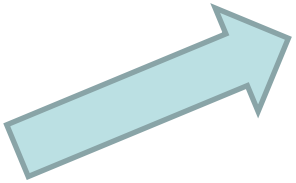
JP-8 Compatible Fuel Cell Gensets at Lockheed Martin

2011 Joint Service Power Expo

Myrtle Beach, SC
4 May 2011



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Motivation – Reduce Genset Fuel Usage

- *Army: 357 million gallons of fuel per year just for gensets.*
  - *Largest single consumer of fuel – and very distributed*
- *Tens to hundreds of dollars per gallon to get to soldiers in field*
- *Major cost in lives*
- *Our JP-8 compatible solid oxide fuel cell (SOFC) gensets can reduce fuel usage*

Fuel convoys are vulnerable to attack.

AP – 1 October 2010 - ISLAMABAD, Pakistan –Assailants in Pakistan launched two separate attacks Friday on vehicles carrying fuel for NATO and American forces in Afghanistan, highlighting the vulnerability of the U.S.-led mission…

AP – 25 February 2011 - ISLAMABAD, Pakistan – Militants in northwestern Pakistan blew up at least 11 tankers carrying fuel for NATO troops in neighboring Afghanistan and shot dead four people, police said.

"Free us from the tether of fuel"
Marine Corps Maj. Gen. Mattis
(now Commander, U.S. Central Command)

"By reducing the need for [petroleum] at our outlying bases, we can decrease the frequency of logistics convoys on the road, thereby reducing the danger to our marines, soldiers, and sailors."
Marine Corps Maj. Gen. Richard Zilmer, former top U.S. commander in western Iraq

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Why Solid Oxide Fuel Cells for Gensets?

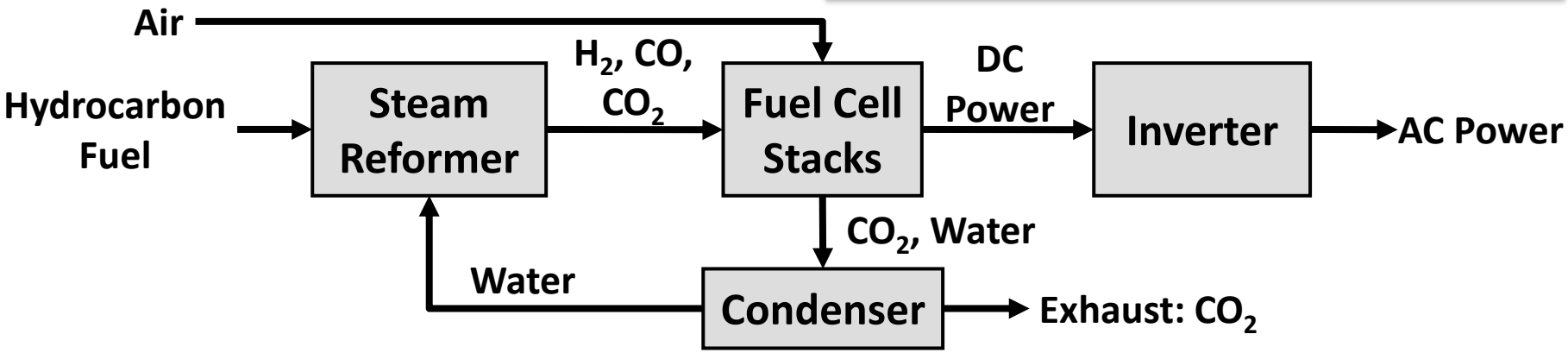
Why SOFC Technology?

