Report back:

Technology specific:

Microturbines

June 2, 2011

ARPA-E strawman metrics

Single Family

Category	ARPA-E's proposed
System rating	7 kWe
Electrical efficiency **(@ ≥50% kW rating)**	≥ 50%
Cost	$10k CAPEX @ 10,000 units per year
Lifetime	>7yrs

Community, Apartment, Small Commercial

Category	ARPA-E's proposed
System rating	350 kWe
Electrical efficiency **(@ ≥50% kW rating)**	≥60%
Cost	$1500/kW CAPEX @ 2,500 units/yr
Lifetime	>7yrs

- What are the technology pathways towards these targets?
- Where is the ARPA-E play?

What ARPA-E thinks this means…

ARPA-E sees several major sources of inefficiency in microturbines…

…and has identified several associated "knobs" that can be adjusted to bring up efficiency

Major sources of inefficiency
Combustion efficiency
Entropy increase from combustion
Exhaust losses
Cooling losses
Small-scale sealing and tip losses
Heat-transfer inefficiency of recuperator

Potential "knobs" to increase efficiency
System architecture
Combustion approach
Component design
Materials

Important that adjusting knobs does not have significant impact on other metrics

Key Takeaways

1. State of the art today is insufficient
2. Technology pathway: **raise T_{hot} without introducing parasitic losses due to cooling**
3. Single family natural gas microturbine is achievable (7 kW, 50% efficient, 7 yr, $10k @ 10k units/yr)
4. Community / Small commercial natural gas microturbine (350 kW, 60% efficient, 7 yr, $1.5k/kW @ 2.5k units/yr) is achievable

Single family target is achievable

7 kW, 50% efficient, 7 yr, $10k @ 10k units/yr

- Keys are:
  - Big, cheap, high manufacturing yield recuperator with 95-98% effectiveness
  - High temperature ceramics or other novel materials
  - Novel combustion cycle (i.e. constant volume combustion)
- Compelling consumer product
  - NG backup generator is $6k → $4k extra to be mostly off-grid
- Will push microturbine technology into new realms
- Full prototype can be built on ARPA-E size award

Small commercial target is achievable

350 kW, 60% efficient, 7 yr, $1.5k/kW @ 2.5k units/yr

- Keys are:
  - Large cheap high manufacturing yield recuperator with 95-98% effectiveness
  - High temperature ceramics or other novel materials
  - Novel combustion cycle (i.e. constant volume combustion)
  - Combined cycle / bottoming cycle or hybridization with fuel cells is necessary to reach 60%
- More options available
- Meeting ARPA-E size budget would require smaller prototype or building and proving out critical subsystems

Other ideas

- Will require improvements in existing materials (Si_3N_4) or new materials / coatings (oxide based, CMCs)
- Modify combustion process to reduce water content
- Pyroelectric electricity recovery
- Constant volume combustion
- Potential supply chain issues should be alleviated by shooting for 10% market penetration
- Emissions – could be solved by after-treatment, depending on local regulations

Questions?

- Can 40-60% efficiency be reached with a single-cycle system, or only with a combined cycle?
  - What cycle-level innovations are necessary to meet 40 or 60% efficiency goal?
  - What component level innovations are necessary to meet 40 or 60% efficiency goal?

50% is achievable single-cycle

bigger cheaper recuperator with 95-98% effectiveness

advanced materials (ceramics, CMCs)

novel combustion cycle (i.e. constant volume combustion)

≥60% requires a combined cycle

Is this an ARPA-E play?

- It is rare to find microturbines <30kW. Is it reasonable to envision microturbines in the 5-10kW segment?
  - What are the challenges in scaling microturbines engines down?
  - What innovations are needed to catalyze microturbines in the 5-10kW range?
- Yes it is doable

Is this an ARPA-E play?

- What are the challenges associated with using high temperature materials in microturbines?
  - Which component(s)?
  - What characteristics would the ideal material have?

- Damage caused by interaction with water vapor
- Can mitigate with better coatings on materials or by increasing the fuel – air ratio

Is this an ARPA-E play?

- If higher combustion temperature is adopted as a design strategy, what strategies are available to manage the emission consequences?

Is this an ARPA-E play?

- Are there any other factors that significantly affect efficiency besides inlet temperature and compressor pressure ratio?

Is this an ARPA-E play?

- Are there architectures/designs that could get around small scale sealing/tip loss issues?

Is this an ARPA-E play?

- How could advances in microfluidics impact design innovations?

Is this an ARPA-E play?

- Where is the ARPA-E white space in microturbines?

- Reviewing the “knobs”, rank them in order of potential highest impact and highest risk relative to ARPA-E’s 3-yr program horizon? (Please add categories if necessary).

Potential “knobs” to increase η	Impact rank	Risk rank
System architecture		
Combustion approach		
Component design		
Materials		

- What can be done in microturbines with a 3yr $30M program? Enough to “move the needle”?

- What are some key design-for-mass-manufacturing issues that must be considered in developing a prototype?

- What do you think is the minimum set of calculations/modeling results/test data that should be required for consideration for ARPA-E funding (For example: thermodynamic cycle analysis? FEA/CFD system analysis? energy calculations, reliability data, cost-modeling, emission data, …)?