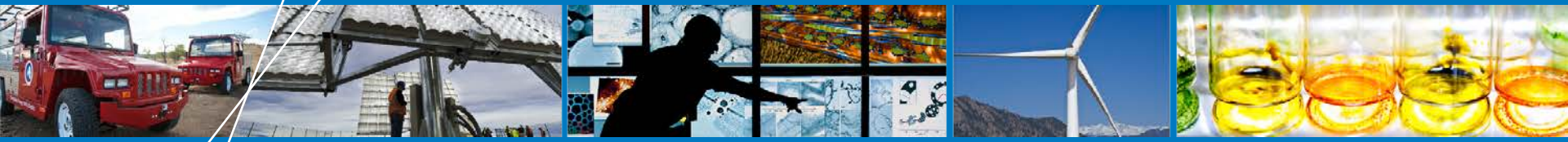
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Overview of Fuel Cell Electric Bus Development

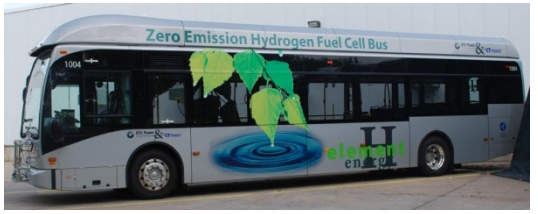


Leslie Eudy, National Renewable Energy Laboratory

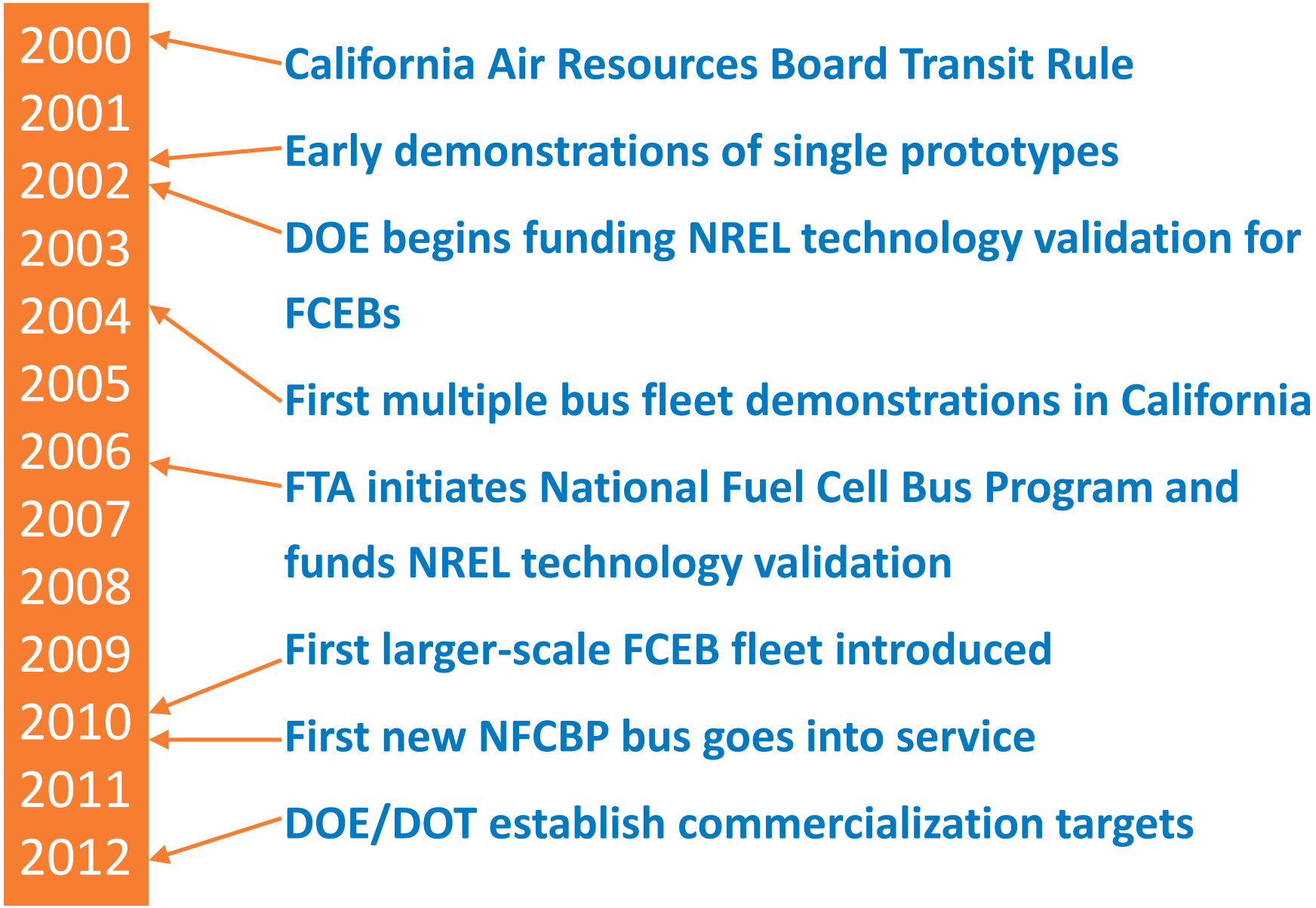
September 12, 2013

Why Fuel Cells for Transit Buses?