- Combined with a fuel reformer, solid oxide fuel cells can be much more fuel efficient than current gensets
- Quiet - no large mechanical moving parts
- Less Pollution – No Combustion

But…

- Must be compatible with JP-8 per DoD "One Fuel Forward" policy
- Problem – sulfur contained in these fuels poison reformer and fuel cell catalysts

Basic reformer / fuel cell system diagram



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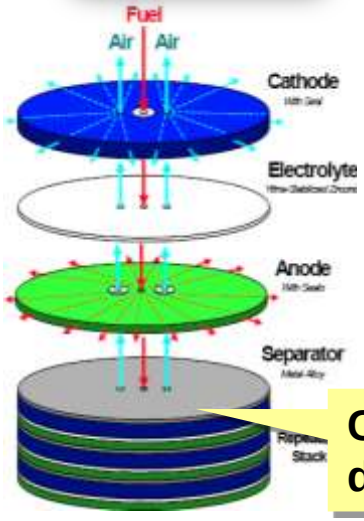
Why TMI's SOFC Technology?

- Sulfur tolerant – Unlike other fuel cells, ours operates directly on JP-8 and other sulfur-containing fuels.
  - Recently completed 1,000-hr test on standard DoD-supplied JP-8
  - No desulfurization complexity or inefficiencies
- Fuel flexibility: Uses JP-8 as well as other fuels such as soybean and other vegetable oils, natural gas, syngas, propane, Jet-A, diesel, biodiesel, etc.
- Simple cell design enables low manufacturing costs
- Quiet and clean – can operate indoors



Core TMI stack technology designed for manufacturability

US Army BGEN Thomas Cole

Lab prototype operating on JP-8, Jet-A and diesel

LM Partner: **Technology Management Inc.**

- Small business
- LM working with TMI since 1993

Our SOFC technology uniquely operates efficiently on standard JP-8 fuel.

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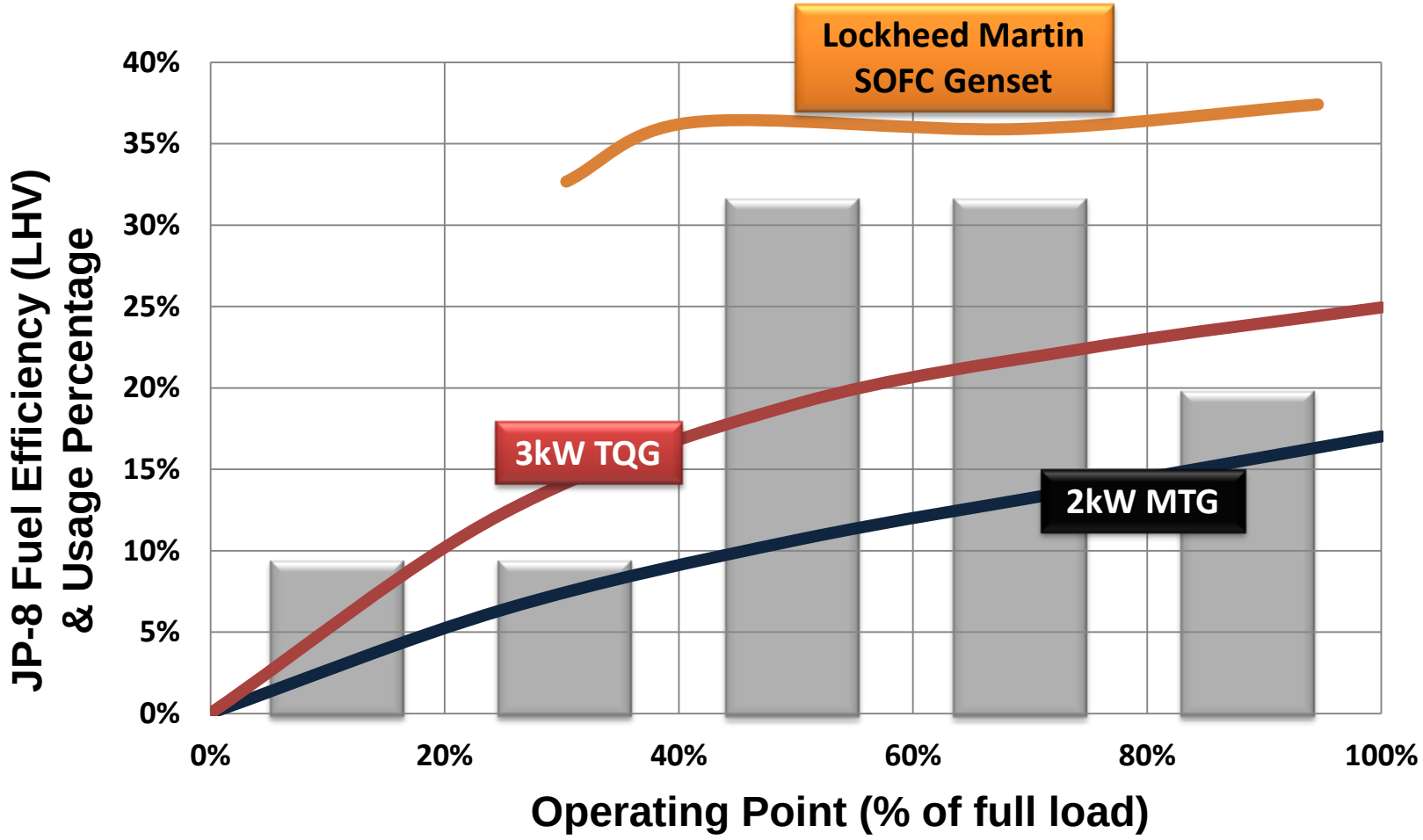
SOFC Genset Efficiency vs. Conventional Gensets



