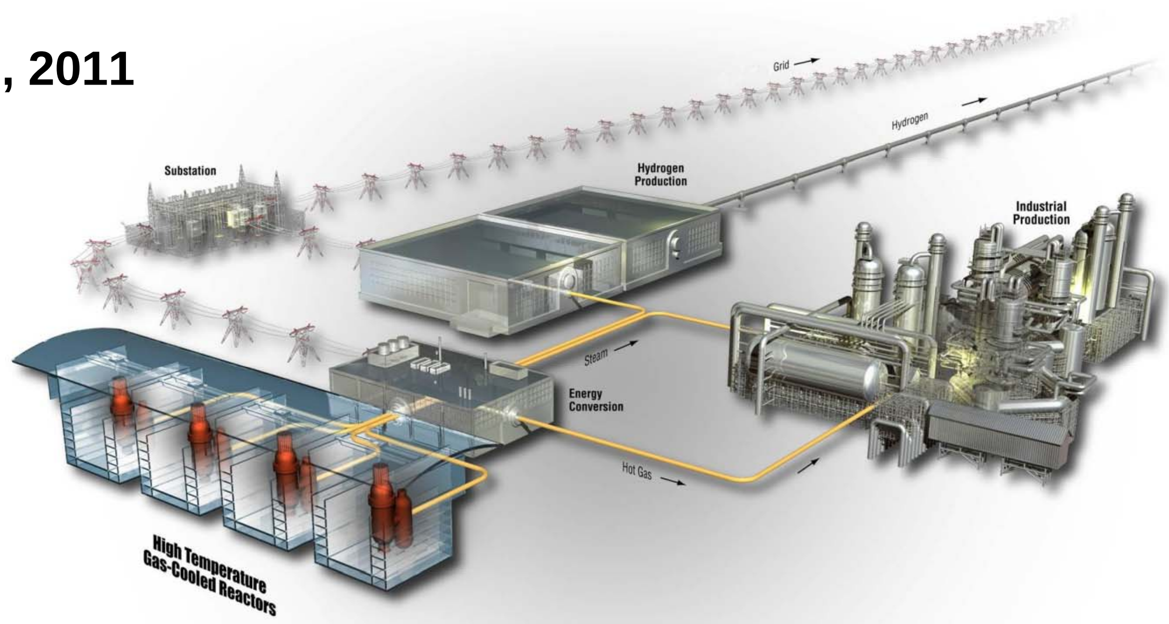
HTGR
Project Costs, NOAK Plant Costs, Market Assessment with Preliminary Economics

Discussion with

NEAC

April 20, 2011



NGNP Next Generation Nuclear Plant

www.inl.gov

INL Idaho National Laboratory

Outline

- NGNP Project Cost Summary
  - Current estimated costs to complete
  - Cost share alternatives
- HTGR NOAK Plant Capital Costs
  - Historical
  - GA CDR and AREVA PBR Status Updates
- Current Market Assessment with Preliminary Economics
  - Co-gen update
  - Current Oil Sands / Oil Shale
  - Hydrogen, Synthetic Fuels and Feedstock

Updated Technical Risk Assessment and Project Cost Estimate

- RSA terminates support of PBMR Pty Ltd. which had been developing the pebble bed reactor design and supporting the NGNP Project
- General Atomics (GA) submits Conceptual Design Report (CDR) in December 2010
- AREVA submits report summarizing status of pebble bed reactor development in January 2011

Updated assessment included:

- Potential additional scope for qualification of pebble bed fuel and graphite
- Reconciliation of technical readiness levels based on design requirements to fulfill end-user functional requirements
- Development of most likely cost to complete the NGNP Project through reconciliation of prior cost estimates and the Project costs cited in the GA CDR

Estimated Costs to Complete the Project

Project Element (2011$ Costs to Complete Project 2012-2026)	Two Plants through COLA Submittal -- One plant selected for completion ($M)	Single Plant Selected Now ($M)
Research & Development	826	671
Selected Plant Design	582	582
Non-Selected Plant Design	286	0
Licensing	318	222
Procurement	1,083	1,083
Construction Labor	619	619
Startup & Testing	54	54
Initial Operations	416	416
Income during Initial Operations	-264	-264
Partnership Management	131	93
Process Heat Development	108	108
Project Total Estimate	**4,050**	**3,476**

Cost Share

- The total Project cost is estimated to be from ~$3.5 to ~$4 billion (depending on the extent of design and licensing work before down select for the plant to be constructed)

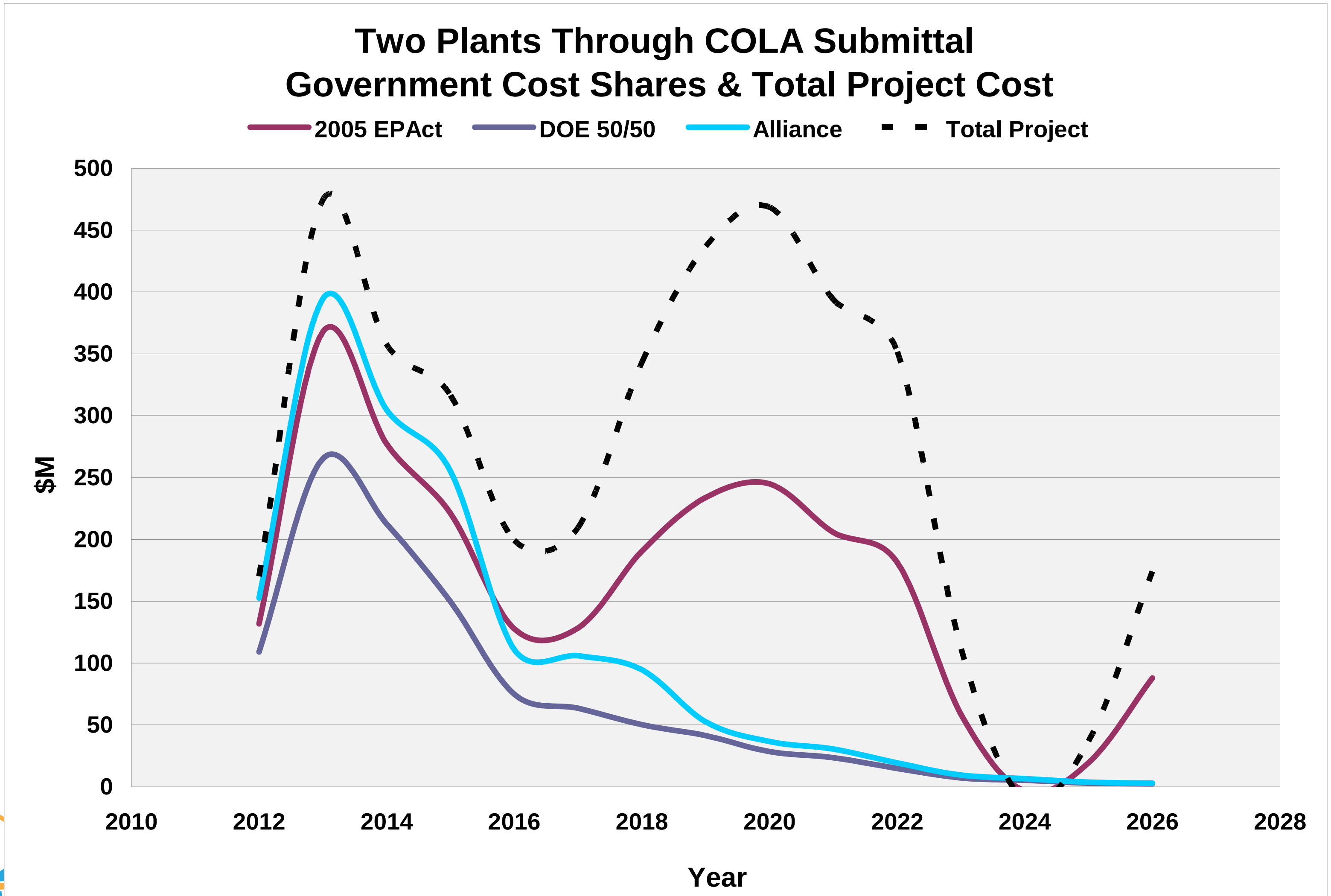
- Government cost share:
  - 59-61% based on EPAct 2005 (R&D, design, licensing and construction)
  - 22-26% based on DOE 50/50 for R&D, design and licensing, and no cost share for plant construction
  - 32-39% using private sector (Alliance) proposed cost share wherein private sector pays for 100% of plant procurement and construction – asks government to take larger upfront cost share and minimal later government cost share commensurate with business risk

- No cost share is occurring because DOE has not secured a comprehensive public-private partnership with the private sector

