Report by Wireless Streetcar Advisory Group
City of Tempe

May 14 City Council Meeting

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At least one “win-win” wireless streetcar technology exists that is:

- Commercially available
- Suitable for Tempe alignment, hours, and climate
- Less expensive (net capital cost savings of $7 to 8 million)
- Reduces local funding gap, thus improving chance of FTA funding
- Attractive and exciting
- Safer
- More sustainable
- Integrates proven technologies

Report assesses risk (technological & financial) and mitigation strategies
Overhead Wires...?
... or Wireless?

NICE, FRANCE

http://1.bp.blogspot.com/_K78YS2Yiswo/TUTAkF8tK2I/AAAAAAAADbw/CTKw_oMAV_A/s1600/800px-Nice_tramway_place_Garibaldi.jpg
Nice, France neighbors Tempe’s Sister City, Beaulieu-sur-Mer

According to Swanson (2013):

“One thing is certain: public opinion is very supportive of wireless or off-wire systems for aesthetic reasons. As this technology becomes even more mature and available, widespread adoption is inevitable.” (p. 189)

Cities Worldwide are Innovating
Substantial Progress Made Since Initial Propulsion Technology Assessment

Worldwide Wireless Streetcar Systems
(for at least part of route)

Number of New Wireless Systems
Cumulative Number of Systems

Planned or Under Construction
Bars represent number of new systems opened in each 5-year period.

The main sources for information on the existing, under construction, and planned systems on this slide and the following tables were:

* Wikipedia (various topics).
* Test-track systems not used in revenue service, such as in Sapporo Japan, are not included in these counts, but their manufacturers are listed.
* Hybrid systems listed under more than one technology in the following slides are counted only once in this bar chart.
Wireless Propulsion Contenders
(Substantial progress and multiple options being deployed globally, since initial Valley Metro assessment)

- **Ground-level Power Systems**
  - Third Rail
  - Induction

- **On-board Energy Systems**
  - Batteries
  - Hydrogen Tanks and Fuel Cells
  - Hybrids

- **Batteries**
- **Hydrogen Tanks and Fuel Cells**
- **Hybrids**

- **Super-capacitors and Flywheels**

Tempe City Council Meeting

May 14, 2015

Ground-level power:

- Can be divided into conductive (requires physical contact) and inductive (transmitted wirelessly). Both provide continuous power over the entire route. Conductive systems are best known as a “3rd rail,” which in streetcar systems is depressed below street level. Inductive systems have some kind of coils or wires in the rail bed that transmit electromagnetic radiation, which is received by coils below the vehicle passing over it.
- Is considered safe. Today’s systems turn on only when the rail vehicle passes over them.
- Is generally more expensive than overhead power. All of the capital costs of providing high-voltage electricity along the entire route, including transformers and substations, remain.
Depending on the types and amounts of energy storage, and how quickly they can be refilled, on-board systems can be filled:

- Overnight at the rail maintenance facility
- At one or both ends of the line when the rail car might sit for 5-10 minutes
- At every station, in less than 1 minute.

On-board energy systems include:

- Super capacitors are used in applications requiring many rapid charge/discharge cycles rather than long term compact energy storage: within cars, buses, trains, cranes and elevators, where they are used for regenerative braking, short-term energy storage or burst-mode power delivery. They charge and discharge much faster than batteries, but are up to 10 times larger than conventional batteries. They were developed in the 1950s and 60s by GE and Standard Oil of Ohio. ([http://en.wikipedia.org/wiki/Supercapacitor](http://en.wikipedia.org/wiki/Supercapacitor)).

- Flywheels are rotating mechanical devices that store kinetic energy in the form of a large rotating wheel. Electrical energy at a station is used to spin the wheel faster, and then this spinning energy is used to drive the wheels to get to the next station ([http://en.wikipedia.org/wiki/Flywheel](http://en.wikipedia.org/wiki/Flywheel)). Auxiliary power may be required.

- Rechargeable batteries convert electrical energy into chemical energy through an electrochemical reaction. The chemical energy is then converted back to electrical energy. Recharge batteries come in many forms, each with different characteristics in terms of cost, storage capacity, charging and discharging speed, performance in different climates, weight, cost, and degradation. Major types include nickel metal hydride and lithium, including several different kinds of lithium batteries. ([http://www.afdc.energy.gov/vehicles/electric_batteries.html](http://www.afdc.energy.gov/vehicles/electric_batteries.html) and [http://www.proterra.com/proterra-introduces-extended-range-electric-bus-flexible-battery-system/](http://www.proterra.com/proterra-introduces-extended-range-electric-bus-flexible-battery-system/)).

- Fuel tanks and internal combustion engines, which need little explanation, can also be used to power a streetcar, but in addition to pollution from the vehicles, electric motors provide more powerful traction than internal combustion, so these combustion systems for rail typically power a generator that produces electrical energy for traction.

Continued on next slide
Other on-board energy systems include:

* Fuel cells can be thought of as similar to batteries but with a continual feed of chemical energy that they convert to electrical energy, so they do not run down or need recharging. Pure hydrogen is the most common form of chemical energy (fuel) used in fuel cells, but they can also run on hydrogen-rich fuels such as methanol or natural gas. In a hydrogen fuel cell, pure hydrogen and oxygen are combined to form electricity and water. Water vapor is the only emission. Fuel cells were first invented in 1838. The first commercial use was in the most demanding conditions: the NASA space program. Fuel cells generate virtually all electricity for space missions, and astronauts drink the water that is formed as a byproduct of generating the electricity. Fuel cells today tend to be 40-65% efficient. Fuel cells can be scaled up or down to any size from a cellphone battery to utility-scale power generation, in what is called a fuel cell “stack.” See [http://energy.gov/eere/fuelcells/types-fuel-cells](http://energy.gov/eere/fuelcells/types-fuel-cells), [http://www.afdc.energy.gov/fuels/hydrogen_basics.html](http://www.afdc.energy.gov/fuels/hydrogen_basics.html), [http://en.wikipedia.org/wiki/Fuel_cell](http://en.wikipedia.org/wiki/Fuel_cell), and [http://energy.gov/eere/fuelcells/downloads/state-states-fuel-cells-america-2014](http://energy.gov/eere/fuelcells/downloads/state-states-fuel-cells-america-2014).

* Technologies for generating hydrogen are also not new, and have been in commercial usage for decades. See later slide on Off-Vehicle Supportive Energy Systems.

* The hydrogen for fuel cells is typically stored in high-pressure metal bottles or cartridges. Much research is being conducted to find cheap ways to store hydrogen more compactly, but this is not really an issue for streetcars, where the hydrogen would be stored in metal bottles on top of the vehicle (between the interior ceiling and the outer roof). Hydrogen is the smallest and lightest chemical element, 14 times lighter than air, so storing it above the streetcar is an ideal solution. Hydrogen combines rapidly with other elements, so it cannot be “mined” from the earth or the atmosphere. Hydrogen must be extracted from other molecules, which requires energy. For a streetcar, hydrogen would be generated at a dispensing station at the rail maintenance facility.

