Fuel Cell Auxiliary Power Units: The Future of Idling Alternatives?

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Truck – APU Demonstrations

Just Kidding

(Courtesy of Gouse, ATA)

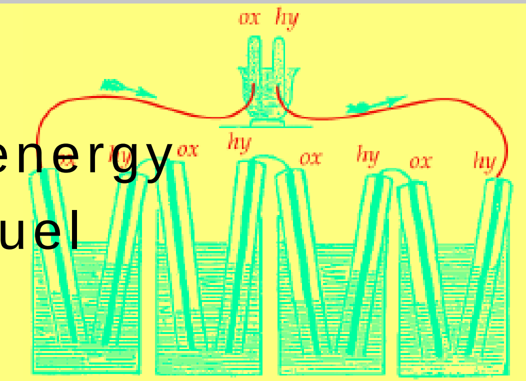
Presentation Outline

- Brief Introduction to Fuel Cells
- State of Truck FC APUs
- Challenges
- Projected Emissions and Fuel Benefits
- Projected Markets and Economics

Fuel Cells

Operation

- Convert chemical energy to electrical energy
- Operate like battery, but use external fuel
- Variety of different types: PEM, SOFC…



In 1839, William Grove, a British jurist and amateur physicist, first discovered the principle of the fuel cell. Grove utilized four large cells, each containing hydrogen and oxygen, to produce electric power which was then used to split the water in the smaller upper cell into hydrogen and oxygen.

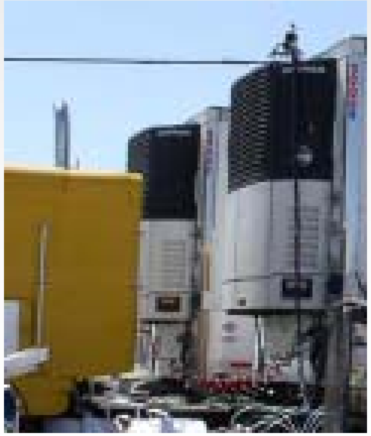
History

- 1839: William Grove succeeds to reverse water electrolysis
- Late 1950s: NASA funds over 200 research contracts for fuel cell technology
- 1990: Fuel cells experience an intense phase of research

Truck FC APU Prototypes

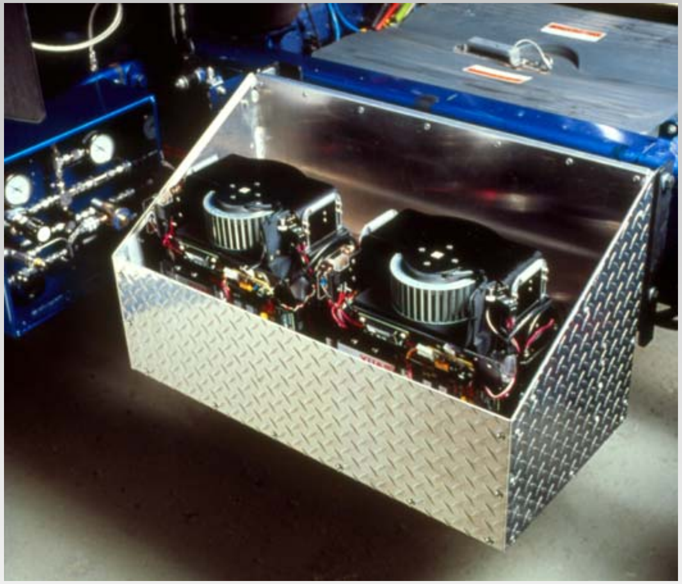
Examples....

- Freightliner/Ballard
- SwRI
- UC – Davis
- GM
- Delphi
- Cummins



Challenges

- Cost
- Size
- Durability
- Lifespan
- Fuel compatibility



Solid State Energy Conversion Alliance Progressive Applications

2005

- $800/kilowatt
- Prototypes: 3 - 10 kilowatts
- Six industrial teams:
  - –Delphi
  - –Cummins/McDermott
  - –General Electric
  - –Siemens Westinghouse Power Corp.
  - –Acumentrics
  - –FuelCell Energy

2010

- $400/kilowatt
- Commercial applications

2015

- FutureGen Plants
  - 70-80% efficient
  - Generate electricity and hydrogen
  - Sequester greenhouse gases
  - Operable on gasified coal
- Transportation
  - <$200/kW