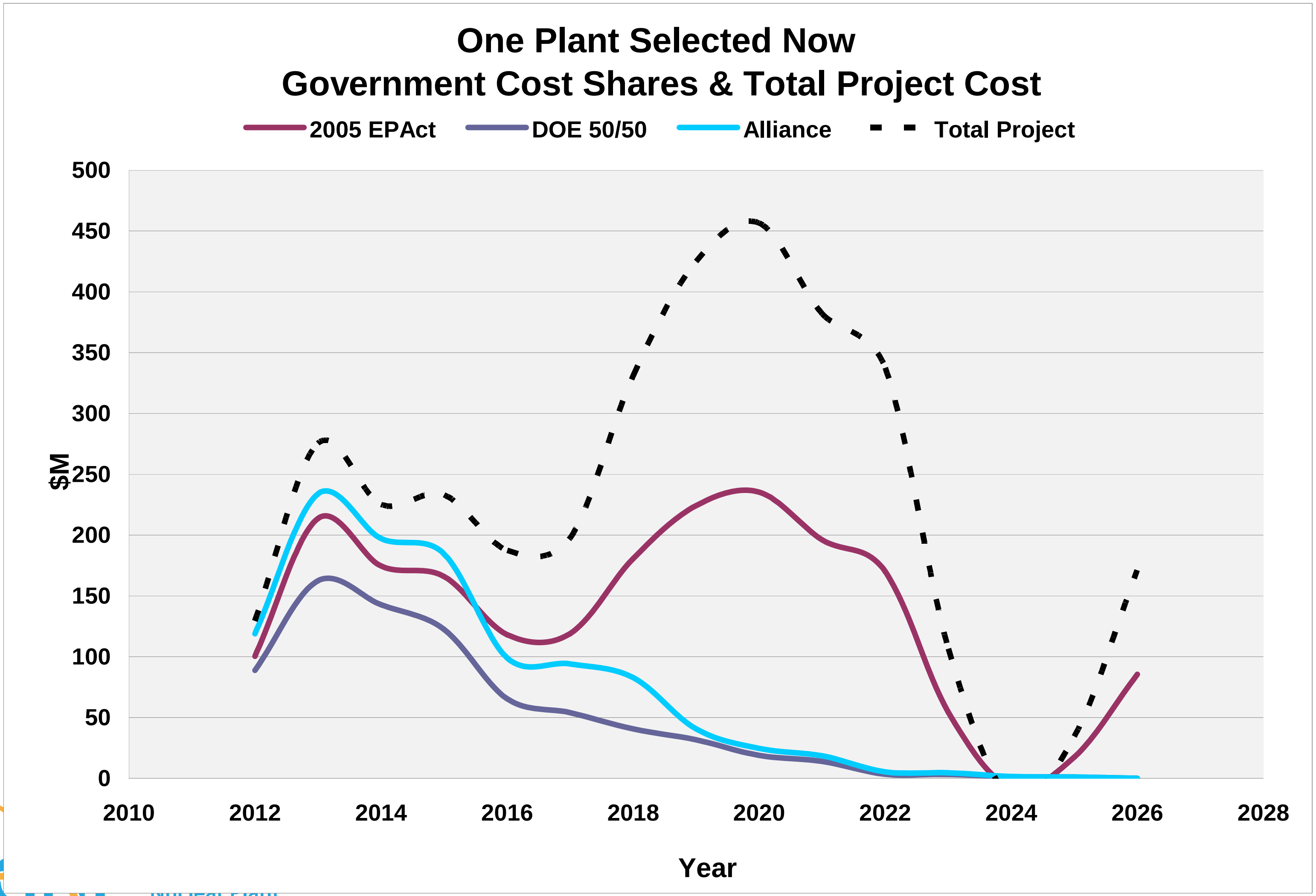
Project Cost, Cost Share and Private Sector Split

Project Element (2011$ Costs to Complete Project 2012-2026)	Two Plants through COLA Submittal			Single Plant Only		
	EPAct Cost Share ($M)	DOE 50/50 Cost Share ($M)	Alliance Cost Share ($M)	EPAct Cost Share ($M)	DOE 50/50 Cost Share ($M)	Alliance Cost Share ($M)
Project Total Estimate	4,050	4,050	4,050	3,476	3,476	3,476
Government Funding	2,487	1,066	1,599	2,048	750	1,107
Private Sector Funding	1,563	2,984	2,451	1,427	2,726	2,369
Nuclear System Supplier Share	316	512	144	221	322	83
Plant Owner Share	1,182	2,389	2,238	1,160	2,342	2,235
Other Share	65	83	69	47	62	50

Project Cost and Government Cost Share



Project Cost and Government Cost Share

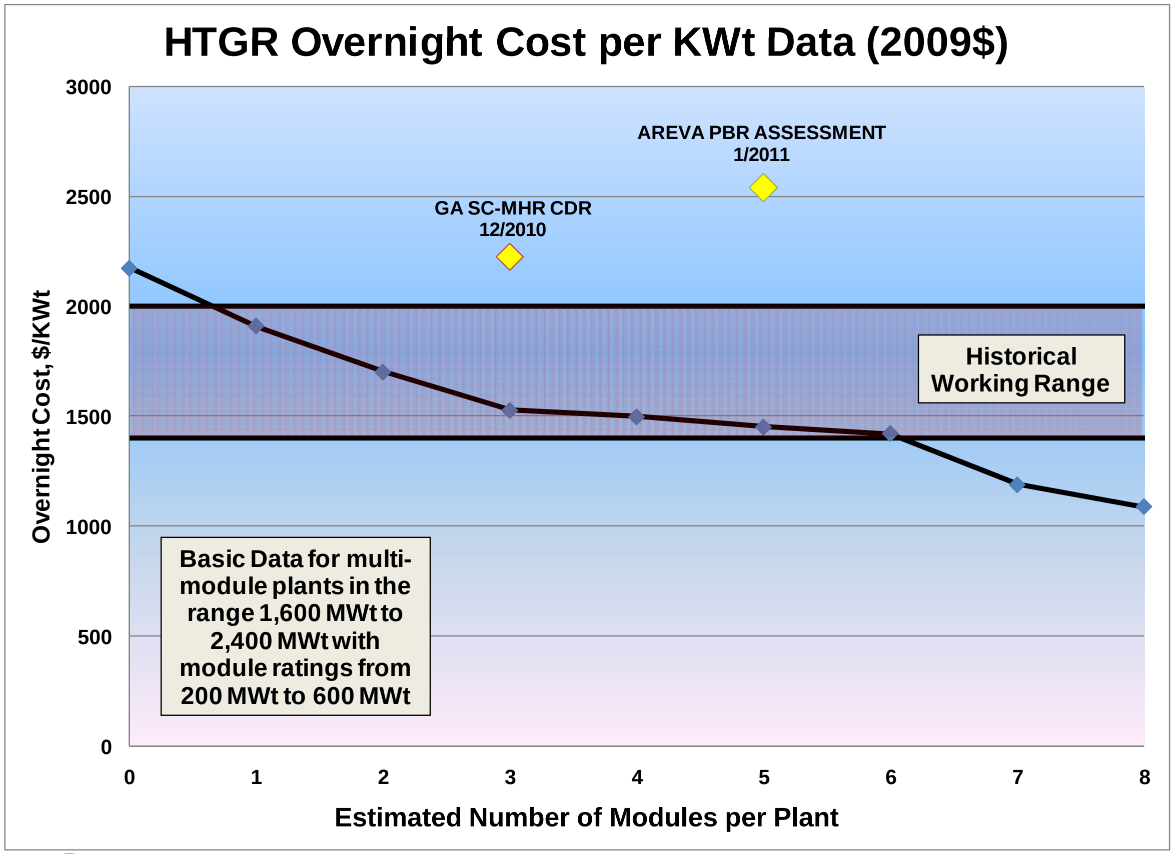


Updates to HTGR NOAK Plant Costs

Updates to HTGR Design & Costs

- Reconciled past estimates for NGNP Demonstration, first of a kind (FOAK) and Nth of a kind (NOAK) plant costs with those developed by General Atomics in the SC-MHR Conceptual Design Report and AREVA in the assessment of the pebble bed reactor design status (based on German HTR Modul)
- Developed an INL detailed plant cost model with the capabilities to develop cost estimates for:
  - Demonstration, FOAK and NOAK Project phases
  - Variations in module rating, module configuration and plant rating
  - Variations in reactor outlet temperature
  - Implemented model in correlations of construction cost (EPC cost) for these variations
- Reconciled INL cost model with the prior GA and AREVA estimates
- Applied INL plant cost models in evaluations of the economics of HTGR use in industrial applications

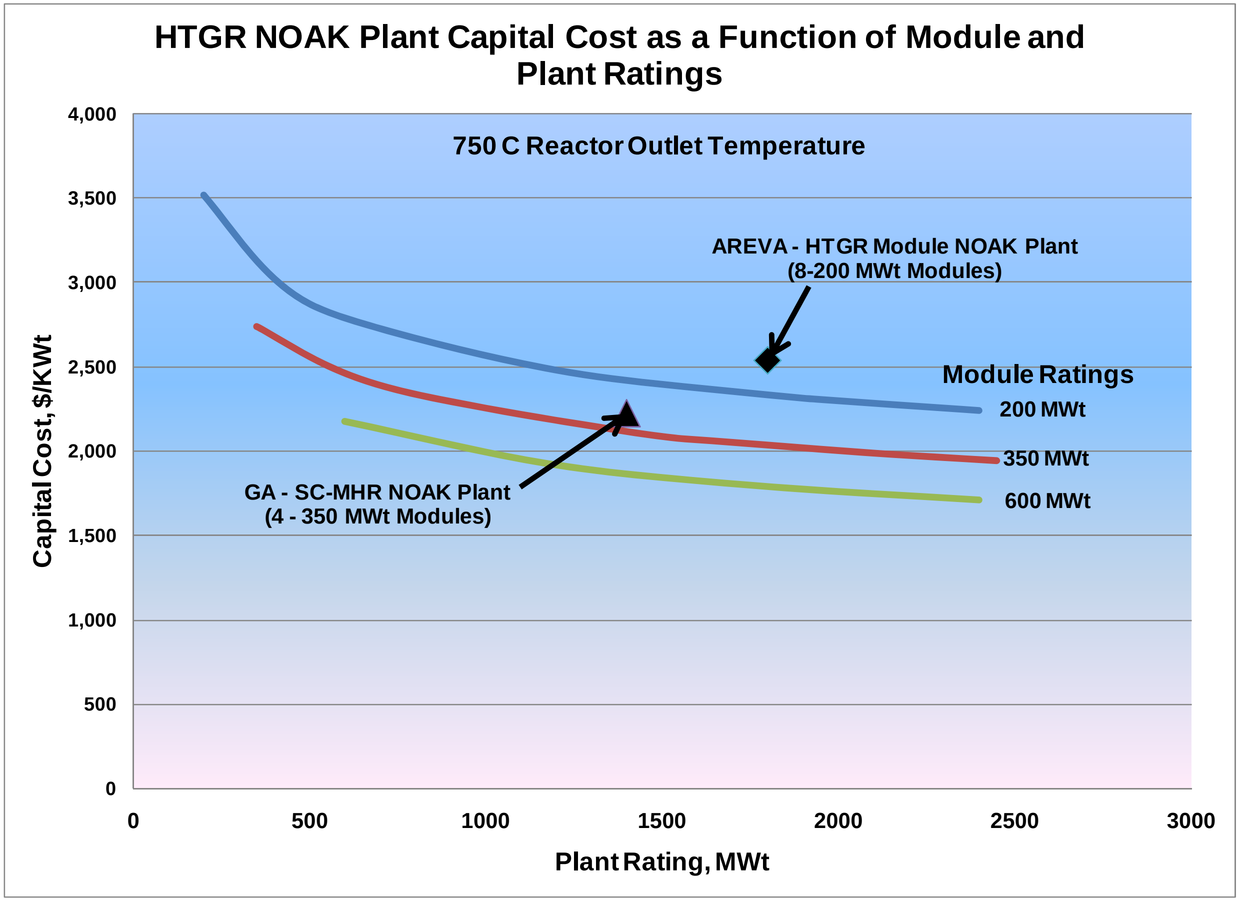
HTGR Capital Cost Estimate -- Historical data in comparison with GA and AREVA estimates



