



# Connecting For Success...

ELECTRIC POWER DAYS 2017

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**CATERPILLAR®**

# Caterpillar Hybrid Microgrids

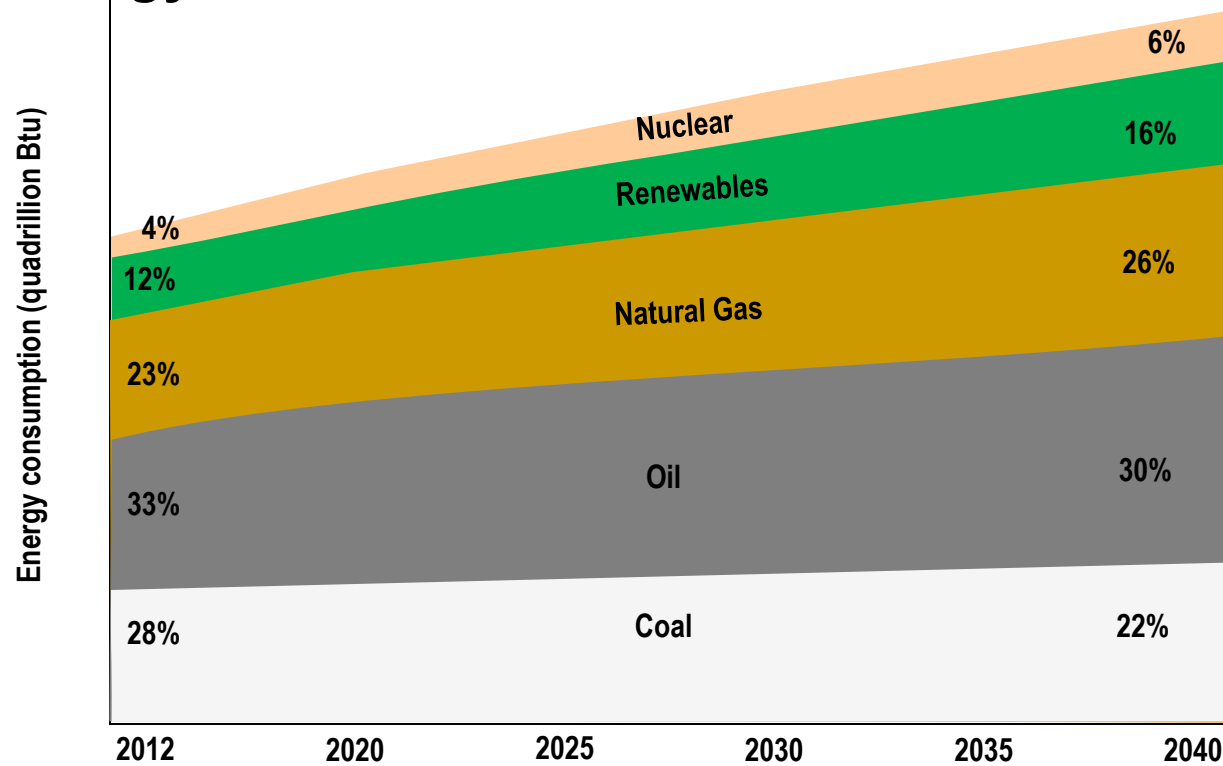
Microgrid

François-Xavier Saury

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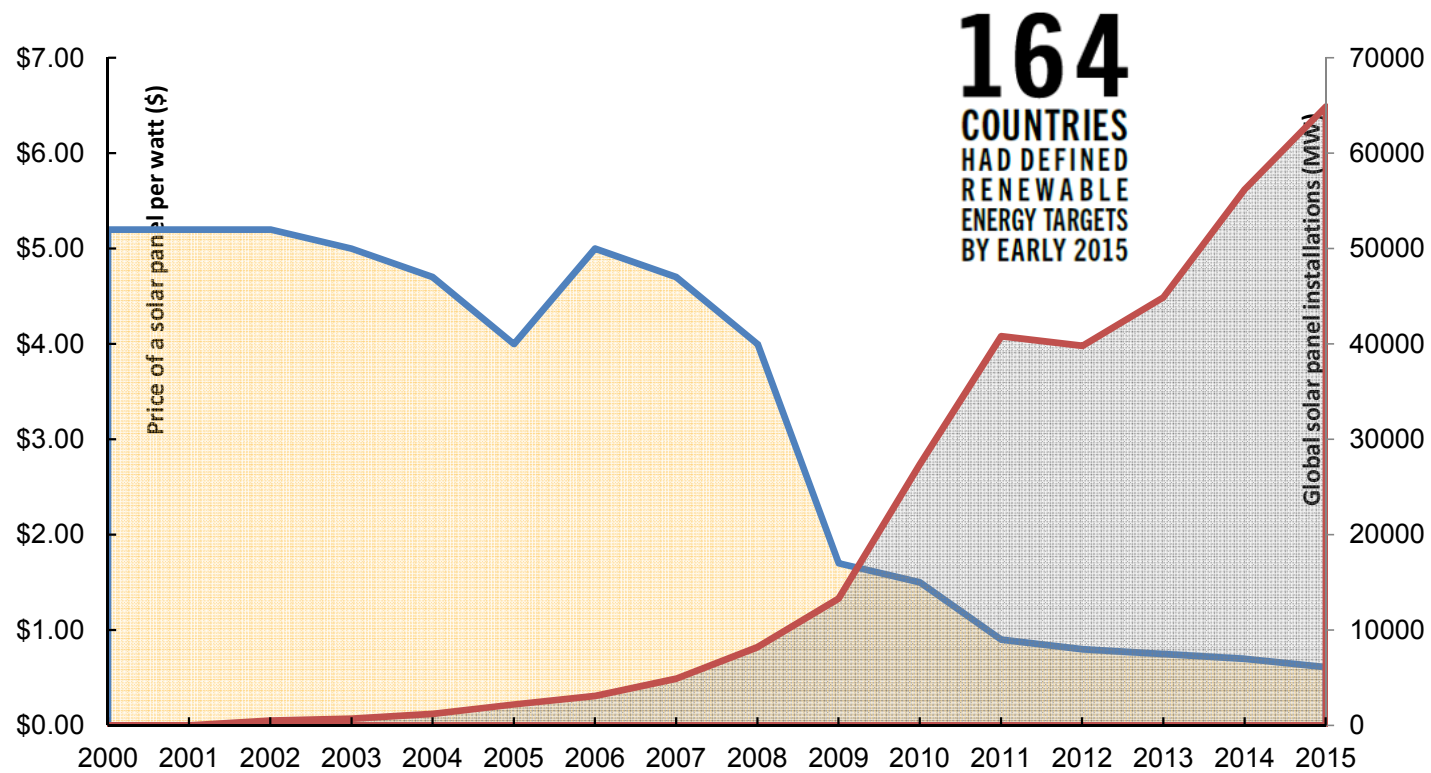
# Global Energy Demand



Source: EIA International Energy Outlook 2016

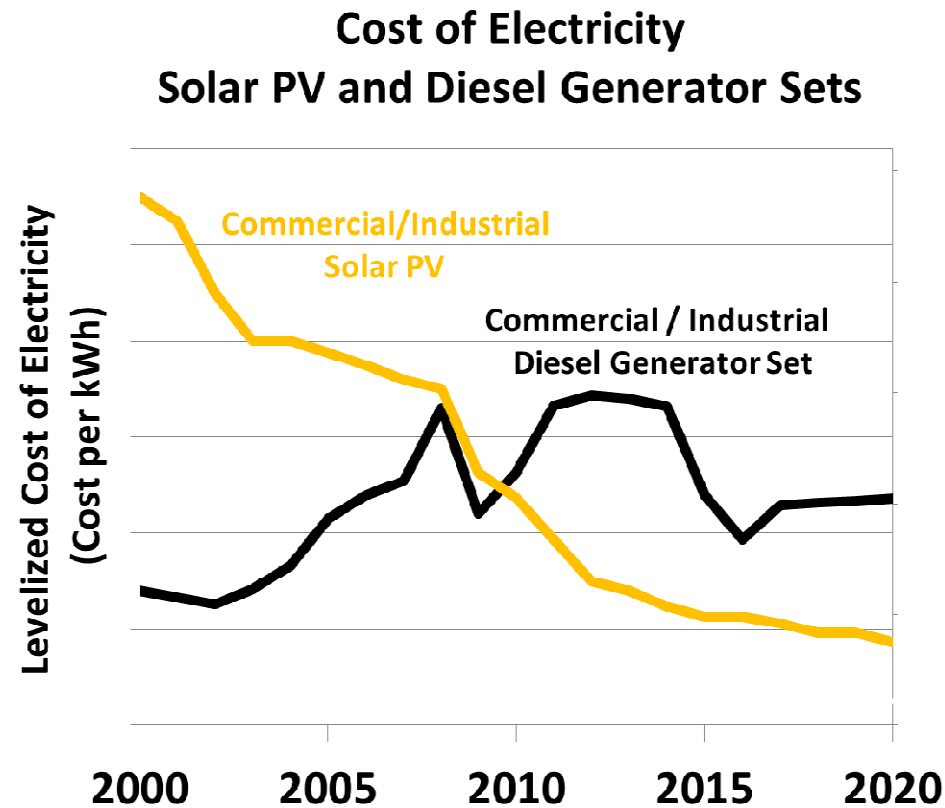
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# As solar panel prices have dropped, installations have soared...



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# Cost of Electricity Solar PV and Diesel Generator Sets



Source: Caterpillar Inc.

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A photograph of a large industrial facility, likely a power plant or manufacturing plant. In the foreground, there are several rows of yellow Caterpillar generators mounted on a metal frame. The generators are arranged in a long line, receding into the background. A worker in a white hard hat and dark clothing is walking away from the camera on a metal walkway to the right. The background shows large industrial structures, possibly storage tanks or silos, and a high ceiling with industrial lighting.

Microgrid is what Caterpillar does for 60+ years

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# What is a Hybrid Microgrid?

## Hybrid Microgrids are:

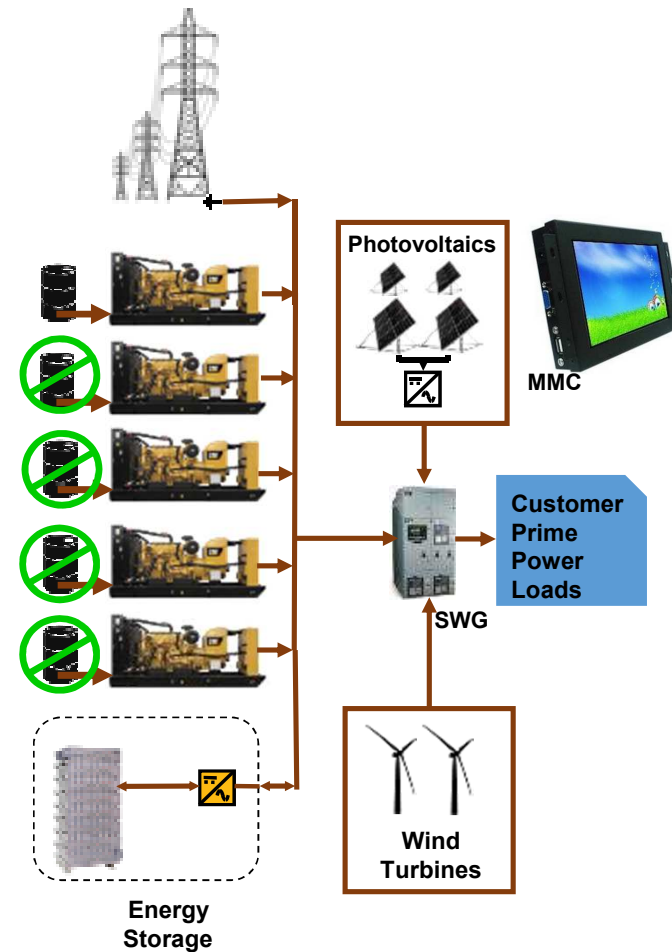
Combining Traditional & New Energy Technologies

**Objective = lower operating cost**

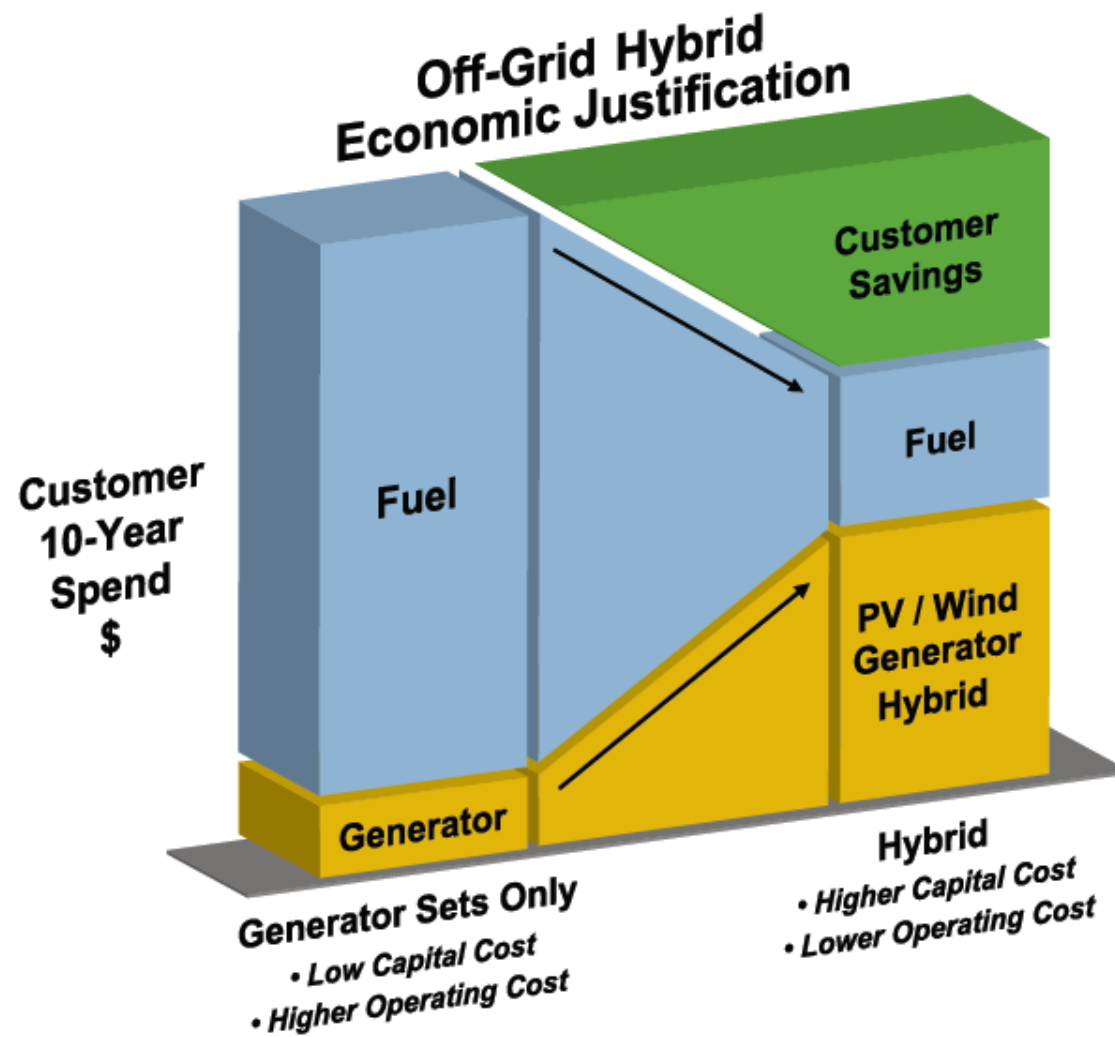
- Fuel consumption can be reduced 10% - 50%+
- Combinations can achieve lowest life-cycle costs

**Capture the Benefits of Each:**

- **Reliable** and **fully dispatchable** generator sets:
- **Cheaper** (free) energy source: solar and wind:
- **Stabilization**, time-shifting, high-penetration:  
energy storage (batteries, ultra-caps, UPS)



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# Why Remote Hybrid Microgrids Now?

