Fuel Cells – Turn up the Heat!

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Agenda

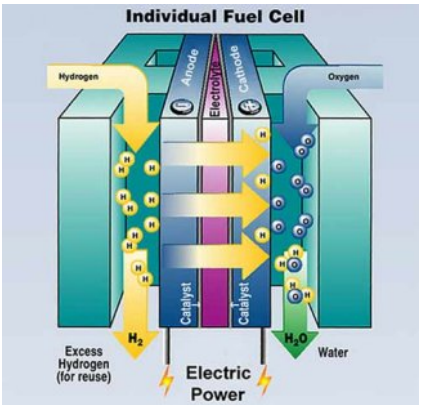
- Introduction
- Fuel Cell Background
- Cost Research Methodology
- Data Collection and Normalization
- Data Analysis
- Application
- Conclusions

Introduction

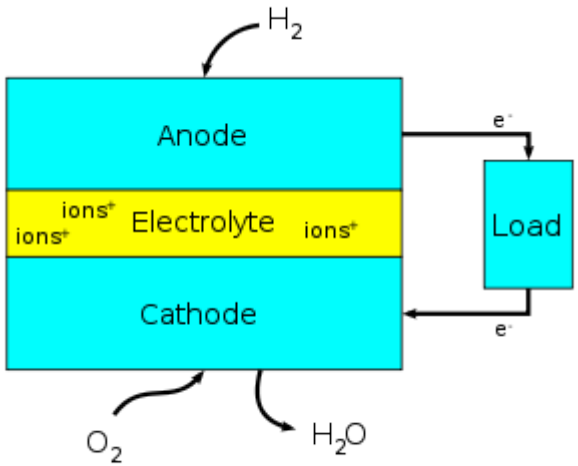
- Fuel Cells
  - Technology around since the 1800's
  - 1960's – used by NASA space program for extended life power delivery
  - Current focus on green technologies has increased interest in commercial applications
  - Applications include
    - Power supply – stationary, backup, portable
    - Transportation – material handling, automotive, bus
- While fuel cell costs are decreasing annually (2-15% y/y) they continue to be a high cost option in many situations

What is a Fuel Cell?

- Electrochemical cell that coverts fuel into electric current
- Waste products include water, heat and/or carbon dioxide
- Electricity is created through a reaction between a fuel and an oxidant in the presence of a catalyst
- As long as there is a continuous supply of fuel, the cell will continue to produce current – no recharging



What is a Fuel Cel?



- Catalyst is used at the anode to oxidize the fuel creating positively charged ions and negatively charged electrons
- Electrolyte allows the ions to pass but rejects the electrons
- Electrons travel through the wire creating electric current
- Electrons rejoin ions in the cathode where another chemical reaction occurs to create water and/or carbon dioxide
- Multiple fuel cells can be connected in parallel or serial to deliver required electricity

Cost Research Methodology

- Goal of the study was to create credible defendable Cost Estimating Relationships (CERs) with publically available data
- Fuel cells seemed a good target for such a study
- Study limited to the following types of fuel cell systems
  - Backup Power
  - Stationary Power
  - Material Handling Power
  - Portable Power

Cost Research Methodology

- Price rather than cost data was collected through search of on-line catalogs, research papers, magazine articles and press releases
- Additional technical data was collected for each system
- Normalization process applied to derive a first piece cost from the price data
- Cost drivers were identified and regression techniques were applied to develop CERs
- CERs were implemented as cost objects in the TruePlanning ® framework

Data Collection

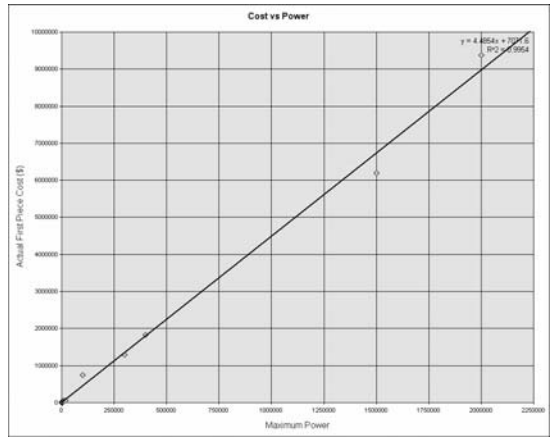
- Substance used for the electrolyte is what defines the type of fuel cell. Data on the following fuel cells was collected for this study:
  - Proton exchange membrane fuel cells (PEMFC)
    - Low temperature range, good power-weight ratio, used in stationary and portable applications
  - Reformed methanol fuel cells (RMFC)
    - Subset of PEMFC uses methanol reformed to hydrogen, small, high temperature, well suited for portable applications
  - Molton carbonate fuel cells (MCFC)
    - High temperature. More efficient than PEMFC, mostly stationary apps
  - Solid oxide fuel cells (SOFC)
    - Very high temperatures, don't require pure hydrogen, stationary and auxiliary power apps
  - Phosphorous oxide fuel cells (PAFC)
    - Less powerful than many other types., requiring larger stacks, mostly stationary apps, buses