Many Cities and Manufacturers Going Wireless Using Ground-Level Power

<table>
<thead>
<tr>
<th>Technology</th>
<th>Manufacturers</th>
<th>Cities (year built) * = On order, H = Hybrid</th>
<th>Wireless Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Induction from transmitters in railbed</td>
<td>Bombardier, TIG/m, Wampfler</td>
<td>The Grove, CA (2002)\textsuperscript{H}, Augsburg (2012), Nanjing (2014), Dallas (2015)\textsuperscript{H}</td>
<td>½ to 1 mile</td>
</tr>
</tbody>
</table>
The wireless length is the distance that the rail cars cover without overhead wires. Some of these distances in this and the following slide are based on page 4 of the propulsion study done for Washington, DC: HDR, Inc. Union Station to Georgetown Alternative Analysis for Premium Transit Service Propulsion Study, Final Report, September 2013.

The * indicates that the system is planned or under construction.

The H indicates a hybrid system with two or more forms of energy other than overhead catenary systems (OCS). In these slides, we are not counting systems that combine OCS with another technology as hybrids. Hybrids, like hybrid cars, usually combine batteries with something else, such as internal combustion, fuel cells, induction, third rail, super capacitors, or flywheels.

For ground-level power systems, the wireless length is largely a function of cost, not technology. Ground-level power systems could move a streetcar as far as desired because they provide continuous power. Most subway system around the world use a third-rail conductive system without overhead wires and run for many miles. For streetcars, the wireless length is constrained by affordability, not technology.

In some cases, induction from transmitters has been combined with on-board energy storage. For instance, the TIG/m system at the Grove retail complex in Southern California and the new system in Dallas use induction in the railbed to recharge the batteries at certain locations.
<table>
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<th>Cities (Year built)</th>
<th>Wireless Length</th>
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<tbody>
<tr>
<td>Flywheels</td>
<td>Parry People Mover</td>
<td>Stourbridge (2009)</td>
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<tr>
<td>Fuel tanks</td>
<td>Siemens, TIG/m (LPG, LNG, CNG, diesel)</td>
<td>Nordhausen*, Qatar*</td>
<td>Far</td>
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<tr>
<td>Fuel cells (H(<em>{2}), CH(</em>{3})OH)</td>
<td>CSR Sifang, FEVE, TIG/m</td>
<td>Dubai (2015)(^{H}), Qingdao*(^{H}), Aruba*(^{H}), Hermann-Hesse*(^{H})</td>
<td>9 miles</td>
</tr>
</tbody>
</table>
On-board Energy Systems: Batteries
Additional Notes on Dallas Streetcar

- The Dallas streetcars are 66-ft, 70% low-floor Liberty design made by Brookville Equipment Corp. Vehicles cost $4.5 million. It uses two 550-volt batteries to cross a bridge over the Trinity River without wires.
- The wireless section consists of 1 mile of the 1.6-mile route (www.brookvillecorp.com/Brookville-Delivers-Dallas-Streetcar.asp?news=news-streetcar.asp).
- Dallas’ historic preservation committee would not permit the Dallas-Oak Cliff Streetcar line to install overhead wires and poles on the Trinity River Bridge” (www.hntb.com/sites/default/files/HNTB_ITX_OffWireTech_914.pdf).
- The project cost $57 million and received $26 million TIGER funding from FTA (www.apta.com/resources/hottopics/circulators/Documents/Downtown-Dallas-Streetcar-Fact-Sheet.pdf).
- Photo gallery is here: https://www.dart.org/newsroom/imagelibrary.asp#DallasStreetcar.
- Environmental documents are here: https://www.dart.org/about/expansion/dallasstreetcar.asp.
- Other links can be found here: http://en.wikipedia.org/wiki/Dallas_Streetcar

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M-1 Rail will open its Woodward Avenue streetcar in 2016.
Over 2 miles of the route will be wireless (60% of length). The streetcars will operate on-wire between Henry and Canfield, and be off-wire everywhere else on the line.
Wires would have interfered with Detroit’s Thanksgiving Day parade.
Streetcar vehicles will use lithium ion batteries on off-wire segments.
Vehicles made by Czech company Inkeon (same as Seattle). Streetcars will be “Buy America” compliant and assembled in Michigan.
Vehicles will be 73 feet long and 100% low-floor, and weigh 76,000 lbs.
According to http://www.hntb.com/sites/default/files/HNTB_ITX_OffWireTech_914.pdf, “Seattle officials opted for off-wire technology on the First Hill Streetcar line to avoid conflicts with existing overhead trolley wires used by the city’s electric bus system.”

Typical voltage of overhead wire systems is 750 volts DC. The Seattle project recommended a battery capable of at least 600 volts DC.

Initially 3 segments totalling about 1 mile (20%) of the route were intended to be wireless, but it was determined that the entire, mostly downhill inbound 2.28-mile segment could be wireless.

Vehicles are 100% low floor by placing the batteries on the roof.

Unit price of the roughly 70-ft vehicles was $3.155 million each, only $90K more than the equivalent conventional streetcar by the same manufacturer (Inkeon of the Czech Republic).


- “Seattle DOT used a two step, best-value procurement process; however, defining basic OESS performance requirements was not as straightforward as in a procurement for conventional cars. Many new performance variables can come into play. Three solid proposals were received.”
- “The cost premium for OESS was originally estimated to be in the range of $500,000 per car, but the Seattle results indicate it may not be as significant as originally assumed.”

# Wireless Technologies - Limitations

<table>
<thead>
<tr>
<th>Ground-Level</th>
<th>Wayside power for full route</th>
<th>Higher capital costs</th>
<th>Lacks energy for 20 hours</th>
<th>Size &amp; weight</th>
<th>Does not work underwater</th>
<th>Longer station dwell times</th>
<th>Vehicle emissions</th>
<th>Slow charge times</th>
<th>Under-powered if used alone</th>
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<tbody>
<tr>
<td>In-ground contact rail</td>
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<tr>
<td>Wireless induction</td>
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## On Board

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<thead>
<tr>
<th>Super capacitors</th>
<th>Wayside power for full route</th>
<th>Higher capital costs</th>
<th>Lacks energy for 20 hours</th>
<th>Size &amp; weight</th>
<th>Does not work underwater</th>
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<th>Slow charge times</th>
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<tbody>
<tr>
<td>Flywheels</td>
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<tr>
<th>HC Fuel tanks</th>
<th>Wayside power for full route</th>
<th>Higher capital costs</th>
<th>Lacks energy for 20 hours</th>
<th>Size &amp; weight</th>
<th>Does not work underwater</th>
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<th>Slow charge times</th>
<th>Under-powered if used alone</th>
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<tr>
<td>Batteries</td>
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<th>Fuel cells</th>
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<tr>
<td>Battery-Fuel Cell Hybrid</td>
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According to Swanson (2013), ground-level power systems “are overall typically 3 to 8 times as expensive as a traditional overhead catenary system (OCS) system, although recent studies by others have estimated these costs to be in the range of 1.5 to 2 times as expensive, not taking into account any additional civil work or utility relocation, etc.” (p. 183).

