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ClearEdge5 Fuel Cell System

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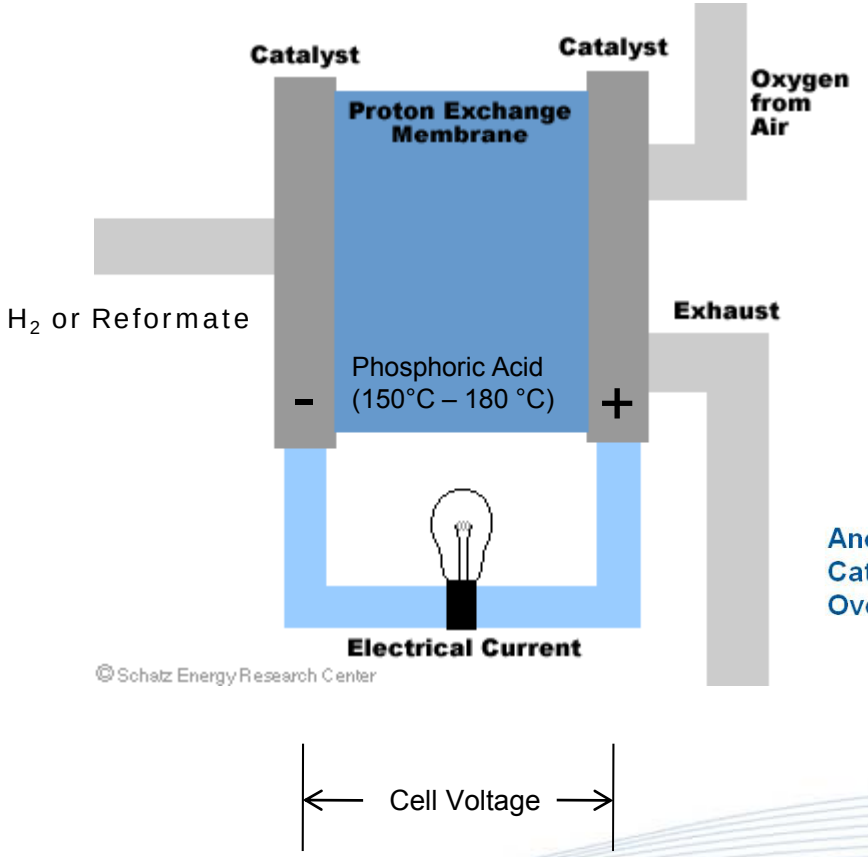
How Does a Hydrogen Fuel Cell Work?

Anode

$H_2 \rightarrow 2H^+ + 2e^-$

Cathode

$2H^+ + 2e^- + \frac{1}{2}O_2 \rightarrow H_2O$



Anode Reaction: $2H_2 \Rightarrow 4H^+ + 4e^-$
Cathode Reaction: $O_2 + 4H^+ + 4e^- \Rightarrow 2H_2O$
Overall Cell Reaction: $2H_2 + O_2 \Rightarrow 2H_2O$