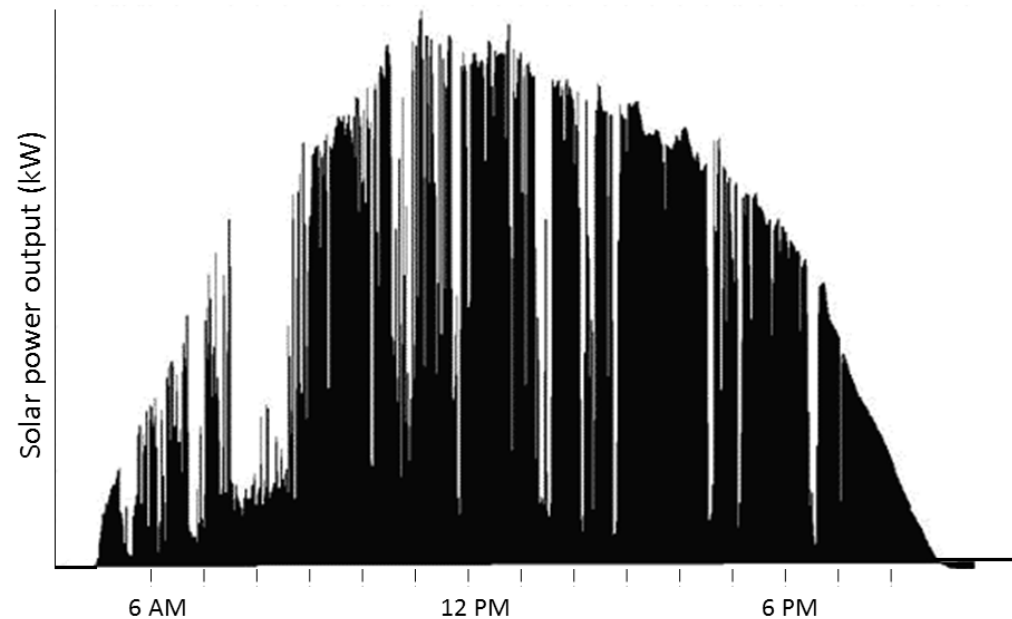
- Advances in:
    - Solar PV
    - Energy Storage
    - System Controls & Power Conditioning
    - Connected Load Side Management
- ➡ Reduced LCOE



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# Advances in Energy Storage minimize renewable natural intermittency

Energy storage can now provide cost effective grid stabilization and maximize PV utilization



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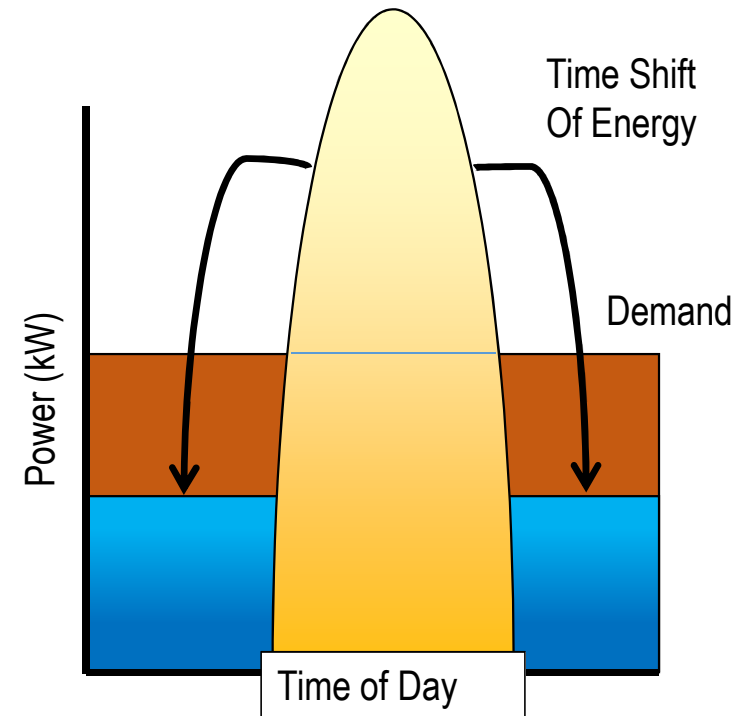
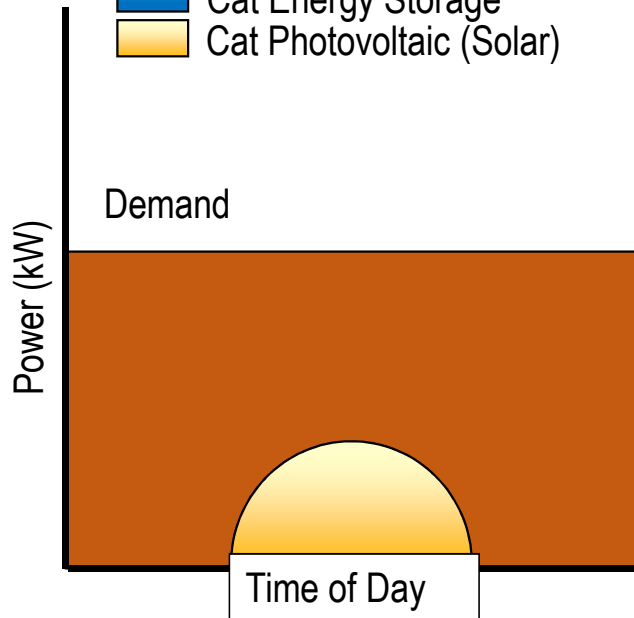
# Stabilization or Time-Shifting of Energy

~ 20% Fuel/grid Substitution



+80% Fuel/Grid Substitution

- Traditional Power Source Genset / Utility
- Cat Energy Storage
- Cat Photovoltaic (Solar)



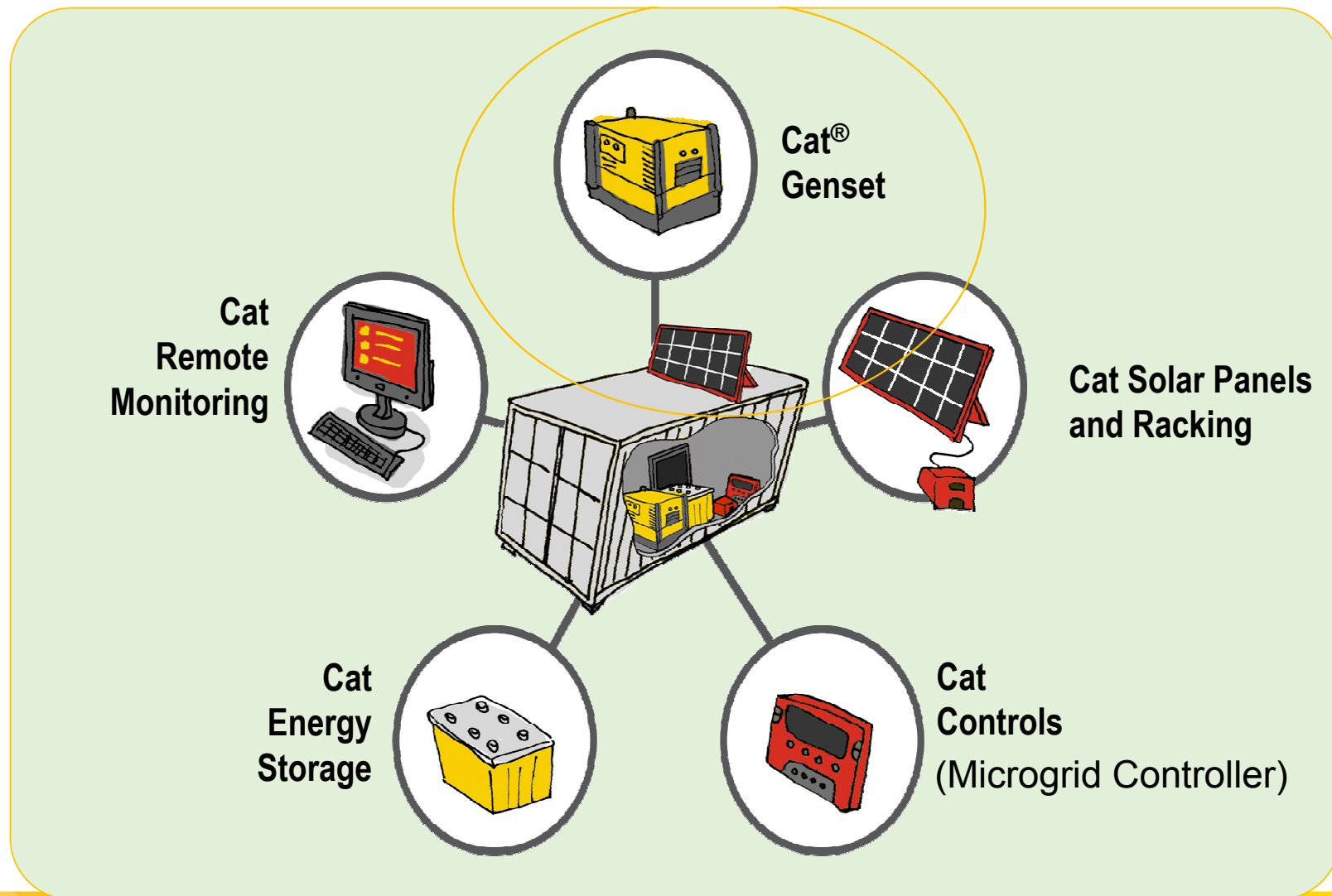
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# Renewable Penetration Levels – Hybrid Microgrid

Fuel Savings Objective	System Configuration	
	Solar PV	Storage
30% to 100% Fuel Savings	PV System Size Greater than Generator Set Capacity	Energy Storage for Power Stability & Energy Time-Shifting
10-30% Fuel Savings	PV Size Equal to Generator Set Capacity	Energy Storage for grid stability
5-10% Fuel Savings	PV Size Under 15-20% of Generator Set Capacity	No Energy Storage
Baseline	Prime Power Generator Sets	



