US High Temperature Gas-Cooled Reactor

Deployment Challenges and Strategies

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Topics

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NGNP Industry Alliance, LLC
(www.ngnpalliance.org)

- **Formed in response to USA Energy Policy Act of 2005**

DOW

SGL GROUP THE CARBON COMPANY

ConocoPhillips

US ULTRA SAFE NUCLEAR

Entergy

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Westinghouse

PTAC

GRAFTech International

TECHNOLOGY INSIGHTS

TOYO TANSO Inspiration for Innovation

Wyoming

SRS COMMUNITY REUSE ORGANIZATION two states, one future

STARCORE NUCLEAR

MERSEN

Advanced Research Center

Manufacturing Excellence Consulting, Inc.

Mission:
Promote the development and commercialization of HTGR technology

End-User Industries

North America, Hawaii, KSA, Japan and Korea

Industries

- Oil Shale
- Oil Sands
- Coal -to-Liquids
- Hydrogen Production
- 560 °C Steam Cogeneration
- Ammonia Based Products
- Seawater Desalination
- Electricity Production

North America Capacity Opportunity

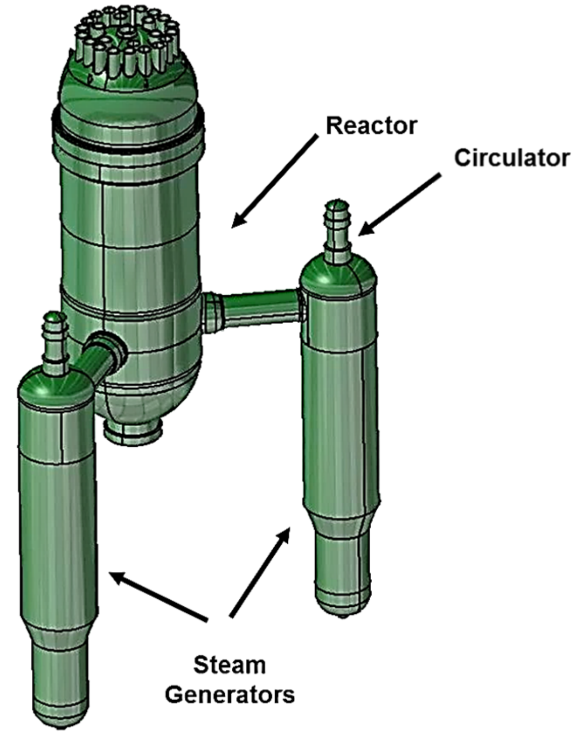
- Petroleum, Petrochemical, Chemical, and other Processing Facilities
  - 75 GWt ~125 modules
- Oil Sands Recovery Operations in Alberta Canada
  - 18 GWt ~30 modules
- Power Generation
  - 110 GWt ~180 modules

Other Electricity Markets

- Hawaii, KSA, Japan, and Korea
  - 80 GWt ~130 modules

Reactor Design
AREVA High Temperature Reactor Steam Cycle-HTGR

- **HTGR technology is fairly well established**
  - **Helium-cooled**
  - **Graphite-moderated**
  - **Coated particle fuel**
- **Modular design and construction**
- **HTGR can meet many needs**
  - **High efficiency electricity for smaller markets**
  - **High temperature process steam**
  - **Cogeneration of process heat and electricity**
- **HTGR has inherent safety characteristics that allow "close-in" siting with energy users**



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Nominal Operating Parameters

Fuel type	TRISO particle
Core geometry	102 column annular 10 block high
Reactor power	625 MWt
Reactor outlet temperature	750°C
Reactor inlet temperature	325°C
Primary coolant pressure	6 MPa
Vessel Material	SA 508/533
Number of loops	2
Steam generator power	315 MWt (each)
Main circulator power	4 MWe (each)
Main steam temperature	566°C
Main steam pressure	16.7 MPa

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Roadmap to Commercialization

- **Time & cost are the main barrier to commercialization**
- **Initial non-commercial support is essential for success**

