Zero Emission Buses

Benefits and Considerations

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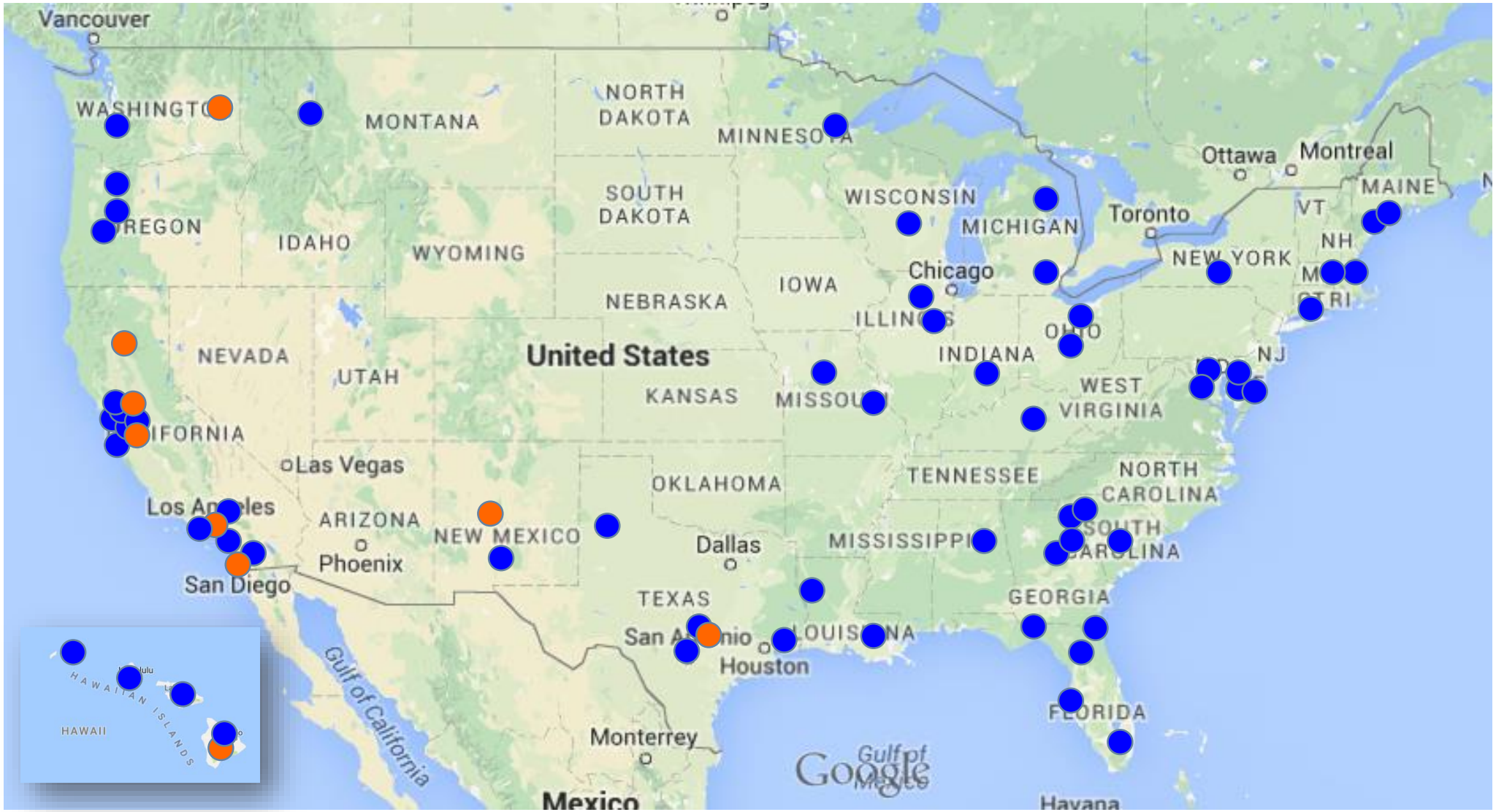
CTE

About CTE

- Mission: To advance clean, sustainable, innovative transportation and energy technologies
- 501(3)(c) non-profit engineering and planning firm
- Portfolio - $550 million
  - Research, demonstration, deployment
  - 95 Active Projects Totaling over $300 million
- Focused on Zero Emission Technologies
- National presence

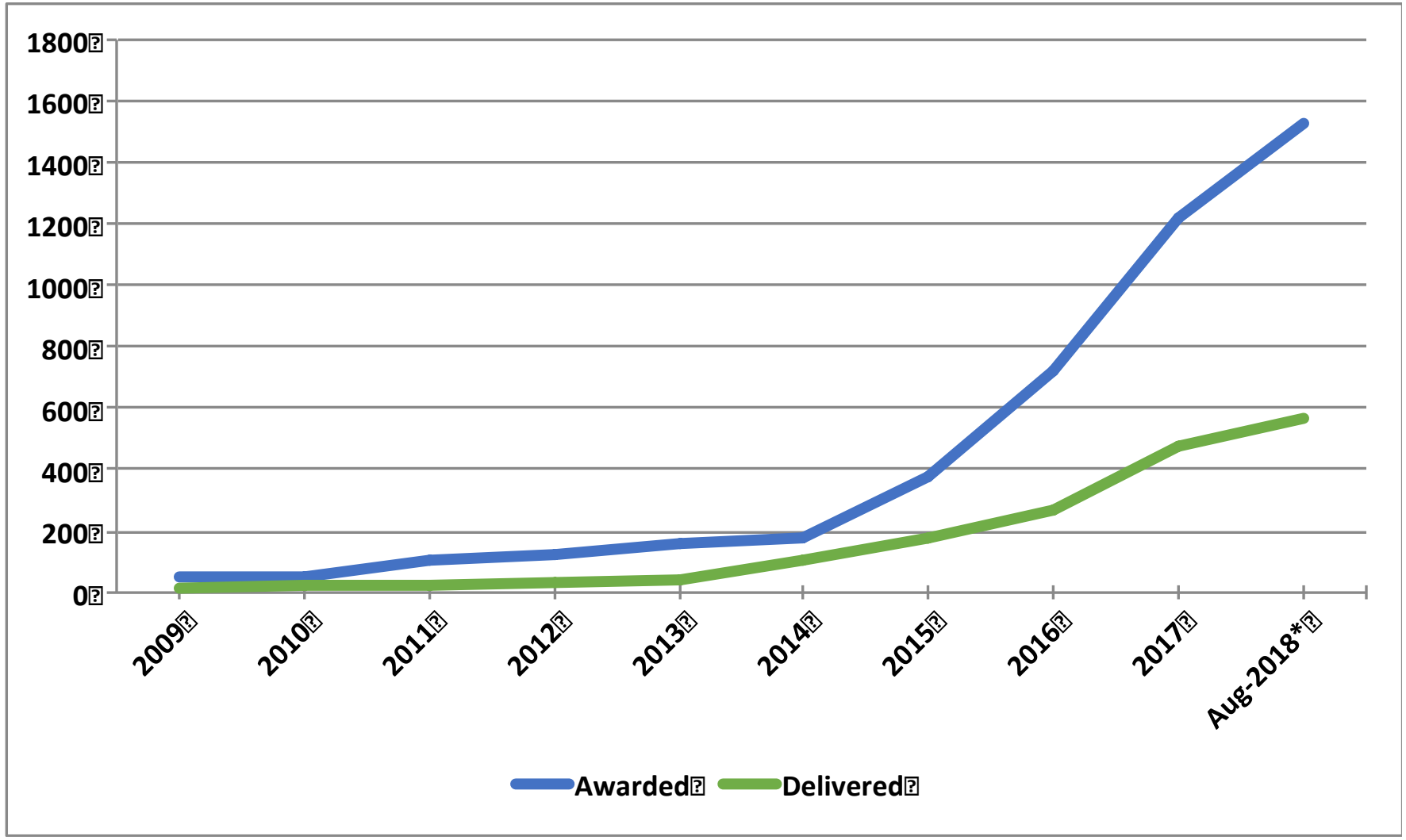
  Atlanta, Berkeley, Los Angeles, St. Paul