Data Normalization

- Process to arrive at a first piece cost from the selling price
  1. Price was converted from base year to 2010 using PRICE Escalation rates
  2. A markup was applied based on an assumed level of production to get unit cost in 2010 dollars
  3. For fuel cell developments done prior to 2010, an adjustment to account for the confirmed fact that fuel cell technology has been improving year to year for all types of applications (2% for stationary, 15% for portable)
  4. Made an adjustment for operating specification so all costs were aligned to a commercial environment (the majority were commercial)
  5. Based on production quantity assumption backed out learning curve to get to a first piece
- Additional normalization required converting kg to lbs and all power to Watts

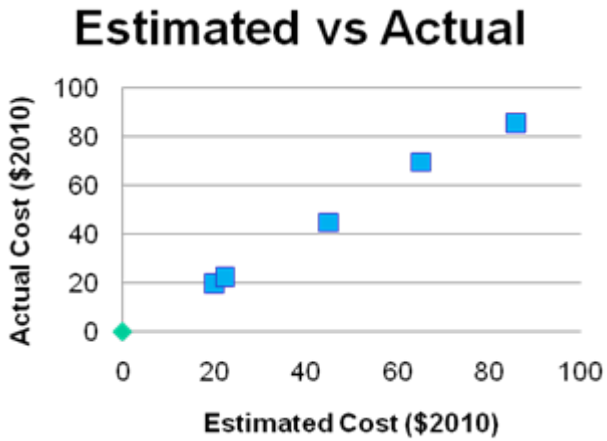
Data Analysis

- Significant cost drivers
  - Type of fuel cell system
  - Fuel cell type
  - Power rating



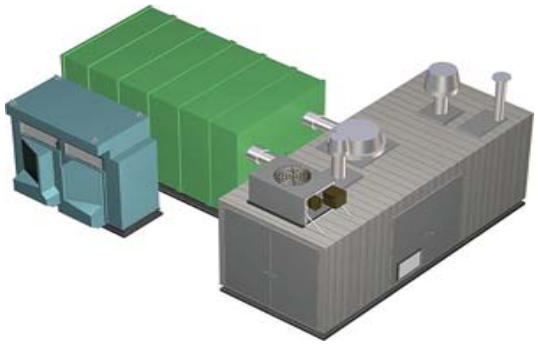
- In most cases weight was directly correlated to power delivered (within each system type) so it adds little value to the relationship
- Not all fuel cell types were equally represented across the data set

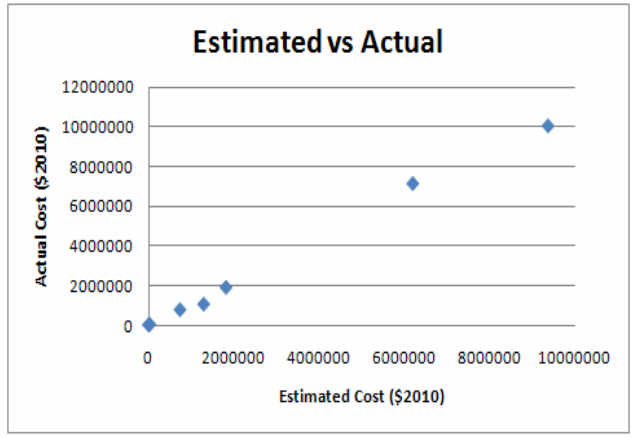
Data Analysis – Portable Power System



System	Power	Fuel Cell Type	First Piece Cost (2010$)	Estimated First Piece Cost (2010$)	GSRQ (r^2)	R^2	adj R^2	StdErr
Ultracell xx25	25	RMFC	3983	3714	0.995924498	0.987943	0.983924	506.6854
Ultracell xx55	50	RMFC	10394	9694				
Jadoo Power Ngen	100	PEMFC	1828	1674				
Trulite KH4	250	PEMFC	2229	2636				
Medis technology Power pack	1	PEMFC	50	183				

