Global Nexus Initiative

Reactor Technology Development Challenges

SESSION II

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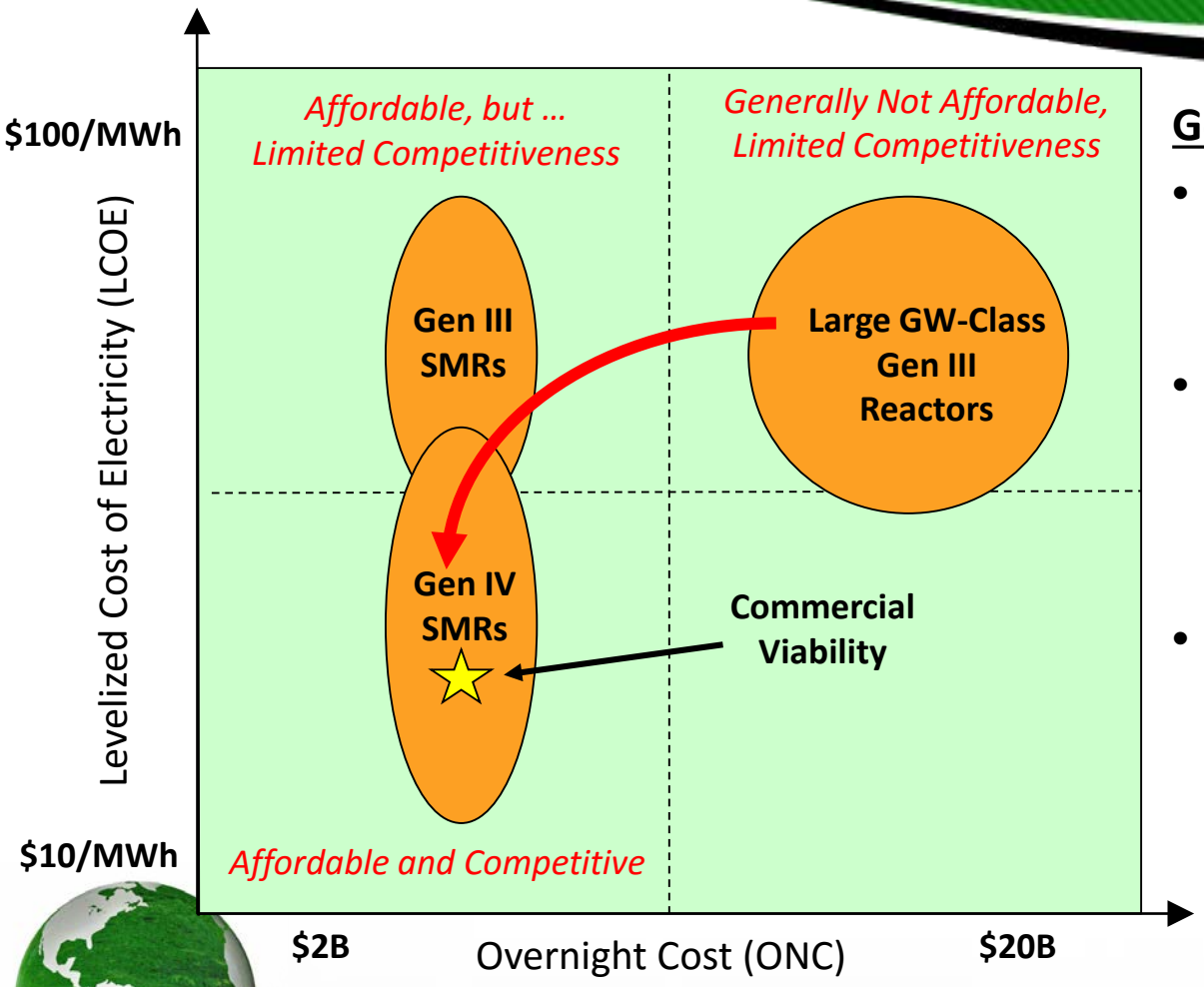
Advanced Nuclear Power: What problem is being solved?

