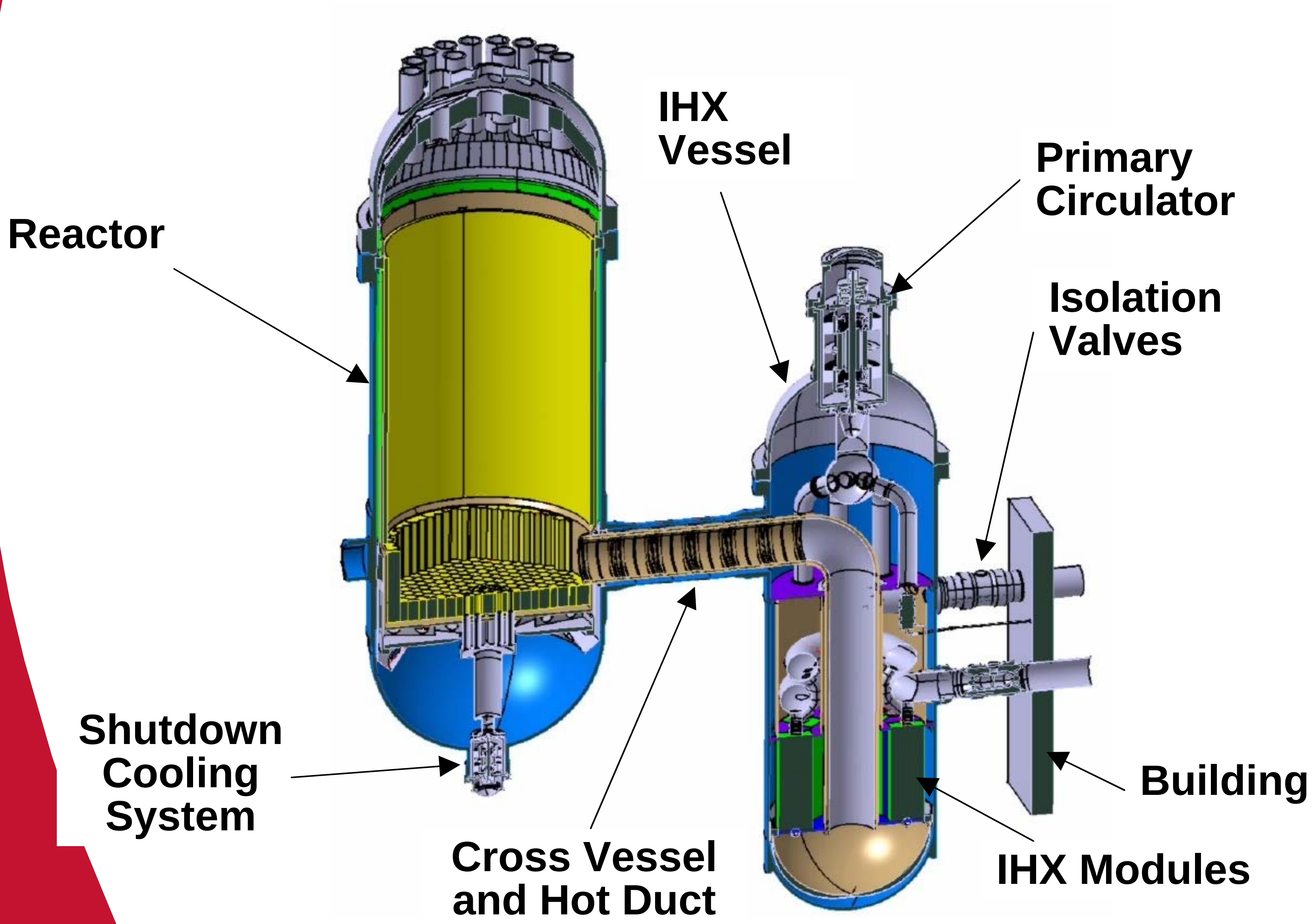
VHTR ANTARES Nuclear Heat Source





Plant design for one primary hot gas duct and one IHX-vessel with plate IHX