Roadmap to Commercialization
Market Rationalization

- HTGRs are designed for markets that:
  - Rely on premium fossil fuels,
  - Have limited water supplies, or
  - Need to reduce carbon footprint
- Addressing the overarching energy policy goals of:
  - Feedstock security
  - Economic growth
  - Water conservation
  - Reduction of carbon footprint
- 60% of global energy needs can be served by HTGRs producing competitively priced electricity and process heat
- Integrated with carbon conversion technologies, HTGRs can provide an economic approach to production of synthetic transportation fuel and chemical feed stocks with minimal carbon foot print

HTGRs provide the option to use the only "game-changing" technology on the horizon

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Roadmap to Commercialization Development and Deployment Plan

Overlapping Steps to Commercialization

- **Technology Development**
  - Fuel and Graphite for SC-HTGRs
  - More Advanced design require additional technology development, i.e. IHX
- **Design Development**
  - A systematic approach to design (CD, PD, FD)
- **Regulatory and Licensing Issues**
  - Work with regulators - NRC, ASN and CNSC
- **Supply Chain and Infrastructure**
  - Component design and manufacturing
- **FOAK Plant Construction and Demonstration**
  - Site preparation, environmental permits, construction and operation
- **Build-out Deployment to NOAK Pricing and Schedule**
  - Order book build up

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Roadmap to Commercialization Challenges (1 of 2)

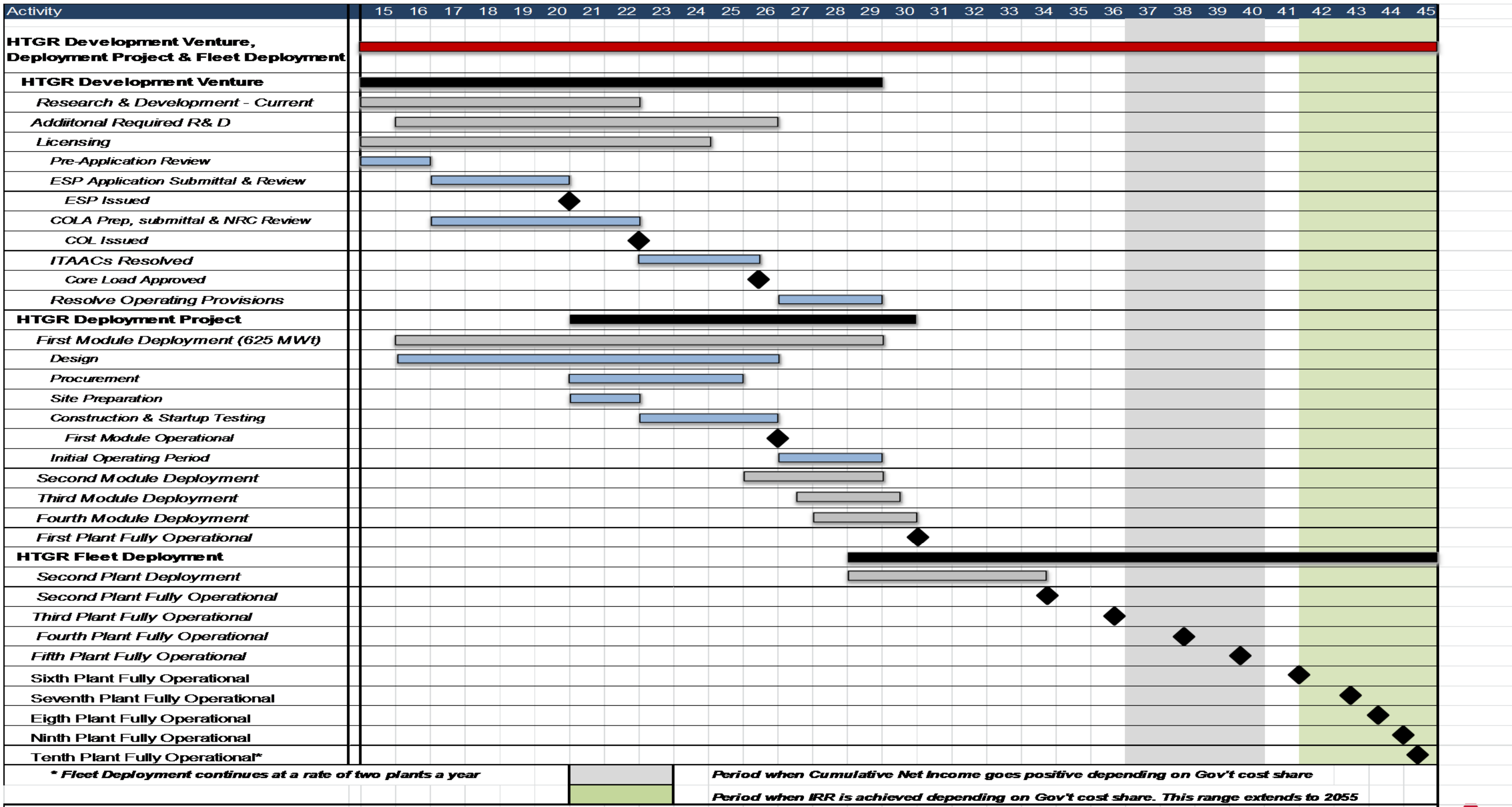
- **Technical Issues**
  - TRISO Particle fuel characterization and qualification
  - Nuclear grade graphite characterization
  - Codes and methods development
  - Thermal effects tests
  - Key components design
- **Regulatory Requirements (country dependent)**
  - In the U.S.A. NPP licensing rules are LWR specific
  - Modular HTGRs are designed for safety but with a different method of achieving the superior safety where regulators are unaccustomed
  - Early interaction with regulator is underway in the U.S.A.
  - To date no "show stoppers" have been identified
  - However, NRC has not carried these topics to become guidance- therefore timeframe to license is uncertain

