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Supply Chain Opportunities for Fuel Cell Buses

SARTA Fuel Cell Bus

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Sponsored by:

Stark Area Regional Transit Authority

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How the Shale Gale Changed the World

- 2005:
  - US oil imports at 12,500 bbls/day
  - Oil at $120/bbl
    - $50 mm/day
  - 60% of US trade deficit was from oil imports.
  - Peak Oil projected for 2025-2035.
- 2015:
  - US oil imports at 5,000 bbls/day
  - Oil at $38/bbl
    - $10 mm/day
  - 10% of US trade deficit from oil imports.
  - No projections on peak oil – *nobody knows*.

So why should we care about fuel cells?

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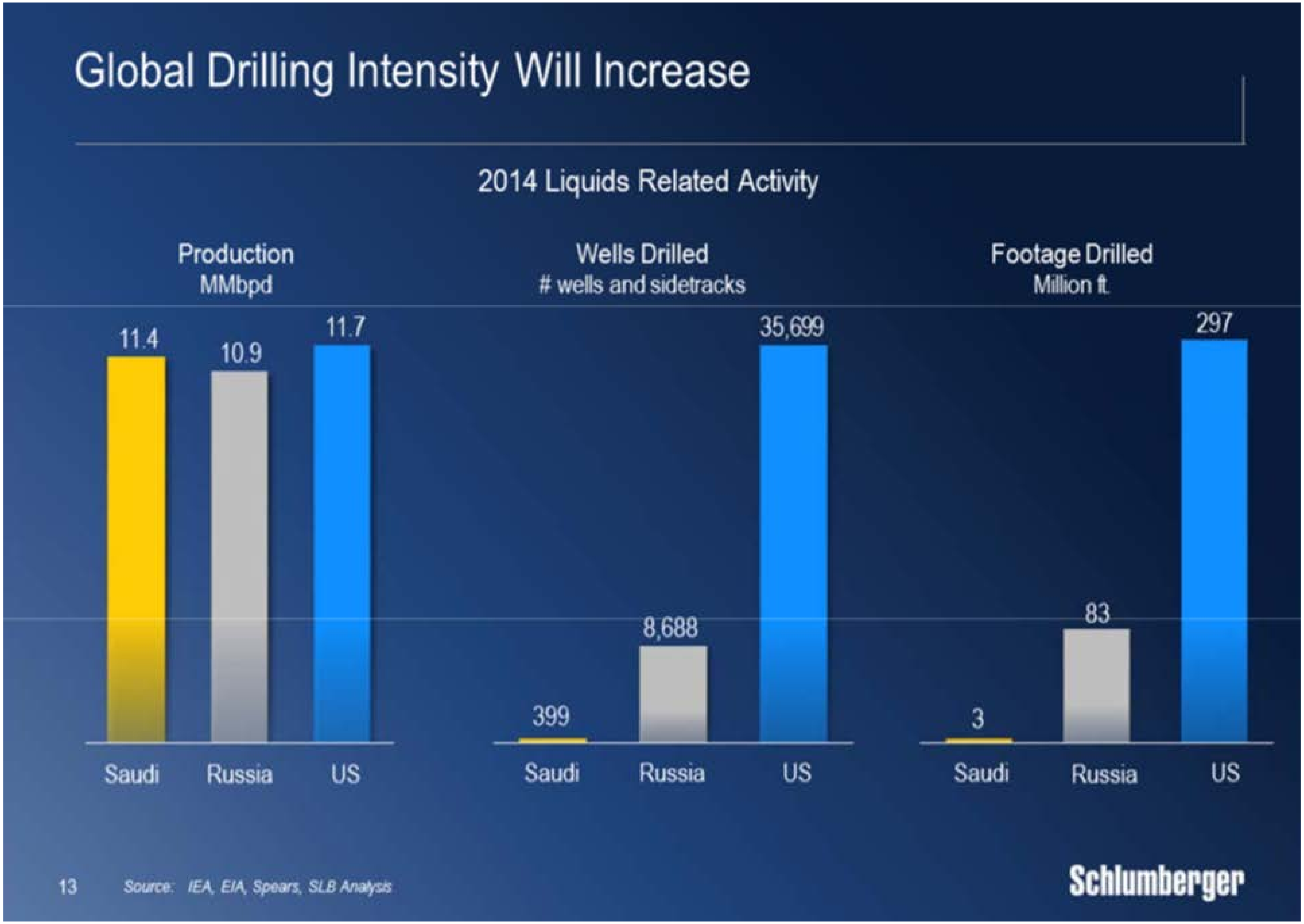
Global Oil Production vs. Global Reserves



