Electric Vehicles Forecasts, Players and Opportunities 2005-2015

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We are grateful to the many experts who have contributed criticism of this text and material.

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Analyses of the electric vehicle (EV) business usually concentrate on glamorous sectors such as cars. By contrast, the manufacturers leverage their skills into many sectors. Toyota makes electric cars, buses, fork lifts, vehicles for the disabled and so on. After all, an electric motor, electronic controller and wheels can be assembled into anything from an electric wheelchair to a robot vehicle and the sectors chosen differ dramatically in profit, size and growth rate. For example, about 90% of those making electric cars go out of business while about 90% of those making electric mobility vehicles for the disabled make enduring profits. The early use of ac motors in fork lift trucks had lessons for other types of electric vehicle. Batteries developed for land vehicle propulsion are used in boat propulsion.

Unusually, this report looks at the whole picture. It concerns electric vehicles (EVs). These are defined as those untethered vehicles that use electric motors for land, marine and airborne motive power wholly or in part. However, we exclude railway locomotives and large military submarines and ships because these have little in common with the vehicles we cover.

Booming sectors come and go

Public perception of the electric vehicle industry, as fed by the press and to some extent supported by the snail like pace of the electric delivery van is that it is a hopelessly unprofitable pursuit of the impractical by manic hobbyists. The truth is otherwise. For thirty years or more there has been a highly profitable, even booming sector of EVs and we summarise these sectors and project them into the future in table 1.

Table 1 Financially successful large sectors of the EV industry and their period of strong growth 1980 to 2040

<table>
<tr><th>1980-90</th><th>1990-2000</th><th>2000-10</th><th>2010-20</th><th>2020-30</th><th>2030-40</th><th>2040-50</th></tr>
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</table>

+ A Hybrid combines an Internal Combustion Engine (ICE) with electric power.

Source: IDTechEx

Ten year forecasts by applicational sector, product type and technology

We forecast the markets and technologies from 2005 to 2015 with indications out to 2050. We also analyse the leading suppliers and technologies, including historical trends and financial performance.

The EV industry is large and prosperous with $31.1 billion sales globally in 2005 at ex factory prices excluding toys. This consists of $16.3 billion of factory sales of vehicles and $14.8 billion in associated spares and services. In 2015 the EV market will have grown to 7.3 times to reach to $227 billion of which $122 billion will be vehicles excluding toys and $101 billion will be spares and services. Much of the growth is not organic growth in sales of existing types/ markets. It is replacement of pure ICE vehicles by hybrid electric ones. In other words, much of the growth of sales of electric vehicles in the next ten years will be caused by reducing the sales of pure ICE vehicles to a figure below what they would otherwise been and not by impacting existing EV markets. However, only a few percent of the volume or value of road vehicles produced in 2015 will be electric (including hybrid).

The number of EVs made will rise fivefold from 5 to 25 million yearly by 2015. The value grows faster because the mix is different, with cars becoming important. Cars are usually sold for more than the fork lift trucks, vehicles for the disabled and light commercial vehicles that are dominant sectors today.

Service includes maintenance, consultancy, design, spare parts etc. Service will not grow as a percentage of the whole because the increased population of vehicles to maintain will be offset by greater reliability and the completion of many major technology developments. 70 per cent of participants make profits on their electric vehicle activity and this will continue.

The largest, most profitable and fastest growing sectors in 2005 are shown in table 2.

Table 2 The largest, most profitable and fastest growing EV sectors in 2005

LARGEST		MOST PROFITABLE		FASTEST GROWING % YEARLY
By value	By numbers	%	Gross	
Heavy industrial Cars	Toys Two wheel Disabled	Disabled	Heavy industrial Disabled	Cars Buses

Source: IDTechEx

In 2015, the largest, most profitable and fastest growing sectors will be as shown in table 3.

Table 3 The largest, most profitable and fastest growing EV sectors in 2015

LARGEST		MOST PROFITABLE		FASTEST GROWING % YEARLY
By value	By numbers	%	Gross	
Heavy industrial Cars	Toys Two wheel Robots	Disabled Robots	Cars Heavy industrial Two wheel	Cars Buses

Source: IDTechEx

Largest EV manufacturer will gain market share

In 2005, Toyota has $3.7 billion in sales of EVs and associated services making it world leader with 11 per cent market share. This is over three times that of its nearest competitor and we do not see Toyota challenged for at least five years. With a commanding lead in EV cars – a small business as yet – and in heavy industrial EVs, Toyota is the only company to plan hybrid versions of virtually all its on road vehicles. It is one of the leaders in developing fuel cell powered EVs – not a business as yet - though not necessarily the leader.

Although Toyota has little or no presence in Two Wheel and Military EVs - two of what will be the four largest EV sectors by value of global sales in 2015 - its performance and investment is so impressive in the two others – cars and heavy industrial – that it is likely that the Toyota market share of the global EV market may rise to 15% by value in 2015 and 20% of the global EV manufacturing market. As today, over 1000 companies will share the rest.

The territory with the most EV sales

In 2005, the territory with the largest EV production by numbers is China and by value it is the US and Japan. However, in 2015, China will be making and servicing more electric vehicles than anywhere.