Models: Engineering and Economics

$$NPV_x = NPV_{x-1} + \frac{\sum(Benefits,\ year\ x) - \sum(Costs,\ year\ x)}{(1+d)^x}$$

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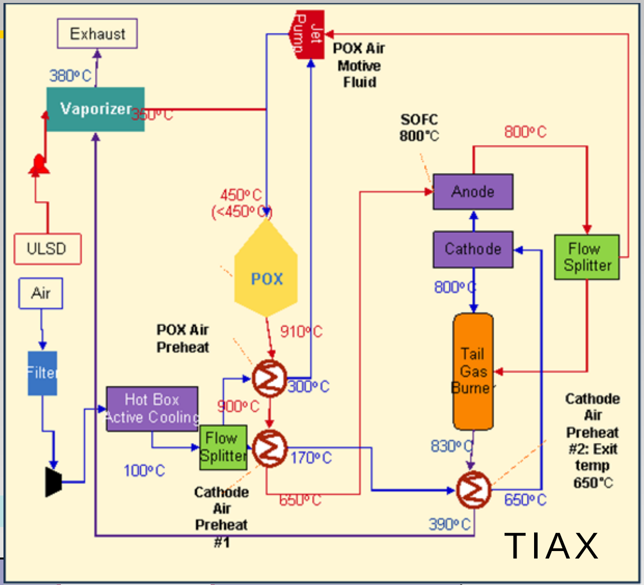

