A Transformational Natural Gas Fueled Dynamic SOFC for Critical Datacenter In-Rack Power

Primary: University of South Carolina
Sub: Atrex Energy

Kickoff meeting
September 21, 2018

Outline

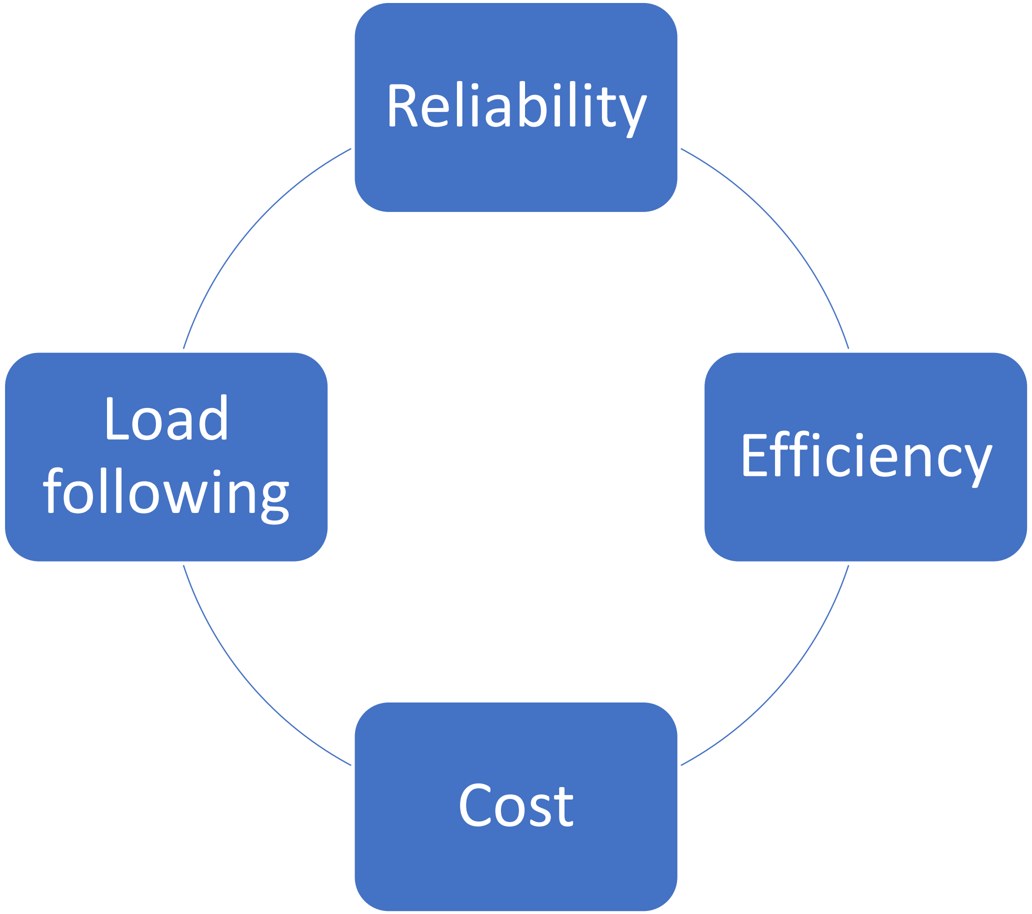
- Background
- Project objective(s)
- Technical approach
- Project structure
- Project schedule
- Project milestones
- Project budget
- Project Management Plan

Datacenter Market and Challenges

- $17 billion global market (2017)
- Expected to grow to $25 billion by 2022
- 8% compound annual growth rate (CAGR)
- $6 billion market in the US alone
- Represents 2-3% of the total energy consumption in the US and Canada

