SECA Fuel Cells for Larger Applications

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Outline

- Background & Objectives
- Methodology
- Results:
  - System design
  - Performance
  - Cost
- Conclusions

Application of stack modules to larger capacity applications is key to SECA's strategy.

- Develop ~5 kW SOFC modules for mass-customization
- Small-capacity applications (1-5 stacks), including:
  - Residential / light commercial DG
  - Auxiliary power for vehicles
  - Remote power
- Larger capacity applications:
  - Large commercial / industrial DG (10-1000s stacks)
  - Sub-station level DG and central generation (synergy with Vision21 program)
- How to scale-up to hundreds of kW or MW?

SECA wanted to understand the issues involved in scaling up to 100-kW to 1-MW systems.

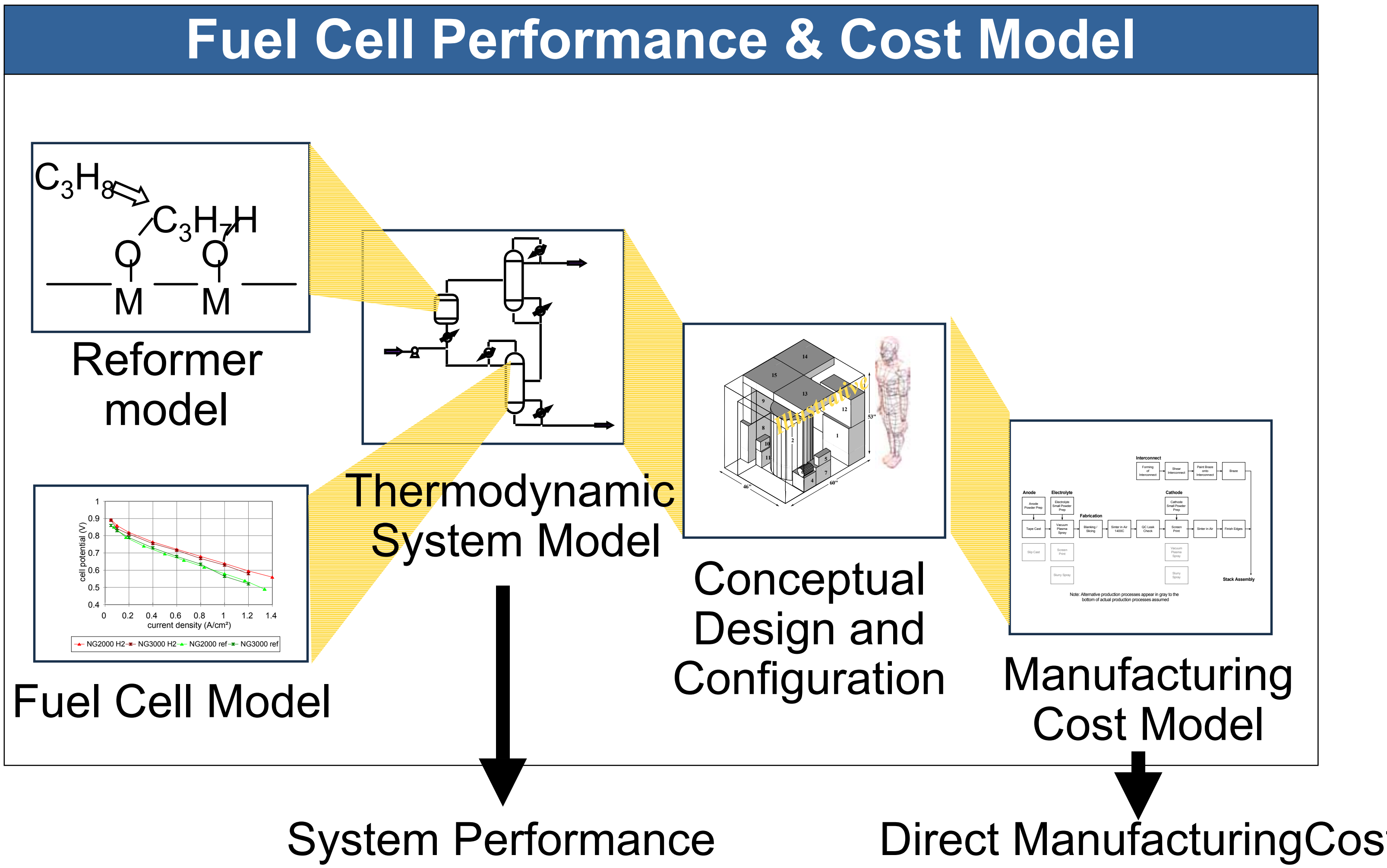
Objective: to assess whether and how SECA stack modules can be integrated into a 250 kWe plant.

