# APRA-e Distributed Generation

## Fuel Cell & Hybrid Technologies

Assessing technology gaps and near-term market potential

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# Agenda

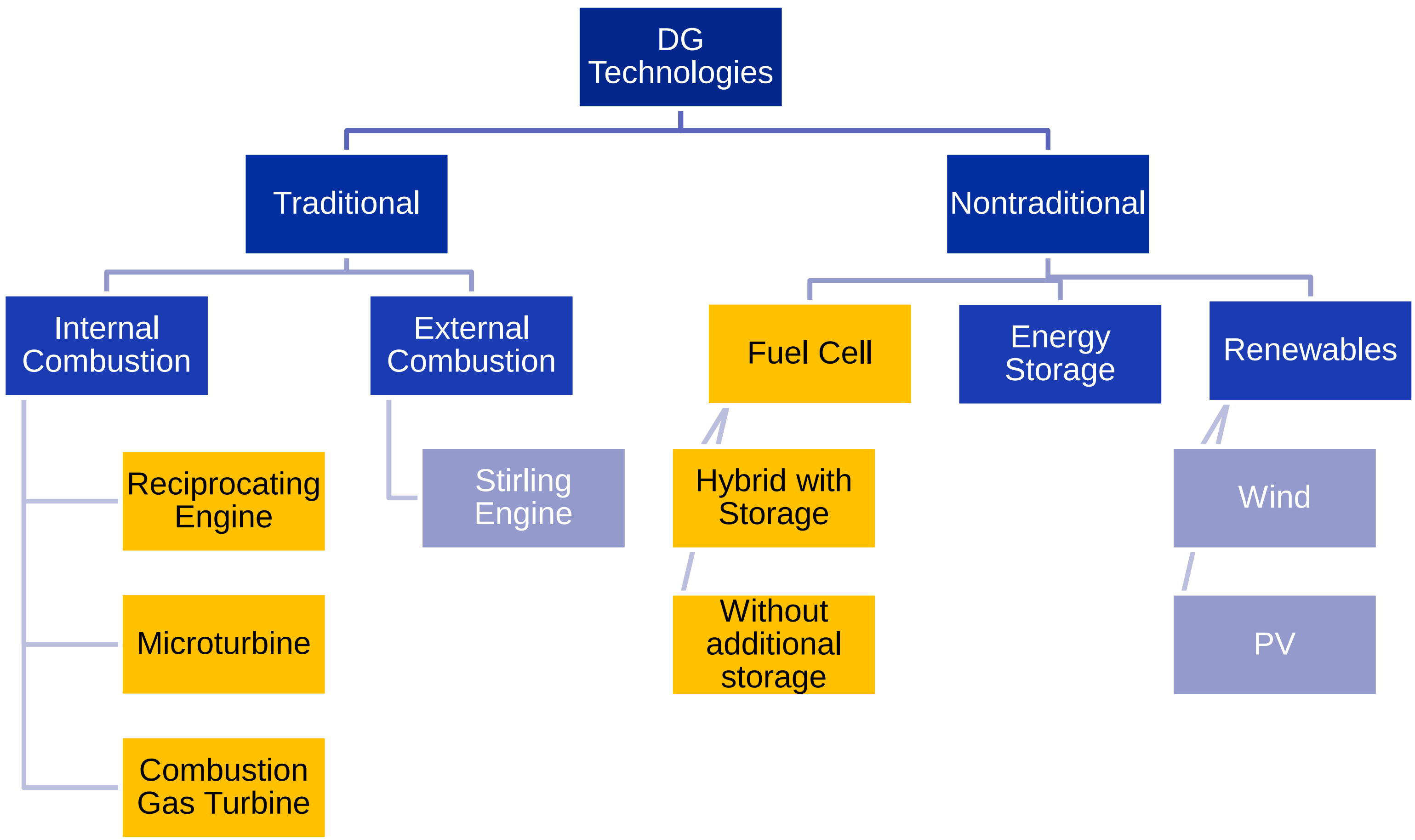
- Focus of the DNV KEMA Study
- Trends in Markets, Grids and Distributed Generation
- DG Applications
- DG Technologies
- Coupled or Hybrid Solutions
- High Potential Applications

