The Automobile Industry

Environmental issues:
- During manufacturing
- During use
- During recycling/disposal

The automobile industry used to be the largest manufacturing enterprise in the world (Mildenberger & Khare, 2000). It has now been surpassed by the electronics industry.
The basic issues

Automobiles
- are relatively massive → issue of quantity of materials
- have a complex design → issues of material variety
  → complex recycling
  → heavy metals, toxics, solvents used in manufacturing
- consume energy during their use → issue of efficiency (car weight, engine type)
- pollute during their use → issue of fuel type
  → issue of used oil disposal (minor issue)
- generate sizeable amounts of solid waste at the end of life
  → issue of recycling (metals, plastics, others)
  → issue of old tires (not recyclable)

Where is the greatest energy consumption? In manufacturing or in using the car?

A rough calculation based on energy consumption estimates:

Manufacturing:
Car weighs about 1400 kg
50 MJ needed per kg of material

\[
\frac{50 \text{ MJ}}{\text{kg}} \times \frac{1400 \text{ kg}}{\text{car}} = \frac{70,000 \text{ MJ}}{\text{car}} = 70 \text{ GJ/car}
\]

Use:
150,000 miles during lifetime
25 miles per gallon
Gasoline generates 31 MJ/L = 117 MJ/gallon

\[
\frac{6,000 \text{ gallons}}{\text{car}} \times \frac{117 \text{ MJ}}{\text{gallon}} = \frac{702,000 \text{ MJ}}{\text{car}} = 702 \text{ GJ/car}
\]
Energy consumed over the lifetime of a typical car. The total amount of energy represented by the pie is 1.2 million MJ.

Toxic releases over the lifetime of a typical car. The total releases represented by the pie are 66.3 kg.


Adding a few extra considerations, such as fuel processing and insurance:

Manufacturing:

Car weighs about 2100 kg
Batteries: 85 kWh weighing 770 kg for @ 828 MJ/kWh
Rest: 1330 kg @ 50 MJ/kg

\[
\frac{828 \text{ MJ}}{\text{kWh}} \times 85 \text{ kWh} + 1330 \text{ kg} \times \frac{50 \text{ MJ}}{\text{kg}} = 70,380 \text{ MJ} + 66,500 \text{ MJ} = 137 \text{ GJ}
\]

Use:

150,000 miles during lifetime
26 kWh per 100 miles

\[
150,000 \text{ mi} \times \frac{26 \text{ kWh}}{100 \text{ mi}} = 39,000 \text{ kWh} = 140 \text{ GJ}
\]

Is this still true for electric cars?

Much more comparable !!!
In applying Design for Environment (DfE) to the automobile, keep in mind the time horizon.

According to BMW:

- It takes 3 to 4 years to design a new model.
- More or less same model is manufactured during 7 to 8 years.
- Once on the road, the car is driven for about 10 to 12 years.

TOTAL length of time impacted by early design decisions:

20 to 24 years!

(Point of reference: 25 years = 1 generation.)
### Possible levels of automotive redesign

<table>
<thead>
<tr>
<th>Level</th>
<th>Example</th>
</tr>
</thead>
</table>
| 1. Re-design of parts: | Aluminum or plastic radiator cap  
Longer-lasting tires and batteries  
Aluminum or steel engines |
| 2. Re-design of assembly: | Eco-friendly painting  
Facilitating disassembly  
Recycling of plastics |
| 3. Re-design of automobile itself: | Alternative fuels (ex. ethanol, methanol)  
Alternative powertrains (hybrids, fuel cells) |
| 4. Re-design of transportation systems: | Smart highways  
Public transportation |
| 5. Re-thinking the need for mobility: | Virtual office (telecommuting)  
Community layout |

### Levels at which effort are being concentrated:

1. **Design for fuel efficiency:**  
   - streamlined aerodynamics (pretty much at its limit by now)  
   - materials for lighter weight  
   - hybrid engines; plug-in hybrids

2. **Design for cleaner fuels:**  
   - biodiesel, used vegetable oil  
   - ethanol (from sugars, from cellulose)  
   - fuel cells with hydrogen as a fuel  
   - electric car

3. **Design for better recycling:**  
   - materials reduction / substitution  
   - labeling of plastics  
   - use or recycled plastics (metals already recycled)  
   - assembly for disassembly  
   - development of recycling infrastructure (prompted by regulations)

4. **Lean manufacturing:**  
   - avoidance of toxics, minimization of solvents, *etc.*
Stage 1:

AUTOMOBILE MANUFACTURING

Environmental impacts during manufacturing

A typical car contains about 15,000 parts, but the first few account for most of the weight of the vehicle (chassis, engine, body panels, etc.)