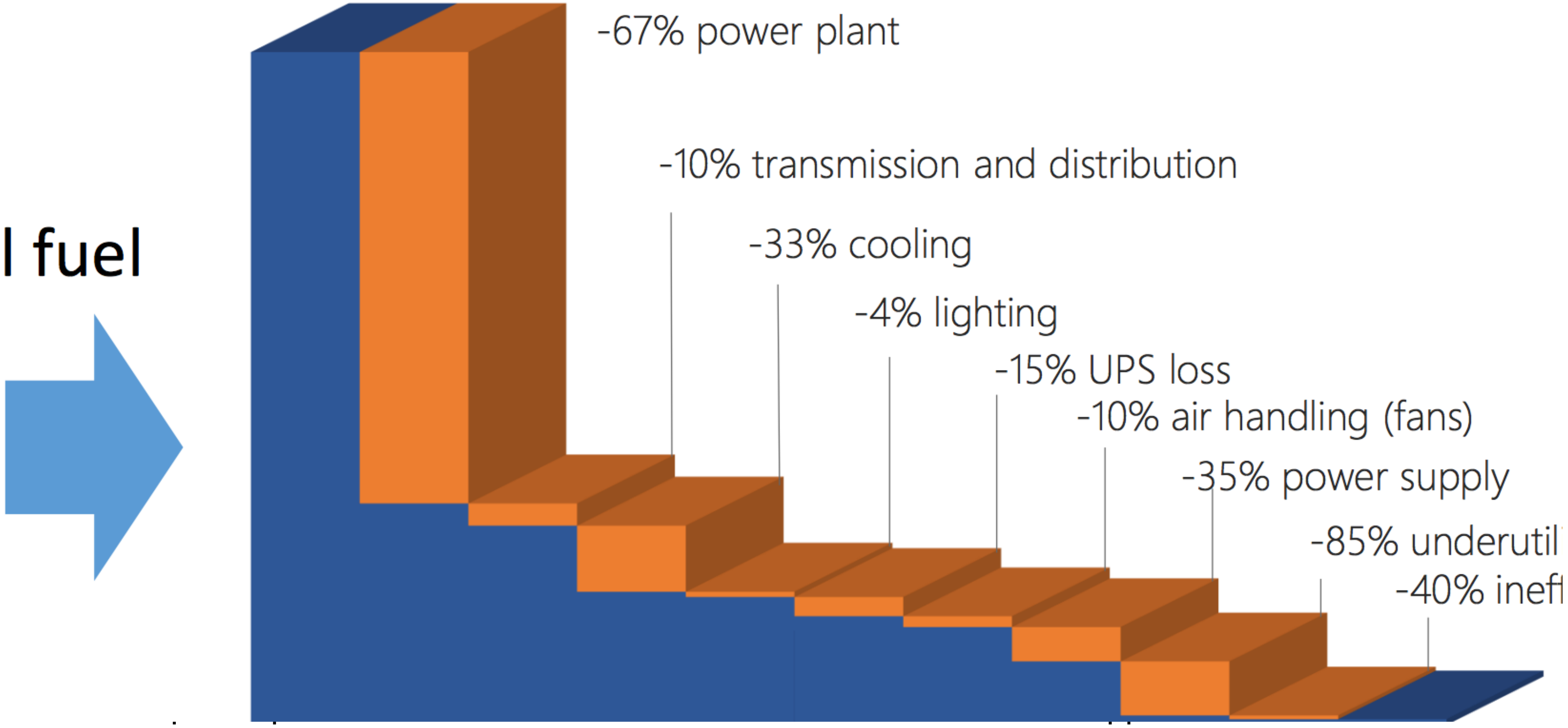
- $150 billion in losses a year due to power incidents
- Low energy efficiency
- Dynamic load characteristic
- 99.999% reliability requirement
- Relying on costly and “dirty” backup systems (diesel generators) to handle datacenter’s load spikes and reliability demands