# Our Focus for the Study

- Study examined the fuel cell market potential in relation to new trends and available technologies
- The focus of this study was to examine mechanisms that could be created to expand fuel cell adoption in the market
  - Where are technologies best applied
  - What are the current technology or performance gaps
  - Should fuel cells be combined with other advanced technologies, such as storage
  - Hybrid application areas
  - Recommendations on paths forward to hybrid applications
- For today, we are going to focus on potential hybrid application and recommended paths forward

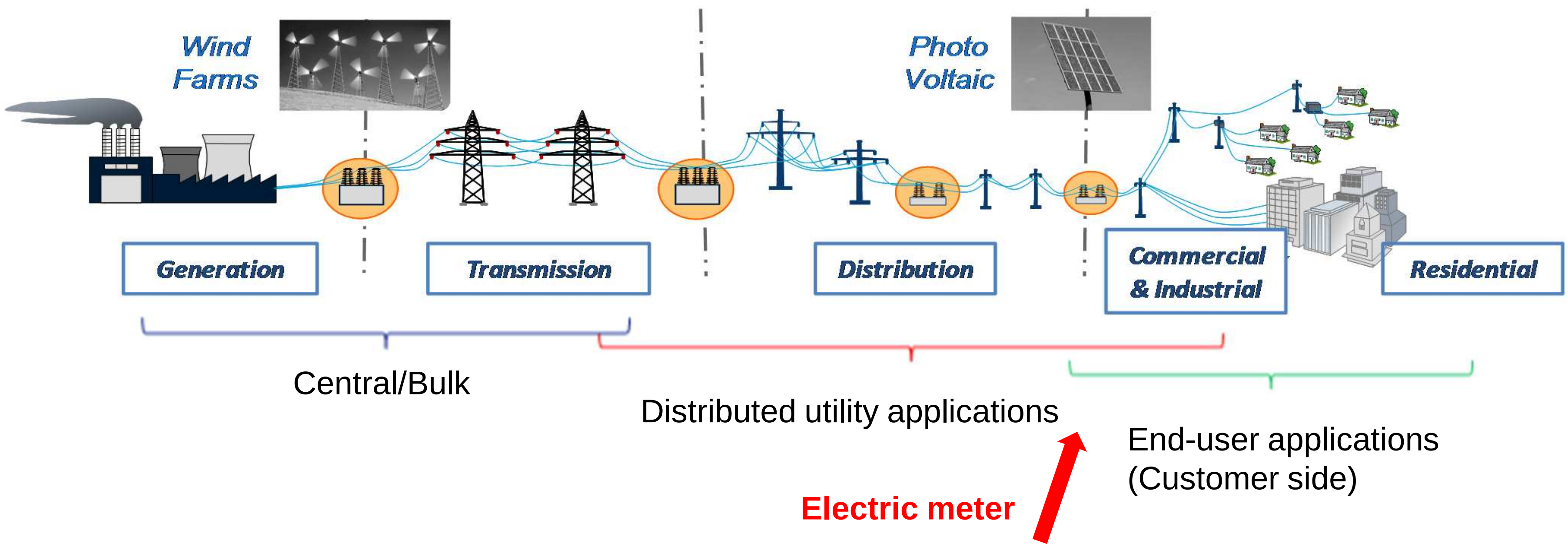
# DG Technology Categories

- Study will compare Fuel Cells with traditional DG technology with the option of coupling with high-efficiency energy storage



# Grid Overview

- Large-scale bulk generation to small-scale distributed generation
- Distributed resources on either side of meter: utility vs. customer side
  - Access to different revenue streams and applications
  - Different rules and regulations
  - Different market drivers