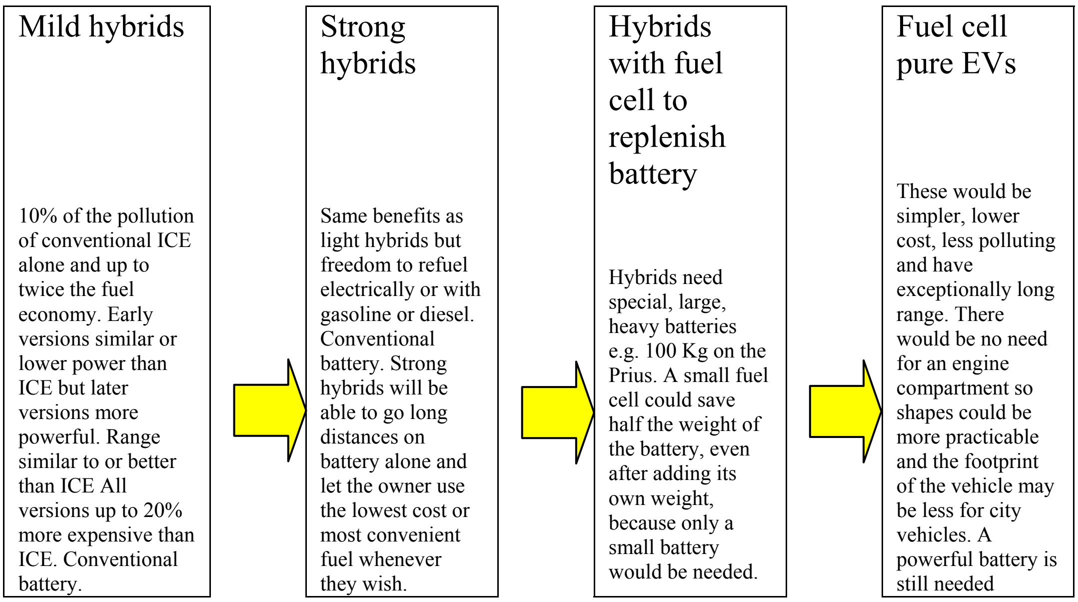
Rapidly changing technology

In 2000, most electric vehicles by numbers and value were pure electric and battery driven i.e. they did not have any other power supply. That was a world of electric fork lift trucks and mobility vehicles for the disabled. However, heavy industrial vehicles such as fork lifts average virtually no growth now and, although vehicles for the disabled remains a rapidly growing market – indeed by far the most profitable EV market – changing technology has led to the largest market becoming road vehicles thanks to the success of diesel-electric and particularly gasoline-electric cars and buses. These hybrids require no change in driver behaviour. They are "mild hybrids" because the ICE is the primary – usually the only - traction device, with the battery and electric motors in a support role of boosting and balancing demand. "Strong hybrids" are coming along that will have electric motors powered by batteries as the primary form of traction. That means they must have the option of plugging into a terrestrial electricity supply for recharging.

Full circle back to pure EVs

Meanwhile, it is now accepted that, although we shall go full circle back to pure electric vehicles in due course thanks to the fuel cell, these are a long way off because of technical, cost and infrastructure problems. Attention has recently turned to small fuel cells for laptops and so on and fairly small fuel cells are now being considered for a secondary role in EVs as we await satisfactory large ones for primary traction. These fairly small fuel cells may charge the batteries in hybrids in a few years. This is summarised in figure 1. However, it is not the only evolutionary route. For example, small fuel cells will also appear in some two wheel vehicles, trickle charging powerful traction batteries. As large fuel cells become viable, heavy industrial vehicles are one of the most attractive uses for them. We forecast a resurgence of the heavy electrical vehicle business around this time as China starts to use automation extensively in its massive manufacturing industry.

Figure 1 Evolution of EV design for on-road and many non-road vehicles



Source: IDTechEx

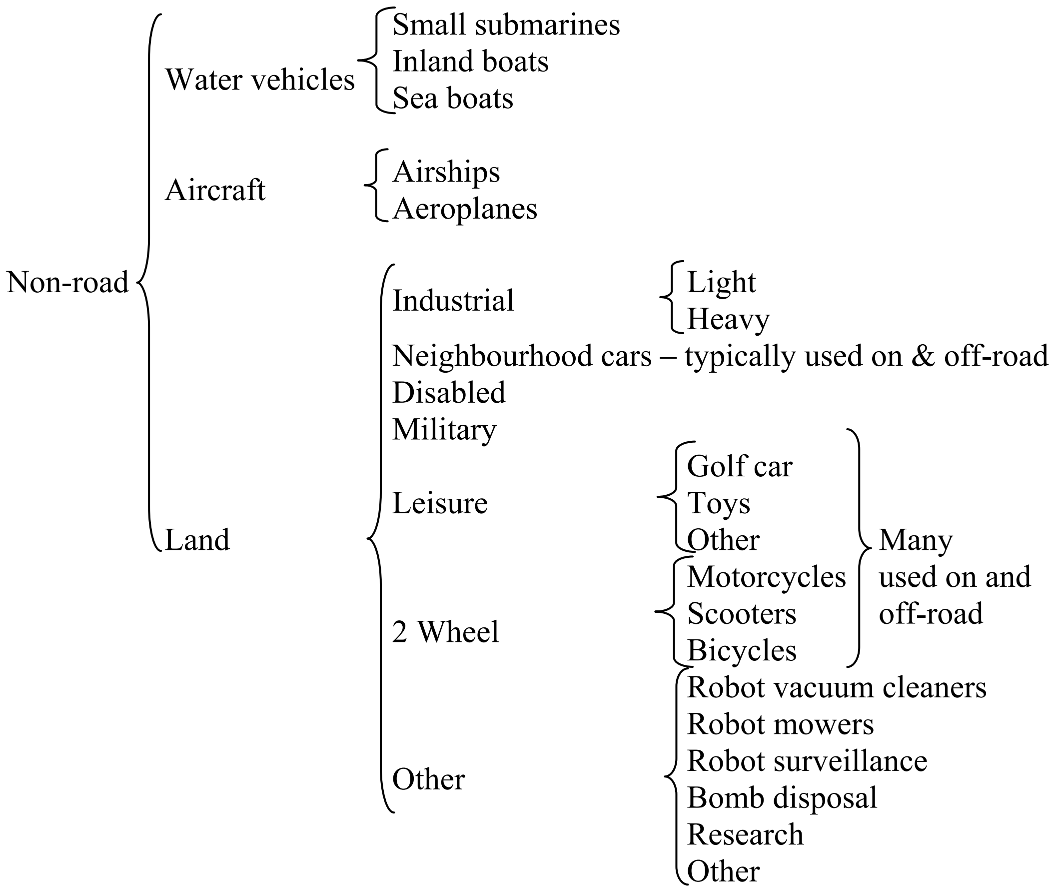
On-road and non-road

Most of the publicity for EVs concerns on road vehicles from cars to buses but, although these will be big markets, they are less than 40 per cent of the business today even if we exclude toys in the overall figure. Figure 2 shows most of the non-road and on/off-road types. In 2008, the value of sales of on road EVs will have overtaken the value of sales of non road EVs. The two decades of EVs being primarily a non road market will be at an end despite many non road applications continuing to grow strongly. In a sense, we shall have gone full circle, because the EV market was mainly on road from 1900 to 1960.

Land, sea or air

EVs that fly and that travel in or on water have long existed. Between 2005 and 2015, the land based EVs will remain over 95% of the market by value. However, marine applications will show strong growth to become about 3% of the market.