About 2,000 fewer parts in an electric car (mostly in propulsion systems)
Not all parts are equally large and important.

Figure 2. Distribution of parts by weight.

Steel on a per-car basis
(1995 numbers)

New steel: 811.6 kg
Recycled steel: 109.3 kg

= 920.9 kg of input
- 70.1 kg losses in processing steel
- 67.6 kg losses during manufacturing
- 783.2 kg into new car
- 76.7 kg losses during use & abandoned cars
- 706.5 kg of hulk going to dismantler
- 25.9 kg losses in dismantling/recycling
- 680.6 kg recycled
- 109.3 kg to auto industry
- 571.3 kg to other industries

Plastics on a per-car basis
(1995 numbers)

Virgin polymers: 117.8 kg
Recycled plastics: 2.5 kg

= 120.3 kg of input
- 3.3 kg losses in processing steel
- 117.0 kg into making parts
- 5.0 kg losses during manufacturing
- 112.0 kg into new car
- 7.5 kg losses during use & abandoned cars
- 104.5 kg of hulk going to dismantler/recycler
- 102 kg waste
- 2.5 kg recycled
More accurate estimates of energy to make and use mid-sized cars:

<table>
<thead>
<tr>
<th></th>
<th>Manufacturing (GJ/car)</th>
<th>Use (GJ/car)</th>
<th>Total (GJ/car)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional car</td>
<td>104</td>
<td>867</td>
<td>971</td>
</tr>
<tr>
<td>Lightweight car</td>
<td>107</td>
<td>759</td>
<td>866</td>
</tr>
<tr>
<td>Conventional car with 90% recycled metals</td>
<td>79</td>
<td>867</td>
<td>946</td>
</tr>
<tr>
<td>Lightweight car with 90% recycled metals</td>
<td>66</td>
<td>759</td>
<td>825</td>
</tr>
</tbody>
</table>

(Source: Automotive Engineering, June 1997, page 80)

Clearly, making a lighter car gives a better environmental return than recycling materials.

Comparing the making and running of different cars:

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric car (not Li-ion batteries)</td>
<td>1385</td>
<td>123.1</td>
<td>42.8</td>
<td>384 (70%)</td>
<td>1.5</td>
<td>0.01</td>
<td>551.4</td>
</tr>
<tr>
<td>PEM fuel cell with Hydrogen from windmill</td>
<td>800</td>
<td>178</td>
<td>~30</td>
<td>195 (48%)</td>
<td>1.5</td>
<td>---</td>
<td>404.5</td>
</tr>
<tr>
<td>Standard ICE vehicle</td>
<td>1395</td>
<td>80.8</td>
<td>15.5</td>
<td>788 (89%)</td>
<td>1.5</td>
<td>2.3</td>
<td>888.1</td>
</tr>
<tr>
<td>ICE with all steel replaced by wrought Al</td>
<td>1045</td>
<td>134.2</td>
<td>16.1</td>
<td>668</td>
<td>1.2</td>
<td>2.3</td>
<td>821.8</td>
</tr>
<tr>
<td>ICE with all steel replaced by 50% recycled Al</td>
<td>1045</td>
<td>96.8</td>
<td>15.7</td>
<td>668</td>
<td>1.2</td>
<td>2.3</td>
<td>784</td>
</tr>
<tr>
<td>ICE with all steel replaced by glass-FRP</td>
<td>1145</td>
<td>85.8</td>
<td>15.6</td>
<td>704</td>
<td>1.3</td>
<td>2.3</td>
<td>809</td>
</tr>
<tr>
<td>ICE with all steel Replaced by carbon-FRP</td>
<td>925</td>
<td>137.4</td>
<td>16.1</td>
<td>624</td>
<td>0.9</td>
<td>2.3</td>
<td>780.7</td>
</tr>
</tbody>
</table>

