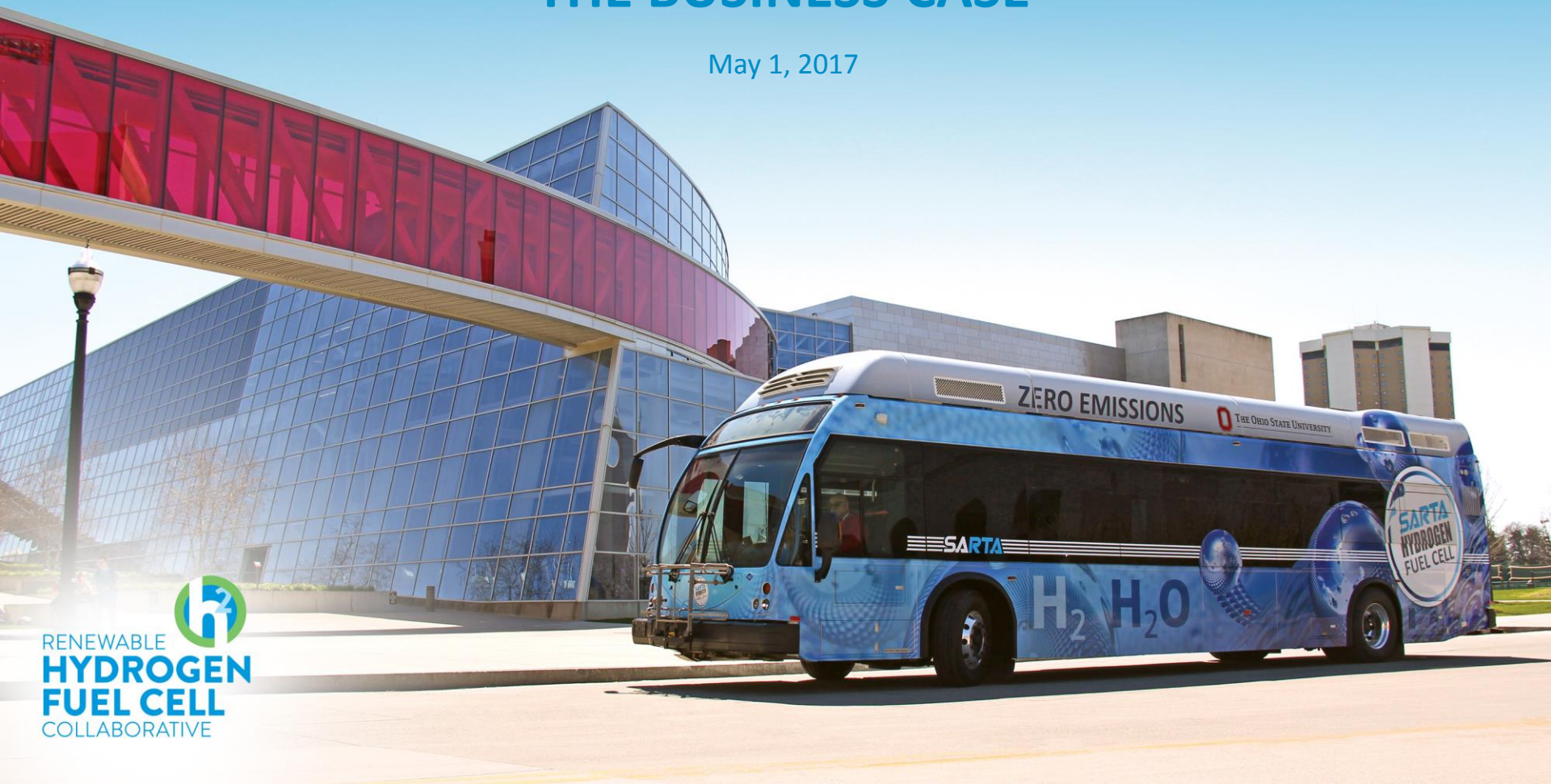
THE **MIDWEST HYDROGEN** CENTER OF EXCELLENCE

A Key Initiative of the Renewable Hydrogen Fuel Cell Collaborative

FUEL CELL BUS WORKSHOP
THE BUSINESS CASE

May 1, 2017



RENEWABLE HYDROGEN FUEL CELL COLLABORATIVE

Introduction

- The motivation
- Case studies
- A Roadmap for Implementing Hydrogen in the Midwest
- The costs of acquiring and operating a fuel cell bus
- What is the business case
- Summary

The Motivation

- No carbon
- No air pollutants (particulate, NOx, Sox, etc.)
- Use locally derived fuels
- Move to renewable and sustainable fuels
- Create jobs in the region
- Reduce noise
- Direct replacement for existing vehicles