Figure 2 Categories of non-road and on/off-road EV



Source: IDTechEx

Hybrid vs pure electric

In 2005, the EV market remains primarily one for pure electric vehicles, with no ICE or other traction power. That has been true for over 100 years but it is about to change and in 2007, the value of sales of hybrid EVs will dominate. Most will be cars but there will be many buses, trucks, heavy industrial vehicles and military vehicles that will be hybrid as well. Indeed many marine surface craft and motorcycles may become hybrid.

In 2005, pure EVs have different characteristics in the market when compared to hybrids.

- Pure EVs often create new markets and are the only option indoors or underwater. However, they are not yet popular as on-road vehicles because of range and recharging time.

- Hybrid EVs usually replace pure Internal Combustion Engine (ICE) vehicles in established markets, typically on-road or for heavy duty outdoors.

Thus one typically buys a pure EV for novelty, convenience, fun or because there is no other way of doing the job. A power chair is a classic example: nothing else can give the disabled or elderly their independence in those environments. An exception is on-road two-wheelers that are battery-only. Here sales are growing exponentially in China because of draconian pollution laws. By contrast hybrid vehicles are usually bought as an alternative to ICE because of cost-over-life, less pollution, fewer refill stops, ability to provide standby electricity and, increasingly, better acceleration etc. This difference will pertain until fuel cells permit pure ICE vehicles and hybrids to be replaced with pure EVs.

The decade of the hybrid has begun
Over the next decade or more, most of the growth in value sales of EVs. By value, hybrids will rise from 6 per cent to 63 per cent of the global EV manufacturing market in that time frame. Hybrids need no new fuelling infrastructure. Well proven in military submarines and rail locomotives for forty years, (not in our statistics), hybrids now have success in buses, cars and similar-sized vehicles. Soon we shall see mainstream sales of hybrids such as full size hybrid family cars sold aggressively. Indeed, Toyota intends to offer hybrid versions of most of its road vehicles within a few years.

Fuel cells
Fuel cells will have only a modest impact overall by 2015, rising from zero to one per cent of EVs sold (by value zero to 11 per cent in that time because initially they will be premium priced in e.g. military applications). This limited progress will be caused by challenges of performance and cost in the main: this is cost both of the fuel cells and the necessary refuelling infrastructure. Investment in fuel cells is higher than ever: finance is not the main problem. The significance of fuel cells is immense. Although the end point is to use them mainly in pure EVs where, contrary to the above arguments for today's battery operated pure EVs, they will not be confined to novelty and indoor operation but should replace hybrids or pure ICE vehicles. The question is when.

Optimal sectors
Some suppliers serve sectors where overall demand usually increases over the years and penetration of electric versions may also increase. However, the success of EV manufacture for these sectors varies greatly because adequate EV technology to grow the market is not always in place.

Table 4 summarises the status of EV markets vs technology.

Table 4 Status of electric vehicle markets - saturation, appropriateness of technology, new sector creation

TYPE	OVERALL MARKET DEMAND (INCLUDING NON EV) IS NOT SATURATING	EV PENETRATION OF SECTOR IS NOT SATURATING	EV TECHNOLOGY USUALLY MEETS MARKET DEMAND	NEW SECTORS BEING CREATED BY EVS
Heavy industrial, golf car and caddy			●	
Cars and commercial, two wheel, marine	●	●	●	●
Light industrial			●	●
Military	●	●	●	●
Disabled, toys, mobile robots	●		●	●
Mining		●	●	

Source: IDTechEx

Imaginative sectors

Curiously, only certain sectors have suppliers producing vehicles that are dramatically new, desirable and useful to customers. The best of these inventions are visually attractive in new ways and create new markets. These lively sectors are disabled, two wheel, underwater, military and mobile robot. By contrast, in other sectors the EV usually looks much like the ICE vehicle, does much the same job and is boring or invisible to the purchaser.

Negative factors

Beyond national economies faltering, there are several other negative factors affecting sales of EVs as shown in table 5.

Table 5 Negative factors in EV markets

SECTOR	NEGATIVE FACTOR
Industrial and commercial	Electrification of airport ground support equipment takes lower priority because of need to deal with the new terrorism and poor financial state of airlines. For heavy types of vehicle, western markets and Japan are saturating in demand. Hybrids not yet widely available. Fuel cell versions not available.
Disabled	Inadequate private disposable income in most countries.
Two-wheel	Most countries require tax, licence plate, hard hat, insurance etc. Fear of theft. Hybrids not yet available.
Golf car and caddy	US market saturated. Few large golf courses elsewhere.
Cars	Inadequate range, charging time and price reduction for pure EV versions. Few hybrid options as yet. Some ICE have equivalent fuel saving.
Mobile robots	Robot lawnmowers, vacuum cleaners and servants few in number. Safety, efficacy and cost concerns.
Military, mining	Need to prove new types. Slow decision making. Few hybrid options as yet.
Toys	Need for other fashionable ideas.
Marine and other	Few hybrid options as yet. Need for price reduction and better performance.

Source: IDTechEx

Drivers of growth

The main factors leading to growth of EV markets in the next ten years are shown in table 6. The advent of hybrid and later fuel cell EVs will be particularly potent because they replace conventional

ICE vehicles, with little effect on applications of EVs today. In other words, their effect is almost totally additive to today's EV markets.

Table 6 Drivers of growth in EV markets

SECTOR	GROWTH FACTORS
Industrial and commercial	Hybrids can now replace many of the heavier ICE vehicles by having lower cost of ownership, greater convenience (less refuelling), less pollution and providing power for accessories when the ICE engine is off. Many provide standby electric power for depots etc. when the ICE engine is on. Many new models available soon. China will buy large numbers of EV buses for the Beijing Olympics. Hybrid buses now well proven. Airline finances recover. US Federal clean air monies for airports etc start to bite. Some creation of new markets in light industrial.
Disabled	Ageing populations, highly mobile and wanting to stay that way. Purchase of two complementary versions by some users. Adequate disposable income for widespread purchase becomes available in more countries. Further creation of extra segments, including variants for people who are not disabled. Fuel cell and hybrid versions (long range).
Two-wheel	Enormous unfulfilled demand in China, backed by legislation. Hybrids, scooters and motorcycles being launched. New concepts. USA easing legal restrictions on such EVs.
Golf car and caddy	Nothing major, but some proliferation of variants for other uses and some growth of golf in emerging countries.
Cars	Replacing ICE cars with hybrids. Many more hybrids becoming available, offering lower cost of ownership, less pollution and fewer stops to refill. Advent of strong hybrids adds to attraction. Fuel cells for even small cars eventually. Some use of EVs as second cars. US zero pollution legislation. European and East Asia legislation.
Mobile robots	Safe, effective home and garden robots start to appear. Many new industrial/military.
Military, mining	Sharp increase in military spend. Need for silent vehicles with no heat or noise signature, superior low speed traction, safer and smaller fuel supply chain.
Toys	New concepts.
Marine and other	Lower cost leisure boats and submarines. Tougher laws for inland lakes. Other environmental pressures. Research, military and forecasting vehicles including Autonomous Undersea Vehicles. Hybrids for larger surface boats. Growth in private and tourist boating and submarines.