- **Reduce transit bus emissions**
- **Improve fuel efficiency**
- **Improve vehicle performance**
- **Consumer Acceptance**
- **Transit industry is excellent test-bed for new technologies**
  - Centrally fueled and maintained
  - Fixed routes with urban stop-go duty cycle
  - Professional operators and mechanics
  - Federal Capital Funding Support
  - High Visibility & High Impact



FCEB Development Timeline since 2000



Promoting Development of FCEBs

California Air Resources Board Transit Rule

- **Set more stringent emission standards for new urban bus engines**
- **Set fleet emission averages**
- **Promoted advances in the cleanest technologies: required demonstrations of zero-emission buses**
  - Fuel cell electric, battery electric, or trolley buses
  - Early demonstrations of 8 FCEBs at 3 agencies
  - Advanced demonstration: 12 FCEBs for SF Bay area

Promoting Development of FCEBs

FTA's National Fuel Cell Bus Program (NFCBP)

- Cooperative research, development and demonstration program to advance FCEB commercialization
- Program authorized by Congress in SAFETEA-LU
- Nearly $90 Million Federal authorized to date
- 50-50 cost share with industry
- Teams and projects competitively selected
- *Balanced portfolio of projects:*
  - FCEB demonstrations
  - Component development projects
  - Outreach/education projects

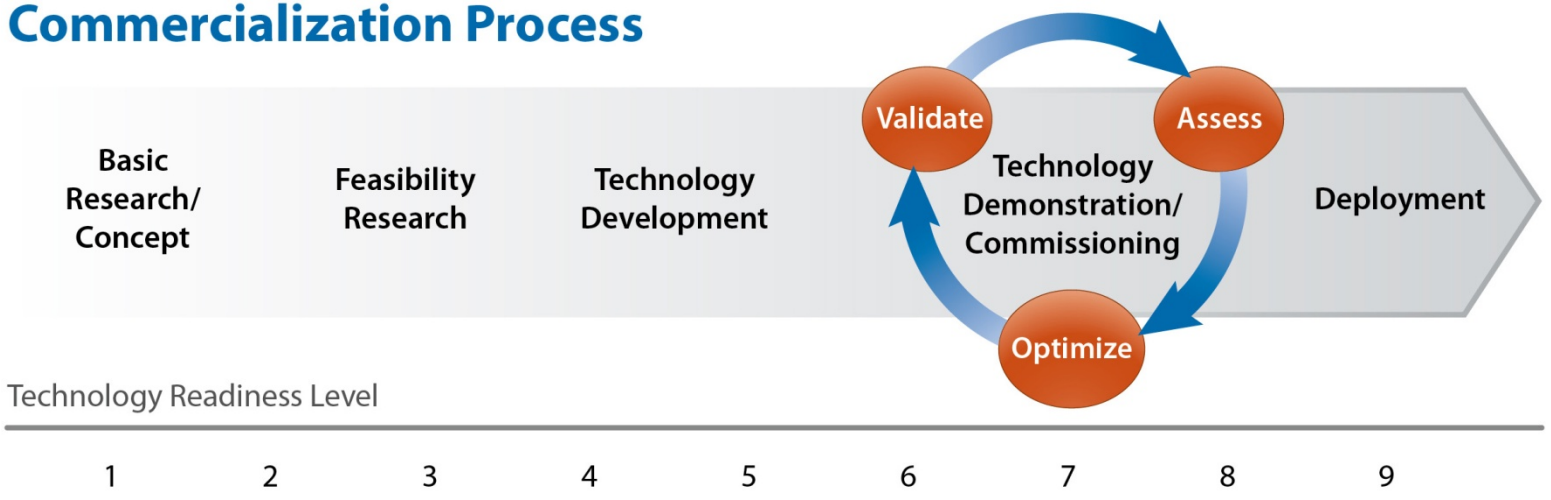
Promoting Development of FCEBs

FTA's National Fuel Cell Bus Program (NFCBP)

