Small-Scale Distributed Generation Workshop

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Why Focus on *Small-Scale* Distributed Power Generation ?

- **Address existing challenge to improve electricity-generation efficiency while reducing GHG emissions**

- ***ARPA-E Vision – Enable transformational & disruptive technologies***
  1) ***24x7x365, reliable, economical system providing full energy needs of the home / neighborhood / building***
  2) ***Complement evolution toward a smarter grid with 24x7x365 local self-generation & dispatchable power/storage***
  3) ***Go beyond meeting "utility functions" by catalyzing energy-use innovations***
  4) ***Support energy demand growth in developing regions without a legacy grid infrastructure***

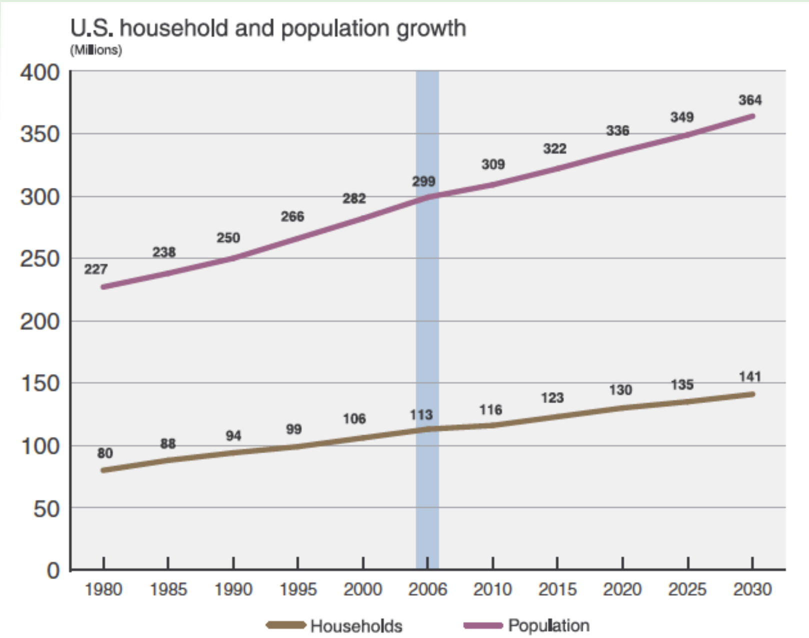
While Industrial-Scale CHP/CCHP is On-Going, the Large # of End-Users & Lower "Unit" Power Provide Unique Challenges for Residential & Commercial Segments

	# of Consumers	Avg Monthly Consumption (kwh)
Residential	125,177,175	908
Commercial	17,561,661	6,203
Industrial	757,519	100,926

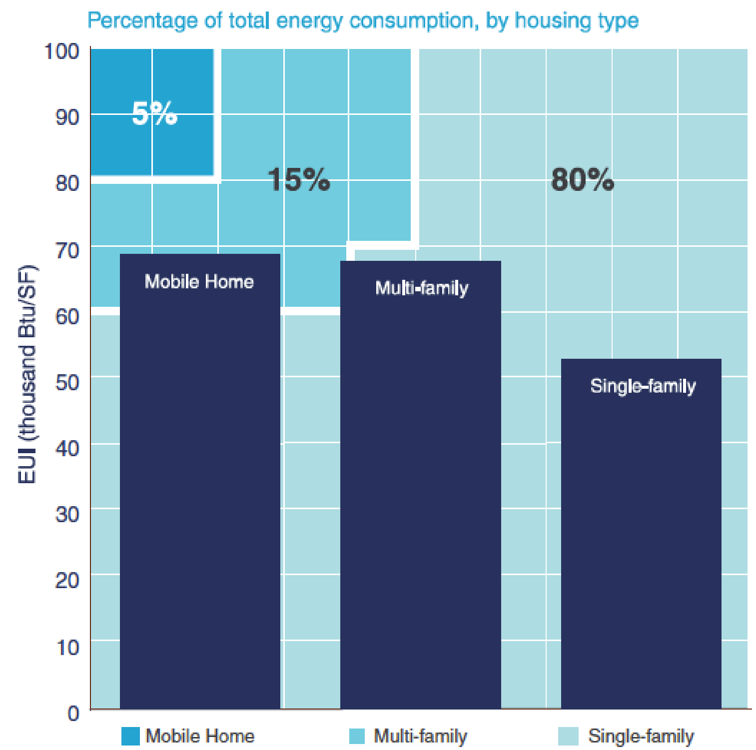
DG already well underway in industrial and "campus" segments

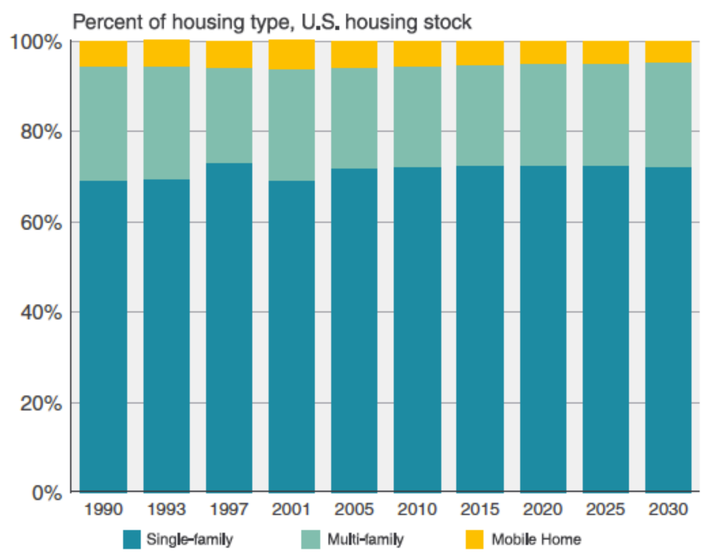
Residential + Commercial = 75% of U.S. Electricity Use

Challenge #1: Need Massively Scalable & Economical Solutions to Achieve National Impact (10% Adoption →1Quad savings)

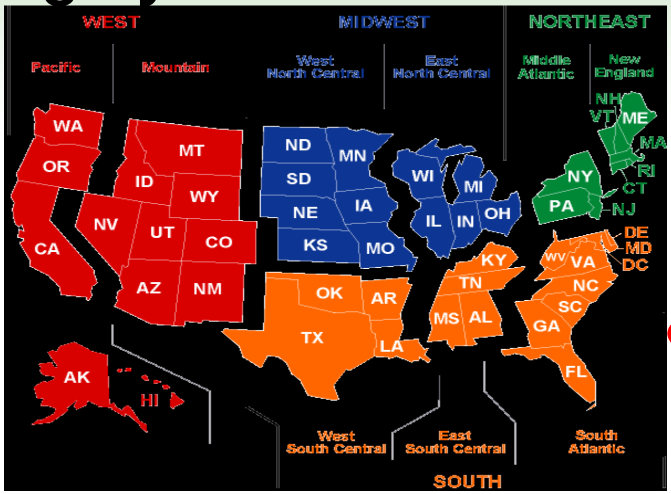


Type of Housing Unit	
Single-Family Detached	72.1
Single-Family Attached	7.6
Apartments in 2-4 Unit Buildings	7.8
Apartments in 5 or More Unit Buildings	16.7
Mobile Homes	6.9





