A Brief History of Transportation

By Prof. Paul A. Erickson
A Brief History of Transportation/Energy

The Dawn of Time

Post-Dawn of Time

Circa 1400

Circa 1800

Circa 1900

Circa 1950
2005 After Katrina

Have we come full circle??
Eras of Transport

Boats Animal drawn transport
1800s steam power locomotives ships industry
1890s Bicycle Boom
1900 Steamers Electric and IC compete for automobile market
1907 Henry Ford uses mass manufacturing techniques to bring low manufacturing costs to IC Engine
1914 WW1 IC engine further developed for aircraft and all transport (21 million people killed)
1920 Wealth increases demand for the IC Engine
1930 Great depression plants the seeds for WW2
1940 WW2 Huge strides in US manufacturing capacity and development of long lasting high power IC engines (73 million people killed)
1950s Development of Gas turbines
1960s Cold war spurs development of gas turbine aircraft and spacecraft
Russo-Japanese War 1904-05

• Coal Powered Ships relied upon friendly ports and/or colliers for at sea refueling.
• 5 days to refuel coal powered ships requiring 75% of the crew (500 men) ships tethered side by side (calm sea required)
• Oil powered ships could refuel in 12 hours requiring 12 men steaming 50-100 ft apart in relatively rough seas
• Russian fleet decided not to refuel at sea in Pacific tried to dash through the sea of Japan to port.
• Entire Russian fleet destroyed in one afternoon

Changed the entire outlook of the world when considering fuel supply
Energy Sources, Conversion

- The vast majority of our energy use involves:
  - Combustion of fossil fuels
  - Heat engines that convert thermal energy to useful work
### Vehicles: Then and Now

| Vehicle                  | Ford Model T *  
|-------------------------|----------------|
| (1908-1927)             | Ford Fusion  
| (2006-present)         |                |
| Engine size (Liters)    | 2.9 L (4-cylinder) | 2.3L (4-cylinder) |
| Power (hp)              | 20             | 160            |
| Weight (lb)             | 1,200          | 3,200          |
| 0-60 mph accel. (s)     | (max speed 45mph) | 9.5 sec        |
| Fuel economy (mpg)      | 13-21          | 20-28          |

* Would *not* meet modern emission and safety regulations
The Earliest Vehicles

Cugnot's steam wagon 1771

Richard Trevithick's 1801 Road Locomotive
The Answer to Environmental Problems (horse manure on the streets)

Benz 1886 IC vehicle
Electric Vehicles Were all the Rage In 1899-1900

- Easy Starting
- No Smell
- Low noise (there were horses still on the road)
- Low power requirements
- Low range requirement (Roads rarely extended out of local town)
- Vehicle speed record (65.71 mph)
- Vehicle one charge range record (180 miles)
Combustion vs Electric Historically

- Poor roads disadvantaged the heavier electrics
- Roads started to lead from town to town… longer range required.
- Fast intuitive refueling for liquid fuels
- Complex Infrastructure required for Electrics (was not easily transmitted and portable like liquid fuel) (early gasoline still needed trough water for cooling) (Steamers needed trough water for steam generation)
- Hand crank replaced by Kettering’s electric starter
- Radiator allowed IC engines to operate longer than a few miles without overheating
- Henry Ford brought low manufacturing expenses with Gas-powered Model T (still had the hand crank)
Manufacturing

• The initiation of mass production of internal combustion engine vehicles by Henry Ford made these vehicles widely available and affordable in the $500 to $1,000 price range. By contrast, the price of the less efficiently produced electric vehicles continued to rise. In 1912, an electric roadster sold for $1,750, while a gasoline car sold for $650.
Fuel Historical Demand

Data from EIA

U.S. Petroleum Consumption by Transportation Mode, 1970-2007

What Primary Energy Resources Can be Used?

Some pathways have more obstacles than others.
Energy Pathways in Transportation

- Energy resource (typically chemical energy)
- Harvest
- Refining (if required)
- Transport to use location
- Convert to shaft power (Typically this goes through temperature to pressure to shaft power)
- Finally “The wheels on the bus (train, car, etc) go around and around”
Modern Miracles

• Transportation and Energy use allows us to live and even thrive in harsh climates i.e. Arizona and Iceland
• Even the poor among us have access to better nourishment and with more variety than the extremely rich just a few hundred years ago, all due to transportation.
• Fruits and vegetables can be eaten out of season due to transportation and refrigeration
Energy Pathways

Energy Source

Energy Conversion Device

Hydrogen

End Use

Energy Conversion = Loss of Energy!!! Always!

