Drivers for Low-Cost Development Towards Economical Fusion Power

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ARPA-E Workshop
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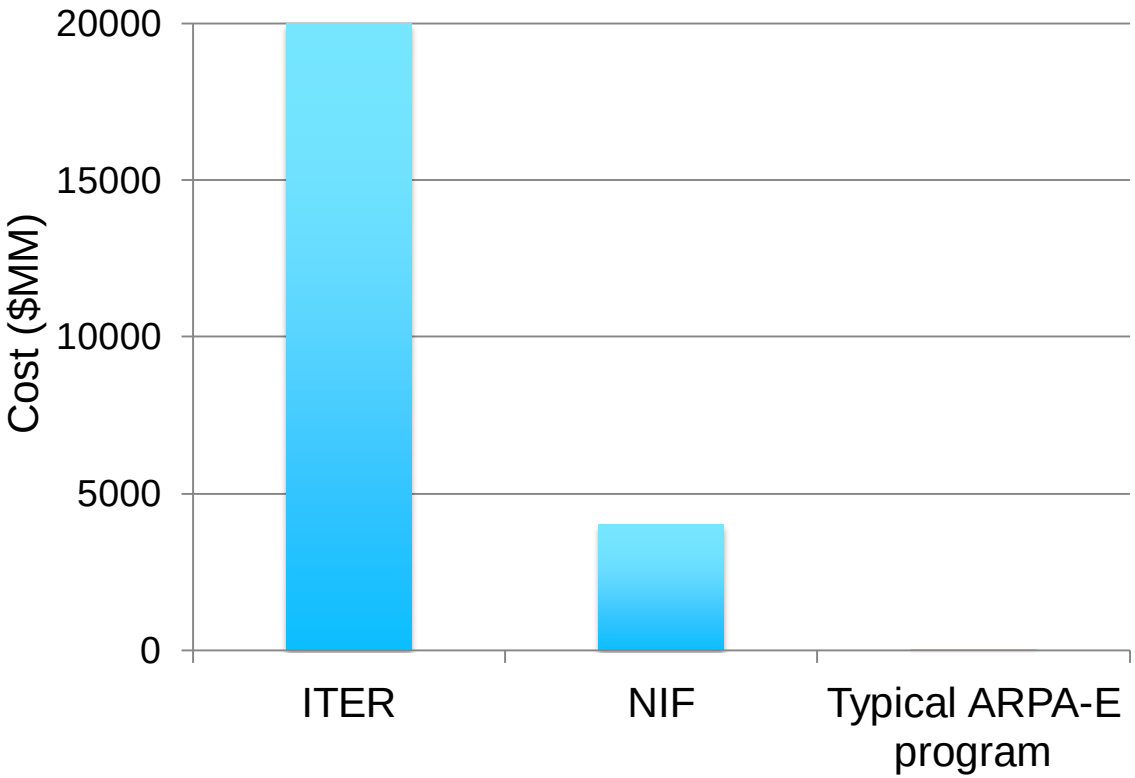
October 29-30, 2013

What are we doing here?



- ARPA-E won't be much help for "incumbents" – any new program will focus on radically new approaches.
- Key question: What can ARPA-E can do to move the needle in fusion R&D?

