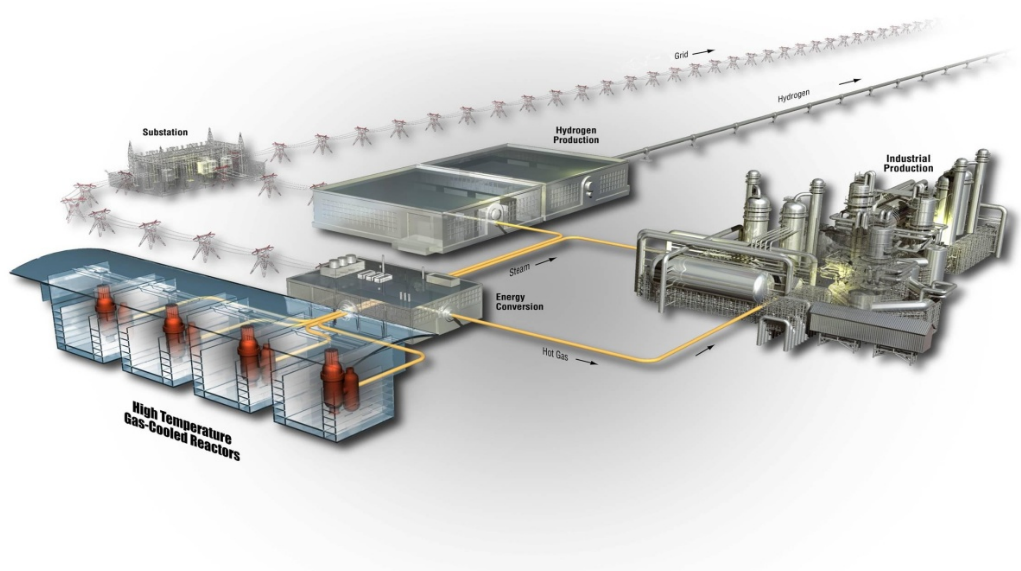
NGNP Industry Alliance

Clean Sustainable Energy for the 21st Century

High Temperature Gas-Cooled Reactor (HTGR) Technology

Presentation To:

The Governor’s Nuclear Advisory Council



Mark Haynes
President, Concordia Power
Senior Advisor, NGNP Industry Alliance

June 13, 2013

The NGNP Industry Alliance

Promote the development and commercialization of High Temperature Gas-cooled Reactor (HTGR) technology