Case Studies

Case Studies - Europe

- After much study, EU found that for transit, Hydrogen was the answer: Fuel Cells & Hydrogen Joint Undertaking FCH JU)
  - Carbon
  - Pollutants
  - Noise
  - Fuel can be produced locally
  - Complete replacement for existing diesel buses
  - Job creation
- By increasing volumes and standardization
  - Goal is to reach capital cost & O&M cost parity with diesel by 2030
  - EU is on track to do this
  - About 70 fuel cell buses in FCH JU

Case Studies - Europe

Business case: hydrogen is the answer so work together as a group to drive costs down to make fuel cell buses cost competitive with diesel buses

Case Studies - China

- China has determined to be a major player in alternative energy, electric vehicles, and hydrogen fuel cells
  - Chinese government has determined to dominate in solar and EVs
  - China has massive transit needs with enormous air pollution issues
  - China is committed to carbon reduction
- China is taking steps
  - Has ordered 333 buses, doubling number of FCBs worldwide
  - Ballard is building a fuel cell factory in China

Case Studies - China

Business case: the government will invest in developing hydrogen;

- it is a part of the solution to China's pollution problem,
- it will assist in China's commitment to reduce carbon, and
- it will allow China to be a major player in this emerging market.

Case Studies - California

- California has determined to move to zero emissions
  - Carbon
  - Pollutants
  - Noise
- Funding & Numbers
  - Move to zero emissions is funded through state taxes
  - Currently there are 109 ZEB in service
  - Total of 350 ZEBs projected in near future

Case Studies - California

Zero Emission Bus Market Growing[1]

In Service	109
Pending	241
Total	350

[1] Buses in transit fleets and universities

Last updated April 2017

RENEW HYD FUEL CELL COLLABORATIVE

Case Studies - California

Business case: moving to zero emissions is imperative for the reduction of carbon and air pollutants. Therefore California will fund this conversion, leaving it up to localities to determine whether is will be BEBs or FCBs

The Roadmap

A Roadmap for Hydrogen in the Midwest

- Hydrogen is happening
- Hydrogen is feasible
- There is a path forward that can succeed in the political and economic climate of the Midwest

Hydrogen Roadmap: it's Happening & it's Feasible

"Fuel cells have the greatest long-term potential to solve society's environmental and energy concerns."

Steve Center, Vice President, Connected and Environmental Business Development Office, American Honda Motor Co., Inc.

Hydrogen Roadmap: it's Happening & it's Feasible

Toyota has announced that starting in 2050, it will no longer sell any vehicle with an internal combustion engine in it

Hydrogen is Happening & it's Feasible

Mike Britt, recently retired Director of Maintenance & Engineering for UPS, believes that the use of hydrogen fuel cells is inevitable at UPS and would like to see the deployment of 100 fuel cell based UPS trucks in the near future

Hydrogen is Happening & it's Feasible

There are roughly 200 FCBs in the world today and this number will soon more than triple

Hydrogen Roadmap: it's Happening & it's Feasible

By the end of 2018, SARTA will have 10 FCBs in its fleet, which will be the largest fuel cell bus fleet in the U.S. outside of California

Hydrogen is Happening & it's Feasible

Warehouses are rapidly converting their battery powered forklifts to fuel cells. There are currently over 17,000 fuel cell powered forklifts in the U.S. with almost 1000 of them in Ohio.

Hydrogen is Happening & it's Feasible

In the last 2 years, Ballard Power Systems, one of the worlds largest manufacturers of fuel cell power systems, has sold more fuel cells than in the previous 36 years of its existence combined.

Hydrogen Roadmap: the path forward

- The Roll Out
  - Use grants to initiate public fleet use of hydrogen establishing initial refueling infrastructure (like SARTA, or DOE grant proposal)
  - In 2018 spread hydrogen use to municipal and commercial delivery vehicles and grow hydrogen fleet based refueling infrastructure
  - In 2023 move to light duty vehicles for municipal and commercial fleets, begin commercial refueling stations
  - In 2024 begin sales of light duty vehicles to the public and grow network of refueling stations

- Fifteen Year Results for the Midwest
  - 65,000 new jobs in the fuel cell supply chain
  - 135,000 fuel cell electric vehicles
  - 250 hydrogen refueling points

