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Topical Report

on:

***Manufacturing Cost Analysis for YSZ-Based FlexCells
at Pilot and Full Scale Production Scales***

to:

**U.S. Department of Energy
Solid-State Energy Conversion Alliance (SECA)**

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*Validation of Novel Planar Cell Design for MW-Scale SOFC Power Systems***

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Abstract

Significant reductions in cell costs must be achieved in order to realize the full commercial potential of megawatt-scale SOFC power systems. The *FlexCell* designed by NexTech Materials is a scalable SOFC technology that offers particular advantages over competitive technologies. In this updated topical report, NexTech analyzes its *FlexCell* design and fabrication process to establish manufacturing costs at both pilot scale (10 MW/year) and full-scale (250 MW/year) production levels and benchmarks this against estimated anode supported cell costs at the 250 MW scale. This analysis will show that even with conservative assumptions for yield, materials usage, and cell power density, a cost of \$35 per kilowatt can be achieved at high volume. Through advancements in cell size and membrane thickness, NexTech has identified paths for achieving cell manufacturing costs as low as \$27 per kilowatt for its *FlexCell* technology. Also in this report, NexTech analyzes the impact of raw material costs on cell cost, showing the significant increases that result if target raw material costs cannot be achieved at this volume.

Introduction

This SECA Core Technology project is aimed at advancing planar solid oxide fuel cell technology for coal-based, megawatt-scale power generation systems. It is anticipated that such systems will be comprised of a multitude of SOFC stack modules to achieve targeted power outputs. In order to increase the power output per stack module (and reduce the number of modules in the system), planar SOFC cells with large active areas will be required. NexTech Materials has established a novel electrolyte-supported planar cell design, termed the *FlexCell* (Figure 1), which offers intrinsic scalability to large areas, as well as other important performance attributes. NexTech established its *FlexCell* membrane design with scandium-stabilized zirconia (6 mol% Sc_2O_3 or ScSZ-6) as the electrolyte material. Although this composition offers an excellent combination of high ionic conductivity and high mechanical strength, its cost is expected to be prohibitive for large-scale power generation systems. This project is focused on making *FlexCell* membranes with lower-cost yttrium stabilized zirconia (YSZ) as the electrolyte material and validating manufacturability and performance capabilities of YSZ-based *FlexCells*. This topical report describes a manufacturing cost analysis that was performed for NexTech's *FlexCells*. As shown schematically in Figure 2, NexTech's manufacturing process for *FlexCells* involves the following steps:

Figure 1. Example of a *FlexCell* membrane.

- (1) Tape casting of the electrolyte tape (30 to 50 microns thick).
- (2) Multiple layers of tape are cut to size and isostatically laminated to form a green mechanical support (100 to 200 microns thick).
- (3) The resultant blank is cut using a laser cutter to produce a support mesh (with external frame).
- (4) The electrolyte layer is cut from a single tape to the same size as the support tape.

- (5) The support and electrolyte layers are isostatically laminated to form a green *FlexCell* membrane element.
- (6) The green *FlexCell* membrane is subjected to thermal treatments for binder removal and sintering.
- (7) Interfacial, active and current collecting anode layers are deposited by spraying and then annealed.
- (8) Interfacial, active and current collecting cathode layers are deposited by spraying and then annealed.

Figure 2. Schematics of the *FlexCell* architecture (left) and manufacturing process (right).

Manufacturing Cost Analysis Assumptions

For both pilot and full-scale manufacturing cost analyses, the area of YSZ-based *FlexCell* was assumed to be 500 cm², and such cells were assumed to produce 125 watts (corresponding to an active-area specific power density of 313 mW/cm²). For comparative purposes, NexTech also analyzed the manufacturing cost of anode supported cells (ASC) at the 500 MW scale, assuming a slightly higher power output of 160 watts for the same cell size. The impact of larger-area cells and higher power densities on *FlexCell* cost were also considered and are presented later in the cost sensitivity analysis section. A production yield of 90 percent was used in both cases in the initial topical report, requiring daily production volumes of 352 and 6,197 cells at the 10 MW and 250 MW per year volumes, respectively, and sensitivity analysis was conducted at 98 percent yield in the full scale production case. In this updated analysis, we are assuming

a manufacturing yield of 98 percent at 250 MW per year, for both the FlexCell and ASC technologies, consistent with similar high volume ceramic based products such as multilayer capacitors and planar oxygen sensors. A five-day single-shift operation was assumed for the pilot scale, with furnaces running continuously seven days per week. A seven-day three-shift operation was assumed at full scale. From these assumptions, annual and daily *FlexCell* production demands were calculated for the two production scales, as shown in Tables 1 and 2.