Key Performance Metrics for Datacenters



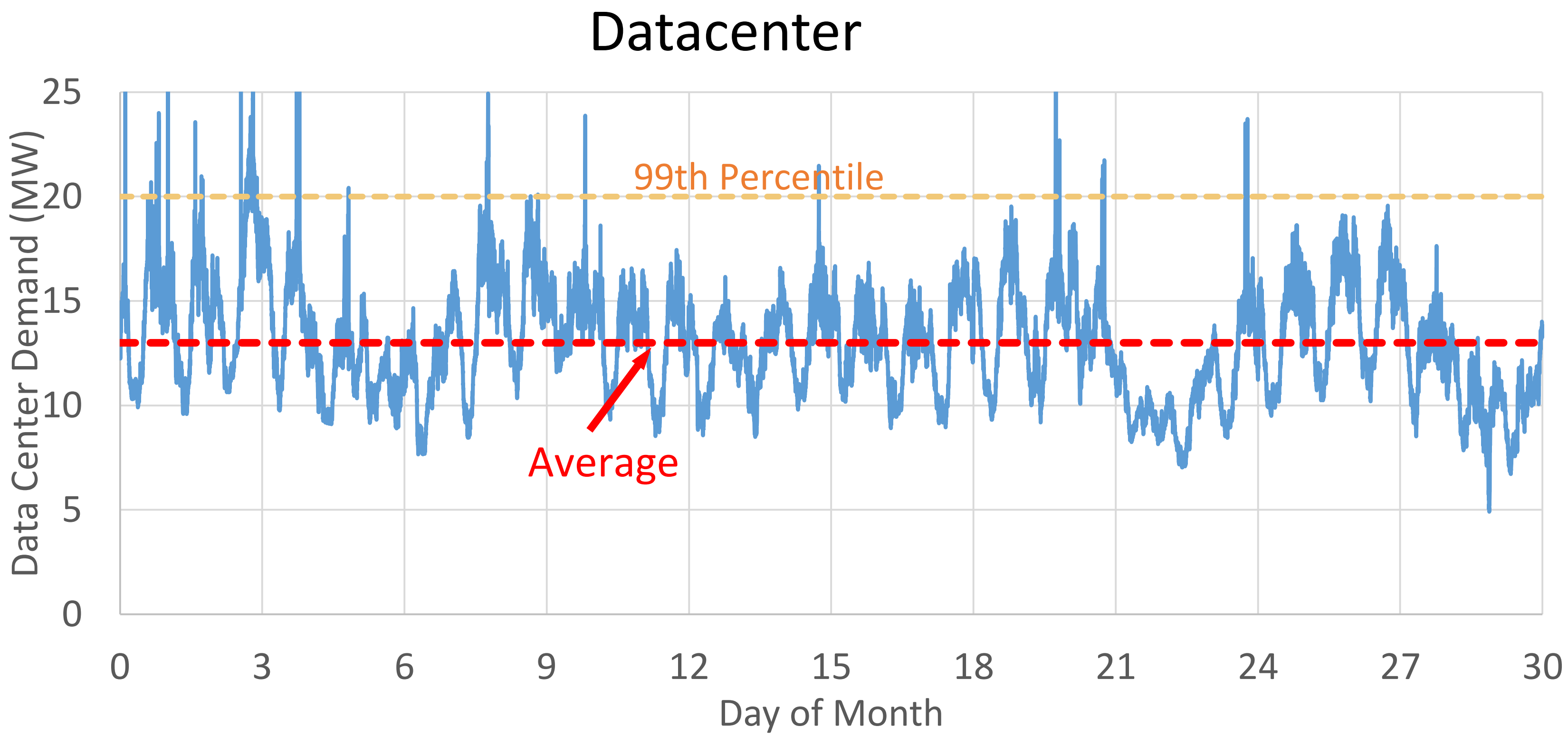
The Datacenter Efficiency Challenge

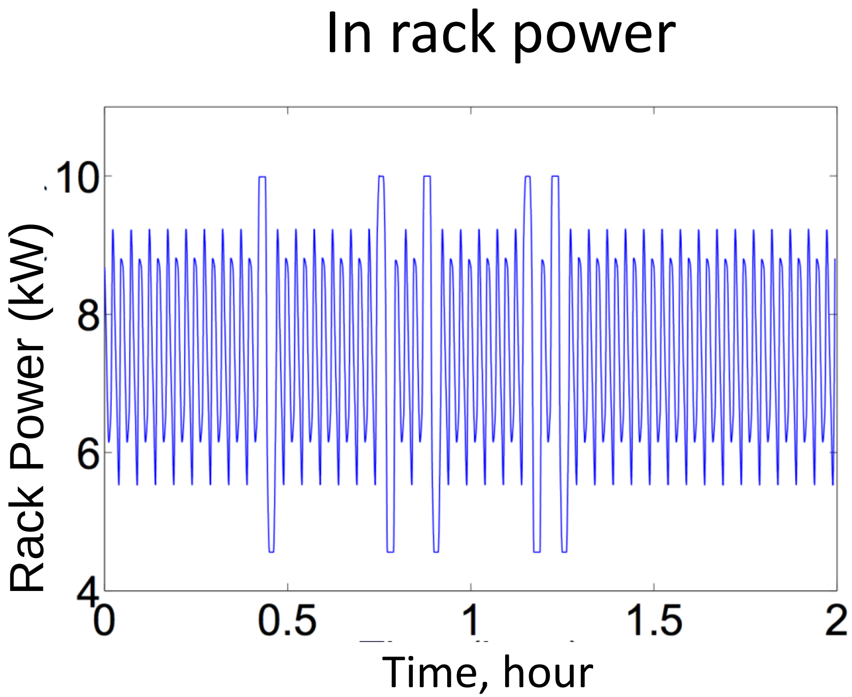
Fossil fuel



Di Wang, “Co-optimization of data center loads and fuel cell systems”, MSFT-UW Fuel Cell Workshop, January 2017.

Dynamics of Power Demand

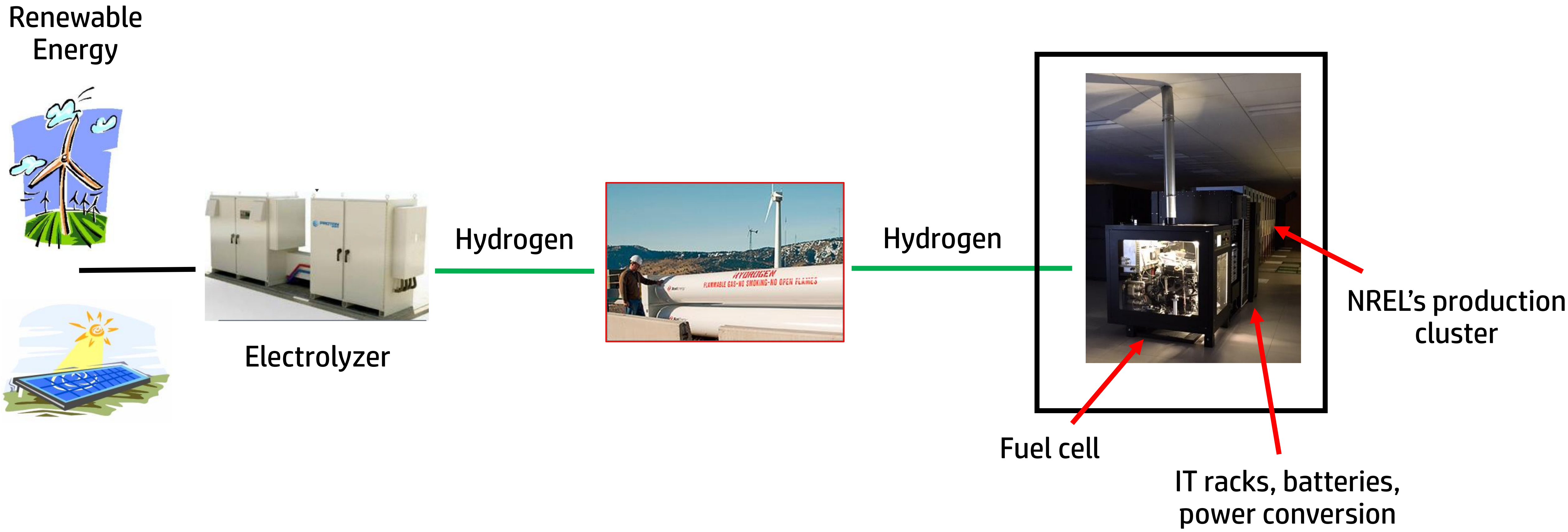




Di Wang, 2017

Arka A. B, David C., Aman K. , Sriram G. and Sriram S, “The Need for Speed and Stability in Data Center Power Capping", IGCC’12