Super capacitors and flywheels also tend to be more expensive than on-board energy systems because they still require high-voltage power, transformers, and substations along most of the route because the super capacitors and flywheels have to be recharged at most stations. Off-wire distances using super capacitors “are typically limited to between 300 and 2,500 ft” (p. 186).

Flywheels “typically require 40 seconds to recharge, twice as long as a normal maximum station dwell time” (p. 184).

Flywheels, super capacitors, and batteries are all heavy and bulky.

Hydrogen storage is bulky but lightweight, and can use virtually unlimited storage on roof of car.

Batteries cannot hold enough energy for the entire route for 20 hours of operation plus HVAC, and they charge too slowly to be recharged during the day. High voltage fast charging degrades battery lifetime more rapidly. Batteries need cooling.

Lithium titanate batteries have potential to charge in roughly 15 minutes at the terminal stations, and do not degrade as quickly as lithium ion or lithium iron phosphate (per Dale Hill, Proterra: http://www.proterra.com/).

Cold-start effects play a significant role in power limitations in a fuel cell vehicle, and may require hybridization (batteries) to supplement available power at start-up.
A Commercially Available Self-Powered Technology Exists

Self-powered through hybridization of:

* Overnight battery charging (off-peak)
* Regenerative braking
* On-board hydrogen tanks and fuel cells

Completely eliminates substations, transformers, high-voltage electricity, and overhead or underground wires for entire 3.1 mile route.

Combines technologies proven in:

* Automotive
* Rail
* Forklifts
* Remote locations
* Space program
TIG/m On-Board Hybrid Propulsion System is Based on Proven Components

- H₂ Tanks
- Fuel Cells
- Battery
- Electric Motor and Wheels
- Regenerative Braking
- Overnight

H₂ Station
“Proof of existence” is an industry term for evidence that if an RFP is issued with certain specifications, at least one company will be able to meet the criteria and prepare a compliant bid. It does not preclude other vendors bidding on the same or different technologies that might also be able to satisfy the same specs.


We determined that the TIG/m product is “proof of existence” of a completely self-powered wireless streetcar technology that can operate 20 hours per day over a 3.1 mile route in Tempe’s climate. Because it requires no high-voltage power anywhere along the route, it can accomplish this while decreasing the capital costs of building the project.
The TIG/m self-powered streetcar uses three sources of on-board energy:

- Overnight battery charging
- Overnight filling of hydrogen tanks
- Regenerative braking that returns some energy to the battery during the day

This technology goes by several names:

- **Battery powered with hydrogen range extension.** The traction power for moving the streetcar comes exclusively from the high-voltage battery. What the hydrogen fuel cells do is extend the driving range of the batteries to more hours and/or longer distance by continually recharging the batteries.

- **Self-powered streetcar.** TIG/m likes to call their technology “self-powered” rather than “wireless” to emphasize the fact that it leaves the rail maintenance facility every morning with all the energy it needs for the entire 20-hour duty cycle. It thus requires no high-voltage power anywhere on the route. That’s where the big capital cost savings come in. The combination of these three sources of energy make this possible.

- **Battery-fuel cell hybrid streetcar.** The design of this technology is very similar to a plug-in hybrid Chevrolet Volt. The Volt is a series hybrid, in the sense that the forms of energy are in a single sequence or series, with a gasoline tank feeding fuel to an internal combustion engine, which runs an electrical generator, which charges the battery during operation. Drivers plug in the Volt overnight and stop at gas stations to fill the tank. GM trademarked the term “range anxiety” because of the clever way the Volt relieves the driver of worry that they will be stranded if their battery runs out. It uses hydrogen tanks and fuel cells to charge the battery. In contrast with the Volt, most other plug-in hybrid EVs, such as the Toyota Prius Plug-in or Ford’s C-Max Energie or Fusion Energie, are “parallel” hybrids in the sense that both the internal combustion engine and the electric motor can drive the wheels directly at the same time (“in parallel”). All of these vehicles also incorporate regenerative braking to use braking energy to recharge the battery.

Returning to the battery-fuel cell hybrid streetcar, it is essentially like a very large Chevy Volt that runs on rails. It is powered by batteries, but with hydrogen storage bottles replacing the gasoline tank, and the fuel cell replacing the internal combustion engine and electric generator, which keeps the battery charged.
A battery-powered streetcar with hydrogen range extension requires supportive, off-vehicle energy systems. These are essential parts of the overall energy system, and would be located at the rail maintenance facility. They include:

- **Battery Charging.** The TIG/m streetcar uses lithium-iron-phosphate batteries that would be charged overnight with numerous 240-volt plugs. They can be charged at 110V, 240V, or 480V (DC), similar to what are known as Level 1, 2, and 3 charging for EVs. Charging at 110V, however, is too slow, while fast-charging at 480V reduces the lifetime of lithium-ion and lithium-iron-phosphate batteries. By having many 240V plugs where each one can charge its set of battery cells in a few hours, the lifetime of the battery is extended. 240V is similar to a typical household dryer or water heater power supply.

- **Hydrogen Station.** Unlike most fuels, it can be more economical to produce hydrogen at the station rather than deliver it to the station. Both models, however, are in use today. The two most common ways to generate hydrogen in commercial use today are steam-reforming of natural gas (CH$_4$) and electrolysis of water (H$_2$O). Steam reforming, however, uses fossil fuels and emits carbon dioxide. See [http://www.afdc.energy.gov/fuels/hydrogen_production.html](http://www.afdc.energy.gov/fuels/hydrogen_production.html).
  
  - We recommend electrolysis, which uses electricity to split water into hydrogen and oxygen. Essentially, electrolysis is a fuel cell in reverse. We recommend it because there are no on-site carbon emissions, and it can use renewable electricity such as solar power. In addition, as grid power gets greener over time, the electrolysis process gets more sustainable.
  
  - After it is generated, the hydrogen is compressed and pumped into a storage tank.
  
  - The pressurized hydrogen and oxygen cartridges on the roof of the streetcar would be refilled each night. Locking air-tight mechanisms located on the side of the streetcar at ergonomic height allow a worker to easily refill the tanks from ground level.

- The battery-fuel cell hybrid streetcar can take maximum advantage of time of use electricity rate plans. Batteries can be charged overnight at the cheapest electricity rates. If equipped with solar panels, the hydrogen station can electrolyze water into hydrogen and oxygen during the day with little to no use of grid electricity. When the sun is down, the electrolyzer can use grid electricity at a cheaper rate.
Blue arrows = renewable electricity and hydrogen

Yellow arrows = grid electricity

Source: Tramways and Urban Transit, January 2015
Individually, all of these technologies have been used for decades and are extremely well understood. In sequence:

- At rail maintenance facility
  - Solar Photovoltaic Panels
  - Electrolyzer
  - H2 tank and pumps
- On board Streetcar
  - H2 Storage in bottles
  - Fuel Cells
  - Lithium-iron-phosphate battery
  - Regenerative braking

Plug-in hybrid automobiles have now been in use for several years, and sales are growing faster than pure electric vehicles.