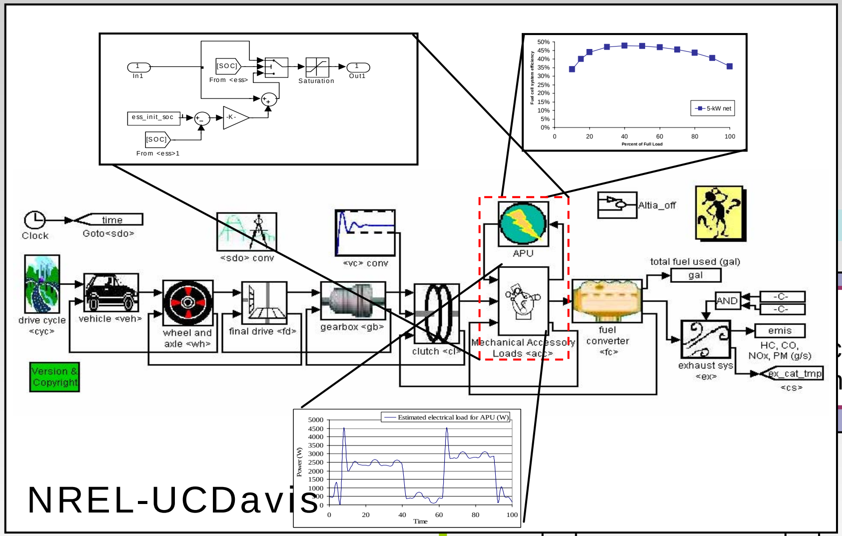

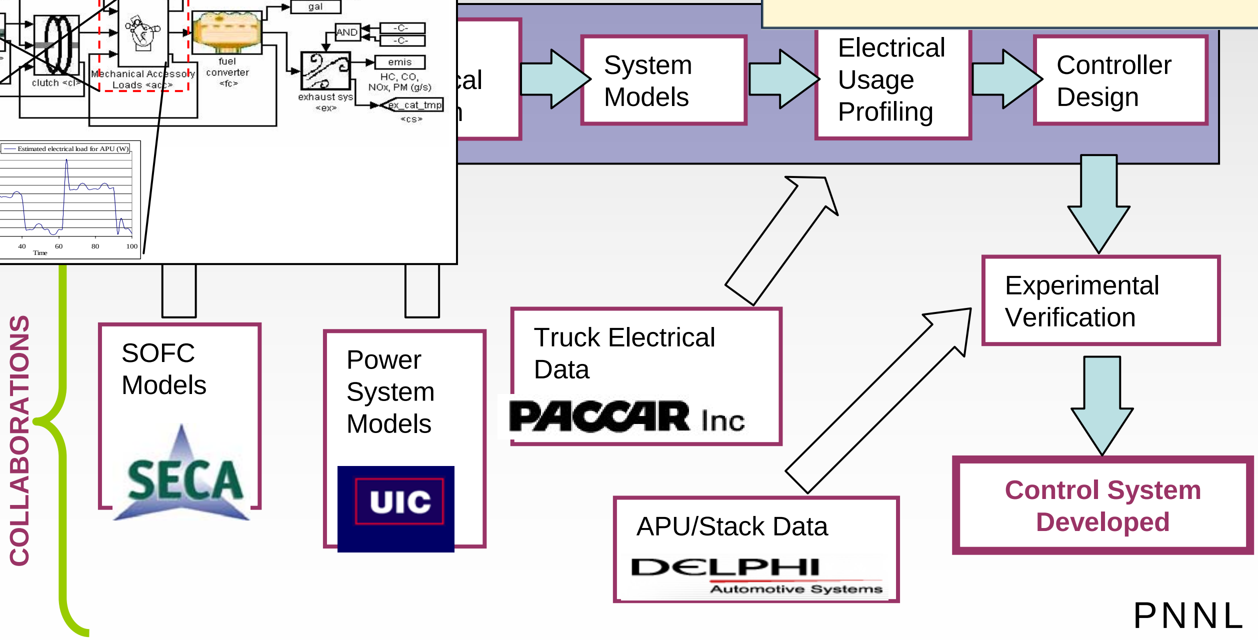

Fuel Savings Projections

	Idling engine		SOFC APU (without idling)	
Accessory load (engine speed)	Diesel consumption (gal/hr)	Average Efficiency	Diesel consumption (gal/hr)	Average Efficiency
"typical" (600 rpm)	0.53	10%	0.14 *(0.10 – 0.16)*	32% (26 – 38%)
"typical" (900 rpm)	0.95	9%	0.14 *(0.10 – 0.16)*	32% (26 – 38%)
"high" (1200 rpm)	1.25	10%	0.17 *(0.14 – 0.21)*	33% (26 – 39%)

NOTES: Idling efficiency measured at engine, not at accessory / end-use;
"Typical" accessory cycle: average 2 kW, max 3.7 kW; "High" load: average 2.7 kW, max 4.7 kW;
( )'s denote 20% error bars in efficiency curve

→ *74 – 86% idled fuel savings with Solid Oxide Fuel Cell*

→ *Potential fuel savings 3-8% of total vehicle energy use for truck.*

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Emissions Savings Data

Condition	NO_x		Fuel Economy	
	g/hr	st. dev.	gal/hr	st. dev.
Idling without accessories on	103	14	0.36	0.03
Idling at 600 rpm with a/c	166	5	0.52	0.04
Idling at 1050 rpm with a/c	254	NA	0.88	NA
Long idling at 1050 rpm with a/c	225	NA	0.93	NA
Cruise at 55 mph	713	41	5.92	0.14

→ *NOx emissions at idle can be ~1/3 of emissions at 55 mph.*

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Emissions Savings Projections

NO_x emissions and CO_2 greenhouse gas savings potential from eliminating truck idling

	Low emissions estimate		High emissions estimate	
	NO_x	CO_2	NO_x	CO_2
Scenario 1: average idle time (1818 hours per year)				
Baseline idle emissions (grams per hour)	104	4034	396	29687
Hours per day idle	6	6	6	6
Days per year idle	303	303	303	303
Emissions at idle (grams per year)	189,072	7,333,812	719,928	53,970,966
Tons per year per vehicle	0.208	8.08	0.793	59.5
Scenario 2: 40% idle time (2424 hours per year)				
Baseline idle NO_x emissions (grams per hour)	104	4034	396	29687
Hours per day idle	8	8	8	8
Days per year idle	303	303	303	303
Emissions at idle (grams per year)	252,096	9,778,415	959,904	71,961,288
Tons per year per vehicle	0.278	10.8	1.06	79.3

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$$$: Economic Analysis of APUs