PEM Fuel Cell Datacenter at NREL

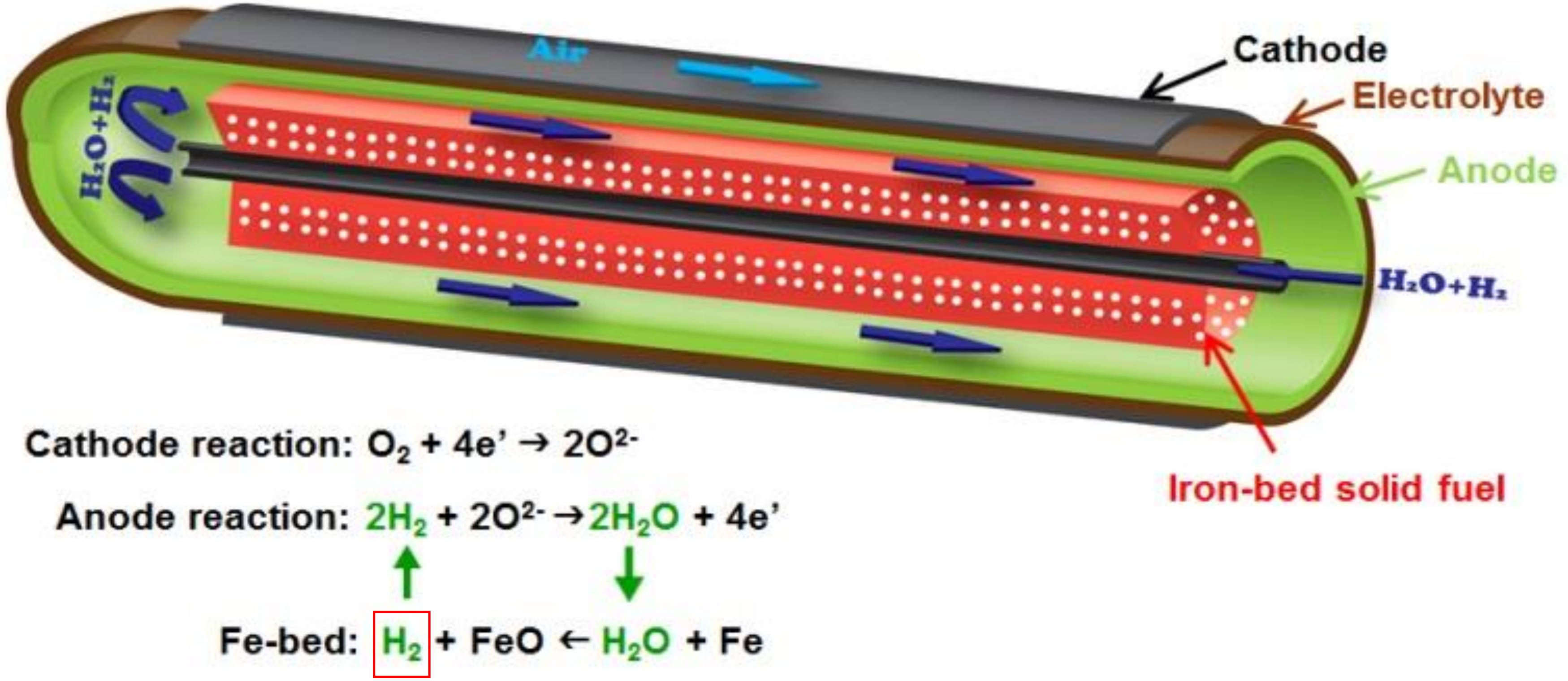


NG-Fueled SOFC Datacenter at Microsoft

Limitations of Conventional SOFCs for Datacenter Applications

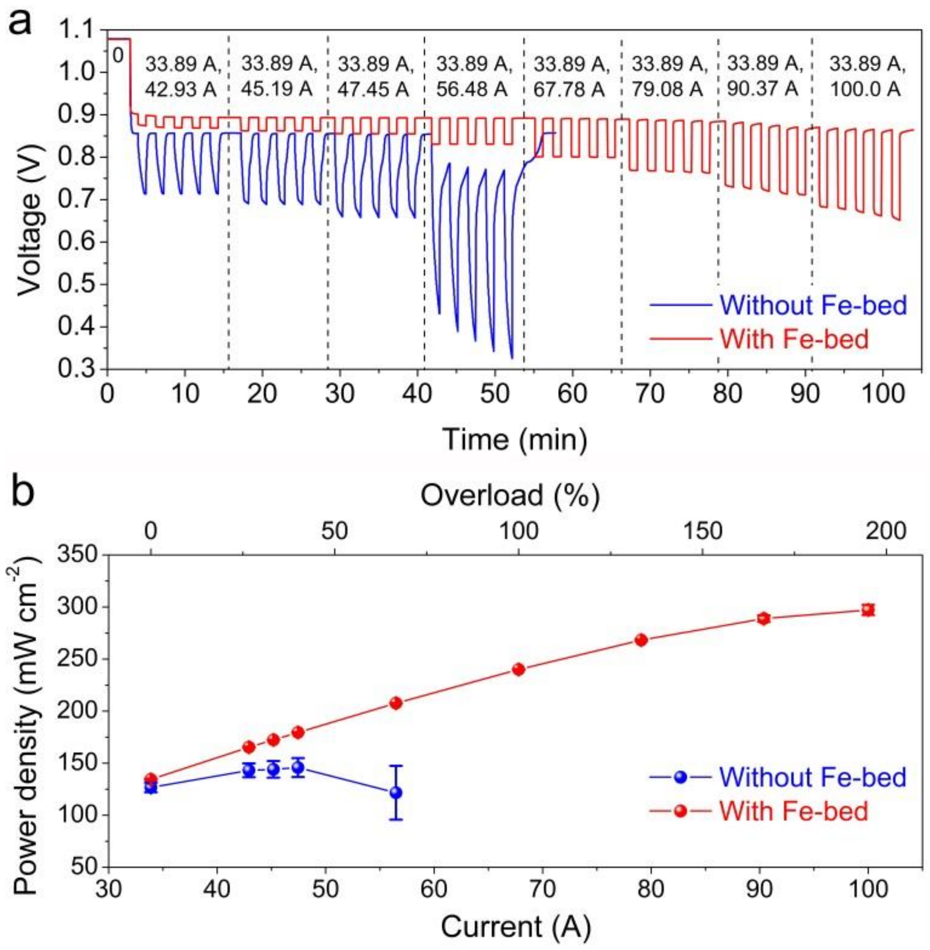
- Designed for baseload power applications at constant fuel and air utilizations