Source: IDTechEx

Basis of forecasts

Our forecasts of numbers of vehicles sold are always more secure than value. This is because some EVs are sold direct and some through distributors and on to retailers and these routes to market are constantly changing. Discounts, subsidies and tax breaks are common and they change over time. To de-risk our value projections we try to estimate only ex factory prices but these are often secret and highly dependent on order size and availability of production capacity. Sometimes sales are bundled with other products or service contracts or are heavily loss-making for many years to back a strategy.

Projections 2005 to 2015

The following table 7 and figures show the numbers of EVs sold globally by applicational sector 2005 to 2015.

Table 7 Numbers of EVs, in thousands, sold globally, 2005 to 2015, by applicational sector

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	275	340	355	370	385	400	453	507	560	621	703
Light industrial/ commercial	130	142	153	164	165	166	167	170	173	176	179
Disabled	800	880	960	1,040	1,120	1,200	1,300	1,450	1,600	1800	2050
Two-wheel	2,500	3,500	4,600	5,300	6,000	6,800	7,000	8,200	9,000	10,000	11,300
Golf car & caddy	265	265	265	265	265	265	265	265	265	265	265
Cars	300	400	601	801	1,012	1,255	1,510	2,015	2,420	2895	3150
Mobile robots	600	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,500	5,500	7,000
Military	6	20	50	101	205	210	210	220	250	250	250
Mining & other	6.0	7.0	7.2	7.4	7.5	7.5	7.5	7.5	7.5	7.6	7.6
Toys	9,000	9,500	10,000	10,100	10,200	10,300	10,400	10,500	10,700	11,000	11,400
Marine	25	32	35	40	46	55	64	79	90	100	110
Total	13907	16,286	18,626	20,088	21,806	23,459	24,577	27,014	29,566	32615	36415
Total excluding Toys	4907	6,786	8.626	10,088	11,606	13,159	14,177	16,514	18,866	21615	25015

Source: IDTechEx

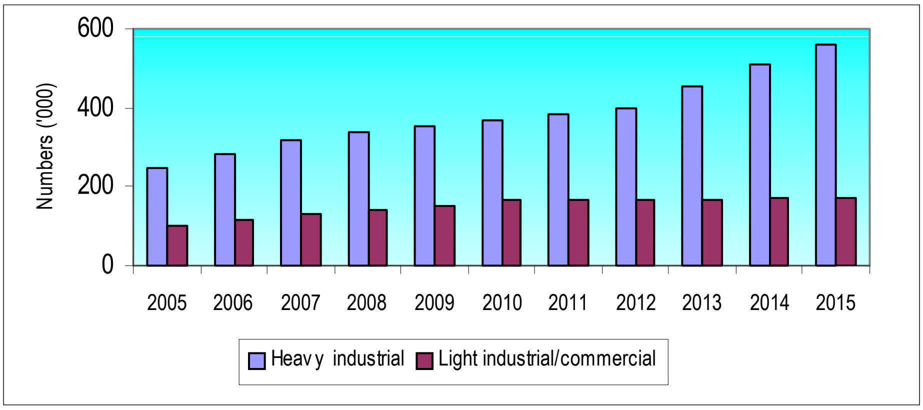
The following table 8 and figures show the value of EVs sold globally by applicational sector 2005 to 2015 at ex factory prices.

Table 8 Total value of EVs, in $ billions, sold globally, 2005 to 2015, by applicational sector

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	3.15	4.91	5.19	5.22	5.34	5.33	6.36	7.41	8.44	9.50	10.72
Light industrial/ commercial	1.180	1.471	1.574	1.679	1.716	1.815	1.900	1.900	2.450	2.70	3.39
Disabled	0.550	0.631	0.716	0.806	0.900	0.965	1.10	1.25	1.37	1.55	1.76
Two-wheel	0.75	2.13	3.00	3.75	4.5	5.44	6.04	6.79	7.82	9.05	11.03
Golf car & caddy	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Cars	6.0	8.0	12.0	16.0	20.2	25.1	27.2	38.7	46.8	52.1	60.4
Mobile robots	0.96	1.68	1.92	2.00	2.4	2.8	3.2	3.6	4.5	5.5	7.0
Military	0.30	1.0	3.0	6.15	12.75	13.5	13.5	15.0	19.5	19.8	20.9
Mining & other	1.50	1.75	1.80	1.85	1.88	1.88	1.88	1.88	1.88	1.91	1.91
Toys	0.90	0.95	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.10	1.14
Marine	1.34	1.53	1.68	1.88	2.12	2.31	2.59	3.24	3.99	3.24	3.99
Total	17.16	24.58	32.41	40.87	53.54	60.70	65.35	81.35	98.34	106.98	122.77
Total excluding Toys	16.26	23.63	31.41	39.86	52.52	59.67	64.31	80.30	97.28	105.88	121.63

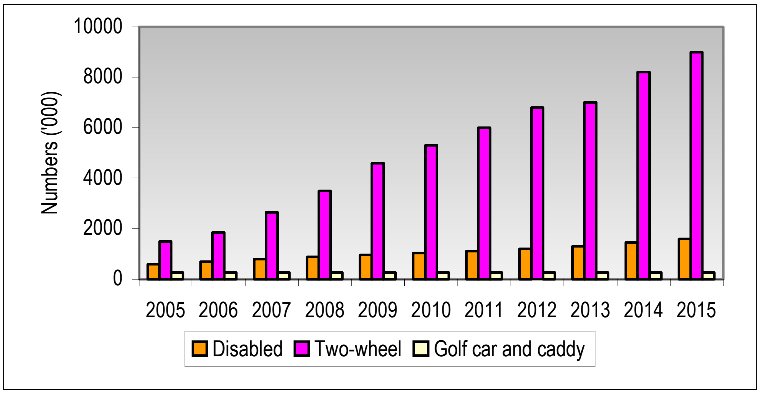
Source: IDTechEx

Figure 3 Heavy industrial and light industrial/commercial EV numbers sold globally, ('000), 2005 to 2015