Cell Voltage

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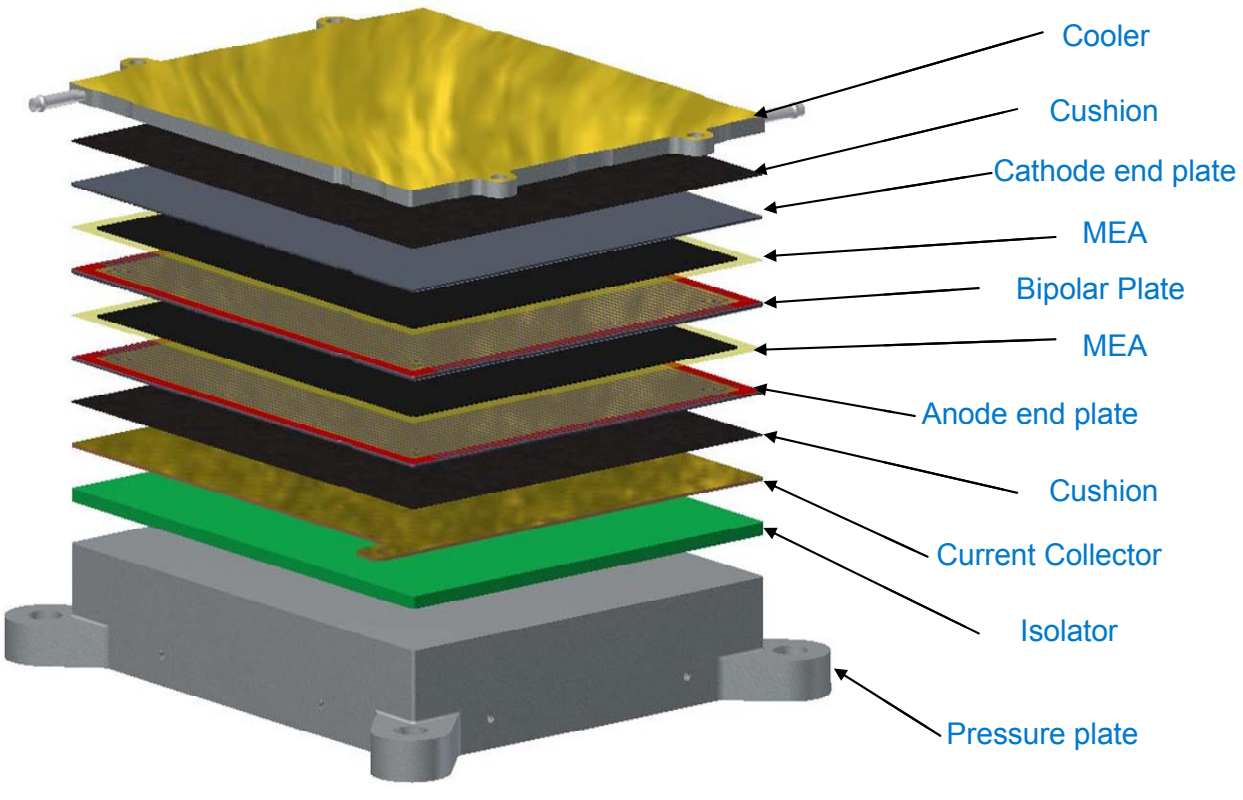
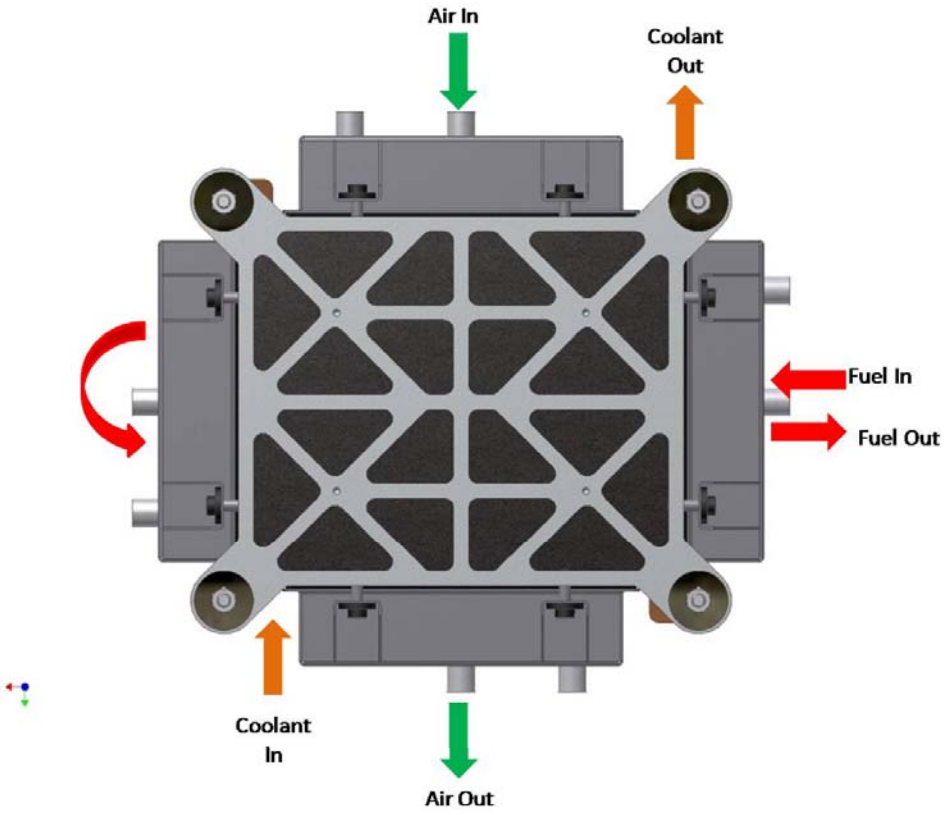
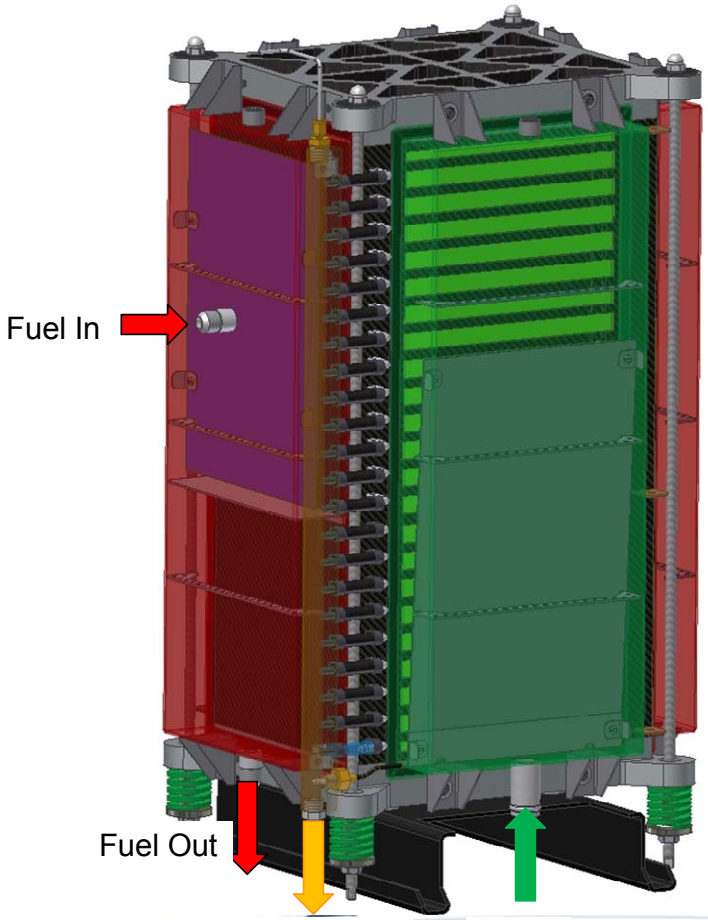
Stack “Repeat Parts”