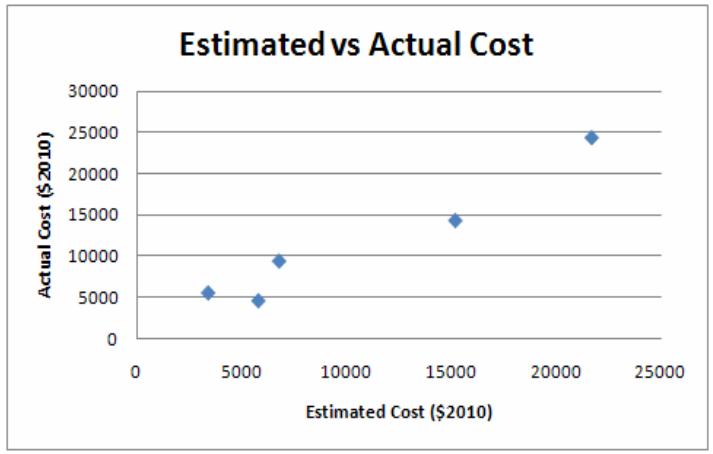
Data Analysis – Stationary Power System





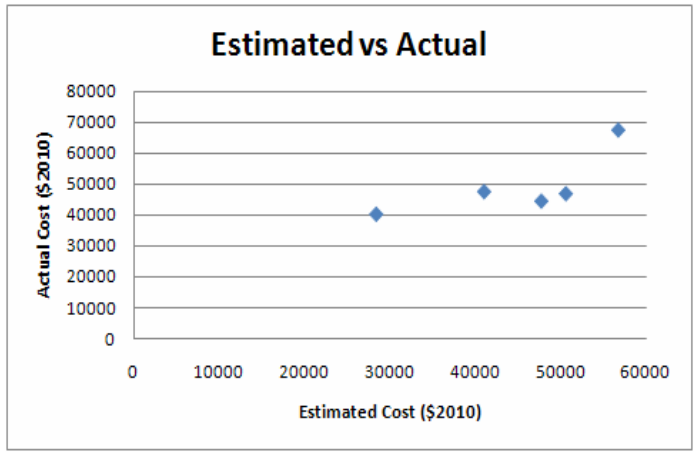
System	Power	Fuel Cell Type	Actual Cost	Estimated Cost	GSRQ (r^2)		R^2	adj R^2	StdErr
PlugPower Gensys 5c,4c	5000	PEMFC	32577	35820.54	0.997136348		0.982779	0.980318	455394.3
FCE DFC300	300000	MCFC	1295911	1053018.9					
FCE DFC1.5M	1500000	MCFC	6199260	7148426.5					
FCE DFC 3MW	2000000	MCFC	9370481	10066710					
UTC PureCell 400	400000	PAFC	1820898	1904743.2					
Bloom box	100000	SOFC	741368	776045.31					
Horizon Greenhub Powerbox 1000	1000	PEMFC	10330	11160.598					
Idatech igen	250	PEMFC	5817	6536.8592					