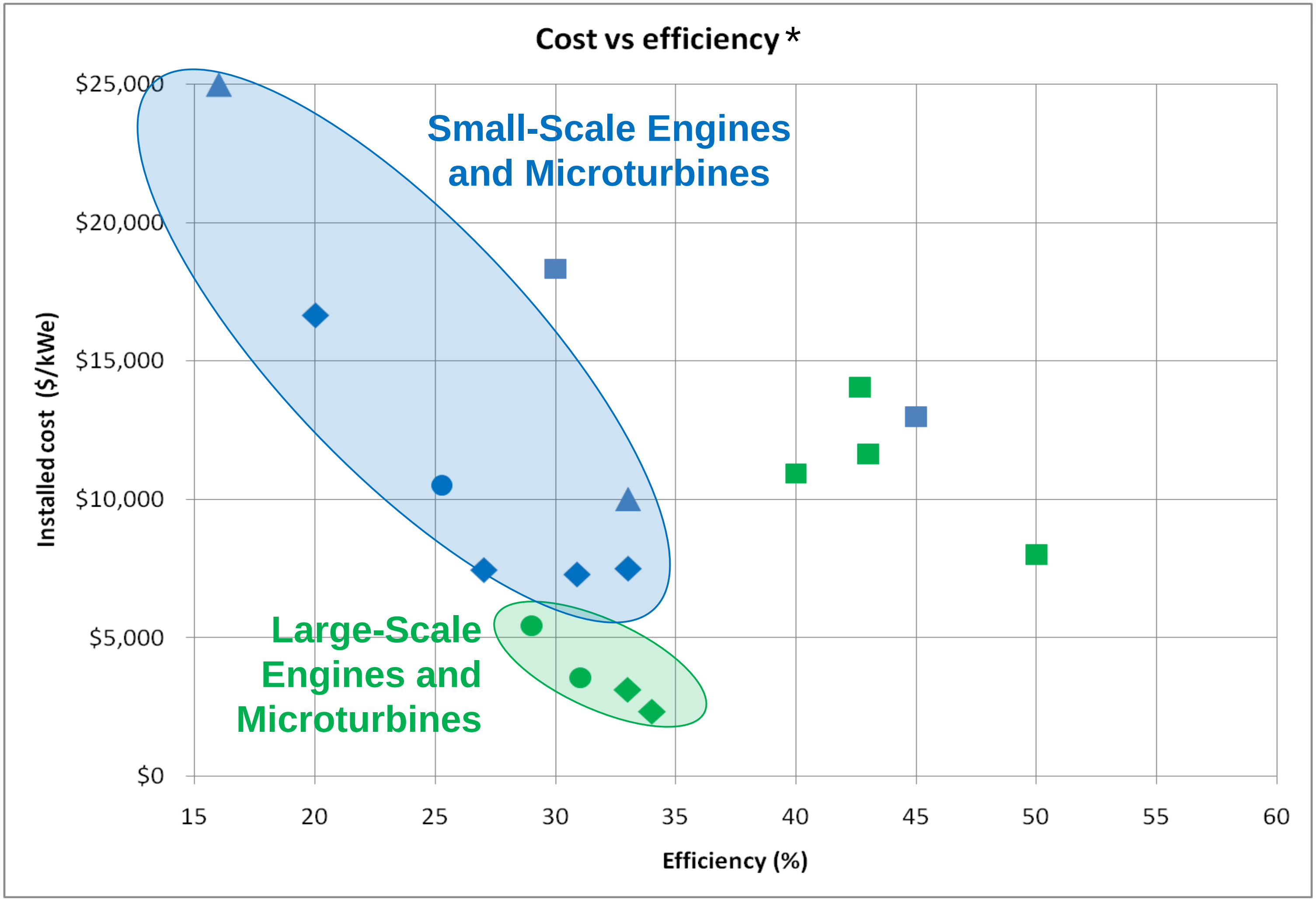
Challenge #2: Ratio of Electricity/Heat (E/H) Demand Highly Variable Across Geography (Season, Time of Day)



Characteristics	Total occupied units	Regions: Northeast	Midwest	South	West
Total	111,806	20,451	25,368	41,586	24,401
All Electric Homes	37,851	2,448	4,362	24,280	6,761
		11.97%	17.20%	58.47%	28.08%

	U.S. Households (millions)	Fuels Used (physical units): Electricity (billion kWh)	Natural Gas (billion kWh)	Fuel Oil (billion kWh)	Kerosene[4] (billion kWh)	LPG (billion kWh)	Total Fuel (billion kWh)	Ratio (Fuel/ Electric)
Total.........	111.1	1,275	1,404	254	5	153	1,816	1.42
Census Region and Division								
Northeast.........	20.6	169	336	211	1	20	568	3.36
New England.........	5.5	41	72	88	Q	6	166	4.05
Middle Atlantic.........	15.1	129	264	124	Q	14	401	3.11
Midwest.........	25.6	276	505	17	Q	52	574	2.08
East North Central.........	17.7	186	378	16	Q	32	425	2.29
West North Central.........	7.9	90	128	Q	Q	20	148	1.64
South.........	40.7	606	275	17	3	53	347	0.57
South Atlantic.........	21.7	319	127	15	2	21	165	0.52
East South Central.........	6.9	110	50	Q	Q	15	65	0.59
West South Central.........	12.1	177	98	N	N	17	115	0.65
West.........	24.2	223	288	9	Q	29	325	1.46
Mountain.........	7.6	82	98	Q	N	17	115	1.40
Pacific.........	16.6	141	190	7	Q	11	209	1.48

Challenge #3: *Small-Scale* DG technologies struggle to provide Sufficient Electricity & E/H Ratio on a 24x7x365, economical basis - *Recip Engines & Microturbines*



KEY (shape)	
○	Microturbine
□	Fuel cell
◇	Recip engine
△	Stirling engine

KEY (Color)	
Blue	Small (≤10kW)
Green	Large (100kW-500kW)