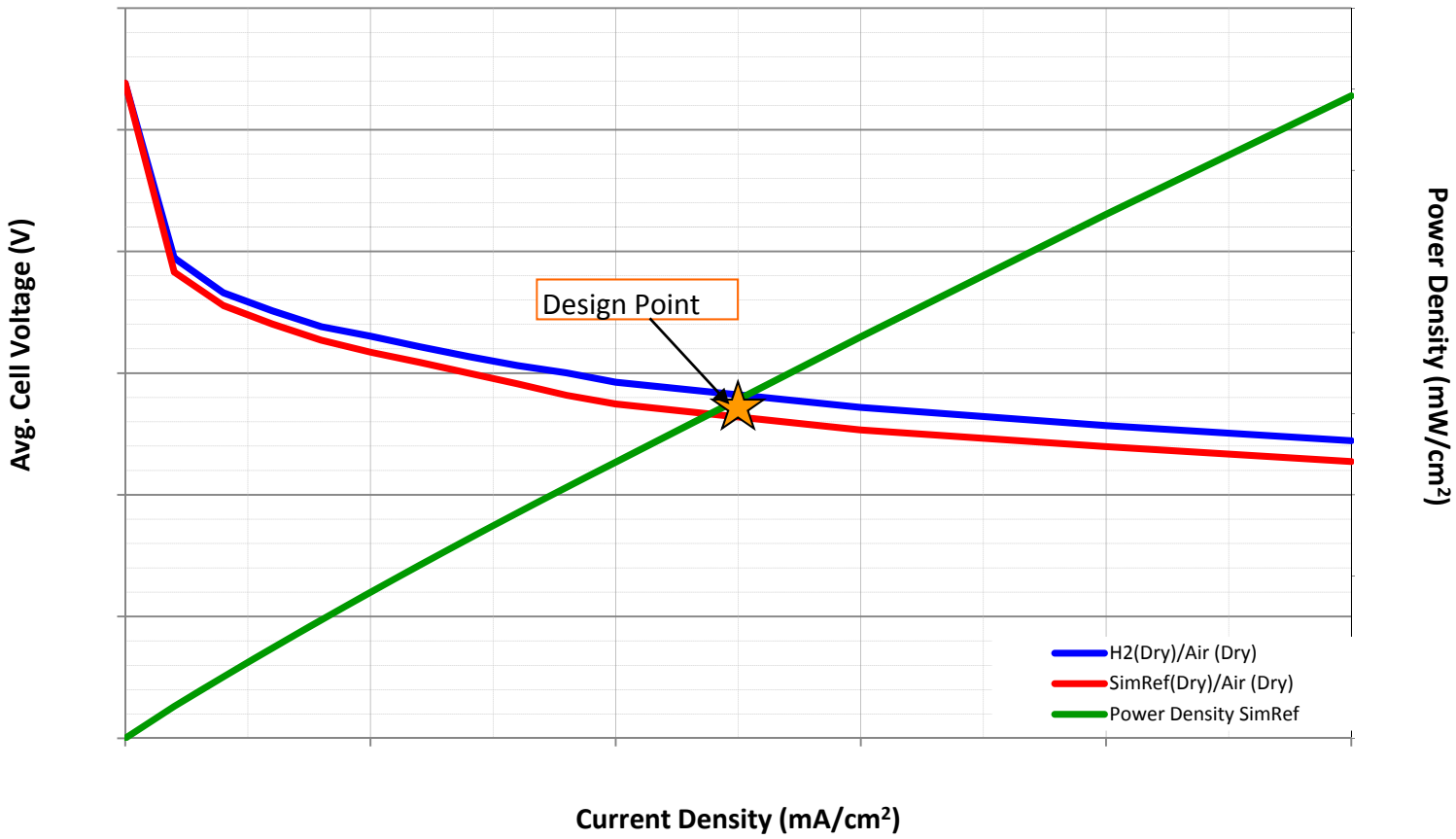


Fuel Cell Stack

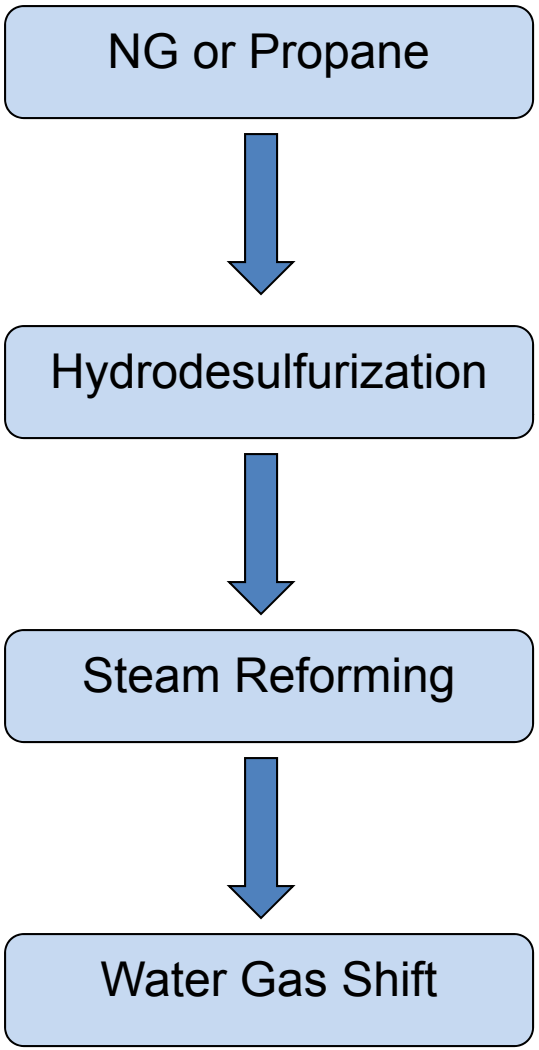




Fuel Cell Stack Performance



Fuel Processing Technology



$R\text{-}SH + H_2 \leftrightarrow R\text{-}H + H_2S$

$ZnO + H_2S \leftrightarrow ZnS + H_2O$

$CH_4 + H_2O \rightarrow CO + 3H_2$

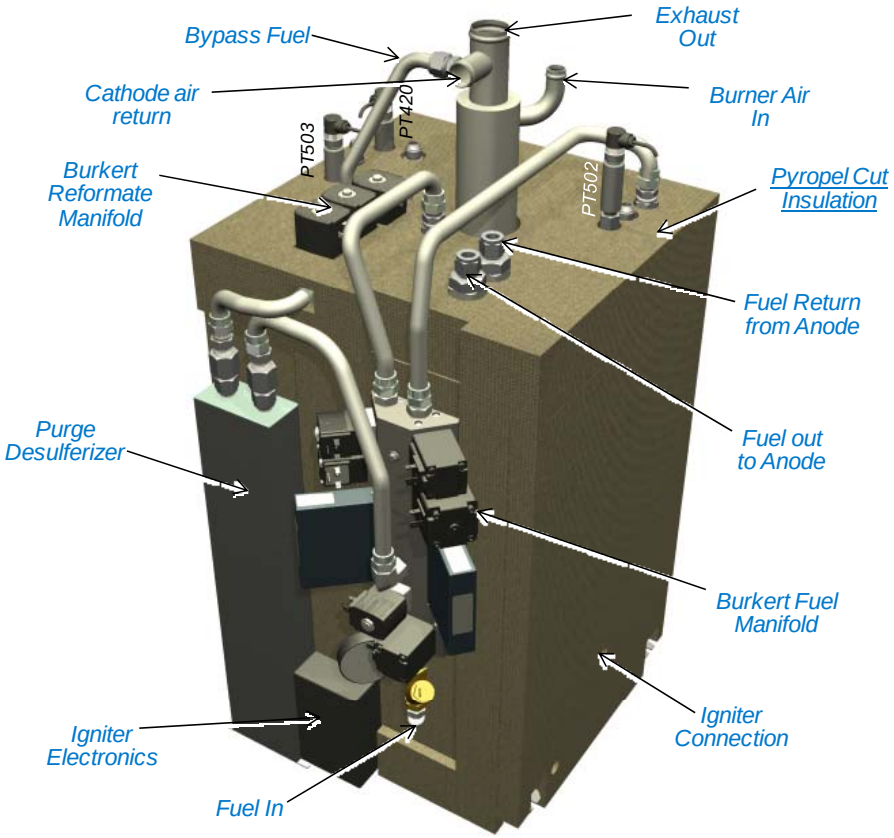
$CO + H_2O \rightarrow CO_2 + H_2$

$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2$

$CO + H_2O \rightarrow CO_2 + H_2$

Typical Composition of Natural Gas		
Component	Typical Analysis (mole %)	Range (mole %)
Methane	95.2	87.0 - 96.0
Ethane	2.5	1.5 - 5.1
Propane	0.2	0.1 - 1.5