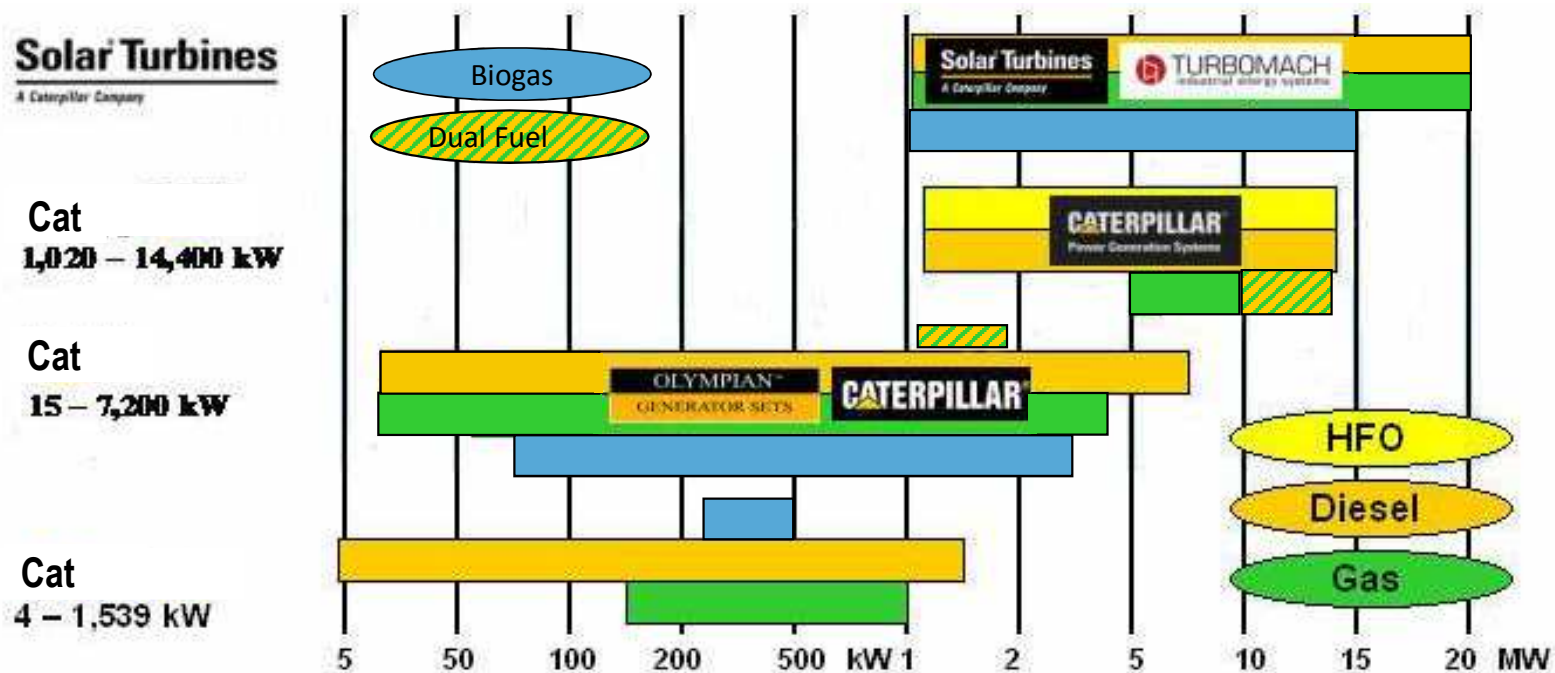
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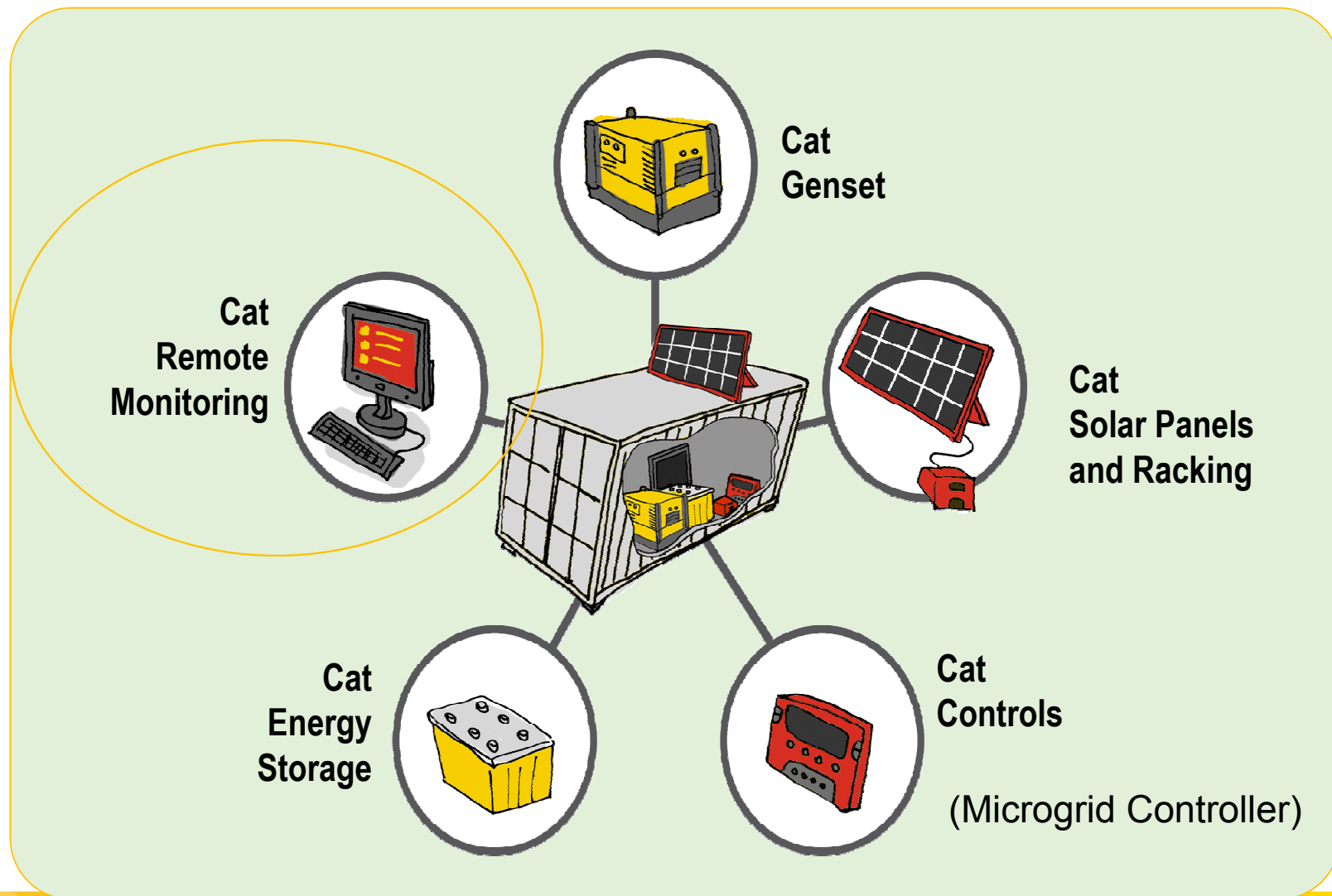
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# Traditional Power Generation Product Portfolio from 4kW to 20MW



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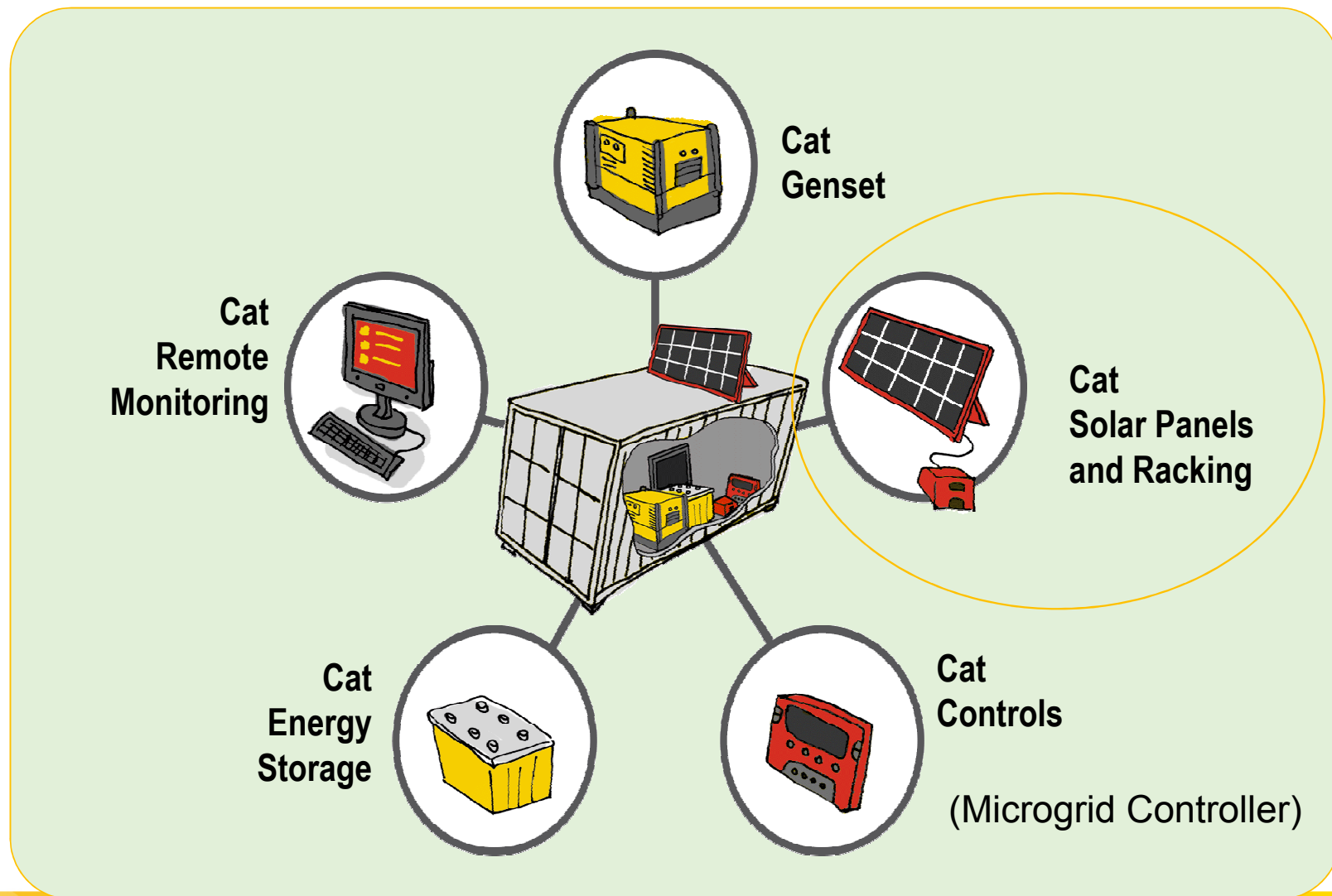


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# Cat Connect for Microgrid Systems



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# Technology Overview



## Cat Branded 115W PV Modules

- Cadmium Telluride thin film - CdTe
- Durable and recyclable frameless glass-glass laminate
- Low temperature coefficient
- Best humidity response
- Robust against shading
- Robust against dust and diffused sunlight
- 10 years Product Warranty
- 25-year Linear Power Output Warranty



60 x 120 cm, 12.0 kg

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## World Record CdTe Solar Cell: 22.1%



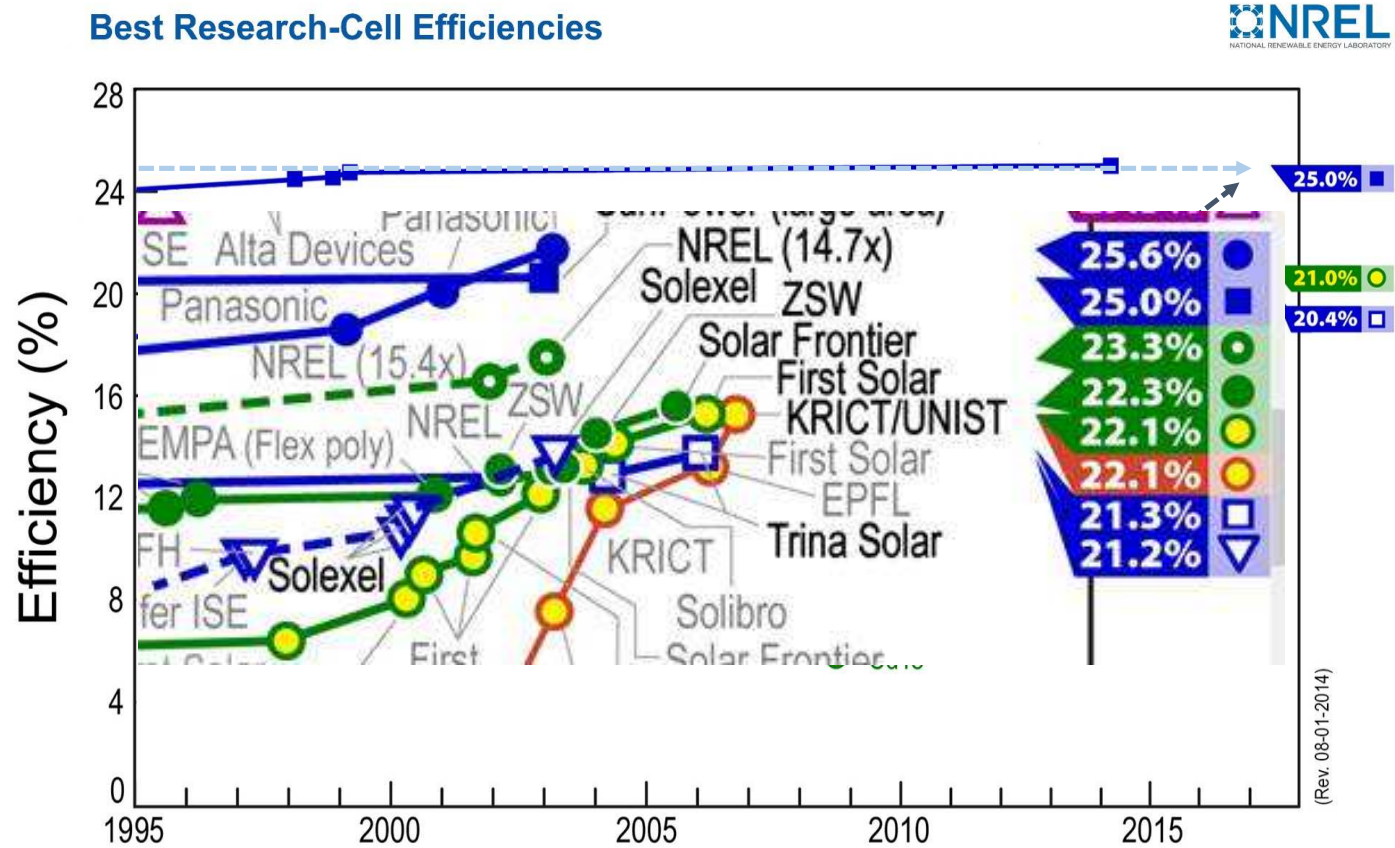
### 22.1% Cell Efficiency

The record-setting cell was constructed using materials and processes found in the manufacturing environment at our Perrysburg, Ohio factory.

Results certified at Newport TAC Lab and documented in the U.S. Department of Energy's National Renewables Energy Laboratory (NREL) Best Research Cell Efficiencies.