- Recent cost estimates are higher than historical data
- Many of the prior estimates were based on adjusting decades old data , (e.g., MHTGR) for general inflation
- 2010 GA cost estimate based on a bottoms up approach
- Escalation of commodity prices has been much higher than average inflation rate
- 2011 AREVA costs based on prior German estimates for HTR Modul nuclear island and bottoms up for remainder of plant
- Detailed reconciliation of GA and AREVA estimates with prior work is in process

NGNP Next Generation Nuclear Plant

INL Independent Plant Capital Cost Model



Observation:

- It is uncertain whether there is a significant difference in the per unit cost of a pebble bed or prismatic reactor based plant

- Detailed reconciliation of GA and AREVA estimates with prior work is in process

Market Assessment & Economics

Market Evaluations Update

- Completed more detailed assessment of co-generation market
  - Visited refinery, ammonia plant, petro-chemical plants
  - Assessed refinery, petro-chemical, paper mill, ammonia and other co-generation plant sizes and energy needs
  - Met with General Atomics on the GA market assessment
    - GA market assessment focused on co-generation only

- Expanded assessment of Alberta Oil Sands
  - Expanded potential application evaluations to supply energy for electricity and hydrogen generation and water treatment
  - Met with PTAC

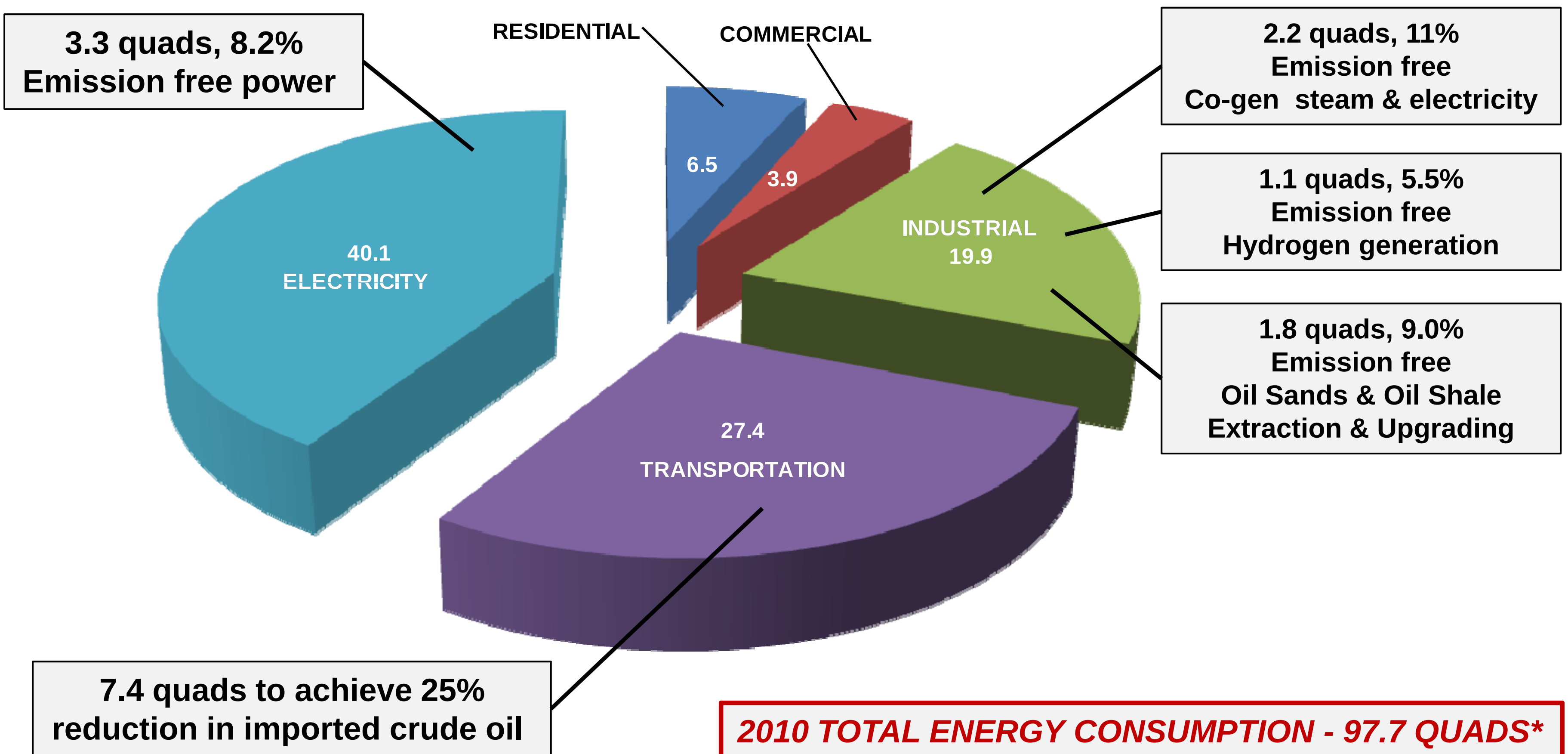
- Evaluated Potential of Oil Shale Market

HTGR Economics

- Application of HTGR technology in the ***Merchant Marketplace*** as an energy supply for varied industrial applications
  - Combined heat and power plants ***dedicated*** to one or more industrial plants
  - ***Long term*** (20 year, renewable) energy supply contract
    - Steam, electricity, high temperature fluid, hydrogen, oxygen
  - Plant life time at least ***60 years***
  - Co-generator supply of electricity to the grid

- ***Independent Power Producer*** supply of electricity to the grid
  - High efficiency – 42% net and above
  - Adaptable to regional conditions and T&D capacities
    - Modular (200 MWt to 625 MWt), low water requirements

Potential Market vs Total Energy Consumption



2010 TOTAL ENERGY CONSUMPTION - 97.7 QUADS*
POTENTIAL HTGR MARKET – 15.8 QUADS (16%)

NGNP Next Generation Nuclear Plant

*** 1 quad = 1 x 10^{15} Btus or ~33.5 GWt (56 – 600 MWt modules)**

Size of the potential market

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

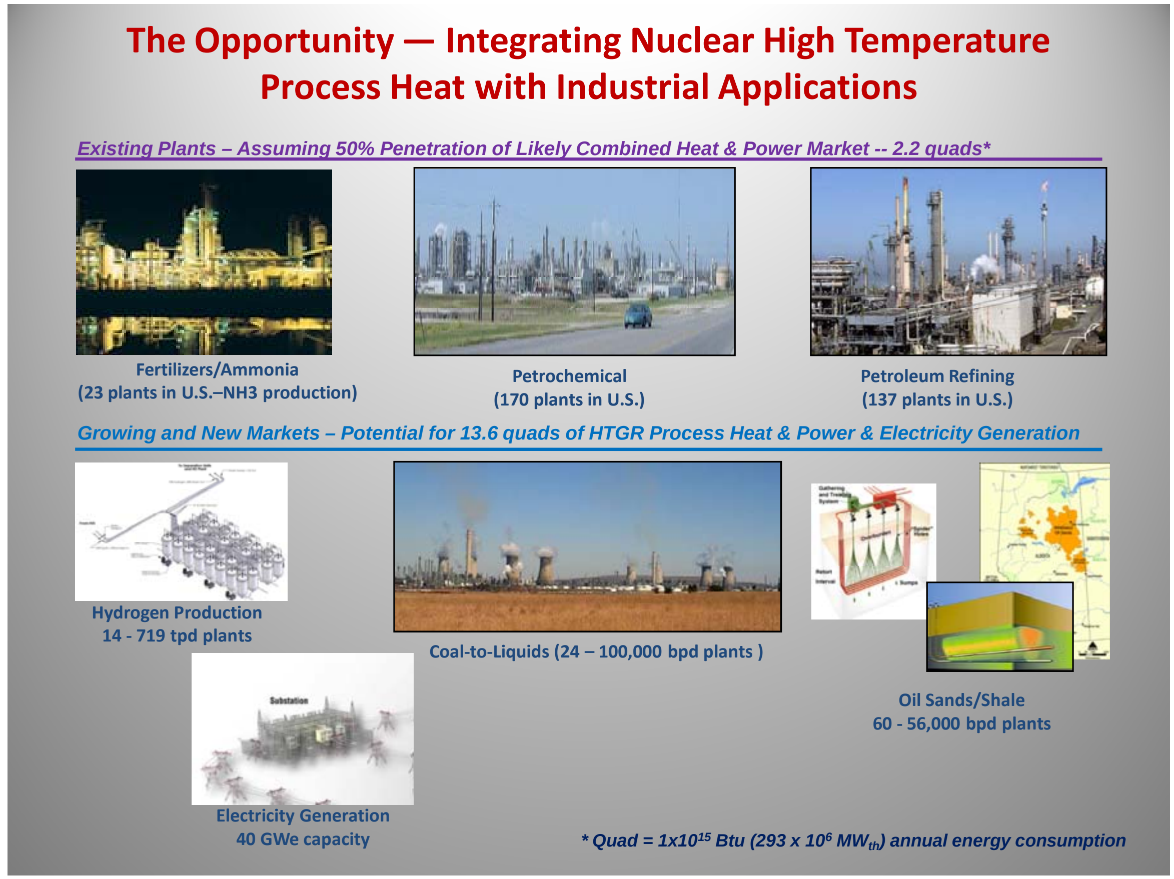
Steam, electricity, high temperature fluids, hydrogen