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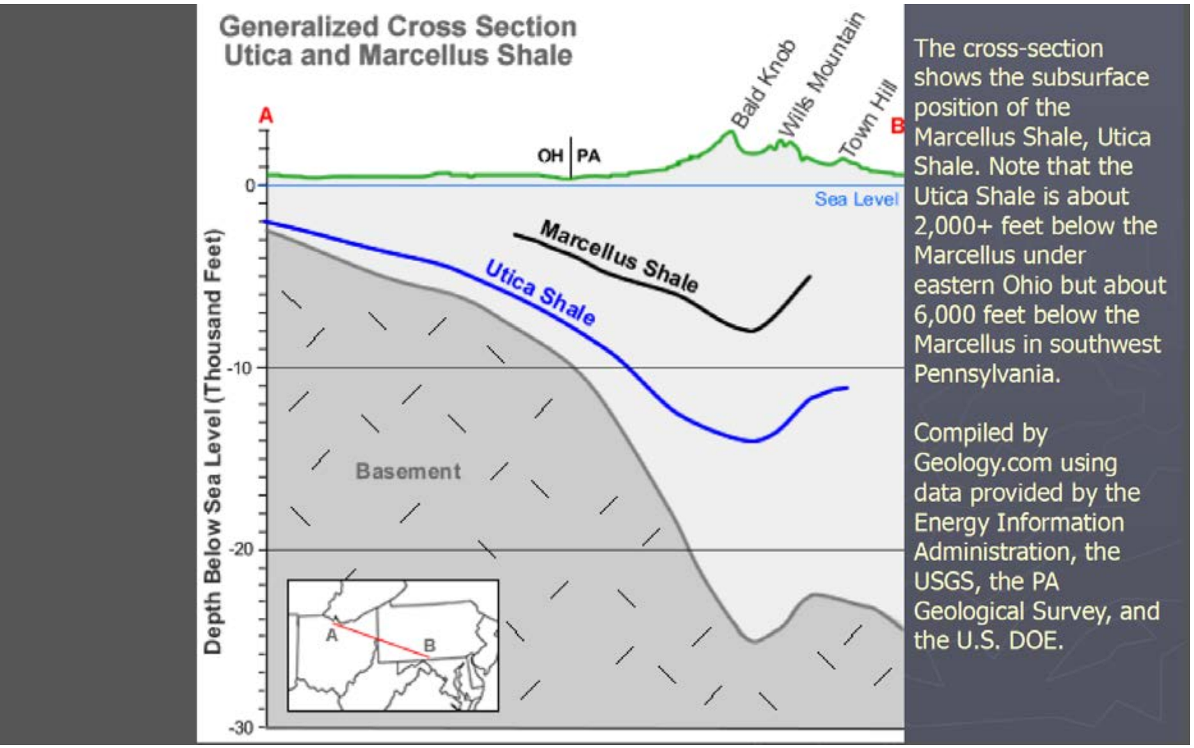
DEPTH OF MARCELLUS AND UTICA



Marcellus Recovery Projections:

- 65 TCF “proved reserves”
- 354 TCF “Total reserves”
- 480 TCF “Technically recoverable”

Utica Recovery Projections:

- 38 TCF “technically recoverable” –
  - USGS 2012
  - (plus 940 mm bbls oil)
- 782 TCF – “technically recoverable” –
  - Univ. West Virg. 2015
  - (plus 1.9 billion bbls oil)

Falling Costs of Hydrogen

- Hydrogen drives 2.5 times as far as gasoline
  - Toyota Highlander FCHV – 68 m/kg
  - Toyota Highlander hybrid – 26 m/gal
- Hydrogen costs -- 2015
  - \$6-12/kg for renewable (electrolysis) - \$1.60 gge
  - \$4-5/kg steam reformed natural gas -- \$4.80 gge (H2carblog 2016)
- *Problem: no where to fill up*
  - California hydrogen is around \$12-16/kg at the pump.
  - 19 cents/mile
    - Prius is 4.1 cents/mile (Edmunds 2016)

2016 Honda Clarity

Infrastructure Problem

- Duplicating existing gasoline filling infrastructure estimated at $100 billion
  - But do not need every station to carry H2
  - Currently have to truck hydrogen to stations.
- Can put reformers at gasoline stations – using natural gas to make hydrogen.
  - But is small scale reforming economic?
  - Solution: *begin with fleets*.