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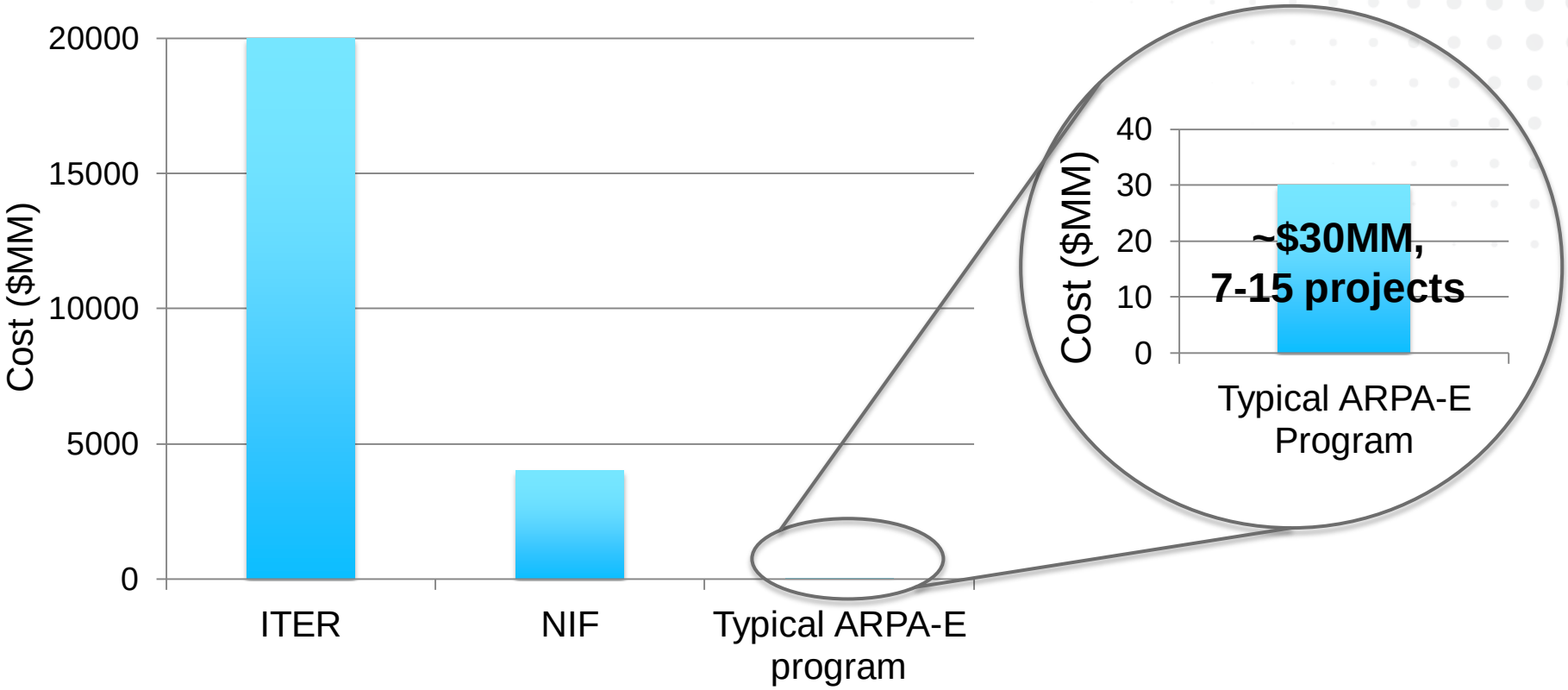

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What can ARPA-E do to move the needle?

- The R&D Tautology:
  We have a low R&D budget, therefore we must lower the cost of R&D.

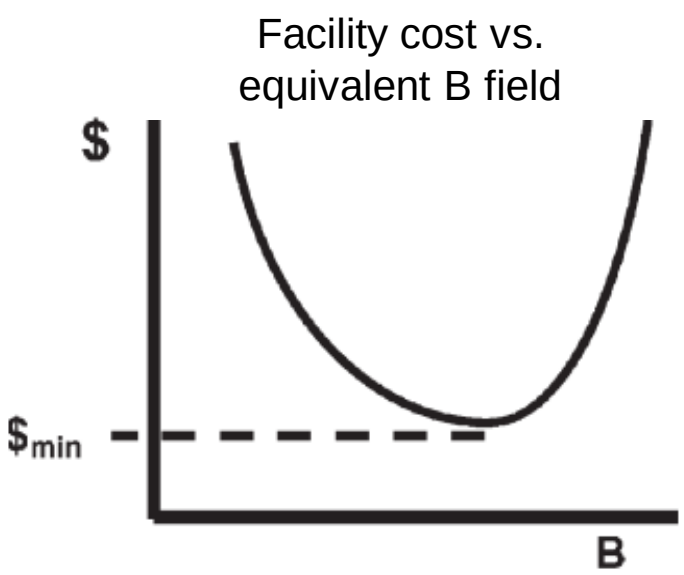
- However, if we lower the cost of fusion R&D the impact may be huge:
  - Lower cost projects open the field to more players.
  - Path to economical fusion power with a “low barrier” transition.

- Can ARPA-E enable fusion concepts that lower the cost of entry by an order or magnitude (or more)?
  - Seek a new path to fusion power with R&D costs <<$1B.

… There is some evidence this may be possible.