Dow

Entergy

ConocoPhillips

PTAC

SGL GROUP THE CARBON COMPANY

AREVA

Westinghouse

Wyoming

Advanced Research Center

TOYO TANSO Inspiration for Innovation

SRS COMMUNITY REUSE ORGANIZATION two states, one future

US ULTRA SAFE NUCLEAR

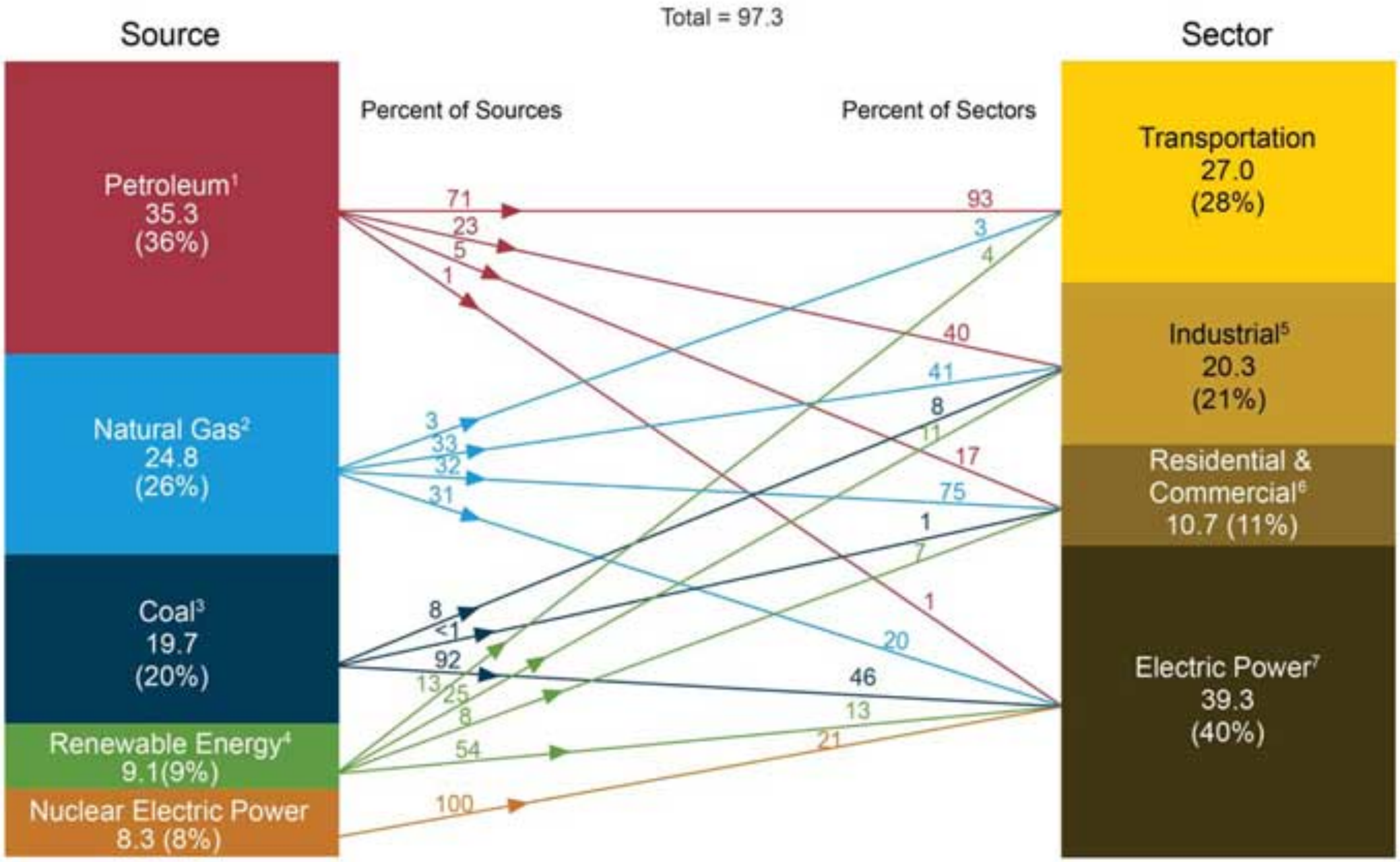
TECHNOLOGY INSIGHTS

MERSEN

GRAFTech International

Manufacturing Excellence Consulting, Inc.

Primary Energy Consumption by Source and Sector*

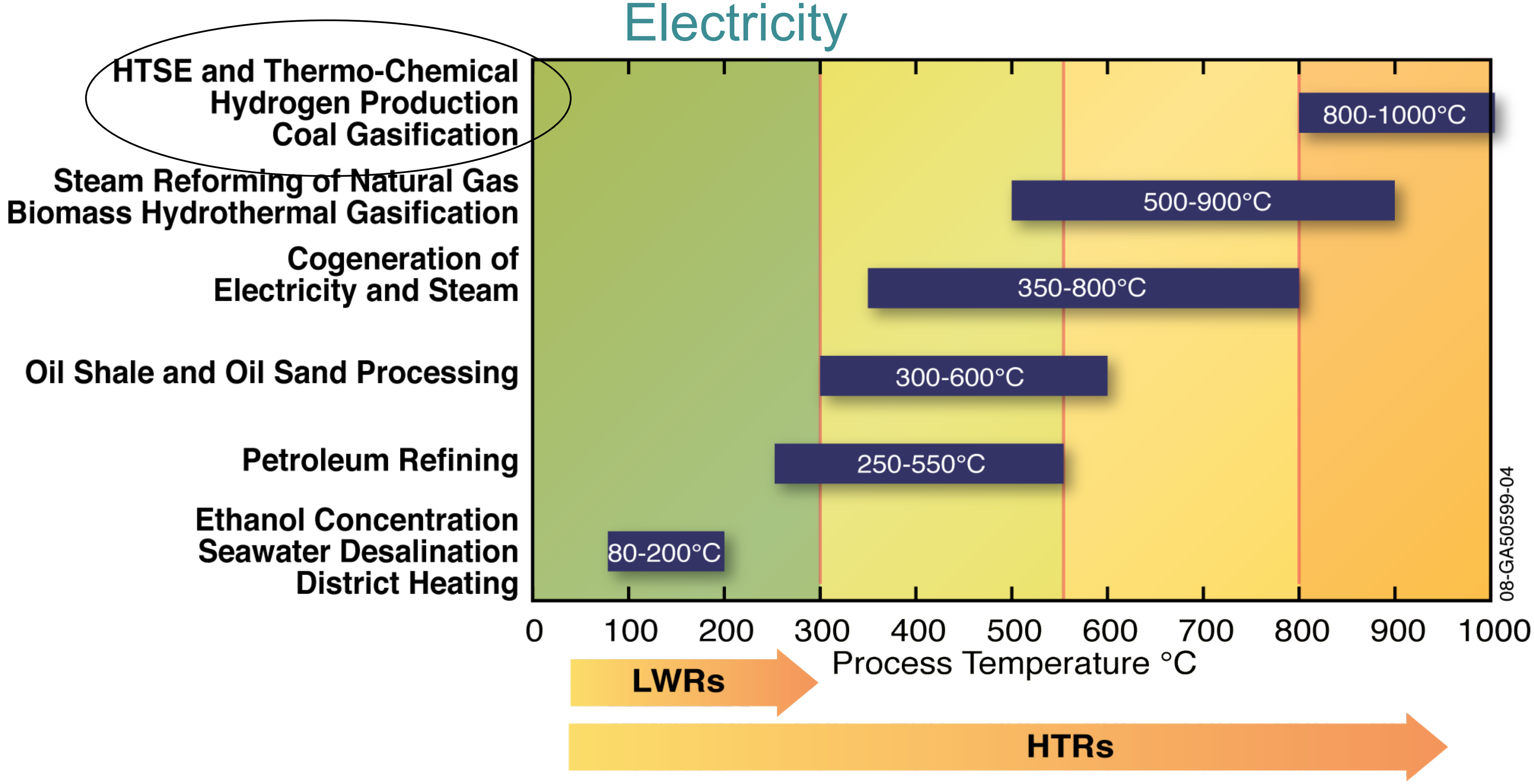


*2011, Energy Information Administration

End-User Interest in HTGR technology

- The intrinsic safety of the HTGR technology is the principal factor considered as it allows collocation or proximate location with major industrial facilities
- High outlet temperatures important for industrial and efficient electric power production
- HTGR technology can be applied to a large number of industrial processes virtually eliminating the carbon footprint:
  - Substitute for the combustion of fossil fuels such as natural gas in production of process heat and electricity
  - Process heat and electricity in conversion of indigenous carbon resources to liquid transportation fuels and chemicals
- Use of the HTGR technology for a process heat source results in:
  - Long term stable energy prices
  - Long term secure and independent source of energy (direct and through conversion)
  - Minimal greenhouse gas and other emissions