Data Analysis – Backup Power System



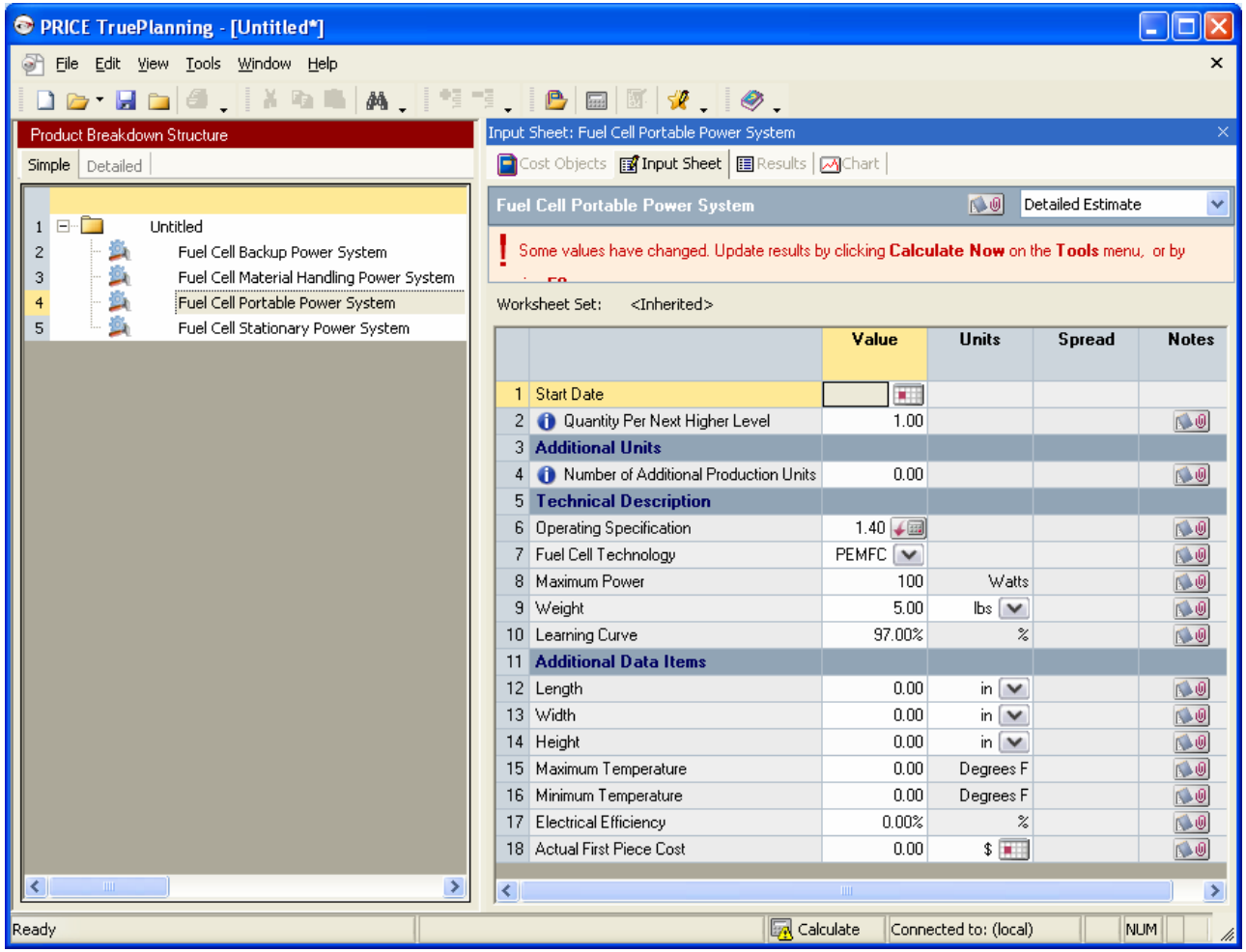
System	Power	Fuel Cell	Actual Cost	Estimated Cost	GSRQ (r^2)	R^2	adj R^2	StdErr
ReliOn t-1000	1200	PEMFC	3389	5496.6596	0.942935717	0.911	0.881333	2637.08
reliOn T-2000	2000	PEMFC	6775	9374.126				
Horizon h-1000	1000	PEMFC	5790	4543.1224				
Horizon h-3000	3000	pemfc	15199	14320.103				
Horizon h-5000	5000	pemfc	21713	24421.824				