Fundamental hypothesis: low cost path to fusion

- Alternative regimes may offer lower cost path to fusion.



Turchi, *IEEE Transactions on Plasma Science*, 2008

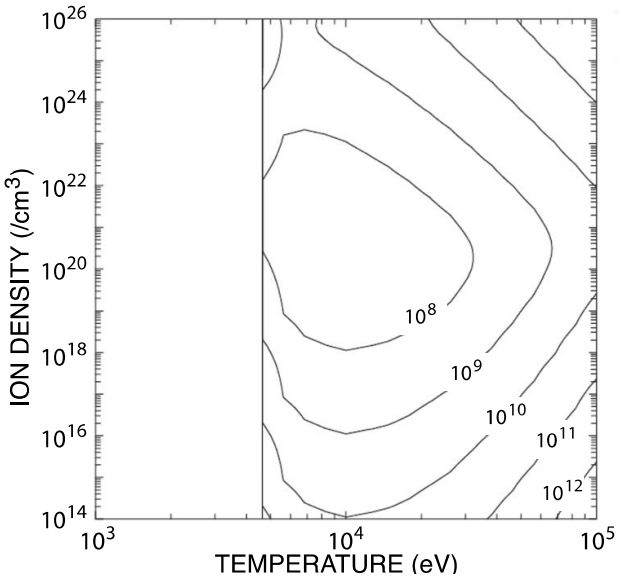


Fig. 7. The minimum facility cost (US $) for magnetized fuel under Bohm conditions (cylindrical geometry, B = 5 MG) operating at $\phi \leq 0.2$.

Lindemuth & Siemon, *American Journal of Physics*, 2009

We will hear from these speakers and others during this workshop.

Quantifying the opportunity

- Lots of ideas in the room to add context and specificity.

  We will see what ARPA-E can do by answering:
  - Which fusion regimes can we attack?
  - What enabling technologies are needed?
  - What alternative(s) exist drivers or target formation?
  - What is the likely cost of development *after* ARPA-E?

- Answers determine if ARPA-E should start program in fusion.
  - Can ARPA-E provide “spark” with enabling technologies?
  - Is there a path forward to low-cost fusion beyond ARPA-E?

Why did we ask for reactor concepts?

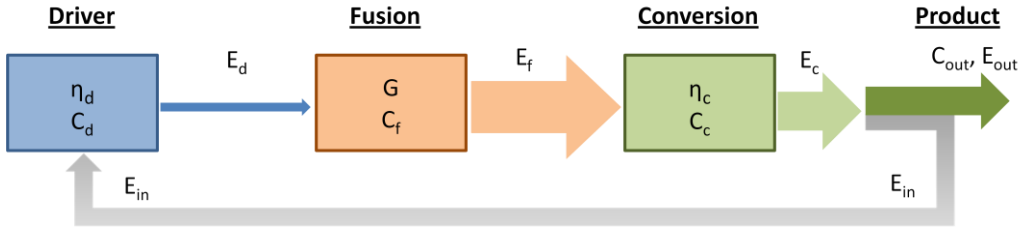
- With a typical ARPA-E program budget, we can't afford to build new reactors.

  So why did we ask for them?