High Temperature Gas-cooled Reactors – Application Beyond Electricity



High Temperature Reactors can provide energy production that supports the spectrum of industrial applications including the petrochemical and petroleum industries

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Market Analysis: North America as an Illustration

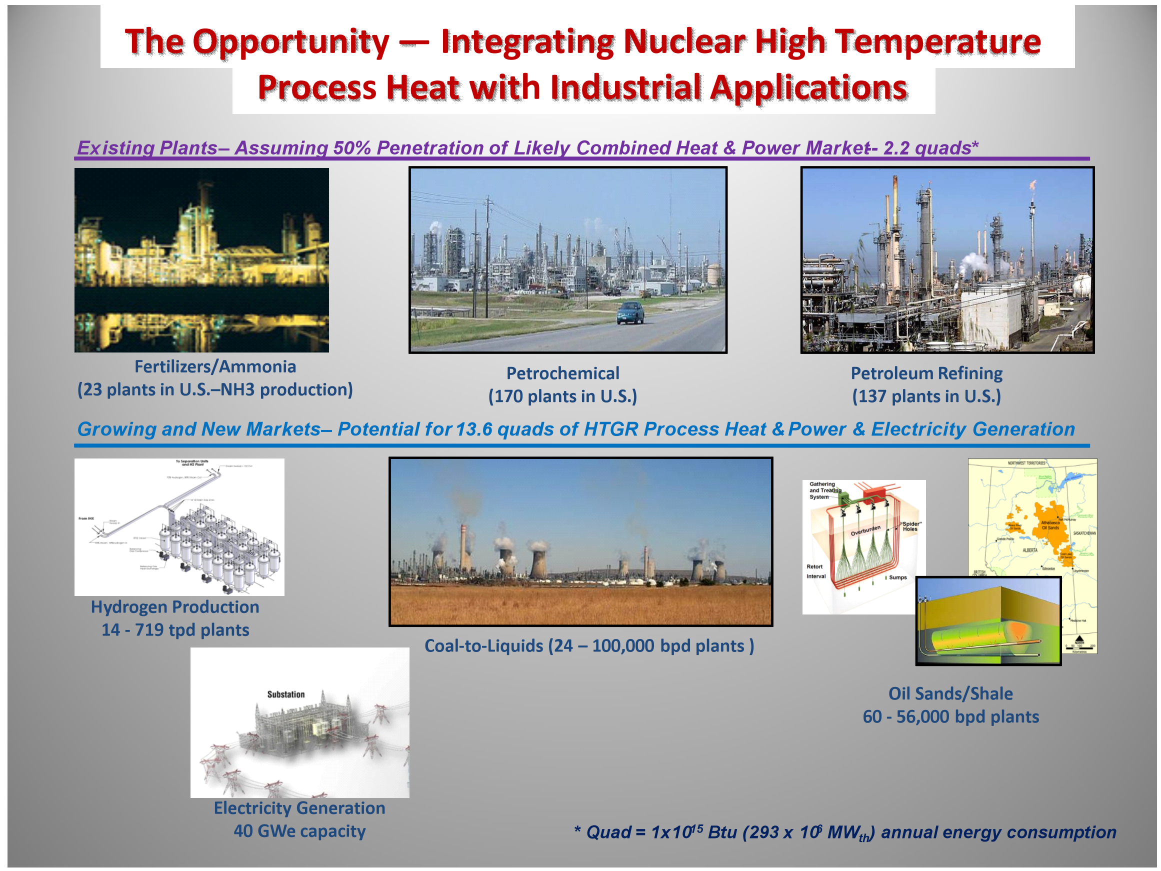
Co-generation
Petrochemical, Refinery, Fertilizer/ Ammonia plants and others
75 GWt (125 – 600 MWt modules)

Oil Sands / Oil Shale
Steam, electricity, hydrogen & water treatment
60 GWt (~100 -- 600 MWt modules)

Hydrogen Merchant Market
36 GWt (60 – 600 MWt modules)

Synthetic Fuels & Feedstock
Steam, electricity, high temperature fluids, hydrogen
249 GWt (415 – 600 MWt modules)

IPP Supply of Electricity
110 GWt (~180 – 600 MWt modules)
10% of the nuclear electrical supply increase required to achieve pending Government objectives for emissions reductions by 2050