CTE Zero Emission Bus Projects

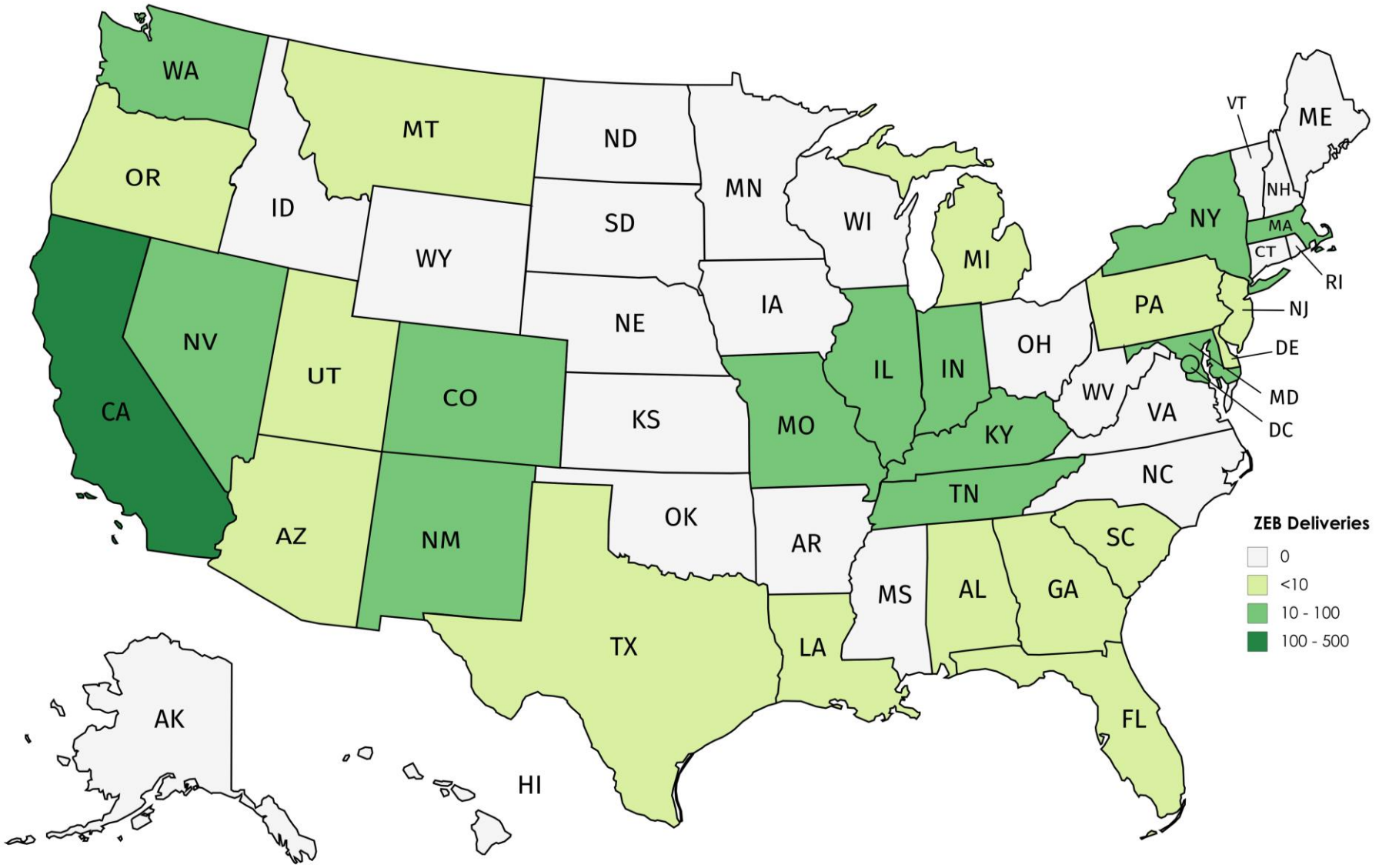


- ***ZEB Planning Projects***
- ***ZEB Deployment Projects***

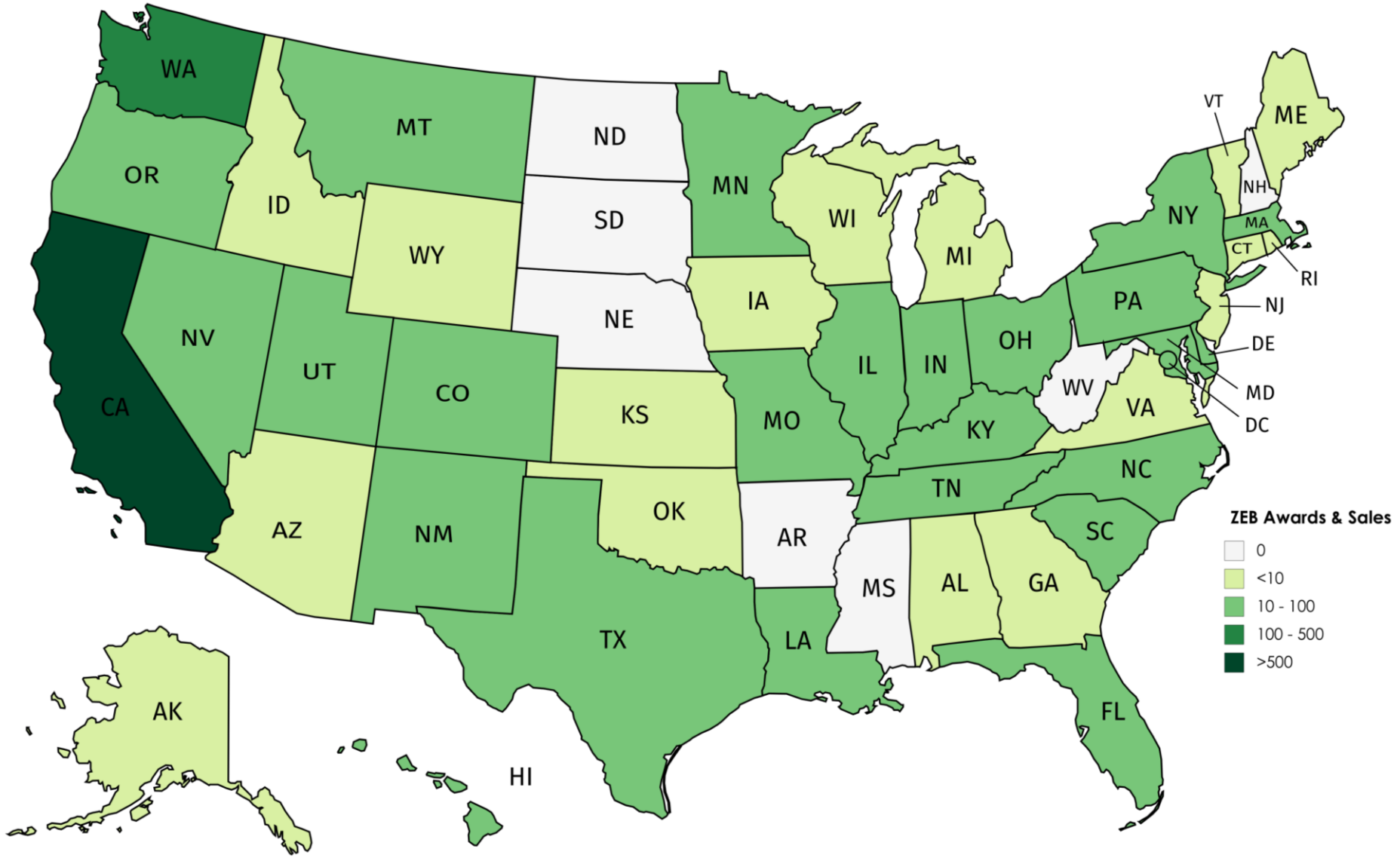
US ZEB Annual Awards & Deliveries



ZEB Deliveries



ZEB Awards & Sales



ZEB Market Development

BEB

Calendar Year	Awards & Sales
2009 - 2014	138
2015	179
2016	322
2017	492
Aug-2018	314