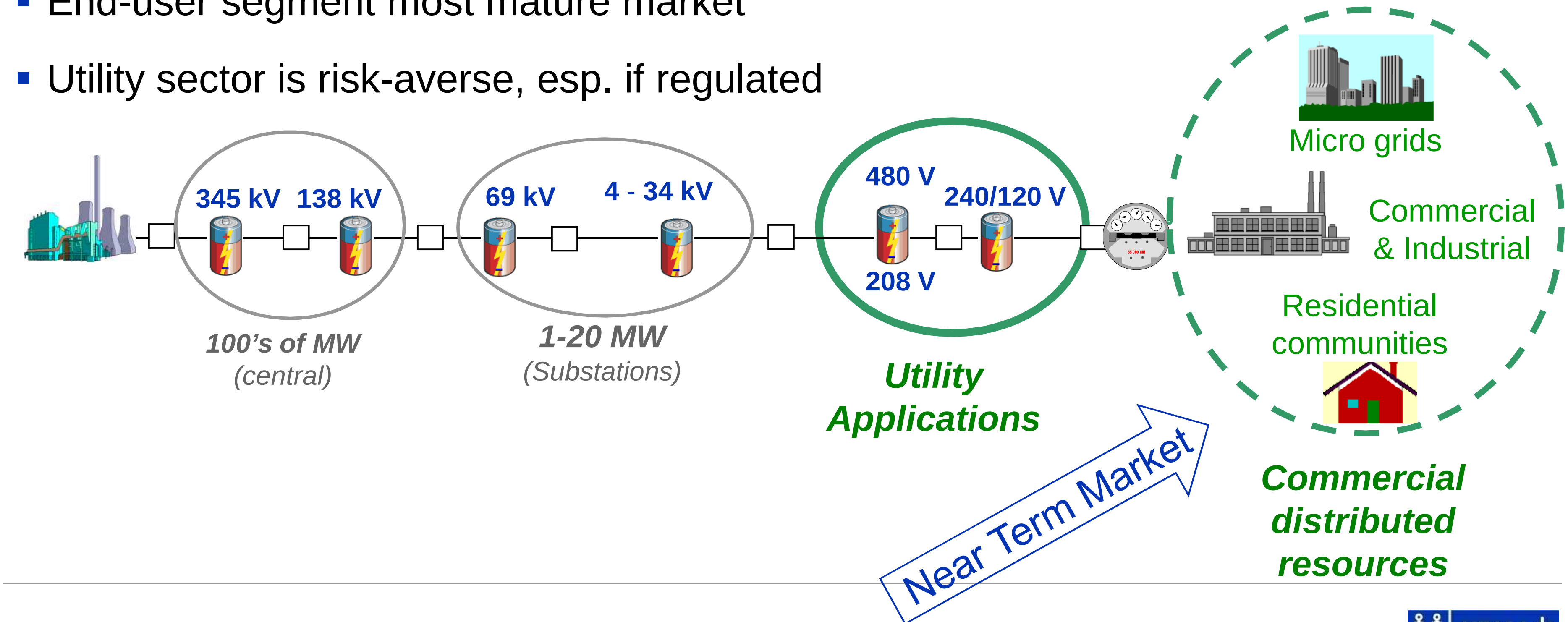


# U.S. grid and market trends

- Macro forces re-trending energy systems back towards distributed assets
  - Advanced technologies in personal lives leading to desires for greater control and utilization of smart systems
  - Major grid incidences and long term outages bringing “resiliency” and “edge of the grid solutions” back into focus
  - Gas prices back to levels last seen in 1999-2000, distributed technologies closer to grid parity (solar, EVs)
- Renewable generation deployment is growing
  - Intermittency of resources creating challenges with grid control and operation – creating need for greater flexibility in system
- Increasing focus on energy efficiency and load management as a means to manage cost
  - Goal of reducing energy use and responding to market opportunities
  - To avoid congestion and new transmission capacity
- Energy markets are responding to changes
  - Product development: Demand Response, Storage, Ramping products, Capacity markets

# Market drivers and environments

- Trends driving the distributed energy resources (DER) market include
  - Resiliency and reliability concerns along with the potential to reduce cost
  - Wholesale market opportunities for DG
  - Renewables integration and policy
  - Microgrid deployment and capabilities
- End-user segment most mature market
- Utility sector is risk-averse, esp. if regulated