Nuclear Heat Source Arrangement



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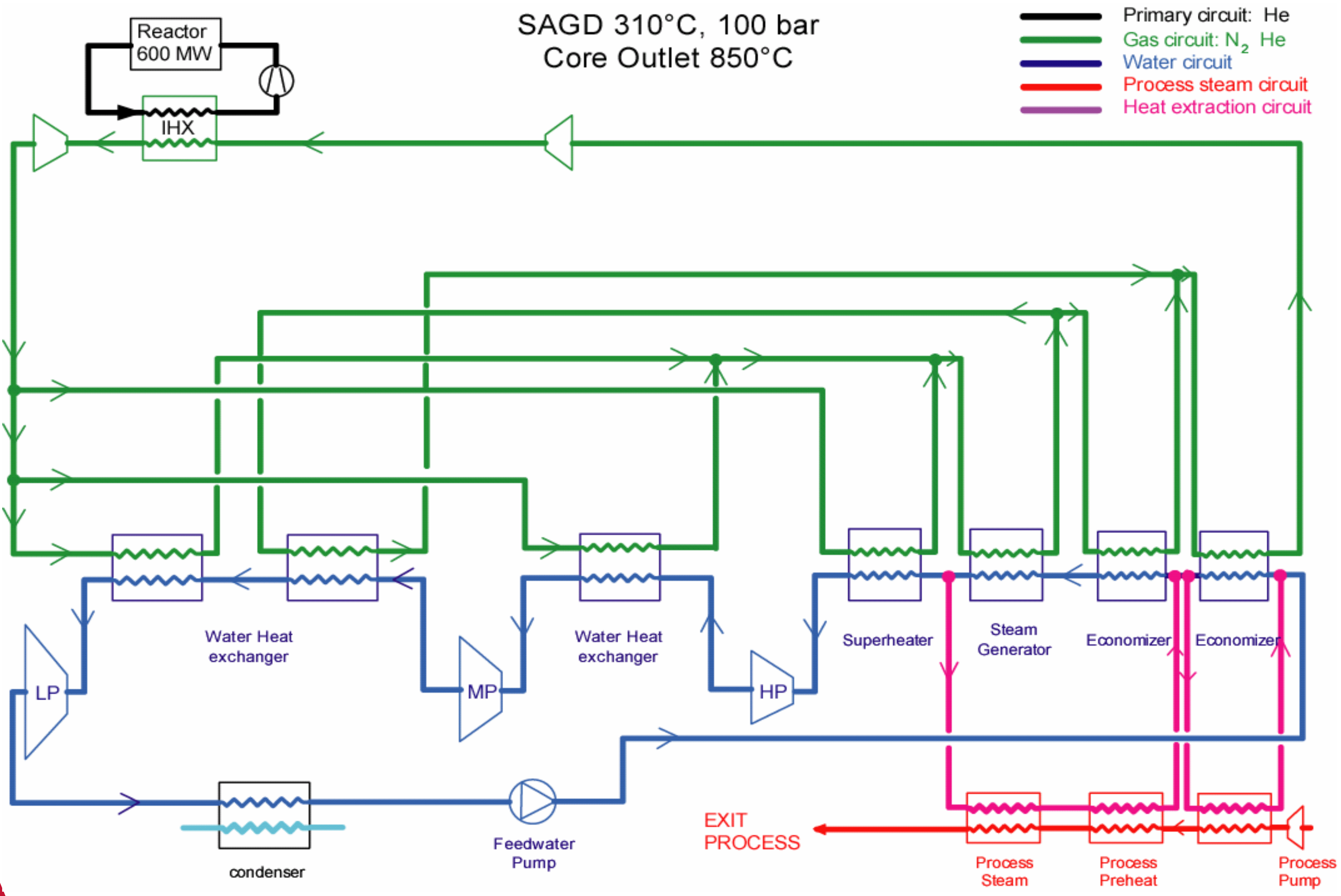
Approximate Plant Design Parameters