Sensitivity to Assumptions of Cost of Idling Alternative

			Parameter			Payback periods for varied parameters (yrs)		
		(unit)	Low	Middle	High	Low	Middle	High
	Annual Vehicle Idling	(hrs.)	1818	2121	2424	2.8	3.2	3.8
Diesel	Idling diesel consumption	(gal/hr)	0.6	1	2.25	1.3	3.2	6.5
Diesel	Diesel fuel cost	($/gal)	1.35	1.51	1.7	2.8	3.2	3.7
Diesel	Lubricant cost	($/hr idled)	-	0.07	-	-	3.2	-
Diesel	Engine overhaul cost	($/hr idled)	-	0.07	-	-	3.2	-
Fuel cell	Fuel cell capital cost	($/kW)	1000	2000	3000	2.8	3.2	3.7
Fuel cell	H2 fuel tank cost	($)	700	1100	1800	3.0	3.2	3.5
Fuel cell	H_2 fuel cost	($/GJ(HHV))	11	25	40	2.8	3.2	3.8
Fuel cell	Idling H_2 consumption	(GJ/hr)	-	0.013	-	-	3.2	-
Fuel cell	Fuel cell installation cost	($)	-	1500	-	-	3.2	-
Fuel cell	Fuel cell O & M cost	($/hr idled)	-	0.05	-	-	3.2	-
Fuel cell	Heater and air conditioner cost	($)	-	1800	-	-	3.2	-
Fuel cell	Plumbing and wiring cost	($)	-	250	-	-	3.2	-
Fuel cell	Trace inverter	($)	-	1300	-	-	3.2	-
Market	Inflation (labor, overhaul)		-	3%	-	-	3.2	-
Market	Inflation (diesel)		-5%	5%	15%	2.6	3.2	4.5
Market	Inflation (H2)		-	3%	-	-	3.2	-
Market	Discount rate		-	10%	-	-	3.2	-

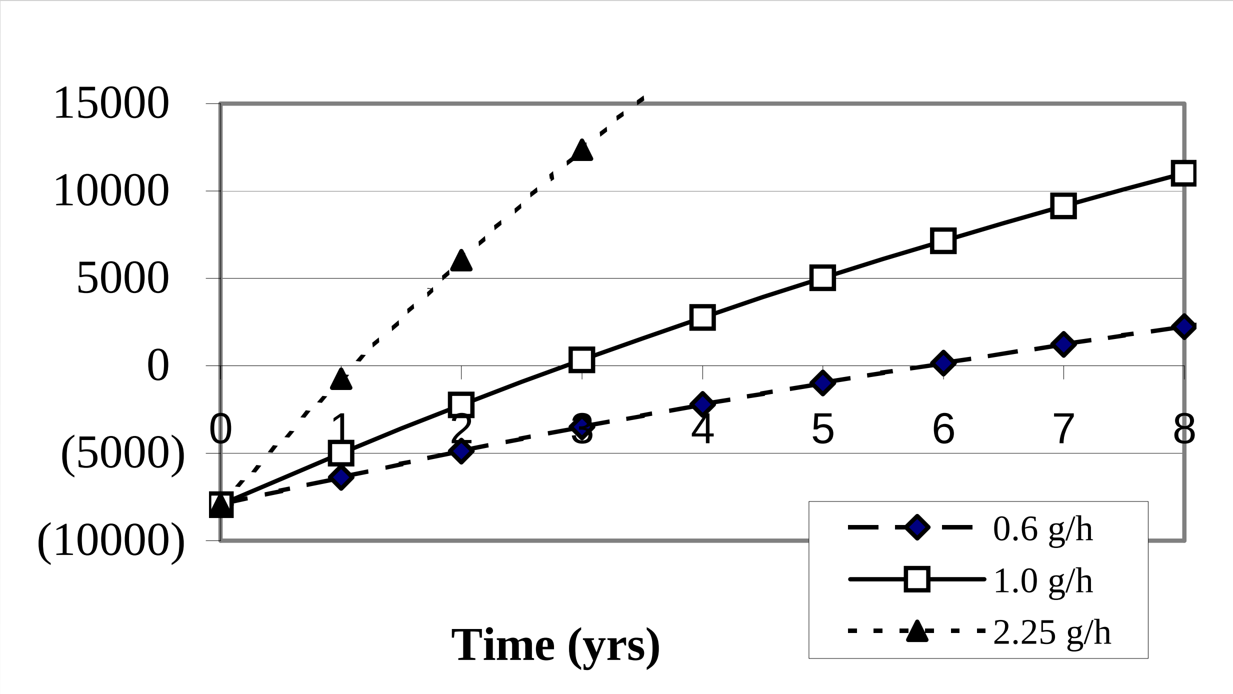
(Brodrick et al., 2002)

Economic Analysis of APUs

Sensitivity Analysis for Fuel Cell APU on Truck

(example from hydrogen fuel cell APU analysis)