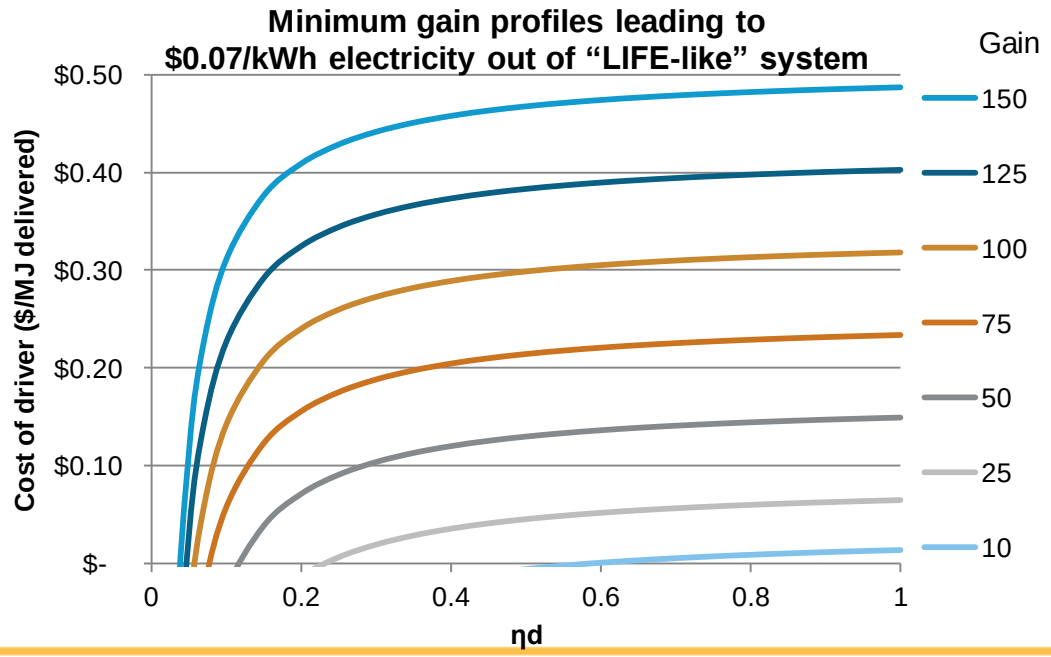
- Reactor concepts tell us:
  - What radically new approaches are available?
  - What enabling technologies can ARPA-E create? *and*
  - Where can those concepts go after ARPA-E investment?

So, why “drivers” ?

- Exploring tradeoff in fusion gain, driver efficiency, and driver cost



- Starting with LIFE cost model as baseline, what happens if we decrease driver cost or increase driver efficiency?
  - *Low gain regimes <u>require</u> low cost, high efficiency drivers.*



Short, 2013. Internal ARPA-E Analysis, adapted from Anklam, 2011, LIFE Cost of Electricity, Capital, and Operating Costs

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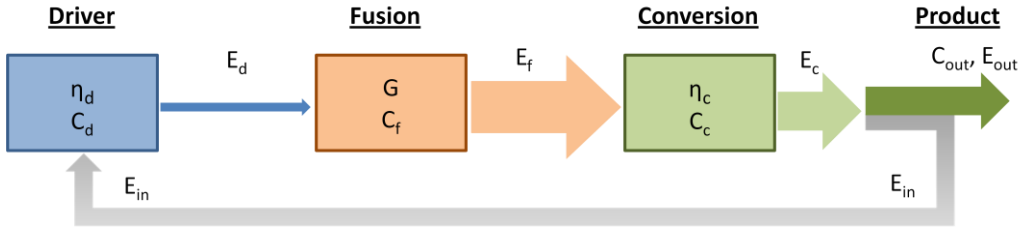

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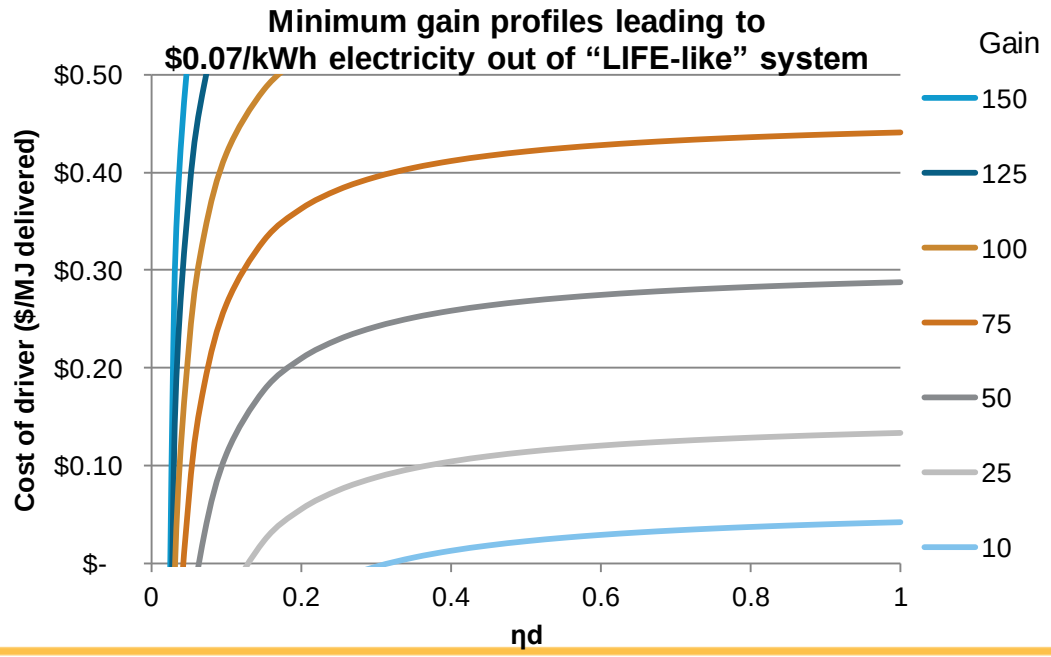