Framing the discussion

- **Geo-political relevance**
  - Carbon and Climate … or … Security and Non-proliferation
  - Stakeholders and their timeframes
- **Gen III+ LWR designs are "safe enough"**
  - The meaning of CDF = 10^{-8}
- **Economics in the global energy industry**
- **Affordability and Competitiveness**
  - The role of subsidies
- **Risk management**
  - Promise versus Proven
  - History of economies of scale and modularization
- **Fuel cycle efficiency and nuclear waste**
  - Stakeholder versus Customer issues

A nuclear power "product" that Customers want, when they need it

Nuclear Power Development: Search for Competitiveness



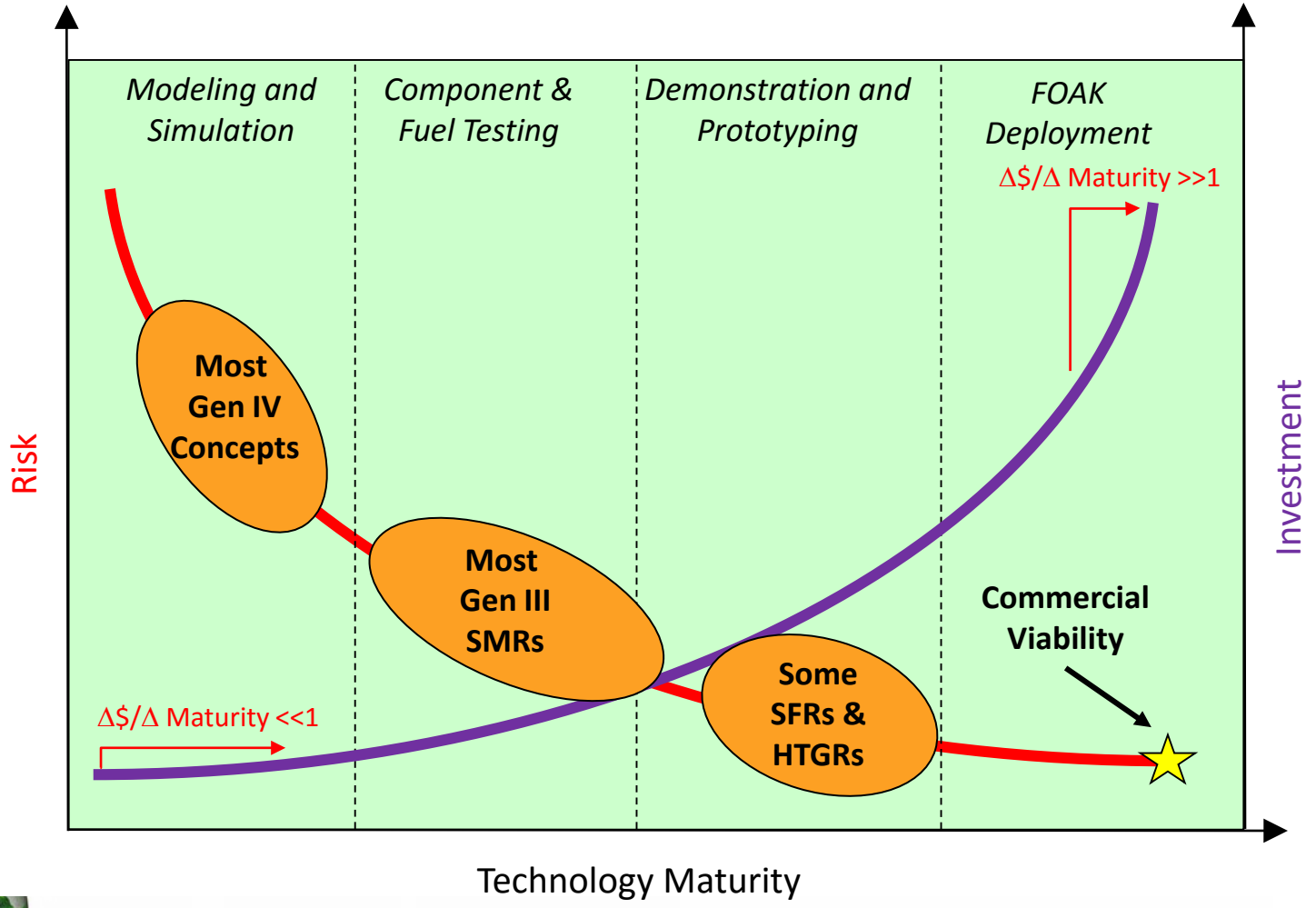
Gen IV SMR Value Proposition

- **Size Optimization**
  - Affordability
  - Flexibility
- **Standardization**
  - Fleet O&M economics
  - Rapid shift to NOAK construction

  … AND ….
- **Inherent safety**
  - Nuclear island simplicity