iso - Butane	0.03	0.01 - 0.3
normal - Butane	0.03	0.01 - 0.3
iso - Pentane	0.01	trace - 0.14
normal - Pentane	0.01	trace - 0.04
Hexanes plus	0.01	trace - 0.06

Fuel Processor



Requirements:

- >115% efficiency (Suitable for 40% Elect. Efficiency)
- Pipeline NG or Commercial grade LPG
- Emissions (system):
  - NOx : <3 ppm (demonstrated in Phase II)
  - CO: <10ppm (demonstrated in Phase II)
  - SOx: Negligible (demonstrated in Phase II)
- Life: 40k + hours

Overall Reaction:

$CH_4 + 2H_2O \Rightarrow 4H_2 + CO_2$

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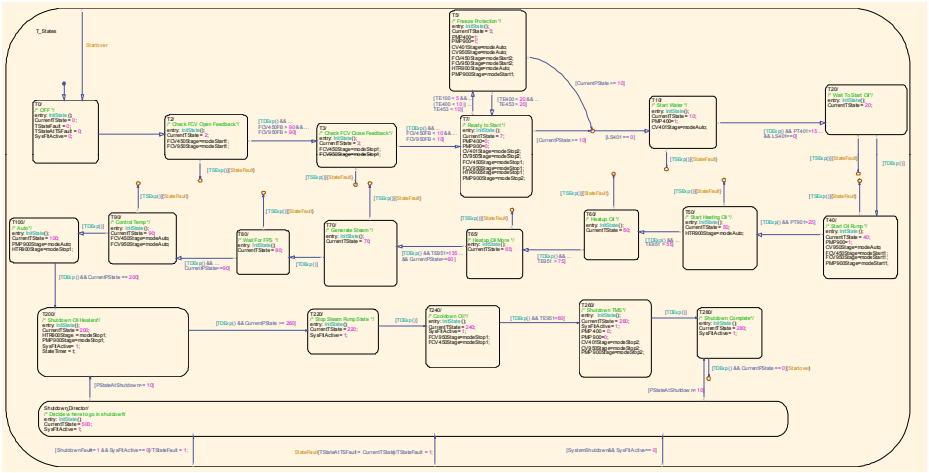
Process Control