- Develop thermodynamic design, system lay-out, performance estimate, and cost estimates
- SOFC stack:
  - Use 5 kW planar SOFC modules *
  - Combine into super-modules
  - *Implications for electric interconnection of the units?*
  - *Implications for manifolding?*
- Balance of plant:
  - Determine scale and integration
  - *Impact of scale-up on system performance and cost?*
- Simple-cycle operation

We developed a conceptual design for a 250-kW$_e$ distributed generation system SOFC.

System Specifications	Assumptions: Stack	Assumptions: Balance of Plant
◆ System output: 250-kW$_e$ net @ 380V 3-phase AC ◆ Electrical system efficiency >50% (LHV) ◆ Availability >99% ◆ $T_{Surface}$ < 45°C ◆ High production volume (10,000 units per year)	◆ 5 kW modules ◆ Cell voltage 0.7 V ◆ Anode-supported technology ◆ T_{stack} 650 - 800°C ◆ Power density 0.6 W/cm^2 ◆ 85% fuel utilization per pass in fuel cell	◆ Water supplied (no water recovery) ◆ Steam reformer ◆ Natural gas fuel, (20” H_2O gauge)

We used a multi-level modeling approach to develop direct manufacturing cost estimates for the system.



To estimate installed cost, value-chain mark-up and installation cost must be added.

Direct Manufacturing Cost

+

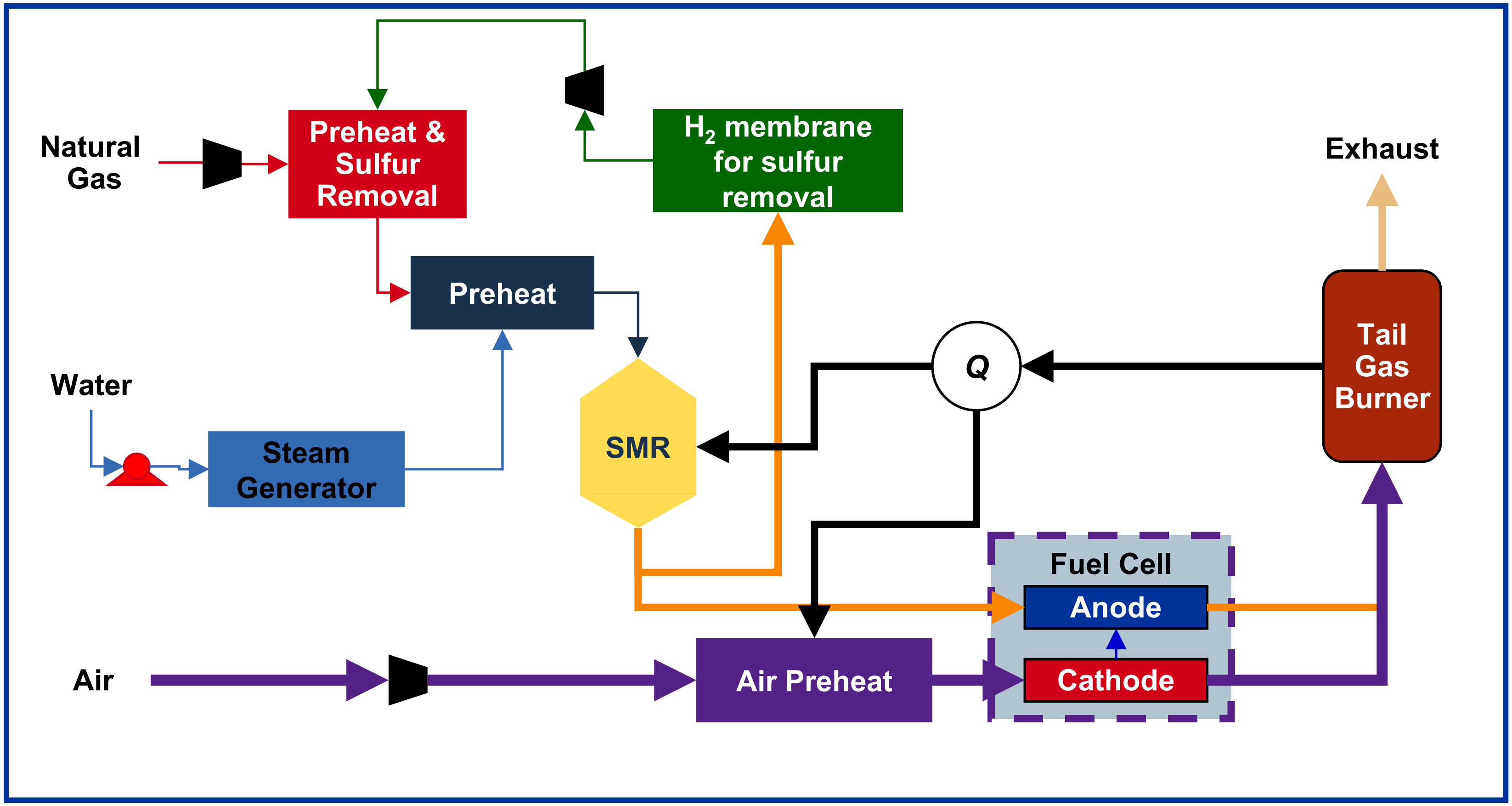
Factory Profit & Overhead

- Profits
- Sales costs
- General overhead
- R&D cost

The cost model contains both purchased components and manufactured components.