  - Limited engineered safety features
  - Mechanistic "Severe Accidents"

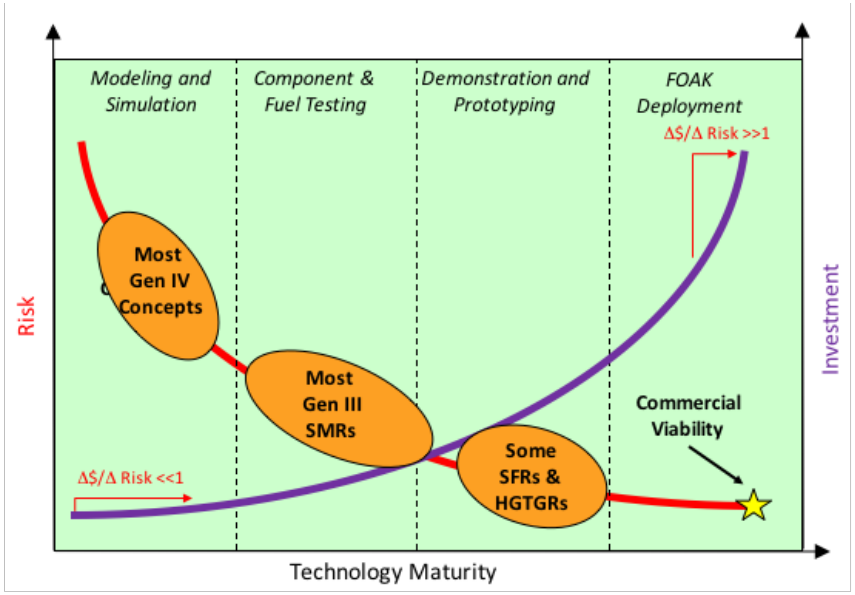
Advanced Nuclear Energy may deliver an Affordable and Competitive product

Nuclear Power Development: Maturity Landscape



Focus on most mature, lowest risk designs can enable Customer relevance

Advanced Nuclear Energy Development: Real Timeline



Phase	Time	Cost	Mortality
Modeling	3 years	$100M	32 ideas
Testing	5 years	$200M	16 concepts
Demonstrating	4 years	$300M	8 technologies
Deploying	8 years	$500M	4 products
TOTAL	**20 years**	**>$1B**	

Comments

- Innovators not looking ”down the road” … reality of cost and time commitments
- Licensing risk-reduction pushed to back-end … not aligned with investment timing
- Deregulated and developing markets averse to FOAK costs and risks … not first movers
- A few Gen IV designs more mature than Gen III+ SMRs … lower risk, less time