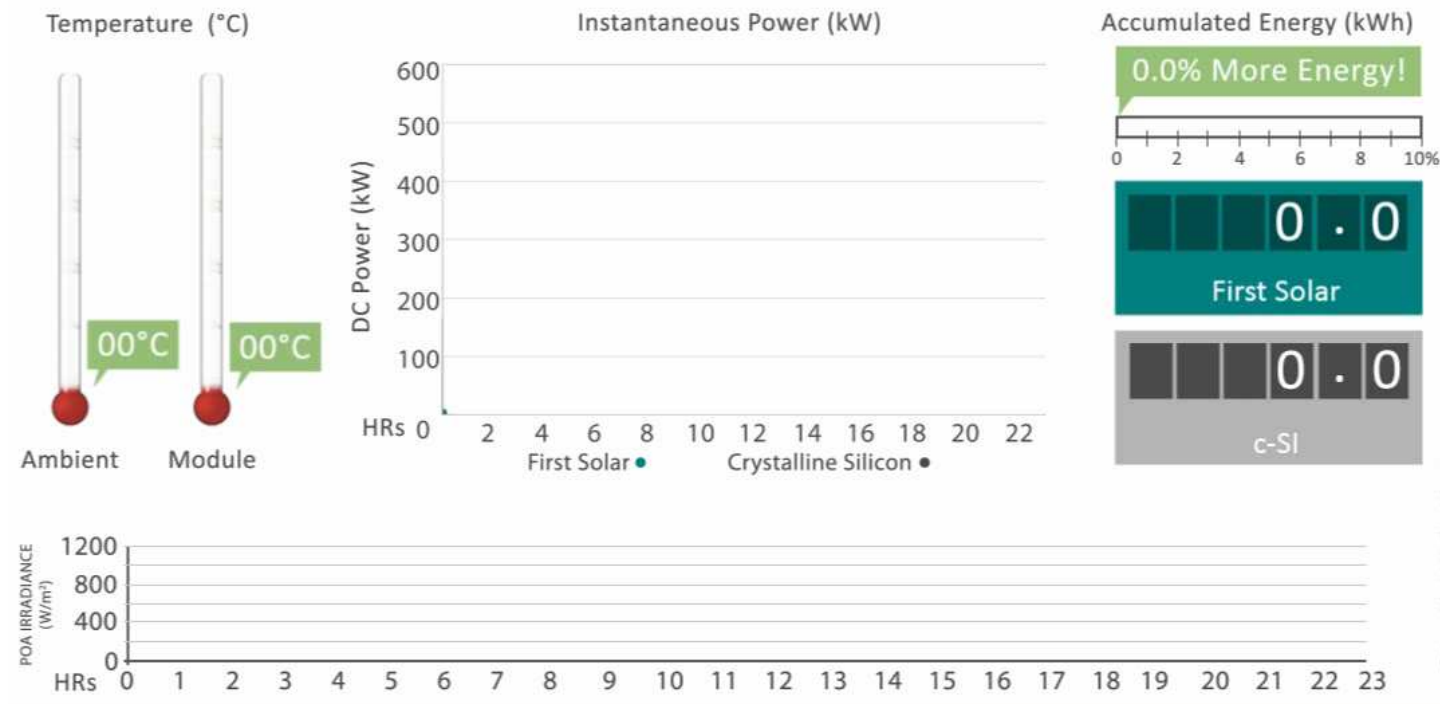
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# Fastest growing performance



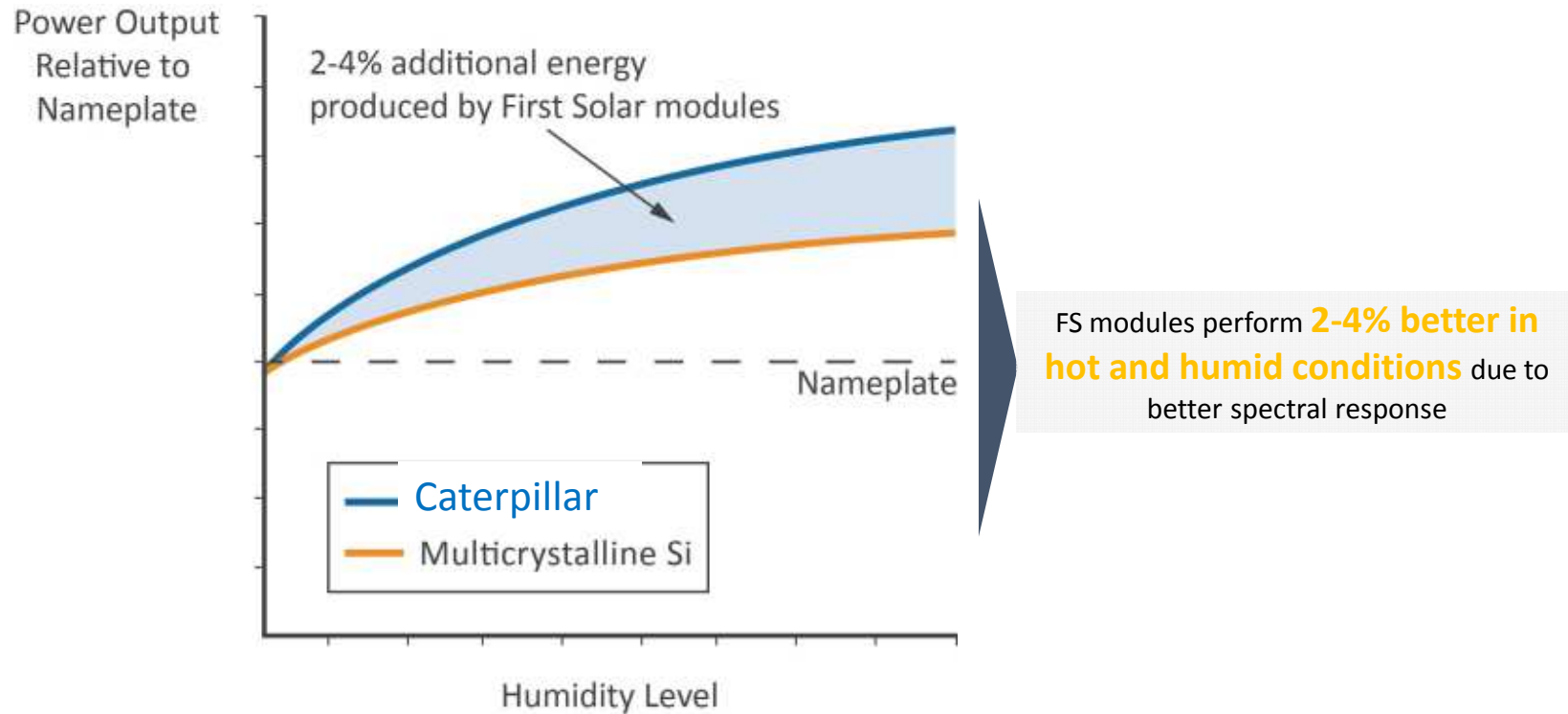
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# Energy Yield Temperature Advantage



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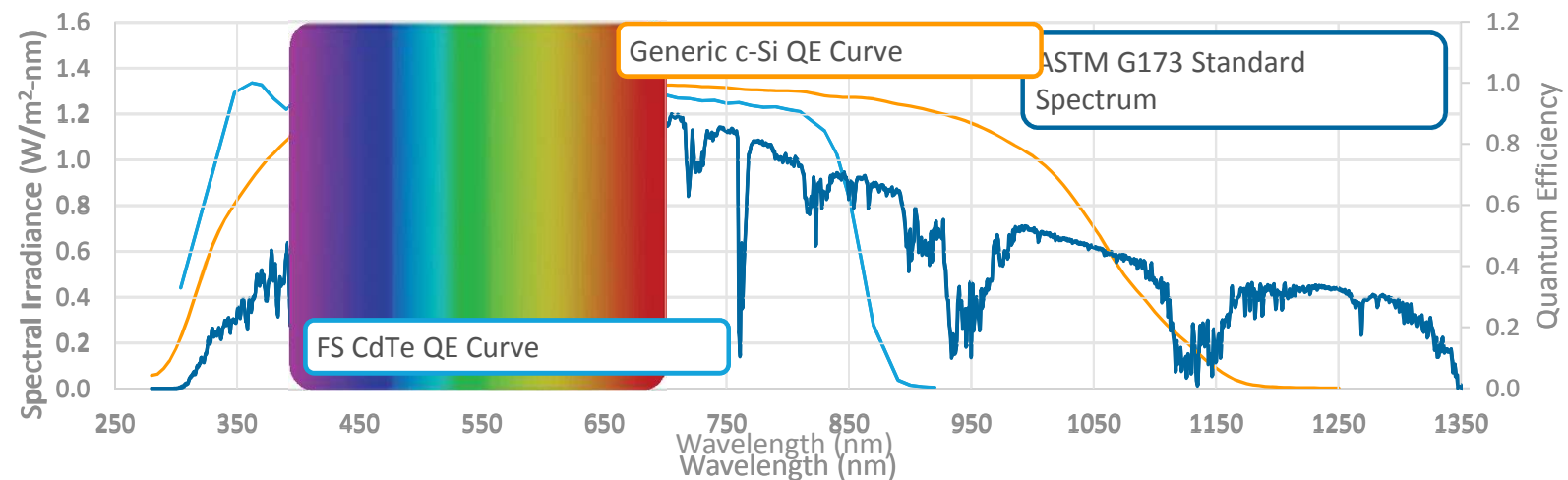
# Higher Energy Yield In Humid Conditions



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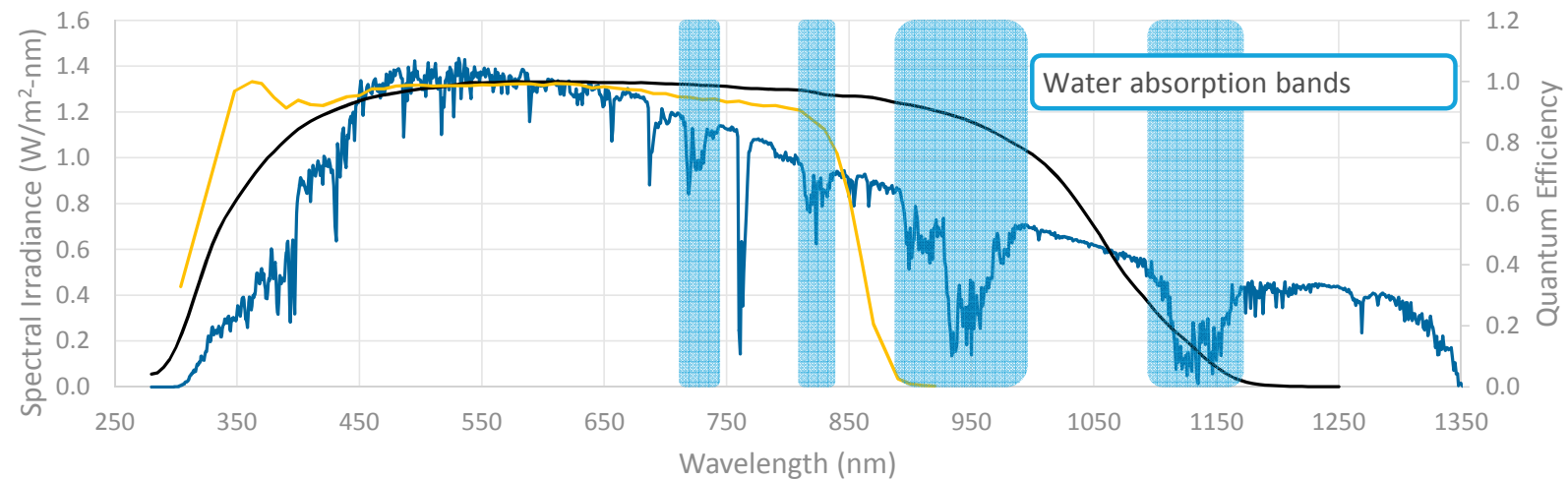
# Spectral Irradiance with Quantum Efficiency Curves by Technology



A module's quantum efficiency curve indicates which wavelengths are "visible" to that technology.

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# Water Absorption Bands in Spectral Irradiance

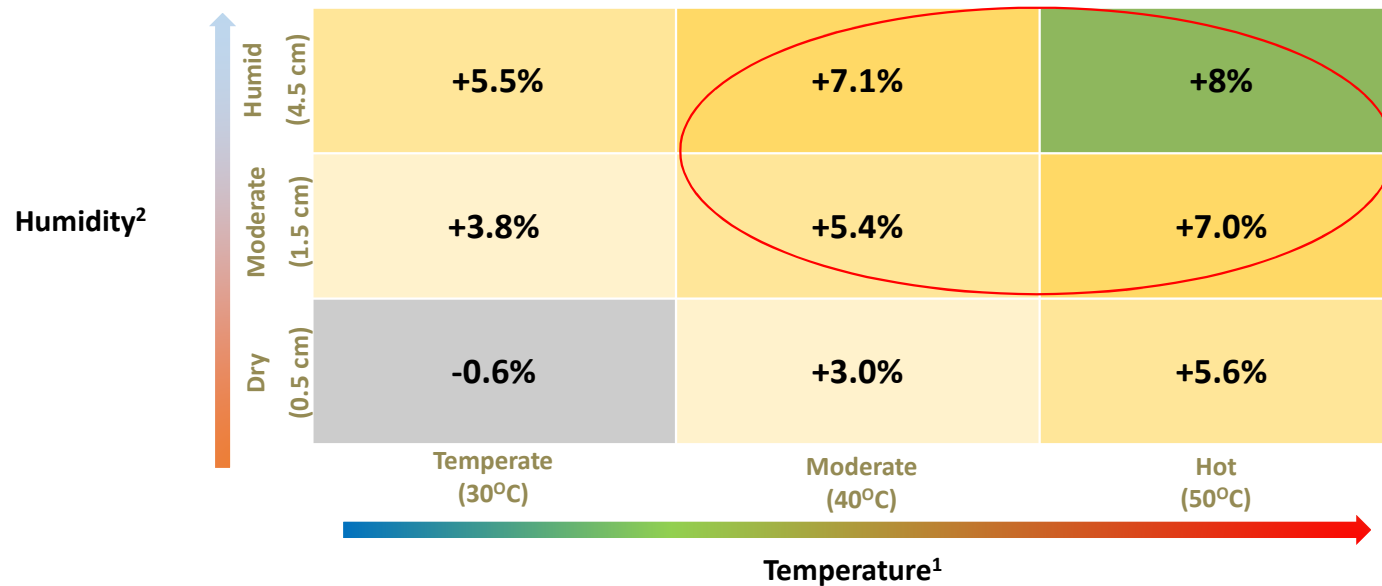


Largest water absorption bands occur at wavelengths “visible” to c-Si but not to CdTe. When the atmosphere has high precipitable water ( $P_{wat}$ ) content, CdTe will have more useful irradiance than c-Si compared to broadband reading.