Technical requirements often require energy conversion steps (crude oil will not burn in a typical automobile engine)… but these steps should be minimized and the efficiency of each step should be maximized.
Energy/cost is not always the bottom line

• Characteristics of End Use are Critical! sometimes but not always this is for niche applications IE
  – Combustion stoves vs Electrical stoves (this has implications for developing countries)
  – Diesel emissions (diesels have always been more efficient)
  – Applications which require/prefer zero emissions Forklifts golf carts etc
• Infrastructure and previous investment IE
  – Liquid fuel infrastructure exists in many locations (gaseous infrastructure does not)
  – Capital in Place
  – Billions of dollars invested solely in tooling for mass production of the ICE

Trump Cards-
2007 Energy Flows in Quads

Fuel Used for Transportation, 2007

- Gasoline (Petroleum): 62%
- Diesel (Petroleum): 22%
- Jet Fuel (Petroleum): 9%
- Natural Gas: 2%
- Other: 5%
- Construction & Agriculture: 4%
- Water: 5%
- Pipelines: 3%
- Trains & Buses: 3%
- Light Trucks: 28%
- Other Trucks: 16%
- Aircraft: 9%
- Automobiles: 32%

Note: Due to rounding, data may not sum to exactly 100%.
Motivation for Alternative Fuel Use

- Energy Security/Economic Security
- Rising Cost of Fossil Fuels
  - Increasing demand
  - Decreasing supply
- Emissions

<table>
<thead>
<tr>
<th>Region</th>
<th>2004</th>
<th>%</th>
<th>2030</th>
<th>%</th>
<th>Increase</th>
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<tr>
<td>North America</td>
<td>55</td>
<td>25.0</td>
<td>60</td>
<td>20.6</td>
<td>25</td>
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<tr>
<td>Latin America</td>
<td>13</td>
<td>5.9</td>
<td>24</td>
<td>7.2</td>
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<td>Europe</td>
<td>39</td>
<td>17.7</td>
<td>46</td>
<td>13.7</td>
<td>18</td>
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<tr>
<td>Russia and Caspian region</td>
<td>20</td>
<td>9.1</td>
<td>28</td>
<td>8.4</td>
<td>40</td>
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<tr>
<td>China</td>
<td>26</td>
<td>11.8</td>
<td>52</td>
<td>15.5</td>
<td>100</td>
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<tr>
<td>Japan</td>
<td>11</td>
<td>5.0</td>
<td>12</td>
<td>3.6</td>
<td>9</td>
</tr>
<tr>
<td>Africa</td>
<td>12</td>
<td>5.5</td>
<td>19</td>
<td>5.7</td>
<td>58</td>
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<tr>
<td>Middle East</td>
<td>11</td>
<td>5.0</td>
<td>18</td>
<td>5.4</td>
<td>64</td>
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<tr>
<td>India</td>
<td>11</td>
<td>5.0</td>
<td>29</td>
<td>8.7</td>
<td>164</td>
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<tr>
<td>Rest of Asia Pacific</td>
<td>22</td>
<td>10.0</td>
<td>38</td>
<td>11.3</td>
<td>73</td>
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<tr>
<td>Total</td>
<td>220</td>
<td>100.0</td>
<td>335</td>
<td>100.0</td>
<td>52</td>
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</table>

Source: Exxon Mobil (2004) and own calculations.
Why Research NEAR-TERM Alternative Fuel Technologies?

Historic US Gasoline Prices

Data from EIA
Current status of transportation technology

- Fuels are presently dominated by liquids
  - Gasoline
  - Diesel
  - Jet A
- Conversion is dominated by the internal combustion engine for terrestrial applications and gas turbine engines for aircraft
- Why?
Characteristics of Fuel Production, Storage, and End use

- Availability (practical)
- Cost
- Ease of use
- Safety
- Power density
- Energy density
- Pollution and other externalities
Ease of Use

Hydrogen refueling in Munich, Germany

Gasoline Station in Indonesia
Gasoline being pumped into an ice chest Friday at a service station in Huntsville, Tex. Many motorists ran out of gas on evacuation routes.