# DG Applications Overview (Technology Independent)

- Mature DG markets include CHP and back-up power
- Near-term market on customer side

| Application | Objective | Side of meter | |
|---|---|---|---|
| | | Utility | Customer |
| **Continuous Power / Base Load** | Generate power on site cheaper than utility on a continuous basis | | C&I |
| **CHP** | Generate power and heat for space/water heating or steam generation | | C&I & Res |
| **Uninterrupted Power Supply (UPS)** | Replace the normal source if it fails. Automatic and instantaneous response. | | C&I & Res |
| **Back Up** | Replace the normal source if it fails. | X | C&I & Res |
| **Back-up with Islanding** | Operate independent of the electric grid for long-duration outings. | | C&I |
| **Renewables** | Smoothing, leveling and storing renewable energy | X | C&I & Res |
| **Peak Shaving** | Supply peak power to reduce overall electricity costs | X | C&I |
| **Demand Response** | Reducing load on utility grid by shifting to DG resource during peak hours. | Aggregator | C&I |
| **Regulation** | Balancing generation and load on second timescale | X, IPP | |
| **Reserves** | Balancing generation and load on a 5-20 min timescale. | X, IPP | |
| **Supply Capacity** | Participating in the capacity market, designed to ensure future resource adequacy. | X, IPP | |
| **T&D Deferral** | Delay the purchase of new transmission or distribution systems and equipment. | X | |

# DG Technology Characteristics –

| | Internal Combustion Technologies | | | Fuel Cell Technologies | | | | Storage Technologies | |
|---|---|---|---|---|---|---|---|---|---|
| Characteristic | Reciprocating Engine | Microturbine | Combustion Gas Turbine | Proton Exchange Membrane (PEMFC) | Phosphoric Acid (PAFC) | Molten Carbonate (MCFC) | Solid Oxide (SOFC) | High Power like li-ion | High Energy like NaS |
| Size | 30kW-6+MW[1] | 30-400kW[1] | 0.5-30+MW[1] | <1kW-500kW [21] | 50kW-1MW (250kW module typical) | <1kW-5MW (250kW module typical) [42] | <1kW - 5MW [42] | few MWs | few MWs |
| Power Density $(mW/cm^2)$ | 2,900 - 3,850 [1] | 3,075 - 7,175 [1] | 1,750 - 53,800 [1] | 350-800 [23] | 140 - 320 [17] | 100 - 120 [23] | 150 - 700 [23] | N/A | N/A |
| Operating Temperature | 450°C (850°F) [30] | 980°C (1800°F) [29] | 1930°C (3500°F) [28] | 50-100°C (122-212°F) | 150-200°C (302-392°F) | 600-700°C (1112-1292°F) | 600-1000°C (1202-1832°F) | ambient | 290-360°C |
| Start-up Time | 10s to 15 mins[8] | Up to 120s [8] | 2 - 10 min [8] | 15 - 30 min [31][41] | 3-4 hrs [27] | 8 - 24 hrs [27] | 8 - 24 hrs [27] | ms | ms |
| Elec. Efficiency (LHV) % | 30-42%[1] | 14-30%[1] | 21-40%[1] | 36-50%[9] | 37-42% [6][9] | 45 - 50% [6] | 40-60% [6] | 93-97% | 85-90% |
| Electric+Thermal (CHP) Efficiency % | 80-85%[1] | 80-85%[1] | 80-90%[1] | 50-75%[9] | <85%[9] | <80% | <90% | 90-94% AC | 78-80% AC |
| Installed Cost ($/kW) | $700-1,200/kW[1] | $1,200-1,700/kW[1] | $400-900/kW[1] | $3,500/kW [21][41] | $4,500 - 9,000/kW [15] | $4,200 - 7,200/kW [15] | $3,500 - 8,000/kW [9] | $1200-1800/kW | $3500-4000/kW |
| Fixed O&M Cost | $600-1000/kW [33] | $700-1100/kW [37] | $600/kW [37] | $1000/kW [21] | $400/kW [17] | $360/kW [15] | $175/kW | $8-30/kW | $15-40/kW |
| Variable O&M Cost | $0.007 - 0.02/kWh[1] | $0.005 - 0.016/kWh[4] | $0.004 - 0.01/kWh[1] | $.003/kWh[41] | $.002/kWh[15] | $.004/kWh[15] | $.0045-.0056/kWh[20] | $0.002-0.004/kWh | $0.03 0.09/kWh |
| Maintenance Interval (hrs)/Fuel Cell Module Durability (Hrs) | 750 - 1000: change oil and oil fiter 8000: rebuild engine head 16000: rebuild engine block [3] | 5000 - 8000 [4] | 4000 - 8000 [3] | 20,000 - 30,000+ [42] | 30,000 - 40,000+ | 40,000+ [9] | 40,000 - 80,000+ [11] | 2 yr interval, 10 yr life | 2 hr interval 10 year life |