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# Module Capacity Factor CdTe Vs C-Si

Best in Industry

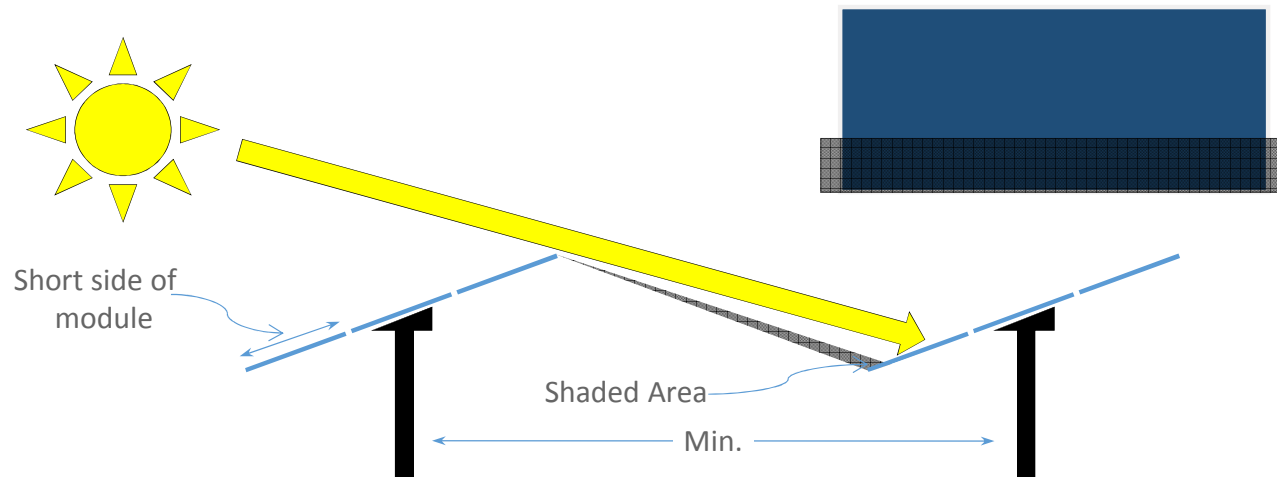


- Source/Assumptions:
- <sup>1</sup>Competitive temperature losses calculated using -0.45%/°C temperature coefficient. Temperatures listed are representative energy weighted annual averages.
- <sup>2</sup>Humidity is a proxy for CdTe spectral shift which is primarily driven by atmospheric precipitable water content; competitive advantage calculation assumes competitor values are 50% of First Solar values. Values listed represent irradiance weighted averages. See "Changes in Cadmium Telluride Photovoltaic System Performance due to Spectrum" for more details.

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# Module Performance – Comparison to c-Si

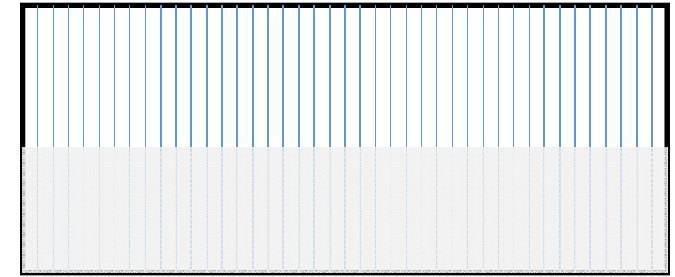
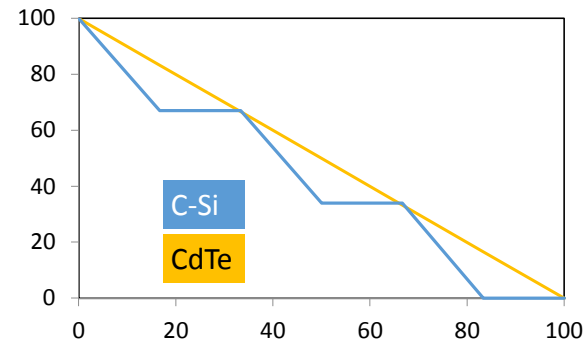
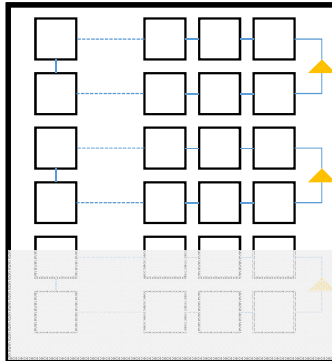
- Robust against shading in landscape orientation (perpendicular to cells)
  - Thin Film Power loss is ~proportional to shading: 10% shading = ~10% output power loss
  - Typical c-Si Power loss: 10% shading = ~30% output power loss<sup>1</sup>
  - Minimizes early morning and late evening energy loss while allowing row spacing (array footprint) to be minimized



<sup>1</sup>Partially Shaded Operation of a Grid-Tied PV System, Chris Deline, National Renewable Energy Laboratory (@ >800W/m<sup>2</sup>)

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# Shading CdTe vs. C-Si



- Effect of shading is dependent on the electrical connections within the module.
  - Some Si modules have multiple rows of series connected which results in non-uniform shading loss
- This result extends to array –level performance
  - Power will drop to zero when voltage of array drops below inverter limit

<sup>1</sup>Partially Shaded Operation of a Grid-Tied PV System, Chris Deline, National Renewable Energy Laboratory (@ >800W/m<sup>2</sup>)

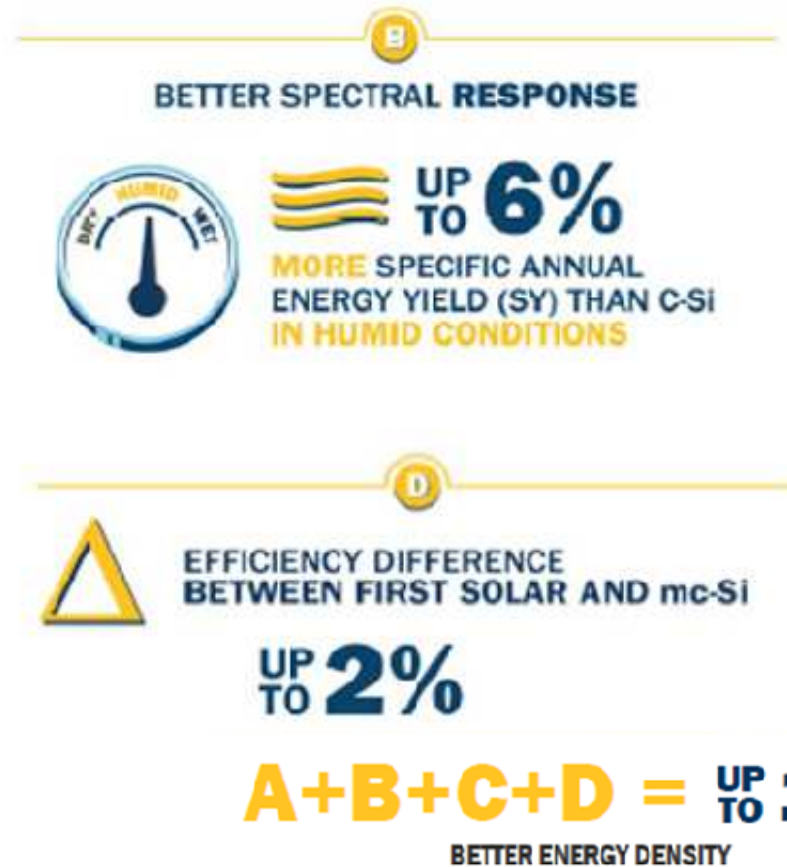
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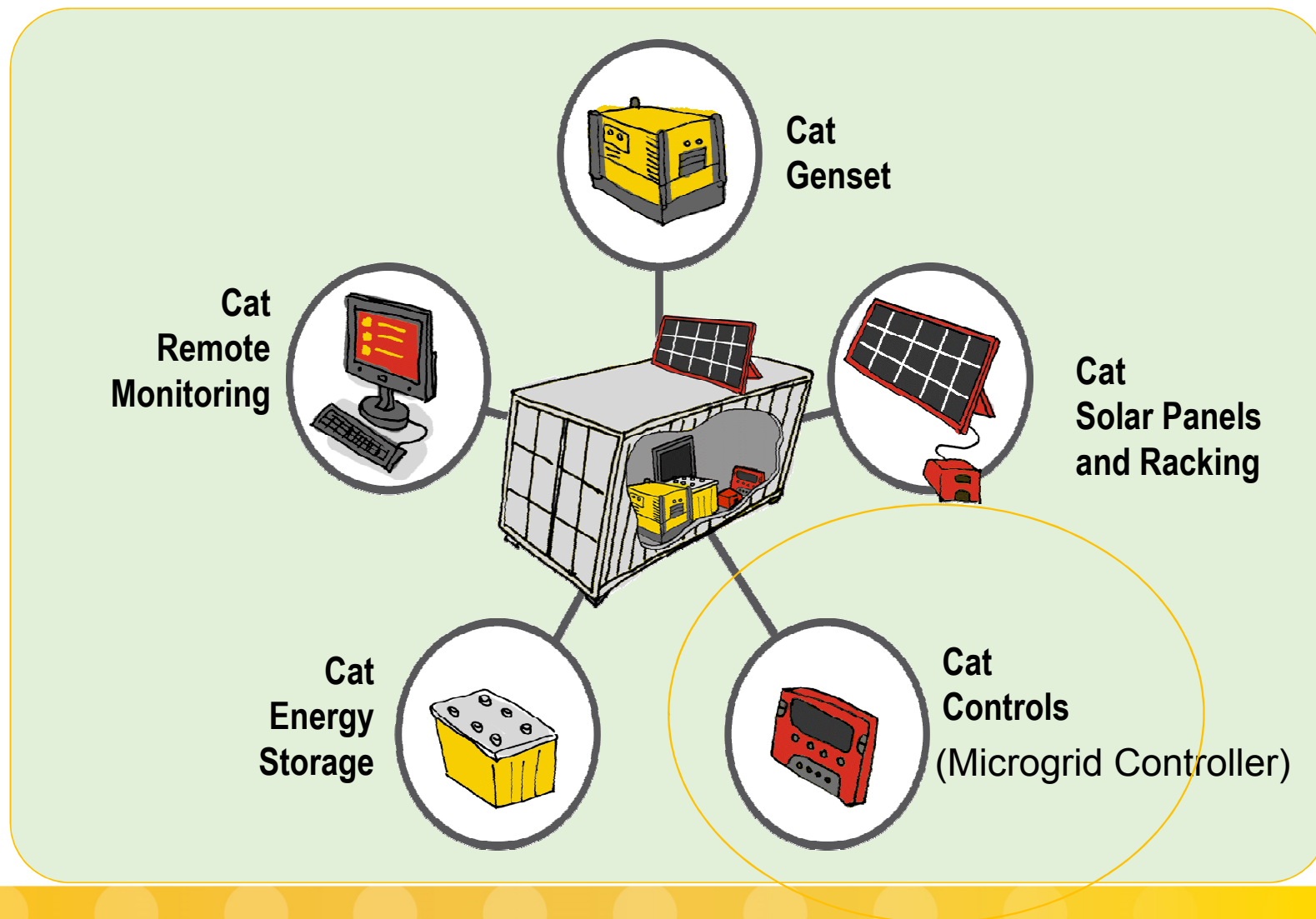
# The Cat Thin Film Advantage



Lower degradation Advantage 0.5%/y

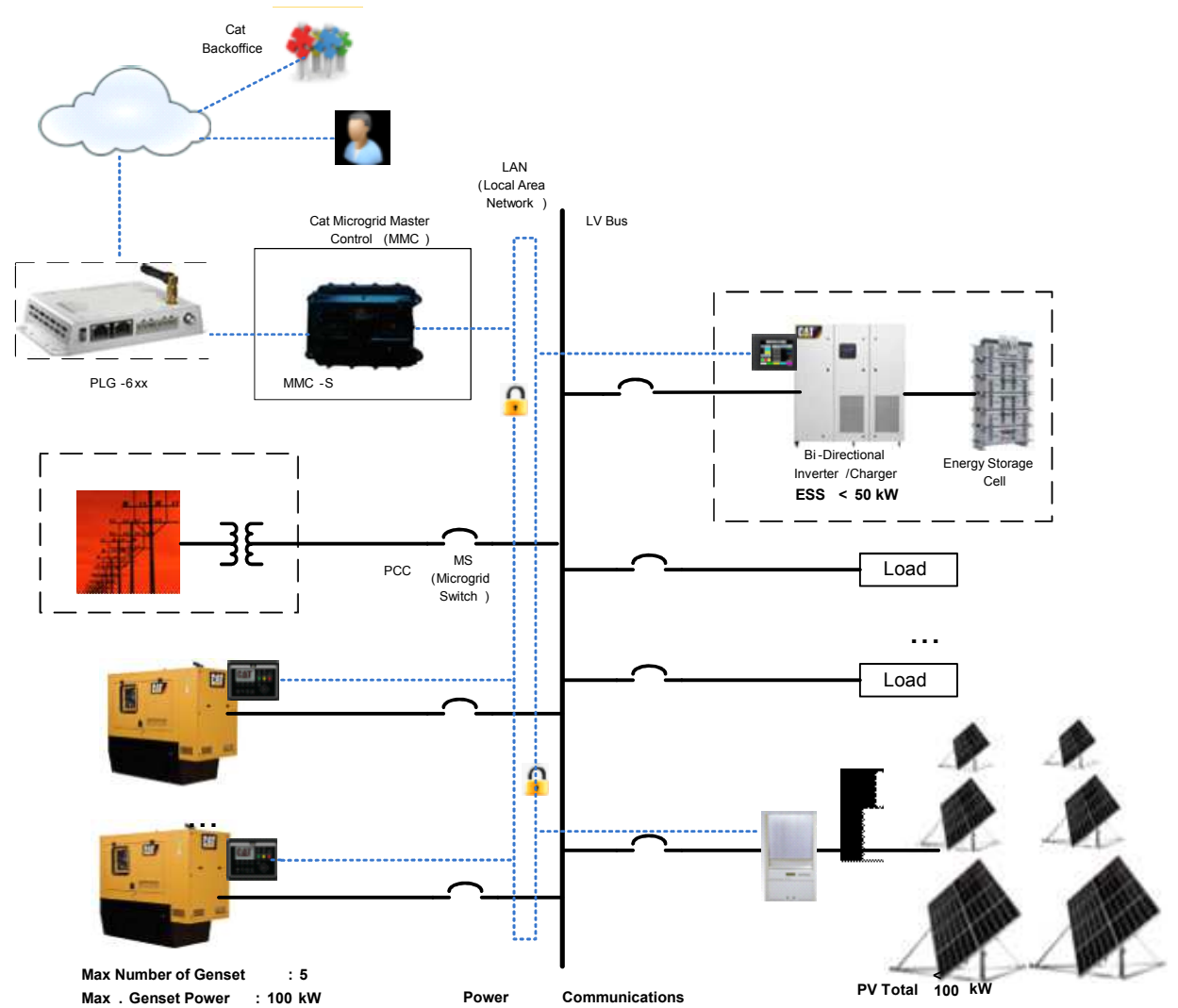


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# Cat Microgrid Master Control (MMC)