FCEV Fleets – First Adopters

- Resolves problem of refueling
  - Refueling stations at bus terminal
- Fuel Cell Bus Fleets
  - California
  - Europe
  - Asia
- Stark Area Regional Transit Authority (SARTA) – Canton, Ohio
  - 10 buses
  - El Dorado frame, Ballard PEM cells
  - Third largest operator of fuel cell buses in U.S.
- Reducing costs:
  - Currently around $1.4 mm/bus.
  - Standard diesel bus is $450,000, hybrid bus is $550,000.

SARTA Hydrogen Refueling Station

Midwest First Adopter: Stark Area Regional Transit Authority

"We want to be at the forefront of commercializing this technology because transit systems, businesses and private citizens will begin to utilize fuel cell-powered vehicles featuring components and technology developed and manufactured in Stark County."

Kirt Conrad, Executive Director, SARTA.

Fuel Cell Bus Fleet Performance Metrics

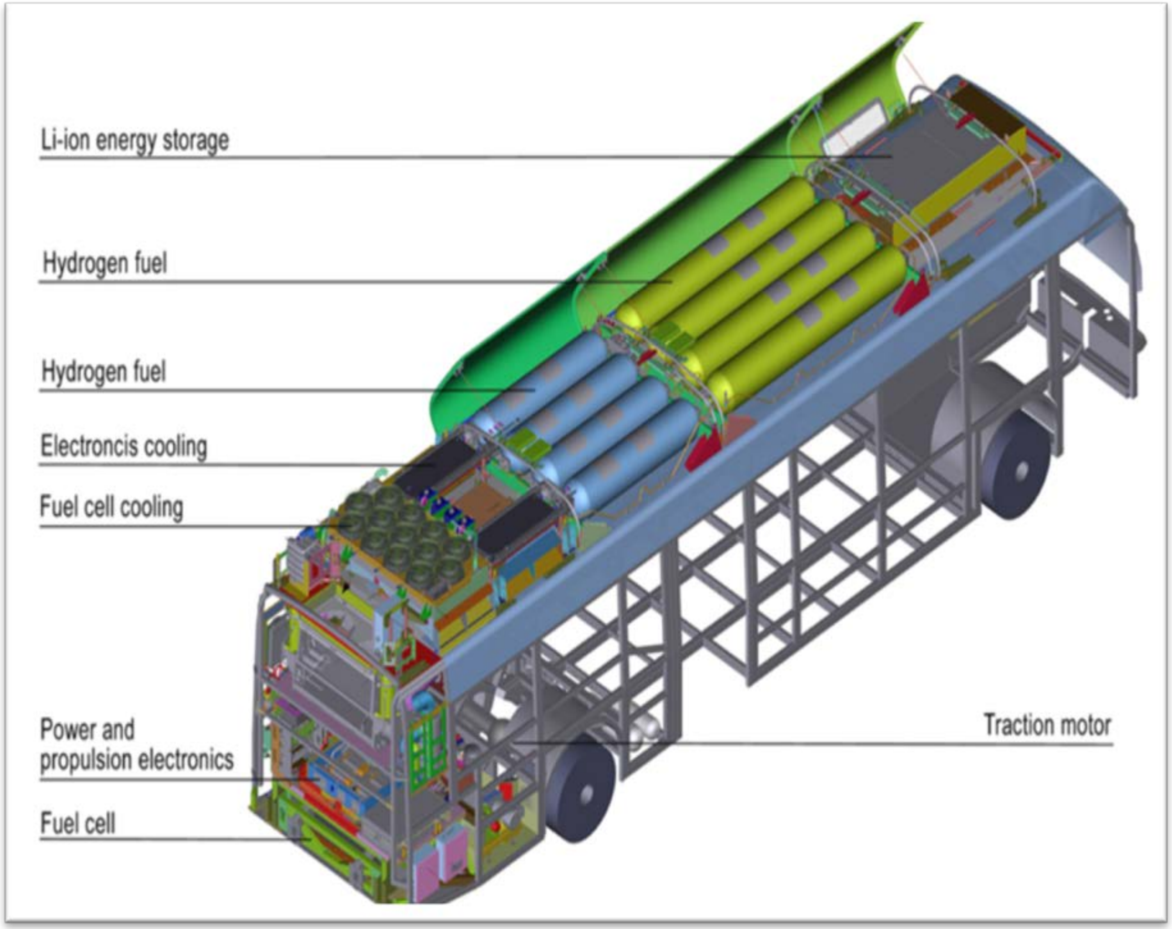
Performance of U.S. Fuel Cell Bus Fleet

	Units of Measurement	Fleet Average (2015)	2016 Target
Bus Lifetime	Years/Miles	3.6/81,108	12/500,000
Fuel Cell/Battery Lifetime	Hours	10,102	25,000
Bus Availability	% of days	73	90
Roadcall Frequency (bus/fuel cell system)	Miles Between Roadcalls	4,280/20,531	4,000/20,000
Operation time	Hours per day	11.8	20
Maintenance Cost	$/mile	1.16	.40
Range	Miles	275	300
Fuel Economy	Miles per Diesel Gas Equivalent	6.8	8