Numerous streetcar propulsion systems combine batteries and regenerative braking with other sources of supplemental energy.

Battery range extension using hydrogen is catching on for automobiles, delivery vans, and buses:

- [http://gas2.org/2015/01/15/solaris-electric-bus-also-packs-a-hydrogen-fuel-cell/](http://gas2.org/2015/01/15/solaris-electric-bus-also-packs-a-hydrogen-fuel-cell/)

TIG/m is a “system integrator” that uses equipment from established component manufacturers such as Plug Power for the fuel cells (see [http://www.plugpower.com/GenDrive_Customers_WhosUsingGenDrive.aspx](http://www.plugpower.com/GenDrive_Customers_WhosUsingGenDrive.aspx)).
Regenerative braking great for stop-and-go streetcar
Fuel cell well suited for recharging battery—less challenging than for traction
Battery warranty doubled by avoiding deep cycling
Fuel-cell for range extension is well suited to rail
  - Rail has less rolling resistance than bus or automobile
  - Rail needs only one centralized hydrogen station
Streetcars operate on city streets with stop-and-go traffic. Much propulsion energy is wasted in the braking process. Without batteries, flywheels, or super capacitors to recapture the braking energy, the system will use more electricity than necessary, especially at peak electricity-rate times of day.

The combination of batteries and fuel cells on a streetcar overcomes limitations of the individual technologies in several ways:

- If a hydrogen fuel cell were to be the only source of traction power for a large streetcar, the fuel cell stack and hydrogen and oxygen storage capacity would need to be significantly larger and more expensive. The fuel cell stack would be called on to provide short, heavy surges of power. Batteries are much better suited to that. However, by using the fuel cells continuously to charge the batteries and run the HVAC units, the fuel cells can be significantly smaller. Thus, hydrogen fuel cells are much better suited to the task of battery range extension.

- Similarly, if batteries are the sole source of power on a wireless streetcar, they would need to be fast-charged during the day (which is too slow and degrades battery life for most types of lithium batteries) or they would have to be much larger and be drawn down to low levels at the end of a long, hot day. L-ion or L-iron-phosphate battery life is reduced, however, by repeatedly deep-cycling down to a low state of charge. By combining lithium batteries with hydrogen range extension, the batteries can maintain a relatively high state of charge over the entire duty cycle, which enables TIG/m to double the battery warranty from 5 to 10 years.

- That being said, with virtually unlimited room on the roof of the streetcars to store additional hydrogen, the fuel cells and storage bottles can be sized to provide as much power as necessary to extend the battery range and power the HVAC systems.

- Like rail in general, streetcars are much more energy efficient than buses and cars. Steel wheels on steel rails exert 70% less rolling resistance than rubber tires on roads. In this sense, batteries with hydrogen range extension have less work to do than even for a bus of half the size.

- Use of very high-efficiency HVAC units is an important additional element of this self-powered energy system.

- Finally, unlike automobiles, streetcars travel a single route all day long. They do not require an extensive network of fuel stations all around the region. The main barrier holding back the introduction of hydrogen fuel cell cars in recent years has been the lack of fuel stations. Also, the hydrogen fuel stations for cars are more expensive because they need to generate and store larger amounts of hydrogen. For the streetcar, the generating and storage capacity is known in advance, and even overbuilding the station to provide a safety margin of excess hydrogen, the station will be much cheaper to build and only one station will be necessary.
The Grove (battery only, 0.4 miles): Built in 2002, it uses 35-ft, open-air, heritage-style streetcar in a retail complex in Southern California. It does not use hydrogen for range extension. The batteries are charged overnight. The streetcar carries about 3 million passengers per year. [http://www.railwaypreservation.com/vintagetrolley/los_angeles.htm](http://www.railwaypreservation.com/vintagetrolley/los_angeles.htm)

Aruba (battery powered with hydrogen range extension, 0.75 miles): the 40-ft heritage-style open-air streetcars have been in service for over 3 years on a completely wireless route. Because Aruba has not completed the code compliance for the hydrogen generation station, they have been running on battery only for 10 hours per day and returning with 50% state of charge. [www.altenergymag.com/news/2013/03/27/tigm-modern-street-railways-delivering-world39s-greenest-streetcars-to-aruba-in-island39s-transition-to-100-sustainability/28761](http://www.altenergymag.com/news/2013/03/27/tigm-modern-street-railways-delivering-world39s-greenest-streetcars-to-aruba-in-island39s-transition-to-100-sustainability/28761) and [http://www.tramz.com/aw/aw.html](http://www.tramz.com/aw/aw.html)

Dubai (battery powered with hydrogen range extension, 4.2 miles): the first car was delivered in February 2015 for testing and rigorous certification based on European standards. They are heritage-style, double-decker streetcars with air-conditioned lower level and open-air upper level with capacity for 74 passengers. The initial segment is 1 km long.

Qatar (battery powered with LPG range extension, 1.1 miles): these are low-floor, 50-ft, modern streetcars. Qatar, an oil-rich nation, decided to use LPG (such as propane) for range extension.

For more information on TIG/m, see:

Status of Other Hydrogen Rail Projects
Additional Notes

Herman-Hesse, Germany, Hydrogen Fuel Cell Regional Rail
* Scheduled to open in 2018, 40 regional trainsets have been ordered. “While the fuel cells will feature proven technology already deployed in the automotive sector, Alstom will provide the software, control and energy storage equipment.”


CSR Sifang Co. in Qingdao, China
* CSR Sifang claims its tram can be refueled in three minutes and run for up to 100km (62 miles) at speeds of up to 70km/h (44mph), carry 380 passengers (60 seated), while storage bottles onboard the vehicle can take 1000kg of hydrogen.

  ▪ International Hydrail Conference: http://hydrail.org/.