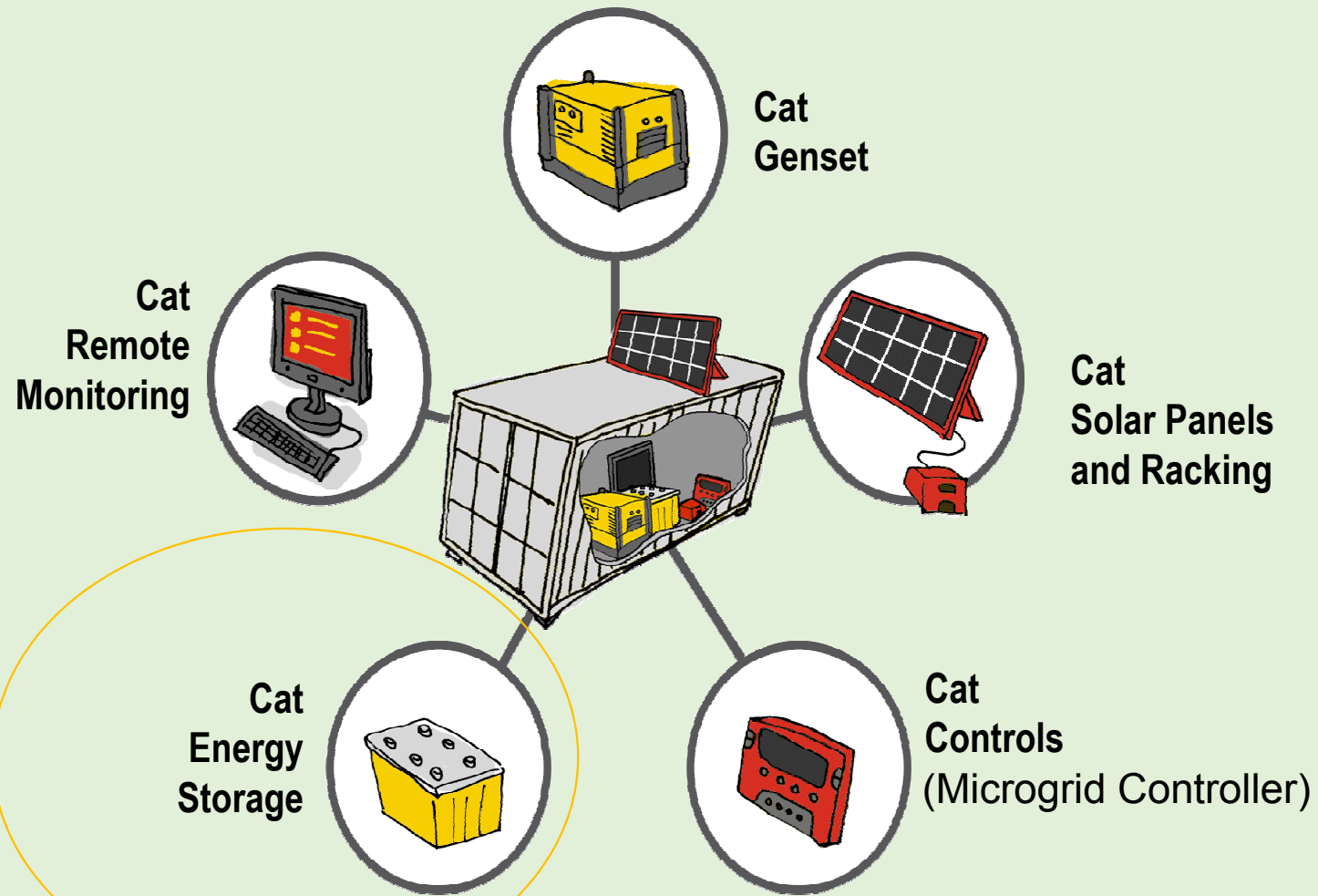
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# Cat Microgrid Master Control (MMC)

- Product range
  - Market Segment Needs Driven
  - Modular and Scalable
  - Retrieval of field Data
- Three Tiered Approaches (MMC-S, MMC-M, MMC-L) :
  - System Complexities
  - Features
  - Price



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# Energy Storage Solutions

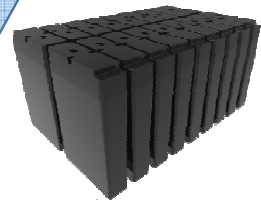
- Suite of technologies to meet a variety of installation requirements
- Leverage a combination of off-the-shelf components and new technology to optimize performance
- Solutions can be pre-packaged in rapidly deployable containers



Ultra Capacitors



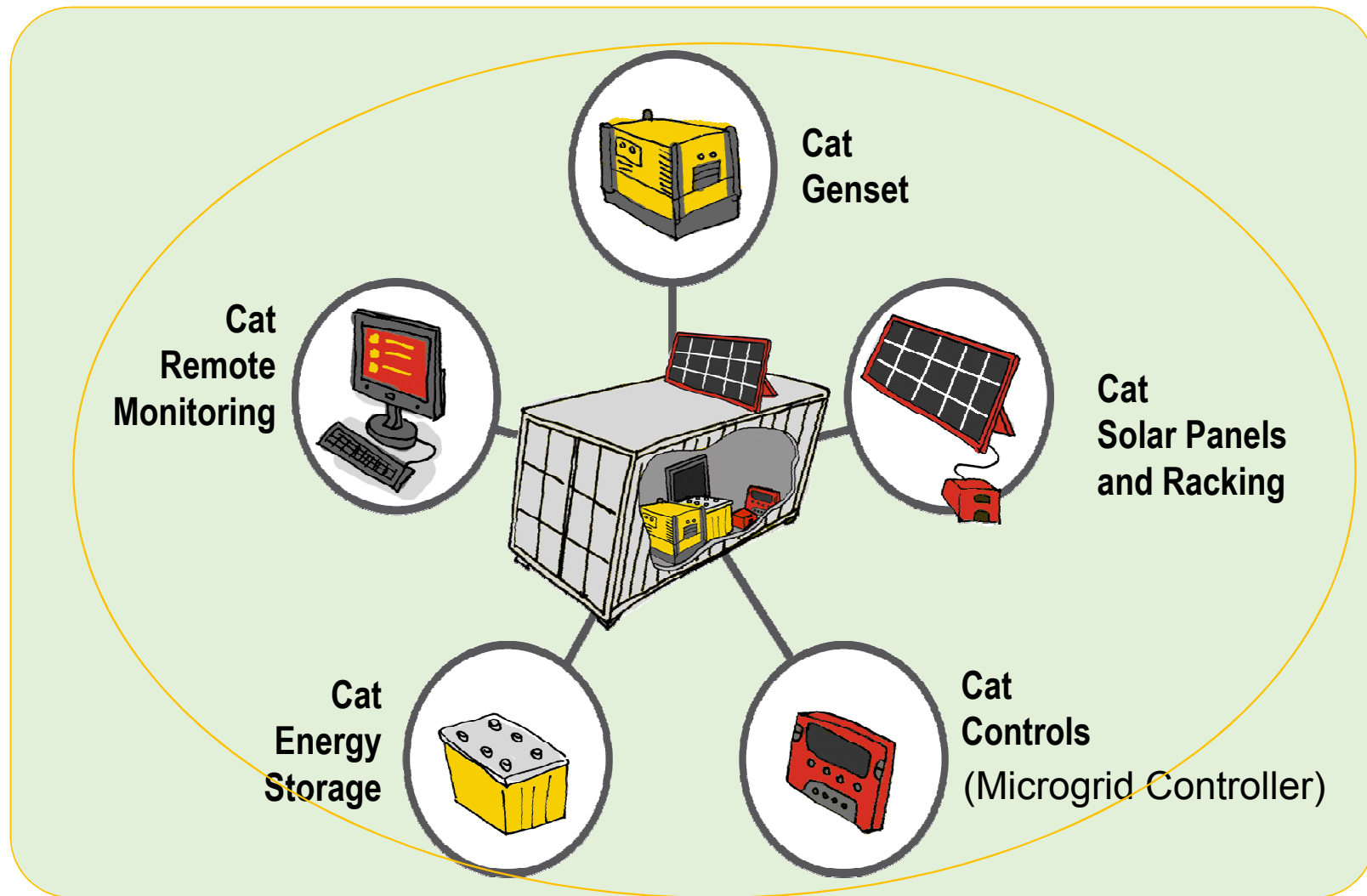
Lithium Ion



Metal-Air

Longer Duration

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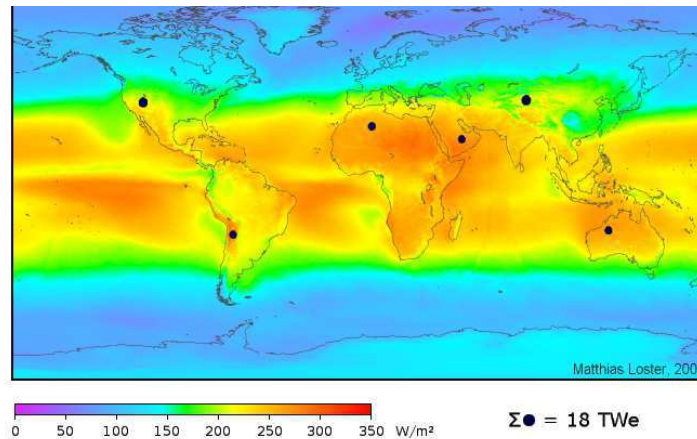


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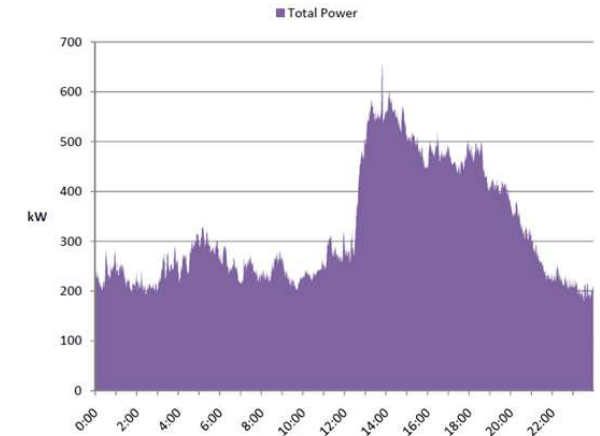
# Hybrid Power Analysis

- Hybrid Power Analysis and System Design
- **Site location**
- **Diesel cost:** \$x/litre
- **Cost of Capital:** z % pa
- **Load Profile:** Refer chart

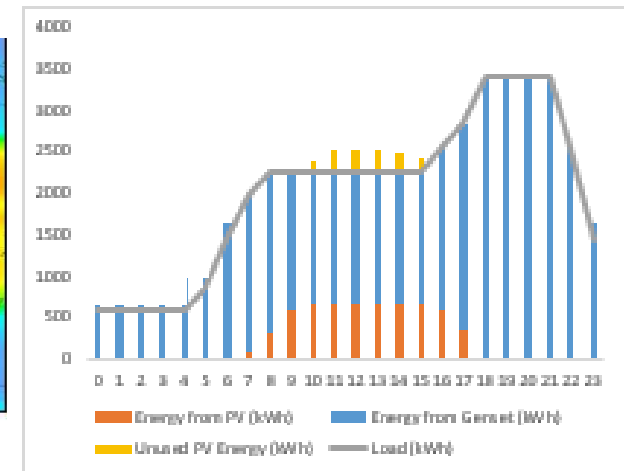
Global Renewable Energy source:



Example Load Profile Data



AVERAGE DAILY ENERGY PROFILE



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Global Solar Irradiance Map



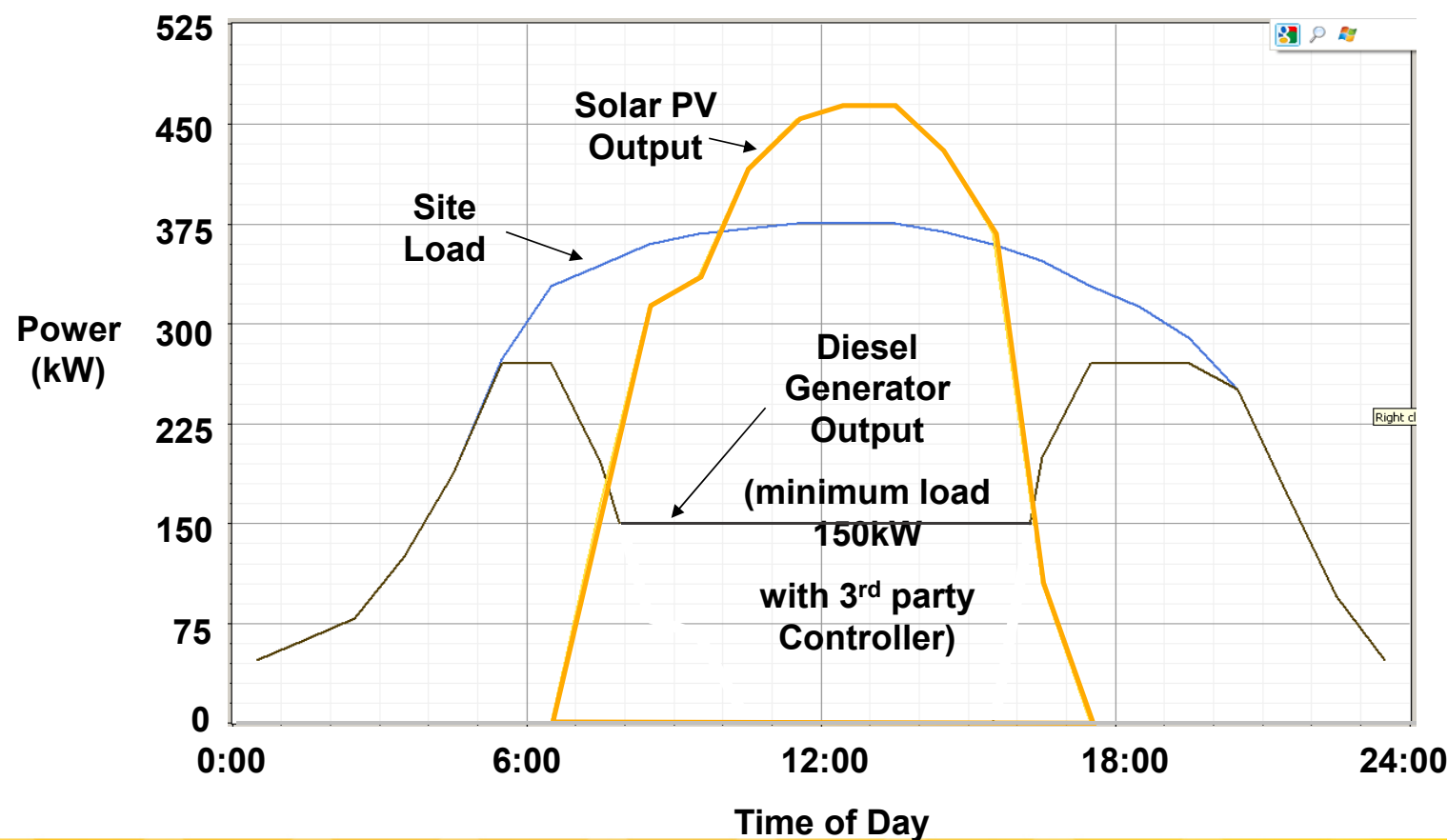


## Tucson Arizona Microgrid 500kWp

- **33% fuel savings**
- Cat 500kWp fixed tilt & tracker
- Cat Diesel Generators
- Cat ESS500kW Li-Ion & UCaps Energy storage

