THE ELECTRIC VEHICLE
Agenda

- History & basic theory of the technology
- State-of-the-art designs and products
- Impacts (technical and social)
- Challenges or R&D focus for the next 5-10 years
- True stories of its application or demonstration
- Related research papers published in the past 5 years
History & Basic Theory of the Technology
Over 100 Years of History

1896
The First Fleet Vehicles
The Electric Vehicle Co. introduced electric cabs to New York City in 1896, and by 1899 the city had more than 60 of them. The cars were intended to fix the significant waste problem from horse-drawn carriages. Cab companies didn’t believe there was a market for personal cars because it would require knowledge of electricity. Consumers did end up purchasing their own, however, because of how easy they were to use.

1900
Electric Advantages In The Market
In 1900, there were more than 4,000 cars on the road -- a third each electric, gasoline and steam-powered. The electric car was quicker to start up than the steam-powered vehicle, and cleaner than the internal combustion engine. Electric cars would also do well in the snow where others couldn’t make it, but cold weather was a drain on battery life. Modeled after stylishly designed carriages, electric cars in this time period would last about 35 miles per charge.

1908
Rise Of Internal Combustion Engines
Henry Ford introduced the Model T in 1908 for $850. By comparison, Anderson Electric, one of the most popular electric car manufacturers, sold its cars for around $2,000. The Model T’s production method would eventually overtake electric vehicles. But even Ford’s wife, Clara, bought an electric car for herself -- like many women of the time, she preferred its cleanliness and ease of use to gas-powered cars.
Over 100 Years of History

1910
The Battery Question
From the start, marketers knew batteries were an issue for consumers. This ad from 1910 hails a battery, invented by Thomas Edison, that "will outlast the life of your car."
Edison was a major force in the battery market, and his nickel-steel battery replaced the lead one, raising the average driving range from 65 to 100 miles. But range anxiety was an issue: One journal article from 1911 noted, “If charging stations could be readily found in every town where there is electric service, the use of electric pleasure cars on fairly long runs would become much more common than it is now.”

1920
The Downfall Of The Electric Car
With more developed roads, car owners wanted to go farther than electric car charges allowed. Many rural farms stocked jugs of cheap gasoline from newly drilled oil fields in Texas, but few had electricity. And the invention of the electric starter meant people were less involved in operating the dirty and dangerous internal combustion engine. By the late 1920s, the electric car was nearly gone from the market.

1973
The Middle Years
The period from the mid-1920s to the early 1990s saw little large-scale production of electric cars. Most were concept cars or small test fleets, which surged in popularity depending on historical events. In England, for example, electric cars became popular as a delivery vehicle during both world wars to save gasoline. Fuel shortages and environmental concerns in the 1970s also had U.S. developers eyeing electric power. Most cars ended up like this Sundancer -- a futuristic prototype never produced on a large scale.
Dave Modisette charges his General Motors EV1 electric car in Sacramento, Calif.

1996

Return Of The Electric Car

In 1996, GM unveiled the EV1, an electric car that traveled about 80 miles per charge. The car was developed partially in response to the California Air Resource Board’s 1990 ruling that 10 percent of the state’s cars must produce zero emissions by 2003, which was later rolled back. EV1s were only available for lease and were taken out of commission in 2003, upsetting many owners. The car was the subject of the 2006 documentary Who Killed the Electric Car?

2006

A Luxury Market

In 2006, Tesla Motors (named after Nikola Tesla, an inventor who worked with Edison) unveiled the Tesla Roadster. Priced over $100,000, the car was meant for a high-income market and aimed to show off what an electric engine could accomplish. The company stopped taking orders for the car in 2011. A second-generation Tesla, with a starting driving range of 160 miles, will go on sale next year at around $58,000.

2010

The New Electric Generation

The all-electric Nissan Leaf went on the market in the fall of 2010. The Leaf can go up to 100 miles per charge and costs around $35,000. Nissan has sold more than 8,000 of the vehicles so far. Like other electric vehicles on the market (the Smart Fortwo, Chevy Volt and the coming electric Ford Focus), the Leaf faces similar problems to those that ailed electric cars at the turn of the last century: consumer desire for longer battery range and a less expensive product.
Basic Theory of the Technology

- DC electricity from the battery is fed into a DC-DC converter and then an AC inverter where it is converted to AC electricity
- This AC electricity is then connected to a 3-phase AC motor which runs the vehicle
- Hybrid: Bidirectional DC–DC converter is used to manage two-way energy transfer and cascading Hybrid Energy Storage System to DC-bus system
Dual-Battery System

- Tesla Motors Patents Hybrid Battery System for electric vehicles.
Metal Air-Batteries

- Lithium-Air Battery

\[ 4\text{Li} + \text{O}_2 \rightarrow 2\text{Li}_2\text{O} \]

- Energy Density of Batteries
Solid-State Power

- Solid Power’s solid-state battery
- View of Solid Power’s Battery (Internally)
Solid-State Battery

**Conventional battery**

- Anode
- Cathode
- Electrolyte

**Problems**
- Liquid leakage
- Narrow range of operation temperature (coagulation and evaporation of liquid)
- Deformation, expansion, and explosion upon heating