* Commercially and near-commercially available systems only

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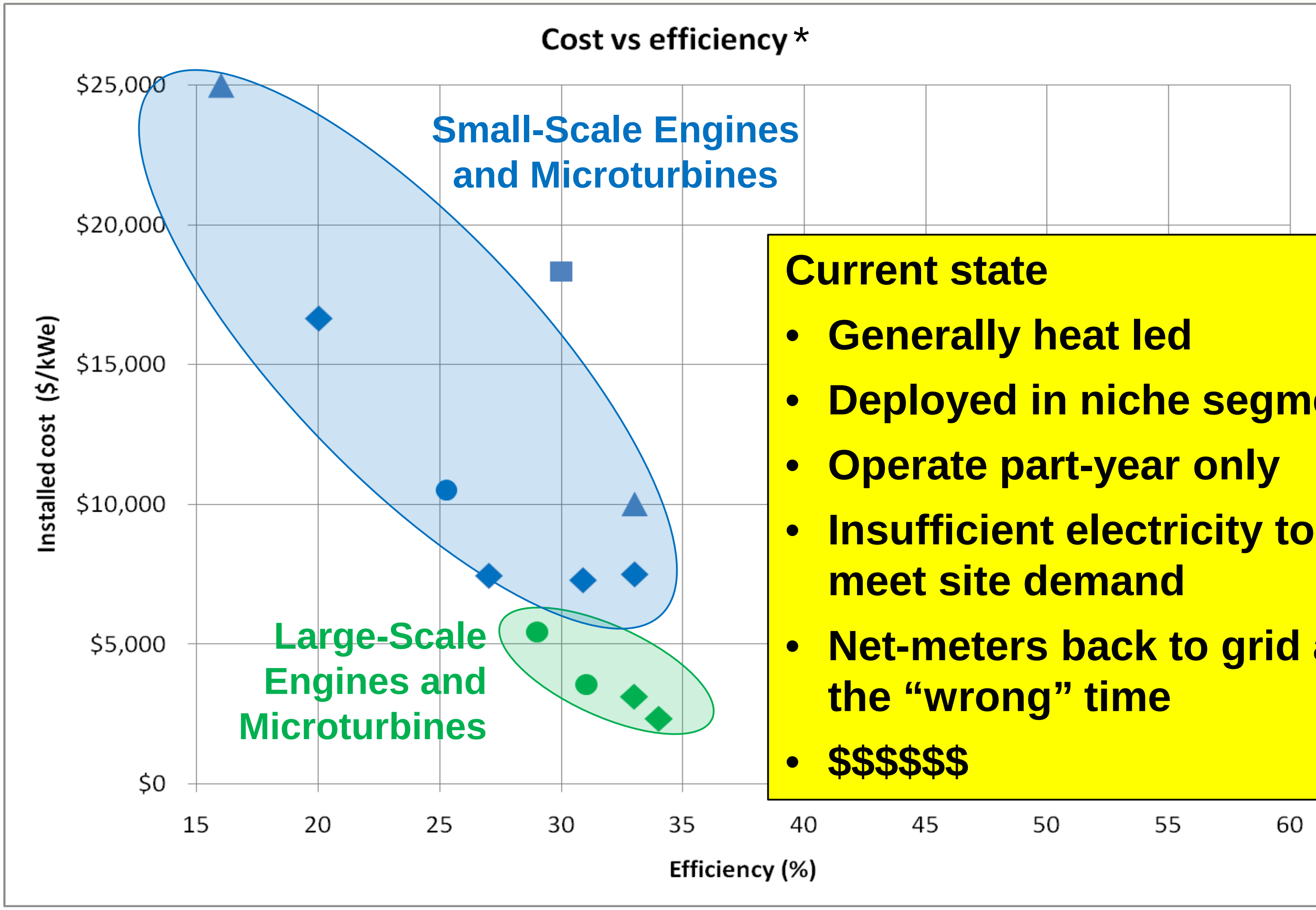

Current state

- **Generally heat led**
- **Deployed in niche segments**
- **Operate part-year only**
- **Insufficient electricity to fully meet site demand**
- **Net-meters back to grid at the "wrong" time**
- **$$$$$$**

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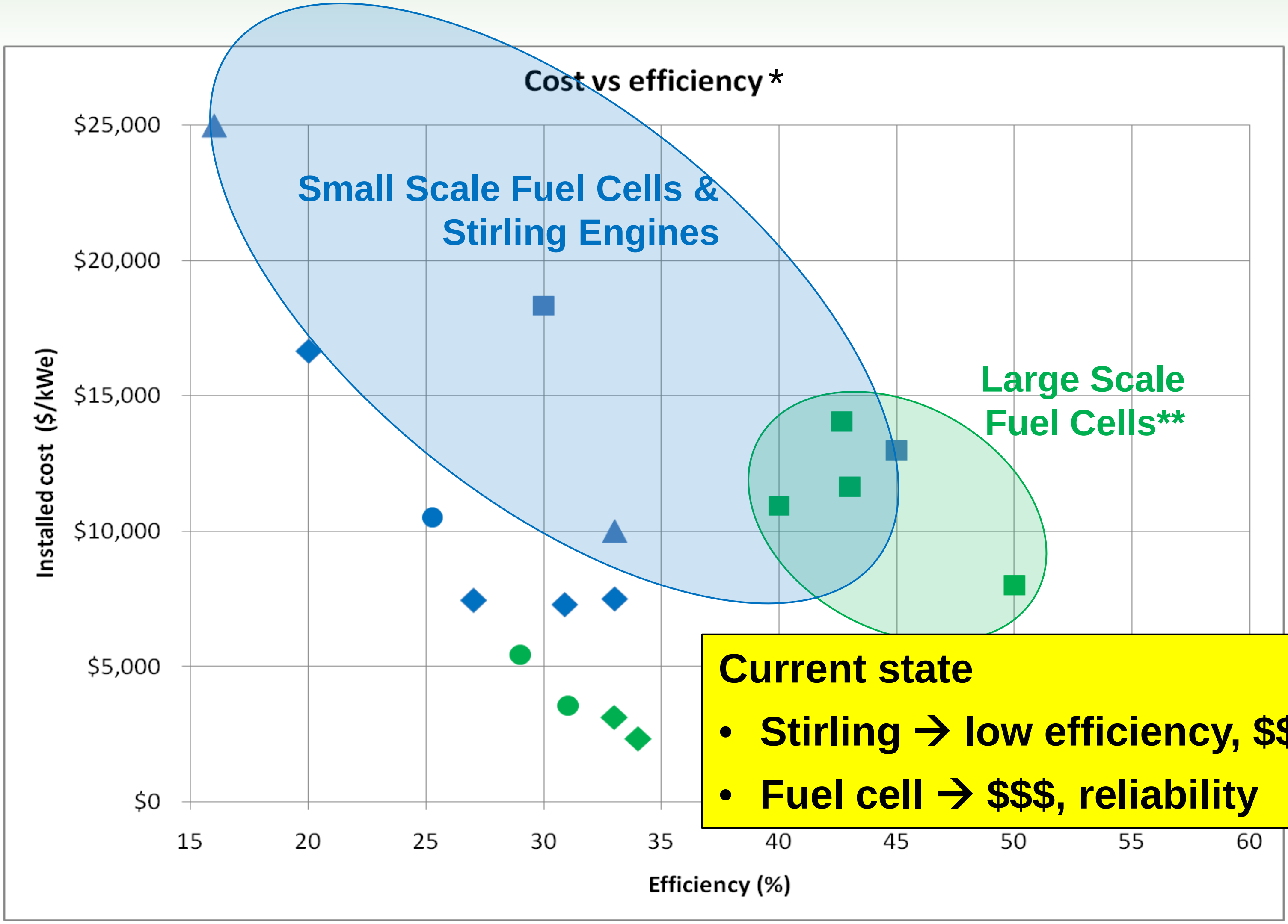

Current state

- **Stirling → low efficiency, $$$$$**
- **Fuel cell → $$$, reliability**

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**Note: No commercial Stirling engines >50kW