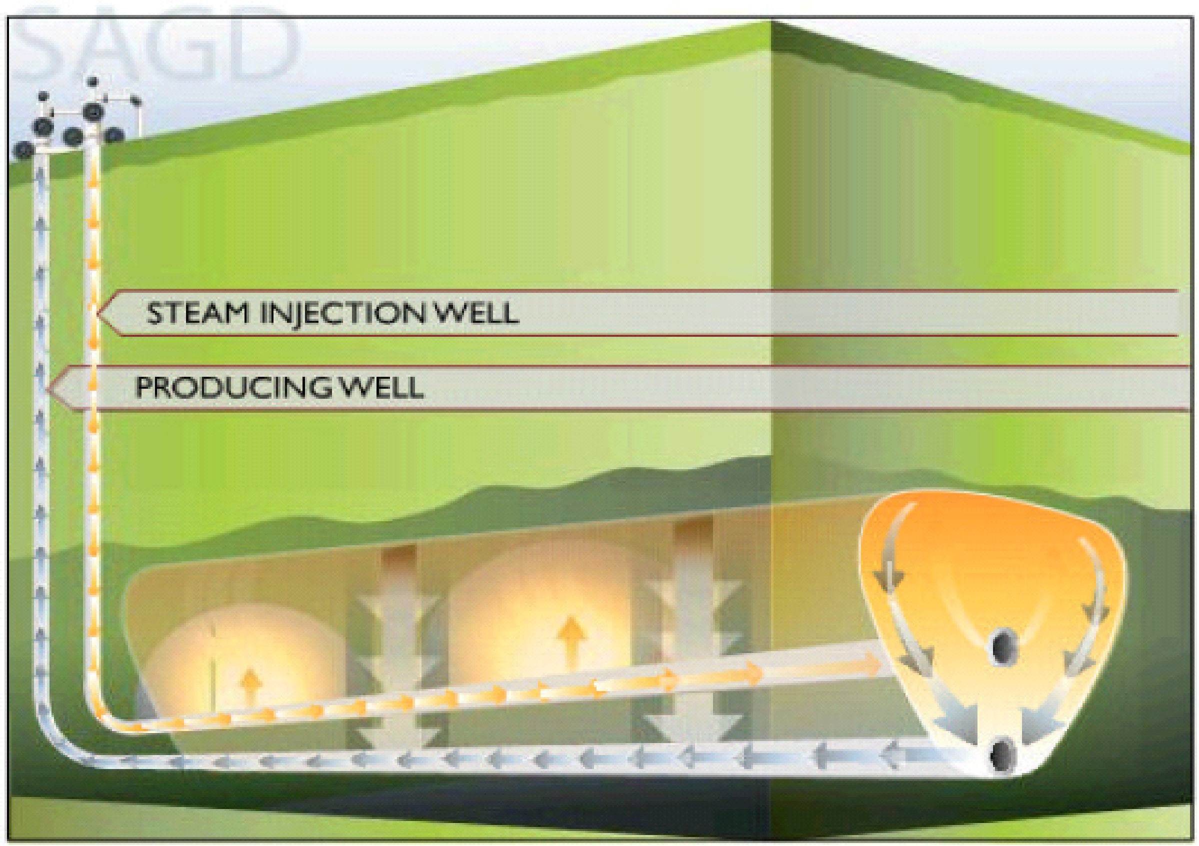
Reactor Power	600 MWt
Reactor Outlet Temperature	850° C
Reactor Inlet Temperature	355° C
Primary Coolant Flow Rate	240 kg/s
Primary Coolant Pressure	5.5 MPa
Reactor Vessel Material	9 Cr – 1 Mo or SA 508
Core Configuration	102 Columns, 10 blocks high.
Fuel Particle Type	SiC Coating UCO or UO_2 kernel
Operating Max Fuel Temp. Guideline	1300° C
Accident Peak Fuel Temp. Guideline	1600° C
IHX Design	Compact
IHX Nominal Heat Load	608 MWt
IHX Effectiveness	90 %
IHX Primary Tin	850° C
IHX Tout	350° C
Secondary Fluid	Nitrogen/helium Mixture
IHX Secondary Tout	800° C
IHX Secondary Tin	300° C
Secondary Flow Rate	614 kg/s
Secondary Coolant Pressure	5.5 MPa