Calendar Year	Base Price	Energy Storage
2010	$1.2 mm	75 kWh
2016	$750k	300+ kWh
2018	$750k	450+kWh

FCEB

Calendar Year	Awards & Sales
2009 - 2014	44
2015	12
2016	28
2017	1
Aug-2018	0

Calendar Year	Base Price
2010	$2.2 mm
2016	$1.2mm
*2020	$900k

ZEB OEMs


NEW FLYER OF AMERICA


GP
GreenPower Bus
The Future of Public Transportation


PROTERRA


BYD


VANHOOL


NOVA BUS


GILLIG


ElDorado
National - California


MOTOR COACH
INDUSTRIES


CCW
COMPLETE COACH WORKS


cte

ZEB Models

Body Style	Length	Energy Storage (kWh)	BYD	CCW	ENC	GILLIG	GreenPower	MCI	NovaBus	Proterra	New Flyer	Van Hool	Total
BEB Low Floor	30	210 - 496	2	1			1						4
	35	94 - 440	1	1			1			5	1		9
	40	94 - 660	2	1	1	1	1		1	7	3		17
	45	320 - 323	1				1						2
	60	320 - 818	1								3		4
BEB Coach	23	134 - 134	1										1
	35	348 - 348	1										1
	40	391 - 391	1										1
	45	496 - 496	1					1				1	3
BEB Double Decker	35	170 - 170	1										1
	45	230 - 478	1				1						2
BEB Total			**13**	**3**	**1**	**1**	**5**	**1**	**1**	**12**	**7**	**1**	**45**
FCEB Low Floor	40				1						1		2
	60										1		1
FCEB Total			**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**2**	**0**	**3**
ZEB Total			**13**	**3**	**2**	**1**	**5**	**1**	**1**	**12**	**9**	**1**	**48**

- ***Altoona Tested?***
- ***Range vs. Passengers?***

BEB Charger Vendors

Charging Equipment Types

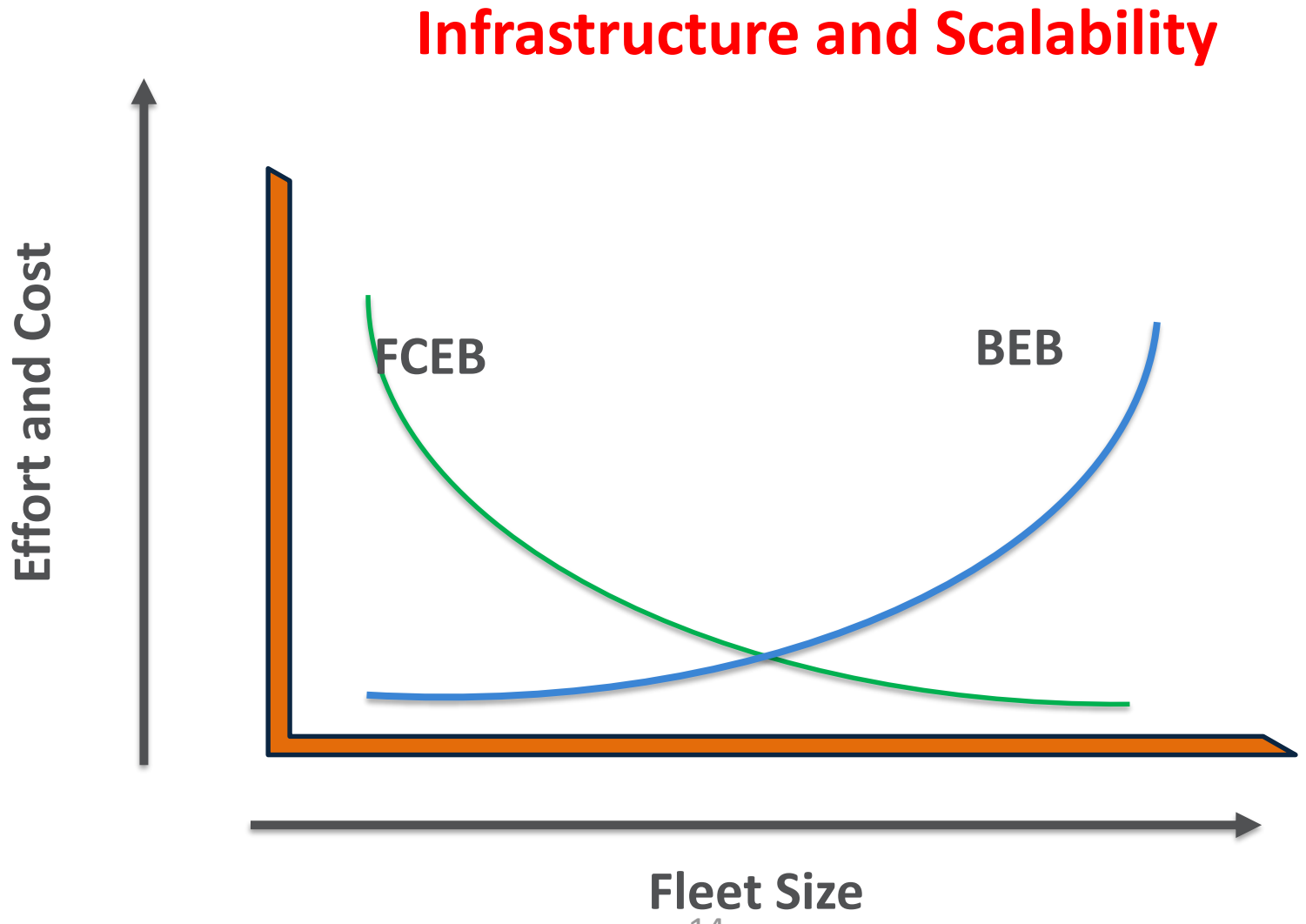
Why Zero Emission Buses

- Reduces dependency on foreign oil
- More efficient
- Cleaner
- Quieter
- Passengers prefer to ride in them
- Lower Operating Costs
- Longer Life
- Stable, US produced fuel source