2012 Awards announced September 4th

Project	Consortia	Location	Partners
FCEB Fleet Extended Operation (ZEBA)	CTE	Oakland, CA	AC Transit
American Fuel Cell Bus	CALSTART	Cleveland, OH	Greater Cleveland RTA, ElDorado National, BAE Systems, Ballard Power Systems
Battery Dominant FCEB	CALSTART	Palm Springs, CA	SunLine, ElDorado National, BAE Systems
Central NY Fuel Cell Transportation Program	CTE	Ithaca, NY	Tompkins Consolidated Transit Authority, ElDorado National, BAE Systems, Ballard Power Systems
Birmingham FCEB Operational Support	CTE	Birmingham, AL	Birmingham Jefferson County Transit
FCEB Altoona Testing	CALSTART	Altoona, PA	National Bus Testing Facility
Best Practices in H2 fueling and maintenance	CALSTART	Pasadena, CA	CALSTART
NFCBP Education & Outreach	CTE	Atlanta, GA	CTE

Technology Readiness Levels

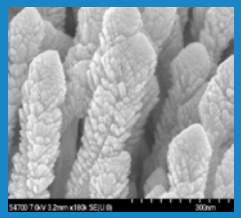


Manufacturer Teams for FCEBs Currently Operating in the United States

Bus OEM	Length (ft)	Fuel Cell System	Hybrid System	Design Strategy	Energy Storage	TRL Level
Van Hool	40	UTC Power	Siemens ELFA integrated by Van Hool	Fuel cell dominant	Lithium-based batteries	7
New Flyer	40	Ballard	Siemens ELFA integrated by Bluways	Fuel cell dominant	Lithium-based batteries	7
ElDorado	40	Ballard	BAE Systems	Fuel cell dominant	Lithium-based batteries	7
Proterra	35	Hydrogenics	Proterra integration	Battery dominant	Lithium-based batteries	6
Daimler (Orion)	40	Hydrogenics	BAE Systems	Diesel hybrid w/ FC	Lithium-based batteries	6 - 7
Ebus	22	Ballard	Ebus integration	Battery dominant	Nickel cadmium	6

DOE – DOT Collaborations

DOE and DOT support the development and deployment of fuel cell technology



Developed low Pt approach

Reduced cost by >30% since 2008, 80% since 2002

DOE RD&D

Data Collection & Validation

NREL

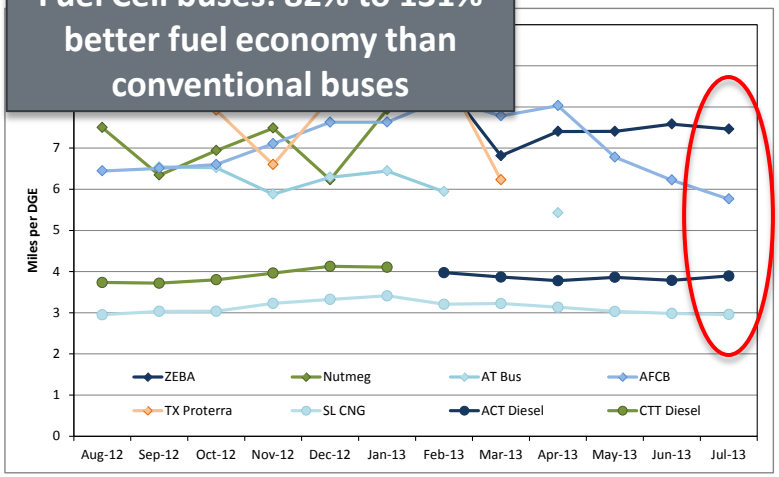
HSDC

NREL's Hydrogen Secure Data Center

National Bus Program ($49 million for 4 years)

DOT Deployment

Fuel Cell buses: 82% to 131% better fuel economy than conventional buses



Accomplishments

Demonstrated:

- Nearly doubled fuel economies (>7 mpg, ~2X compared to diesel buses)
- 87% increase in average miles between roadcall for all bus systems (~4,200 MBRC)
- Demonstrated more than 13,000 hr fuel cell durability

CENTER FOR TRANSPORTATION
AND THE ENVIRONMENT

Global Fuel Cell Bus Activities

September 12, 2013

Lauren Justice
Project Manager, CTE

National Fuel Cell Bus Program

Global Overview

- US
  - National Fuel Cell Bus Program
  - ZEBA
- Europe
  - Fuel Cell Hydrogen Joint Undertaking
  - High V.LO City
- Canada
- India, South America, China

National Fuel Cell Bus Program

Active US FC Bus Operations

Site	Fleet Size	Manufacturer Team	Fuel Economy Achievement
AC Transit ZEBA	12	Van Hool, ClearEdge*, Siemens	7.55 mi/DGE**
Nutmeg: CT, Flint, & Cleveland	4	Van Hool, ClearEdge*, Siemens	6.72 mi/DGE (CTTransit)
SunLine AT	1	New Flyer, Ballard, Siemens	5.29 mi/DGE
SunLine All American	1	ElDorado, Ballard, BAE	6.93 mi/DGE
TOTAL	18		