ICE = Internal Combustion Engine
PEM = Proton-Exchange Membrane (fuel cell)
FRP = Fiber-Reinforced Polymer
Lean Manufacturing

**VERY LIMITED SLACK**: Toyota Motor Company
The Toyota Production System was created by Taiichi Ohno, the chief engineer of Toyota Motor Company in the years following the second world war. Ohno based his "lean production" system on the elimination of all wasted time and re-work from the mass production system of the American auto manufacturers. Toyota's Takaoka Assembly Plant produces cars with a gross assembly time of under 18 hours, and with only 45 assembly defects per 100 cars. As a result of this efficient production system, Toyota is able to produce high quality automobiles as one of the industries lowest cost producers. Toyota Motor Corporation is an example of a company with very limited slack evidenced by there being little or no waste and inefficiency.

**SOME SLACK**: General Motors Corp.
GM's production system requires more than twice as many assembly hours to build a car as Toyota does. (40.7 hours at G.M.'s Framingham Assembly Plant vs. 18.0 hours at Toyota's Takaoka plant.) Furthermore, GM workers rack up three times as many defects as the Toyota workers (130 defects per 100 autos vs. 45 at Toyota). General Motors is an example of a company which has some slack which could be eliminated.

**LOTS OF SLACK**: Morgan Motor Company
Morgan Motor Company is proud to be the producer of the last coachbuilt car in the world. The Morgan factory is an anachronism in today's auto world. These true sports cars are built one at a time...by hand...just as they were when the factory was established in 1919. Skilled panel beaters form steel body panels over a frame made of wood. The company proudly advertises "There is no moving assembly line where tasks have been reduced to a monotonous routine." The staff numbers 130. Morgans are cult cars. The Morgan Plus Eight is one of the fastest accelerating cars in the world, capable of 0 to 60 in under 6 seconds. Demand for Morgans outstrips the company's production capability of 500 cars per year. As a result there is a 4 to 5 year waiting list for one of these fine automobiles. Morgan Motor Company is an example of a company which has survived in spite of a production process which has lots of slack. Compared to modern auto manufacturing plants, the Morgan plant embodies lots of waste and inefficiency. Even so, the high demand for the product relative to the production allows Morgan Motor Company to charge a premium price and stay in business.

Lean Manufacturing of the Smart Car

The different parts of the production system "SMART-PLUS":

- Assembly of large parts
- Engine, transmission
- Windows etc.
- Smaller parts
- Detail
- Quality checks
- Final inspection
- Common place

Manufacturing plant in Hambach, France:
- Green building
- Workers trained in separating wastes
- Environmentally conscious suppliers
- Just-in-time manufacturing
- Press-fit plastic panels
- Other DfRecycling measures
- Minimization of transport
- etc.

4.8 L/100km = 49 mpg
>10% in recycled content
Subaru assembly achieving zero solid waste

Inside the Subaru Automotive plant in Lafayette IN in July 2018. This Indiana plant, which produces 350,000 cars a year and employs 5,600 employees, sends nothing to the landfill, a first among automakers in North America.

Biggest environmental issues in automotive manufacturing is **PAINTING**.

Largest fraction of environmental expenditure at an automobile assembly plant.
- High capital costs for air emission and waste treatment equipment
- High operating costs due to high energy and material use
- High operating cost due to waste treatment and disposal.

- **Air emissions** – Paint processes are subject to local authority regulation and visits from the authorities to ensure compliance. VOC emissions are the main concern, due to their potential to cause respiratory problems particularly for workers and local communities. European VOC Directives lowers emissions limits requiring either more capital equipment for abatement or alternative low solvent paints such as high solids, water-based paints or powder coats.

- **Solid Waste** – The primary source of hazardous waste from automotive plants is from painting, mostly from cleaning processes in the paint department. Solvents and heavy metals left in residues force the waste to be classified as hazardous. Although much material is recovered, this waste is typically around 25% of a plant’s total hazardous waste by weight.