Integrated timeline, cost, and risk underestimated by many stakeholders

Development History: Schedule & Cost Performance

<u>Domestic</u>: Most recent U.S. experience is 31 years and counting …

- Westinghouse AP-1000
  - Began life as AP-600 in 1985
  - Attempted to grow out of LCOE problems with shift to AP-1000
  - Final NRC Design Certification amendment issued after 19 revisions to the design
- The uncertain legacy of NP-2010 and the Energy Policy Act of 2005
  - 50/50 cost-sharing program through design certification, with some FOAK risk reduction and PTC
  - GE's ESBWR was never built
  - Westinghouse sold to BNFL in 1999, then to Toshiba in 2006, then tech transfer deal with SNPTC

<u>International</u>: Olkiluoto-3 EPC construction planned for 5 years, now 14 years+

- Variations in licensing requirements, redesign, and component/construction quality issues
- Cost estimate increased by almost a factor of 3 from €3B to €8.5B

Recent nuclear development schedule and cost performance unsustainable
… after all this effort, there is no firm backlog of new orders for these designs

Nuclear Power Development: Timeline "lessons learned"

1. NP-2010 cost-sharing ended after licensing, with 50% of development cost remaining
2. Limited backlog of customer orders drives focus on FOAK cost minimization, short-view
3. Financial pressures drive reactor designers and EPC partners to start construction early
4. Designs not "shovel-ready" when construction begins, causing delays, rework
5. Supply chain not ready due to late engineering and planning
6. Deployment of new GW-class reactors treated as projects, not products
   - Limited standardization
   - Local content and workforce
7. Government involvement in many global procurement processes biases EPC decisions

Root-cause of deployment cost overruns and missed schedules lie in development

Nuclear Power Development: Private Sector Role

Private sector capital can help bring innovation and a sense of urgency, but …

- **Many large fully-public industrial firms not significantly engaged in advanced nuclear**
  - GE, Westinghouse, B&W, Siemens, Rolls-Royce, Toshiba, Mitsubishi, Hitachi, etc.
  - Legacy challenges and experiences with GW-class technology development programs
- **Most claimed $1.6B in "new" private capital investment is skewed to a few programs**
  - Bill Gates' TerraPower "Black Swan" … 20 year+ planning horizon
  - Gen III+ SMRs … still waiting for the first firm Customer order
- **Many venture capital-backed early stage startup companies "plan" early exit**
- **Private sector investment demands significant change to "business-as-usual"**
  - Utility-scale technologies which are economically competitive
  - 10 year development-to-deployment timeline
  - U.S. NRC regulatory reform that enables step-wise licensing with step-wise investment
  - Harmonization of global nuclear regulations to support design certification standardization
  - Exponential increase in market demand or subsidies to offset development costs

Entrepreneurs can unlock Gen IV's potential … with a major landscape shift

Nuclear Power Development: Public-Private Partnerships

Fully or partially nationalized deployment partnerships:

- China – largest new-build program in the world, full spectrum of technologies
- Russia – robust nuclear industry, in spite of severe domestic economic turmoil
- France – continued slow new-build, development and deployment of EPR

=> Investments immune to free-market economics, implementing national energy policies

Regulated or quasi-regulated utilities

- TVA, Southern Company and SCANA only new-build programs in U.S.