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However, drivers are not enough

- Low cost drivers are necessary, but not sufficient.
  - Target formation and stabilization
  - Interaction of driver with target

- So what ideas might fit in the scope of an ARPA-E program?

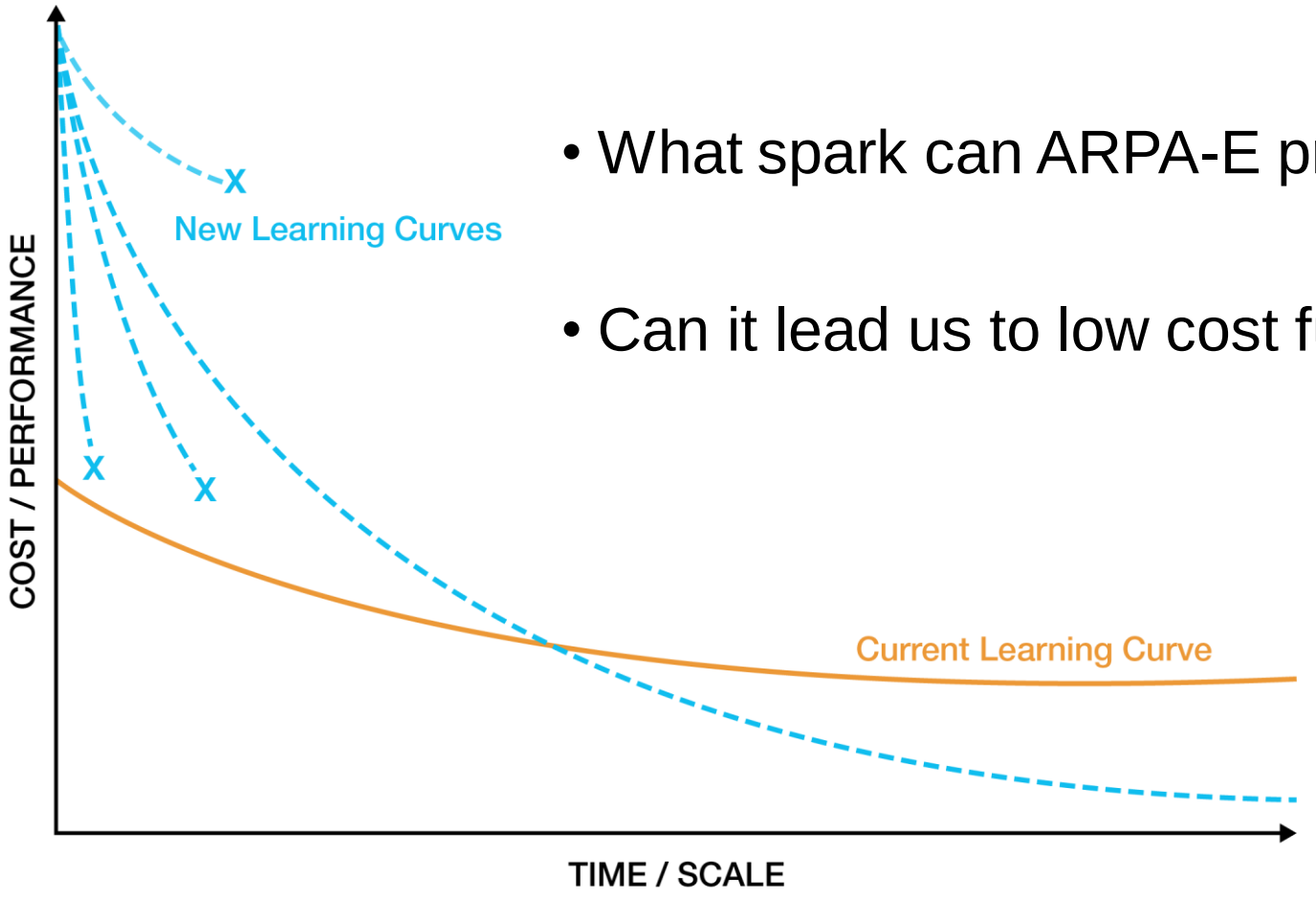
Topic	Fit for ARPA-E?	Why?
Low-cost, high-efficiency driver	Yes	Required for new fusion regimes
Target preparation	Yes	Critical for any new approach
Modeling	Yes	Guidance and validation of new approaches
Experimental validation (*possibly* including breakeven)	Yes	Confirmation of performance, Support/credibility for follow-on work after ARPA-E
Conversion of fusion power to electricity	No	We should be so lucky
Tritium breeding	No	We should be so lucky
Engineering first wall materials	No	We should be so lucky