CE5 Controller Hardware



CE5's 'secret sauce' – Process controller development using Simulink/ Stateflow

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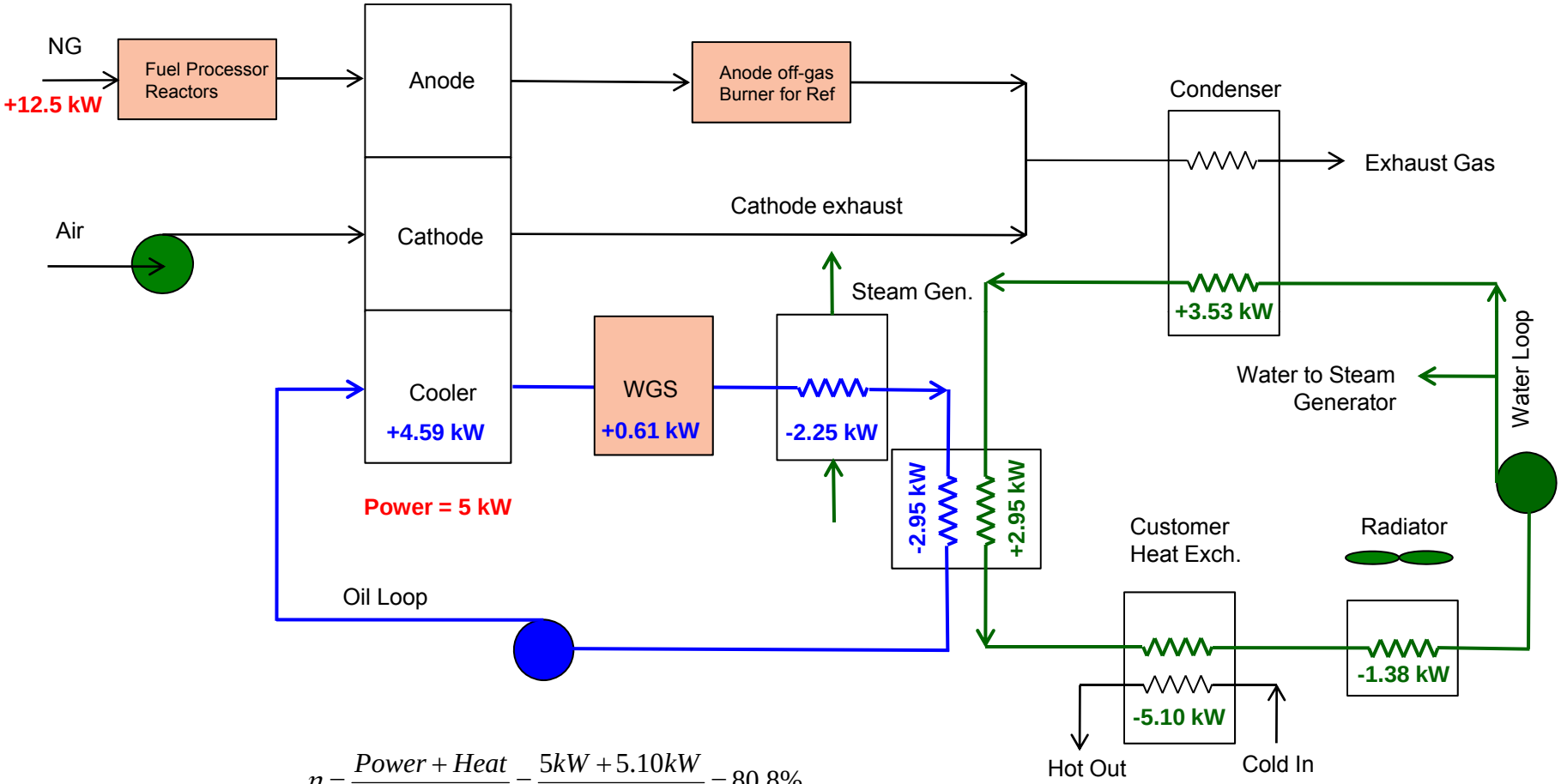
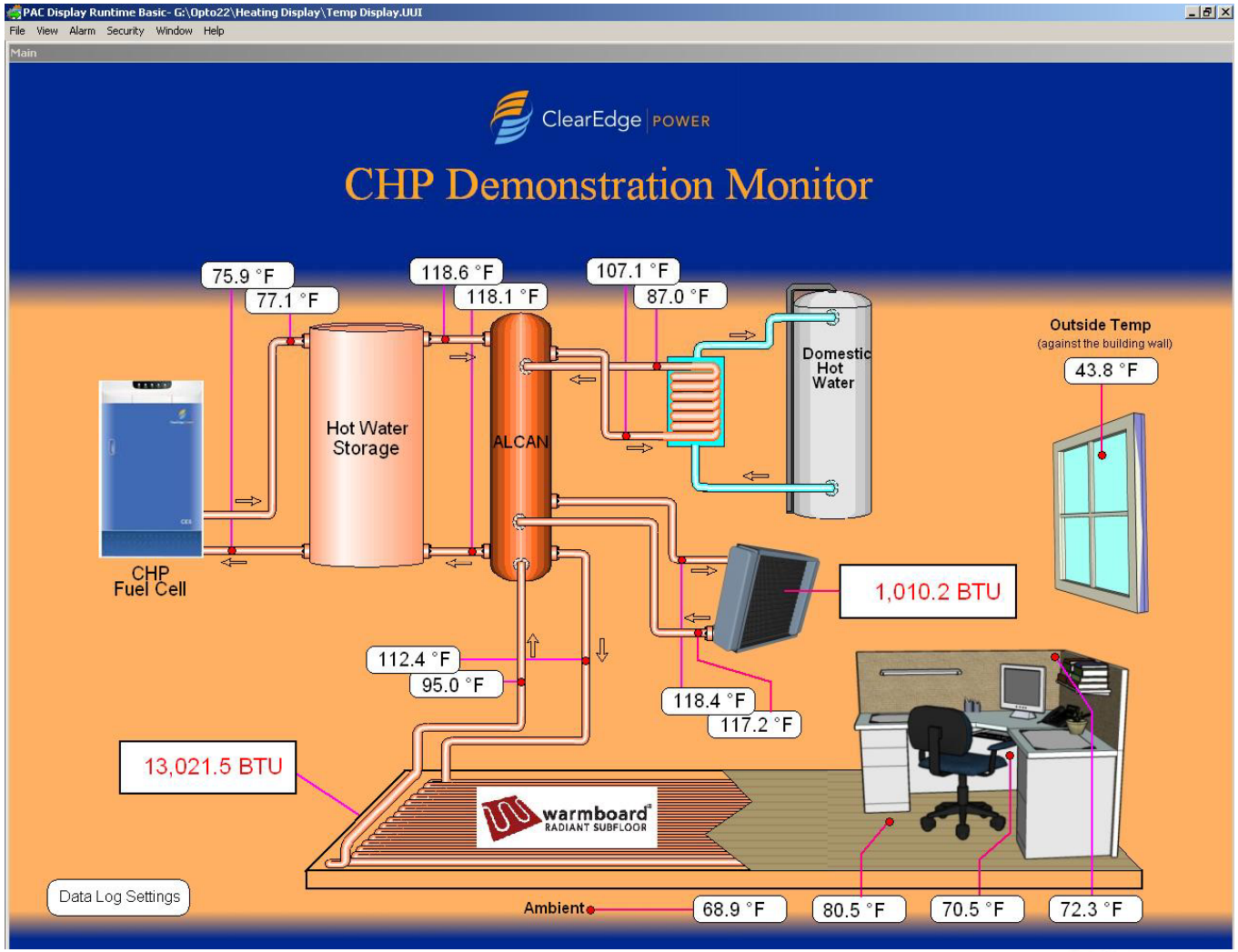
Fuel Cell "System"