Table 1: Pilot-scale cost analysis assumptions		
Assumption	Value	Units
Annual plant capacity	10	MW
Operation time (per week)	5	days
Operation time (per day)	8	hours
Total cell area	500	cm ²
Active cell area	400	cm ²
Area-specific power density	0.313	W/cm ²
Power output per cell	125	Watts
Cells per year (required)	80,000	cells
Cells per year (90% yield)	88,000	cells
Cells per day (90% yield)	352	cells

Table 2: Full-scale cost analysis assumptions		
Assumption	Value	Units
Annual Plant Capacity	250	MW
Operation time (per week)	7	days
Operation time (per day)	24	hours
Total cell area	500	cm ²
Active cell area	400	cm ²
Area-specific power density	0.313	W/cm ²
Power output per cell	125	Watts
Cells per year (required)	2,000,000	cells
Cells per year (98% yield)	2,040,000	cells
Cells per day (98% yield)	5746	cells

FlexCell Manufacturing Costs at Pilot-Scale Production Volume

NexTech considered a 10 MW per year production volume for its pilot scale cost analysis. To achieve this production volume, 352 cells must be fabricated every day of a 5-day workweek, assuming a 90% production yield. From this daily demand, equipment capacity requirements were determined for each unit operation of the *FlexCell* manufacturing process. The production process was separated into two general steps: (1) fabrication of the YSZ electrolyte membrane; and (2) deposition of electrodes onto the YSZ membranes. Value stream maps for each of these *FlexCell* production steps are shown in Figures 1 and 2. Capital investment equipment and labor requirements for each unit operation, identified in the value stream maps, are detailed in Table 3.

Figure 1. Electrolyte fabrication value stream map.

Figure 2. Electrode deposition value stream map.

In the pilot line cost analysis, a time frame of five years was used to calculate the depreciation of assets. A direct labor rate of \$17.50 per hour for pilot-line operators was used in the labor calculations. At this 10 MW/year scale, the fabrication of large-area *FlexCells* is labor intensive. Many unit operations, such as cutting and stacking of electrolyte tapes, are highly manual at this scale. Labor cost, therefore, is a major contributor of the total cell manufacturing cost. The raw material cost estimates were based on the current fabrication and labor involved in acquiring these materials at the pilot scale. Raw material costs at the 10 MW/year scale are given in Table 4.

It is also important to note that these raw material costs have been updated to comprehend recent improvements in cell design. As discussed in the latest quarterly report, NexTech has focused efforts recently on optimizing the cathode architecture of its FlexCell for improved cell performance and long term stability. By increasing the thickness of both its cathode inner layer and outer current collector layer, a 3-fold improvement in degradation rates has been demonstrated.

Table 3. Capital equipment and labor requirements at 10 MW/year scale.			
Manufacturing Operation	Capital Equipment	Labor (FTE's)	Labor Cost
<i>Electrolyte Fabrication</i>			
Clean Room	\$600,000	-	-
Prepare Tape Slurries	\$20,000	0.25	\$26,000
Cast Tape	\$258,000	0.60	\$62,400
Cut and Stack Layers	\$290,000	2.60	\$270,400
Sinter electrolyte	\$1,000,000	0.20	\$20,800
<i>Electrode Deposition</i>			
Anode Deposition	\$166,000	1.25	\$130,000
Dry Anode	\$20,000	0.50	\$52,000
Sinter Anode	\$700,000	0.10	\$10,400
Cathode Deposition	\$203,000	1.25	\$130,000
Dry Cathode	\$20,000	0.50	\$52,000
Sinter Cathode	\$500,000	0.10	\$10,400
Total	\$3,777,000	7.35	\$764,400

Table 4. Raw material costs at pilot-line production volume (10 MW/year).	
Material	\$/cell
Cathode materials (LSCF-based)	\$1.22
Cathode inner layer materials (ceria-based)	\$0.72
Anode materials (Ni-Co/ceria-based)	\$4.16
Electrolyte materials (YSZ-based)	\$5.11
Direct Supplies (Mylar, etc.)	\$3.90
Total	\$15.11

From these cost estimates, an updated total cell manufacturing cost of \$41.50 per cell (\$365 per kW) was estimated, as shown in Table 5. The main contributors to this cost are the raw materials for the cell, depreciation of capital equipment, and operating labor. At the full-scale production level, these factors will be greatly reduced due to the increased level of automation that will be implemented.