- Poor overload tolerance – causing local fuel starvation, Ni-oxidation and cracks in anode
- Slow fuel supply response system – mass flow controller
- Lack of robust control algorithms

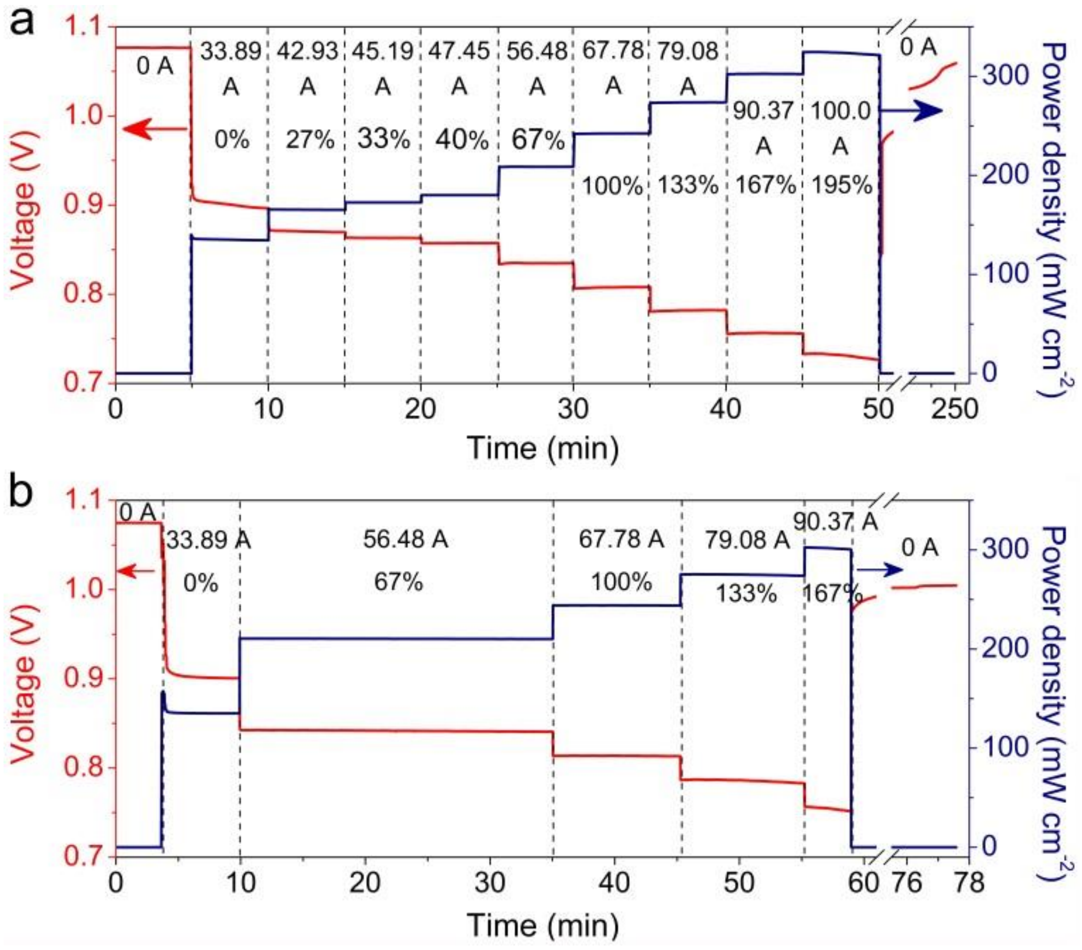
The Technology for SOFC Datacenters – Fe-Bed SOFC