Criteria for ARPA-E program

- Critical points to build the case:
  - Opportunity to create new, low-cost approaches in fusion
  - Enabling technologies that require ARPA-E investment (drivers, target preparation, etc.)
  - Path forward (beyond ARPA-E) without new $BB research initiatives

- If an ARPA-E program can put us on a new learning curve in fusion, that learning curve needs to lead somewhere.
  - Creating new regime for $BB research initiatives *will not fly.*

New learning curves for fusion?



- What spark can ARPA-E provide?
- Can it lead us to low cost fusion?

Workshop structure

Day 1

- Objective: Identify and explore promising approaches and opportunities in fusion and understand their driver requirements
- Morning talks
- Breakout 1 Breakeven Experiment
- Breakout 2a Fusion Power Concepts

Day 2

- Objective: Identify and explore promising approaches to low cost drivers and understand their challenges
- Morning talks
- Breakout 2b Fusion Power Concepts
- Final exercise

Goals for Breakout 1

- Why would ARPA-E look at scientific breakeven?
  - Low-cost breakeven could build credibility and attract investment.
  - Breakeven experiment can inform the physics of new approaches.

- Why might some be skeptical of ARPA-E involvement?
  - ARPA-E is generally not in the business of funding basic research, so a breakeven demonstration must be in the *interest of the program* and/or *technology transition*.

- This breakout will help determine if there are options for breakeven that:
  - Make budgetary sense for ARPA-E
  - Make sense for technology development and program transition