Table 5. Breakdown of <i>FlexCell</i> production costs at 10 MW/year scale.			
Contribution to Cost	Yearly Cost	Cost Per Cell	Cost Per kW
Raw Materials	\$1,329,874	\$15.11	\$132.99
Depreciation	\$943,041	\$10.72	\$94.30
Operating Labor	\$772,873	\$8.69	\$76.44
Utilities	\$355,688	\$4.24	\$37.29
Operating Supplies	\$132,987	\$1.51	\$13.30
Local Taxes	\$58,940	\$0.67	\$5.89
Maintenance & Repairs	\$26,597	\$0.30	\$2.66
Insurance	\$23,576	\$0.27	\$2.36
Total	\$3,652,290	\$41.50	\$365.23

FlexCell Manufacturing Costs at Full-Scale Production Volume

At the 250 MW/year volume level, the work week will be increased to a seven-day, three-shift operation to maximize capacity of the highly automated manufacturing equipment. Continuous tunnel kilns will be used for all firing operations in order to achieve the demanding cycle times and capacity requirements at such volumes. A gas-fired tunnel kiln will be used for sintering electrolyte substrates, while electrically heated kilns will be used for firing electrodes. The capital equipment cost needed for the full-scale (250 MW) *FlexCell* production facility is given in Table 6, based on values obtained from vendor surveys and quotations. Where necessary, equipment costs were estimated by scaling up the cost and throughput quotes for pilot-plant production equipment (Table 6). Such equipment will likely require customization in order to meet the process, quality control, and capacity requirements at this volume level, and was also considered in the cost estimates.

In this updated analysis, we re-evaluated the overall process and requirements for the clean room, since this represents the highest cost piece of capital equipment. Through discussions with equipment vendors, identified solutions to significantly reduce the overall size requirement of the clean room. The tape casters, for example will be fully enclosed, only requiring clean room chambers on the slurry hopping

(front end of the tape caster) and take-up rolls (back end of the tape caster). Through these design and layout modifications, the cost estimate for the clean room was reduced from \$12M to \$3M, lowering the cell cost by approximately \$5 per kilowatt under the assumed amortization schedule.

At this volume, the direct labor rate was reduced to \$15/hour based on the difference in skill sets required in this highly automated production process. The overhead rate was reduced to 75%, typical of a high volume production facility. The fixed capital investment, based on the direct and indirect costs for building the full-scale production plant, comprehends the land, building, equipment, and labor necessary for the plant to be operational. A breakdown of the fixed capital investment is given in Table 7.

Table 6. Capital equipment and labor requirements at 250 MW/year scale.			
Manufacturing Operation	Capital Equipment	Labor (FTE's)	Labor Cost
<i>Electrolyte Fabrication</i>			
Clean Room	\$3,000,000	-	-
Prepare Tape Slurries	\$20,000	0.25	\$73,357
Cast Tape	\$160,000	0.25	\$73,357
Cut and Stack Layers	\$500,000	1.00	\$293,429
Laminate	\$500,000	0.25	\$73,357
Final cut	\$1,250,000	0.25	\$73,357
Sinter electrolyte	\$6,400,000	0.05	\$14,671
<i>Deposit Electrodes</i>			
Anode Deposition/Dry	\$1,780,000	2.00	\$586,858
Sinter Anode	\$2,000,000	0.10	\$29,343
Cathode Deposition/Dry	\$890,000	2.00	\$586,858
Sinter Cathode	\$1,750,000	0.10	\$29,343
Totals	\$18,250,000	6.25	\$1,833,930

The raw material costs for the full-scale production plant were based on high volume estimates and raw material costs provided by SECA. The raw material costs for full-scale production are given in Table 8. Later in this report, we present sensitivity analysis at higher raw material pricing, assessing the impact on cost if SECA cost targets cannot be achieved for YSZ, Ni, LSCF, and other key cell raw materials. As discussed in the pilot scale manufacturing scenarios, raw material costs were updated to comprehend the thicker cathode layers, optimized for improved cell performance and long term stability. The raw material costs in Table 8 have been updated to include these greater materials volume per cell.