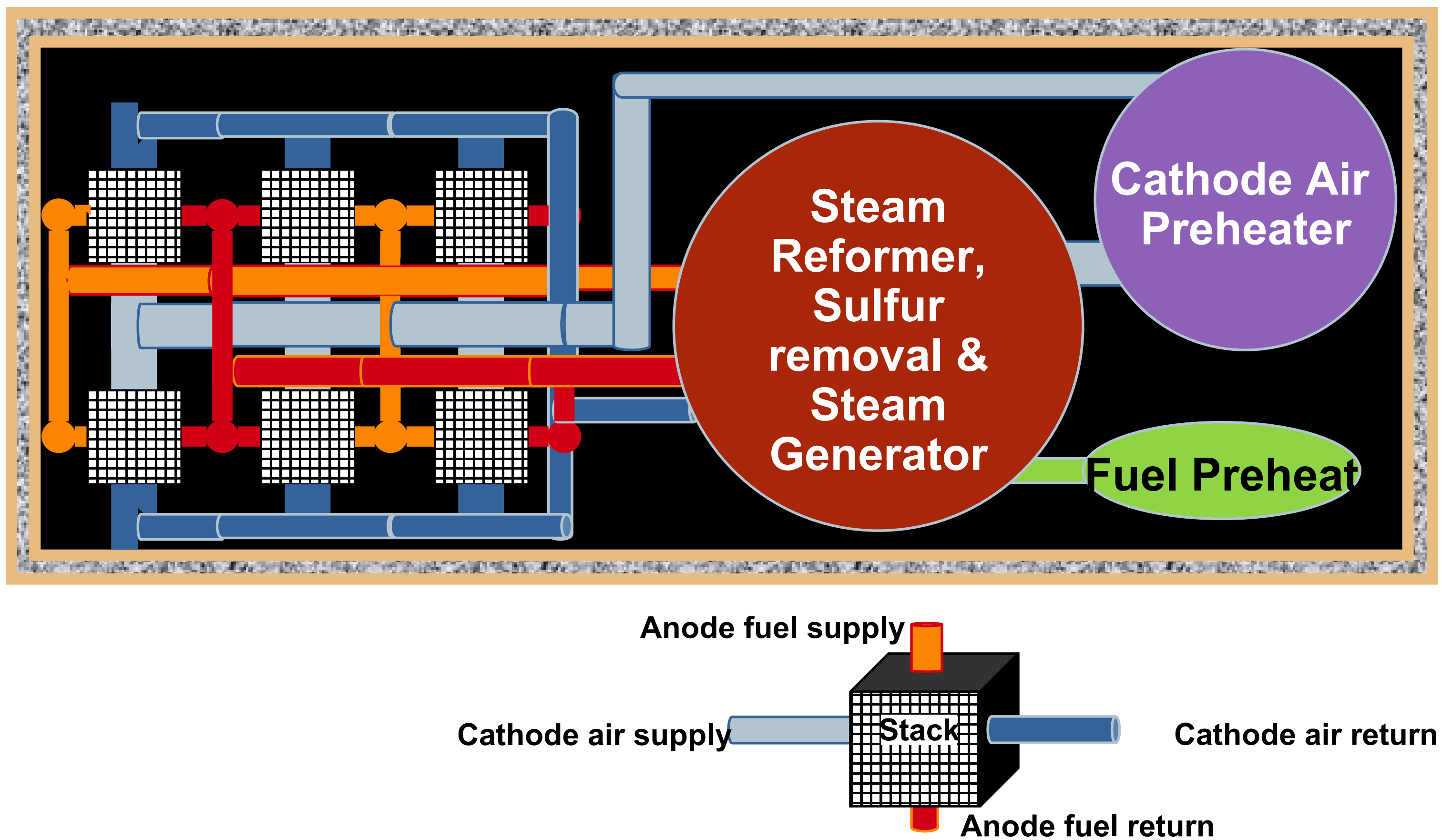
Purchased Components	Manufactured Components
◆ Air blowers	◆ Fuel cell stack
◆ Natural gas compressor	◆ Fuel cell stack hardware
◆ Water pump	◆ Fuel cell packaging
◆ Air and fuel filters	◆ Recuperators
◆ Control and solenoid valves	◆ Zinc bed
◆ Controllers for rotating equipment, processors and hardware	◆ Steam reformer
◆ Piping, fittings & connectors	**Raw Materials**
◆ Thermocouples/sensors	◆ Steel sheet
◆ Wiring for sensors & valving	◆ Metal foil
◆ Insulation (high and low temperature)	◆ Chemicals
	◆ Nickel oxides

Use of a SMR offers opportunities for tight thermal integration.