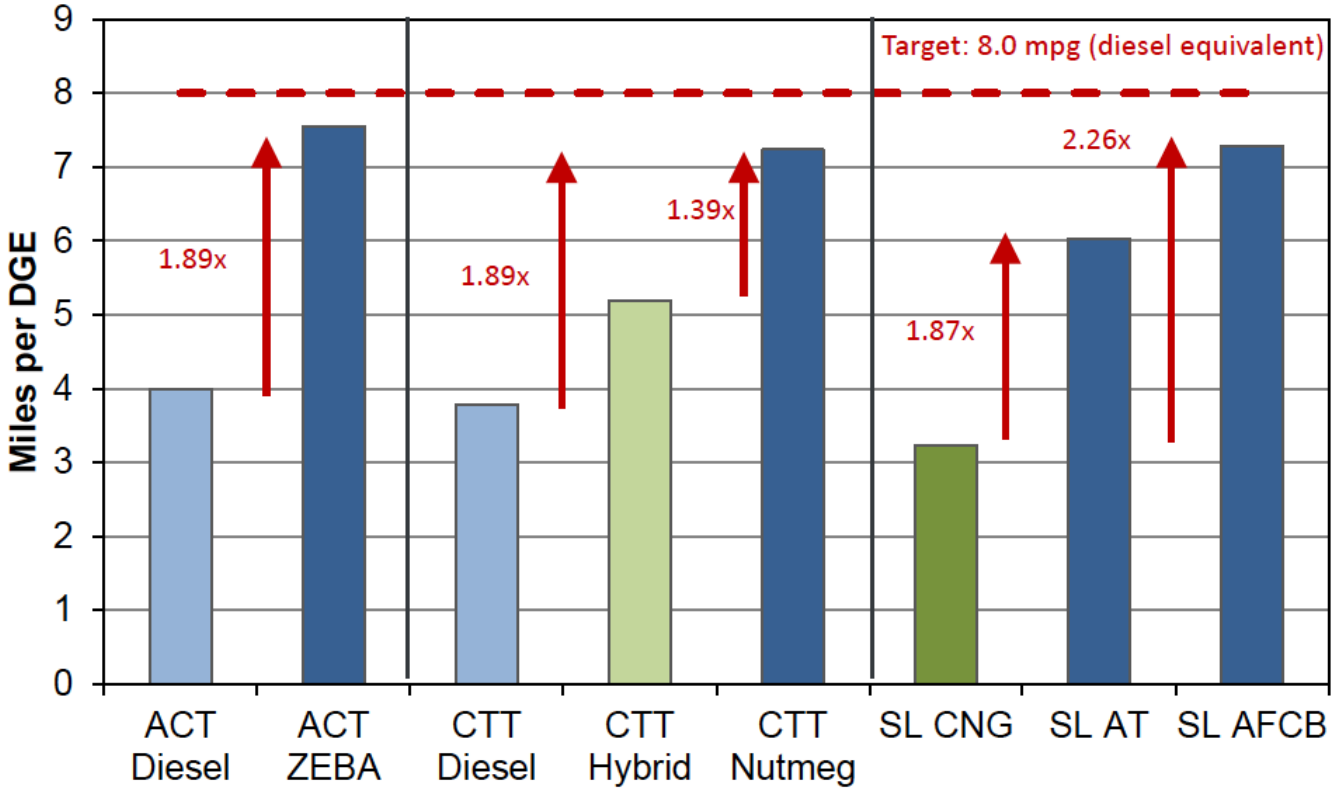
National Fuel Cell Bus Program

* Formerly UTC Power

** Diesel Gallon Equivalent

Current US FC Bus Accomplishments

From NREL's FC Bus Technology Evaluation*:



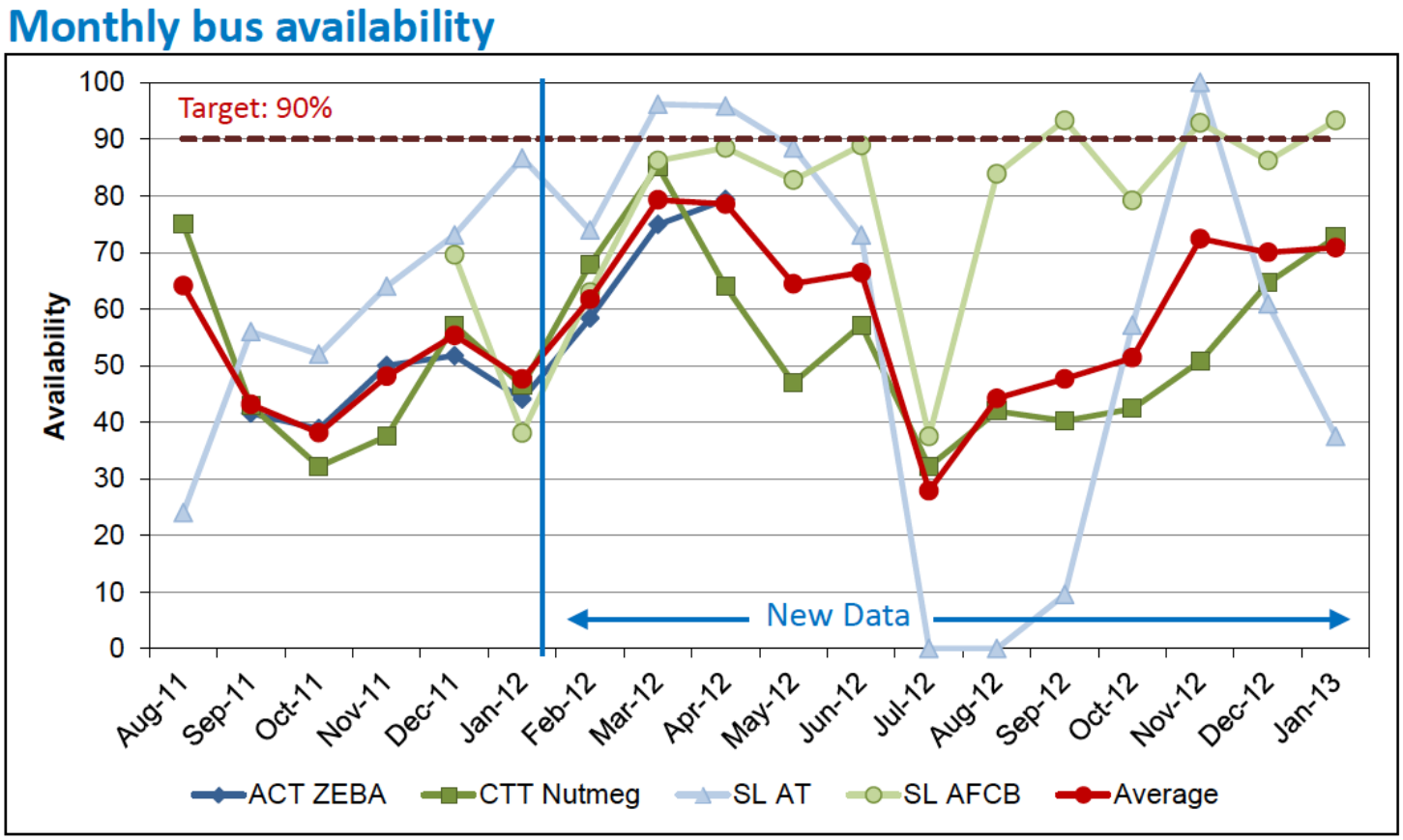
New FC bus designs have twice the fuel economy as diesel buses

National Fuel Cell Bus Program

** NREL 2013 Annual Merit review presentation*

Current US FC Bus Accomplishments

From NREL's FC Bus Technology Evaluation*:



Availability = planned operation days compared to actual operation days

National Fuel Cell Bus Program

** NREL 2013 Annual Merit review presentation*

Planned US FC Bus Operations

Site	Fleet Size	Location	Manufacturer	Estimated delivery
SunLine All American	2	Thousand Palms, CA	ElDorado, Ballard, BAE	Late 2014
Chicago All American	1	Chicago, IL	ElDorado, Ballard, BAE	Early 2014
CT All American	1	Hartford, CT	ElDorado, Ballard, BAE	Early 2015
Proterra Next Generation	1	Austin, TX & DC	Proterra, Hydrogenics, USHybrid	Early 2014
EVAmerica	1	Birmingham, AL	EVAmerica, Ballard, EPC	Fall 2013
Compound Hybrid	1	San Francisco, CA	Daimler, Hydrogenics, BAE	Fall 2013
TOTAL	7			

cte

National Fuel Cell Bus Program

Current European FC Bus CHIC Projects

Site	Fleet Size	Duration	Manufacturer	Recent Achievements
Hamburg, Germany	4 (3 more 2013)	2011-2017	Daimler/Evobus, AFCC	Fuel economy: 8.76 mi/DGE
Aargau, Switzerland	5	2011-2016	Daimler/Evobus, AFCC	Fuel economy: 8.76-10 mi/DGE
Milan, Italy	3	2011-2016	Daimler/Evobus, AFCC	
London, UK	4 (3 more 2013)	2011	Wrightbus, Ballard	8.15 mi/DGE; Avail=51% (& improving); 156,187 mi
Oslo, Norway	5	2012-2017	Van Hool, Ballard	
Cologne, Germany	2	2011-	APTS, Ballard, Vossloh	70% availability
TOTAL	23			