Table 8. Raw material costs at full-scale production volume (250 MW/year).	
Material	\$/cell
Cathode materials (LSCF-based)	\$0.13
Cathode inner layer materials (ceria-based)	\$0.17
Anode materials (Ni/Co/ceria-based)	\$0.61
Electrolyte materials (YSZ-based)	\$0.44
Total	\$1.34

Using the above-described costs, along with an asset depreciation range of 15 years and bulk raw material costs provided by SECA, an updated cost estimate of \$35.47 per kW is estimated (Table 9). Increased automation within the production line greatly reduced the labor cost for the fabrication of these YSZ-based *FlexCells* over the pilot scale cost model. Although raw material costs increased due to the increased cathode material usage, the impact of the clean room cost reduction more than offset this. Moving from a batch process to continuous firing and continuous spray deposition of electrodes also substantially reduced operating costs.

Table 7: Fixed capital investment at 250 MW/year scale.	
Cost Category	Estimated Cost
<i>Direct Costs</i>	
Purchased Equipment	\$18,250,000
Installation	\$4,562,500
Instrumentation and Controls	\$2,737,500
Piping	\$1,825,000
Electrical	\$3,650,000
Buildings	\$4,562,500
Service Facilities	\$7,300,000
Land	\$730,000
<i>Total Direct Costs</i>	<i>\$43,617,500</i>
<i>Indirect Costs</i>	
Engineering and Supervision	\$4,361,750
Construction Expenses	\$4,361,750
<i>Total Indirect Costs</i>	<i>\$8,723,500</i>
<i>Working Capital</i>	<i>\$1,825,000</i>
Total Fixed Capital Investment	\$54,166,000

Table 9. Breakdown of <i>FlexCell</i> production costs at 250 MW/year scale.			
Cost Category	Yearly Cost	Cost Per Cell	Cost Per kW
Raw Materials	2,735,977.27	1.34	10.94
Depreciation	2,031,225.00	1.00	8.12
Operating Labor	1,833,930.00	0.90	7.34
Utilities	904,973.81	0.44	3.62
Operating Supplies	547,195.45	0.27	2.19
Local Taxes	541,660.00	0.27	2.17
Maintenance & Repairs	54,719.55	0.03	0.22
Insurance	216,664.00	0.11	0.87
Total	\$8,866,345	\$4.35	\$35.47

Anode Supported Cell Cost Analysis (250 MW Scale)

For benchmarking against its electrolyte supported *FlexCell* technology, NexTech also analyzed the manufacturing cost of anode supported cells. In a recent DOE funded SBIR project (Contract Number DE-SC0004845), NexTech analyzed the manufacturing cost of anode supported cells at the 500 MW production scale. In this project, we modified that model to estimate manufacturing cost at the 250 MW scale to enable direct comparison to the estimated *FlexCell* cost at that volume.

Similar assumptions were used for cell size (500 cm² total area, 400 cm² active area), work schedule (7-day, 3-shift operation), labor rate (\$15 per hour), overhead rate (75%), and production yield (98%). A slightly higher power output of 160 watts was assumed, reducing the cell production requirement to 4,491 per day. The unit operations and process flow assumed in the ASC manufacturing cost analysis is shown in Figure 3. From this, equipment and labor requirements were determined. Using SECA-provided raw materials costs, where available, and the same depreciation schedule used in the FlexCell cost model, a manufacturing cost estimate of \$33.94 per kW was determined for anode supported cells (see Table 10).

Figure 3. Anode Supported Cell manufacturing process at 250 MW scale production

Table 10. Breakdown of ASC production costs at 250 MW/year scale.			
Cost Category	Yearly Cost	Cost Per Cell	Cost Per kW
Raw Materials	2,454,865.28	1.57	9.82
Depreciation	2,031,225.00	1.30	8.12
Operating Labor	1,833,930.00	1.17	7.34
Utilities	866,867.52	0.55	3.47
Operating Supplies	490,973.06	0.31	1.96
Local Taxes	541,660.00	0.35	2.17
Maintenance & Repairs	49,097.31	0.03	0.20
Insurance	216,664.00	0.14	0.87
Total	\$8,485,282	\$5.43	\$33.94

Opportunities for Cost Reduction and Sensitivity Analysis

In the initial topical report, NexTech identified several opportunities for further reducing the estimated *FlexCell* price. Some of these included: cell size, thickness, active area, power density, and manufacturing yield. In Tables 11 – 13, NexTech updated this sensitivity analysis to include the modifications discussed previously, including the reduced clean room cost assumption and thicker cathode prints. For reference, the baseline cost analysis, detailed above, is provided in the first row of Table 11, at the 90% and 98% yield scenarios.