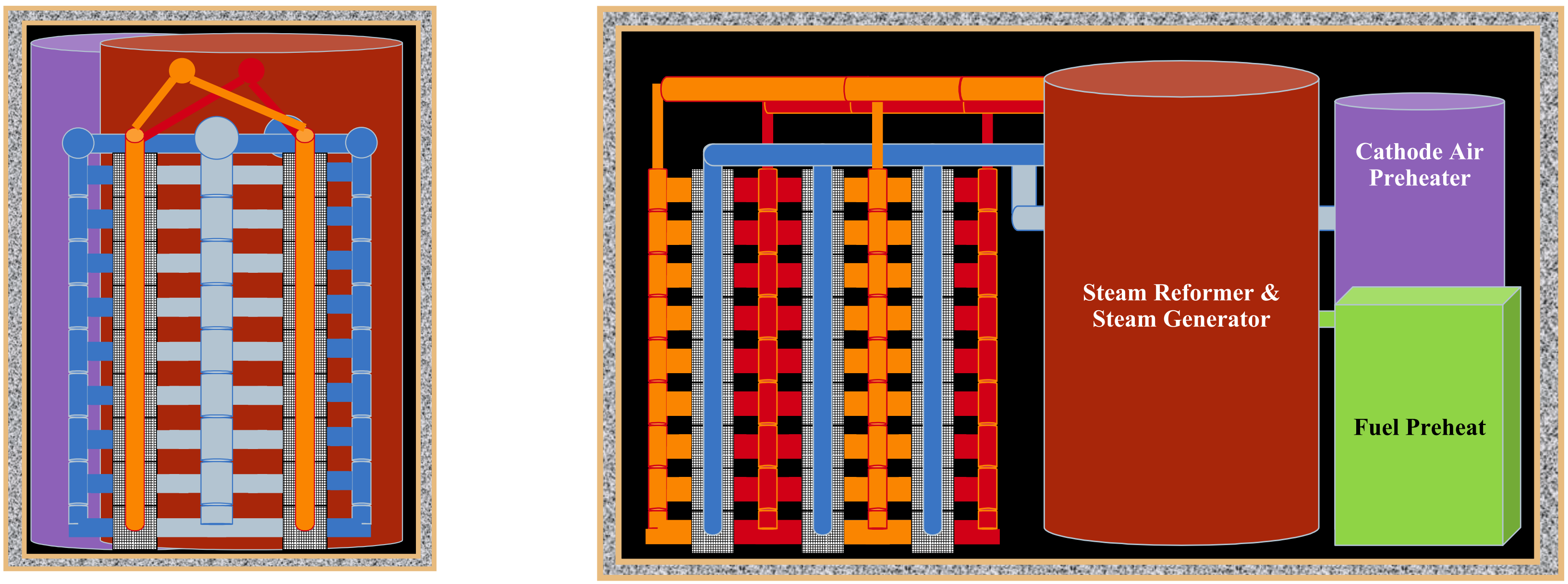
We developed a conceptual system design, to assess implications of manifolding and interconnection.

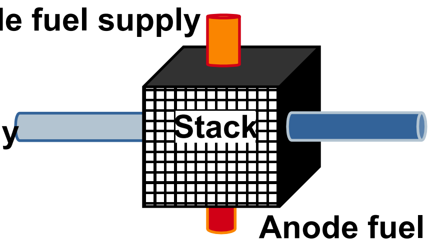
Hot Box Configuration with Rectangular Cross-Flow Cells: Top View



We limited integration to the reformer and air preheaters, to maintain reasonable access.