$$\eta = \frac{Power + Heat}{LHVofNG} = \frac{5kW + 5.10kW}{12.5kW} = 80.8\%$$

Fuel Cell CHP System Integration



ClearEdge5 Requirements

- ✓ 5 kW electrical power @ 120/240 VAC 60 Hz, with 12 kW for 7 sec (transient overload capability)
- ✓ Electrical efficiency of 40% at rated power (LHV, new system), with lifetime overall energy utilization efficiency of ≥80% in CHP mode
- ✓ Designed for base-load operation, capable of grid connect/ grid independent mode
- ✓ Provides backup power during grid outage
- ✓ Operates on residential grade natural gas or Propane
- ✓ Heat output: Up to 6.5 kW @ 65º C, suitable for hot water system, radiant heating or pool/spa heating

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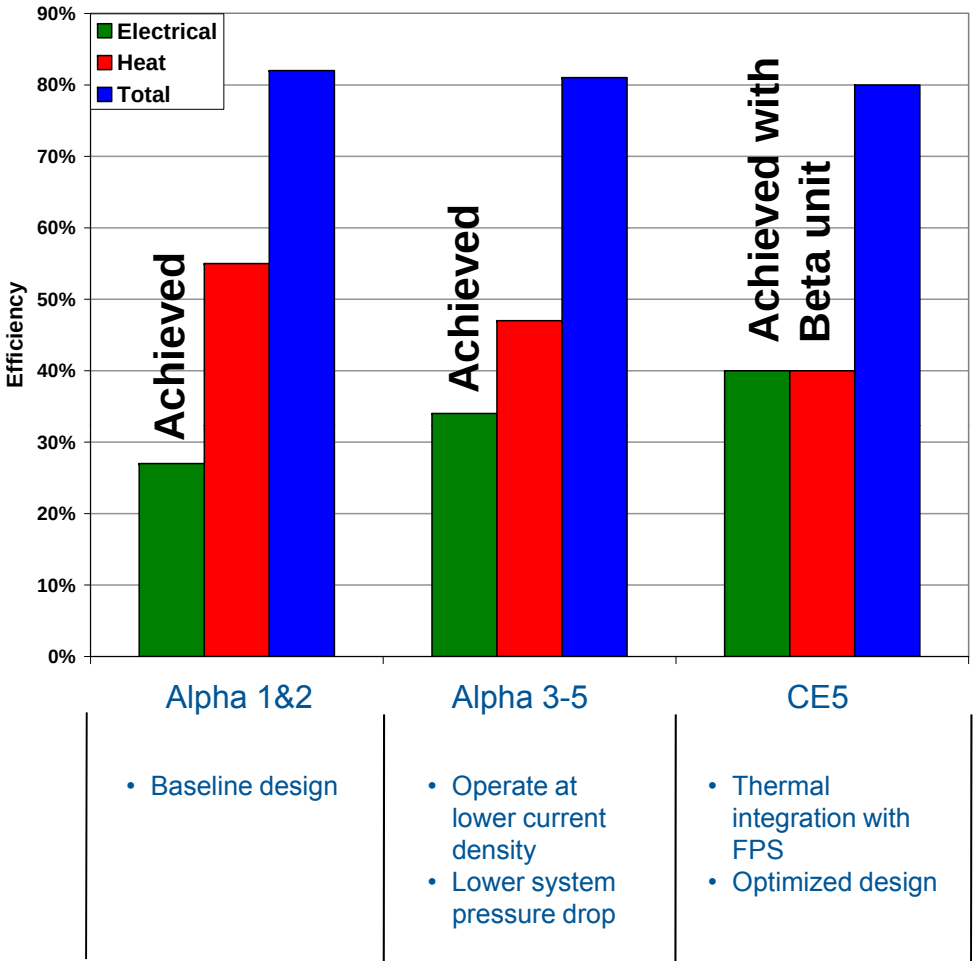
Design Milestones