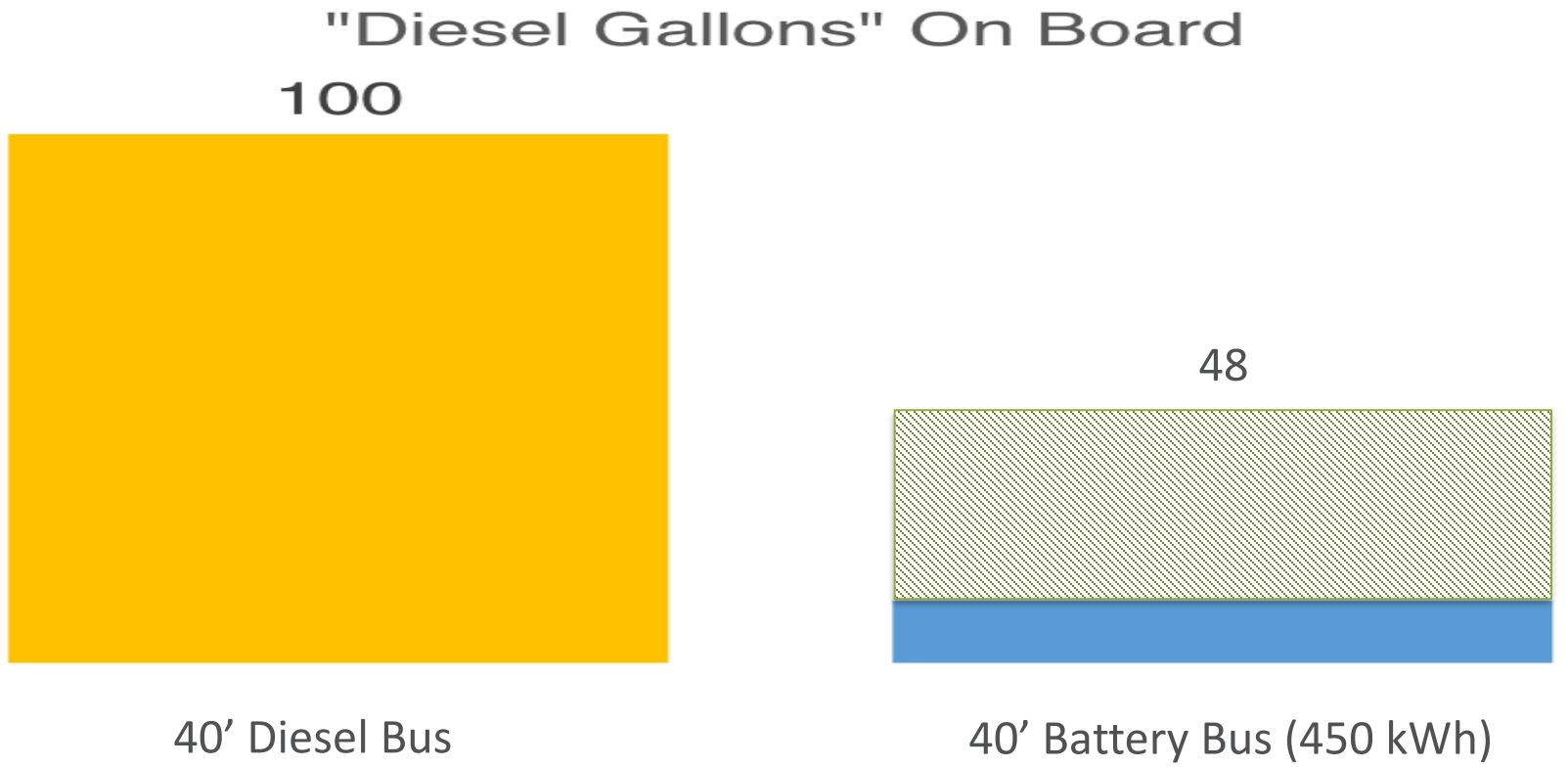
Hydrogen Fuel Cell Buses

- Vehicle fueling is similar to CNG
  - 10 minute filling
  - Operationally consistent with typical transit workflow
  - Small overall station footprint
- Sufficient range for most transit service
- FC system can be used to support cabin heat
- Bus Costs are still high and fuel costs are still inconsistent

Both ZEB Technologies Will Play a Role



The Biggest Challenge for BEBs



Electric Drive is four times as efficient as the Internal Combustion Engine. 12 DGE can deliver power equal to 48 gallons of Diesel

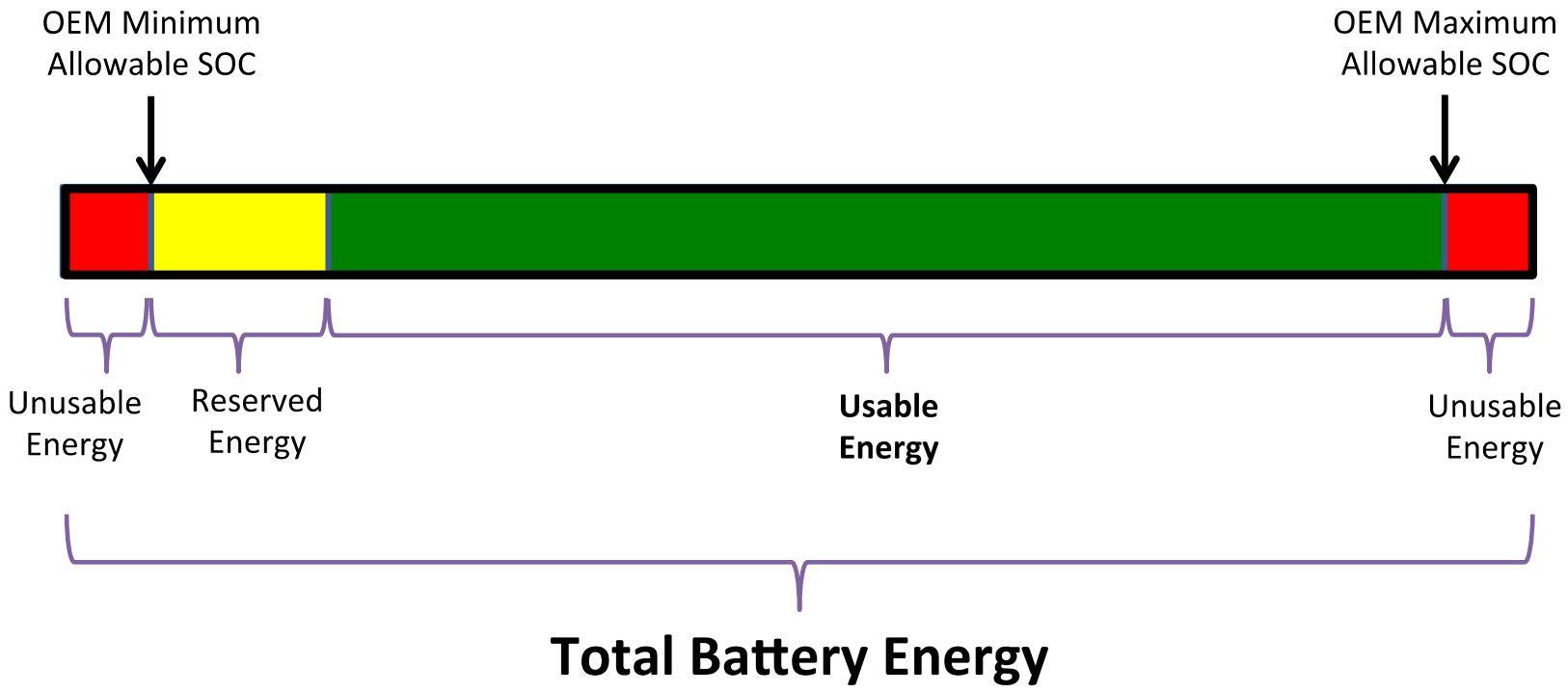
U.S. Department of Energy: 38 kWh is equivalent to 1 gallon of diesel

BEB Deployments are Complicated

- Fuel costs can change hour-to-hour
- Bus performance can change drastically route-to-route and season-to-season
- Bus efficiency can range from <1 kwh m to >6 kwh/m
- Usable service energy is +/- 75 percent of total battery capacity
- Battery capacity decreases over time
- Auxiliary loads have a large effect
- Drivers can have a huge influence on efficiency