Energy & Environmental Science*, 4** *(2011), 4942;* ***9 *(2016), 3746 – 3753*

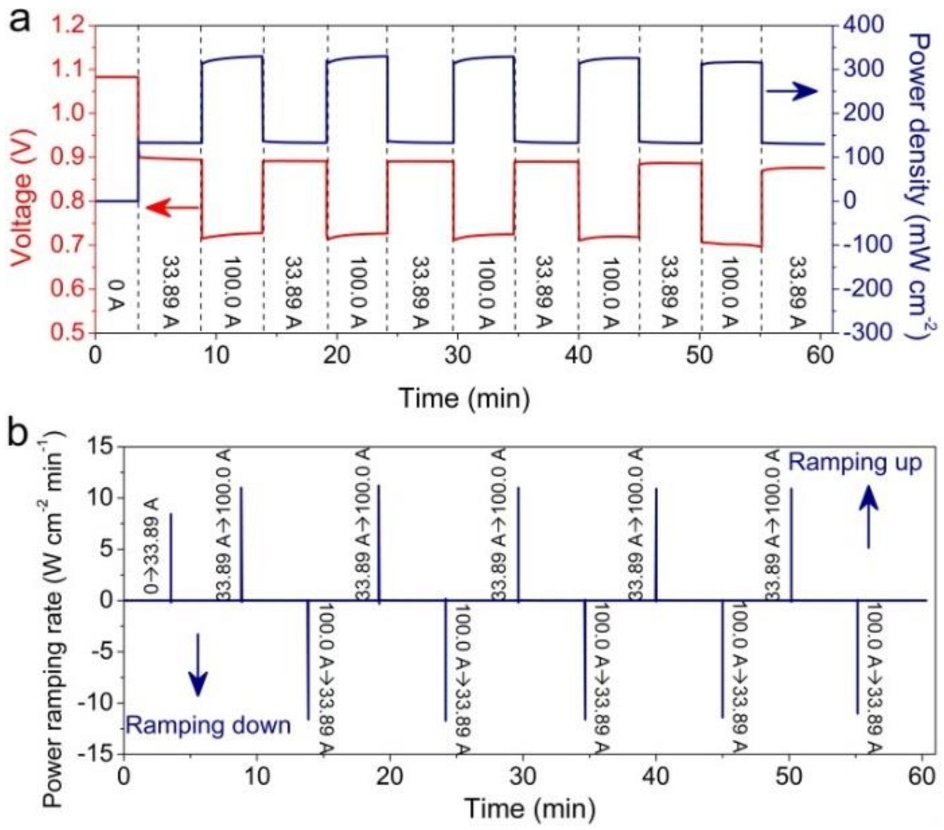
Background - Promises

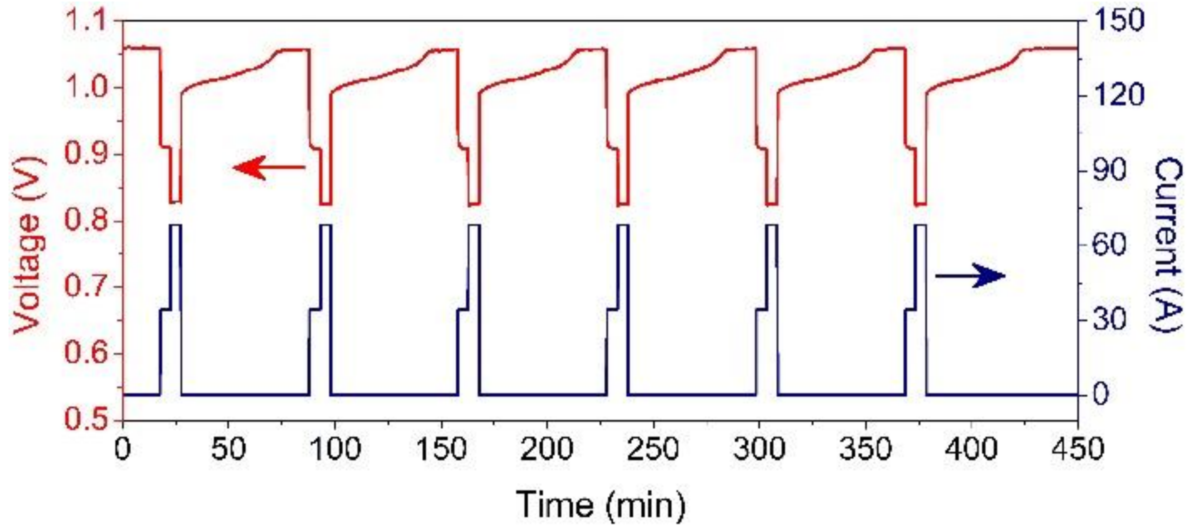




Energy & Environmental Science, ***9*** *(2016), 3746 – 3753*