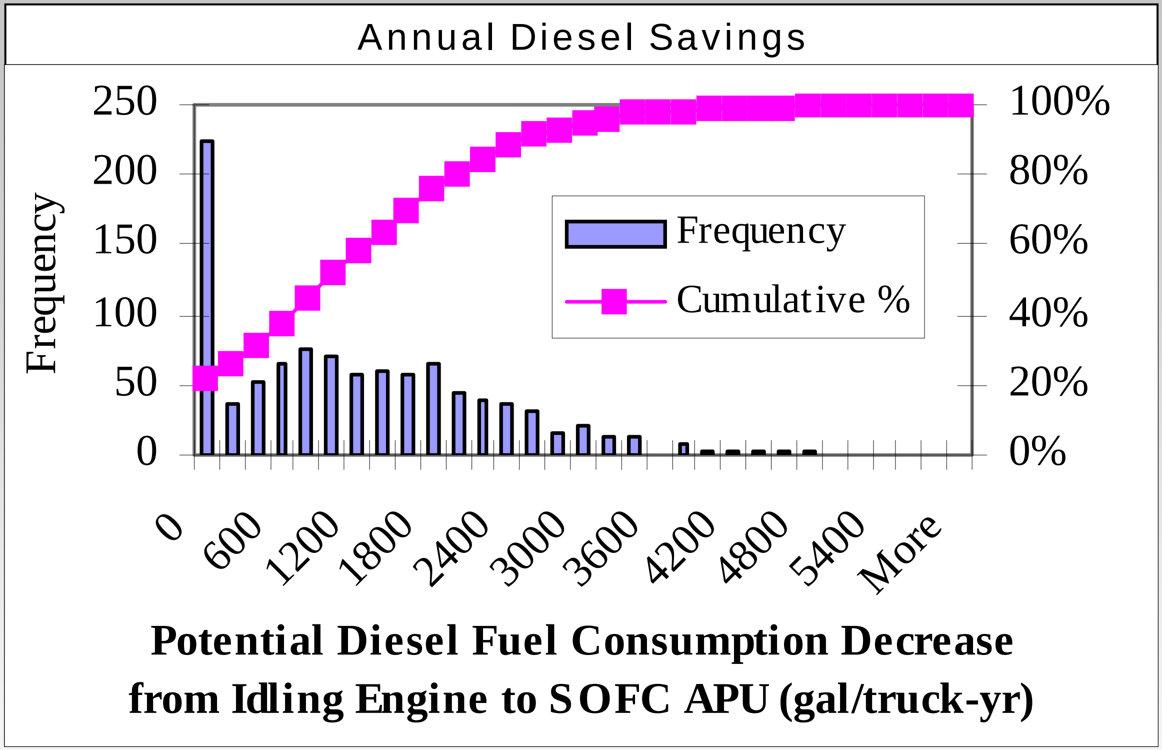
NPV ($)



Payback period is very sensitive to idling fuel consumption of the truck

(Brodrick et al., 2002)