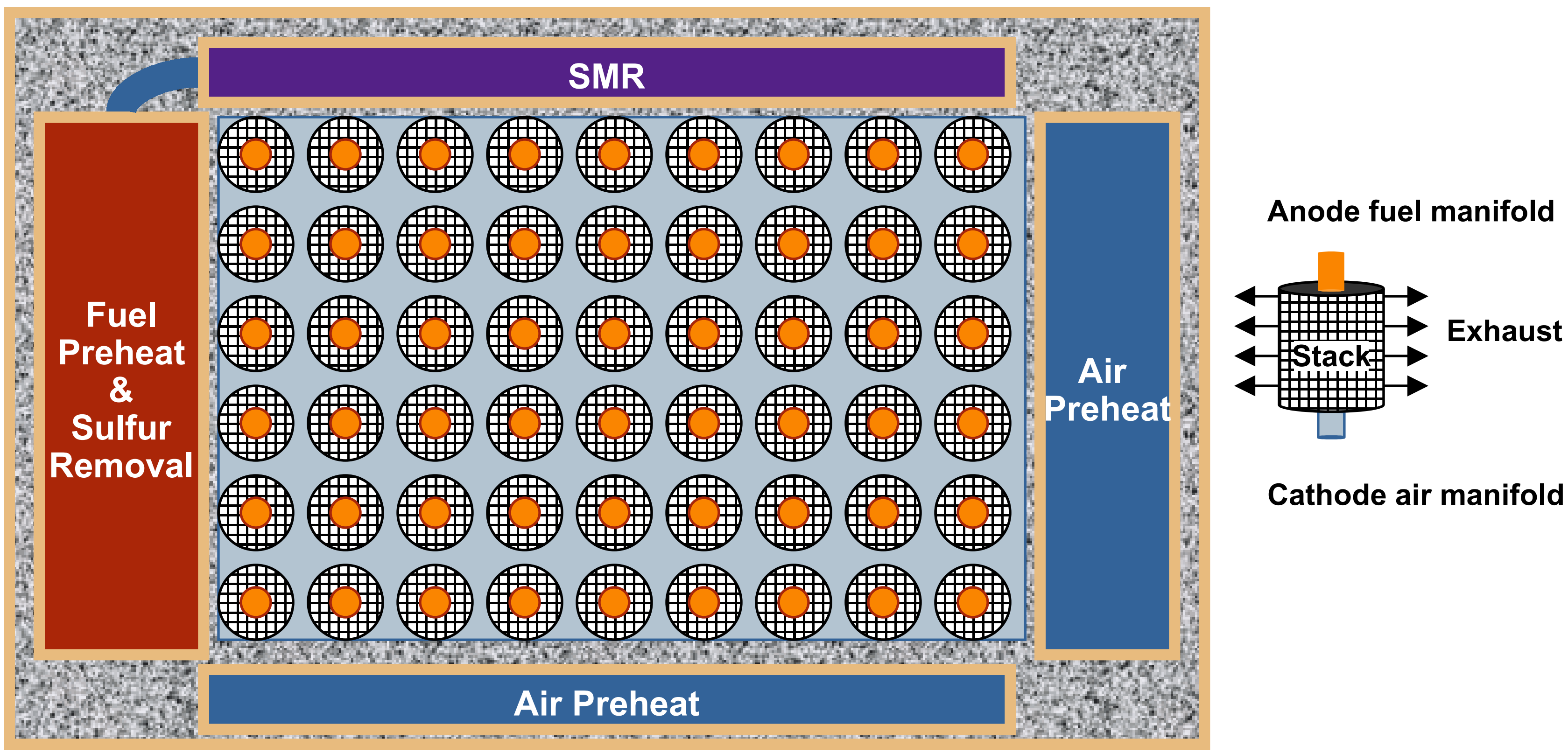
250-kW System Configuration: Side Views





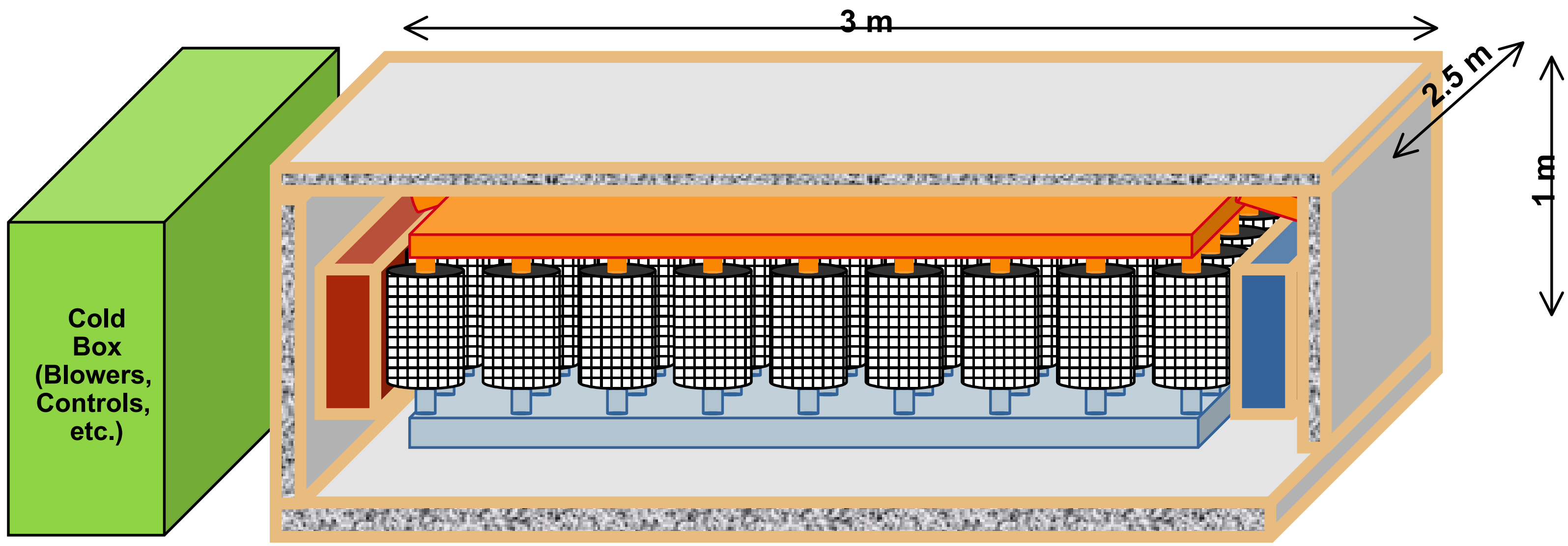
With cylindrical stacks, a simpler manifolding arrangement may be feasible...