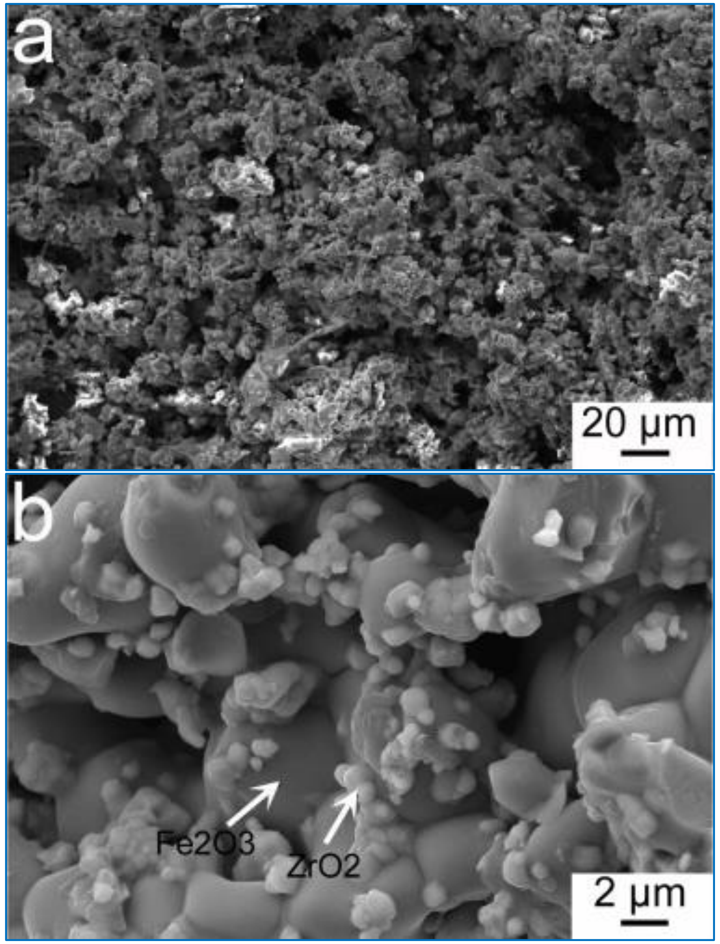
Background - Promises



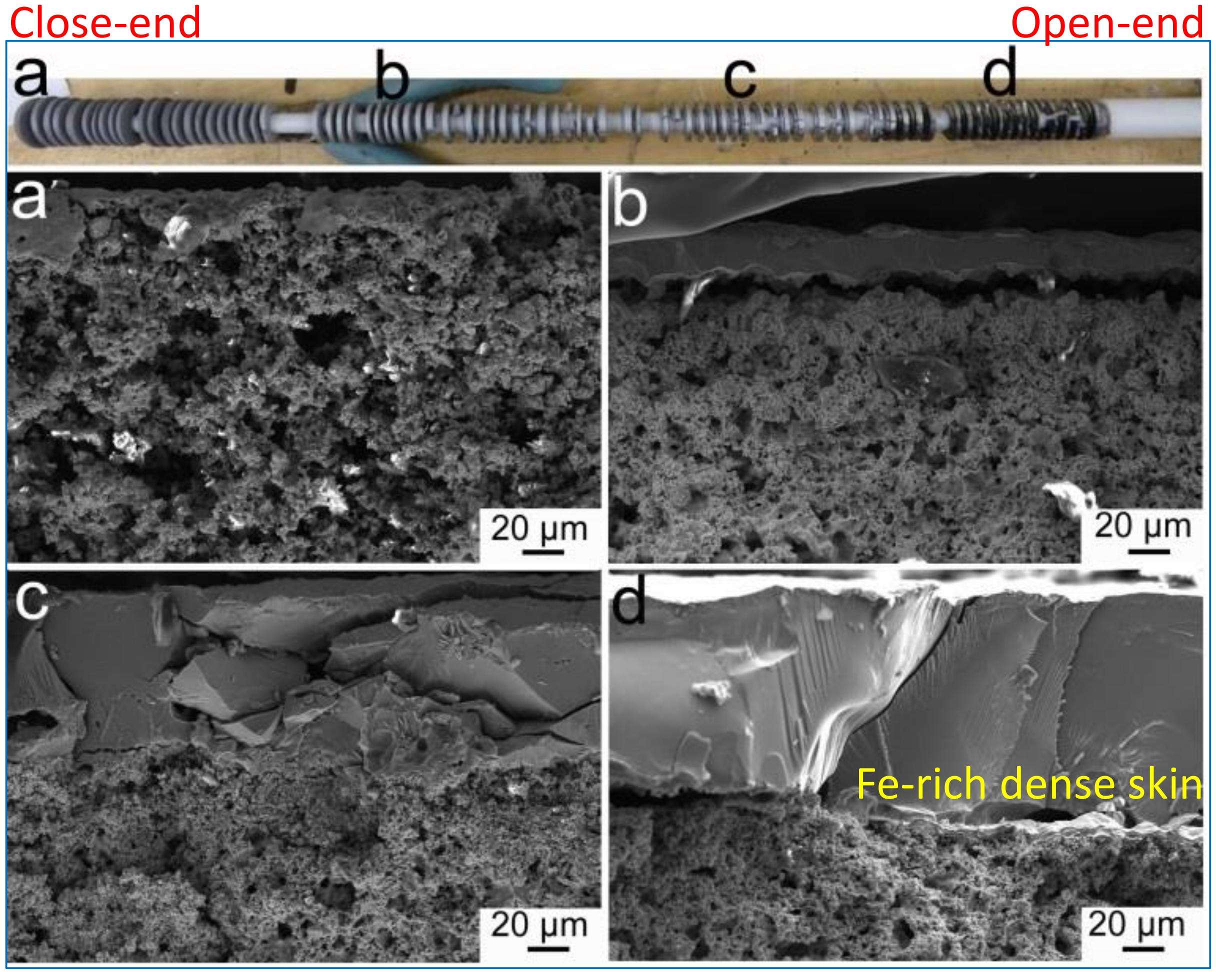


Energy & Environmental Science, ***9*** *(2016), 3746 – 3753*

Background - Issues



Before testing



After testing

Project Objective(s)