Projected usage of TQGs as function of load. *Source: ORNL: "Advanced Power Generation Systems for the 21st Century"*

LM's SOFC Gensets are *double* the efficiency of current DoD Gensets

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LM/TMI SOFC Genset Features

Feature	LM SOFC System
Fuel Efficiency	Up to twice as fuel efficient on JP-8 as conventional TQG
Fuel Flexibility	Core technology has been demonstrated with wide range of liquid and gaseous fuels, including JP-8, Jet-A, diesel, ammonia, natural gas, propane, soybean oil, jatropha oil, alcohols, syngas
Modularity	Core power electronics enable synchronization with external 60Hz source
Renewables Integration	Internal architecture enables simple addition of external renewable sources, such as solar panels, to further reduce fuel consumption
Lower Acoustic Signature	No large internal combustion engine noise. Only small, readily isolatable air blowers
Less Polluting	Less CO_2 per unit energy. Non-combustion process when operating; no NO_x, particulates

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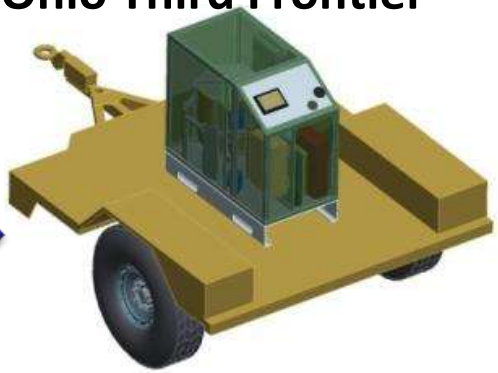
Recent SOFC System Accomplishments

- **System Readiness**
  - 1000-hour continuous test of JP-8 SOFC genset completed
    - Including transporting the operating system 42 miles (Cleveland to Akron)
  - Completed shock & vibration testing of integrated stacks and reformer
  - Conducted initial environmental testing for arid and humid environments
- **Incorporated design improvements**
  - Ruggedization, reliability, maintainability
  - Operability - One-button stand-alone start up process
  - Embedded controller
  - Developed flex-fuel and renewables interface
- **Achieving/exceeding fuel efficiency objectives**
  - Significant efficiency improvement measured against conventional gensets
  - Validated over a wide range of loads
- **Development contracts with the Army CERDEC and Ohio Third Frontier**

Ruggedizing our proven JP-8 compatible fuel cell technology



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System Testing and Ruggedization