Data Analysis – Material Handling Power System



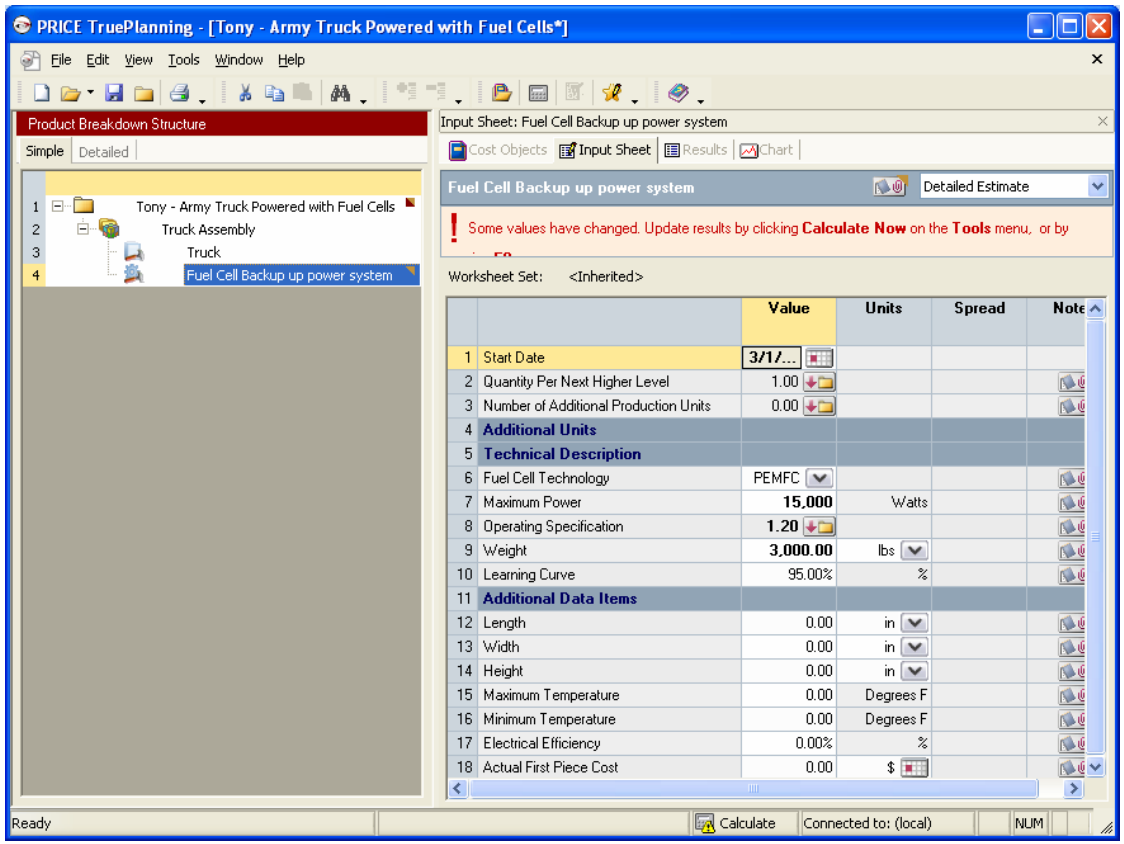
System	Power	Fuel Cell Type	Actual Cost	Estimated Cost	GSRQ (r^2)	R^2	adj R^2	StdErr
PlugPower Gendrive GD-240	10500	PEMFC	40959	47707.48	0.569714892	0.290619	0.054158	10517.37
PlugPower Gendrive gd-160	8700	PEMFC	47661	44693.768				
PlugPower Gendrive GD-170	10100	PEMFC	50534	47068.82				
Ballard FCVelocity 9ssl	4400	PEMFC	28333	40448.07				
Ballard FCVelocity 9ssl	19300	PEMFC	56667	67562.874				