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



Next Generation Nuclear Plant

Thermal *Power Requirements for Potential Markets*

- ✓ **75,000 MWth Co-Generation Supply of Process Heat to Industrial Processes**

  (50% of most likely candidates for HTGR Process Heat & Power, including electricity)

- ✓ ***36,000 MWth for Production of Hydrogen***

  (25% of growth in the merchant market)

- ✓ **60,000 MWth for Oil Sands & Oil Shale Bitumen Recovery & Upgrading**

  (25% of projected growth in energy required to extract & upgrade bitumen)

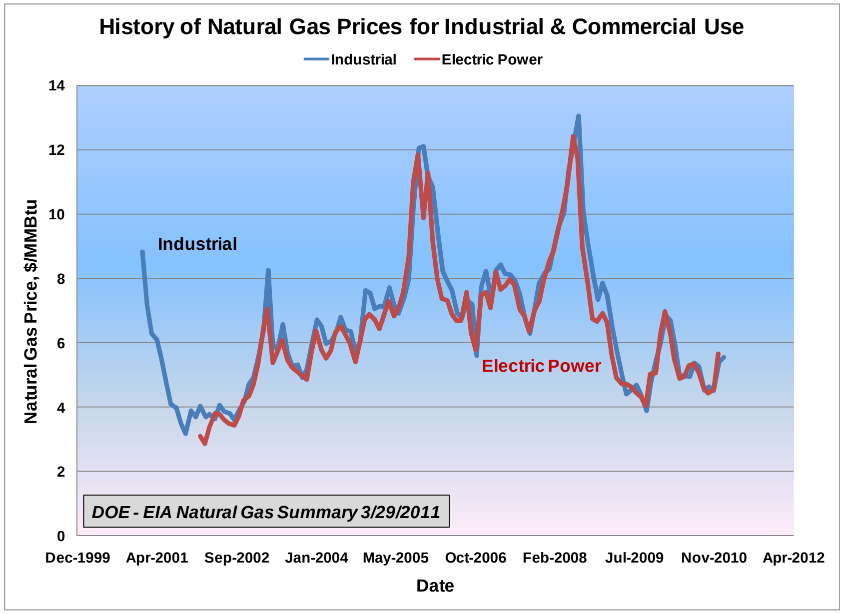
- ✓ **249,000 MWth for Coal Conversion to Transportation Fuels & Feedstock**

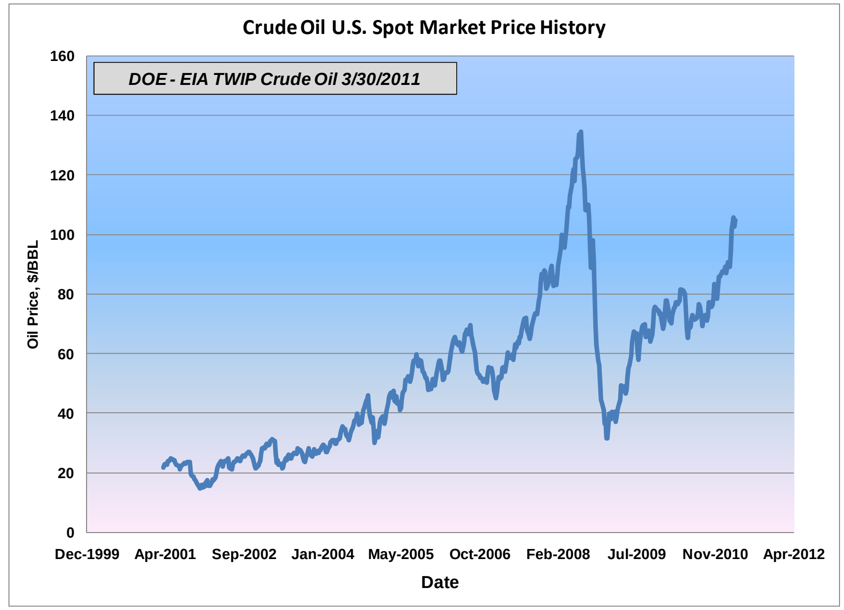
  (Reduces imports by 25% of 2010 imports of crude oil – 9.2 MMBPD)

- ✓ **110,400 MWth for Electricity Production**

  (10% of the nuclear electrical supply increase required to achieve pending Government objectives for emissions reductions by 2050)

History of Natural Gas & Crude Oil Prices





Usage	Average	Maximum	Minimum
Residential	12.4	20.8	7.1
Commercial	9.9	15.6	6.3
Industrial	6.6	13.1	3.2
Electric Power	6.4	12.4	2.9

Item	$/BBL
Average	52.2
Maximum	134.4
Minimum	14.9

Postulated Deployment of HTGR Results in Stable Energy Prices, Secure Source sand Reduced Emissions -- HTGR Energy Prices are affected only by normal inflationary factors, (e.g., wages, material)

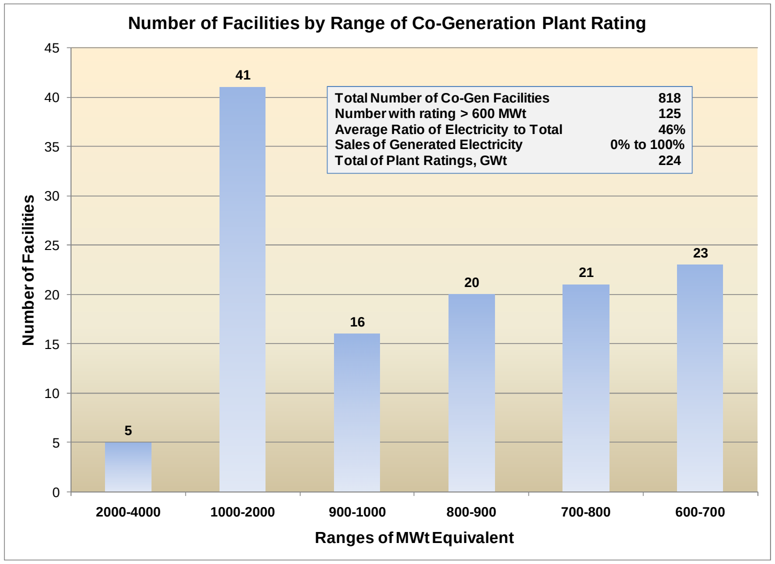
Next Generation Nuclear Plant

Characteristics of Potential Market – Co-Generation

- HTGR technology is readily applied as a substitute for conventional fossil fired sources of energy used in co-generation applications for steam & electricity generation
- Market is highly varied ; comprised of multiple plants with varying ratings supplying energy to different industries
  - Petrochemical, aluminum & plastics plants, paper mills, crude oil and bio-refineries, ammonia & fertilizer plants
  - 125 sites out of 820 in U.S. with ratings > 600 MWt have potential for HTGR application
  - Most likely sites for application of HTGR technology consume on average ~130 GWt
  - Most likely sites for HTGR application have a combined energy ratings of 150 to 160 MWt

50% of most likely market – ~75 GWt, equivalent to ~120 – 600 MWt plants

Characteristics of Co-Gen Plants in U.S.