Fuel Cell Bus Design

Key Components:

- Bus Chassis
- Electric Drive System
- PEM Fuel Cell
- Hydrogen Storage Tanks
- Lithium Ion Battery



Source: BAE Systems

Hydrogen Storage System on Roof

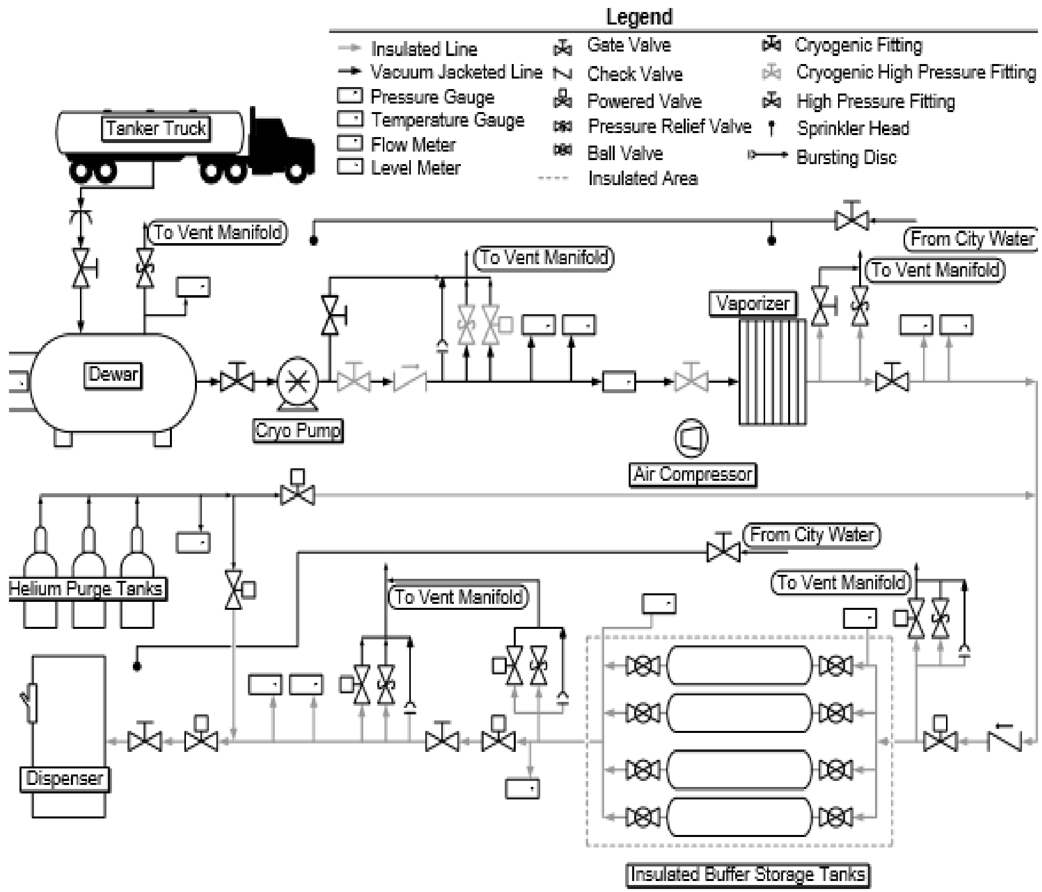
Relative Cost of Certain Fuel Cell Bus Components

Bus Component	$ Estimated Cost	% of Total Cost
Electric Drive System	60,000	4
Battery	4,000	1
PEM Cell	705,000	52
Storage	100,000	7
Base Vehicle	310,000	23
Other	146,000	13
Total	1.4 mm	100

Source: CalStart (2016).

Hydrogen Refueling Station

- 2016 – 23 US public refueling stations
- Cost: $2-5 mm, depending upon size
- Steam reforming typically offsite, hydrogen trucked in.
- Key Components:
  - Cryogenic dewars (tanks)
  - Cryogenic pumps
  - Insulated pipes
  - Vaporizer
  - Solenoid, pressure regulator
  - Compressor
  - Nozzle, valves, hoses
  - Manifold
  - Safety equipment, sensors



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