Roadmap to Commercialization Challenges (2 of 2)

- Financial Needs
  - Sustained funding for development, licensing, and FOAK plant construction is the most challenging aspect of the advanced reactor commercialization
  - Current costs, estimated at $3.8B over sixteen years is a major hurdle to overcome
- Five categories of work and their funding estimates
  - Technology development – R&D ~ $300 M
  - Design development – one time cost for three design phases CD, PD, FD ~ $800M
  - Equipment and infrastructure costs ~ $1.25B
  - Licensing costs ~$200M
  - Construction and commissioning costs of the first module~$1.2B

FOAK & Fleet Deployment Schedule

16 Years of Intensive Effort with US Licensing



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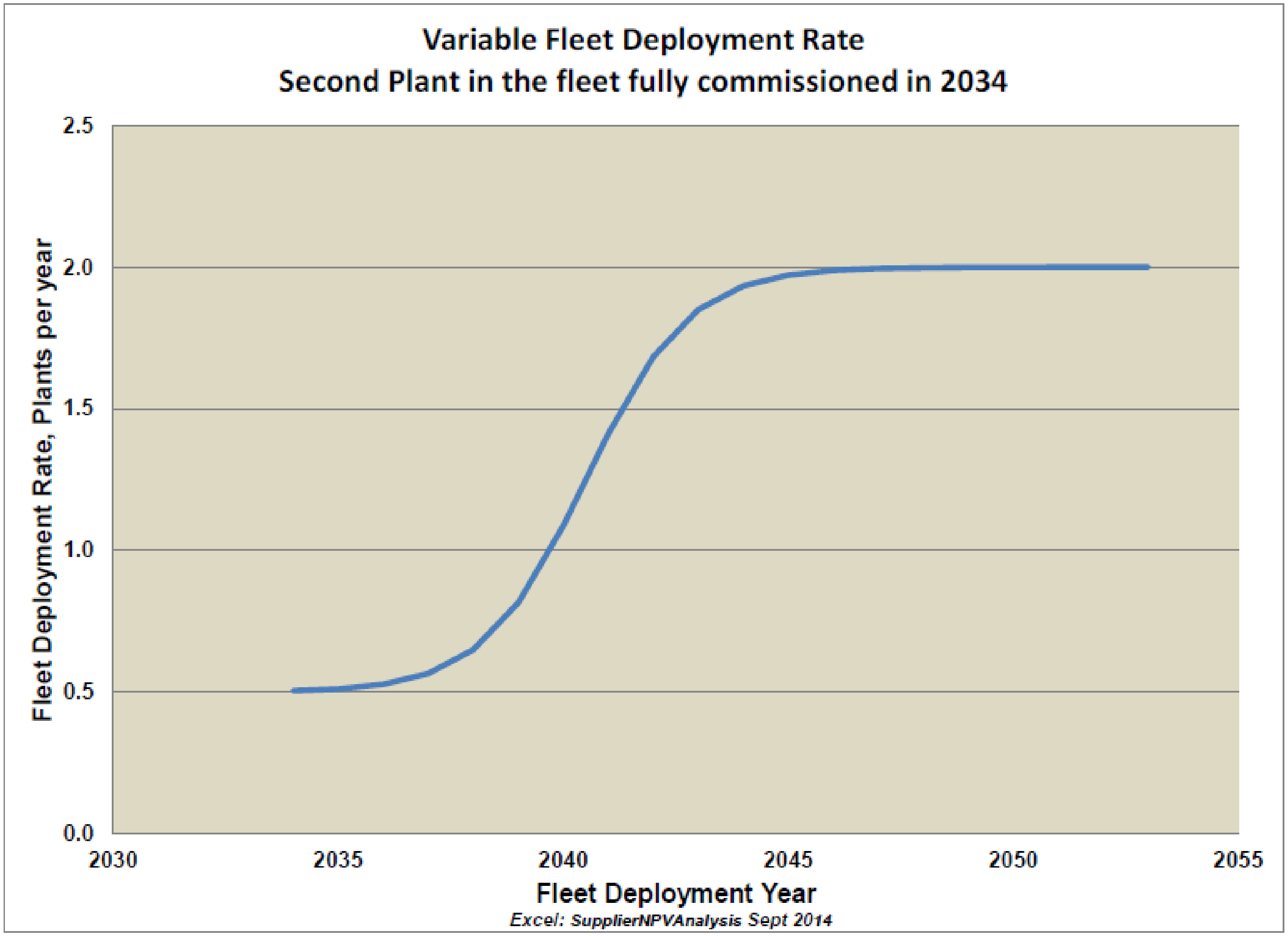
Variable Rate of Fleet Deployment



Roadmap to Commercialization Economic Model

- **Funding scenarios studied**
  - **No government funding**
  - **Government support of R&D only**
  - **50% government support of the project**
  - **80% government support of the project**