**Features**
- Low ionic conductivity of solid electrolyte

**All-solid-state battery**

- Anode
- Cathode
- Solid electrolyte

**Problems**
- Good safety
  - No use of explosive substances
  - Low occurrence of short-circuits
- High stability
  - No use of volatile substances
  - No liquid leakage
  - High robustness to deformation

**Simple fabrication**
- No need for tough metal package
- Flexible fabrication in various shapes (e.g., thin-film shape)
State-of-the-Art Capacitor

- New Capacitors that can improve the electric vehicle by increasing performance and reducing weight
State-of-the-Art Designs or Products

- Power Density (W/kg) and Energy Density (Wh/kg) of Porous Silicon, Graphene-coated Si, and carbon based capacitors
Impacts (Technical and Social)
Impacts

- Environment benefit
- Grid
- Social – Daily life
Environmental Impacts

- No green house gas emissions from the car
  - Does not burn fossil fuels
- How much is it really helping?
  - Majority of energy still produced by fossil fuel burning plants
  - Transmission line losses
Energy Generation

From wikipedia.org “Electricity sector of the United States”
Power Grid Impacts

- Energy for the car is now coming from the power grid
  - Charging Stations
- Will add a significant amount of load to the grid if the EV continues to evolve and catch on
  - Issues include Phase balancing and Transformer loading
    - “Clustering”
Nashville Area EV’s
Social Impacts

- Charging Stations, not gas stations
  - Will need to be built, or modify gas stations
- Current range of one full charge
  - Where is the next station?
    - Charging times – Currently long
Challenges or R&D Focus for the Next 5-10 Years
Research and Development – Wireless Charge

Vehicle approaches charging pad, aligns and negotiates with WPTB station, commences charging.
Research and Development – Wireless Charge

Dynamic Wireless Power Transfer (WPT) Experimental Results

- Illustration of system hardware
- Power flow as function of vehicle position

HF inverter system with HF transformer and self contained thermal management system

- Future directions in dynamic WPT
  - Infrastructure issues (roadway integrity)
  - Communications requirements (latency)
  - Grid power distribution (intermittency)
  - Coil sequencing and power modulation & alignment
  - Local energy storage (smoothening)

- Promote dc distribution along highway
- Highly distributed vs. centralized HF stage
Challenges

- Increased popularity of electric cars would put an increased load on the power grids.
- This demand if raised too rapidly would cause black outs.
- A house in San Francisco might only draw two kilowatts of power at times of peak demand, according to Pacific Gas & Electric. In comparison, a new electric vehicle on a dedicated circuit could draw 6.6 kilowatts.
- The grids would need to be upgraded prior to demand spike to avoid catastrophe.
Challenges

- A major challenge for electric car is energy storage.
- One challenge in this area is physical storage space of energy as batteries are large and more power means more batteries making the vehicles larger and heavier compounding the problem.
- Another challenge is safe and reliable rapid charging of batteries which hold dangerous chemical and run the risk of spilling and even exploding.
True Stories of its Application or Demonstration
Application – Not Successful Story

General Motors EV1 (1996-2003) – First mass-produced and purpose-designed EV from a major auto maker

- **Background:** 1. Favorable reception for its electric concept car; 2. mandate of zero-emission vehicles from California government
- **Reaction:** 1. Customers were positive; 2. GM believed that EV1 was unprofitable car
- **Ending:** 1. All cars are repossessed; 2. Cost over $1 billion in total for 1160 produced EV1
Application – Successful Story

- **Tesla motors (2003-) – One of the most promising electric vehicle company**
  - **Background:** 1. Several main auto companies stopped EV program in 2003; 2. A few wealthy people still prefer to have an EV
  - **Reaction:** Both the two delivered EV models (Roadster and Model S) achieves a huge success in the market
  - **Future:** 1. Extend car models; 2. Mass-producing fully electric vehicles at a price affordable to the average consumers
Demonstration – Successful Story

- EV built in the Delft University of Technology – World’s fastest accelerating electric vehicle ever
  - World’s new record of 2.13s from 0-100 km/h; compared to the old record of 2.3s for production cars and 2.68s for EVs
  - Four electric motors with a total power output of around 135 horsepower

- It proves that EV can out-muscle internal combustion engine cars
Related Research Papers Published in the Past 5 years
Control strategies for electric vehicles

- Fuel Cells (FCs) disadvantages:
  - Low power density
  - Slow startup and slow power response
  - Lower efficiency at low and high output power
  - Increasing the cost

- These drawbacks can be reduced by combining FCs with other energy storage systems:
  - Batteries
    - Provide power for longer period
  - Super capacitors (SC)
    - More efficient
    - Longer life time (Charge/ discharge cycles)
Control strategies for electric vehicles
Control strategies for electric vehicles

- The energy Management system is responsible for:
  - Controlling the system operation
  - Providing the power needed
  - Optimize the energy generated
  - Control the battery and SC

- Constraints and limitations:
  - FCs output power is kept between \((p_{fc}^{max}, p_{fc}^{min})\)
  - FCs dynamic response is limited in slope
  - Battery power and current \((p_{Bat,char}^{max}, p_{Bat,dis}^{max})\) & \((I_{Bat,char}, I_{Bat,dis})\)
  - The dynamic limitation of the battery
  - The battery and SC are kept around their reference
  - ...
Control strategies for electric vehicles

- Operating Mode Control (OMC)
  - OMC generates the FC and battery reference powers

![Diagram of operating mode control](image)
Questions ?