=> Regulated return on investment, CWIP

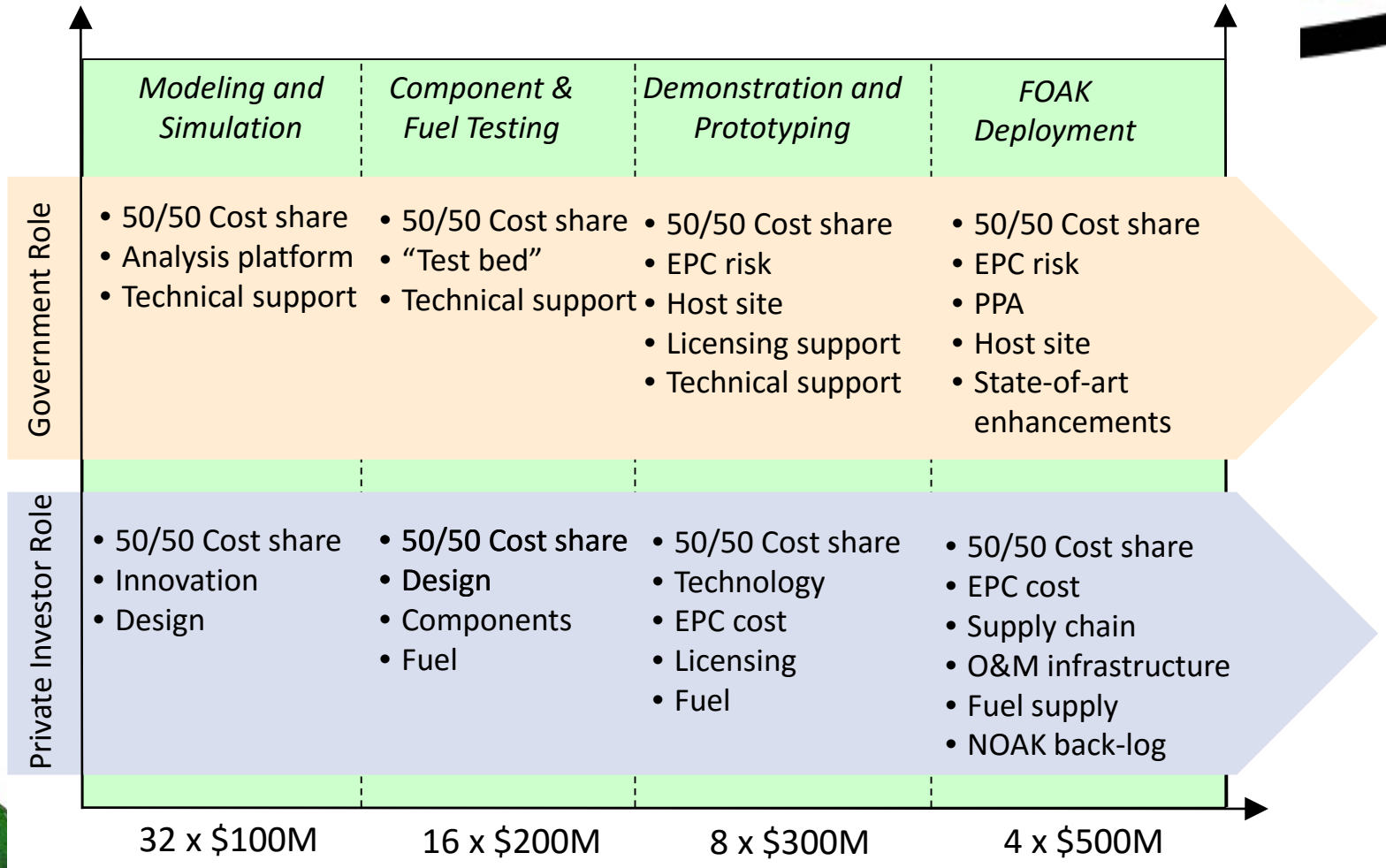
Deregulated energy markets

- UK – No new build construction after more than a decade of policy incentives
- US – No new build projects underway

=> No comprehensive public-private partnership addressing full market realities

Global new build only progressing where public financing overcomes challenges

Partnerships for Gen IV: A Notional Path Forward



$10.8B … exactly the same as the U.S. DOE spent on SFS technology alone

Reactor Technology Development Challenges: Conclusions

- Advanced nuclear technology offers promise of products that customers want
- Some Gen IV design ready for deployment by mid-2020's … geo-politically relevant
- 20 year+ development timelines and $1B+ investments are a major challenge
- Too much pressure on private sector results in undesirable deployment outcomes
- Significant new private sector investment will require industry landscape shifts
- Public-private partnerships necessary in deregulated, non-nationalized markets
- Full-scale Gen IV program is notionally $10B, and delivers FOAK by mid 2020's

Nuclear development and deployment challenges are solvable … by 2020's