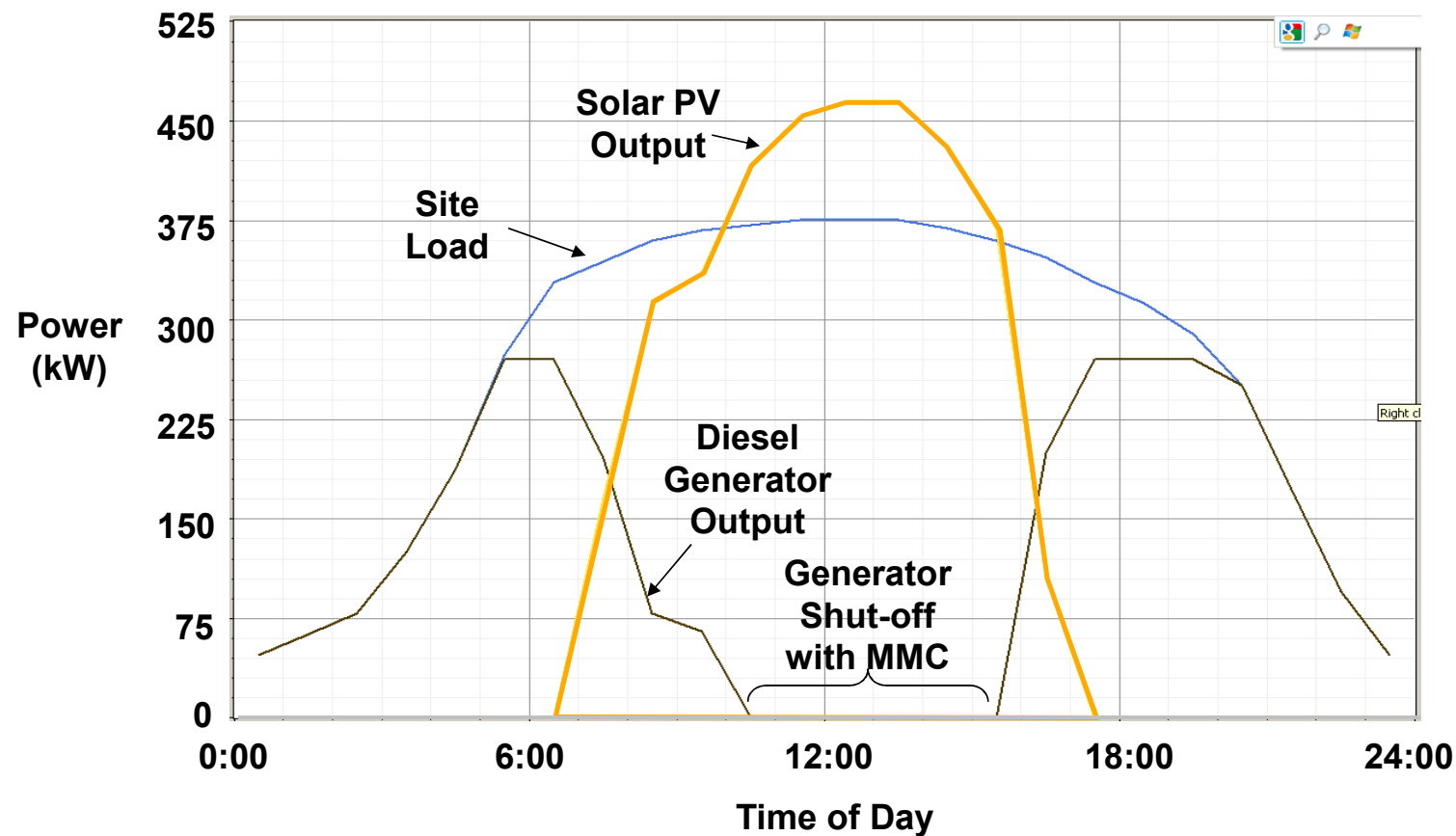
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# Typical Microgrid Operation: Daily Load & Generation Profiles



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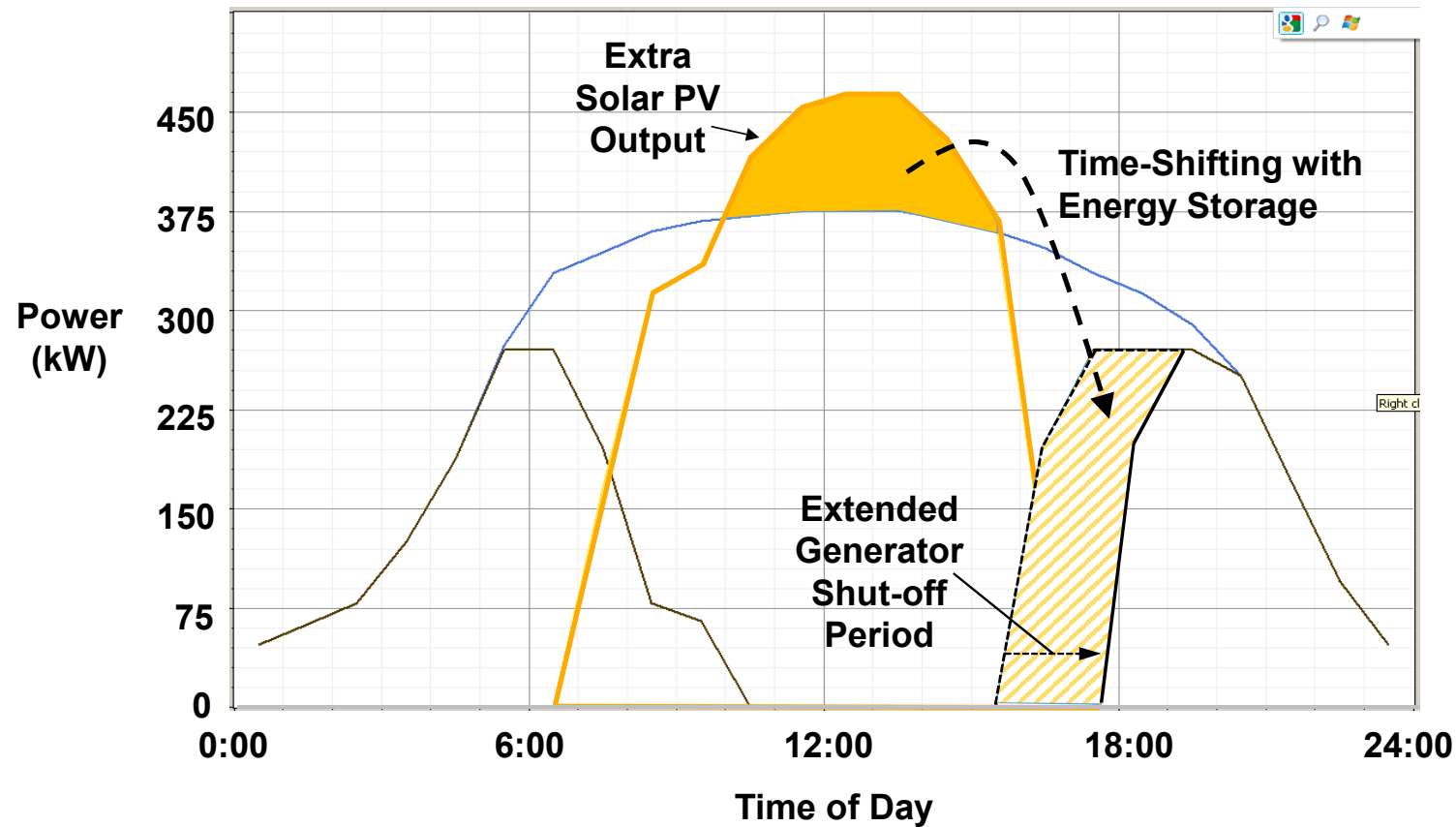
# Typical Microgrid Operation: Daily Load & Generation Profiles



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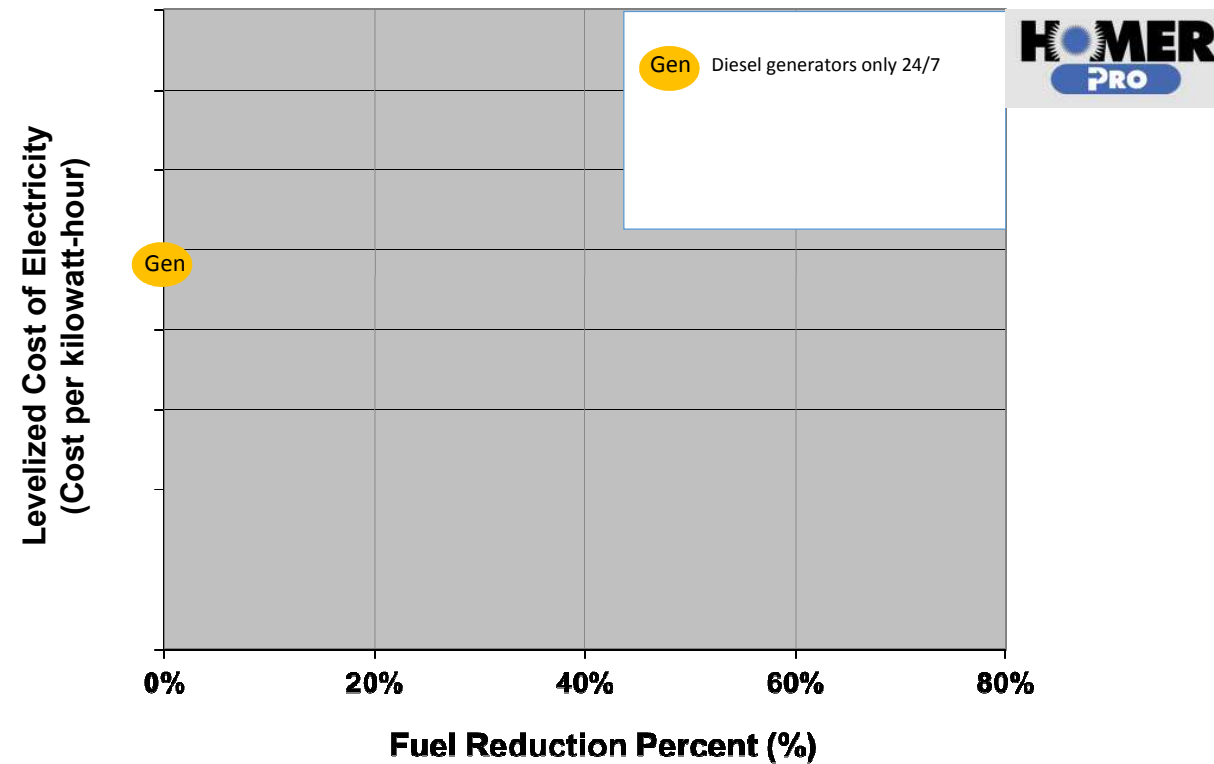
# Typical Microgrid Operation: Daily Load & Generation Profiles



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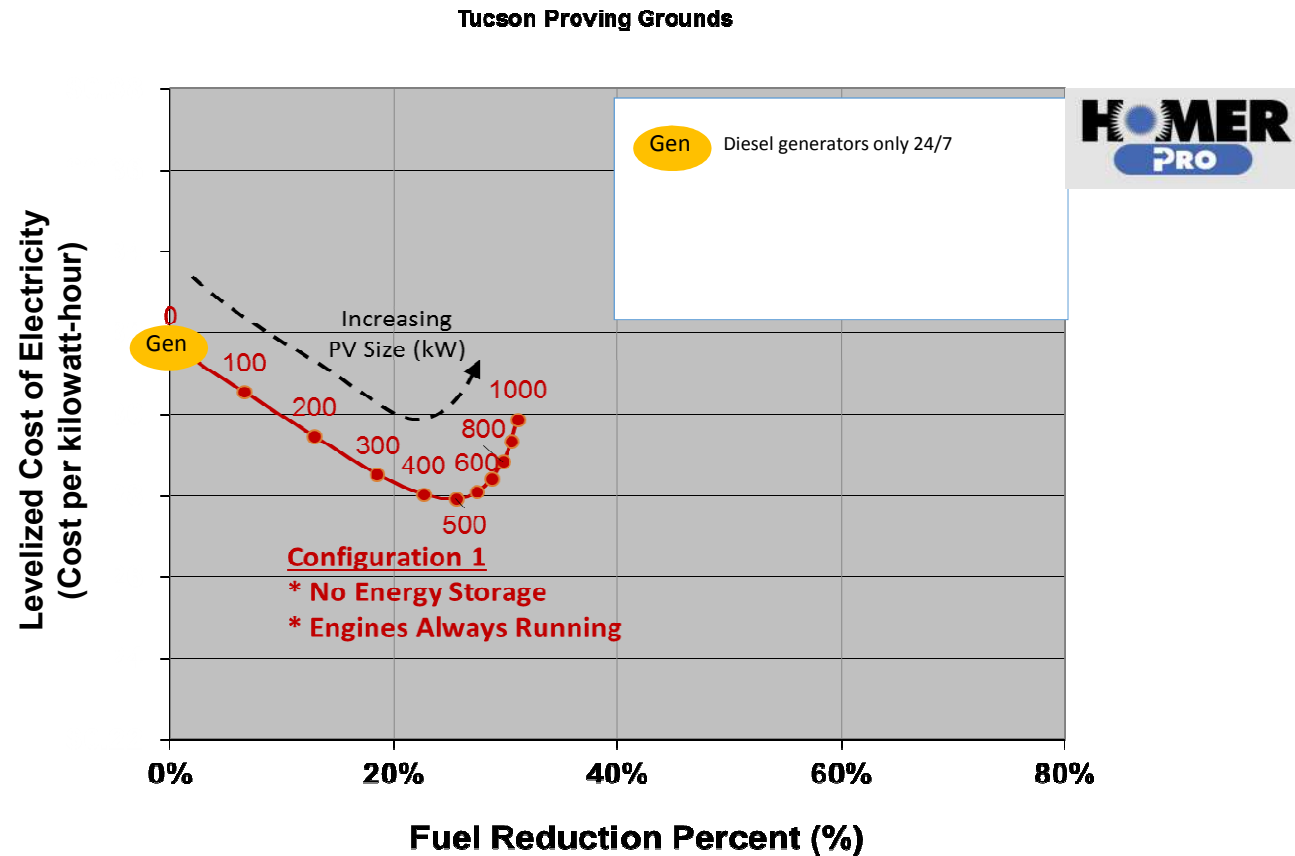
# Selection of Optimum PV & Energy Storage Size