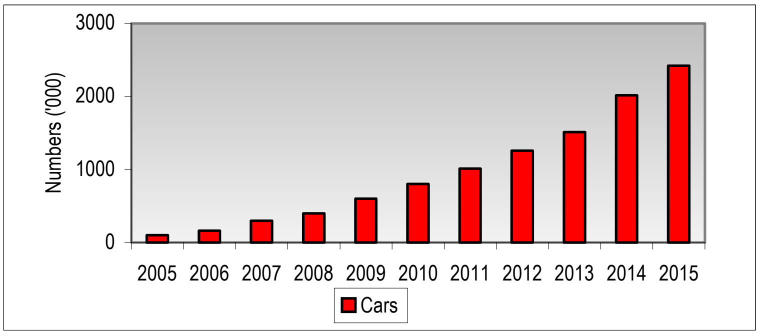
Source: IDTechEx

Figure 4 **Disabled, two wheel and golf car and caddy EV numbers sold globally, ('000), 2005 to 2015**



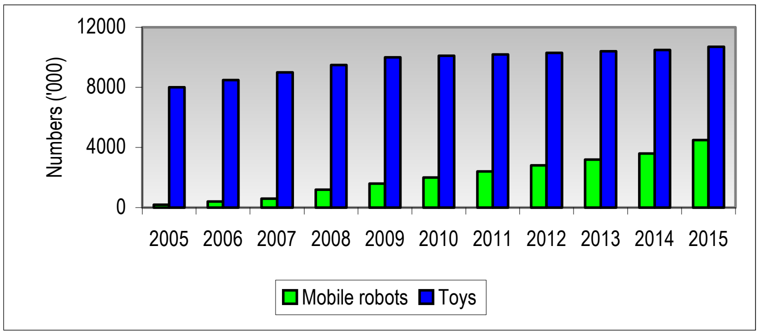
Source: IDTechEx

Figure 5 **Car EV numbers sold globally, ('000), 2005 to 2015**



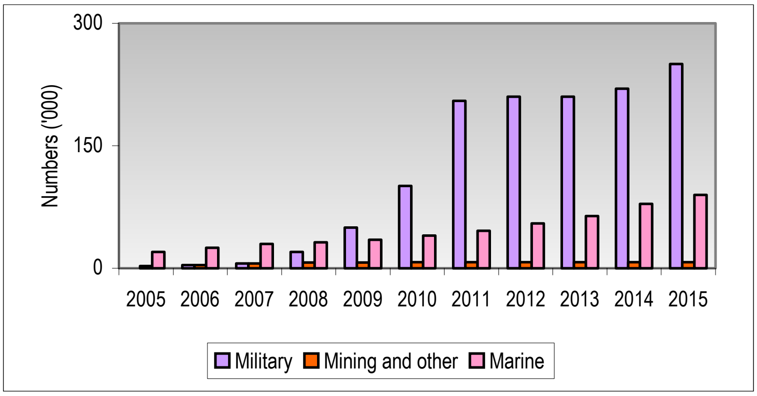
Source: IDTechEx

Figure 6 **Mobile robot and toy EV numbers sold, ('000), 2005 to 2015**



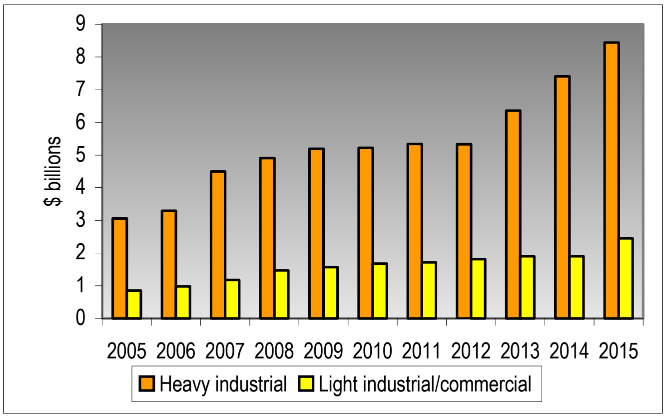
Source: IDTechEx

Figure 7 Military, marine and mining and others EV numbers sold, ('000), 2005 to 2015



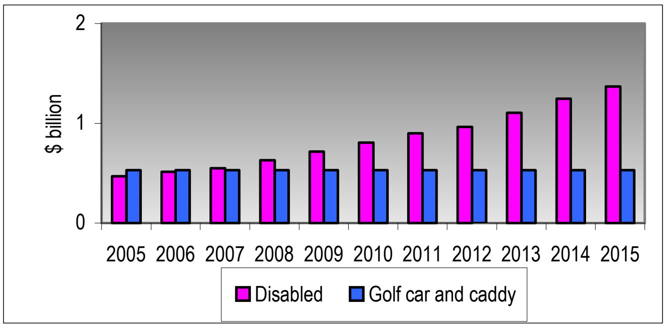
Source: IDTechEx

Figure 8 Heavy industrial and light industrial/commercial EVs sold by value, ($ billions), 2005 to 2015



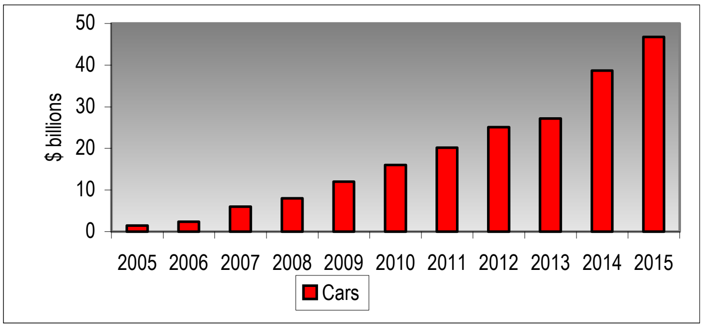
Source: IDTechEx

Figure 9 Disabled and golf car and caddy EVs sold by value, ($ billions), 2005 to 2015