Shock and Vibration

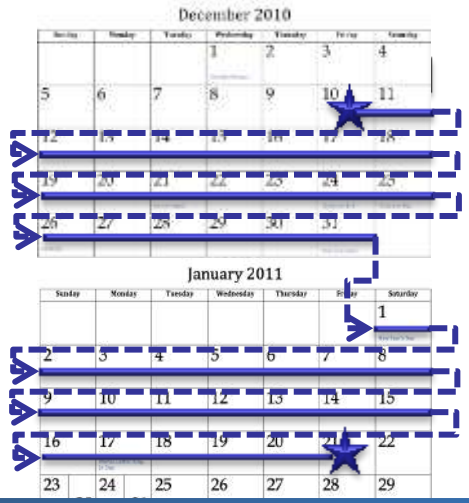
Developed shock & vibe mounting approach and performed testing of Hot Subassembly and major BOP components.

- Vibration: MIL-STD-810G 514.6C-2, Random Vibration – Two-Wheeled Trailer
- Shock: MIL-STD-810G 516.6-8, Functional Test for Ground Equipment

Endurance Testing

1000-hour test recently completed

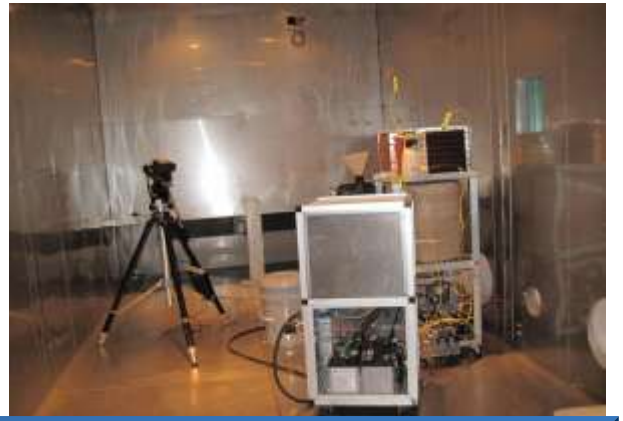
Running with standard JP-8 fuel provided by AFRL Wright-Patterson



Temperature & Humidity

Initial temperature & humidity testing of system

- Temperature 110°F; low RH (~20%)
- Temperature 95°F; high RH (~90%)
- Day / night cycling
- Focus on initial quick assessment of COTS components in system



Moving the TRL forward

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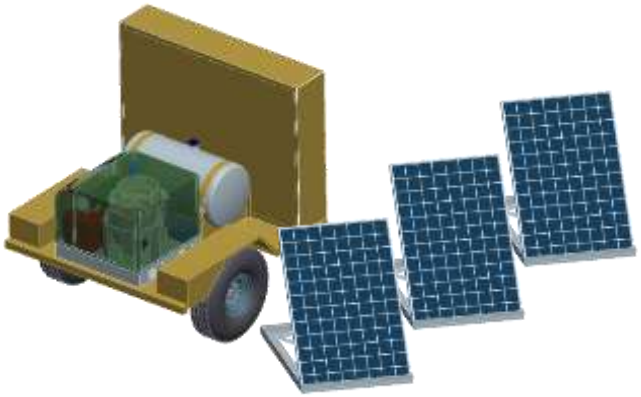
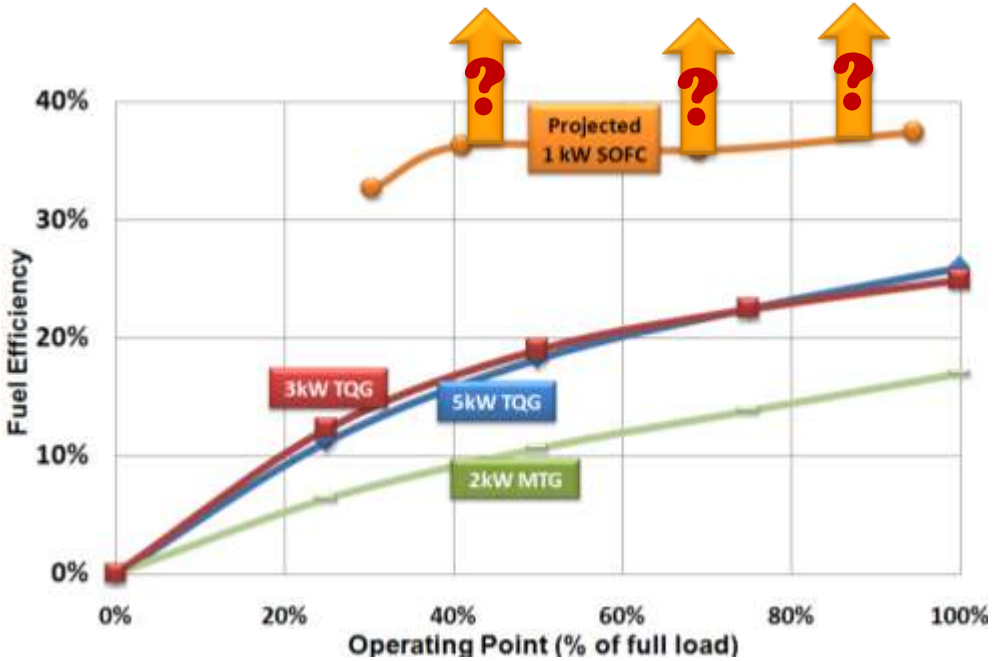
Energy Node Concept