- **Energy** – Curing ovens use vast amounts of energy for the paint to dry in an acceptable time. The shorter the curing time, the higher the energy use. This is further exacerbated by water-based paint requiring more time in curing ovens than solvent-based paint. Powder coats also require more use of ovens because of the thicker coats.
Dilemma: Organic-solvent or water-based paints?

<table>
<thead>
<tr>
<th></th>
<th>Organic-solvent paint</th>
<th>Water-based paint</th>
<th>Air emissions:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Well tested technology</td>
<td>Newer technology</td>
<td>- Workers exposure</td>
</tr>
<tr>
<td></td>
<td>Existing equipment</td>
<td></td>
<td>- Air-emission treatment</td>
</tr>
<tr>
<td></td>
<td>Lower energy use in drying</td>
<td>Higher energy use in drying</td>
<td>No air emissions</td>
</tr>
</tbody>
</table>

Air emissions:
- Workers exposure
- Air-emission treatment

Automotive painting: From a purchase to a service

Old way – purchase: Assembly plant purchases paints by the bucket from a paint supplier (chemical company). It is in the paint supplier’s interest to sell as much paint as possible. The more waste, the better from the paint supplier.

New way – service: Assembly plant hires people from the paint supplier to do the painting of its cars. The paint supplier is paid not by the amount of paint used but by the number of cars painted. It is now in the paint supplier’s interest to use the least paint possible, certainly to waste the least paint possible. Waste is reduced.

Stage 2:

AUTOMOBILE USAGE
Environmental impact during use

Environmental impact of driving an automobile  =

\[
\text{Pollution}^* / \text{unit of fuel} \quad \times \quad \text{Units of fuel / kilometers traveled} \quad \times \quad \text{Kilometers traveled / trip} \quad \times \quad \text{Number of trips / car} \quad \times \quad \text{Number of cars}
\]

* Air pollutants or carbon footprint

(reduce by switching to an alternative fuel that pollutes less)
(reduce by increasing fuel efficiency or by decongesting traffic)
(promote mixed use of land to decrease distances between home, shops, schools and place of work, or move people from suburbs back to cities)
(incite people to drive less or promote public transportation)
(make it “hip” no longer to have a car – cultural change)

Which of those factors are for engineers to work on?

Why an electric motor?

Because the internal-combustion engine is so bad...

No idling

Direct drive –
No driveline losses

More efficient – This number is smaller
## A Comparison of Two Engines

<table>
<thead>
<tr>
<th>Internal-combustion engine</th>
<th>Electric motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Only 35% efficient at best (needs a radiator for cooling)</td>
<td>80-90% efficient (no need for a radiator)</td>
</tr>
<tr>
<td>Air emissions</td>
<td>Zero direct emissions</td>
</tr>
<tr>
<td>Peaky torque-rpm curve (needs a transmission)</td>
<td>Broad torque-rpm curve (does not need a transmission)</td>
</tr>
<tr>
<td>Power loss in idle</td>
<td>No idle</td>
</tr>
<tr>
<td>Irreversible energy conversion</td>
<td>Regenerative braking</td>
</tr>
<tr>
<td>Big and heavy (250 hp in 600 lbs = 0.7 kW/kg)</td>
<td>Small and light (75 kW in 13 kg = 5.8 kW/kg)</td>
</tr>
<tr>
<td>Noisy</td>
<td>Quiet</td>
</tr>
</tbody>
</table>

---

### So, why did we wait so long before making electric cars?

Because we did not have good enough ways to store or produce electricity on board of the vehicle!

---

### Ways to get electricity on board of a moving vehicle:

1. **Batteries, but**
   - they are heavy
   - slow to recharge (overnight at home instead of a few minutes at a pump)
   - too slow to charge to permit 100% regenerative braking
   - cannot hold energy for more than 250 or so miles (< 500 miles)
   - only as environmentally clean as the electricity at home ("elsewhere pollution"?)

2. **Alternator:**
   - reversible (doubles with the electric motor)
   - highly efficient (85 to 90%)
   - light weight
   - but mechanical energy needs to come from somewhere: conventional internal-combustion engine? flywheel? supercapacitor?