- Overarching objective: to develop a new generation of dynamic SOFC system operated on NG for datacenter applications
  - Primary objective -1: to develop durable metal-bed design and compositions
  - Primary objective -2: to demonstrate the new cell technology at pilot-scale

Technical Approach

Optimizing active metal/supporting-oxide ratio	Materials development
New Fe-X compositions and segmented bed design	
New sintering-resistant and active oxides	
Sintering-resistant active metal particles	
Metal-steam reaction kinetics	Characterization
Alloy activity study	
Computational modeling	Theory
Pilot-scale testing	Validation

Project Structure

- USC
  - Optimizing active M/MO ratio
  - Fe-X and segmented bed design
  - Sintering-resistant and active oxides
  - Fe-steam reaction kinetics
  - Fe-activity study
  - Modeling
  - Pilot Scale testing
    - Atrex Energy
      - Testing in homogeneous bed
      - Testing in segmented bed
      - Testing in H_2 fuel
      - Testing in CPOX fuels
      - Testing in SMR fuels

Project Schedule

Task	Task Description	1	2	3	4	5	6	7	8
1	Task 1.0: Project management								
	Task 1.1 Communication between team members								
	Task 1.2 Communication with NETL project managers								
	Task 1.3 Technical reports, conference presentations, journal articles, patents								
2	Task 2.0: Development of robust SF-bed compositions								
	Task 2.1 Optimizing active metal/oxide ratio								
	Task 2.2 New active metal compositions								
	Task 2.3 New sintering-resistant active oxides								
	Task 2.4 Sintering-resistant active metal particles								
	Task 2.5 Reporting								
3	Task 3.0: Characterization								
	Task 3.1 Redox stability by isothermal TPO/TPR cycling								
	Task 3.2 Microstructural examination								
	Task 3.3 Reporting								
4	Task 4.0: Computational modeling								
5	Task 5.0: SF-bed validation at Atrex								
	Task 5.1 Using H_2-fuel								
	Task 5.2 Using CPOX fuel								
	Task 5.3 Using SMR fuel								
	Task 5.4 Reporting								
	Progress ▲ Milestone Go/No Go								

Quarters after start of program

Go/No-Go decision

Project Milestones

ID	Milestones	Work Task	Schedule (Qtrs)	Verification methods
1	Selection of the optimized M/SO ratio	2.1	1-2	Isothermal TPO redox cycle
2	Selection of new Fe-X showing balanced Po_2	2.2	1-2	Oxygen concentration cell
3	Selection of H^+-containing ceramic composition	2.3	2-4	Isothermal TPO redox cycle
4	Selection of MLD parameters	2.4	2-4	TEM and Isothermal TPO redox cycle
5	• >30% power enhancement • >100% overload tolerance for a continuous 30-minute operation • $15 Wcm^{-2} min^{-1}$ power response rate and <0.5%/kh degradation rate for 1,500 h	4.1-4.3	5-8	Testing at Atrex with homogeneous and segmented beds using H_2, CPOX and SMR fuels

Project Budget

Project funding profile of government share

	Year 1		Year 2		Total	
	DOE funds	Cost share	DOE funds	Cost share	DOE funds	Cost share
University of S. C.	$ 223,756	$ 51,267	$ 226,244	$ 61,233	$ 450,000	$ 112,500
Atrex Energy	$ 0	$ 0	$ 50,000	$ 12,500	$ 50,000	$ 12,500
Total ($)	$ 223,756	$ 51,267	$ 276,244	$ 73,733	$ 500,000	$125,000
Total cost share (%)	18.64%		21.06%		20%	

Project costing profile of government funding

Month	Year 1 ($)	Year 2 ($)
October	10,482	13,591
November	8,284	14,987
December	8,584	13,591
January	15,685	21,991
February	8,184	13,591
March	8,584	13,591
April	10,282	14,988
May	8,434	13,591
June	60,417	60,370
July	60,517	60,370
August	16,185	21,991
September	8,119	13,591

Project Management Plan – Risk Management

Foreseeable risks	Mitigation approaches
Fe-X alloy compositional optimization assuming ideal Fe-X solution model	Use of oxygen concentration cell method to directly determine a_{Fe} in Fe-X alloys
Fe-bed consumption under nominal 75% fuel utilization SOFC operation	Developing Fe-bed compositions that only allow Fe-bed consumption at > 75% (or any other) fuel utilization
Project on-schedule	Monthly teleconference with Atrex Quarterly teleconference with Diane
Project on-budget	University financial monitoring system