Our SOFC Genset internal design enables further fuel efficiency enhancements:

- **Simple additions enable *insertion of renewable sources* to reduce fuel usage – leverages existing inverter and controls**
- **Multiple SOFC *gensets designed to be directly paralleled***
- **Core technology is *flex-fuel capable* – just need to provide simple interface and controls in balance-of-plant**





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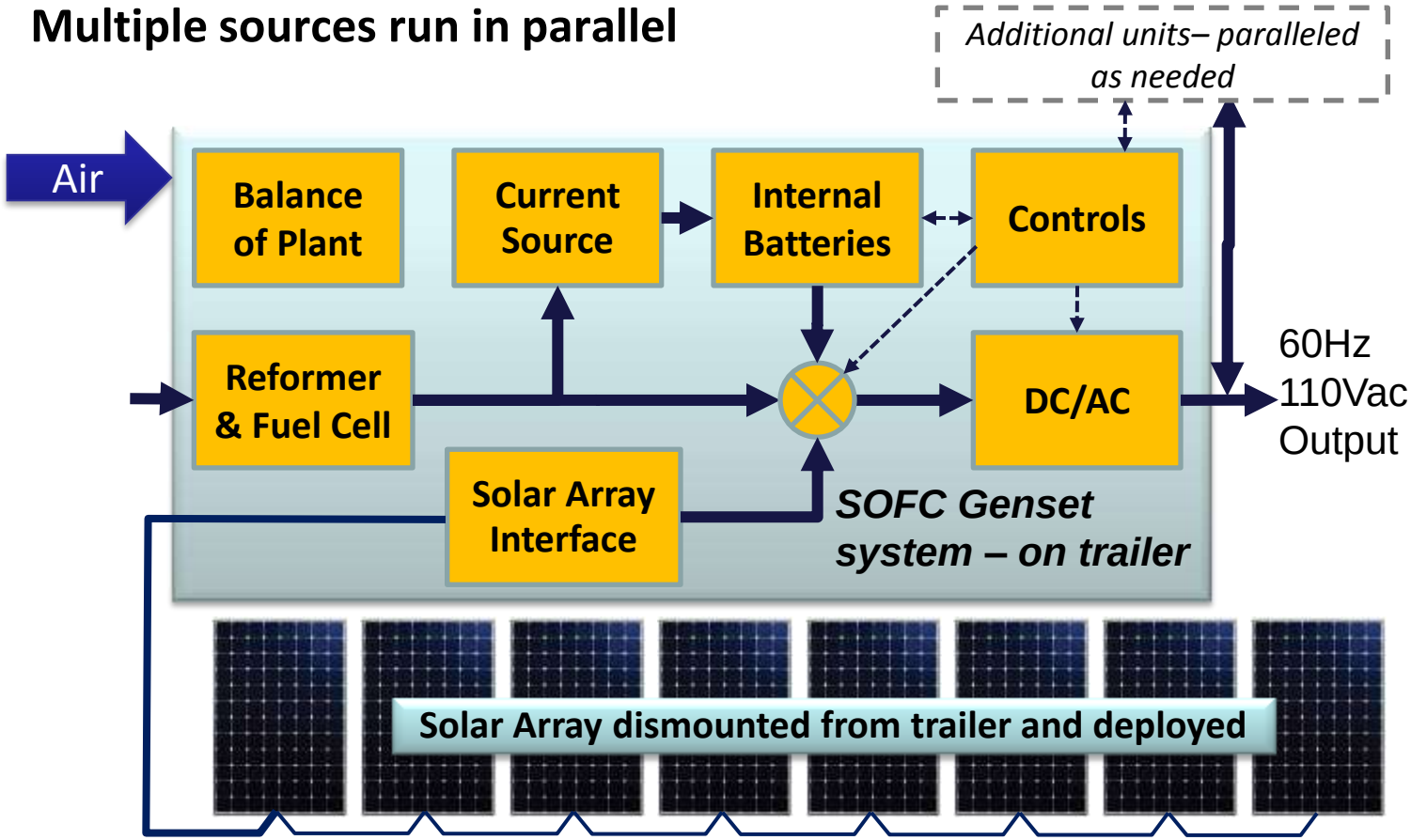
Adding Renewable Sources