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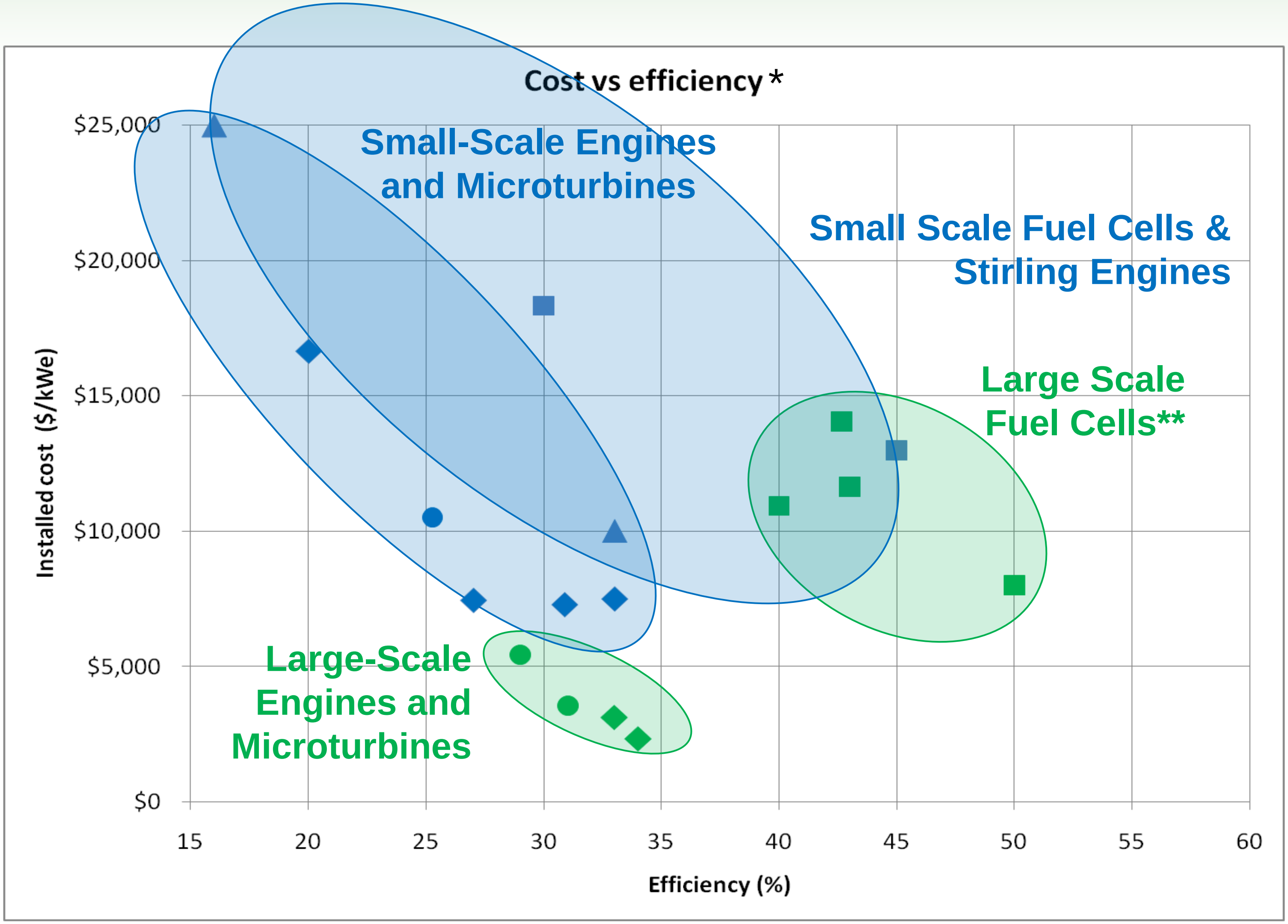

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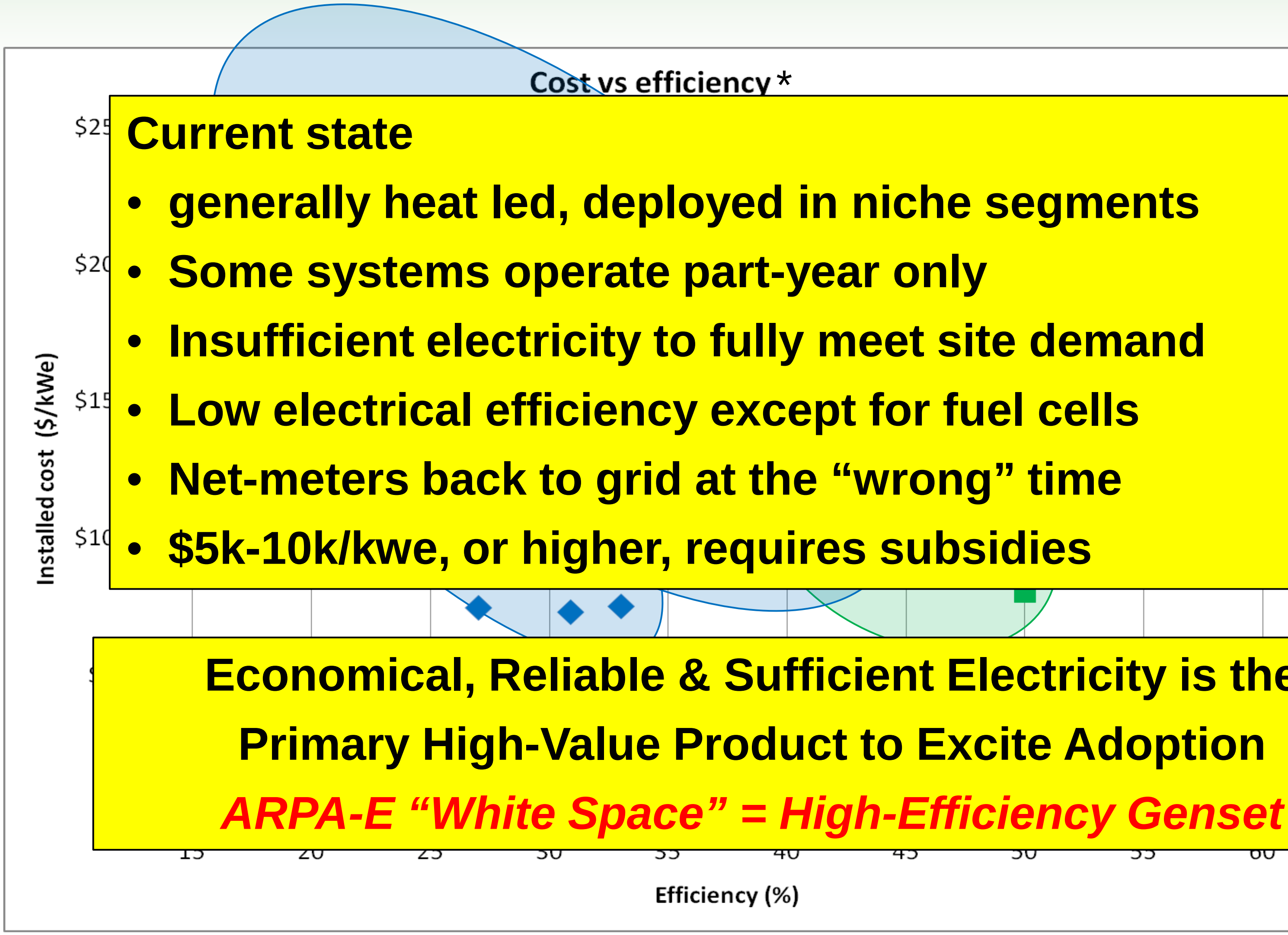