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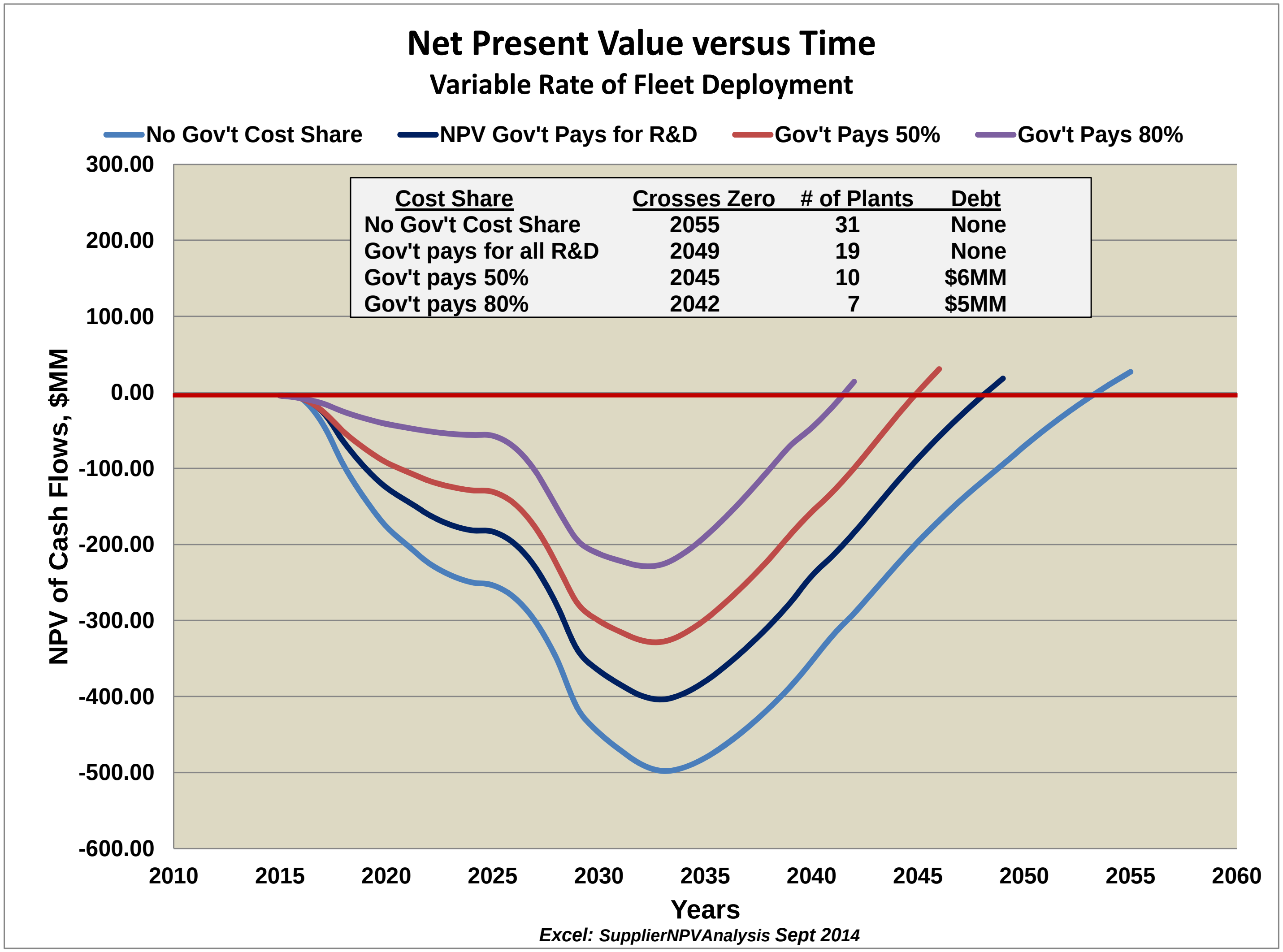
Net Present Value vs. Time



- **Variable fleet deployment rate**
- **Time to zero NPV is from 28 to 41 (years)**
- **Required IRR (10%) achieved at NPV=0**
- **# Plants 7 to 31**
- **The larger Gov't support the sooner NPV is positive**