As discussed in the first Topical Report, membrane thickness has the greatest impact on cell cost due primarily to the expected improvement in area-specific power density. Comparing rows one and three, a \$4/kW cost reduction is anticipated by reducing the membrane from 32 to 24 microns and the support from 160 to 80 microns. A decrease in support thickness alone, from 160 to 120 microns only marginally affects cell cost. NexTech has fabricated and tested *FlexCells* of such thin dimensions successfully. Evaluation of mechanical integrity for meeting durability requirements is in progress with support from the Ohio State modeling team.

In Table 11, we also consider the impact of the support architecture (i.e., the relative percentage of thin membrane area to the total active area of the cell). By changing this ratio from 62 percent to 70 percent, a modest reduction in cell cost can be realized (\$1/kW). As shown in the last row of Table 11, cell costs of \$31/kW can be achieved at the 500 cm² cell size if these improvements can be implemented.

The scalability of the *FlexCell* technology allows us to consider cells substantially larger than the 500 cm² assumed in the baseline cost analysis. NexTech has successfully fabricated *FlexCells* as large as 1200 cm². In Tables 12 and 13, we consider the effect of cell size on manufacturing cost at 650 and 800 cm², respectively. If a fixed sealing width around the cell perimeter is assumed, the active area of the cell increases as a percentage of total cell size. Using the same power densities and yields as those considered at the 500 cm² size, this greater active area results in further cell cost reductions. At the 650 cm² cell size, an ultimate cell cost of \$28/kW can be achieved, while this is further reduced to \$27/kW at 800 cm² cell area.

Table 11. Cost reduction opportunities for *FlexCells* with 500-cm² area.

Support/Membrane Thicknesses (microns)	Percent Thin Membrane in Active Area	Ratio of Active Cell Area to Total Area	Expected Power Density	Cells /day (90% yield)	Cell cost (90% yield)	Cells/day (98% yield)	Cell cost (98% yield)
160 / 32	62%	80%	313 mW/cm ²	6,198	\$36.63/kW	5,746	\$35.47/kW
120 / 32	62%	80%	325 mW/cm ²	5,959	\$35.19/kW	5,526	\$34.14/kW
80 / 24	62%	80%	375 mW/cm ²	5,165	\$32.17/kW	4,789	\$31.33/kW
160 / 32	70%	80%	325 mW/cm ²	5,959	\$35.32/kW	5,526	\$34.26/kW
120 / 32	70%	80%	337 mW/cm ²	5,739	\$34.18/kW	5,321	\$33.19/kW
80 / 24	70%	80%	387 mW/cm ²	5,004	\$31.54/kW	4,640	\$30.73/kW

Table 12. Cost reduction opportunities for *FlexCells* with 650-cm² area.

Support/Membrane Thicknesses (microns)	Percent Thin Membrane in Active Area	Ratio of Active Cell Area to Total Area	Expected Power Density	Cells /day (90% yield)	Cell cost (90% yield)	Cells/day (98% yield)	Cell cost (98% yield)
160 / 32	65%	85%	312 mW/cm ²	4,487	\$33.34/kW	4,160	\$32.42/kW
120 / 32	65%	85%	325 mW/cm ²	4,314	\$32.08/kW	4,000	\$31.25/kW
80 / 24	65%	85%	375 mW/cm ²	3,739	\$29.54/kW	3,467	\$28.89/kW
160 / 32	70%	85%	325 mW/cm ²	4,314	\$32.20/kW	4,000	\$31.36/kW
120 / 32	70%	85%	337 mW/cm ²	4,160	\$31.21/kW	3,858	\$30.44/kW
80 / 24	70%	85%	387 mW/cm ²	3,623	\$28.99/kW	3,359	\$28.38/kW

Table 13. Cost reduction opportunities for *FlexCells* with 800-cm² area.