An Example

DOW

Energy Uses

900,000 BBL Oil Eqiv / Day

Oil & Gas

Feedstock
Ethane, Propane
Butane, Naphtha

Steam

Power

600 trillion Btu/yr

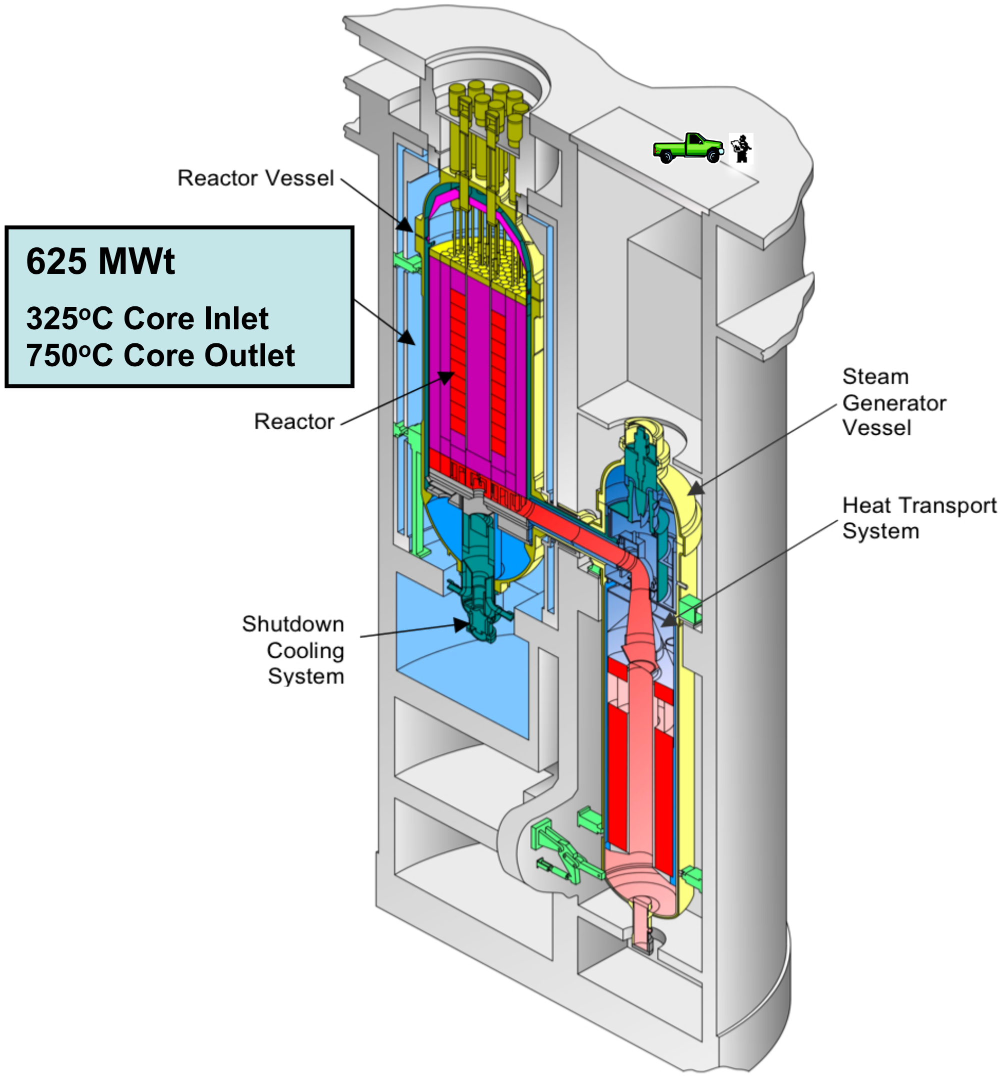
An Example

Dow Energy:

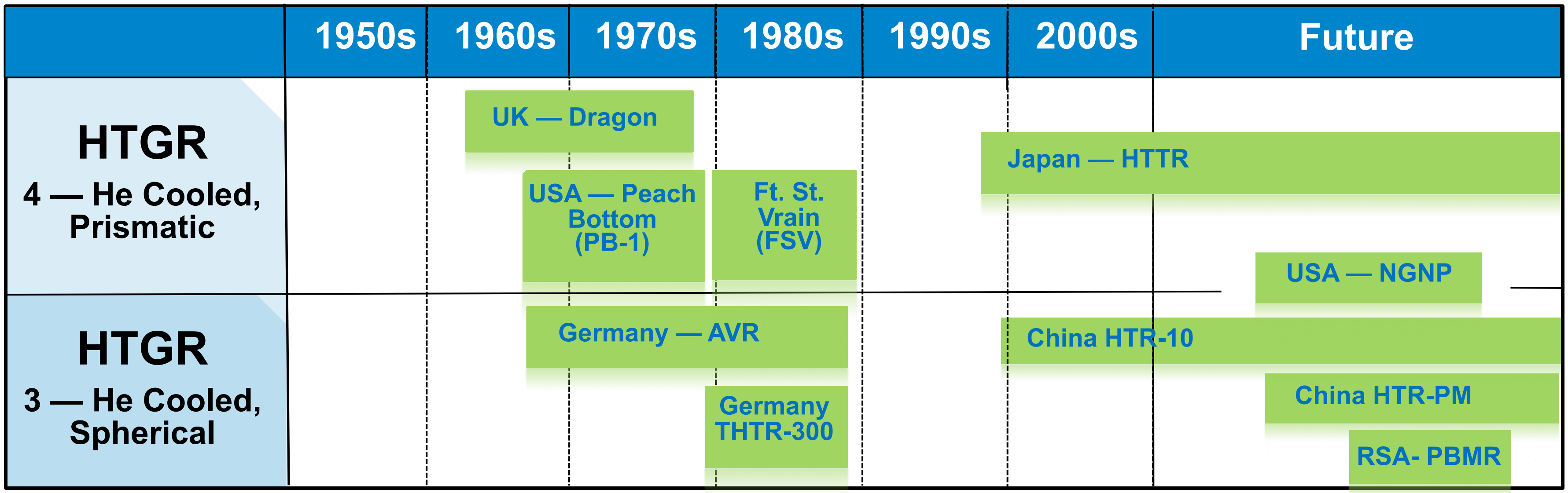
- **$8+ billion in assets**
- **6.5 gigawatts of power & steam annually**
- **13 direct operating sites**
- **Supporting 120 sites in total**
- **More than $2 billion in annual energy purchases**
- **Turning energy cost & climate change risk into an opportunity**

HTGR technology is the only option in the next few decades that can displace fossil fuels for the production of high temperature process heat.