cte National Fuel Cell Bus Program

Next European FC Bus Projects

Site	Fleet Size	Demo Start	Manufacturer
Bolzano, Italy	5	Exp. Deliv. Yr end 2013	Daimler/Evobus
High V.LO City - San Remo, Italy	5	Exp. Deliv. Yr end 2013	Van Hool
High V.LO City - Aberdeen, Scotland	4	Exp. Deliv. Yr end 2013	Van Hool
High V.LO City - Brussels, Belgium	5	Exp. Deliv. Early 2014	Van Hool
TOTAL	**19**		

Europe's FCB Adoption : Strategic Regions

- FCH JU Study: *Urban Buses: Alternative Powertrains for Europe*
- Next phase of Powertrain study
  - Will detail EU roadmap for hydrogen and FC in transit
- FCH-JU released RFP for new demonstrations
  - Projects must have 5 buses/site
  - Priority given to linking hydrogen networks
  - Strong interface with renewable hydrogen production

Other FCB Projects Worldwide

	Fleet Size	Manufacturer Team	Details
ACTIVE: Whistler, Canada / BC Transit	20	New Flyer/Ballard	Demo: 2010-2014
ACTIVE: Japan	6 (various locations)	Toyota	2005 models
PLANNED: Sao Paolo, Brazil	3 + 25	Tutto/Ballard	
PLANNED: India	12	Tata/Ballard	First bus in testing
PLANNED: China		Ballard/Azure	Signed MOU
PLANNED: Korea		Hyundai	Unveiled in 2009

October Workshop

Bundesministerium für Verkehr, Bau und Stadtentwicklung

cte

DAIMLER

hySOLUTIONS

HYER

New Energy World JU
fuel cells & hydrogen for sustainability

NOW
National Organisation Hydrogen and Fuel Cell Technology

INTERNATIONAL
FUEL CELL BUS
WORKSHOP

2013

OCTOBER 16 & 17
HAMBURG, GERMANY
Panoramadeck • Dammtorwall 15, 20355

TOUR HAMBURG'S STATE-OF-THE-ART HYDROGEN STATION

HYDROGENICS
Advanced Hydrogen Solutions

BALLARD

Linde

SIEMENS

BAE SYSTEMS

ENERDEL

PROTERRA

US Hybrid

cte

National Fuel Cell Bus Program

Questions?

CENTER FOR TRANSPORTATION & THE ENVIRONMENT
Lauren@cte.tv
www.cte.tv

FCB rollout strategy California

Nico Bouwkamp

September 12, 2013

California and the future

“How can FCEBs become one of the advanced vehicle technologies that transit agencies will choose to fulfill California’s goal of decreasing transportation air pollution?”

"FCEB Road Map" focus

A step change in the FCEB market from the current pre-commercial phase of deployment and manufacturing to the early commercial phase

NREL Technology Readiness Levels for FCEB Commercialization

Technology Readiness Level	Description (abbrev.)
TRL 9	Technology in its final form. Fully commercial products.
TRL 8	Last step in true system development (50-100 buses/location)
TRL 7	Full-scale demonstration and reliability testing (5-10 buses/location)
TRL 6	First tests of prototype buses in actual transit service (1-2 buses/location)
TRL 1-5	R&D → lab scale testing & early prototype/mule

US DOE / US DOT targets

Table 1. Performance, cost, and durability targets for fuel cell transit buses.

	Units	2012 Status	2016 Target	Ultimate Target
Bus Lifetime	years/miles	5/100,000[1]	12/500,000	12/500,000
Power Plant Lifetime[2,3]	hours	12,000	18,000	25,000
Bus Availability	%	60	85	90
Fuel Fills[4]	per day	1	1 (< 10 min)	1 (< 10 min)
Bus Cost[5]	$	2,000,000	1,000,000	600,000
Power Plant Cost[2,5]	$	700,000	450,000	200,000
Hydrogen Storage Cost	$	100,000	75,000	50,000
Road Call Frequency (Bus/Fuel Cell System)	miles between road calls	2,500/10,000	3,500/15,000	4,000/20,000
Operation Time	hours per day/days per week	19/7	20/7	20/7
Scheduled and Unscheduled Maintenance Cost[6]	$/mile	1.20	0.75	0.40
Range	miles	270	300	300
Fuel Economy	miles per gallon diesel equivalent	7	8	8