Current state

- **generally heat led, deployed in niche segments**
- **Some systems operate part-year only**
- **Insufficient electricity to fully meet site demand**
- **Low electrical efficiency except for fuel cells**
- **Net-meters back to grid at the "wrong" time**
- **$5k-10k/kwe, or higher, requires subsidies**

Economical, Reliable & Sufficient Electricity is the Primary High-Value Product to Excite Adoption

ARPA-E "White Space" = High-Efficiency Genset

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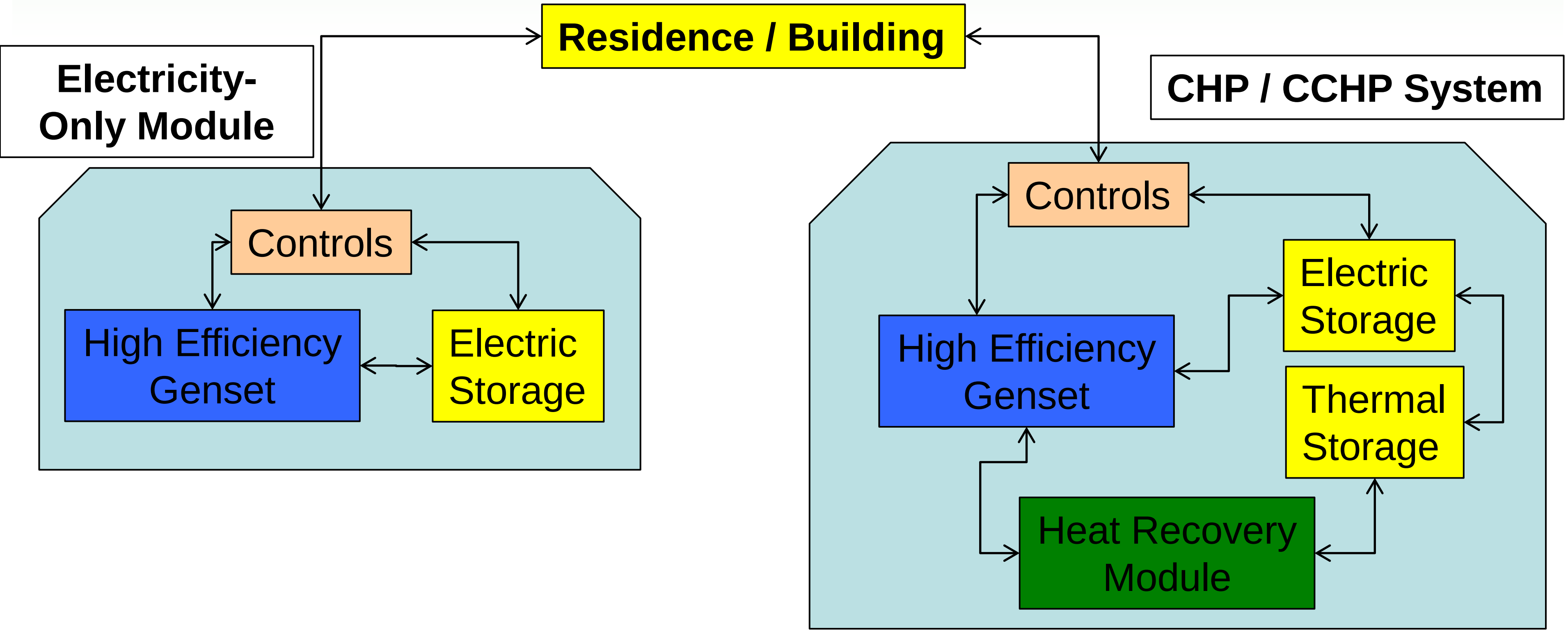
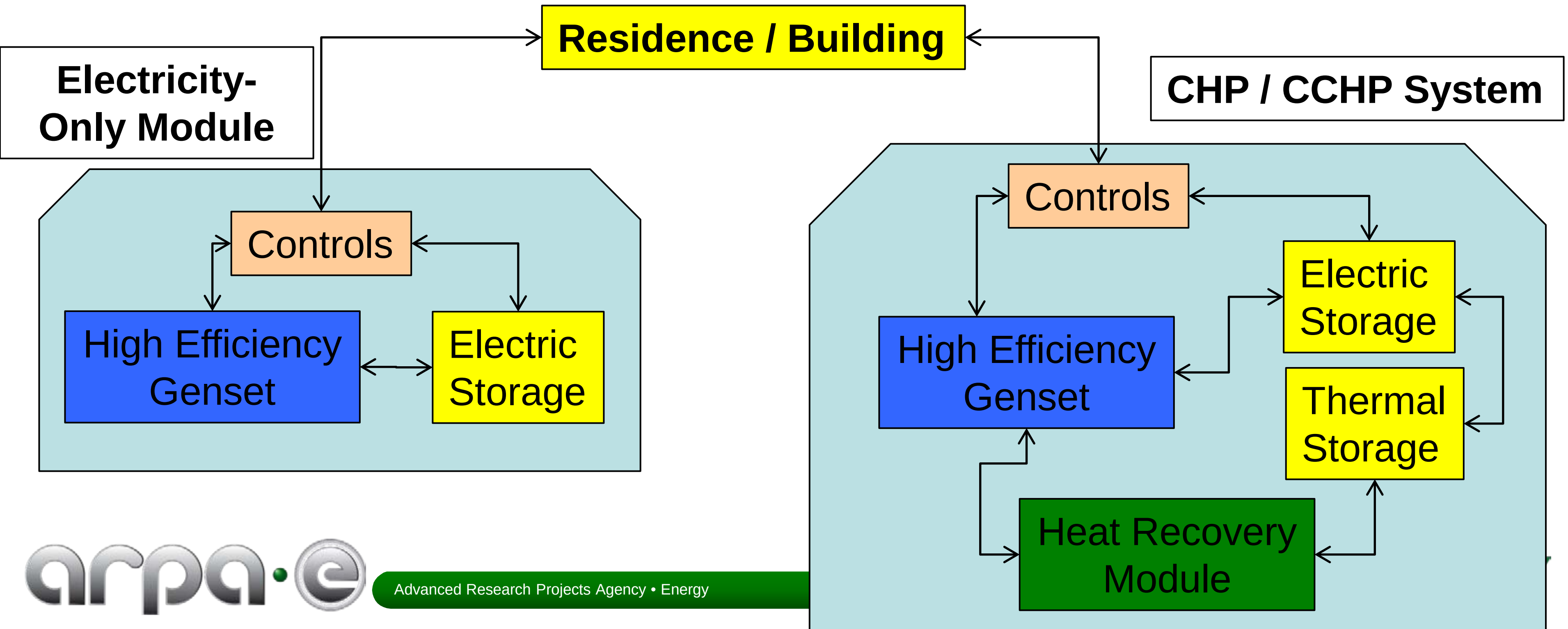
ARPA-E Vision: Mass Adoption of High-Efficiency Genset - 24x7x365 Economical Electricity Generator