Alliance Selection of AREVA's Prismatic Block HTGR Based On 625 MWt Size



Helium Cooled Reactor History



EXPERIMENTAL REACTORS

COMMERCIAL SCALE DEMONSTRATION OF BASIC HTGR TECHNOLOGY

DRAGON
(U.K.)
1963 -1976

AVR
(FRG)
1967 - 1988

HTTR
(Japan)
1998 - Present

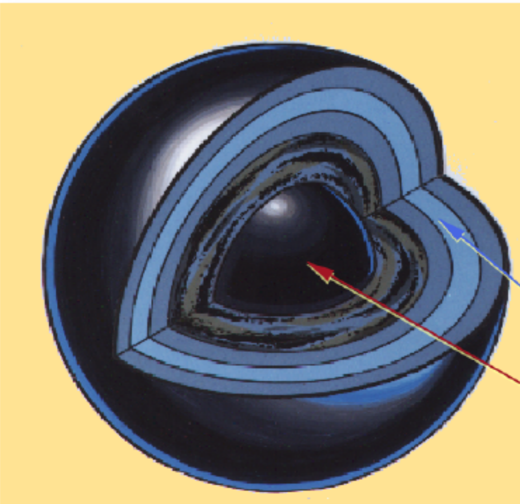
HT10
(China)
2003 - Present

PEACH BOTTOM 1
(U.S.A.)
1967 - 1974

FORT ST. VRAIN
(U.S.A.)
1976 - 1989

THTR
(FRG)
1986 - 1989

Prismatic Reactor Core - Chosen Design



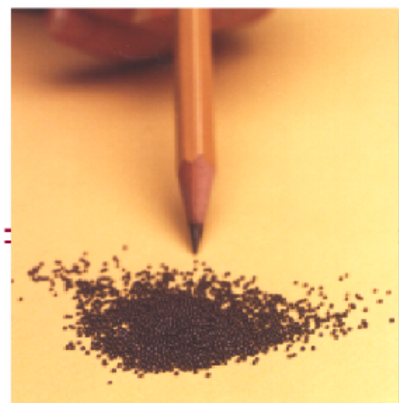
TRISO Coated Fuel Particles:

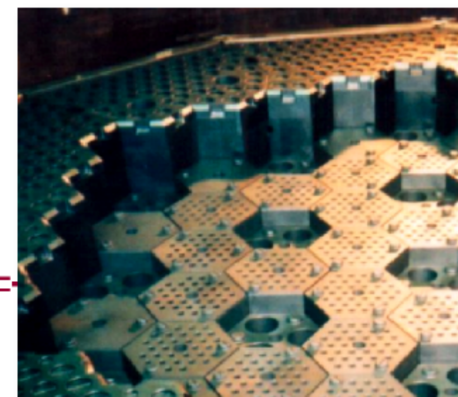
- ***Lots of cladding - extremely strong***
- ***Little fuel - fully encapsulated***

Each fuel particle forms a separate pressure containment vessel for the kernel (to 1000 atm)

Ceramic Coatings

Fuel Kernel (U, Pu, Th, TRU)