- Adjustments to internal design allows generic DC sources to displace fuel cell-generated power as required
- Controls select which current sources to use which maximizes efficiency of fuel cell system
- Multiple sources run in parallel



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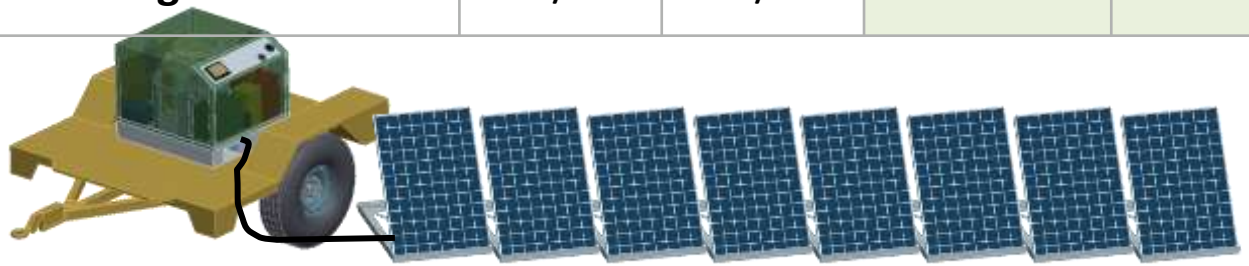
Energy Node – Even Greater Fuel Savings

- Significant fuel savings, even if solar is not available
- Addition of simple solar panels further increases fuel savings
- No need for extra components to convert solar power, interface to grid, energy storage, etc.

	3kW TQG		3kW SOFC Genset	
Operating Load	50%	100%	50%	100%
Fuel usage per day	5.1 gpd	7.9 gpd	2.9 gpd	5.8 gpd
Savings (just fuel cell)	n/a	n/a	43%	27%
With solar panels *	5.1 gpd	7.9 gpd	1.3 gpd	3.9 gpd
Fuel savings with solar	n/a	n/a	74%	51%



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Summary

- Definitive need to substantially drive down fuel usage in theaters of operation
  - Savings in both lives and dollars
- Lockheed Martin's proven SOFC JP-8 genset will help achieve this goal by using 50% less fuel than currently deployed gensets
- The Lockheed Martin/TMI genset is inherently designed to be compatible with "plug-n-play" energy solutions such as micro-grid and renewable power sources
  - This compatibility will dramatically increase energy efficiencies while driving down costs
- Fuel flexibility provides the additional benefit of using indigenous fuels on an as needed basis

As a "stand alone" system or as part of a networked solution, the Lockheed Martin SOFC genset will significantly remove tankers from convoy supply lines

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