Hot Box Configuration with Radial-Outflow Cells: Top View



… and a more compact overall design.

Hot Box Configuration with Radial-Outflow Cells: Side View

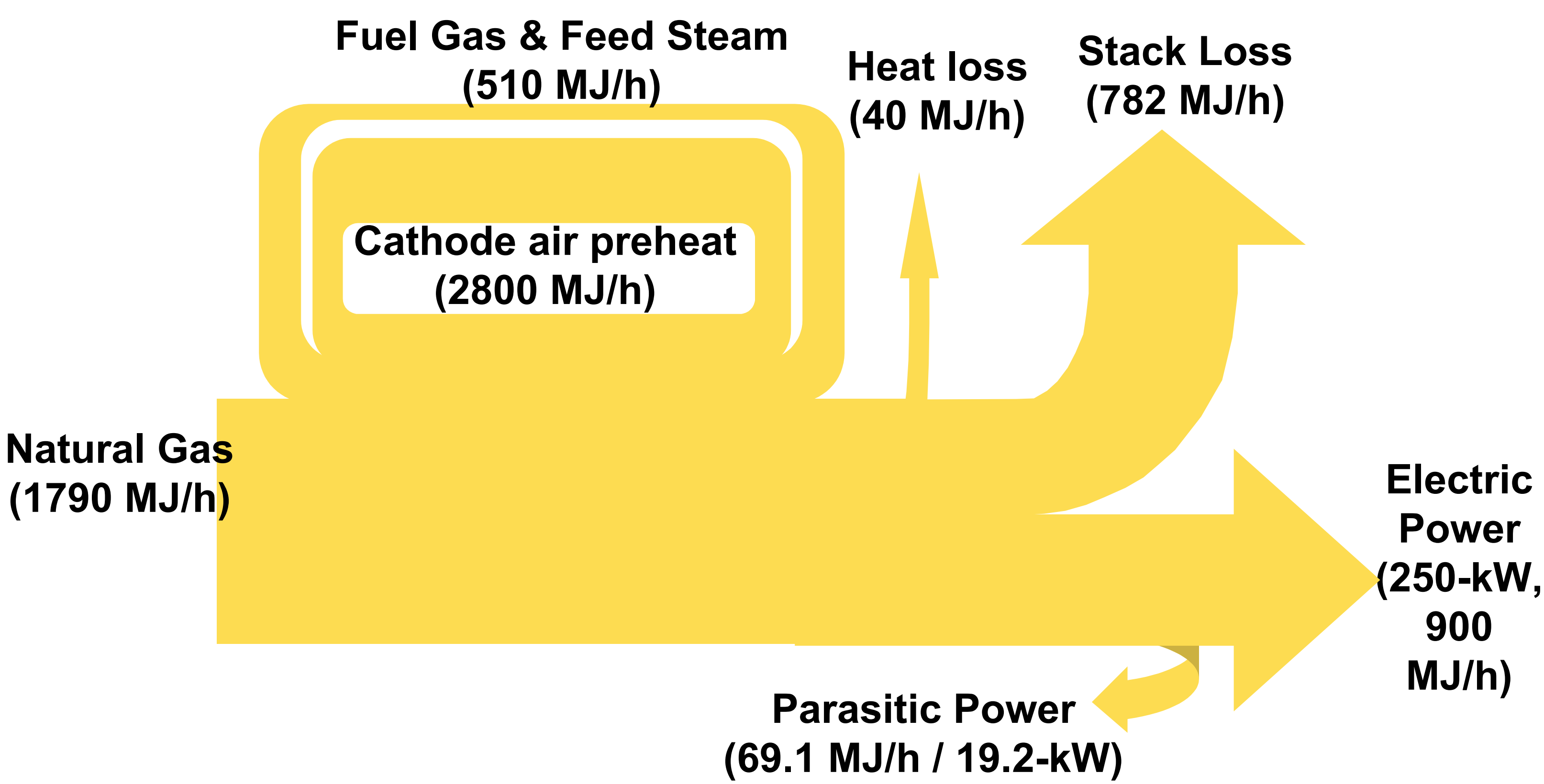


With careful thermal integration, a system efficiency of 51% can be achieved in simple-cycle configuration.