Asturias, Spain
* Built by Spanish company FEVE

Confirmed by Dec. 22, 2014 conference call with Valley Metro and TIG/m CEO

Further confirmation in Mar. 8, 2015 conference call with ASU Group and TIG/m CEO

80% low-floor (heavy batteries under elevated driver’s seat and rear seats)

Buy American – TIG/m headquartered in Southern California

Meets all European specs – generally tougher than US specs

Proof of Existence – If RFP is issued, at least one company will be able to meet the criteria and prepare a compliant bid
Overhead Transmission Wires are Ugly But Also Expensive and Unnecessary

<table>
<thead>
<tr>
<th>Element</th>
<th>Year of Expenditure $</th>
<th>TOTAL (Million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction power - substations</td>
<td>$ 7.5</td>
<td></td>
</tr>
<tr>
<td>Traction power - catenary</td>
<td>$ 11.1</td>
<td></td>
</tr>
<tr>
<td>Total Electrical</td>
<td>$ 18.6</td>
<td></td>
</tr>
</tbody>
</table>

Source: Tempe Streetcar _SCC_Workbook_Rev_16_SMALL_STARTS_021315.PDF

Different Style TPSS

- Light Rail – Prefab Substations
- Commuter Rail – Outdoor Substations
Overhead Transmission Wires are Ugly But Also Expensive and Unnecessary

Additional Notes

With a completely self-powered streetcar, without overhead or ground-level power or charging on the route, we can avoid the cost of the following along entire 3.1 mile route:

* High-voltage electricity
* Overhead wires
* Underground wires
* Substations
* Transformers
Overhead transmission wires are ugly but also expensive

Additional Notes

* Here are the relevant lines from the budget worksheet for the Tempe Streetcar project:

<table>
<thead>
<tr>
<th>MAIN WORKSHEET-BUILD ALTERNATIVE</th>
<th>Quantity</th>
<th>Base Year Dollars w/o Contingency (X000)</th>
<th>Base Year Dollars Allocated Contingency (X000)</th>
<th>Base Year Dollars TOTAL (X000)</th>
<th>Base Year Dollars Unit Cost (X000)</th>
<th>Base Year Dollars Percentage of Construction Cost</th>
<th>YOE Dollars Total (X000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempe Streetcar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7,486</td>
</tr>
<tr>
<td>Tempe, Arizona</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11,093</td>
</tr>
<tr>
<td>Marina Heights to Dorsey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50.03 Traction power supply: substations</td>
<td></td>
<td>6,246</td>
<td>625</td>
<td>6,871</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50.04 Traction power distribution: catenary and third rail</td>
<td></td>
<td>9,256</td>
<td>926</td>
<td>10,182</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* We have not included any costs of planning and maintaining electrical substations, overhead catenary system, and treework.

* Source: Tempe Streetcar _SCC_Workbook_Rev_16_SMALL_STARTS_021315.PDF
## Capital Cost Tradeoffs (rough estimates)

<table>
<thead>
<tr>
<th>Cost Savings</th>
<th>($ millions)</th>
<th>Cost Increases</th>
<th>($ millions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wayside power systems</td>
<td>- $18.5</td>
<td>Vehicles (Est $0.5 million more per vehicle x 6)</td>
<td>+ $3.0</td>
</tr>
<tr>
<td>Hydrogen Station</td>
<td></td>
<td></td>
<td>+$1.25</td>
</tr>
<tr>
<td>Battery Replacement x 7 (10/20 yrs)</td>
<td></td>
<td></td>
<td>+ $1.2</td>
</tr>
<tr>
<td>Spare streetcar</td>
<td></td>
<td></td>
<td>+ $5.4</td>
</tr>
<tr>
<td><strong>TOTAL SAVINGS</strong></td>
<td>- $18.5</td>
<td><strong>TOTAL INCREASE</strong></td>
<td>+ $10.85</td>
</tr>
</tbody>
</table>

Net capital savings of roughly **$7.65 million** (helps to close funding gap) plus aesthetic and reputation benefits.
By building a completely self-powered wireless streetcar system such as the TIG/m battery-powered hybrid with fuel cell range extension, we think the Tempe Streetcar could be built for roughly $7 to 8 million less than currently budgeted.

This is the net savings, based on:
- decreased costs of $18.6 million by eliminating all wayside power
- increased costs of $10.9 million for costlier vehicles, a spare streetcar, a hydrogen station, and battery replacement

These savings can reduce the current funding gap for the local match, improving our chances of FTA funding.

We are using YOE (Year of Expenditure) numbers, which refers to the year when money is spent, not current costs. This is the far-right column of the budget spreadsheet.

Details:
- On the positive side of the ledger, the cost of all wayside high-voltage (750 Volt) power on the route would be eliminated. This means no substations, transformers, overhead wires, poles to support the wires, etc. Even at the rail maintenance facility where the streetcars would be charged overnight, no special electrical systems are needed. The charging ports use the same voltage as a household dryer. Valley Metro estimates this cost at $18.6 million.

Continued on next page.
On the negative side of the ledger, there would be several kinds of new capital costs as well as other costs that would increase relative to building the traditional system with overhead wires.

We conservatively estimate the battery-hydrogen hybrid vehicles to cost $500K more than conventional streetcars, which have been budgeted at $4.9 million (YOE). Multiplied by 6 vehicles adds $3 million to the wireless system cost.

- In a conference call with Valley Metro, TIG/m gave rough ballpark estimate of $4 to 4.5 million including spare parts, while in a conference call with our committee, TIG/m said vehicle costs for each job are “custom” but they don’t think it will be a problem delivering cars within Tempe’s budget.
- Seattle reported budgeting $500k more for battery-powered streetcars and getting bids that were only $90K - $400 higher.
- Dallas’s battery-powered 66-ft modern streetcars cost $4.5 million each.
- While batteries, fuel cells, and tanks will be added to the cost of each vehicle, there are also savings from not needing a pantograph on top of the vehicle (the arm that connects to the overhead catenary wires).

FTA requires spare vehicles for times when other vehicles are being maintained. The number of spares should be 10-20% of the total fleet. Valley Metro is planning to use regular Metro light rail vehicles as spares, saving this cost entirely. Light rail vehicles could not, however, be used as spares on a wireless route. We therefore include the cost of one spare streetcar at $5.4 million, which is $500K above the $4.9 million YOE estimate.

TIG/m can provide a complete turnkey system, including a hydrogen station, which they estimated at $1 million. We add a 25% contingency and include $1.25 million for the hydrogen station. Note that this is still less than the cost of a public automotive hydrogen filling station, mainly because the tank and generating capacity are much smaller, and public access is not required.

TIG/m would warranty batteries for 10 years. Valley Metro estimates a vehicle lifetime of 25 years. This means batteries would need to be replaced twice during the vehicle lifetime, at 10 and 20 years. TIG/m estimates the traction battery cost at $100K per vehicle. We think battery costs are likely to come down over time, while performance is likely to improve. Also, there is a market for repurposing large lithium batteries after they are no longer adequate for transportation purposes. Here, we include a contingency factor of 15% in light of these considerations, and estimate battery replacement for 7 vehicles at $115K. We discount these future costs at a conservative discount rate of 2% annually, as typically done in life-cycle financial budgeting exercises. This reduces the present value of the future battery replacement costs from $1.6 million to $1.2 million.
Several factors are not included in these tradeoffs:

* We did not include the costs of solar power for the hydrogen station. While desirable, they are not absolutely necessary – the electrolyzer will need to also run on grid electricity. Also, we believe there is a strong chance for the solar panels for this project to be funded by grants.