TRL 7 TRL 8 TRL 9

http://hydrogen.energy.gov/pdfs/12012_fuel_cell_bus_targets.pdf

FCEB rollout strategy

Goal

- Move FCEB deployment and manufacturing from pre-commercial (2012-2015) to early commercial (2016-2017)

Major objectives

- Create two Centers of Excellence
  - One in Northern and one in Southern California
- Achieve US DOE/US DOT 2016 FCEB targets
- Provide information to support state and federal decision making

AC Transit fueling station (Photo courtesy of L. Eudy, NREL)

Centers of Excellence

Key components

- A single bus configuration per site, manufactured under a serial production run of 40 units over 1 to 2 years
- Vehicles meet transit agency requirements & operate in revenue service on scheduled runs (e.g. no compromise or deviation in service)
- A 12-year operating period
- A single H2 fueling station with sufficient throughput to achieve fuel cost/mile comparable to conventional buses
- Vehicles introduced in 2015-16 timeframe
- Regional training and education for transit staff and stakeholders

Fueling station assumptions

Category	Details
Station lifetime	15-20 years
Fuel quality	SAE J2719
Fuel pressure	35 MPa
Fill time per bus (pending on bus design)	5-8 minutes
Average fill amount per bus	30 kg/day
Station capacity (based on 30 kg/day/bus, 40 FCEBs)	1,200 kg/day
Number of dispensers capable of fueling simultaneously	2 dispensers
Bus fleet fueling window	4-5 hours/day

Financial budget (TRL 7→8)

- For 12-yr deployment capital cost per site is $50.2M
- At $1M/bus the incremental cost is ~$30M/location compared to conventional buses (bus cost only)

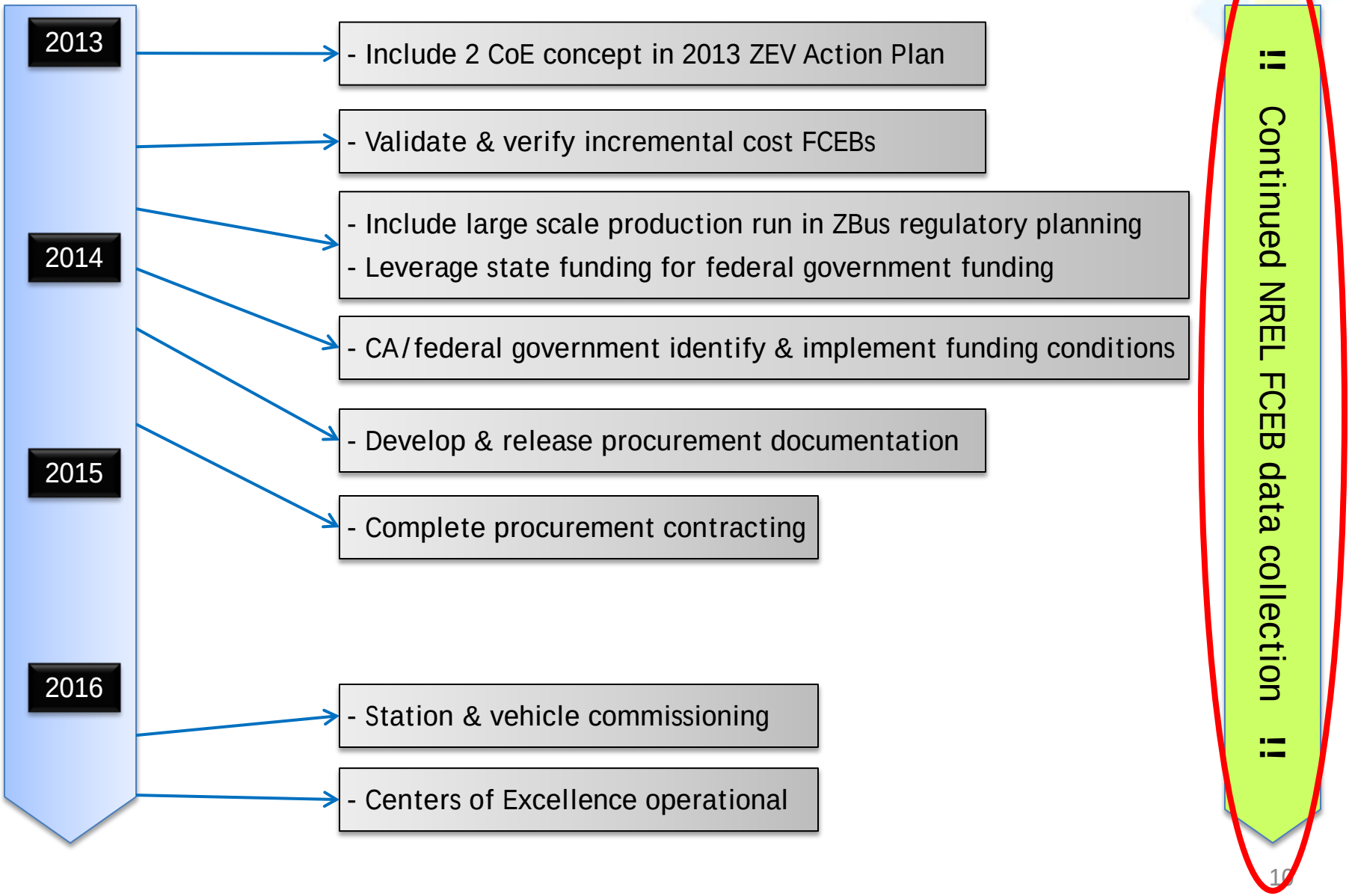
Capital equipment	Units per Center of Excellence	Capital cost per location	Capital cost for two Centers of Excellence
FCEBs	40	$40M	$80M
H2 station	1	$5M	$10M
Maintenance facility	1	$2M	$4M
Mid-life overhaul of bus power plant (6 yrs)	40	$3.2M	$6.4M
Total	**n/a**	**$50.2M**	**$100.4M**