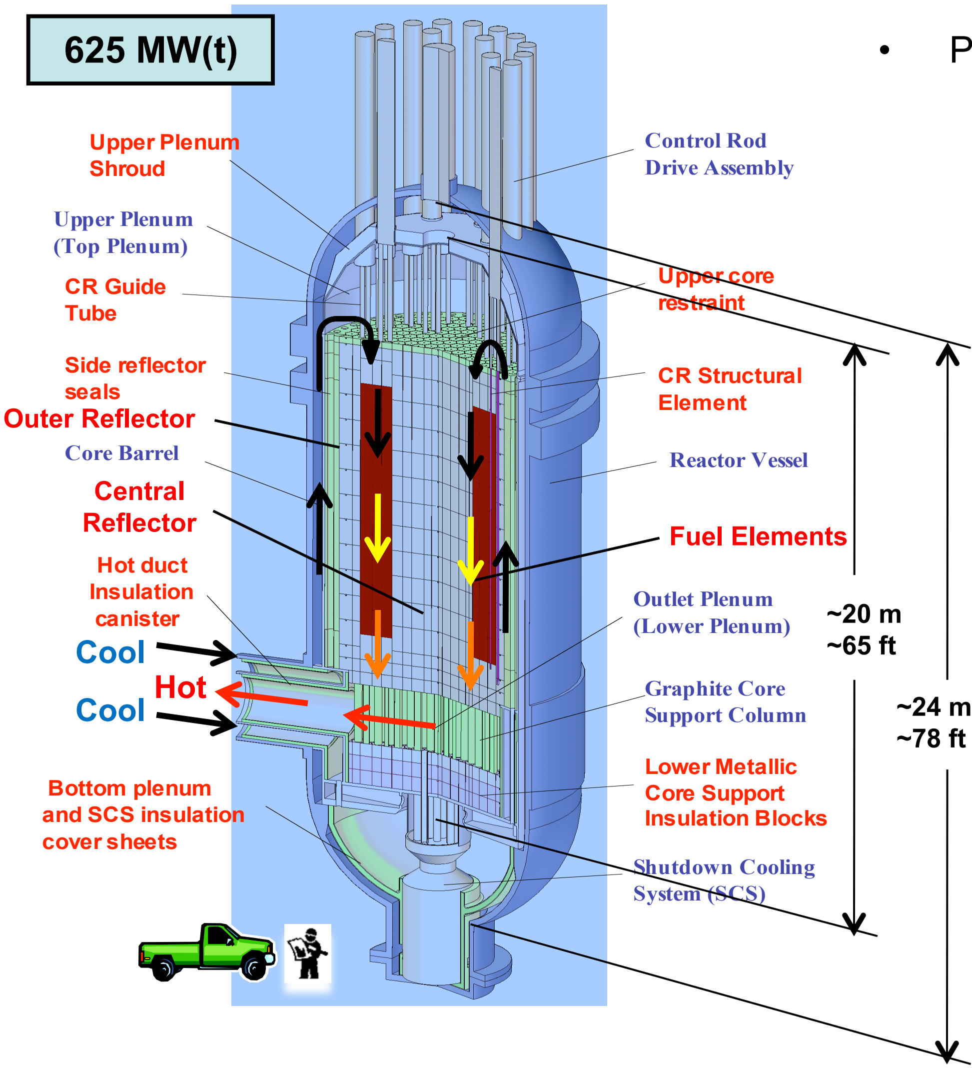


COMPACTS **FUEL BLOCK** **HTGR CORE**

PARTICLES

Prismatic concept illustrated - Pebble Bed variant also possible

Design Approach



- Passive safety features
  - **Negative temperature coefficient reduces reactivity as temperature rises**
  - **Helium coolant**
    - **Non-moderating**
    - **Gaseous phase during all conditions**
    - **Radioactively & chemically inert**
      - **(can be carrier gas)**
  - **Ceramic coated-particle fuel**
    - **Maintains structural integrity during LOCA**
    - **Contains fission products during normal operation**
  - **Low power density (5.8-6.6 w/cc)**
    - **Maintain acceptable temperatures during normal operation and accidents**
  - **Annular graphite core with high heat capacity**
    - **Limits fuel temperature during LOCA (1600°C)**
    - **High temperature structural stability**
      - **(Graphite sublimates ~3700°C)**
    - **High thermal inertia - long temperature rise time for LOCA**
  - **Cool reactor vessel & metallic internals with core inlet gas**

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Highest Level of Safety

Intrinsic Nuclear Safety

No need to evacuate or shelter the public and no threat to food or water supplies under any conditions.

Multiple assured barriers to the release of radioactive material are provided.

Reactor power levels are limited and the nuclear reactor shuts down if reactor temperatures exceed intended operating conditions.

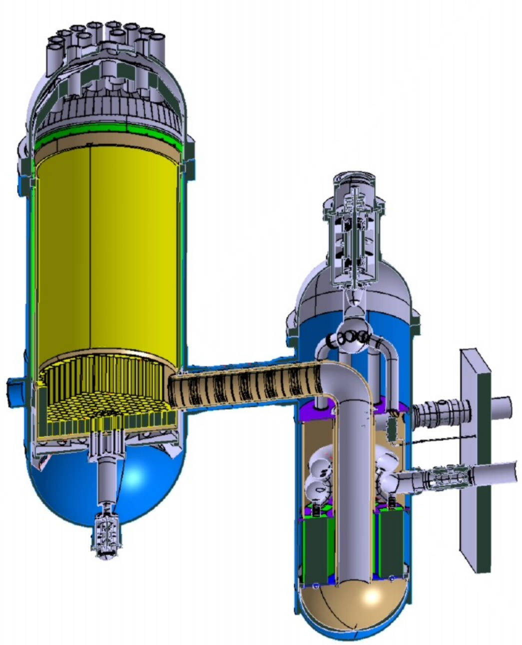
No actions by plant personnel or backup systems are required to either ensure shutdown of the reactor or ensure cooling.

No power and no water or other cooling fluid is required.

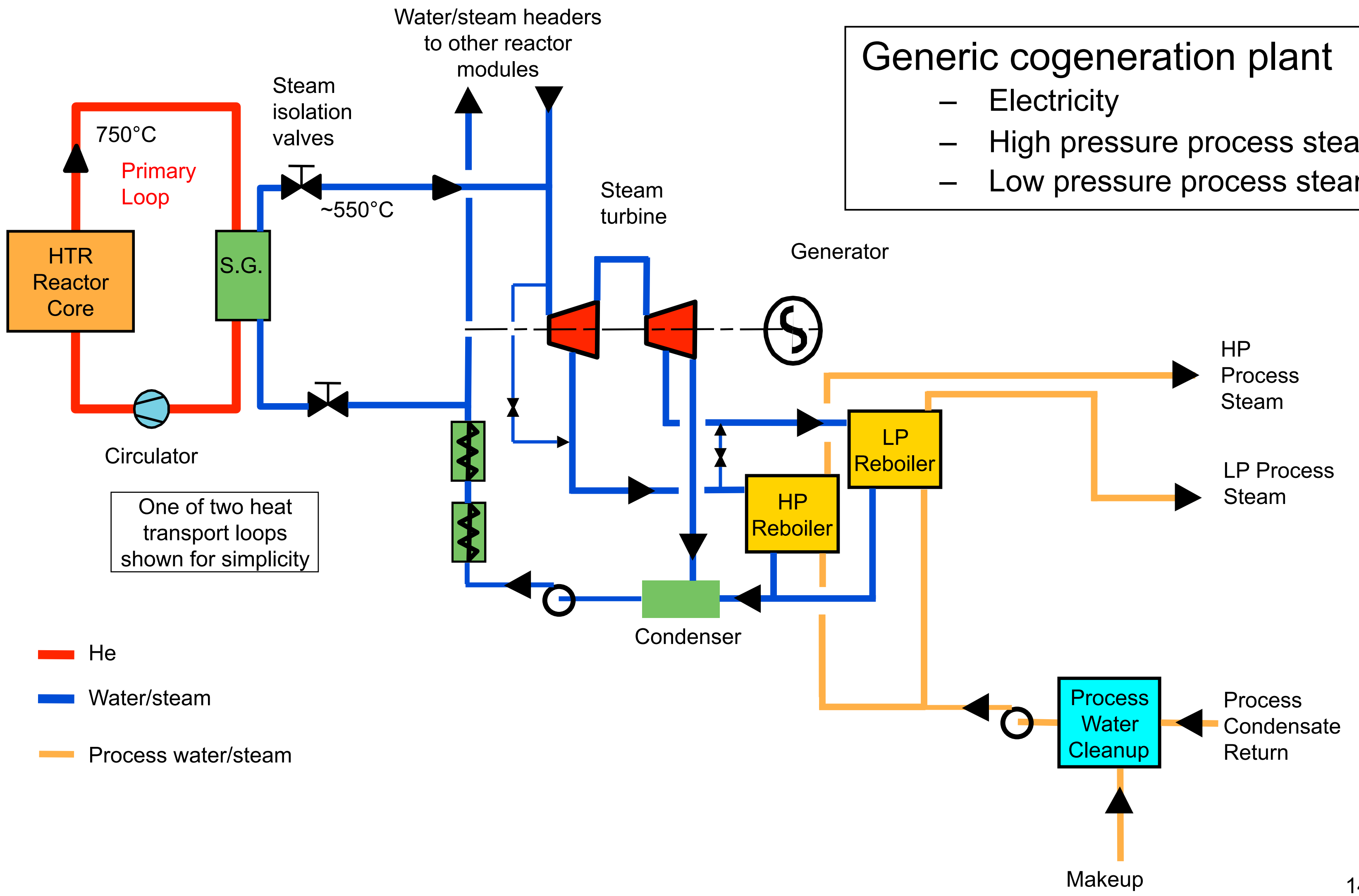
Reactor materials including the reactor fuel are chemically compatible and in combination will not react or burn to produce heat or explosive gases.