# Technology Capabilities

- Key features of each technology make them suited for different applications
- Fuel Cells can compete in niche applications where traditional DG technology may be inadequate
  - Regions where environmental restrictions drive technology choices
  - Emission sensitive areas
  - High reliability needed
  - Thermal-electrical profiles map to technology

| | IC Technologies | | | Fuel Cell Technologies | | | | Storage | |
|---|---|---|---|---|---|---|---|---|---|
| Characteristic | Recipro-cating Engine | Micro turbine | Combustion Gas Turbine | Proton Exchange Membrane (PEMFC) | Phosphoric Acid (PAFC) | Molten Carbonate (MCFC) | Solid Oxide (SOFC) | High Power like Li-Ion | High Energy like NaS |
| Startup response | fast | fast | medium | medium | slow | slow | slow | fast | fast |
| Ramping response | fast | fast | fast | fast | slow | slow | slow | fast | fast |
| Baseload feasibility | low | low | high | medium | high | high | high | low | low |
| Fixed O&M | high | medium | high | low | high | high | low | low | medium |
| Variable O&M | high | high | high | medium | medium | medium | high | medium | medium |
| Noise pollution | high | high | high | low | low | low | low | low | low |
| Emissions | high | low | low | low | low | low | low | low | low |
| Operating temp. | medium | high | high | low | medium | high | high | low | high |

# Are there gaps with Fuel Cell technologies?

- Challenges
  - Fuel cells are slow to start-up
  - Fuel cells are not built to ramp up or down
  - Cost is a barrier to widespread penetration
  - Temperature makes handling and siting a challenge (some technologies)
  - Fuel supply
  - Public concerns around safety and storage
- Impacts
  - Poor ability to load follow and limited flexibility forces device into “baseloaded” roles
    - Limits ability to tap into future market revenue opportunities such as demand response and address peak loading scenarios
  - Poor “transitional” capability to grid incidences limits the device to be used to handle intermittency or island during outages
  - High efficiency makes device relatively poor combined heat and power system

**Can some challenges be addressed by coupling with other technologies?**

# Application feasibility

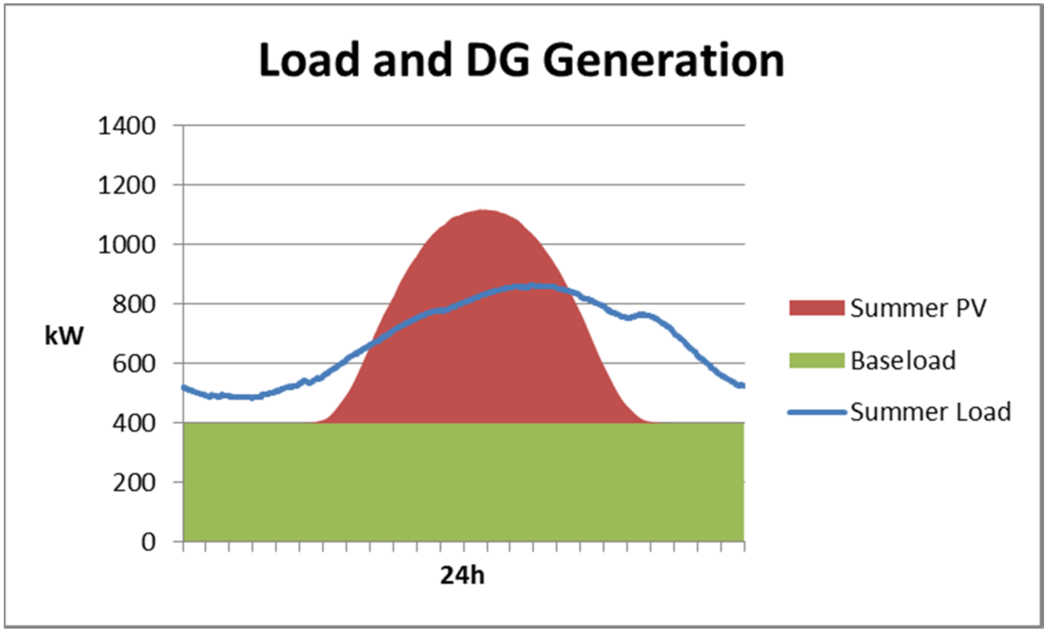
- Coupling fuel cells with energy storage technologies or in MG contexts, may give access to new revenue streams and markets
- Coupled or hybrid solutions can more closely match load profile for specific application or customer