SAGD

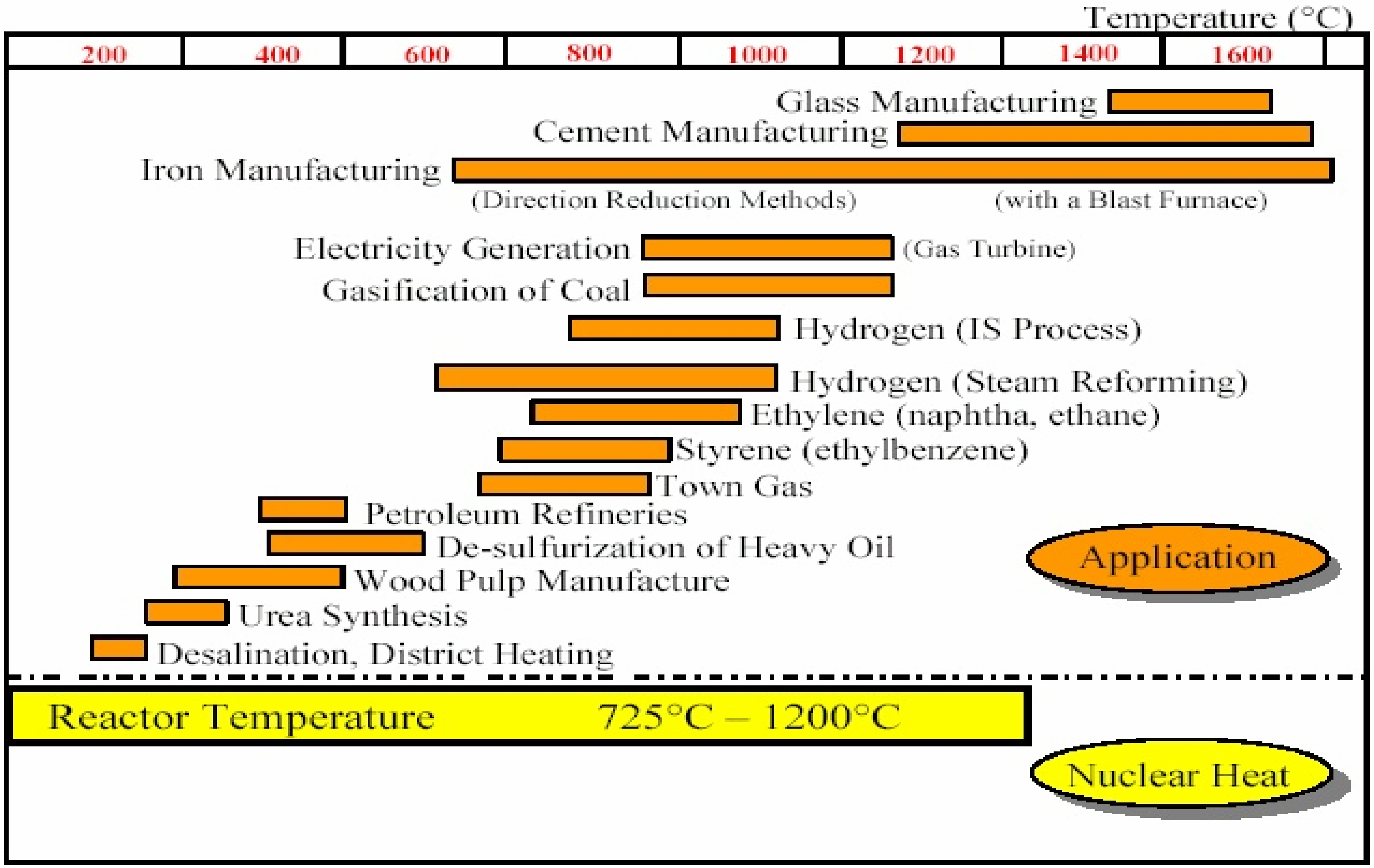
Steam at 310°C, 100 bar



SAGD Principle of bitumen recovery



Temperature Range of Industrial Heat Uses



igure 2. Potential uses of nuclear heat from Generation IV Systems.

Natural gas price volatility