Tucson Proving Grounds



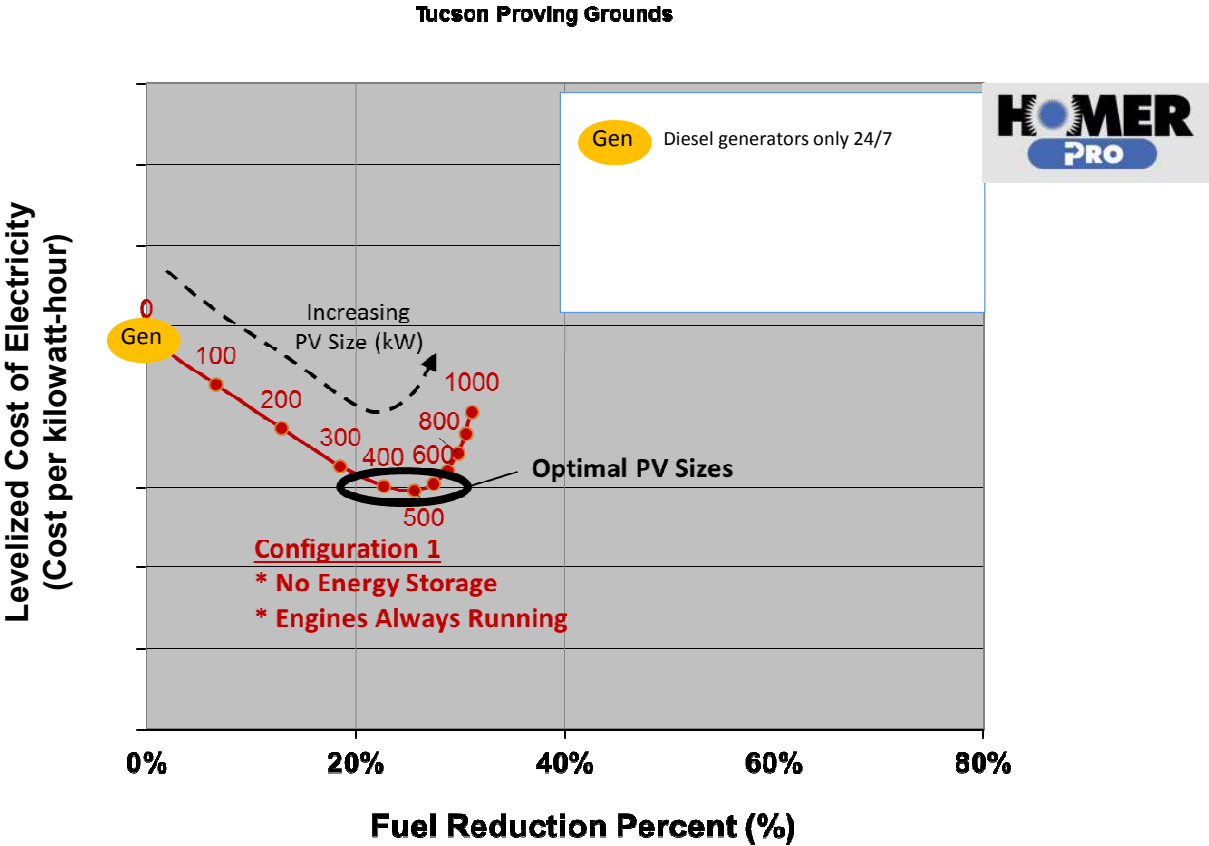
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# Selection of Optimum PV & Energy Storage Size



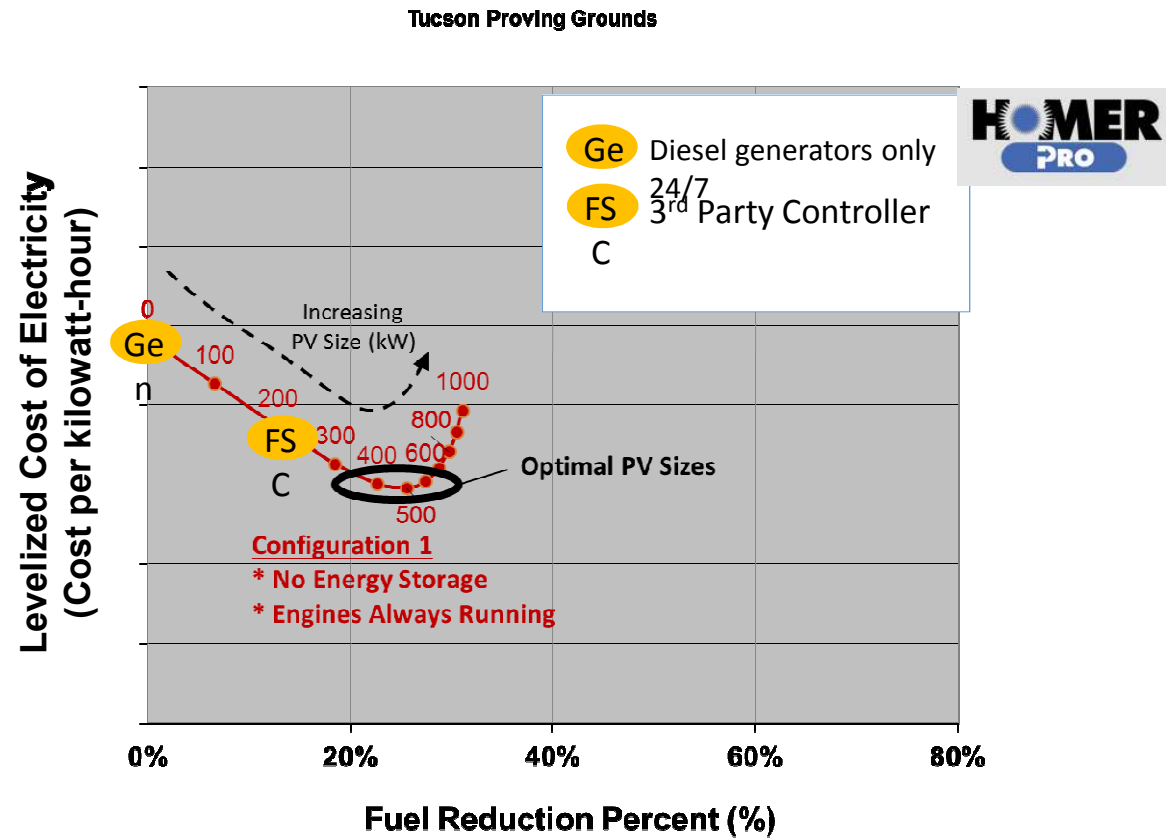
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# Selection of Optimum PV & Energy Storage Size



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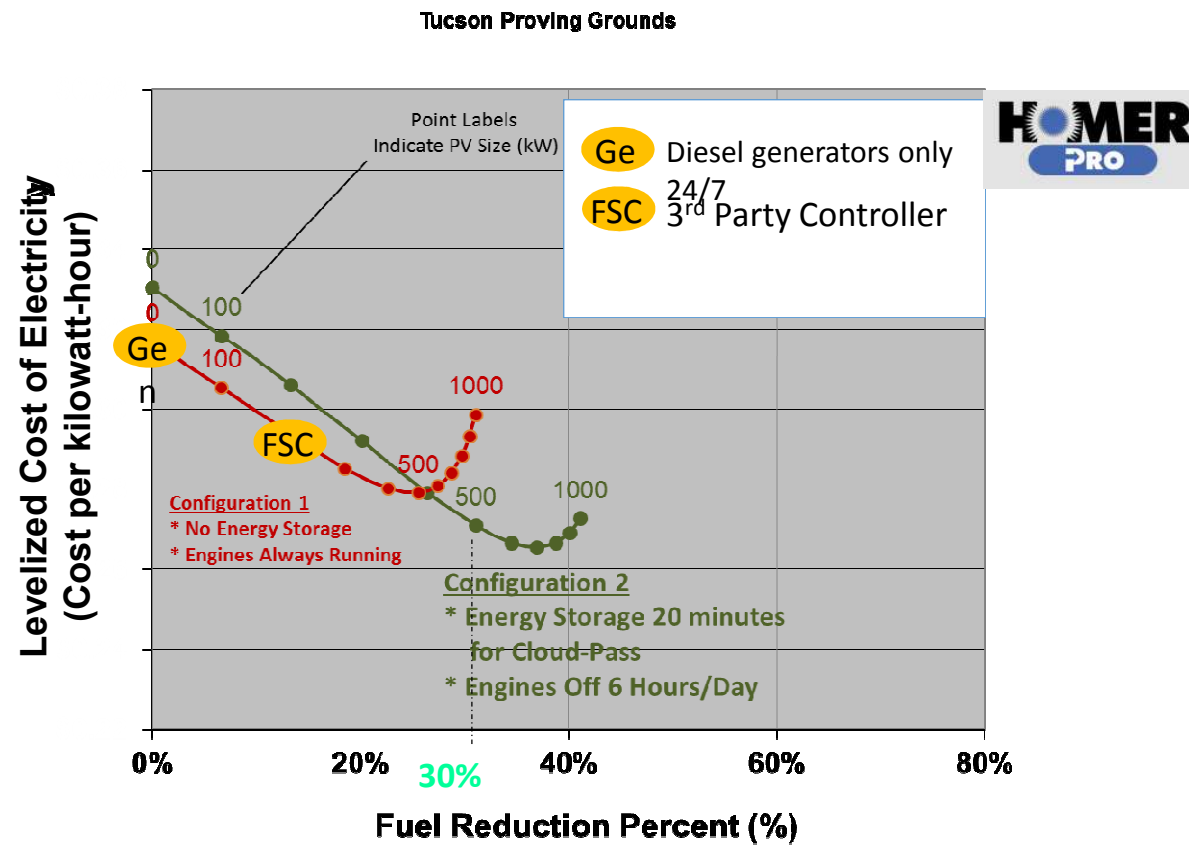
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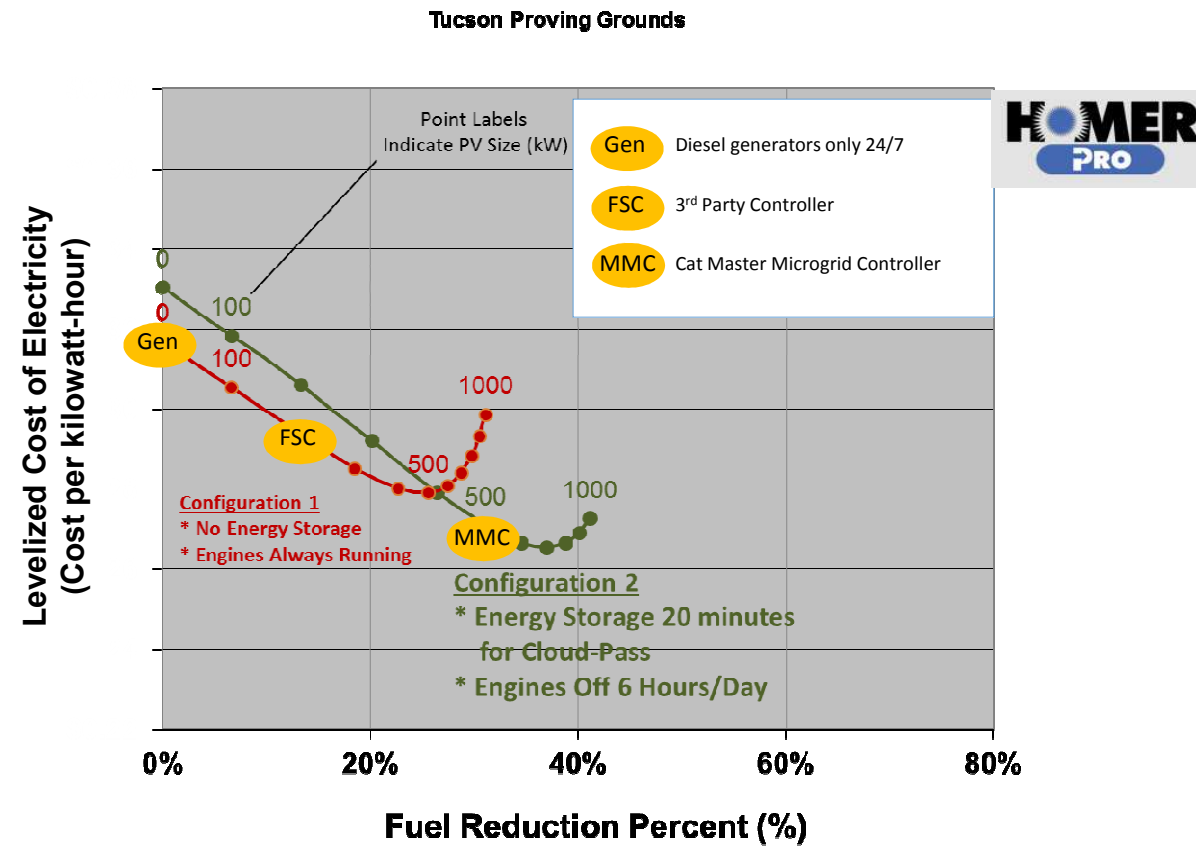


# Selection of Optimum PV & Energy Storage Size



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# Selection of Optimum PV & Energy Storage Size



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## Conclusions

- Hybrid Microgrid solutions permit lower levelized cost of electricity
- Multiple small Microgrids can be quickly and cost effectively implemented in off-grid and weak-grid locations.
- Caterpillar provides fully integrated Hybrid Microgrid solution
  - Generator set
  - Photovoltaic system
  - Energy Storage
  - Service

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**Questions?**

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