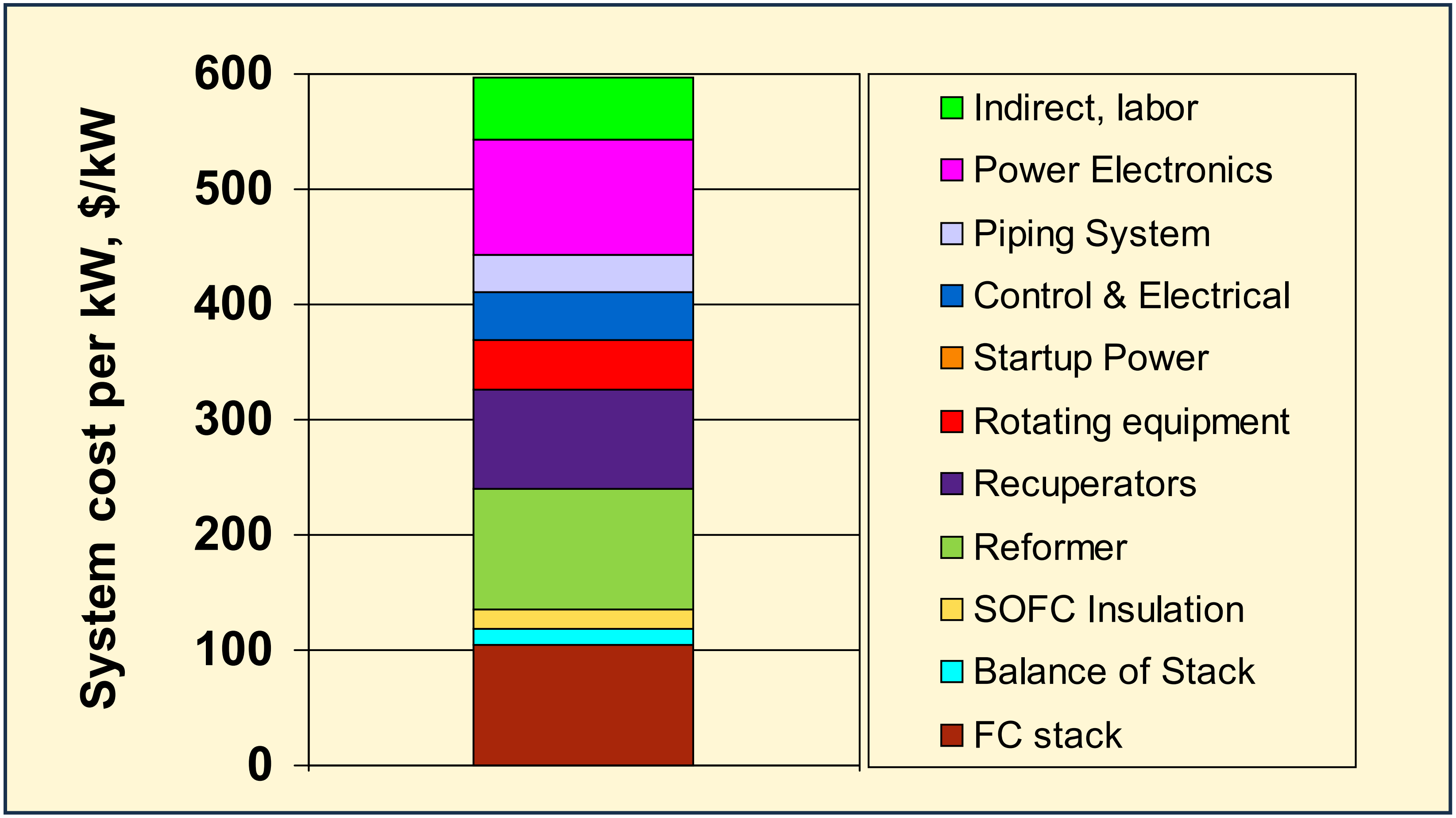
Anode Fuel Utilization	85%
Fuel Cell, Cell Voltage	0.7 V
Fuel Cell Efficiency	47.1%
Cathode Inlet Air Temperature	650ºC
Cathode Excess Air (for Cooling)	7.7 times
Blower Pressure	1.17 bar
Exhaust temperature	177 ºC
Parasitic Loads	19 kW
Required Fuel Cell gross power rating	269 kW
Resultant Overall Efficiency	51%

Extensive energy recovery from hot exhaust gas is critical to achieving high system efficiency.

Energy Flow in 250-kW SOFC system (all on LHV)



The direct manufacturing cost of the 250 kW system is estimated to be around $150,000.



Installed cost ~ $1000 / kW, CoE 5 - 9 ¢/kWh.