- Fuel and station O&M cost paid by vehicle operator
  - $4-9 kg (depending on mode of supply) and O&M ~$200,000/year
- Costs could be reduced by utilizing existing infrastructure

Funding scenario

Funding source	% of CoE
US DOT FTA Conventional	47%
California Energy Commission AB118	19%
Cap and Trade Auction Proceeds	19%
California Air Resources Board Hybrid Voucher Program	7%
Air Quality Management Districts	5%
Regional Matching Funds	2%
Total	100%

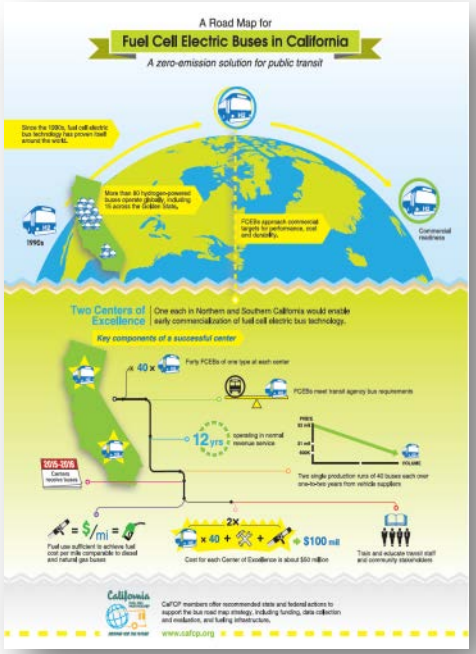
Typical funding (bus only): US DOT FTA 80% - local sources 20%


2013
2014
2015
2016
- Include 2 CoE concept in 2013 ZEV Action Plan
- Validate & verify incremental cost FCEBs
- Include large scale production run in ZBus regulatory planning
- Leverage state funding for federal government funding
- CA/federal government identify & implement funding conditions
- Develop & release procurement documentation
- Complete procurement contracting
- Station & vehicle commissioning
- Centers of Excellence operational
!! Continued NREL FCEB data collection !!

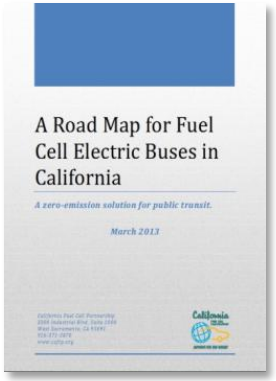
CaFCP Members

Air Liquide
Air Products
Alameda-Contra Costa Transit District
Automotive Fuel Cell Cooperation
Ballard Power Systems
California Air Resources Board
California Department of Food and Agriculture
California Energy Commission
California State University-Los Angeles
Center for Energy Efficiency and Renewable Technologies
Chrysler
Daimler
Energy Independence Now
General Motors
Honda
Hydrogenics
Hyundai
Institute of Transportation Studies, UC Davis
Linde North America, Inc.
National Fuel Cell Research Center, UC Irvine
National Renewable Energy Laboratory
Nissan
Powertech Labs
Proton OnSite
Sandia National Laboratories
South Coast Air Quality Management District
Southern California Gas Company
SunLine Transit Agency
Toyota
U.S. Department of Energy
U.S. Department of Transportation
U.S. Environmental Protection Agency
US Hybrid
Volkswagen

Questions or comments?



Nico Bouwkamp
nbouwkamp@cafcp.org
(916) 375-8050



Available at:
http://cafcp.org/carsandbuses/busroadmap

Thank You

gregory.kleen@go.doe.gov

hydrogenandfuelcells.energy.gov