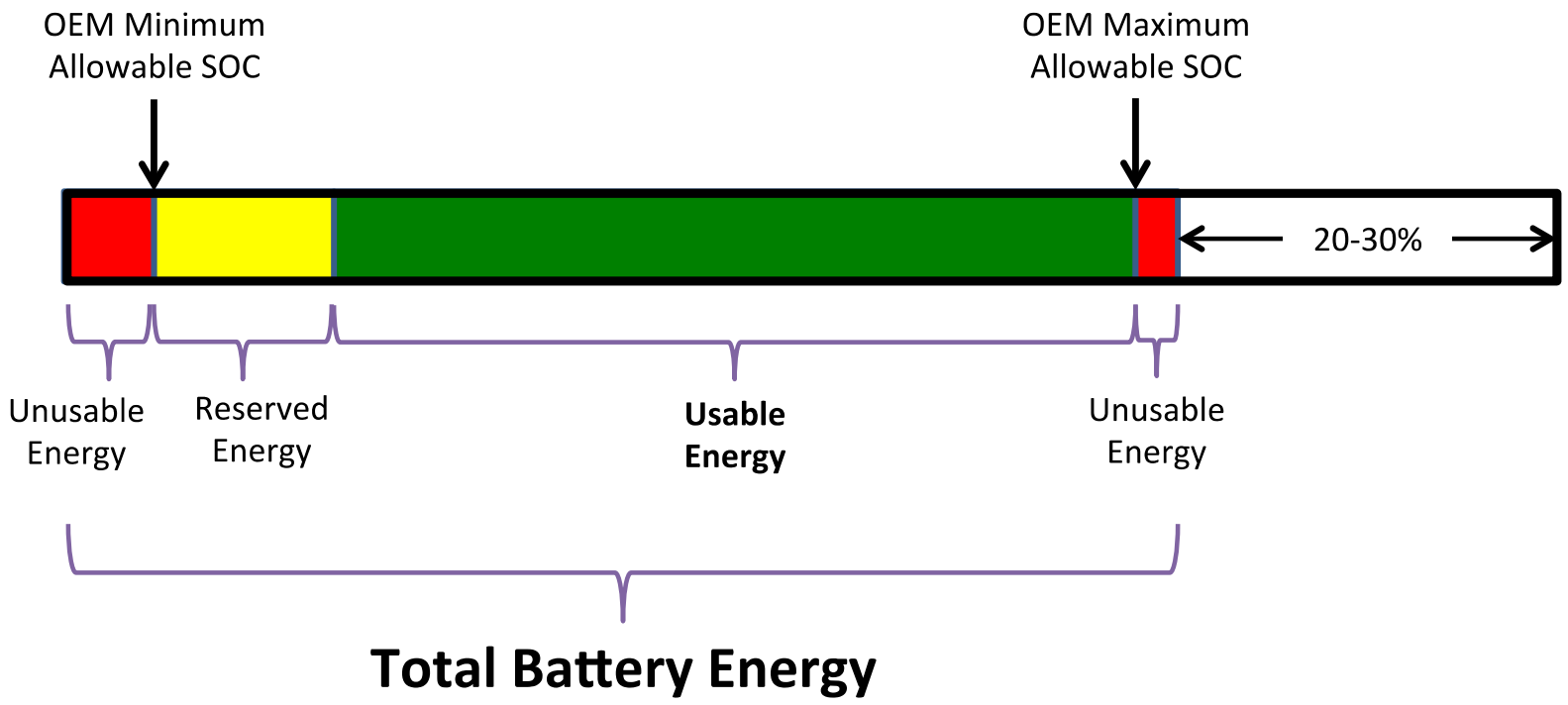
Battery Capacity Terminology

Beginning-of-Life Batteries



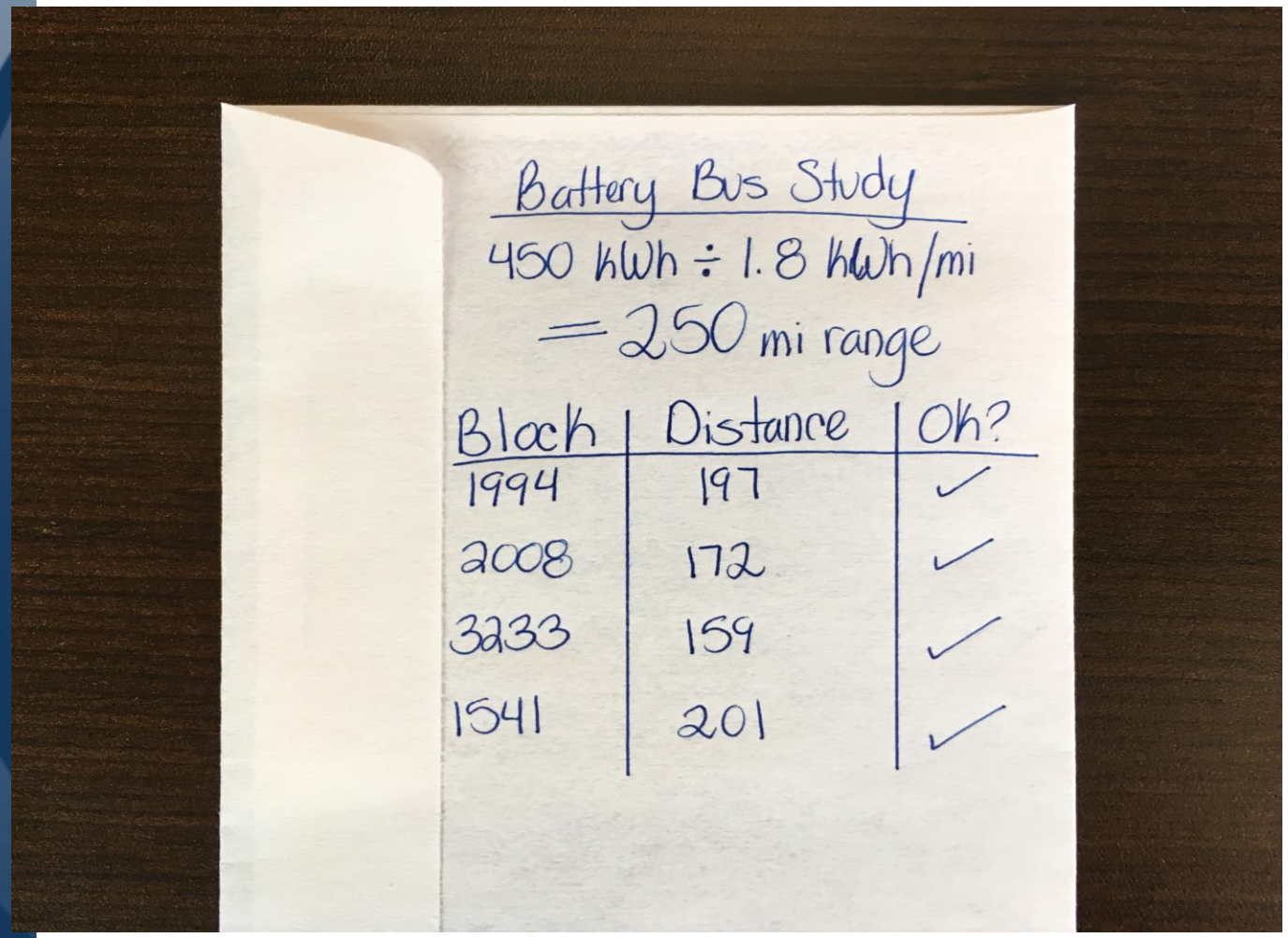
Battery Capacity Terminology

End-of-Life Batteries