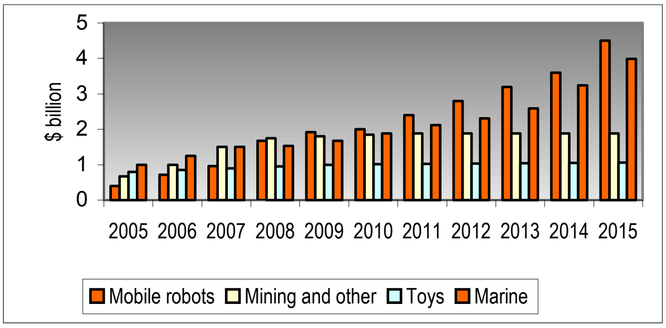
Source: IDTechEx

Figure 10 Cars EVs sold by value, ($ billions), 2005 to 2015



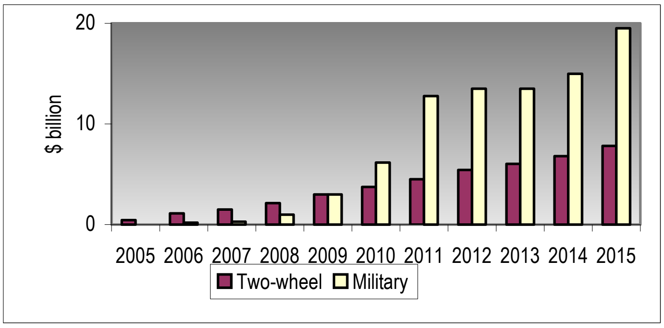
Source: IDTechEx

Figure 11 Mobile robot, toys, marine and mining and others EVs sold by value, ($ billions), 2005 to 2015



Source: IDTechEx

Figure 12 Two-wheel and military EVs sold by value, ($ billion), 2005 to 2015



Source: IDTechEx

Tables 9 to 13 and figures 13 to 18 give the global number sold ('000) and manufacturing sales value ($ billions) by technology.

Table 9 Global market for battery-only EVs, by number ('000), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	270	280	285	290	295	300	303	307	310	316	323
Light industrial / commercial	127	136	144	146	146	146	144	144	144	144	145
Disabled	800	880	960	1040	1120	1200	1300	1450	1600	1800	2050
Two-wheel	2650	3100	4000	4500	5000	5500	6000	6500	7000	7500	8000
Golf car & caddy	265	265	265	265	265	265	265	265	265	265	265
Cars	15	20	30	88	131	162	195	260	312	370	440
Mobile robots	600	1200	1600	2000	2400	2800	3200	3600	4500	5500	7000
Military	1	2	5	20	50	50	50	50	50	50	50
Mining & other	6	7	7	7	8	8	8	8	8	7.5	7.5
Toys	9000	9500	10000	10100	10200	10300	10400	10500	10700	11,000	11,400
Marine	25	25	26	28	28	30	32	35	40	45	50
Total	13759	15415	17322	18484	19643	20771	21897	23119	24929	26,757	29,730
Total excluding toys	4759	5915	7322	8384	9443	10461	11497	12619	14229	15,757	18,330

Source: IDTechEx

Table 10 Global manufacturing market for battery-only EVs, by value ($ bn), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	3.00	3.11	3.16	3.22	3.27	3.33	3.36	3.41	3.44	3.51	3.59
Light industrial / commercial	1.02	1.11	1.17	1.20	1.20	1.20	1.20	1.21	1.23	1.25	1.28
Disabled	0.55	0.63	0.72	0.81	0.90	0.97	1.11	1.25	1.37	1.55	1.76
Two-wheel	0.75	0.93	1.20	1.35	1.50	1.54	1.62	1.69	1.82	1.95	2.08
Golf car & caddy	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
Cars	0.30	0.40	0.60	1.76	2.62	3.24	3.51	4.68	5.62	6.66	7.48
Mobile robots	0.96	1.68	1.92	2.00	2.40	2.80	3.20	3.60	4.50	5.5	7.0
Military	0.05	0.10	0.30	1.20	3.00	3.00	3.00	3.00	3.00	3.0	3.0
Mining & other	1.50	1.75	1.80	1.85	1.88	1.88	1.88	1.88	1.88	1.88	1.88
Toys	0.90	0.95	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.10	1.14
Marine	0.80	0.85	0.91	1.01	1.01	1.08	1.15	1.26	1.44	1.62	1.80
Total	10.36	12.04	13.31	15.94	19.33	20.60	21.60	23.56	25.88	28.55	31.54
Total excluding toys	9.46	11.09	12.31	14.93	18.31	19.57	20.56	22.51	24.82	27.45	30.40

Source: IDTechEx

Table 11 Global market for hybrid EVs, by number ('000), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	5	60	70	80	90	100	150	200	250	300	350
Light industrial / commercial	3.8	6.4	10	19	20	21	22	24	27	30	33
Disabled	-	-	-	-	-	-	-	-	-	-	-
Two-wheel	-	400	600	799	988	1295	1490	1580	1950	2300	2750
Golf car & caddy	-	-	-	-	-	-	-	-	-	-	-
Cars	285	380	570	712	879	1088	1305	1740	2088	2500	3080
Mobile robots	-	-	-	-	-	-	-	-	-	-	-
Military	5.0	18	45	80	150	150	150	150	150	130	118
Mining & other	-	-	-	-	-	-	-	-	-	-	-
Toys	-	-	-	-	-	-	-	-	-	-	-
Marine	-	7.0	9.0	15	18	25	32	44	49	55	62
Total	298.8	871	1304	1705	2145	2679	3149	3838	4514	5315	6393

Source: IDTechEx

Table 12 Global manufacturing market for hybrid EVs, by value ($ bn), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	0.15	1.8	2.0	2.0	2.1	2.1	3.0	4.0	5.0	6.0	7.0
Light industrial / commercial	0.2	0.3	0.3	0.4	0.5	0.6	0.6	0.7	1.1	1.4	1.8
Disabled	-	-	-	-	-	-	-	-	-	-	-
Two-wheel	-	1.2	1.8	2.4	3.0	3.9	4.5	5.0	5.9	6.9	8.3
Golf car & caddy	-	-	-	-	-	-	-	-	-	-	-
Cars	5.7	7.4	11.4	14.2	17.6	21.8	23.5	31.3	37.6	45.0	52.4
Mobile robots	-	-	-	-	-	-	-	-	-	-	-
Military	0.25	0.9	2.7	4.8	9.0	9.0	9.0	9.0	9.0	7.8	7.1
Mining & other	-	-	-	-	-	-	-	-	-	-	-
Toys	-	-	-	-	-	-	-	-	-	-	-
Marine	-	0.24	0.32	0.54	0.72	1.13	1.44	1.98	2.50	2.75	3.41
Total	6.65	11.8	18.5	24.3	33.9	38.5	42.0	52.0	61.1	69.85	80.01