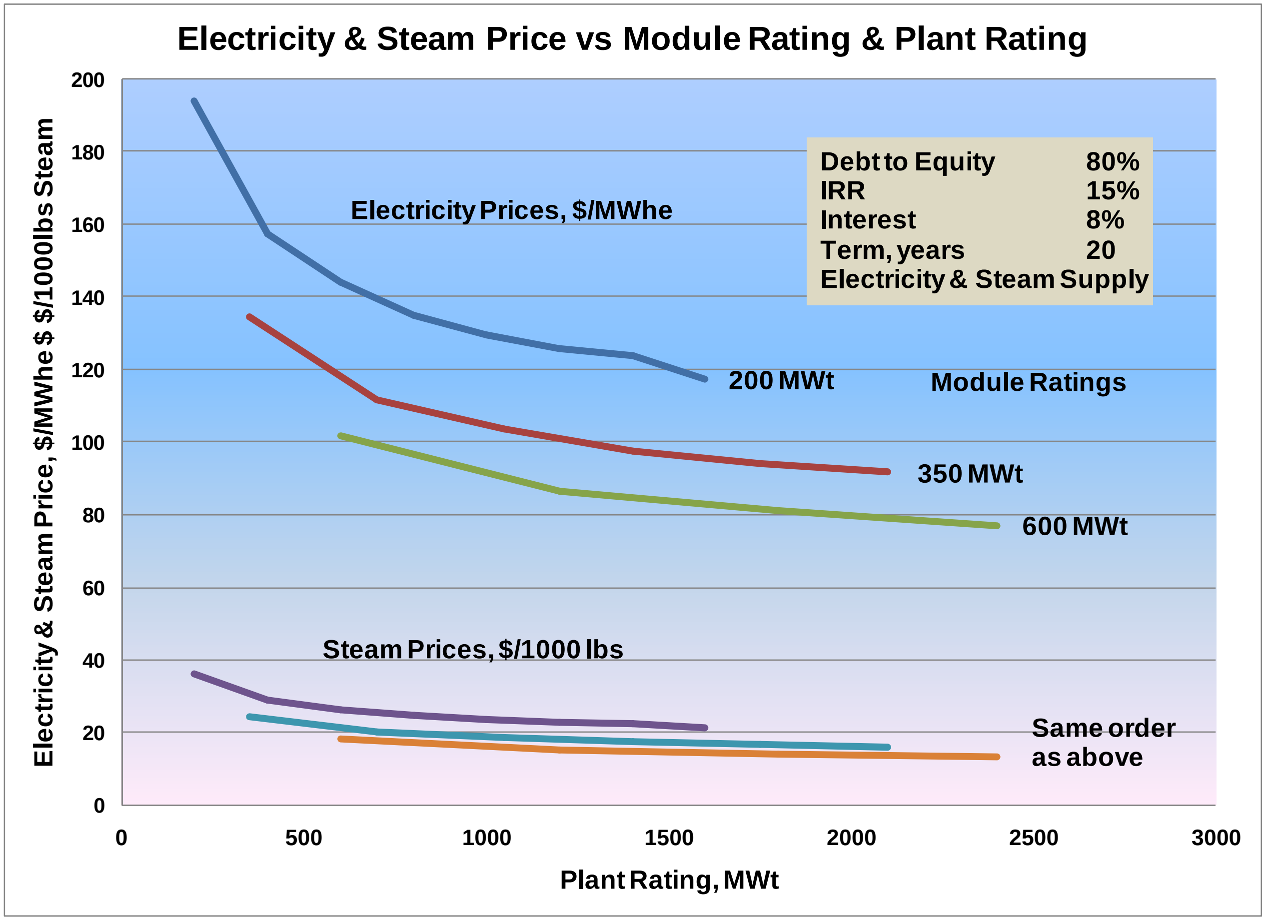
- The 62 plants with ratings > 900 MWt are the more viable on a pure economic basis; others have potential if carbon emissions are regulated
  - ~80 GWt out of a total of ~130 GWt
- ~50% of the total energy consumed by these plants is used to generate electricity
- For those plants that supply both steam and electricity ~50% of the electricity is sold off-site

- Peak to average demand ran ~120% in 2009 (see next slide): total capacity for the 125 plants > 600 MWt is ~160 GWt
- Excess plant capacity is required to accommodate variations in demand and availability requirements
- Excess electricity generation capacity with sales to the grid is used to meet these requirements

Plant Rating Range, MWt	Average Ratio of Energy used for Generation of Electricity to Total Energy	Average Rating of Plants in Range, MWt	Number of Plants In Range	Total Potential Market, GWt
2000 - 3000	39.3%	2,437	5	12.2
1000 - 2000	55.1%	1,363	41	55.9
900 - 1000	50.1%	946	16	15.1
800 - 900	45.6%	854	20	17.1
700 - 800	24.7%	754	21	15.8
600 - 700	46.9%	643	23	14.8
Totals			126	130.9

Next Generation Nuclear Plant

Economics Supplying Steam & Electricity

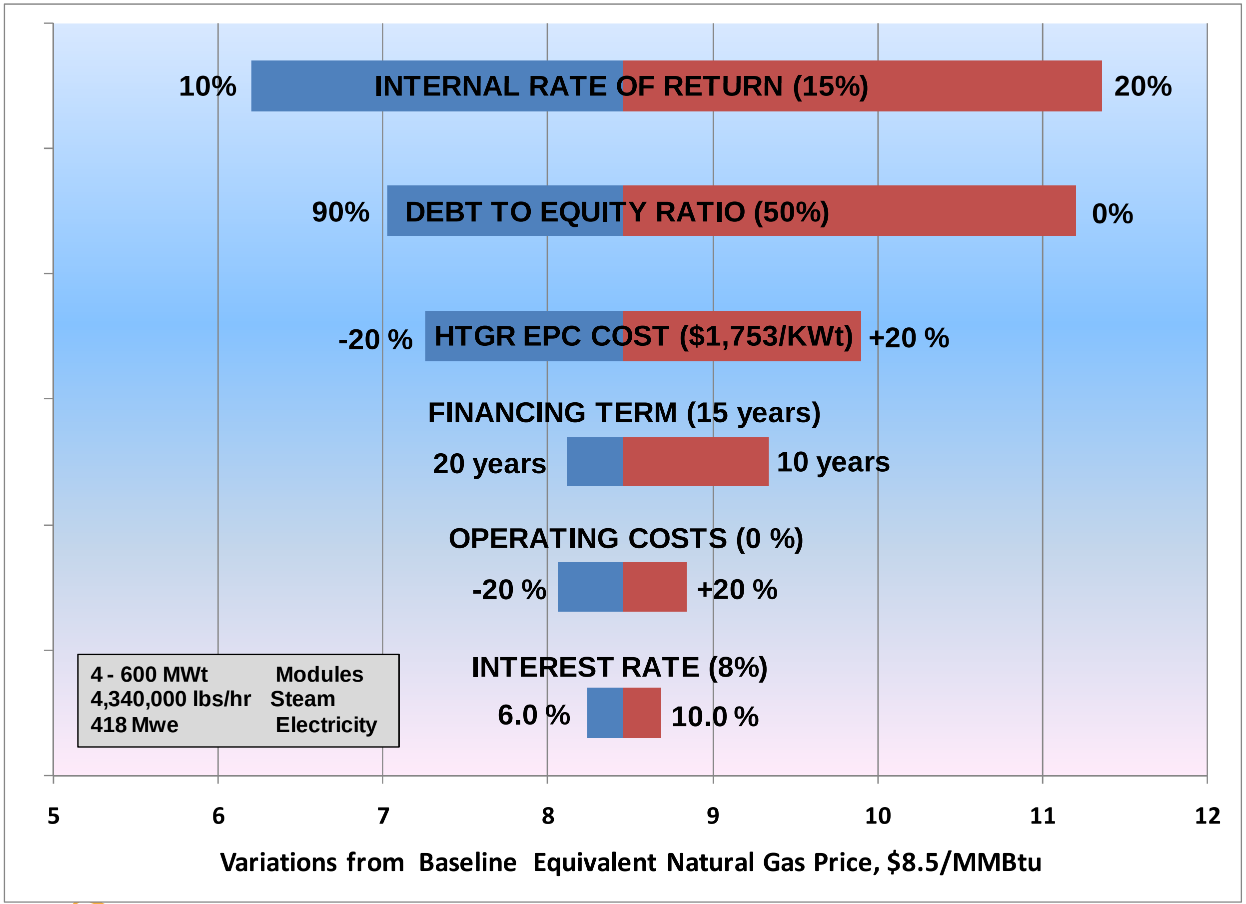


Equivalent Natural Gas Prices

200 MWt / 1600 MWt -- $11.1/MMBtu
350 MWt / 1400 MWt -- $8.3/MMBtu
600 MWt / 2400 MWt -- $6.5/MMBtu

Reducing IRR from 15% (shown) to 10% reduces energy price by ~15%

Sensitivity of Equivalent Natural Gas Price to Variations in Financial Parameters



A Nominal Case:

IRR	10%
Debt	80%
Interest	8%
Term	20 yrs
Capital	$1,753/KWt
O&M	$16/MWhe
Refueling	$18/MWhe

Equivalent NG Price: $5.6/MMBtu

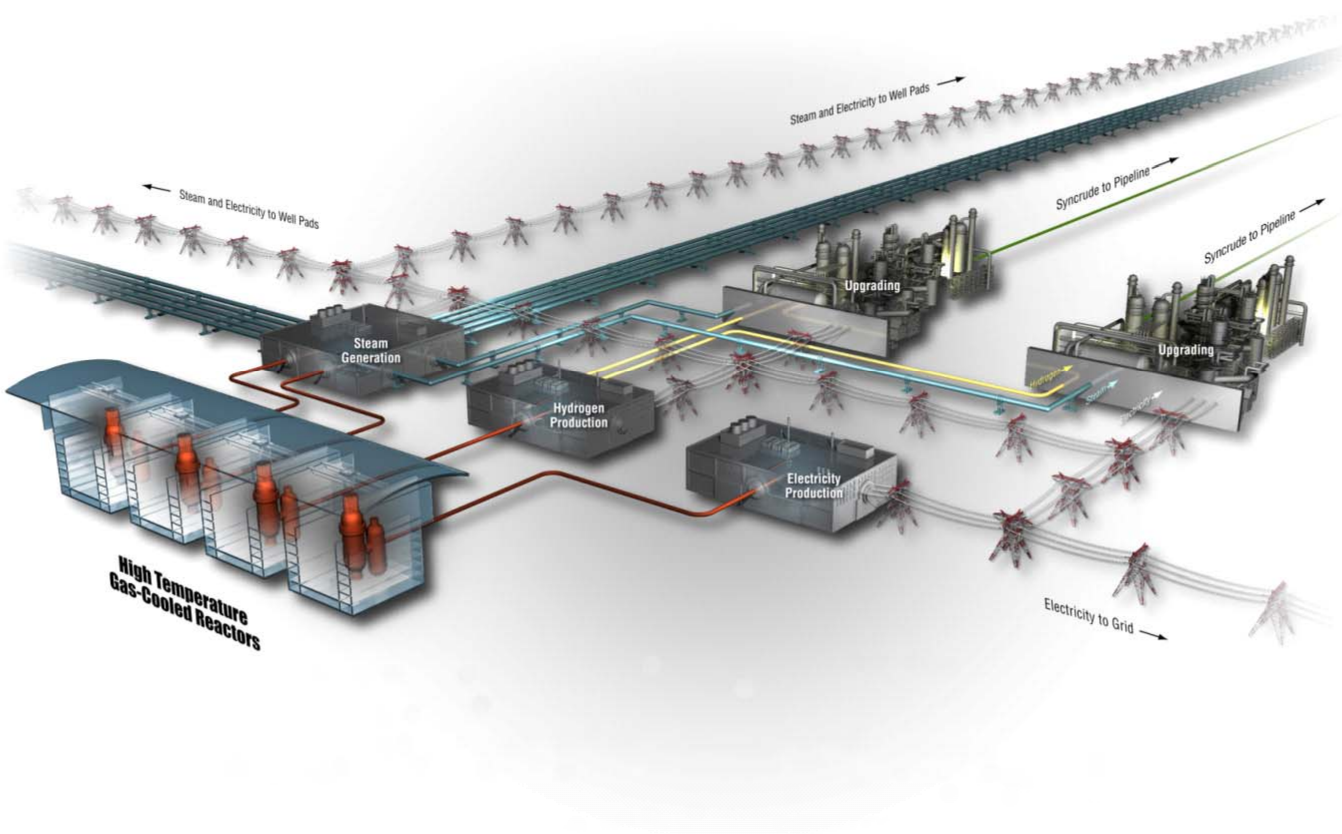
Characteristics of Potential Market – Oil Sands & Oil Shale