Achievable levels of air or water intrusion do not result in substantive degradation of the capability to contain radioactive materials.

Spent or used fuel is stored in casks or tanks in underground dry vaults that can be cooled by natural circulation of air and shielded by steel plugs and concrete structure.



Single Reactor Module Design Supports Many Applications



Generic cogeneration plant

- Electricity
- High pressure process steam
- Low pressure process steam

Development Venture

R&D	$ 316MM[19]
Conceptual and Preliminary Design	$ 280MM
Final Design	$ 200MM
Licensing thru COLA Preparation	$ 165MM
Equipment and Infrastructure Development	$ 648MM
Inspections, Testing and Modifications (FOAK initial operations)	$ 75MM
Total	**$ 1684MM**

<u>Currently ongoing activities include R&D and pre-application licensing</u>

- Status of R&D is on the next slide. Objectives include:
    - Resolving generic gas-cooled reactor technology issues
    - Leveraging return on $285M R&D investment made over past 9 years

- NRC positions on a broad range of HTGR-specific topics are being formalized at present based on review of topical white papers

R&D Status

- TRISO fuel qualification – fabrication, irradiation and safety testing for UCO
  - Results to date are consistent with design basis for fuel performance and safety design basis for radionuclide retention under accident conditions
  - UCO irradiation performance has been confirmed – no failures in 300,000 particles for high burnup (19.4% FIMA), peak fast fluence of $4.5x10^{25}$ n/m^2 and peak average temperature of 1250^{o}C
  - In-reactor testing continues – large scale and accident testing
- Graphite qualification – characterization, irradiation testing, modeling and codification
  - Irradiation testing and post-irradiation examination underway
  - Fundamental mechanistic behavior being codified
- High temperature materials qualification – characterization, high temperature testing and codification
  - Thermomechanical behavior characterized for IN617, 800H and A508/533
  - Data available for code cases and new design rules being developed
- Design and safety methods – development and validation
  - Two large experimental validation facilities at Oregon State and ANL
  - Collaboration with HTTR in Japan

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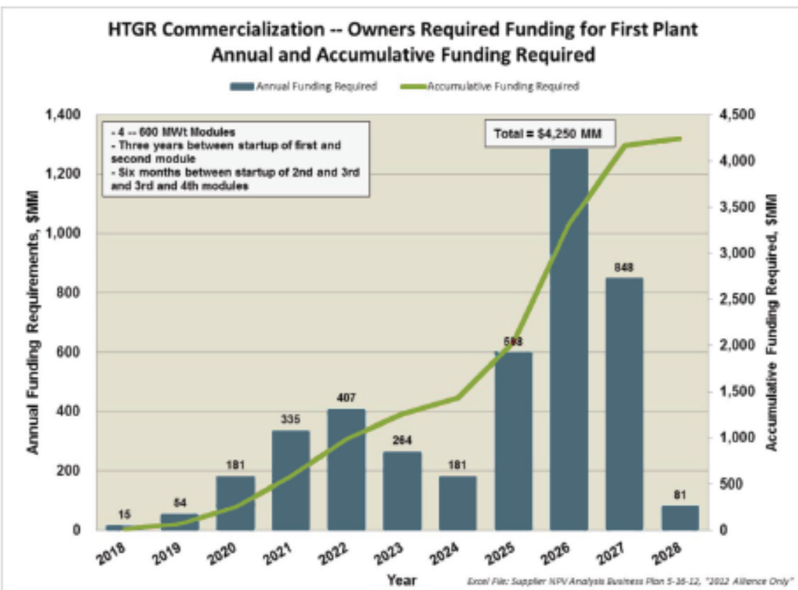
Deployment Project