“You will never see widespread use of a fuel unless you can put it in a barrel” PAE

Scott Dalton for The New York Times

Published Sept 24, 2005
Power Density of Engines

Figure 2.2 Aviation Engine Power Density

Future Alternatives

- Must attain or exceed the technical specifications of current technology
  - Must have equal or better performance
  - Must have equal or lower cost
  - Must be largely transparent to user

“The stone age didn’t end because we ran out of stones”
Only ask for one miracle at a Time!

Original Design

Trinity 2004-2007

- Hydrogen powered fuel cell
- Plug-in Capable Hybrid
- Bioderived alcohol as IC fuel + hydrogen enrichment
Increasing Efficiency

Technical Specifications - utility, acceleration, top speed, lifetime, reliability, safety, visibility, comfort

Light Wt. Oil

\[ C_4H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 3.76(12.5)N_2 + \text{Light Wt. Oil} \]
Possibilities

- Hydrogen fuel cell vehicles
  - Hydrogen economy?
  - Electric economy?
- Biofuels and other Renewably Produced Fuels
  - Land use?
  - Food vs Fuel?
- Hybrid Vehicles (commercial now)
- Plug in Hybrid
- Battery Electric Vehicles
  - Battery lifetime?
  - Full scale
  - Neighborhood EV
  - E-bikes
- Grid connected vehicles (subways, trams, buses)
- HPVs and Bikes

Increasing Efficiency of Diesel and Otto cycles

\[ C_4H_{18} + \frac{12.5}{2} (O_2 + 3.76 N_2) \rightarrow 8CO_2 + 9H_2O + 3.76(12.5)N_2 \]
• In 1998 Fuel cell target was to mimic range of gasoline powered vehicles (250-300 miles at the time)

• In 2007 GM demonstrates 300 mile range fuel cell vehicle (Honda Clarity has 240 mile range)

• Toyota Prius has a 10 gallon tank and gets 50-60 miles per gallon. New target should be 500-600 miles per tank
Transportation Concerns/Distractions

• Criteria Pollution ($O_3$, CO, NOx, SOx, PM, Pb)
  – Regional and Local Problem
  – Largely solved by application of air pollution and aftertreatment systems, PCV, EGR, TWC - many areas of the world do not have vehicle air pollution regulations or controls

• Peak Oil

• Dependence on Foreign Sources (Canada 16%, Mexico 12%, Saudi Arabia 11%, Venezuela 11%, and Nigeria 8% were the largest exporters to the US in 2005)

• Traffic Congestion
  – “If you build it they will come”
  – “If you don’t build it they will still come” It’s a lifestyle/housing problem

• Traffic Safety

• CO$_2$ Emissions
“The 19th century was the century of the steam engine. The 20th century was the century of the internal combustion engine. The 21st century is the century of solar hydrogen and the fuel cell.”

Maybe??

“Hydrogen is the fuel of the future… and always will be.”
• 95%+ of Hydrogen is currently produced from Natural Gas not from Renewables or Nuclear Power (Merchant H₂ used for hydrogenation in gasoline production [~27 scf/gal gasoline], electronics, food, metal, and glass processing and fertilizer production) (Must be cost effective)

• Even though technologies are well established for the large scale, Hydrogen proves difficult to produce, store, transport, and use as fuel itself cost effectively. (Especially in small quantities).

• Much research is required to get scaled breakthroughs in hydrogen production, storage and general durability/reliability.

• Competing technologies (gasoline hybrids, Battery technologies)

• Magnitudes of energy requirements (17,006,290 bbl/day of crude oil processed in US 2005)
29 Quad BTU per annum (2007) used for US Transportation