Market Analysis



Average savings with fuel cell APU: ~1,400 gallons/truck-yr

90th percentile savings with fuel cell APU : ~2,500 gal/truck-yr

95th percentile savings with fuel cell APU : ~3,000 gal/truck-yr

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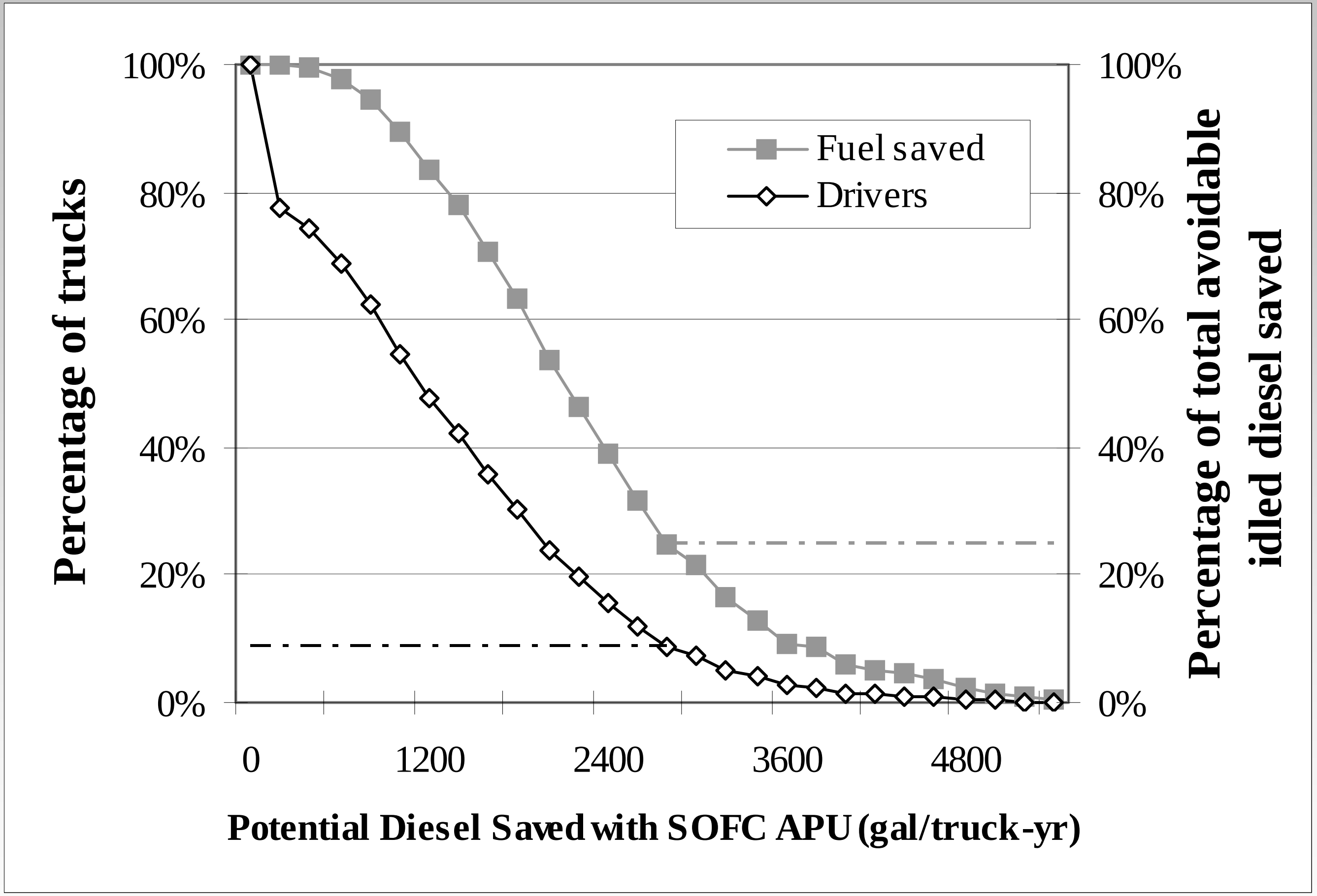
Market Analysis, Con't.



Equipping the ~9% of line-haul trucks that idle the longest with fuel cell APUs could achieve ~25% savings of idled diesel

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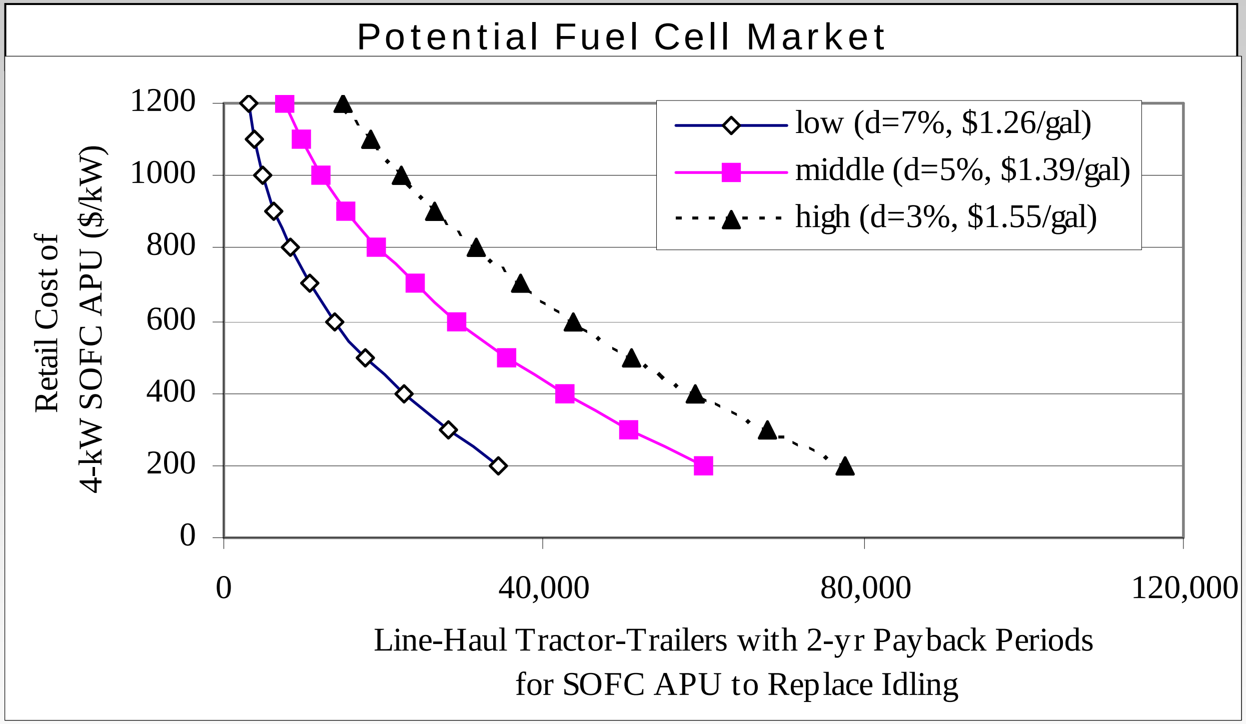
Market Analysis, Con't.