Goals for Breakout 2a and 2b

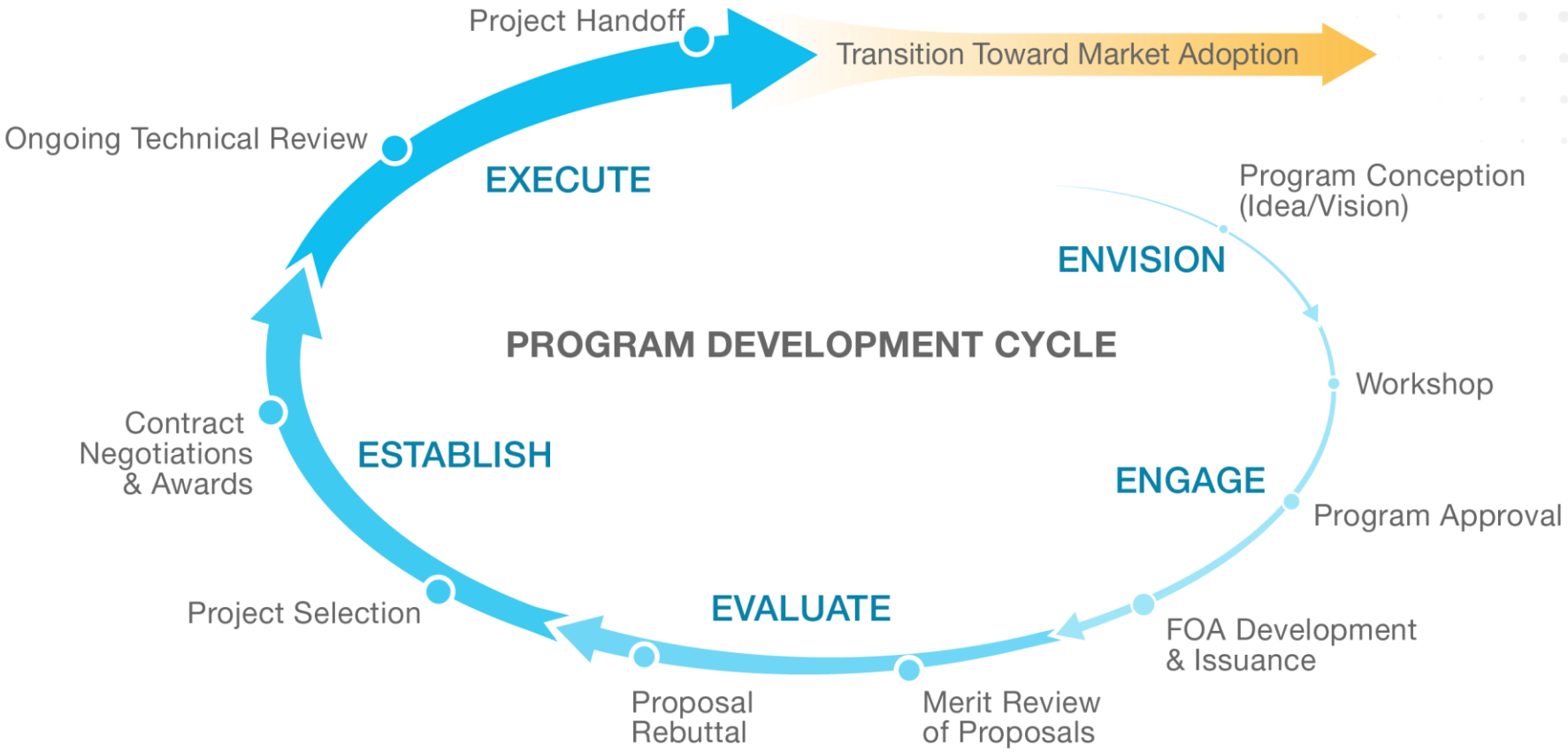
- Are there new fusion concepts that offer a low-cost R&D path, and can ARPA-E provide the spark to enable them?

- Breakout 2a will look at the fundamentals of a few proposed concepts and place them in fusion parameter space
  - What is the target?
  - What are the requirements to achieve ignition of that target?
  - What does this imply about the trade-offs in gain and driver performance?
  - Any “show-stoppers” lurking?

- Breakout 2b will look at the technologies that need to be developed to enable the concepts from Breakout 2a
  - What drivers or target formation technologies can ARPA-E develop to enable these new fusion concepts?
  - Are there other pieces of technology development that will be required for success?

BACKUPS

Technology Acceleration Model



Questions: Breakeven Opportunities

For a given experimental breakeven demonstration:

- What is the most probable failure point?
  - Is there design headspace to address failure or shortfalls? If so, how much?
- Diagnostic plan:
  - What parameters will you measure to track progress, performance, and validate your model?
  - What techniques are required and what will they cost?
  - Statistics/ number of shots required?
- Cost & Schedule:
  - How much will this experiment cost? Why?
  - How long will it take? Why?
  - Can existing equipment be used or upgraded?
- What fusion regimes can be informed by this experiment?

Questions: Regions for Economical Fusion

- Locate the proposed concept in the fusion parameter space
- Characterize the target
  - *Density, temperature, size, magnetic field, energy*
- Quantify the critical parameters for the driver
  - *Energy, power density (W/cm^2), velocity, pressure, symmetry, pulse width*
- What essential technology advances are needed for this concept? Are these advances near-term (within 5 years) or long-term (15+ years)?
  - *For example, technology advances to enable required repetition rate, standoff, first wall, tritium breeding, energy conversion, durability, lifetime, etc.*
- What is the projected fusion gain for these target and driver parameters?

Breakout 2b: Path to Economical Fusion 2: Driver development for new reactor concepts

- Given the critical parameters of each of the approaches from Day 1:
  - What are options for forming the target?
  - What drivers could be appropriate to implode the target?
  - What makes these ARPA hard challenges?
  - What will the driver cost (in $/MJ cumulative output from the driver over its lifetime)?
  - What will be the cost per target in a power reactor?
  - Can any of the breakeven experiments discussed yesterday inform the physics of this approach?