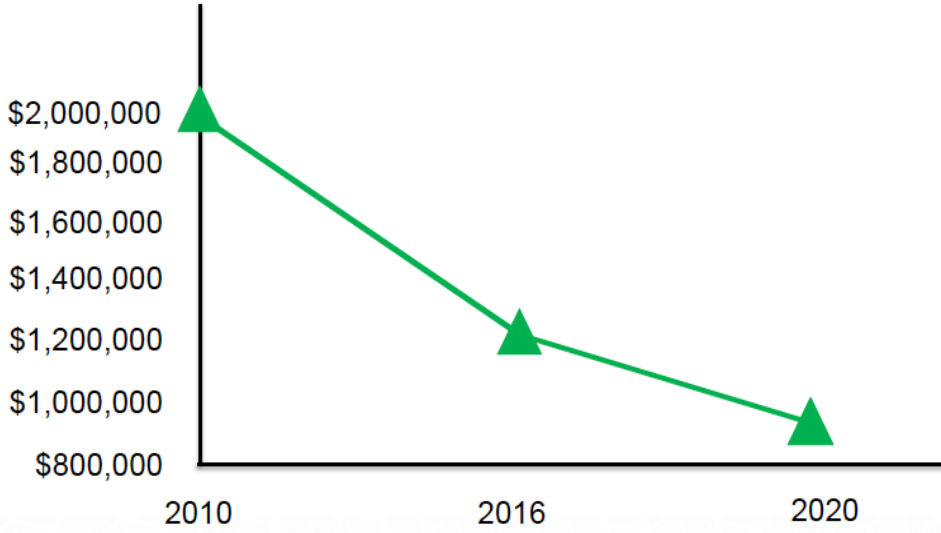
The Costs

Fuel Cell Bus Costs

- Cost Overview
  - FCB capital costs
  - FCB life
  - Refueling infrastructure costs
  - O&M costs
  - Facility upgrade costs
  - Hydrogen fuel costs
  - Training costs

Fuel Cell Bus Costs - Capital

- Capital Cost Overview
  - Two main suppliers: Eldorado & New Flyer
  - A commercial product, have undergone Altoona Testing
  - Current costs about $1.2M
  - In last two years price cut in half
  - Significant cost reductions predicted in the future
  - Ballard $1/watt program to bring significant further cost reductions



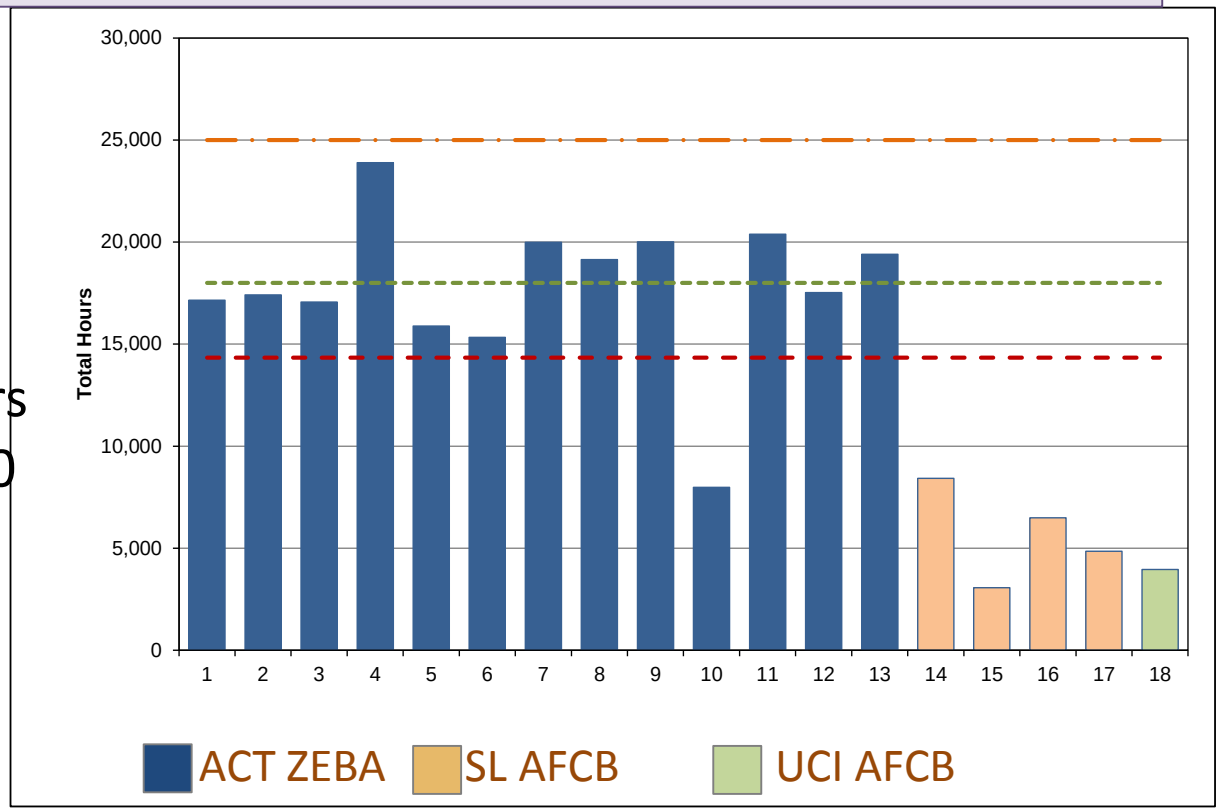
Courtesy of New Flyer

Fuel Cell Bus Costs - Life

Top fuel cell powerplant (FCPP) >23,800 hours, surpassing DOE/DOT 2016 target; 67% of FCPPs (12) more than 15,000 hours