Implementation and Application

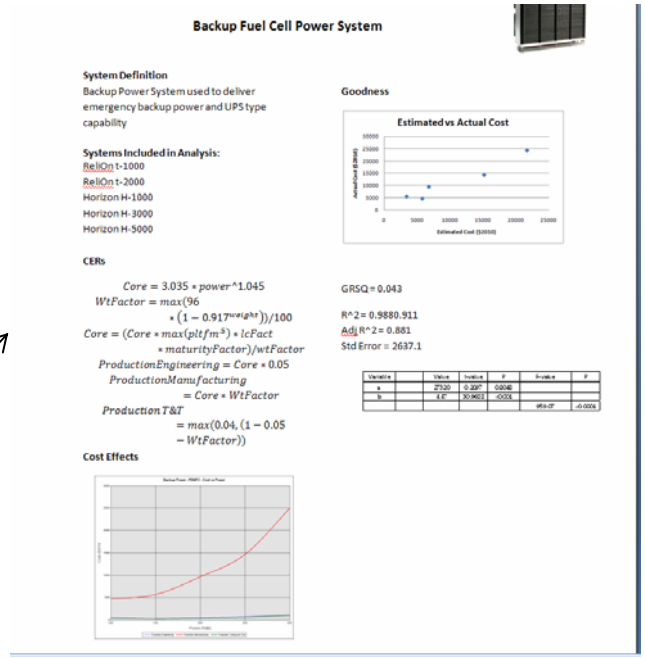


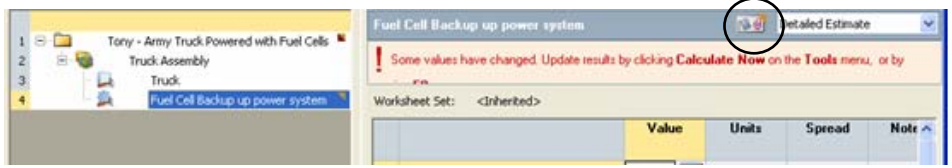
Implementation and Application

- Prepare an estimate using True Hardware COTS for a small military truck with a backup fuel cell power supply



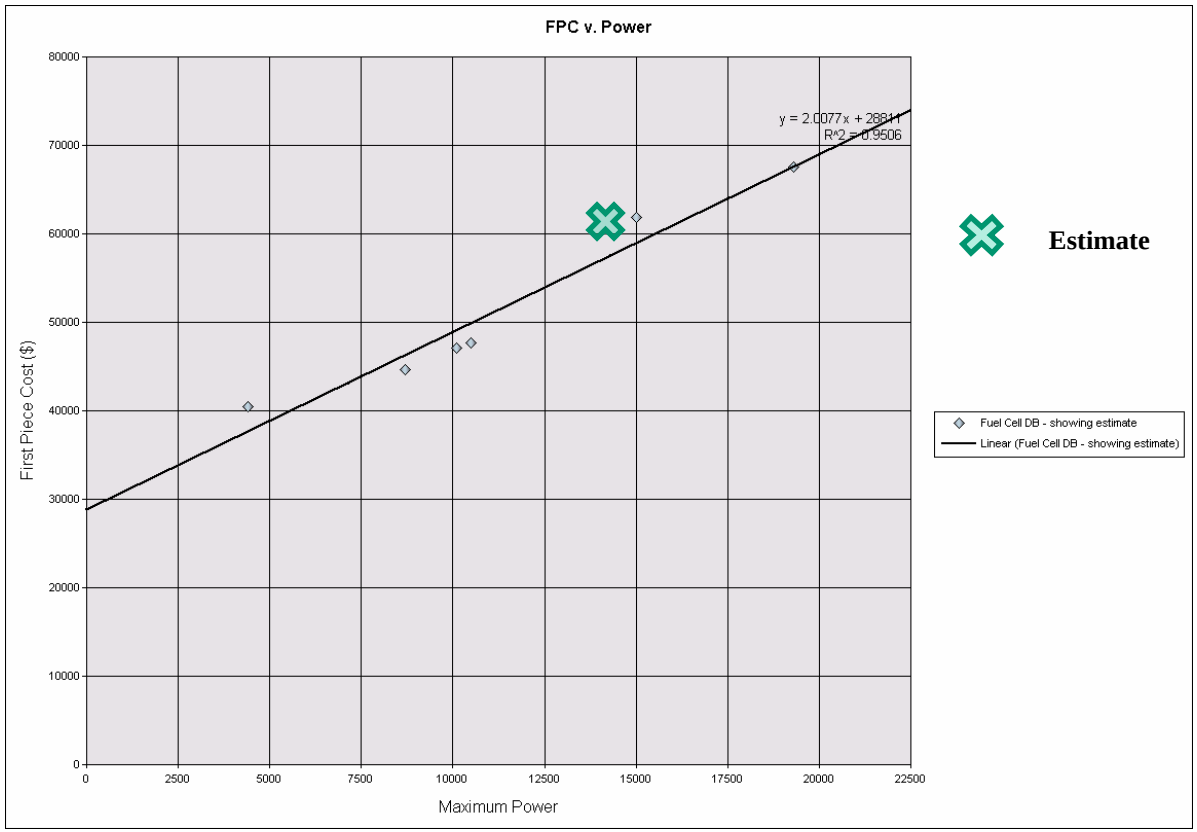
- Fact sheet for CERs embedded in the project file





Implementation and Application

- Compare estimate for fuel cell backup power system to other systems in the database



Conclusions

- This research study provided two significant results
  - A set of CERs that can be used to estimate certain types of fuel cell systems
  - An method of sharing results of cost research studies to the cost community in a way that it can be
    - Understood
    - Defended
    - Used easily to support good decisions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