Note: Batteries all lose capacity through use and aging

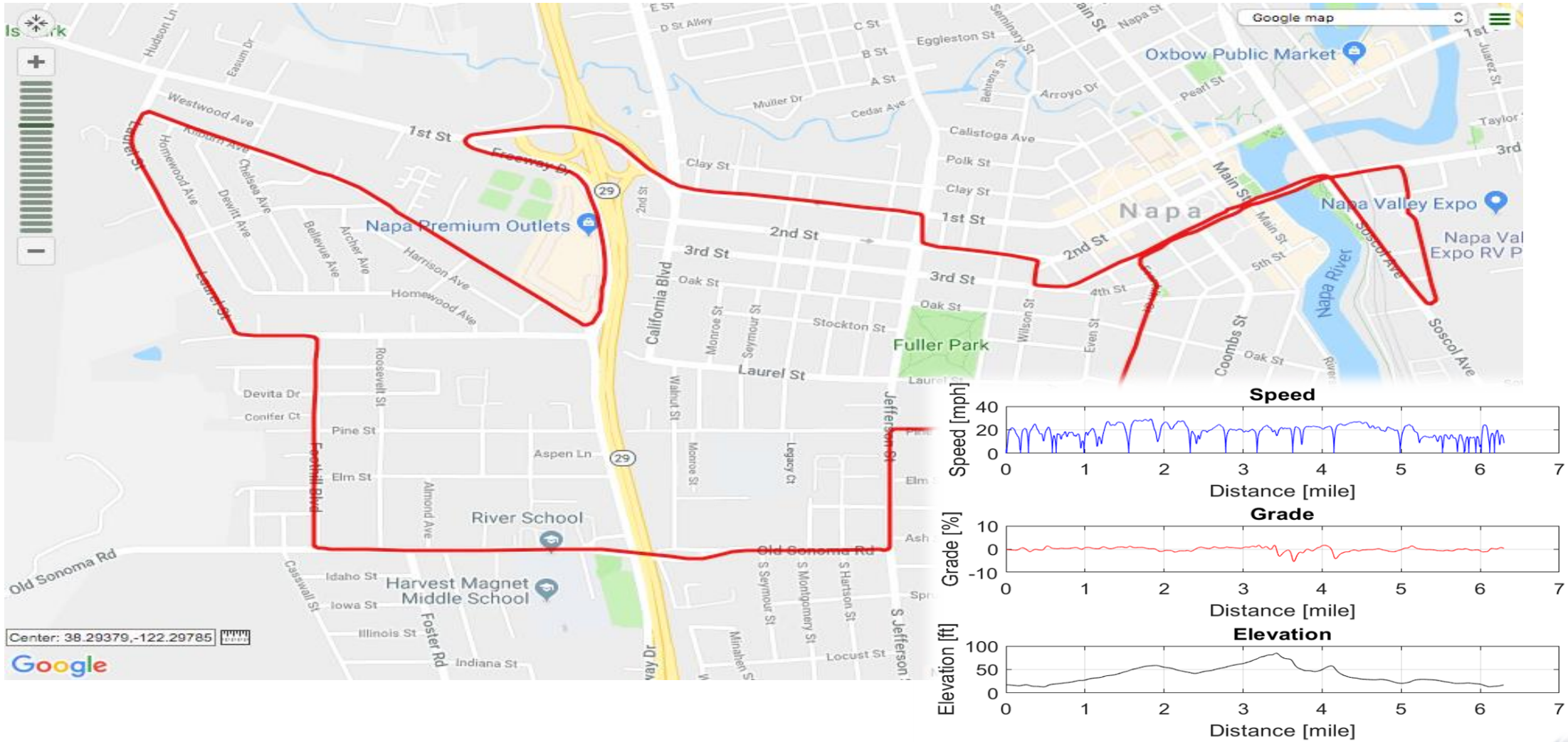
Naïve Method—Range



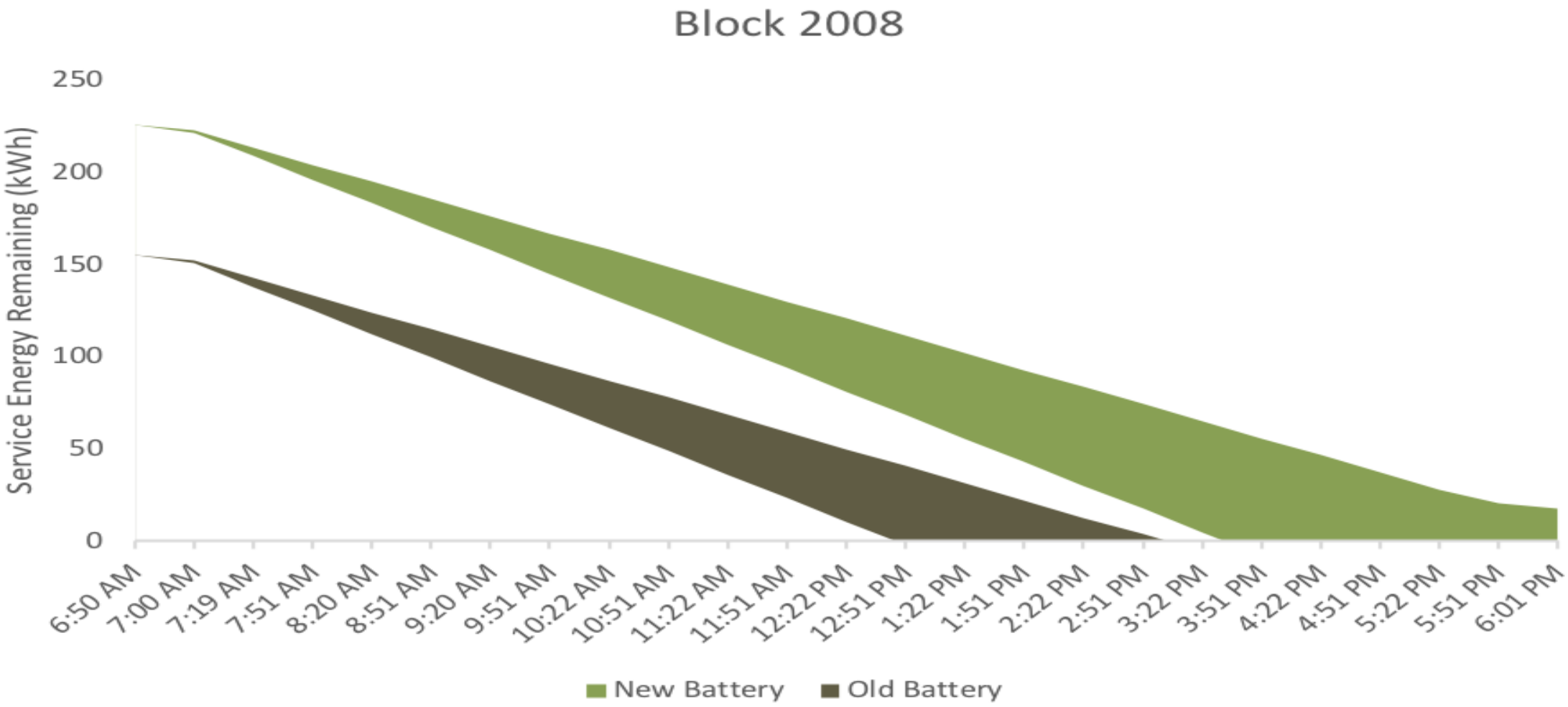
Agencies have seen a range of BEB efficiencies in service:

- **< 1 kWh to > 6 kWh!!!**
- **Only 75% of Capacity is Available**
- **Auxiliary Loads have a huge effect**
- **Drivers have a huge effect**
- **Battery Capacity decreases over time**

Prudent Method—Model the Routes

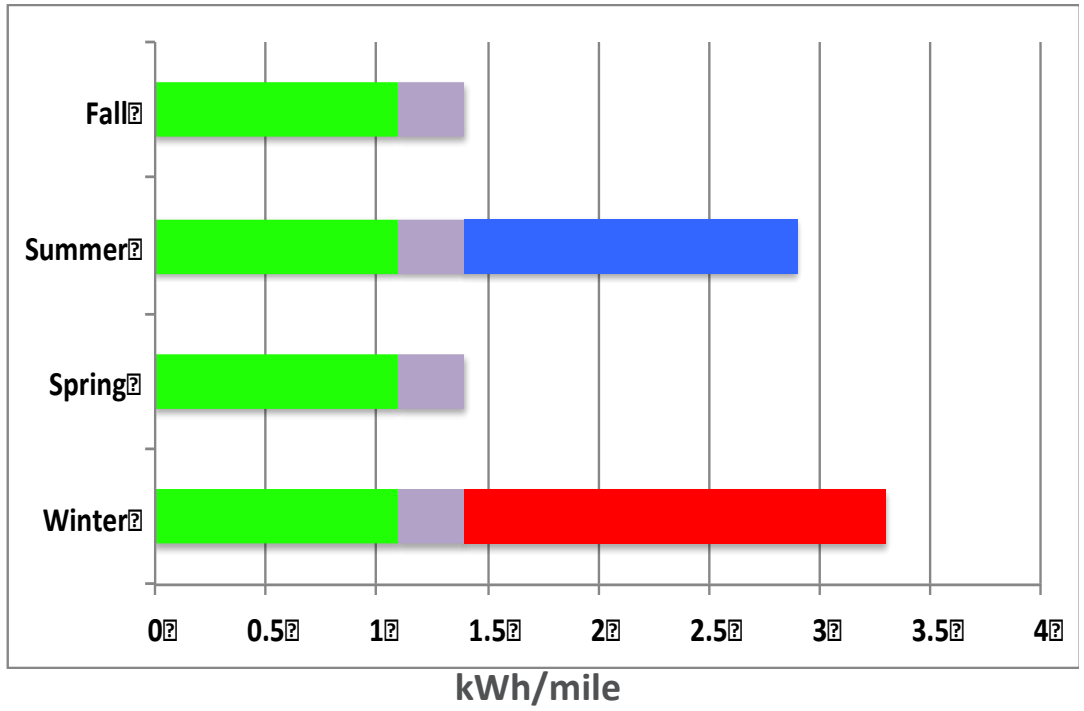


Prudent Method—Model the Blocks

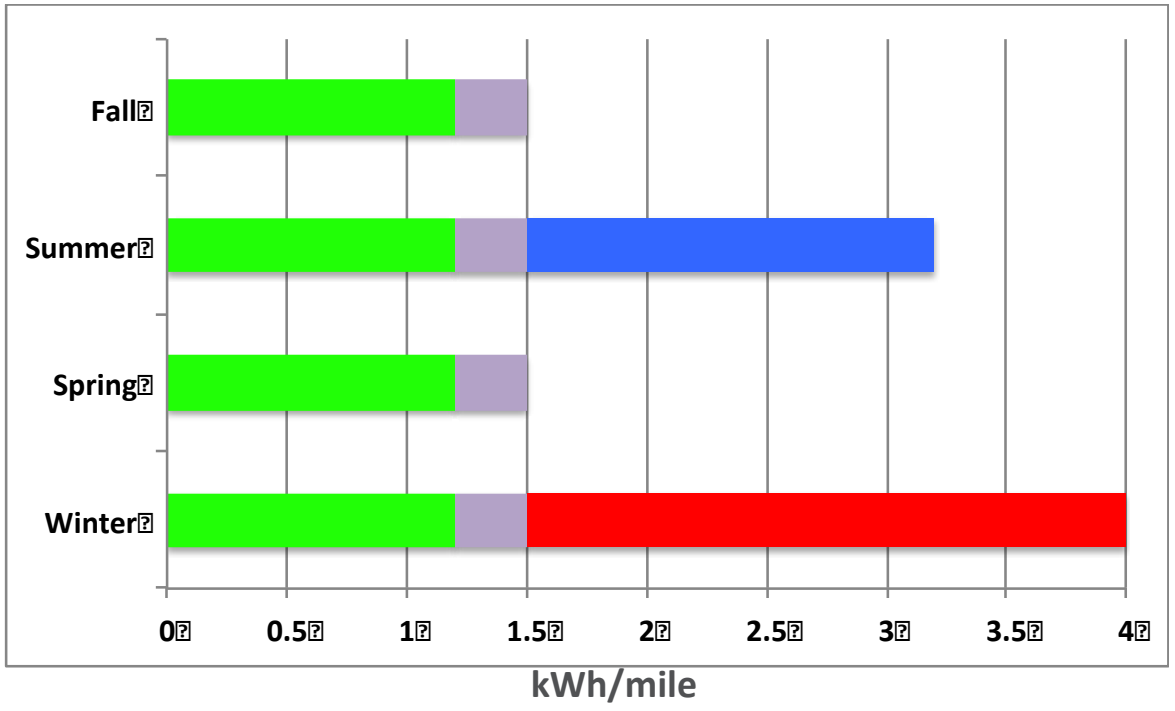


Prudent Method—Include HVAC

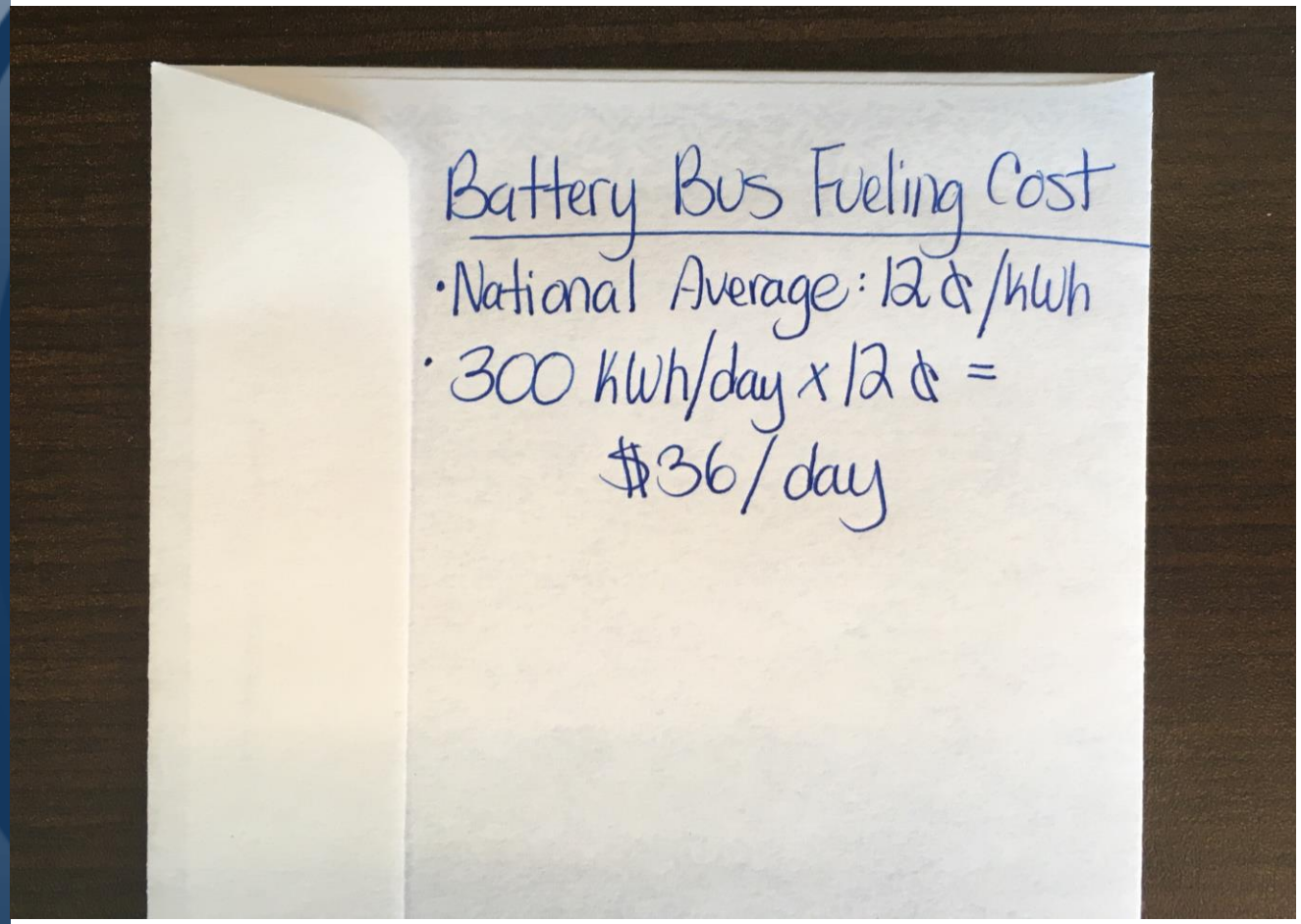
Route A



Route B



Naïve Method—Fuel Cost Estimates

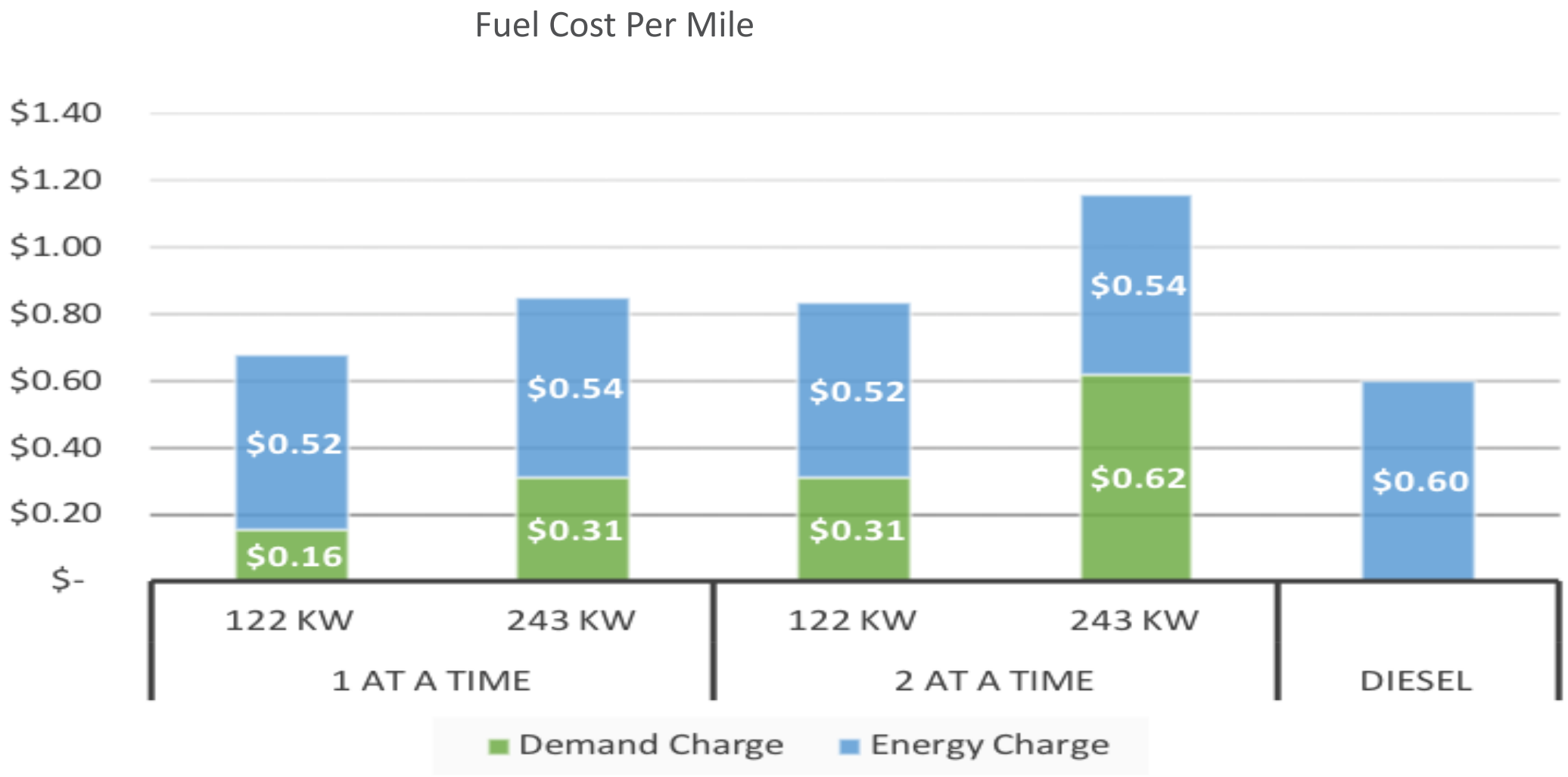


Electricity costs are highly variable across the country.

Charges can change by:

- **Time of Day**
- **Day of week**
- **Season**

Prudent—Charge & Rate Modeling