- 969 GW
- At 185 W/m² solar power (avg. US solar insolation not including Alaska) and 10% conversion efficiency
- 52.4 x 10⁹ m² or 52.4 x 10³ sq km
- At 25% land use this increases to 209,636 sq km or 51.8 million acres
- Total Area in California = 424,000 sq km
- At a dollar per peak watt that is 969 billion dollars (current price is roughly 6$/W installed so that’s 5.8 trillion [plus 40% off peak although that might be offset by more efficient use of the energy] plus the electric vehicles to use the energy… oh did we mention the price of land? What about the sunk cost of previous investment? Hmm?)
<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Average passengers per vehicle</th>
<th>BTU per passenger-mile</th>
<th>MJ per passenger-kilometre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanpool</td>
<td>6.1</td>
<td>1,322</td>
<td>0.867</td>
</tr>
<tr>
<td>Efficient Hybrid</td>
<td>1.57</td>
<td>1,659</td>
<td>1.088</td>
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<tr>
<td>Motorcycles</td>
<td>1.2</td>
<td>1,855</td>
<td>1.216</td>
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<tr>
<td>Rail (Intercity Amtrak)</td>
<td>20.5</td>
<td>2,650</td>
<td>1.737</td>
</tr>
<tr>
<td>Rail (Transit Light &amp; Heavy)</td>
<td>22.5</td>
<td>2,784</td>
<td>1.825</td>
</tr>
<tr>
<td>Rail (Commuter)</td>
<td>31.3</td>
<td>2,996</td>
<td>1.964</td>
</tr>
<tr>
<td>Air</td>
<td>96.2</td>
<td>3,261</td>
<td>2.138</td>
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<tr>
<td>Cars</td>
<td>1.57</td>
<td>3,512</td>
<td>2.302</td>
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<tr>
<td>Personal Trucks</td>
<td>1.72</td>
<td>3,944</td>
<td>2.586</td>
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<tr>
<td>Buses (Transit)</td>
<td>8.8</td>
<td>4,235</td>
<td>2.776</td>
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</table>

US Transportation Energy Data Book 2006 data
<table>
<thead>
<tr>
<th>Transportation mode</th>
<th>Fuel consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BTU per short ton mile</td>
</tr>
<tr>
<td>Class 1 Railroads</td>
<td>341</td>
</tr>
<tr>
<td>Domestic Waterborne</td>
<td>510</td>
</tr>
<tr>
<td>Heavy Trucks</td>
<td>3,357</td>
</tr>
<tr>
<td>Air freight (approx)</td>
<td>9,600</td>
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</tbody>
</table>

US Transportation Energy Data Book 2004 data
Examples of Different Aircraft Types' Fuel Burn Rate

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Fuel burned (kg of fuel)</th>
<th>Number of seats</th>
<th>Fuel burned per passenger (kg of fuel)</th>
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</thead>
<tbody>
<tr>
<td>A320</td>
<td>11,608 kg</td>
<td>150</td>
<td>77.4 kg</td>
</tr>
<tr>
<td>B767-300ER</td>
<td>21,445 kg</td>
<td>218</td>
<td>98.4 kg</td>
</tr>
<tr>
<td>B747-400</td>
<td>42,920 kg</td>
<td>416</td>
<td>102.4 kg</td>
</tr>
</tbody>
</table>

(Source: Gillespie, TRX Travel Analytics 2007)

May not hold together in a storm…. but it burns less fuel!
Comparison of Shipping Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Net ton-miles per gallon</th>
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<tbody>
<tr>
<td>Truck</td>
<td>82.4</td>
</tr>
<tr>
<td>Rail (mountainous US)</td>
<td>437.0</td>
</tr>
<tr>
<td>Rail (plains US)</td>
<td>640.1</td>
</tr>
<tr>
<td>Barge</td>
<td>544.5</td>
</tr>
<tr>
<td>30,000 dwt Ship</td>
<td>574.8</td>
</tr>
<tr>
<td>50,000 dwt Ship</td>
<td>701.9</td>
</tr>
<tr>
<td>70,000 dwt Ship</td>
<td>835.1</td>
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<tr>
<td>100,000 dwt Ship</td>
<td>1,043.4</td>
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</table>

Estimates of Total Fuel Consumption in Transporting Grain from Iowa to Major Grain Countries by Alternatives Modes and Routes
C. Philip Baumel, Charles R. Hurburgh, and Tenpao Lee
Conclusion

• Much is still to be done in improving transportation systems and not just in efficiency.
• There are overriding concerns that are more important than efficiency and cost.
• With established systems in place step changes in the transportation system are unlikely.
• Much of the world does not have access to personal transportation.
• Much research and development is required to improve access, improve utility and bring down cost
The future