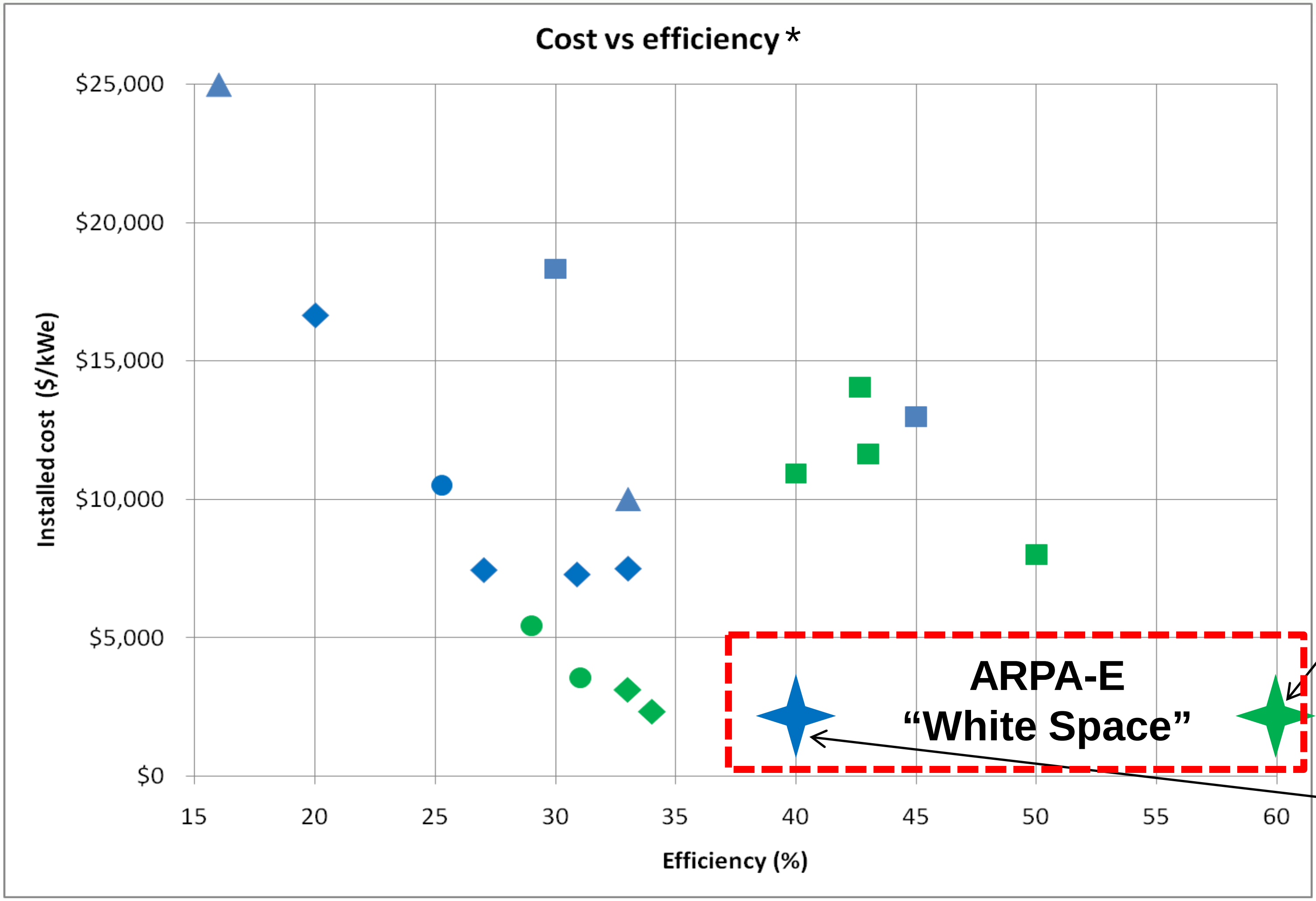
High-Efficiency Genset – Strawman Characteristics

- Fuel-only or *integrated* hybrid of renewable with fuel firming
  - Single prime-mover
  - Two primer-movers for hybrid or combined-cycle system
  - A collection of integrated low-power primer-movers
- Fuel: Natural gas, opportunity fuels, or natural gas focused dual-fuels

- 24x7x365 operation, economical, reliable, full energy needs
- 5-10kwe – 40%+ efficiency; 200-500kwe – 60%+ efficiency
- Additional functional, emissions, and cost metrics ($500-$2000/kwe)



Overall, Current Systems do not meet Strawman Baseline Targets, Especially not at Low Cost



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Community Scale Goal

Single-Family scale goal

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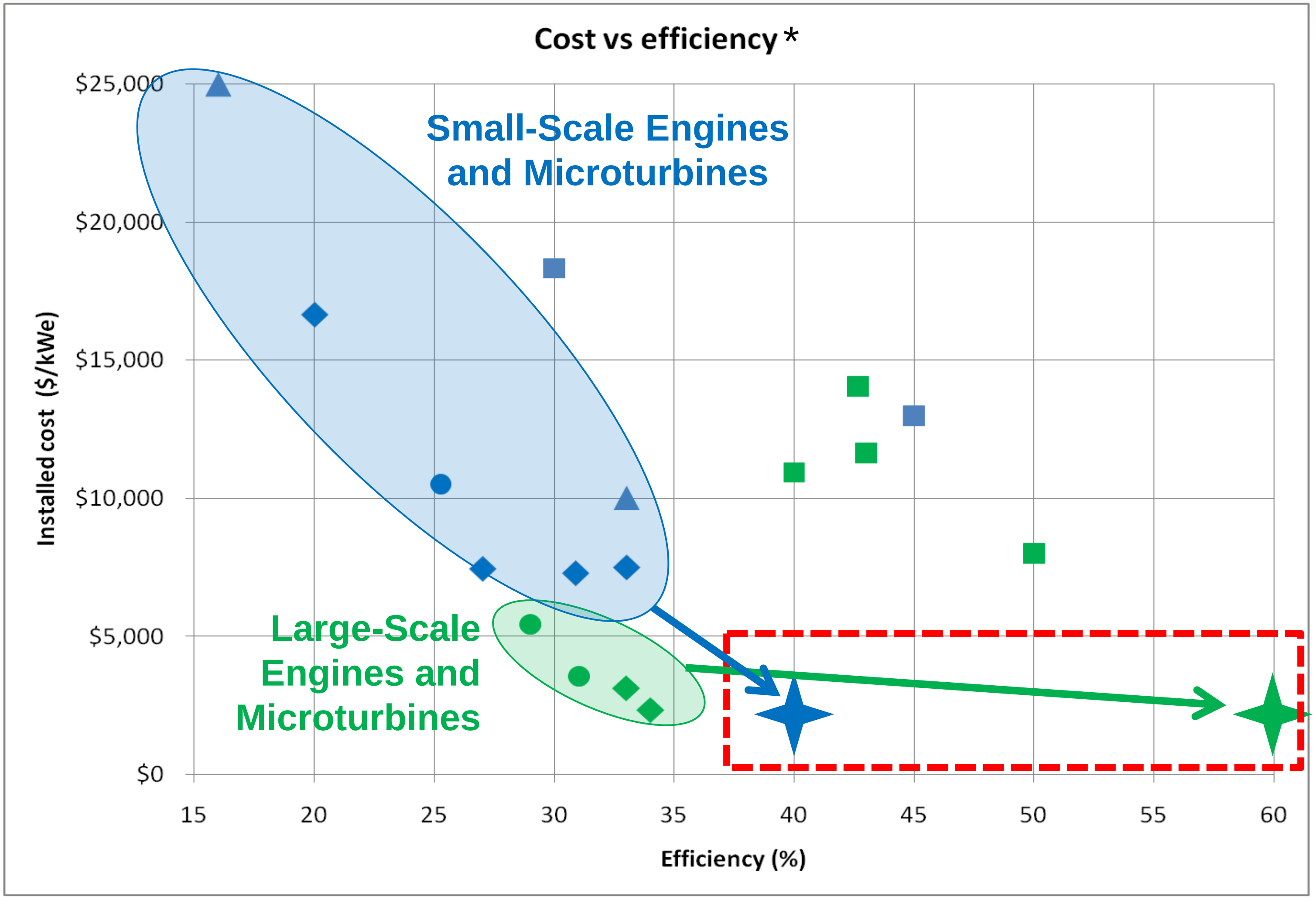
Recip Engines & Microturbines → Cost and/or Efficiency Gaps