- Bitumen recovery; supply of steam to multiple oil sands well pads and oils shale wells
- Bitumen upgrading; supply of process heat and hydrogen to support upgrading to Synthetic Crude Oil
- In Oil Sands:
  - Electricity supply; centralized highly efficient electricity supply & distribution
  - Water treatment; critical issue, modest heat and electricity supply required

Oil Sands market projected to grow at ~3%/year through 2050
Oil Shale market projected to be at 2.5 MMBPD by 2030

25% of growth markets – ~60 GWt, equivalent to ~100 – 600 MWt modules

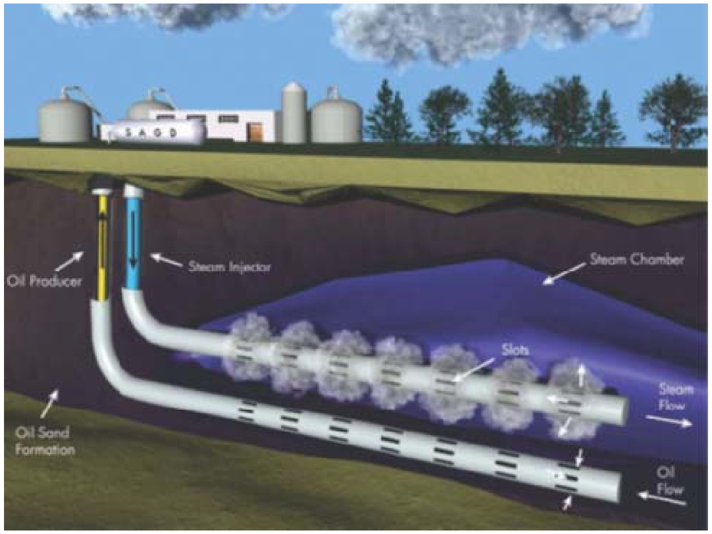
A Central Fully Integrated HTGR Energy Supply



Full HTGR Integration for Oil Sands Energy for 60 years

- **Bitumen recovery -- central HTGR facility supplying 2,400 MWt of steam:**
  - Bitumen recovery of 224,000 barrels per day
  - Reduction in natural gas consumption – 81.8 billion SCF/year
  - Reduction in CO_2 emissions – 5.3 million tons/year
  - Over 60 years this rate of steam supply from the HTGR plant would result in:
    - Supplying 52 simultaneous well pads for 12 years each
    - Supplying 260 well pads over the life of the reactors
    - Covering 65,200 hectares of land
    - Reducing natural gas consumption by 4.9 trillion SCF
    - Reducing CO_2 emissions by 317 million tons
  - ~10 plants required by 2050
- **Electricity and water treatment**
  - ~5 plants (equivalent) required to supply 25% of electricity and water treatment energy

Total potential deployment
15 multi-module plants; 36 GWt

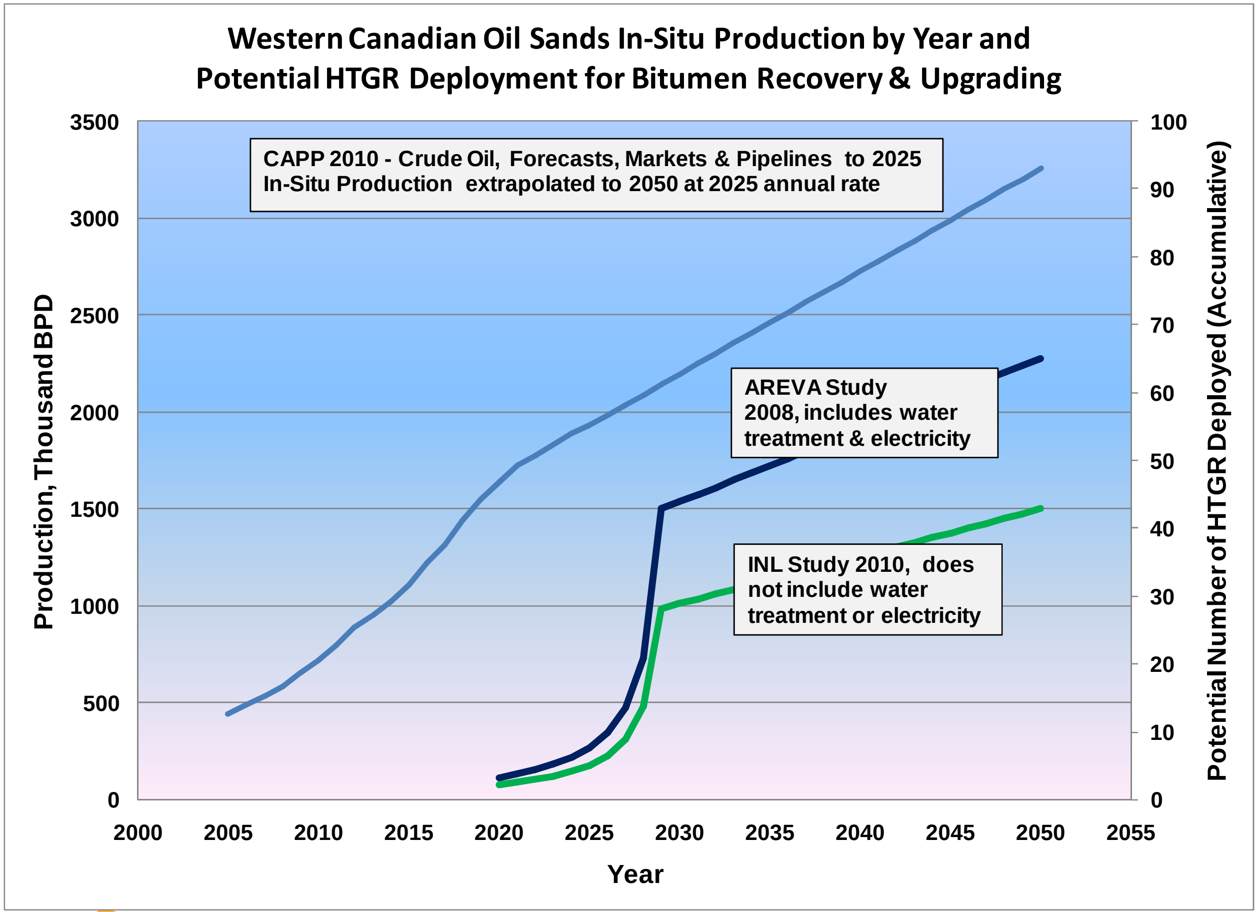


SOURCE: J&W COMMUNICATIONS. THE PEMBINA INSTITUTE

NGNP Next Generation Nuclear Plant

Idaho National Laboratory

Projections of HTGR Deployment through 2050



In-Situ Oil Sands Production projected to grow at ~3% per year 2020 - 2050

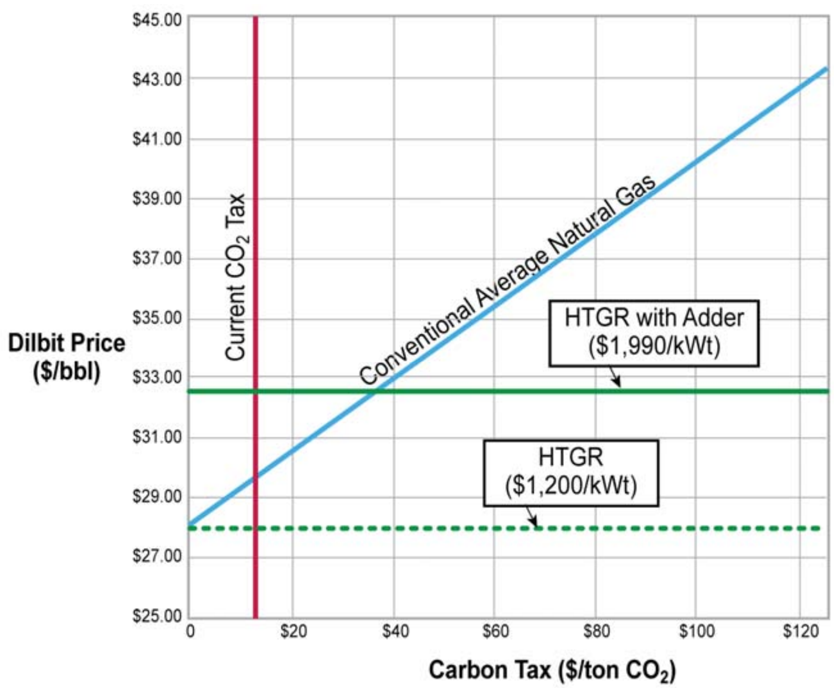
HTGR Deployment projected to start in 2020 and over 10 years account for 25% of energy needs