3. **Fuel cell:**
   - only 40% efficient
   - bulky, problems with variable loads, problems with freezing
   - problematic storage of hydrogen: high-pressure gas? liquified? bound in metal hydride?
For reference, gasoline contains 13,000 Wh/kg but the internal combustion engine is only 35% efficient, delivering 4,550 Wh per kg of gasoline.

The so-called Ragone Plot displaying various energy storage technologies according to their holding capacity (specific energy, in Wh/kg) and their retrieval rate (peak power, in W/kg).


Since 1997 in Japan.
Since 2000 in United States.
They are now commonplace in the US.

HYBRIDS
Since 1997 in Japan.
Since 2000 in United States.
They are now commonplace in the US.
Two types of hybrids

Parallel hybrid (on the market; ex. Toyota Prius)

Series hybrid

Modes of functioning of a parallel hybrid system

- starting
- cruising
- up-hill driving
- braking
A plug-in hybrid (PHEV) is a hybrid car with larger batteries and an extension cord. It can be filled up at the gas station or plugged in into a domestic 110-volt outlet. “It’s like having a second fuel tank that you always use first – only you fill up at home, from a regular outlet”, at an equivalent cost of under $1/gallon.

From the opposite perspective, the car can also be seen as an electric vehicle with a gas-tank backup.

There is more:

• If driving is mostly local, filling with gas may become unnecessary.
• Lifetime service costs are lower for a vehicle that is mainly electric.
• A PHEV can provide power to an entire home in the case of an electrical outage.
• A fleet of PHEVs could power critical systems during emergencies.

What other alternatives do we have besides hybrids and plug-in hybrids?

A car riding on biomass?
Alternatives for energy source and drivetrains, ranked according to greenhouse gas emissions

<table>
<thead>
<tr>
<th>Primary energy source – Onboard energy storage – engine type</th>
<th>Percentages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Solar – Electricity – Electric motor</td>
<td>1.2%</td>
</tr>
<tr>
<td>2. Wood – Ethanol – Internal combustion engine</td>
<td>2.2%</td>
</tr>
<tr>
<td>3. Solar – Hydrogen – Fuel cell</td>
<td>2.4%</td>
</tr>
<tr>
<td>4. Solar – Hydrogen – Internal combustion engine</td>
<td>6.5%</td>
</tr>
<tr>
<td>5. Nuclear – Battery – Electric motor</td>
<td>6.6%</td>
</tr>
<tr>
<td>6. Nuclear – Metal hydrides – Fuel cell</td>
<td>14.9%</td>
</tr>
<tr>
<td>7. Wood – Methanol – Fuel cell</td>
<td>15.1%</td>
</tr>
<tr>
<td>8. Wood – Methanol – Internal combustion engine</td>
<td>24.9%</td>
</tr>
<tr>
<td>9. Wood – “Natural” gas – Internal combustion engine</td>
<td>28.5%</td>
</tr>
<tr>
<td>10. Nuclear – Metal hydrides – Internal combustion engine</td>
<td>32.7%</td>
</tr>
<tr>
<td>11. Natural gas – Methanol – Fuel cell</td>
<td>56.2%</td>
</tr>
<tr>
<td>12. Natural gas – Battery – Electric motor</td>
<td>65.8%</td>
</tr>
<tr>
<td>13. Natural gas or oil – Liquid propane gas (LPG) – Internal combustion engine</td>
<td>74.0%</td>
</tr>
<tr>
<td>14. Natural gas – Natural gas – Internal combustion engine</td>
<td>78.2%</td>
</tr>
<tr>
<td>15. Nuclear – Liquid hydrogen – Internal combustion engine</td>
<td>82.4%</td>
</tr>
<tr>
<td>16. Oil – Diesel – Internal combustion engine</td>
<td>98.9%</td>
</tr>
<tr>
<td>17. Natural gas – Methanol – Internal combustion engine</td>
<td>99.0%</td>
</tr>
<tr>
<td>18. Marginal electric power – Battery – Electric motor</td>
<td>100%</td>
</tr>
<tr>
<td>19. Oil – Standard gasoline – Internal combustion engine</td>
<td>100%</td>
</tr>
<tr>
<td>20. Oil – Reformulated gasoline – Internal combustion engine</td>
<td>100%</td>
</tr>
<tr>
<td>21. Coal – Methanol – Fuel cell</td>
<td>102.2%</td>
</tr>
<tr>
<td>22. Coal – Battery – Electric motor</td>
<td>106.7%</td>
</tr>
<tr>
<td>23. Corn + coal – Ethanol – Internal combustion engine</td>
<td>112.4%</td>
</tr>
<tr>
<td>24. Coal – Methanol – Internal combustion engine</td>
<td>166.8%</td>
</tr>
</tbody>
</table>

Percentages are in comparison with the base-case emissions.