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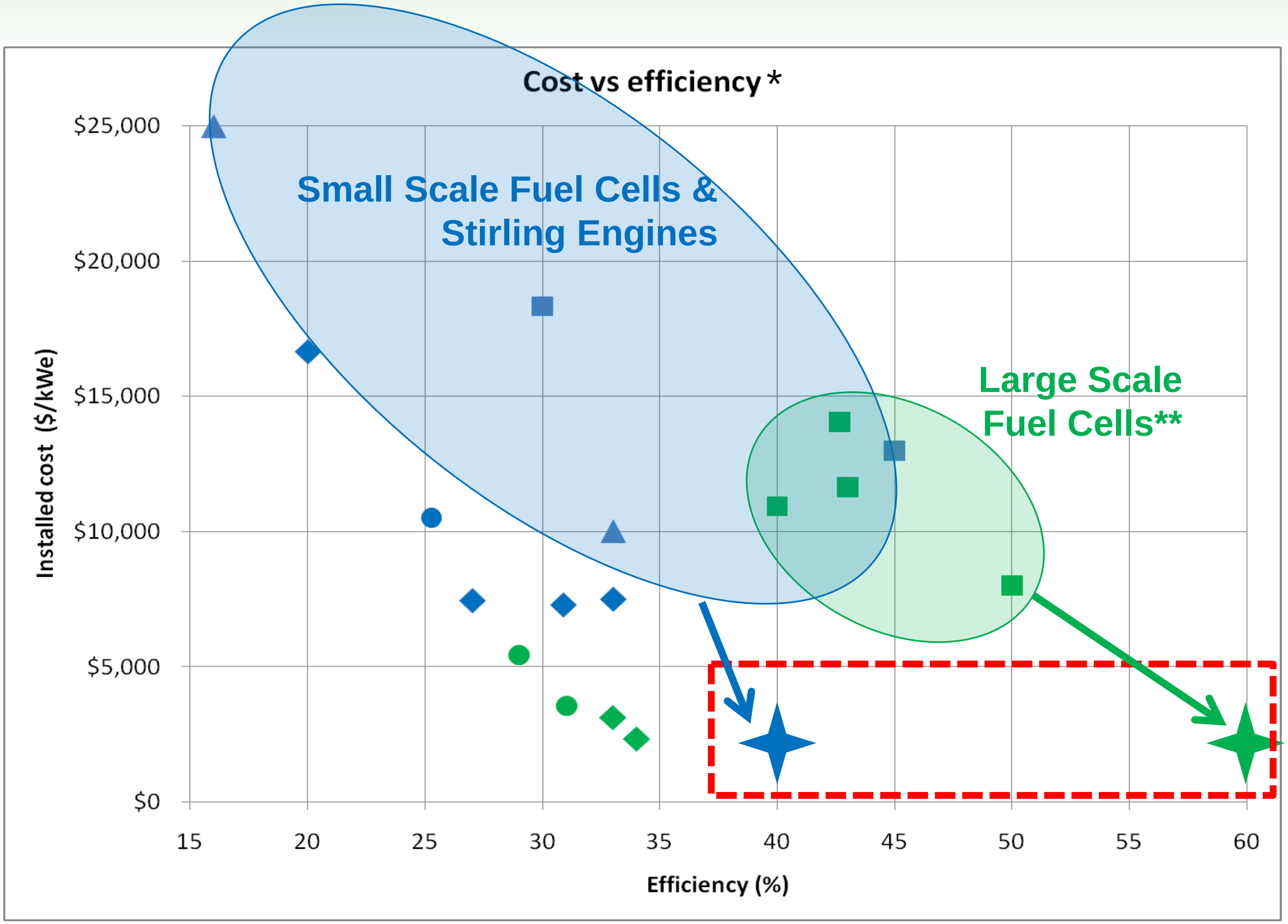
Fuel Cells & Stirling Engines → Cost & Efficiency Gaps



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Workshop Objectives

- Identify major end-use requirements in the small-scale (5-10kwe, 200-500kwe) distributed generation market segments – residential & commercial
- Identify most-challenging technical barriers to very high efficiency, low-cost *gensets*
- Identify promising new R&D paths to meet identified challenges
  - Prime-mover(s) innovations
  - Control – computer, sensors, software
  - Advanced materials, small-scale multiphysics effects
  - Simulations: material, components, process, system
- Develop realistic, quantifiable metrics to evaluate progress and deliverables

Internal Combustion Engine efficiency gap breakdown and possible R&D areas

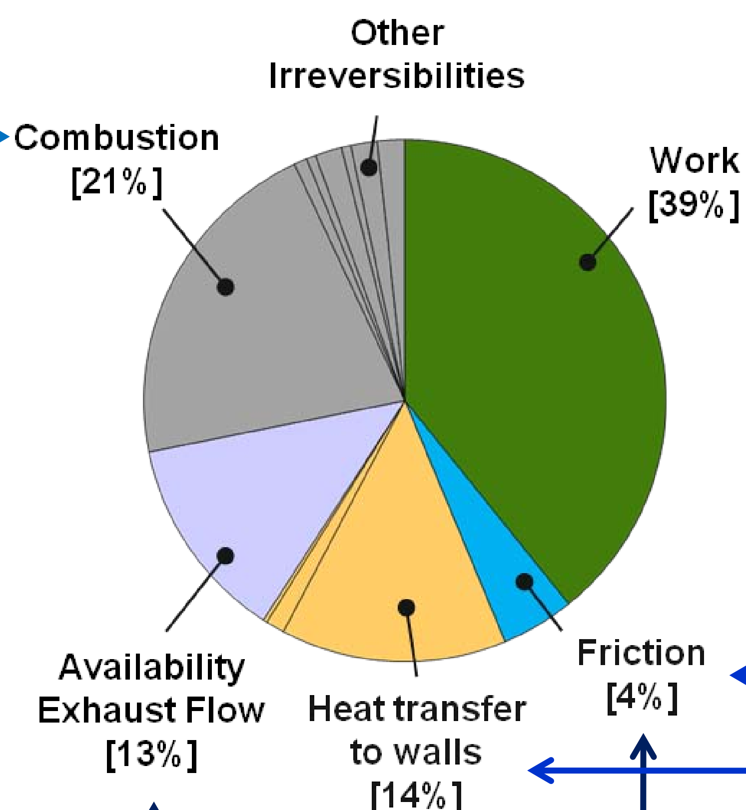
Combustion*

- Emerging methods:
  - HCCI: Homogeneous charge compression ignition
  - RCCI: Reactivity controlled compression ignition
- Synergy with new designs and materials
- Focus of DOE VTP program