For a given fuel cell cost, how big is the potential fuel cell APU market for trucks?

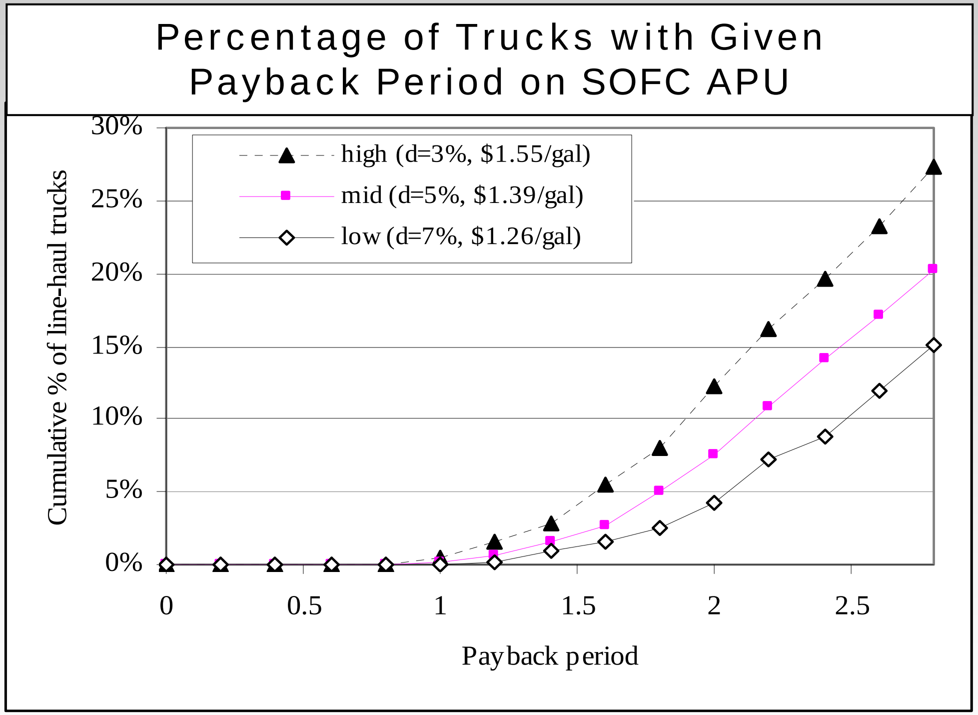


Notes: Based on 500,000 line-haul trucks; Assumed fuel cell-associated costs - $1000 inverter, $2000 heat pump, $500 miscellaneous, $1200 installation labor

The U.S. DOE target for SOFC R&D efforts is $400/kW for 2011 timeframe

Market Size for 2 Yr. Payback Times

Calculating payback period on a fuel cell APU investment with high, mid, and low estimates on key economic parameters (assuming DOE 2011 target of $400/kW).



With ~500,000 line-haul trucks, 4-12%, or 20,000 to 50,000 trucks, could have payback times of less than 2 years for fuel cell APUs

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