Source:
Table 4. Required Infrastructural Changes/Development for Alternative Fuel Utilization

<table>
<thead>
<tr>
<th>Technology</th>
<th>Off-Vehicle</th>
<th>On-Vehicle</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Production</td>
<td>Conversion</td>
<td>Delivery</td>
</tr>
<tr>
<td>Battery/Solar/Electric</td>
<td>3.2</td>
<td>3</td>
<td>1.3</td>
</tr>
<tr>
<td>Ethanol/Wood, Bio.</td>
<td>2.6</td>
<td>2.5</td>
<td>1.2</td>
</tr>
<tr>
<td>Hydrogen/Nuclear/Electric</td>
<td>3.3</td>
<td>3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Methanol/Wood, Bio.</td>
<td>1.9</td>
<td>1.8</td>
<td>1.1</td>
</tr>
<tr>
<td>Methane/NG, Fuel Cell</td>
<td>3.3</td>
<td>3.2</td>
<td>3.1</td>
</tr>
<tr>
<td>Hydrogen/Nuclear/Electric</td>
<td>2.4</td>
<td>2.9</td>
<td>3.1</td>
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<td>3</td>
<td>1.6</td>
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<td>3</td>
<td>1.9</td>
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<td>2.8</td>
<td>3.1</td>
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<td>Methane/NG, Fuel Cell</td>
<td>1.1</td>
<td>1.5</td>
<td>1.6</td>
</tr>
<tr>
<td>Battery/Solar/Electric</td>
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<td>0.6</td>
<td>1.6</td>
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<td>1.1</td>
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<tr>
<td>Methane/NG, Fuel Cell</td>
<td>0.7</td>
<td>0</td>
<td>0.8</td>
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<td>Hydrogen/Nuclear/Electric</td>
<td>2.4</td>
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<td>1.2</td>
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<td>Methane/NG, Fuel Cell</td>
<td>0.6</td>
<td>2.1</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Ratings for infrastructural change/development:
1. Minor qualitative modification to existing infrastructure/major expansion
2. Significant modification to existing infrastructure
3. Substantially new technology, minor development work required
4. Substantially new technology, major development work required, major constraint to implementing alternative

Results reflect ratings from eight completed surveys received out of eleven sent out.

![Figure 3. Greenhouse gas emission reduction in relation to required infrastructural change/development.](image)

Emission reductions = 100 - values from Table 1. The Y-axis scale is the average from Table 4. Identification numbers are as for Table 4.
1. Jet engines

During World War II, automotive companies inspired by advances in jet engines tried to adapt the technology for use in cars. Chrysler's so-called Turbine Car (right) used a rotary fan, propelled by rapidly burning fuel, to drive the vehicle.

By 1963, such experimental turbine engines could run on gasoline, jet fuel, or even vegetable oil, and like actual jet engines, they provided powerful acceleration. But they also suffered from significant problems, among them high fuel consumption. Rover's Jet-1, for instance, traveled just six miles per gallon.

2. Nuclear propulsion

The Ford Nucleon concept car symbolized the 1950s Atomic Age, when nuclear energy seemed to offer a clean alternative to traditional fuels. Engineers proposed that the Nucleon (right) would be powered by a small nuclear reactor, which would split atoms to release energy in the form of heat.

The heat would convert stored water into steam, and the steam would propel turbine fans to drive the engine. But the envisioned pint-sized reactors Ford was counting on to be developed did not materialize, even as recognition of the inherent danger did.

In the end, no working prototypes were built.
3. Steam

Steam cars were in vogue by the late 19th century. Of these, the Stanley Steamer, produced from 1896 to 1924, was the most popular, often outselling conventional gas-powered cars. It even reached a record-breaking 127 mph in 1906.