Up to 35 GWt of HTGR energy required by 2050 to supply 25% of energy for bitumen recovery, upgrading, water treatment & electricity

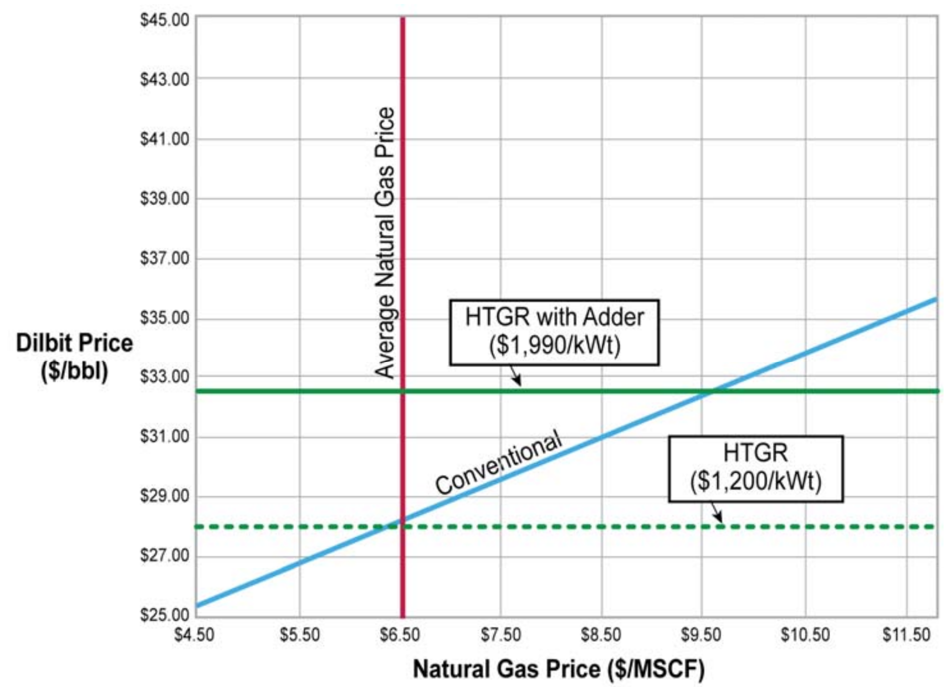
Next Generation Nuclear Plant

Economic Results

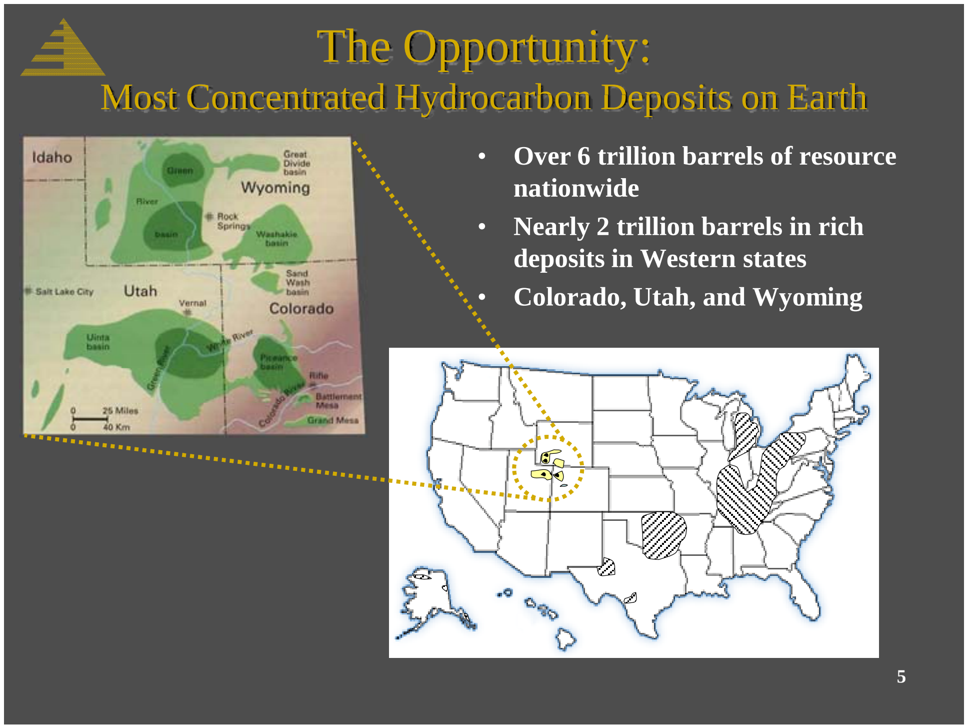
224,000 bpd w/ 2400 MW_{th} HTGR Facility



Natural Gas @ $6.50/MMBtu



Characteristics of Potential Markets – Oil Shale



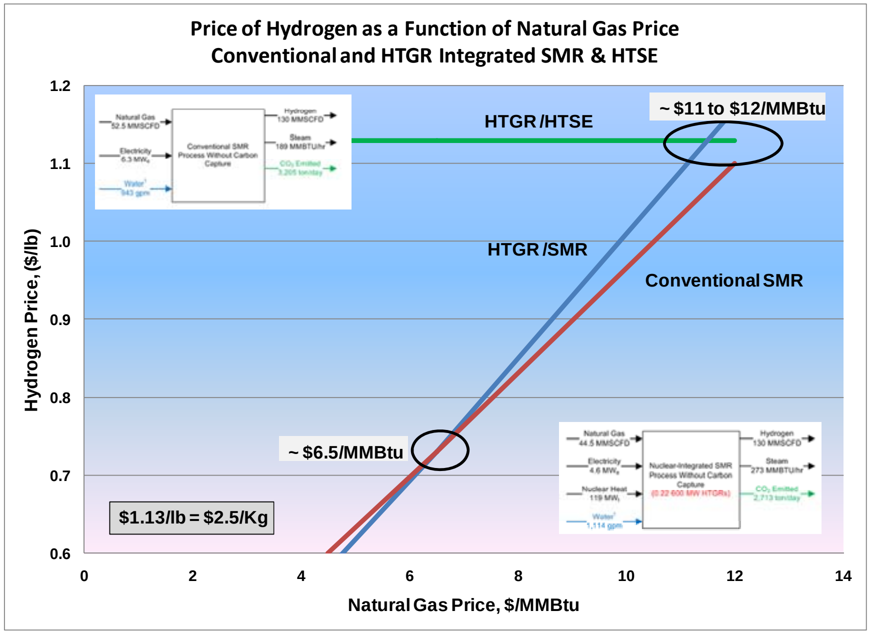
Potential Development of United States Oil Shale Resources, Khosrow Biglarbigi, INTEK, INC., March 28, 2007, presented at the 2007 EIA Energy Outlook Conference, Washington, DC

- Potential emerging market
- US has largest oil shale deposits in the world
- ~2 trillion barrels recoverable
- 2.5 million barrels per day projected as production rate in 2030
- Ex-situ and in-situ production processes
- 50,000 BPD production
  - Ex-situ -- ~2200 Mwt
  - In-Situ -- ~1000 Mwt
- HTGR supplies 25% of this energy in 2030 – 2050

Total potential deployment
~13 - 50,000 BPD plants; 24 GWt

Next Generation Nuclear Plant

Hydrogen Production using HTGR

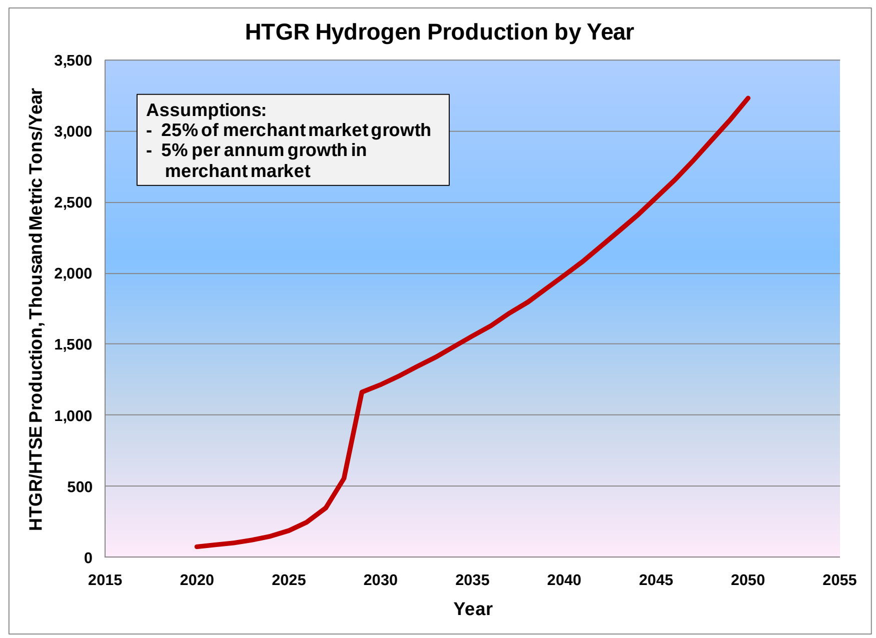


Two potential HTGR applications

- SMR- Substitute for natural gas firing
  - ✓Significant residual CO_2 emissions (80% of conventional)
  - ✓Lower cost
- High Temperature Steam Electrolysis
  - ✓No CO_2 emissions
  - ✓Higher cost (crossover at $70 to $90/MT)