Source: IDTechEx

Table 13 Global market for fuel cell EVs, by number ('000), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	-	-	-	-	-	1	1.5	2.5	5.0	2.5	5.0
Light industrial / commercial	-	-	-	-	-	-	1.8	1.9	3.8	6.2	8.3
Disabled	-	-	-	-	-	-	-	-	-	-	-
Two-wheel	-	-	-	1.0	2.0	5.0	10	20	50	85	140
Golf car & caddy	-	-	-	-	-	-	-	-	-	-	-
Cars	-	-	-	-	-	5.0	10	15	20	25	30
Mobile robots	-	-	-	-	-	-	-	-	-	-	-
Military	-	-	-	1.0	5.0	10.0	10.0	20.0	50.0	60	72
Mining & other	-	-	-	-	-	-	0.05	0.08	0.10	0.13	0.17
Toys	-	-	-	-	-	-	-	-	-	-	-
Marine	-	-	-	-	-	-	-	-	1.0	1.5	2.0
Total	-	-	-	2	7	21	33	45	129	180	276

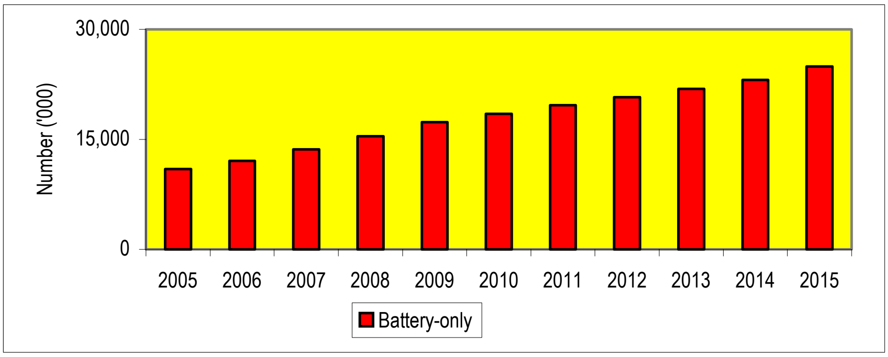
Source: IDTechEx

Table 14 Global manufacturing market for fuel cell EVs, by value ($ billion), 2005 to 2015

SECTOR	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Heavy industrial	-	-	-	-	-	0.03	0.05	0.07	0.76	0.81	1.25
Light industrial / commercial	-						0.06	0.07	0.14	0.21	0.31
Disabled	-	-	-	-	-	-	-	-	-	-	-
Two-wheel	-	-	-	-	0.01	0.02	0.03	0.06	0.15	0.26	0.42
Golf car & caddy	-	-	-	-	-	-	-	-	-	-	-
Cars	-	-				0.10	0.18	0.27	0.36	0.45	0.51
Mobile robots	-	-	-	-	-	-	-	-	-	-	-
Military	-	-	-	0.15	0.75	1.50	1.50	3.00	7.50	9.0	10.8
Mining & other	-	-	-	-	-	0.01	0.01	0.02	0.03	0.03	0.04
Toys	-	-	-	-	-	-	-	-	-	-	-
Marine	-	-	-	-	-	-	-	-	0.05	0.08	0.1
Total	-	-	-	0.15	0.8	1.7	1.8	3.5	9.0	10.8	13.4