The Steamer burned gasoline or kerosene to heat water in a boiler; the boiling water then generated steam, and pressure from the steam powered the engine.

Their price tag doomed steam cars by the start of the Great Depression, however. Steamers cost thousands of dollars apiece, compared to Ford's Model T, which sold for less than $500.

4. Compressed air

In 1979, as America found itself embroiled in an energy crisis, Missouri-based engine designer Terry Miller built a car that ran on an abundant, zero-emission fuel source—air. Compressed-air engines had been used in some locomotives and trucks since the 1800s, but Miller streamlined the design for his Air Car One (top photo).

Pressure generated by the release of compressed air from onboard tanks drove the car's engine. Miller's vehicle was never commercially produced, but interest remains. India's Tata Motors, for one, has developed a compressed-air car prototype (bottom photo).
5. Electric car

Automakers have produced electric cars off and on for over a century. Ohio-based Baker Motor Vehicle Co. was among the most successful, selling thousands of its electrics to wealthy consumers (including Thomas Edison) from 1899 to 1915.

But while each Baker (1916 model in photo) ran on no fewer than 12 cell batteries, its top speed was just 14 miles per hour. In contrast, many less expensive, gas-powered cars could exceed 40 mph. Today, as battery technology has improved, all-electric cars are making a serious comeback.

6. Gas-electric hybrid

In 1901, Czech engineer Ferdinand Porsche unveiled the Mixte (photo). French for "mixed," the car was a forerunner to today's gas-electric hybrids, which use less gasoline and create fewer emissions than conventional gas-powered cars. But unlike Porsche's later sports cars, the Mixte was too far ahead of its time.

The four-seater model required nearly two tons of batteries, which made it too expensive to be produced in bulk.

Improved battery technologies have helped reduce costs and allow modern hybrids like Toyota's Prius to sell increasingly well.
7. Solar electric

In 1987, General Motors harnessed solar rays to help run its Sunraycer experimental racing vehicle (above). The Sunraycer's photovoltaic cells converted the sun's energy directly into electrical energy; the electricity then powered an electric motor that drove the car. Although similar technology is still used in special aerodynamic racecars, any purely solar-powered road vehicle designed to meet general safety standards would be larger and much heavier than the Sunraycer, requiring more power than can yet be generated to achieve highway speeds.

8. Biofuels

Henry Ford (photo, at the wheel of a Model T) designed his "Tin Lizzie" to run on either gasoline or a hemp-based fuel. But with the discovery of large crude-oil deposits in the early 20th century, oil prices dropped and gasoline derived from the oil became Ford's and other carmakers' fuel of choice. Unlike fossil fuels, biofuels come from renewable resources, typically plants.

Although biofuels have many advocates, skeptics point out that they currently require too many resources to be used on a widespread commercial basis. They may also cause adverse health effects by their new mix of exhaust chemicals.
Could ethanol vehicles pose a significant risk to health?

Although it is widely touted as an eco-friendly, clean-burning fuel, ethanol carries health hazards, according to a 2007 study by Stanford University atmospheric scientist Mark Z. Jacobson. If every vehicle in the United States ran on fuel made primarily from ethanol instead of pure gasoline, respiratory-related deaths and hospitalizations likely would increase, he claims.

“We found that E85 vehicles reduce atmospheric levels of two carcinogens, benzene and butadiene, but increase two others—formaldehyde and acetaldehyde,” Jacobson said. “As a result, cancer rates for E85 are likely to be similar to those for gasoline. However, in some parts of the country, E85 significantly increased ozone, a prime ingredient of smog.”


9. Hydrogen fuel cells

Fuel cells combine fuel (usually hydrogen) and oxygen to produce electricity through chemical reactions similar to those that occur in batteries. While some automakers are now trying to develop hydrogen fuel-cell cars, General Motors actually designed its own, the Electrovan, as early as 1966. While the Electrovan (photo) could travel up to 70 mph and 120 miles between refuelings, it was too expensive to produce commercially.