* We did not include maintenance cost tradeoffs. Fuel cells and batteries have fewer moving parts than a pantograph system, and we have heard anecdotally of the high costs of maintaining overhead wires on the route and trees that can interfere with them.

* Training of transit staff and emergency service providers for dealing with hydrogen should be anticipated.

* We have not included operating costs tradeoffs here. This needs further detailed study, and is affected by a large number of variables, some of which we list here:
  * Fuel cells and electrolyzers have much higher efficiencies compared with internal combustion, but energy will still be lost in converting from electricity to hydrogen and back to electricity.
  * Solar power for generating hydrogen during the day will offset substantial electricity costs and losses associated with electrolysis.
  * Charging batteries overnight on a time-of-use plan will further offset electricity costs compared with using power from overhead wires during peak periods.

* Tempe, Phoenix, and Valley Metro may want to build a larger hydrogen station at the rail maintenance facility for future fuel cell buses and public use of pumps. Typically, many early hydrogen and CNG stations are built at fleet bases with unmanned pumps “outside the fence” for the general public to use with swipe-card access. If a larger station is desired for these purposes, we think the added cost could be funded by grants.
A report by HDR, Inc. for Washington, DC studied this exact question in a section on the “Feasibility, including cost, of converting to non-aerial motive power where aerial wiring has been installed”

* They analyzed a 2.4 mile wireless segment of the H St. line (5 miles round trip).
* The report estimated the cost of removal, salvage, and demolition of the overhead catenary system and power substations at $2 million
* In addition, they estimated the loss of the initial investment in the OCS and substation at $22 million
* The total economic cost of installing and later removing the wires was estimated at $24 million.
* In addition, there would be the cost of retrofitting the streetcars to operate wirelessly on part of the route, or to buy new streetcars.
* **Conclusion:** converting a wired system to wireless after it is built would be very expensive.
## Environmental Tradeoffs

<table>
<thead>
<tr>
<th>Positive Impacts</th>
<th>No Impact</th>
<th>Negative Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower grid energy use and carbon emissions (if solar power is used to generate hydrogen)</td>
<td>No emissions from vehicles for either option (except pure water vapor)</td>
<td>Greater grid energy use and carbon emissions (if grid electricity is used to generate hydrogen)</td>
</tr>
<tr>
<td>Reduced “visual pollution”</td>
<td>No change in equity across groups (same route, same populations served)</td>
<td></td>
</tr>
<tr>
<td>Fewer tree trimming or removal – more shade</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The environmental impact analyses are an important part of the federal evaluation and funding process. This consists of an ecological, health, and safety analysis as well as an environmental justice (equity) analysis.

* The good news is that the major parts of the environmental impacts would not change at all:
  - The vehicle emissions would be completely unaffected by changing the propulsion system. A traditional wired streetcar is a zero-emission vehicle, but so is a battery-hydrogen fuel cell hybrid vehicle, which emits only water vapor, which is not an EPA criteria pollutant.
  - The alignment would be completely unaffected by changing the propulsion system. The line would go through the same neighborhoods and would serve and impact the same socio-demographic groups.

* There would be some minor changes to the broader environmental impacts.
  - On the negative side, we explained earlier that some energy is lost converting electricity to hydrogen and back to electricity. This would result in more total electricity consumption.
  - However, on the positive side, some of the electricity for generating hydrogen could come from solar power. Whether solar power could offset the energy losses depends on how much solar capacity is installed, which would likely depend on grant funding. We think there is a good chance that these impacts would mostly offset each other.

* Other environmental benefits:
  - Improved visual aesthetics.
  - Less need for tree trimming and removal to prevent interference with overhead wires. The result would be more shade, which would promote walking and biking and reduce the urban heat island effect.
# Safety Tradeoffs

<table>
<thead>
<tr>
<th>Positive Impacts</th>
<th>Negative Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safer for firefighters – no ladder trucks near wires</td>
<td>Risk of hydrogen fire at H₂ station or vehicle</td>
</tr>
<tr>
<td>No downed live wires from storms or crashes</td>
<td></td>
</tr>
<tr>
<td>No substation/transformer explosion risk</td>
<td></td>
</tr>
</tbody>
</table>

**Safety Risk Assessment**

- Hydrogen is 14X lighter than air and stored above ceiling of streetcars – any release goes up
- Hydrogen station isolated at light-rail maintenance yard
- Tempe Firefighters and Valley Metro staff will need training in dealing with hydrogen
On the **positive** side of the ledger:

* In Tucson, firefighters were concerned about the wires 19 feet above street level interfering with firefighting and ladder trucks. Firefighters had to be trained in cutting the high-voltage power lines. Increased risk to firefighters and a delay in response times are a likely result of dealing with the high-voltage wires while fighting fires in multi-story buildings along the route. This can be avoided entirely by using a completely self-powered streetcar:

* High-voltage wires pose a safety hazard to citizens. Downed wires can occur by:
  - Crashes into poles or problems with pantographs. See for instance:
  - Trees and large branches being knocked down by monsoon storms, microbursts, or crashes. See:

* Electric substations and transformers are at risk of explosion and fire. Numerous examples can be found online by Googling for images of substation and explosion.
On the **negative side of the ledger:**

* Hydrogen is not necessarily less safe or more safe than more familiar fuels such as gasoline or electricity—it’s just different and has some unique properties.
  - [https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_safety.pdf](https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/doe_h2_safety.pdf)
  - [http://www.arhab.org/pdfs/h2_safety_fsheet.pdf](http://www.arhab.org/pdfs/h2_safety_fsheet.pdf)
* Hydrogen is an invisible, odorless, colorless, and tasteless gas that is flammable and explosive.
* Hydrogen is 14 times lighter than air, which means it rises and disperses very quickly. Storing hydrogen on the roof of the streetcar thus removes much of the risk hydrogen could pose to riders.
* With the hydrogen station at the rail maintenance facility, few people would be exposed to any risk, in contrast with the high-voltage wires on crowded pedestrian streets.
* It is very unlikely to cause asphyxiation because of how quickly it disperses.
* A hydrogen fire has significantly less radiant heat than a hydrocarbon fire.
* The US currently produces and safely uses more than 9 million tons of hydrogen each year.
* Hydrogen is not well known or understood by the general public. It may be associated in people’s perceptions with a hydrogen bomb or the explosion of the Hindenburg zeppelin in the 1930s.
* Transit workers and emergency services will need training in dealing with hydrogen.
Safety Tradeoffs
Additional Notes

* Comparison of vehicle fire between hydrogen and gasoline vehicles

www.arhab.org/pdfs/h2_safety_fsheat.pdf
Since 1993, CTE has managed $290 million of clean, sustainable, innovative transportation and energy technology projects.

CTE can produce detailed modeling of energy and cost for specific route, location, vehicle, and rate structure, usually +/- 5% (contract cost would be $60K-$75K).

CTE is trusted by FTA as honest, 3rd party evaluator of new technology.

CTE routinely works with FTA, DOT, DOE, DOD, NASA.