Engine design*

- Utilize higher efficiency thermodynamic cycles
- Stationary let automotive R&D lead – *novel but unproven architectures*
  - Free piston
  - Compact design
  - Split-cycle

Example 2nd Law Distribution for a 200kW diesel engine** [3]



Materials*

- Enable high temperature and compression ratio
- Enabler for new engine designs
- Minor focus of DOE VTP program, but face different constraints (weight, size)
- Outreach: Materials to investigate not well defined

Note: distribution for mini-engines differs
- **Work will be smaller fraction**
- **Heat loss and friction will be larger fractions**

Microturbine efficiency gap breakdown and possible R&D areas

Microturbine efficiency analysis

- Community recognizes certain key aspects that control efficiency:
  - Compressor pressure ratio
  - Inlet temperature
- Note that no U.S. commercial MTs <30kW
  - Tip losses
  - Compressor/ turbocharger fabrication and tolerances

Advanced MT designs*

- High temperature recuperator enables low compressor pressure ratios

Materials and coatings*

- Enable high temperature
- Component scale
  - Turbine, Recuperators
  - Compressor
- Outreach: Materials to investigate not well defined beyond "ceramics".

Fabrication

Small scale compressor tolerances

- Advanced manufacturing for small scale blades
- Sealing to eliminate spacing that leads to tip losses

Stirling engine gap breakdown and possible R&D areas

Stirling engine cost

- Engine head is the biggest cost item (about 50%)
  - Exotic materials
  - Exotic liquid metal working fluids
  - Double containment
- 50% in BOS system heat exchanger, alternator and other components
- Most engines on the market are prototypes with no manufacturing base to support production

Stirling engine efficiency

- If focused on efficiency, largest opportunity is in heat exchanger design
- Note: Claimed efficiencies >20% have been challenged for small-scale stirling engine

Materials and working medium

- Enable higher temperature operation
- Advanced liquid metal working fluids

Fabrication

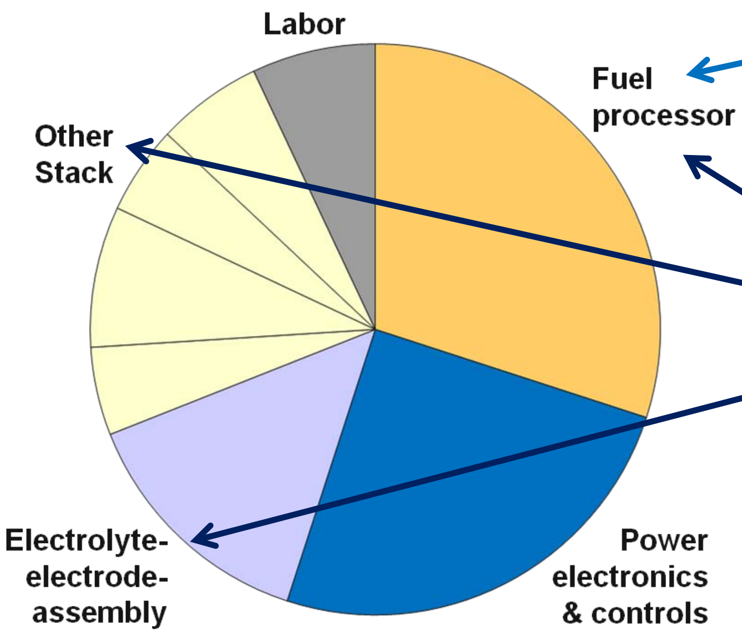
- Allow streamline manufacturing
- Build lower cost alternators
- Improve reliability

Novel engine designs*

- Advanced heat exchanger designs
- Enable higher efficiencies >40%

Fuel cell cost gap breakdown and possible R&D areas

Example fuel cell cost breakdown (5kW SOFC)



Low cost catalysts and/or materials

- Non Pt PEMFC catalysts or non ceramic SOFC materials
- Significant DOE funding over the years

Intermediate temperature designs*

- Way around conventional catalysts/materials
- Two directions:
  - High temperature proton conductor
  - Lower temp SOFC materials

Temperature	Catalyst $	Materials $
Low temp	High	Low
High temp	Low	High
Intermediate	?	?

Hybrid systems*

- For higher efficiency
- Pressurized high temp FC w/ MT or RE

Agenda : Day 1

10:00-10:10	**Summary & Charge** *Dave Shum, ARPA-E*
10:10 –10:25	Break
10:25 – 12:25	**Breakout 1: "Product Specs" in 6-10 years and Beyond**

- **The application space**
  - **Single-family, apartment, neighborhood, small commercial**
  - **Wide range in electric/heat ratio (1:4 to ½:1 to all-electric)**
  - **Enabling genset module in electricity-only or CHP/CCHP system**
  - **24x7x365 high-efficiency genset providing full energy needs**
  - **5-10kwe @ 40%+, 22,000 kwh/yr,**
  - **200-500kwe @ 60%+; 1,000,000 kwh/hr**
  - **$500-$2000/kwe**
  - **Massively scalable & economical design**
- **Have we properly captured the key functional and cost metrics for this genset via the strawman?**

Agenda : Day 1

- The application space
  - Single-family, apartment, neighborhood, small commercial
  - 24x7x365 high-efficiency genset providing full energy needs
  - 5-10kwe @ 40%+, 200-500kwe @ 60%+
- Key functional and cost metrics for this genset

3:20 – 4:30	**Breakout 2: 3-year Must-Have Metrics**
4:30	Dismissal
5:30 – 7:00	Informal Networking

- What subset of metrics must we deliver in 3 yrs time that would excite and continue to engage the private sector toward commercialization in 3-7 yrs?
- Given a typical ARPA-E project horizon (3 yrs, $30MM), could we move the needle?

Agenda : Day 2

- **Breakout 1: Product Specs in application space**
- **Breakout 2: 3-yr Must-Have Deliverables**

9:05 – 11:05	**Breakout 3: Technology-specific**
11:05 – 11:15	Break

- **What are the technology-specific challenges & opportunities to achieve the 3-yr must-have deliverables?**
  - **Internal combustion engine**
  - **Stirling engine**
  - **Microturbine**
  - **Fuel cell**
  - **Hybrid cycles**