Recent advances have made affordable fuel cells more likely, and in 2003 the U.S. Congress pledged $1.2 billion to make such vehicles cost-effective by 2020.
The complete fuel-cell system is more than the cell stack...

http://www.pbs.org/wgbh/nova/sciencenow/3210/01-car-nf.html
Entertaining as well as informative:

NOVA documentary with the Car-Talk guys

“Car of the Future”

http://www.pbs.org/wgbh/nova/car/program.html

Study comparing efficiencies if source of energy is oil

ICE, Internal Combustion Engine

HICE, Parallel Hybrid

AFC, Fuel Cell

Fig. 1. Energy flow for various vehicle configurations. (A) ICE, the conventional internal combustion, spark ignition engine. (B) HICE, a hybrid vehicle that includes an electric motor and parallel drive train which eliminates idling loss and captures some energy of braking. (C) AFC, a fuel cell vehicle with parallel drive train. The configuration assumes on-board gasoline reforming to fuel suitable for PEM fuel cell operation.

… but, wait a minute:

1. The fuel cell car does not have an internal combustion engine at all and therefore needs no transmission. This reduces the drive train loss from 31% to 10%.

2. Projections are to put hydrogen on board (instead of methanol + reformer).

This changes the picture significantly:

Paths to get there:

Stage 3:

AUTOMOBILE RECYCLING
The basics of recycling automobiles

Old cars are typically hauled to an automobile dismantler, where reusable parts are removed. After removing the reusable parts and other items like batteries, tires and fluids, the **hulks** are usually shipped to ferrous scrap processors where they are weighed for payment and unloaded.

At a scrap yard, hulks go into the **shredder**. The shredding process, which handles one car every 45 seconds, generates three streams: iron and steel; nonferrous metal; and **fluff** (fabric, rubber, glass, etc.). The iron and steel are magnetically separated from the other materials and recycled.

The iron and steel mix is then shipped to end markets or steel mills where it is recycled to produce new steel, most of it going to the construction industry.

By weight, the typical passenger car consists of about 65% steel and iron. The steel used in car bodies is made with about 25% recycled steel.

**Environmental benefits**

Recycling steel saves energy and natural resources. The steel industry annually saves the equivalent energy to power about 18 million households for a year. Recycling one ton of steel conserves 2500 pounds of iron ore, 1400 pounds of coal and 120 pounds of limestone.

SORTED PLASTICS – Researchers built a series of tanks to separate recycled plastics by type using Argonne’s froth flotation process. The polyolefin flows down by chemist Joe Pomykala while chemical engineer Jeff Spangenberger works at the next separation station.

RAINING PLASTIC – Chemist Joe Pomykala checks the flow of polyolefin coming from a tank that separates the recycled auto plastic concentrate into its constituent parts.
RECYCLED AUTO PLASTICS – Project Manager Sam Jody holds a knee bolster for a car processed from recovered polyolefin. Automotive plastic recycling begins with auto shredder residue (left), is separated into specific plastics (right) – in this case polyolefins – and made into plastic parts for new cars.

There is now a closed loop for Carbon Fiber Reinforced Polymers (CFRP). Carbon fiber reclaimed from old aircrafts, and soon also from automobiles, can be repurposed for use in automobile composites. Source: MIT-RCF
Tires: A real problem at end of life

A few statistics:

About 300 million tires sold in US annually

More than 4 million tons per year

Equivalent to about 1 tire per person per year

Discarded tires: 80% passenger cars

20% trucks, buses

“Recycling”: 15%

Use in highways: 31%

Burning as tire-derived fuel: 51%

Incinerated or landfilled: 2%

New tires: no more than 2% “recycled” rubber

Retreads: up to 75% reused content

Tire “recycling” is really cascading: use in playground, artificial reefs, floor mats, dock bumpers, carpet padding, tracks and athletic surfaces.

Issues faced in automotive recycling

- Economics:
  Low-value parts and materials make it difficult to run a profitable business
  Prices on the recycling markets fluctuate greatly.
  Auto Shredder residue (ASR) has to be landfilled at a cost.

- Sorting of plastics:
  Plastics recycling requires sorting, and a large variety of similar looking plastics creates complications.
  Labeling of plastics has helped greatly, but it is still absent in older models.

- Environmental regulations:
  Contamination by spilled fluids and handling of hazardous materials have been the object of strict regulations.
  Incineration and landfilling of ASR is subject to regulations as well.