CTE has on staff engineers, economists, lobbyists, project managers:

- Project Planning
- Grant Writing
- Technical and Lifecycle Evaluation
- Technical Specifications
- Inspection
- Deployment Oversight
- Performance Monitoring
- FTA Reporting
The Center for Transportation and the Environment, based in Atlanta, was highly recommended by Mr. Dale Hill, founder of Proterra, a South Carolina maker of fuel cell and electric buses. CTE helped get FTA funding for a number of their projects.

Members of our study team had individual and group discussions with Dan Raudebaugh, Director of CTE.

See attached document (CTE One Pager.pdf) for more information, or see http://www.cte.tv/.

“CTE’s mission is to improve the efficiency and sustainability of the United States’ energy and transportation systems. As a member-based non-profit, non-governmental organization, [they] bring people together to advance clean, sustainable, innovative transportation and energy technologies.”

CTE’s services include:
- Project Planning & Initiation
- Route Modeling & Analysis
- Technical Specification
- Technical Evaluation
- Rate Modeling and Life Cycle Cost Analysis
- Oversight/Inspection of the Bus Build
- Deployment Oversight
- Operational Data Collection
- Key Performance Indicator Analysis & Reporting
- Weekly Project Status Meeting & Coordination
- Monthly Project Status Reporting
- Quarterly FTA Status Report Preparation
- Final report and project close-out

One concern is their experience with FTA relates almost exclusively with buses. See next page.
Center for Transportation and the Environment (CTE)  
Additional Notes
* CTE is enthusiastic about working with Tempe and Valley Metro.
* They have offices in Atlanta and northern and southern California, with full-time lobbyists based in Washington DC and Sacramento.
* They have decades of experience working on fuel cells and battery buses.
* They have developed a strong working relationship with FTA as an honest, 3rd-party evaluator of technologies.
* They do advanced modeling of transit energy systems to make sure they will be successful in real-world applications. They validate their models with data from original equipment component manufacturers and based on post-implementation testing are usually within +/- 5% of actual usage.
* They would lose credibility with FTA and other federal agencies if their advance modeling were biased. Therefore, they are careful not to recommend technologies that are not ready or are not likely to succeed in the proposed application with its particular duty cycle, route, estimated loads, and climate.
* Recently, 4 out of 10 demonstration projects funded by FTA were managed by CTE.
* They think their participation would improve the chances of FTA approval of a fully self-powered and wireless streetcar Small Starts application, and they think there would be support for this within the FTA.
* CTE quickly put together a detailed proposed budget for modeling, simulation, and evaluation of wireless streetcar propulsion systems. The estimated budget comes to approximately $75k. They can reduce that cost to around $60k by excluding electricity rate modeling and the life cycle cost analysis.
<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
</table>
| What if company goes out of business?     | • A risk even for established companies  
• Purchase insurance to cover future maintenance |
| What if on-board systems don’t generate enough power? | • Shouldn’t happen – easily modeled by manufacturer and CTE  
• Require a performance guarantee in contracts  
• Could design with extra capacity at the station, tanks, fuel cells  
• Fuel cell buses have seen little to no degradation or maintenance over 9,000-15,000 hours  
• Mobile hydrogen delivery to vehicles en route is possible |
| What if streetcars cost more than estimated? | • Not an issue with a fixed-price contract |
| Few vendors and limited experience        | • Vendors really want that first US customer  
• Several companies now implementing hydrogen fuel cells w/ or w/o batteries in a wide range of vehicles and stationary power  
• Hydrogen production with electrolyzers is not new and is growing |
Going with a relatively new wireless propulsion technology would not be without added risks. Here we address some of the risks that are causing concerns, and what can be done to manage and mitigate those risks.

* We spoke with the former Chair of the Transportation Research Board Subcommittee on Self-Powered Rail Cars, who suggested that one of the largest risks is that a new company can go out of business. We note that United Streetcar, the company that built the streetcars for Tucson, has subsequently gone out of business, so this can happen with any propulsion technology. See http://www.washingtonpost.com/local/trafficandcommuting/us-effort-to-help-build-homegrown-streetcar-manufacturer-falls-short/2014/11/29/98c649b0-70b9-11e4-ad12-3734c461eab6_story.html. Insurance can be purchased to cover costs associated with a supplier going out of business.

* Concerns have been voiced that wireless streetcar using on-board energy storage systems are at risk of running out of power over the course of a long, busy, hot day such as around July 4 in Tempe. Our study committee thinks this is an easy risk to address and it is very unlikely to happen. Streetcar manufacturers have models to simulate worst-case energy usage scenarios, and can easily determine if the sizes of the batteries, fuel cells, storage tanks, hydrogen station, and HVAC units are adequate to maintain the interior temperature and battery state of charge for successful operation. CTE offers independent analysis. Performance guarantees can be written into the contracts. Extra capacity can be added to all components with some additional cost to provide an additional margin of error. In a worst case scenario, a mobile hydrogen delivery truck can be used to deliver additional energy.

* Some concerns have been expressed that the streetcars could end up costing more than budgeted. While this can be a risk for cost-plus construction contracts, it is not a problem for streetcar procurement. Vendors would bid on an RFP and a fixed-price contract will likely be awarded. The risk of any cost overrun falls on the winning vendor.

* An additional risk is that few vendors, or only one, with limited experience, will be able to bid on the project. This risk can be managed by careful preparation of the specifications for the project in an RFP, which can be framed in such a way that more than one company or technology can bid. The RFP does not have to specify a single technology, but rather the required conditions and performance of the vehicles. A paper by 2013 paper by Porter and Melone goes into detail on how Seattle developed the RFP specifications for their battery-wireless streetcar:

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTA prefers proven technologies</td>
<td>• FTA doesn’t exclude off-wire technologies</td>
</tr>
<tr>
<td></td>
<td>• Individual component technologies all proven</td>
</tr>
<tr>
<td></td>
<td>• Integration of technologies also proven, just not on a streetcar in revenue service</td>
</tr>
<tr>
<td></td>
<td>• FTA trusts CTE as honest 3rd-party broker</td>
</tr>
<tr>
<td></td>
<td>• CTE managed 4 of 10 projects recently funded by FTA</td>
</tr>
<tr>
<td>FTA prefers US testing</td>
<td>• “Laws of physics are the same everywhere”</td>
</tr>
<tr>
<td>FTA funding contingent on local match</td>
<td>• By reducing capital costs by $7 to 8 million, FTA funding prospects will improve substantially</td>
</tr>
<tr>
<td>Changing propulsion now might delay FTA application</td>
<td>• Propulsion system does not have to be specified at this time</td>
</tr>
<tr>
<td></td>
<td>• Environmental clearances can be modified</td>
</tr>
<tr>
<td></td>
<td>• RFP could be broad enough for multiple bids (e.g., Seattle specified battery and/or super capacitor—but better to specify required attributes and not specify the technology)</td>
</tr>
<tr>
<td></td>
<td>• Tempe would need representation on review committee to choose best bid</td>
</tr>
<tr>
<td>Delay may allow other Valley cities to leapfrog Tempe</td>
<td>• This is a political question beyond the scope of our study</td>
</tr>
</tbody>
</table>
A second set of risks revolve around not getting or delaying FTA Small Starts funding or delaying regional funding from Proposition 400 monies.

