Report back:

Technology specific:

Internal Combustion Engines

June 2, 2011

ARPA-E strawman for single family systems

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

- Within each technology platform, what are the technology pathways towards these targets?
- Where is the ARPA-E play?

Key takeaways for single-family Internal Combustion Engines

- Efficiency is the key metric, cost and reliability are much more feasible
- Getting to this high efficiency constrains your shaft speed

- For low power engines, the ICE will need to have ~55% brake thermal efficiency
- This sets the challenge to hit this efficiency
- This would be a transformational change, and perceived to be very difficult

- Challenge will be producing an engine that is small enough at high efficiency

- Cycles available in order of highest efficiency

(1) New cycles
(2) Brayton
(3) Diesel
(4) Atkinson
(5) Otto

Key takeaways for single-family Internal Combustion Engines

- Knobs available in order of highest impact

(1) Thermodynamic cycle
(2) Engine architecture and combustion approach
(3) Materials

(1) Thermodynamic Cycle
- Complete expansion, camless, split cycle, high gamma (use argon)

(2) Ignition
- Plasma, HCCI

(2) Combustion
- Oxyfuel – remove N2, use EGR or add argon

(2+3) Low Heat Loss
- Low turbulence, low wall K, high wall temperature

(3) Low Friction
- Piston rod, non-piston cylinder, advanced oils, oil-less engine

ARPA-E strawman for community, apartment, small commercial systems

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

- Within each technology platform, what are the technology pathways towards these targets?
- Where is the ARPA-E play?

Key takeaways for Community Scale Internal Combustion Engines

1. Incorporation of a Bottoming Cycle onto an ICE.
    - With current technology it should be possible to hit 60% efficiency with an engine + bottoming cycle
    - ***Challenges:***
    - Efficient engine designs are already ~ $1500/kW
    - Adding a bottoming cycle (roughly ~750 $/kW now) will push it beyond the price point
    - Success involves bending the cost curves on ***both*** the engine and the bottoming cycle.
    - Low cost heat exchanger is a big need for the bottoming cycles

Key takeaways for Community Scale Internal Combustion Engines

2. New Engine Architectures
    - There are a number of people sitting on promising blueprints.
    - Accept new engine architecture proposals, result at the end of three years should be:
        - ~50 kW prototype
        - Efficiency targets ~50%-55% with path to 60% at scale
        - Business plan with necessary cost reductions at scale
    - Experimental data validating concept a big plus, modeling only data requires heavy scrutiny
    - Free piston engine a possibility
    - Linear alternator would be a huge advance

Questions from White Space from Community Scale ICE Group

- Emerging Combustion Methods
  - Pulsed Plasma Ignition Discussed (Martin Gunderson)

- New Engine Cycles
  - No one knew what a Humphrey cycle is.
  - Atkinson could be a promising cycle, lower energy density is a constraint in mobile applications, less so in stationary.

- Materials Advances
  - Not a lot space of white space on friction advances, industry tackling it
  - Material advances currently not a constraint

- Differences Stationary/Mobile
  - Lower volumetric and specific power density is a plus
  - Have to take into account the installation cost (laying concrete, etc)
  - Can pick a sweet spot for operation, less transients cycling than mobile operations
- What is needed to evaluate proposal
  - Experimental data validating concept is a big plus, modeling only data requires heavy scrutiny

Data Tables for White Space from Community Scale ICE Group

Major sources of inefficiency	
Entropy increase from combustion	~20%
Cooling losses	~10-15%
Exhaust losses	~5-10%
Friction losses	~5%
Emission controls	~1-3%

Potential “knobs” to increase η	Impact rank	Risk rank
Engine architecture	1	1
Thermodynamic cycle	Tied @ 2	3
Combustion approach	Tied @ 2	2
Materials	4	4