Support/Membrane Thicknesses (microns)	Percent Thin Membrane in Active Area	Ratio of Active Cell Area to Total Area	Expected Power Density	Cells /day (90% yield)	Cell cost (90% yield)	Cells/day (98% yield)	Cell cost (98% yield)
160 / 32	62%	90%	312 mW/cm ²	3,443	\$31.25/kW	3,192	\$30.48/kW
120 / 32	62%	90%	325 mW/cm ²	3,310	\$30.11/kW	3,070	\$29.43/kW
80 / 24	62%	90%	375 mW/cm ²	2,869	\$27.89/kW	2,660	\$27.36/kW
160 / 32	70%	90%	325 mW/cm ²	3,310	\$30.23/kW	3,070	\$29.53/kW
120 / 32	70%	90%	350 mW/cm ²	3,193	\$29.33/kW	2,960	\$28.70/kW
80 / 24	70%	90%	400 mW/cm ²	2,780	\$27.41/kW	2,578	\$26.91/kW

At the 250 MW production scale, raw material costs are the largest contribution to total manufacturing cost, as shown previously in Table 9 for *FlexCells* and Table 10 for anode supported cells. In NexTech's analysis, SECA raw material costs were used where available; elsewhere, current manufacturing costs were used with reductions made for high volume scaling (summarized in Table 14).

Table 14. Raw Material Costs Used in Analysis	
Raw Material	Cost (\$/kg)
GDC	\$60
LSF	\$10
LSM	\$12
LSZF	\$25
NiO	\$8
YSZ (8 mol% Y ₂ O ₃)	\$10
YSZ (3 mol% Y ₂ O ₃)	\$10
YSZ-NiO Ink	\$34
GDC-NiO	\$55
LSF	\$10
LSM - GDC	\$45
LSZF-GDC	\$45

Several of these raw materials currently are significantly higher than those presented in Table 14. Specifically, GDC, LSZF, NiO, and YSZ represent the greatest risk to the estimated costs if these high volume costs are not realized. In Table 15, the impact on *FlexCell* manufacturing cost was analyzed under scenarios in which costs of each of these materials was higher than that assumed in the analysis. Costs were based on vendor quotes at 250MW scale volumes for YSZ and NiO, and scaling assumptions using current NexTech manufacturing costs. In all cases, the baseline cell configuration (32 micron thick membrane, 160 micron thick support) was used, yielding an estimated cost of \$35.47/kW. This value is provided in the first row of Table 15 for reference.

As Table 15 shows, YSZ cost has the greatest impact on total cell manufacturing cost, due to the amount of YSZ used in the electrolyte support and membrane. An increase in YSZ cost from the \$10/kg value provided by SECA to those shown in Table 14 results in an 82% increase in cell cost. Higher LSZF and GDC costs also significantly impact cell cost, yielding a 24% and 21% increase in cell manufacturing cost, respectively. Combining all of these higher cost values, yields an estimated cell manufacturing cost of \$83.64, a factor of 2.3 higher than that estimated with the raw material costs presented in Table 9. Efforts must, therefore, focus on reducing raw material costs in order to achieve cell cost targets.

Similarly, NexTech analyzed the impact of these higher raw material costs on anode supported cell manufacturing cost (see Table 16). While the estimated cell cost is slightly lower than the FlexCell using SECA-provided raw material costs, this materials sensitivity analysis shows that the ASC is at risk of substantially higher manufacturing cost if these raw material cost targets are not achieved. As Table 16 shows, an increase in NiO to \$53 per kg would result in a cell cost of \$83 per kilowatt. Combining all higher raw material cost values presented in Table 14 would result in an ASC cost of \$93 per kilowatt.

Table 15. Impact of Raw Material Costs on <i>FlexCell</i> Manufacturing Cost Estimate			
Material	Higher Cost Assumption (\$/kg)	Raw Material Costs (\$/cell)	Cell Cost (98% yield) (\$/kW)
--	--	\$1.34	\$35.47
GDC	\$218	\$2.00	\$42.80
LSZF	\$99	\$2.11	\$43.92
NiO	\$53	\$1.44	\$36.57
YSZ-3 YSZ-8	\$67 \$71	\$3.98	\$64.63
All of above	listed above	\$5.68	\$83.46

Table 16. Impact of Raw Material Costs on Anode Supported Cell Manufacturing Cost Estimate			
Material	Higher Cost Assumption (\$/kg)	Raw Material Costs (\$/cell)	Cell Cost (98% yield) (\$/kW)
--	--	\$1.54	\$33.94
GDC	\$218	\$2.05	\$38.34
LSZF	\$99	\$2.34	\$40.85
NiO	\$53	\$7.29	\$83.63
YSZ-3	\$67	\$1.88	\$36.89
All of above	listed above	\$8.43	\$93.48