* FTA’s policy on funding new technologies is not well understood. Clearly, they want to be confident that public monies are well spent on technologies that will perform as expected. However, FTA does not exclude off-wire technologies, as evidenced by the FTA funding of the Dallas streetcar project. It is not clear where exactly is the threshold for a technology to be considered “proven” enough for FTA funding. Certainly, all of the individual technologies in a battery-fuel cell range-extended hybrid streetcar are proven and well understood. Integration of these technologies is also proven, though not yet for a streetcar in revenue service. Dubai is testing the battery-fuel cell hybrid streetcars currently, and results may be available later in 2015. Independent modeling of this and alternative wireless technologies by CTE could increase confidence in the technology within FTA.

* Some concerns have been expressed that FTA requires new technologies to be proven in the United States. Several experts this committee has spoken with have disagreed with that, and clearly if that were the case, no new technologies would ever be tried in US transit systems unless done for the first time without any FTA funding, which is clearly not the case. Experts have said that “the laws of physics are the same everywhere,” and that FTA does consider technologies proven outside the US.

* Certainly, FTA funding is contingent on Tempe closing the local funding gap. By eliminating the wayside high-voltage power requirements, Tempe can reduce up-front costs by $18 million. Added costs of about $10 million for a hydrogen station, vehicles including an additional spare, and replacement batteries bring the net savings down to about $7-8 million. This could make a significant contribution toward closing the estimated $23 million funding gap, which as it currently stands would eliminate any chance of FTA funding.

* Concerns have been expressed that it could be too late to modify the propulsion technology at this stage, with plans to submit the FTA Small Starts funding application in September 2015. However, TRB experts suggested that FTA would allow the proposal and environmental documents to be modified after approval, especially if it did not increase the costs or change the route, and that it is too soon to worry about specifying the propulsion system before the project gets FTA approval. As described earlier, after FTA approval, an RFP could be crafted with clear but broad specifications that would allow multiple vendors of different technologies to bid on the Tempe Streetcar project. Seattle’s wireless streetcar RFP specified either of two technologies—batteries or super capacitors—but it would be better to specify the required attributes of the performance and not specify the technology.

* TRB experts emphasized that FTA should be viewed as partners more than judges, and it is important for Tempe and Valley Metro to engage in discussions with FTA to assess these issues.
Intangible Benefits

- Striking aesthetics
- Faster construction/less disruptive to business
- International reputation for innovation
- Study tours from other cities
- High-tech start-up companies
- Jumpstart on the hydrogen economy
- Valley Metro already a national leader in alt fuels
- Solar-hydrogen partnerships with ASU, APS, SRP, First Solar
- Removable streetcar windows (TIG/m)
Conclusions

* Proof of existence that at least one “win-win” self-powered streetcar technology is commercially available and:
  - More attractive and more exciting
  - Suitable for Tempe route, hours, and climate
  - Net capital cost savings in neighborhood of $7 to 8 million
  - Safer and more sustainable
  - Integration of proven technologies

* There are ways to manage technological, perception, and financial risks through partnering with CTE, open RFP, careful contracting, insurance, additional performance margins, and contingency planning

* Reducing the funding gap improves chance of FTA funding
Work with Valley Metro to continue advancing a proposal for FTA funding while keeping propulsion options open.

Budget $60 to 75K for CTE to do cost and energy modeling of battery/fuel cell hybrid system and other wireless streetcar technologies for Tempe route and climate.

With CTE’s 3rd-party analysis in hand, partner with CTE and Valley Metro to engage with FTA and build FTA support.

Begin developing appropriate RFP specifications and performance guarantees that would allow multiple vendors to propose competing technologies for a completely self-powered (or with extensive wireless segments) streetcar system with no high-voltage power requirements that would reduce capital costs, assess and mitigate risks, and help close the funding gap.
Questions?
Dr. Ellen Stechel

Dr. Ellen Stechel is a Professor of Practice in Chemistry and Biochemistry at ASU, and Deputy Director of LightWorks. Prior to coming to ASU, she managed research departments in solar and emerging energy technologies at Sandia National Laboratories and before that at Ford Motor Company managing Chemistry and Environmental Science in the Scientific Research Laboratory and proving/deploying new low-emissions technologies in Ford Product Development, which included Ford’s hybrid vehicle. Dr. Stechel earned her PhD in Chemical Physics from University of Chicago.

Dr. Michael Kuby

Dr. Michael Kuby is Professor in Geographical Sciences and Urban Planning at ASU, and Director of the Interdisciplinary Graduate Certificate Program in Transportation Systems. He specializes in alternative-fuels vehicles and infrastructure and light-rail ridership. He has co-edited the last two Background Reports on Transportation for the Arizona Town Hall. He is Location Area Editor for the journal *Networks and Spatial Economics* and on the editorial boards for *International Regional Science Review* and *Journal of Transport Geography.* Dr. Kuby earned his PhD in Geography from Boston University.

Dr. Mikhail Chester

Dr. Mikhail Chester is an Assistant Professor in Civil, Environmental, and Sustainable Engineering at ASU, where he runs a research laboratory focused on transportation life cycle assessment and infrastructure resilience to climate change. Dr. Chester has worked with a variety of public and private passenger and freight agencies to develop energy and environmental assessments of transportation systems including infrastructure, vehicle, and energy production processes, in addition to vehicle operation. Dr. Chester earned his PhD in Civil and Environmental Engineering from UC Berkeley.
Appendix 2
Experts Consulted by Study Group

* Dr. Aaron Golub, Associate Professor, School of Geographical Sciences and Urban Planning, ASU
* Dale Hill, Founder, Proterra (electric and fuel cell bus company), Greenville, SC
* Jason Hanlin, Director of Technology Development, Center for Transportation and the Environment, Atlanta, GA
* Monica Meade, Parsons Brinckerhoff, Baltimore, MD and Chair, Streetcar Subcommittee, Transportation Research Board
* Brian Nadolny, Charlotte Area Transit System, Charlotte, NC
* David O. Nelson, Director of Transit Planning, Jacobs Engineering Group, Boston, MA and former Chair, Self-Powered Rail Car Subcommittee, Transportation Research Board
* Dr. Nathan Parker, Assistant Research Professor, School of Geographical Sciences and Urban Planning, ASU
* Dan Raudebaugh, CEO, Center for Transportation and the Environment, Atlanta, GA
* Brad Read, President, TIG/m Modern Street Railways, LLC, Chatsworth, CA
* Stan Thompson, Founder, International Hydrail Conference, Charlotte, NC