FCB Life

- Gold Standard is 12 years, 500,00 miles with one engine rebuild
- Goal for FCB life is 12 years with fuel cell life of 25,000 hours (about 5 years)
- Continued improvements expected along with reduced rebuild costs
- Goal of 25,000 hours achievable now



NREL AMR Report 2017

Fuel Cell Bus Costs – Refueling Station Costs

- Refueling Station Costs
  - Similar to CNG station costs
  - Depending on size, from $500K to $2M
- SARTA Example
  - Capital cost of $1.2M for Air Products station with lease of $500K cryogenic pump
  - Hydrogen is produced with steam reforming in Canada and liquefied and trucked down to Canton and delivered at $4.25/kg
  - Station can easily refuel 15 buses per day
- Significant equipment cost reductions expected in the future

Fuel Cell Bus Costs – Maintenance Costs

- Expect comparable or slightly lower costs than diesel
  - Fewer moving parts
  - Fewer fluids
  - Regen braking
- Data is trending as expected

Source	Maintenance Cost ($/mile)
NREL FCB Data	$ 0.99
EU FCB Data (from Ballard)	$ 0.65
Latest Sunline FCB Data (NREL report)	$ 0.42
NREL CNG Data	$0.56
Latest Sunline CNG Data (NREL report)	$ 0.48
NREL Diesel Data	$ 0.46

Fuel Cell Bus Costs – Facility Upgrade Costs

- Facility upgrade costs
  - Similar to CNG station costs: open overhead doors, turn on ventilation fans, sound alarm
  - Depending on size of facility, from $500K to $1.5M
- SARTA Example
  - Capital cost of $750K to go to CNG
  - Additional $50K to add hydrogen sensing
- Expect some significant reductions as codes are standardized and equipment costs are reduced

Fuel Cell Bus Costs – Fuel Costs

- Hydrogen math
  - One kg of hydrogen has the rough energy equivalency of 1 gallon of diesel fuel
  - Given that FCBs are roughly twice the efficiency of diesels, the cost of fuel per kg can be divided by 2 to get $/DGE
- Prices are dropping as purchased quantities rise

Source or time period	Fuel Cost ($/kg)	Fuel Cost ($/DGE)
2016 CARB Estimate	$ 8.00	$4.00
2017 CARB Estimate	$ 7.00	$3.50
2018 CARB Estimate	$ 6.00	$3.00
2019 CARB Estimate	$5.00	$2.50
2020 CARB Estimate	$ 4.00	$2.00
Current Sunline Cost	$ 6.50	$3.25
Current SARTA Cost	$4.25	$2.00
DOE Goal	$2.00	$1.00

Fuel Cell Bus Costs – Training Costs

- Technician training is required
- Bus manufacturers offer comprehensive training
- Sunline also has excellent training materials available
- SARTA Example
  - 40 hours per tech is required

Fuel Cell Bus Costs - Summary

- Costs break down into initial capital costs, fuel costs and maintenance costs. All costs are decreasing.
  - Currently it's hard to justify the additional capital costs (above diesel), but operating costs (fuel and maintenance) are in the range of diesel costs and are expected to decline further
- Therefore, if grant money can pay for the delta in capital costs, a fuel cell bus can be operated at parity with diesel and CNG
- In the future, as costs continue to decrease, it should be possible to justify all the costs of a hydrogen fuel cell bus

The Business Case

The Business Case

- Use grant money to pay for initial capital expenses
- FCB Operating costs are currently at parity (or close to it) with diesel costs and are dropping
- If CNG is in current or planned usage, initial capital costs are significantly decreased
- All costs are continuing to decrease, so that the EU's goal that FCB complete costs of ownership (ROI, overall life, lifecycle, or total cost per mile) be at parity with diesel, could be a reality

Summary

Summary

- Fuel Cell Buses are feasible and happening
  - 200 now, 600 soon
- Initial capital costs are high but operating costs are approaching parity with diesel
- Most locations justify higher capital costs through environmental or policy mandates
- Our Roadmap gives a clear plan on how to make hydrogen in the Midwest
- The business case for this region depends on grants to "prime the pump" by covering initial capital costs until cost reductions take effect
- All costs are continuing to decrease, so that the EU's goal of complete cost of ownership could be at parity with diesel could be a reality
- Significant additional benefits in emissions reduction & job creation