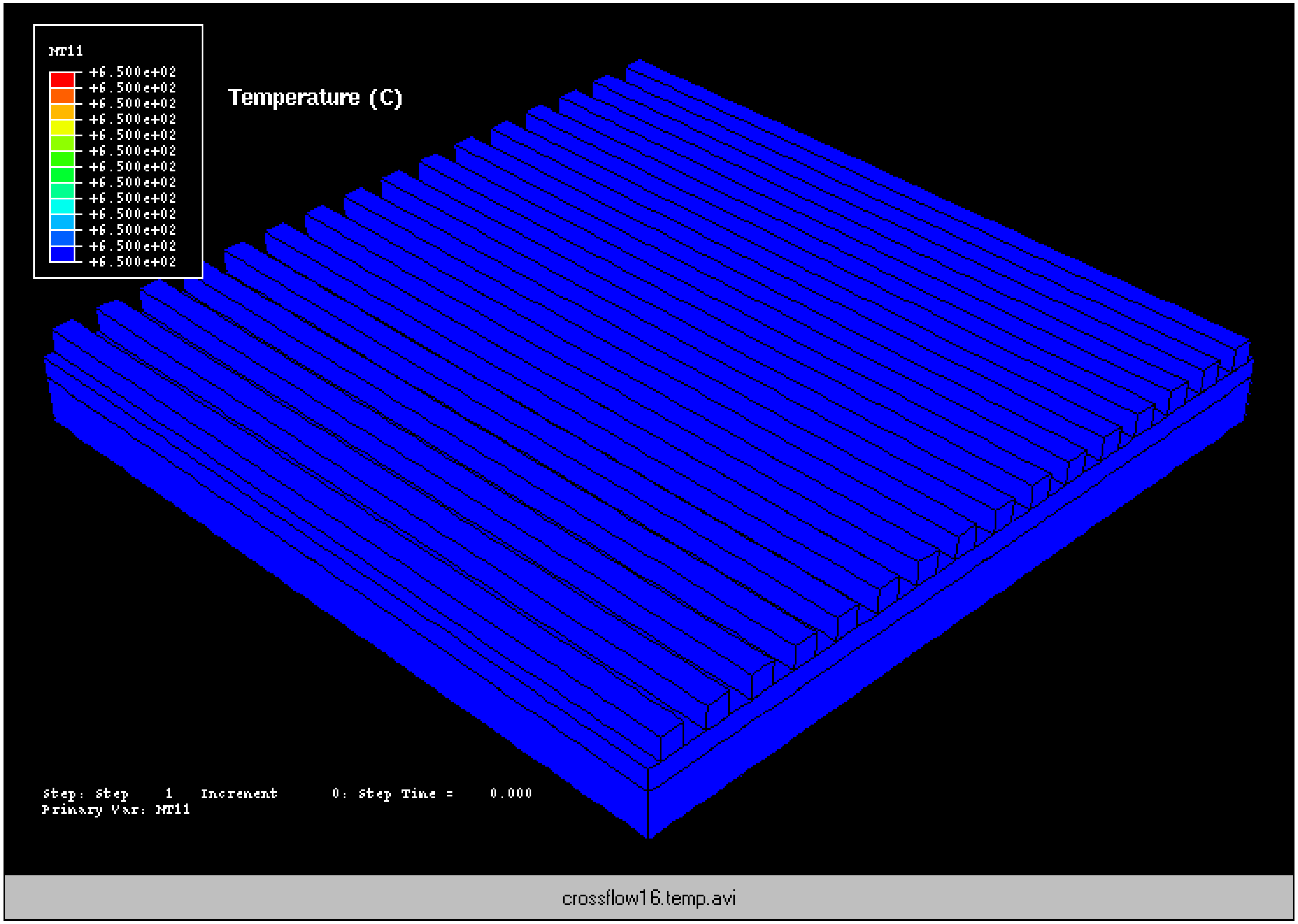
Integration of SECA modules into cost-effective high-performance larger-scale systems appears feasible.

- Integration of over fifty stacks appears feasible:
  - Several manageable configurations identified
  - Manifolding and interconnection losses acceptable
  - Cost savings in balance of plant
- High-efficiency simple-cycle plant appears feasible, and result in attractive cost
  - Lower-efficiency, lower-cost systems may be more flexible in operation and preferable in some situations
  - Combined-cycle configurations may ultimately lead to even higher efficiency
- Cost and performance would be attractive
  - In the 250 kW system, benefits of economy of scale are largely offset by lower production volumes compare to 5 kW systems

Further improvements could be made, but additional challenges must be overcome.

- Achieving projected cost and performance requires:
  - Raising power density under realistic conditions
  - Proving long life and high reliability (steady state and cycling)
  - Subsystem and component design and development
  - Achieving high manufacturing volumes (cost at intermediate production volumes may be critical to ultimate success)
- Ultimately, further system improvements could be made, mainly by improving stack performance:
  - Lower temperature operation
  - More internal reforming / direct oxidation
  - Increased stack temperature gradient
  - Larger stack tiles

SOFC GROVE™ Initial Results Temperature in 6 x 6 cm^2 cell



SOFC GROVE™ Initial Results Current Density in 6 x 6 cm^2 cell