Complete site-specific design	$ 100MM
Construction permit/license application/review	$ 65MM
Equipment procurement	$ 432MM
Construction	$ 625MM
Startup & testing	$ 55MM
Initial operations (3 years)	$ 348MM
Revenue (initial 3 years)	–$ 265MM
Total	**$1,360MM**

Demonstration Module



First Four-module Plant

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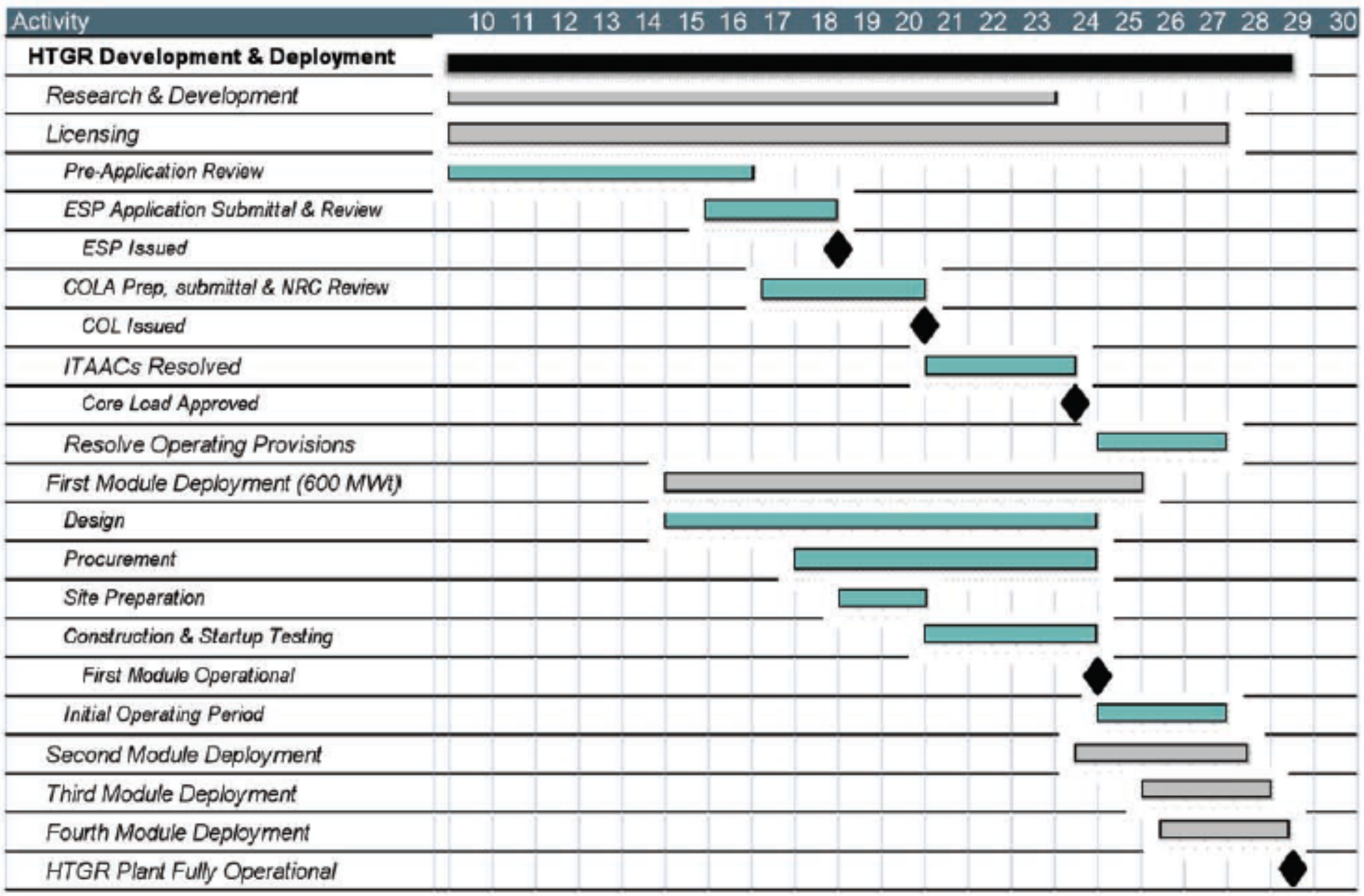
Schedule for the Deployment Project



Some Important Milestones

- Study completed on locating an HTGR cogeneration plant on an operating nuclear power plant site to supply process heat for petrochemical industry end-users - Waterford, LA study performed. Aiken - Augusta area is also ideal location
- Study completed on integration of HTGR technology with oil-sands processes in Alberta, Canada
- Studies completed on HTGR assisted carbon conversion industry in two US states (Wyoming and Kentucky)
- Multiple studies for use of HTGR technology to provide energy for industrial process plant applications
- January 2013, DOE awards Alliance 50/50 contract to further economic and market studies on HTGRs
- Formation of European analog to our Alliance,NC2I and plans for a fall meeting in Washington D.C.
- Discussions in Saudi Arabia on HTGRs
- MOU with KAERI in Korea on HTGR hydrogen production
- Working to find coal industry partners

Proposed Actions

- State of South Carolina, SRNL, NGNP Industry Alliance and INL work together to scope/explore potential joint study on HTGR uses in Aiken - Augusta area
- State entity join NGNP Industry Alliance and work nationally and internationally to advance HTGR demonstration and commercialization
- Encourage SC Industry to work with Alliance
- State works with Alliance in Washington to increase federal support

HTGRs Present A Unique Opportunity to Extend The Benefits of Nuclear Energy Beyond Electric Power and to Help Rebuild the U.S. Industrial Base and Balance of Trade

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