Market – 36 GWt by 2050 (HTSE)

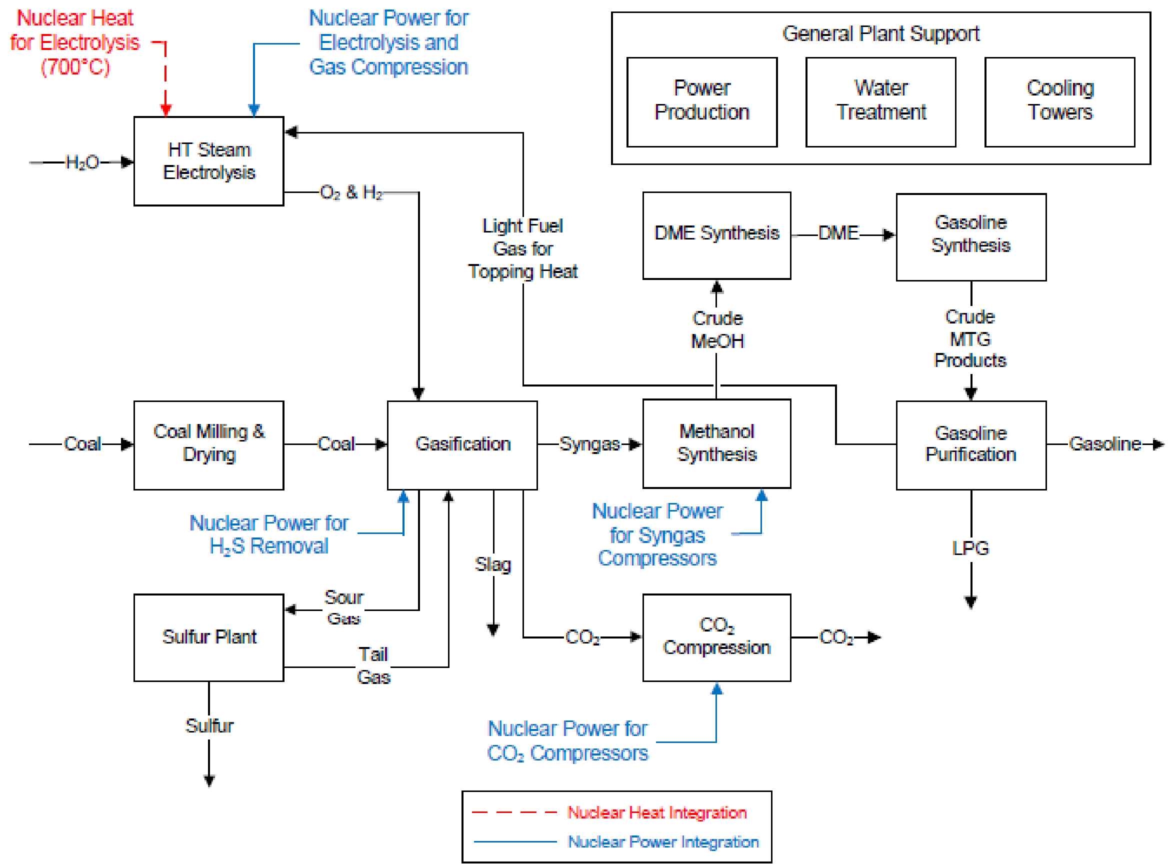
- Merchant market
  - ✓Projected to grow at 5% per year (NHA)
  - ✓HTGR market potential assumes 1%/year
- Potential HTGR Market
  - ✓2020-2030 increase deployment to supply 25% of merchant market
  - ✓Maintain supply at 25% of market



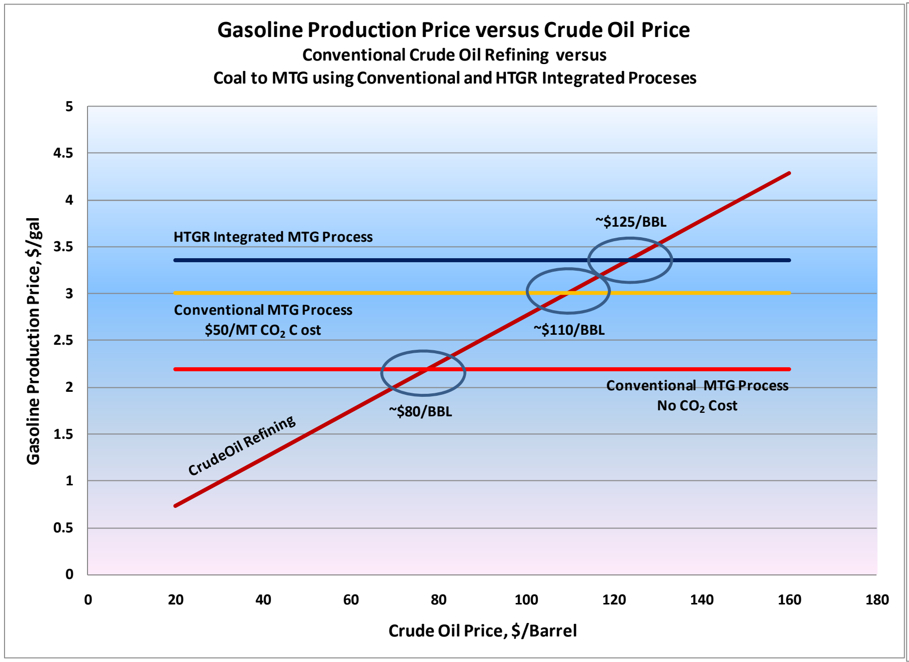
Conversion of Coal to Diesel & Gasoline

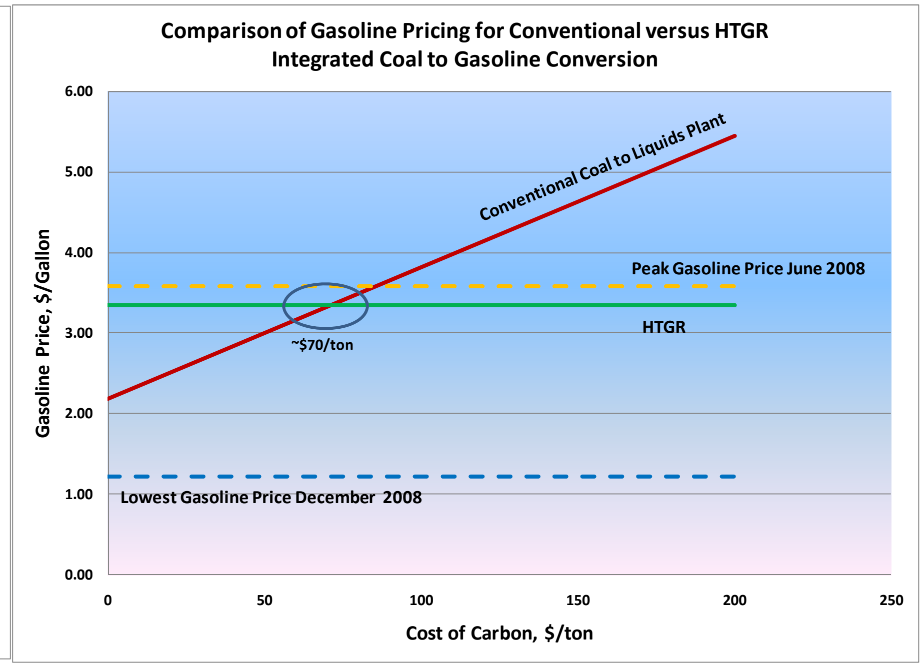
- Carbon conversion to transportation fuels is one step toward energy independence
- Imports accounted for 63% of the U.S. crude oil supply in 2010
  - 50% of the imports came from OPEC
- Crude oil demand internationally is growing & prices are once again above $100/BBL and gasoline prices hover near $4/gallon
- Application of HTGR technology to conversion of coal to gasoline and diesel is technically & environmentally sound and economic at $4/gallon
- Offsetting 25% of imports requires deployment of 24 – 100,000 BPD plants – 249 GWt (415 – 600 MWt modules)

Nuclear Integrated Coal to Gasoline (MTG Process)



Conversion of Coal to Gasoline (MTG Process)





Economic Factors

HTGR Plant Capital Cost	*$1,700/KWt*
CCGT Capital Cost	*$625/KWt*
Debt	*80%*
Internal Rate of Return	*15%*
Financing Interest	*8%*
Financing Term	*20 years*
Tax Rate	*38.9%*

Summary Take-away

- The go-forward cost of the NGNP Project to complete R&D, design, licensing and construct the demonstration HTGR modular reactor plant is estimated at $3.5 to 4 billion. A partnership between government and the private sector is necessary to complete the NGNP Project with acceptable financial risk

- There is a large potential marketplace in the US for the HTGR equivalent to >16 quads – an appreciable portion of current energy production. The potential marketplace embraces the industrial and transportation sectors as well as electric power generation.

- The NOAK plant capital cost (all-in) is expected to range from ~$1750 to $2200 per KWt (~$4100 to $5300 per KWe) varying with the module and plant thermal rating
  - The price for co-generation of steam and electricity for typical applications is expected to be equivalent to natural gas at a price of ~$6 to 9 per MMBTUs
  - Synthetic gasoline can be produced from nuclear integrated MTG processes at a price of $3 to $4 per gallon

Discussion