- Baseline design
- Operate at lower current density
- Lower system pressure drop
- Thermal integration with FPS
- Optimized design

CE5 Efficiency Breakdown

Efficiency	BOL	40k Hrs
Electrical:	40.1%	35.5%
Heat:	45.0%	49.8%
Total:	85.1%	85.3%

- ✓ System efficiency exceeds all expectations!!
- ✓ > 20 units are currently operated in the field.
- ✓ Over thousands of operation hours are collected.

Remote Monitoring

Each system contains 1 GB of NVM *rolling memory*, equivalent to a "Black Box"

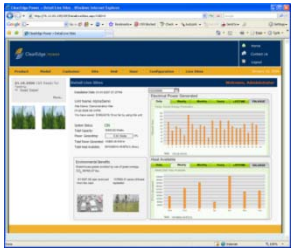
Real time monitoring of all safety and control parameters via remote HMI

Real Time Data

Sends SMS or email to FSE in the event of an issue

Central Data Server

Real time customer interface



Web monitoring system (custom integration with other home monitoring systems possible)

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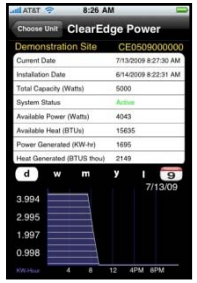

iPhone

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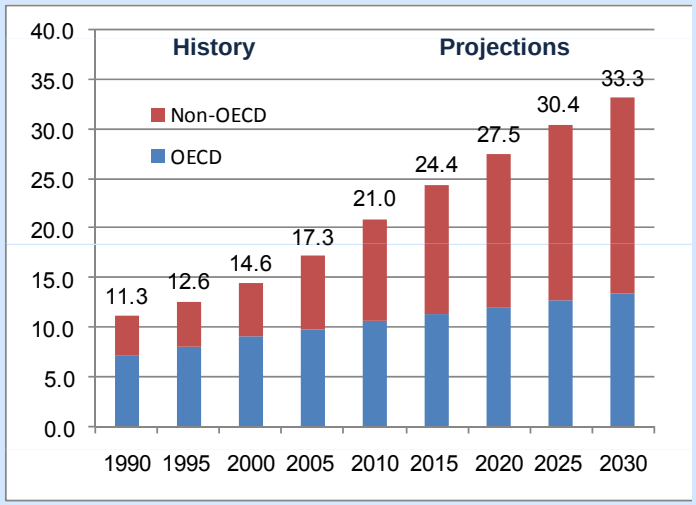
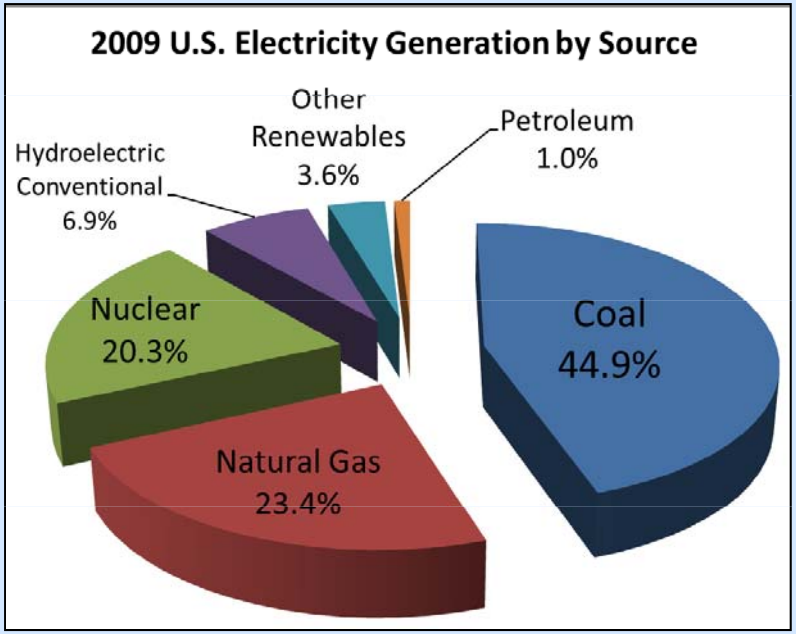
Why Fuel Cells? – Need More Power



Sources: History: Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), website www.eia.doe.gov. Projections: EIA, System for the Analysis of Global Energy Markets/Global Electricity Module (2008).