| | Stand-Alone Technologies | | | | Coupled Technologies | | | |
|---|---|---|---|---|---|---|---|---|
| Application | Traditional DG | Fuel Cell | Storage - Power | Storage - Energy | FC+ES | FC + electro-lyzer | FC + PV + ES | Microgrid |
| Base Load | Medium | High | Low | Low | Medium | Medium | High | High |
| CHP | High | Medium | Low | Low | Medium | Medium | Low | High |
| UPS | Medium | Low | High | Medium | High | Low | High | High |
| Back up | High | Medium | Low | High | High | Low | High | High |
| Back up w/ Islanding | Low | Low | Low | Low | Low | Low | High | High |
| Renewable Integration | Medium | Low | Medium | High | High | High | High | High |
| Peak Shaving | High | Medium | Medium | High | High | High | High | High |
| Load Leveling | High | Medium | Low | High | High | High | High | High |
| Demand Response | High | Medium | Medium | High | High | High | High | High |
| Regulation | High | Low | High | Medium | High | High | High | High |
| Reserves | Medium | Low | Low | High | Medium | Low | Medium | High |
| Supply Capacity | Medium | Medium | Medium | Low | Medium | Medium | Medium | High |
| T&D Deferral | Medium | Low | Low | High | Medium | Medium | Low | Low |

# Fuel Cells, Batteries and PV

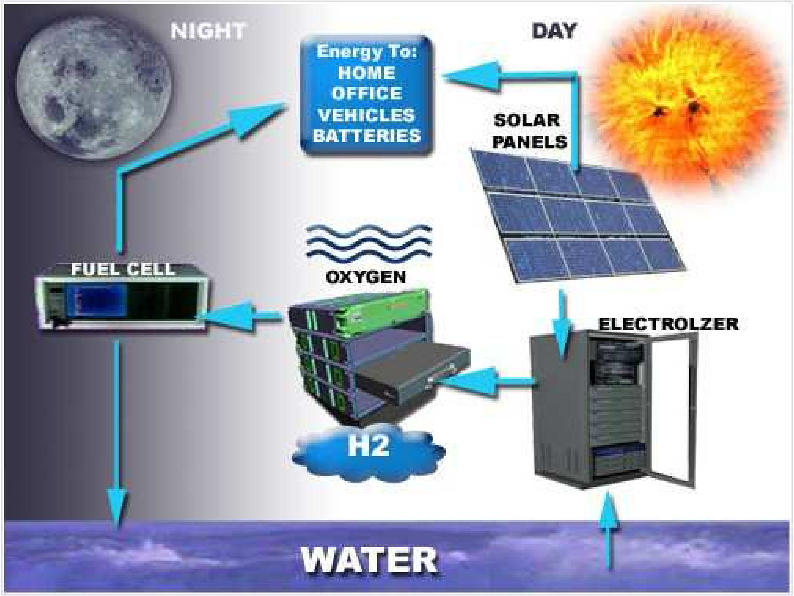
- Fuel cells and batteries are used in tandem in many applications, including advanced vehicles. Batteries can
  - Act as as a bridge to islanding
  - Help cover “peak” loads of facilities, over Fuel Cell baseload
  - Combine with baseload applications to cover market opportunities such as demand response and peak shaving applications. e necessary power at remote locations.

- Adding PV to equation
  - Hybrid PV/fuel cell/battery systems can provide the necessary power at remote locations.
  - Fuel Cells provide the baseload
  - PV provides additional energy, often coinciding with peak load
  - Batteries can help match generation to load profile by smoothing PV production and time-shifting excess energy.