BEB Solicitations – What Does Not Matter (much)

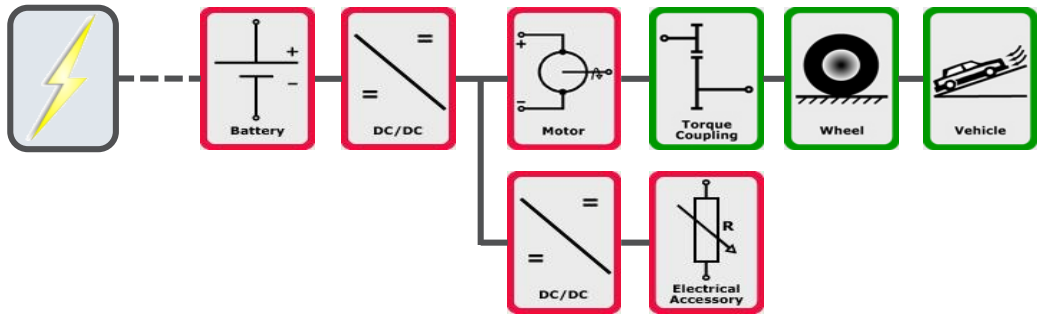
- Bus advertised range
- Bus Range Performance at Altoona
- Bus Range Performance at other transit operators
- Fuel Costs at other transit operators
- Average energy costs in your area

BEB Solicitations – What Really Matters

- How will the bus perform on your route, in your climate?
- Which rate schedule will work best for you under your operation scenario and vice versa?
- What will the bus do under strenuous use cases?

End of battery life
Heavy passenger load
Heavy Traffic load

Poor Driver or Driver Behind Schedule
Warmest Day
Coldest Day



Thank You!

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