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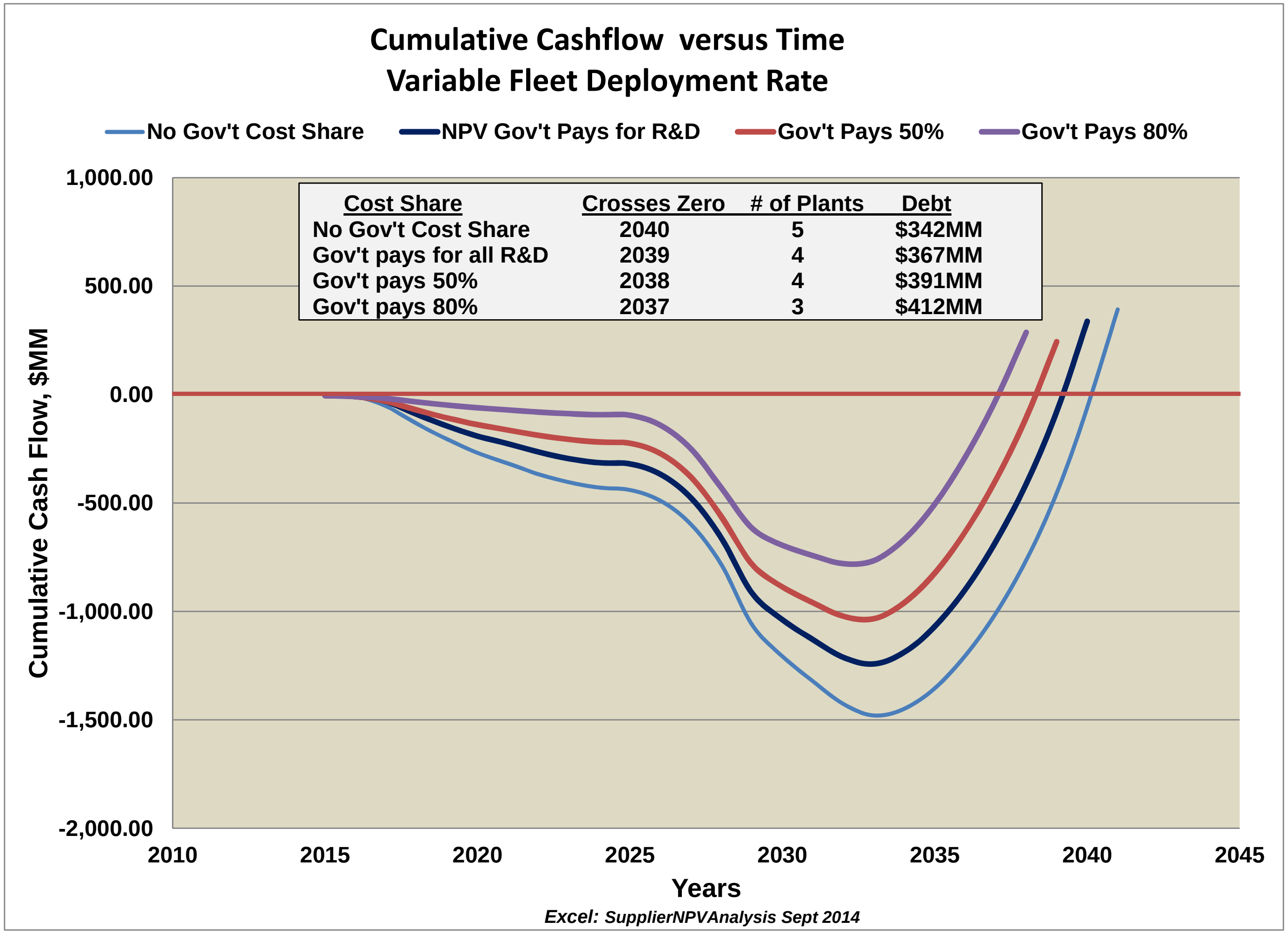
Cumulative Cash Flow vs Time



- Variable fleet deployment rate
- Time to positive CCF is from 23 to 26 (years)
- # Plants 3 to 5
- The larger Gov't support the sooner cash flow becomes positive

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Funding Sources

- **Funding sources**
  - **Internal R&D funds**
    - Individual partner companies
  - **Private investor funding and financing**
    - Positive returns IRR, IP ownership, positive cash flow expectation
  - **Sovereign investments**
    - Social and economic benefits
- **Funding Approaches**
  - **Initially non-commercial sources (government or philanthropic)**
  - **Investor community (graded risk financing)**
  - **Supplier companies**
  - **International collaborations**

Conclusions and Observations

- **Markets for HTGRs are fully developed and exist today**
  - **These markets are solely dependent on fossil fuels, mainly natural gas and natural gas liquids**
  - **Modular HTGRs are Gen-IV reactors with superior safety and security ideal for close-in siting and public safety**
  - **Modular HTGRs unparalleled intrinsic and passive safety offer low investment risk for co-location with end-user community**
  - **Modular HTGRs can serve electricity markets where SMRs are desired and are an advantage when water is restricted and close siting is desired.**

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Conclusions and Observations (cont'd.)

- **Development and deployment financial barriers**
  - **Long development period (especially in the US)**
  - **Large development cost (especially in the US)**
  - **Uncertain market demand, i.e. order book**
- **No single or groups of suppliers can afford to bear the development costs**
- **Public and private partnerships are needed**
  - **Governments**
  - **Investment groups**
  - **Supplier groups**
- **Philanthropic and public financing is necessary during the initial years of development venture**
- **Historically civilian nuclear programs started with substantial public support – HTGRs are no exception**

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THANK YOU

QUESTION?

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