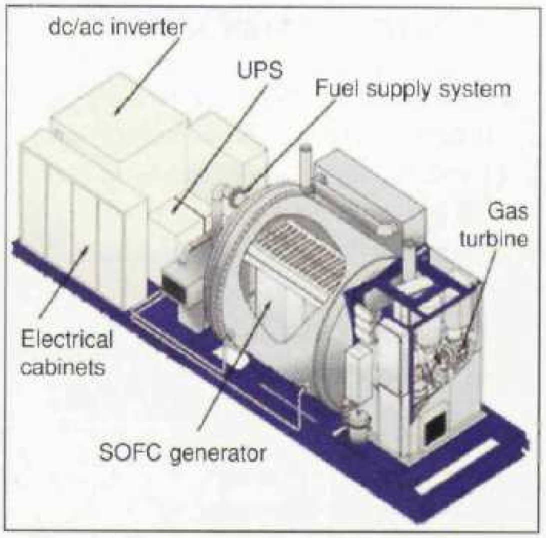
# Fuel Cells and Electrolyzers

- Electrolyzers add storage capability
  - Where longer durations are needed, H2 storage can be an option to battery storage
  - Electrolyzers can be used for load management to provide DR or peak shave
  - Excess renewable can be stored
- Wind + Electrolyzer + Fuel Cell
  - Use hydrogen generator to address wind power intermittent problem
  - Avoid curtailment or selling at negative prices
  - NREL, in partnership with Xcel Energy, launched a wind-to-hydrogen (Wind2H2) demonstration project at the national wind technology center in Boulder, Colorado.
- Solar + FC
  - Limnia, Inc. technology provides a solution to eliminate intermittent production in solar or wind generation technologies. This system can also provide frequency regulation.



# Fuel Cell and Microturbine

- Fuel cells integrated with microturbines result in the following:
  - Improved system efficiency
  - Lower lifetime costs
  - Higher heat recovery
- MCFC and SOFC are better candidates due to their high operational temperature
- NETL states that these systems may be the only option for meeting the DOE's efficiency goal for advanced coal-based power systems by 2020
  - 60+% HHV efficiency
  - Near zero emissions
  - Competitive costs for multi-MW class central power plants
- FCE, GE, Siemens and UC Irvine are actively prototyping these systems in partnership with NETL and the DOE




*A schematic of the Siemens Westinghouse hybrid design. (Courtesy of Siemens Westinghouse)*

# Examples of hybrid or coupled solutions

- FC in hybrid solutions tend to provide baseload, while other technologies offer different capabilities

| Company | Location | Fuel Cell | PV or Wind | Other | Fuel Cell manufacturer | FC Application |
|---|---|---|---|---|---|---|
| Apple data center | Maiden,NC | 4.8 MW | 20 MW | N/A | Bloom Energy Fuel Cell (SOFC) | Baseload |
| Hartford Life building | Windsor Connecticut | 300 kW | 202 kW | N/A | FuelCell Energy | Baseload |
| CBS Corp. Studio Center/Television City | Los Angeles, CA | 2.4 MW | 411 kW | N/A | UTC Power PureCell (SOFC CHP) | Baseload, CHP, Islanding, Back-Up |
| Cox Rancho Santa Margarita Facility | Orange County, CA | 800 kW | 100 kW | N/A | UTC Power PureCell (PAFC) | Baseload |
| Adobe Systems | San Jose, CA | 1.2 MW | 24 kW Wind | N/A | Bloom Energy Fuel Cell (SOFC) | Baseload |
| Forest City Covington | Albuquerque, NM | 80kW | 50 kW | 160 KW ES and 240 kW NG turbine | | Baseload, Islanding |
| Herten | Germany | 50 kW | N/A | N/A | Hydrogenics | Baseload, Renewable Integration |

# Conclusions

- In some cases, fuel cells compete with the potential hybrid technology partners, but "grid" trends toward flexible resources. Multiple capabilities will favor hybrid systems and solutions rather than separate, competing applications.
- Interest and opportunities to deploy storage still continue today, but the technology still hasn't moved significantly on closing performance gaps with technologies
  - This prevents systems from performing in multiple roles that may allow the systems to tap additional revenue streams or improve operating characteristics
- Hybrid applications have the ability to fill those gaps when performance characteristics are mapped against multiple applications
  - Extra cost of new technology can be offset by the additional applications that the system can perform
- Fuel Cells can play the role of baseload in a hybrid solution if the fuel supply question is addressed.

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