Increasing power demand driven by:

- Fundamental shift from mechanical to electrical products
- Increasing population urbanization

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Why Fuel Cells? – Environmental Impact

How You Receive Energy Today

Natural Gas
Nuclear
Coal

Efficiency: 35%
4223 therms

Electricity → 43.8 MWh/annual

Natural Gas

Efficiency: 80%
2175 therms

Heat → 51 MWh/annual

6398 therms total

…And Will Tomorrow

Electrochemical Conversion

Electricity → 43.8 MWh/annual

Natural Gas

Efficiency:
up to
90%

Heat → 51 MWh/annual

3840 therms total

Environmental Impact
8.35 lbs CO_2 per hour
34 Tons per Annum

ClearEdge5 System Provides
a 40% Reduction in Fuel Comsumption
and a 37% Reduction in CO_2

Environmental Impact
5.3 lbs CO_2 per hour
22 Tons per Annum

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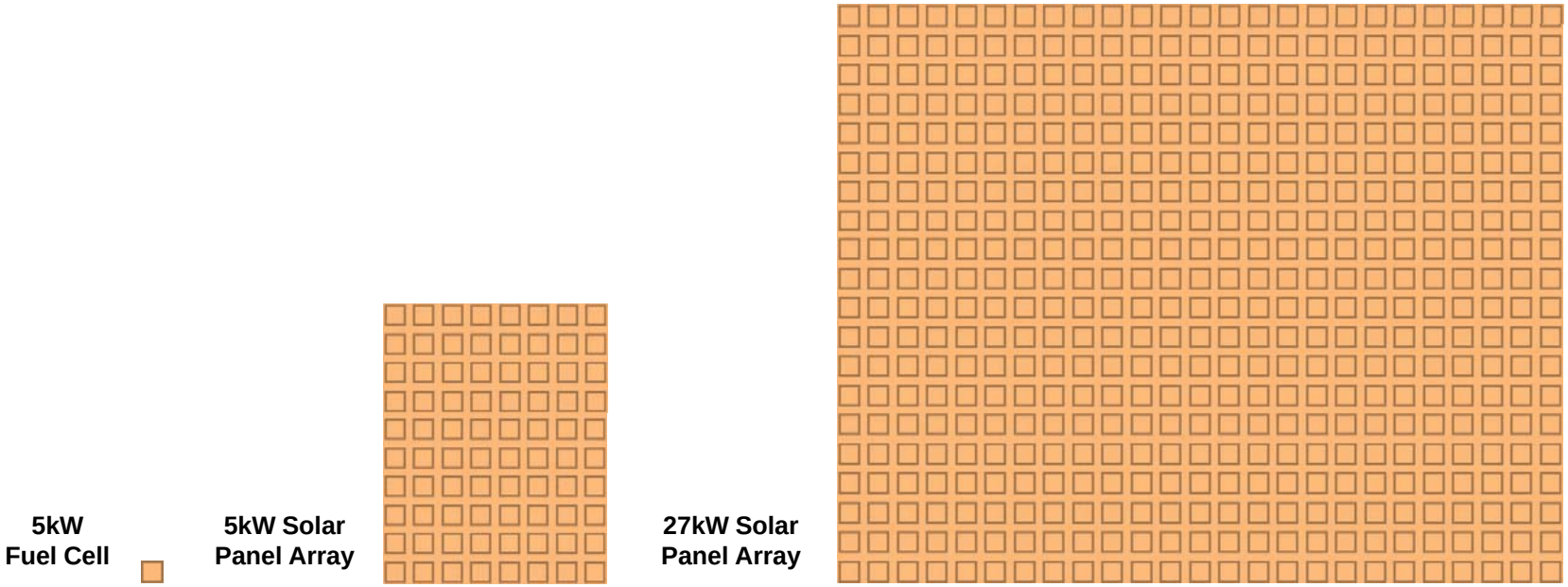
Fuel Cell microCHP vs. Solar Comparison

High Efficiency	5 kW Fuel Cell	5kW Solar	27kW Solar
Electric Production-Annual	43,800 kWh	8000 kWh	43,200 kWh
Heat Production	51,000 kWh	None	None
Space Required	6 sq. ft.	500 sq. ft.	3000 sq. ft.



*Solar Calculation Source: PVwatts1 Performance Calculator (San Diego Site)

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Why Fuel Cells? – Because It Is the Right Answer!!

✓ ***Lower Cost Power than Grid –*** as low as $.06 per kWh operating cost with full heat load being utilized.

✓ ***Cleaner than Grid Power –*** 37% less CO_2 with untraceable NOx or SOx.

✓ ***High Efficiency & Less Fuel Required –*** Over 90% CHP energy efficiency requiring 40% lower fuel consumption than conventional combined cycle or heating systems.

✓ ***Continuous Power –*** Operates in both grid parallel and grid independent modes to provide uninterrupted power during grid outages.

✓ ***Multi-Fuel & Scalable –*** Operates on common infrastructure fuels available.

✓ ***Aesthetic Design –*** Compact and quiet system operates both indoors or outdoors without compromising architectural design.

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Target Vertical Markets

Commercial

Hotels
Restaurants
Health & Athletics
Entertainment
Agriculture & Greenhouses

Institutional

Utilities
Schools
Government
Medical
Military

Residential

Residential Single Family
Multi-Tenant:
- **Planned Communities**
- **Senior / Affordable Housing**
- **Condos & Apartments**

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