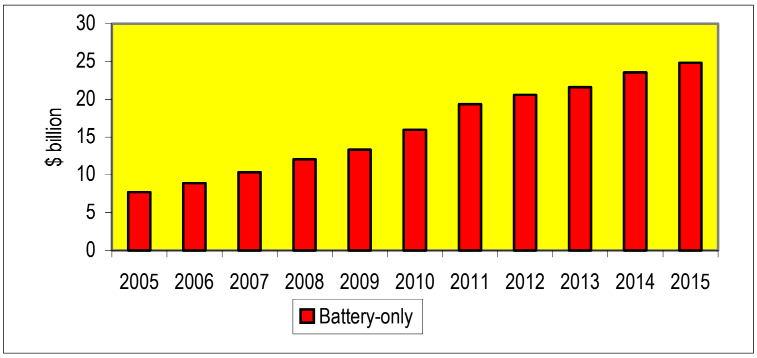
Source: IDTechEx

Figure 13 Global numbers sold ('000) of battery-only EVs, 2005 to 2015



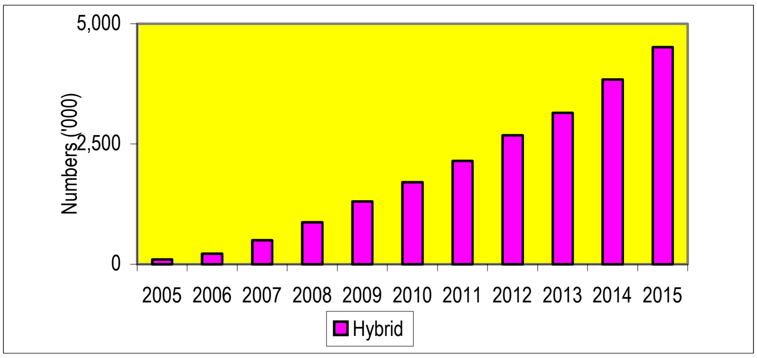
Source: IDTechEx

Figure 14 Global sales value ($ billions) of battery-only EVs, 2005 to 2015



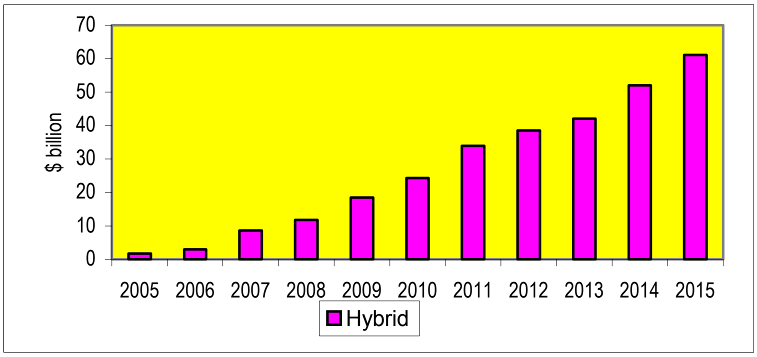
Source: IDTechEx

Figure 15 Global numbers sold ('000) of hybrid EVs, 2005 to 2015



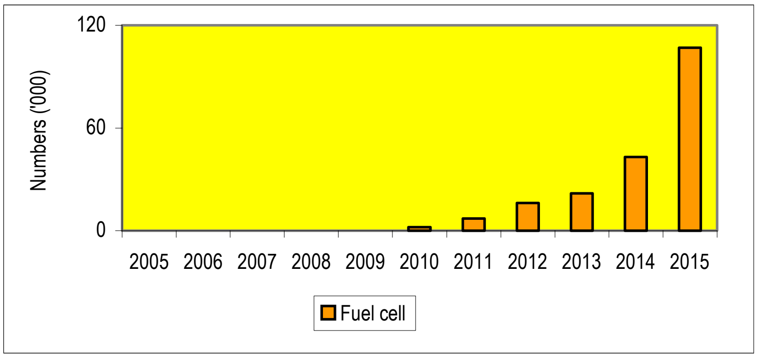
Source: IDTechEx

Figure 16 Global sales value ($ billions) of hybrid EVs, 2005 to 2015



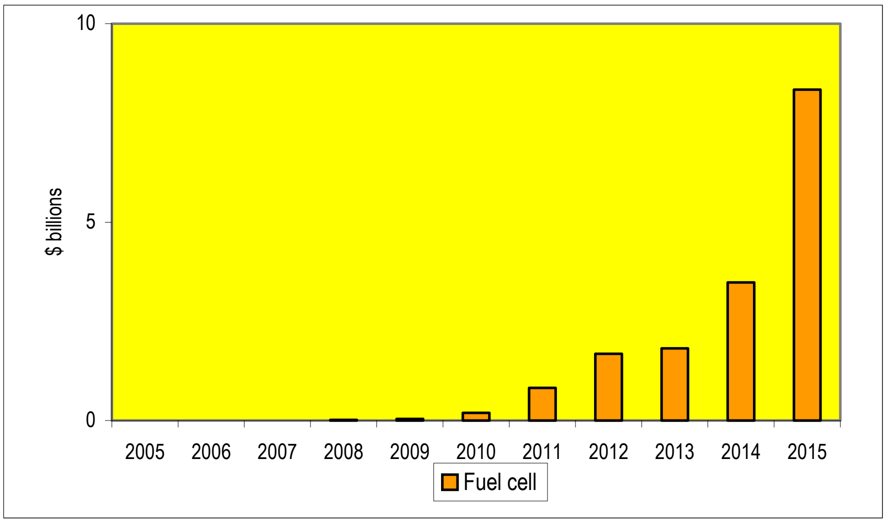
Source: IDTechEx

Figure 17 Global numbers sold ('000) of fuel cell EVs, 2005 to 2015



Source: IDTechEx

Figure 18 Global sales value ($ billions) of fuel cell EVs, 2005 to 2015



Source: IDTechEx

Geographic penetration

Sale of EVs by sector is far from uniform across the world and geographic penetration is sharply different between sectors. This diversity will pertain but the dominant geographical area for some sectors will change. See table 14

Table 15 Territory with largest sales of EVs by value 2005 to 2015

SECTOR	DOMINANT USER		REASON
	2005	2015	
Industrial	Europe	East Asia	Largest number of potential users.
Commercial	USA	East Asia	Location of strongest innovation and support for use.
Disabled	USA	USA	Disposable income.
Two-wheel	China	China	Largest number of potential users, strongest legislation.
Golf car and caddy	USA	USA	Most golf courses.
Cars	USA	East Asia	Location of most innovation and support.
Mobile robots	USA	East Asia	Consumers most keen.
Military	USA	USA	Biggest spend.
Toys	USA	East Asia	Number of children with money.
Marine and other	USA	USA	Largest leisure markets.

Source: IDTechEx

Global leaders by application sector are shown in table 13.

Table 16 Global leaders by sector in EVs in 2005 as measured by value of sales

SECTOR	COMPANY	MAIN RELEVANT PRODUCT
Heavy industrial	Toyota	Fork lifts
Light industrial/commercial	DaimlerChrysler	Buses
Disabled	Pride	Power chairs
Golf	Textron	Golf cars
Cars	Toyota	Family cars
Two wheel	Chinese companies	Bicycles
Marine	US Submarines	Submarines – personal and tourist
Total market	Toyota	Fork lifts, cars

Source: IDTechEx

Major EV launches, market and other developments 2005 to 2050

China – a 30 year programme for world leadership

China is pressing on with its nuclear programme, commissioning 27 new nuclear power plants by 2020, but for the long term it is looking to develop renewable sources. The national mid-to-long term plan which builds on this targets seven key areas, principal of which is the development of hydrogen and fuel cell technologies. Early in 2005, China published a roadmap for its transition to a hydrogen economy. This called for a technology development phase to run until 2020 followed by a 30-year implementation programme to develop the infrastructure for power and transports.

In the immediate future the more visible elements will be China's tests of a hydrogen-powered public transport system, which features several fuel cell buses and its rapid rollout of home-produced hybrid cars and buses. With the eyes of the world focusing on Beijing for the 2008 Olympic Games, China is planning to have a public transport infrastructure that leads the world.

Below, IDTechEx give some indications of the major vehicle and market developments expected over the next ten years by ourselves and other experts with some indications to 2050.

Table 17 Major EV launches, markets and other developments

Year – 2005

EV launches	Mitsubishi Motor Corp and Mitsubishi Heavy Industries Ltd have a joint project to develop fuel cell-powered vehicles for seven years. A commercially feasible vehicle was to be ready in 2005. This is now unlikely. Mitsubishi Heavy Industries, from which Mitsubishi Motors was spun off in 1969, already made fuel cells for power generation. GM Launch hybrid version of Saturn Vue. DaimlerChrysler, Ford and GM launch new HEVs including hybrid Dodge pick-up truck. Toyota expects to sell 300,000 hybrid cars with many new models available. Modec launched pure electric delivery van with Zebra NiNaCl battery, expecting to sell 1000 in the year Hyundai "will spend 10.6 billion won ($8.7 million) to build 300,000 hybrids in the next few years."
Markets	Toyota may reach 20 per cent share of the global market for EV manufacture by value – world leader. DaimlerChrysler once expected to sell 100,000 fuel cell vehicles in 2005. It will not happen. Honda expects to sell 24,000 hybrid on-road vehicles Ford plans to make 20,000 Escape hybrids. Local government of Aichi Japan targets 80,000 road EVs. Dyson originally expected $3 billion sale of robot vacuum cleaners in 2005. None are yet available. Electricity to EVs in US has a charging value of $673 million (EPRI). This is now unlikely. The Japanese continue to launch the most new EV models and the largest number of road EVs offering unusual consumer benefits. Reva Electric Car Company, India originally expected to sell 15,000 pure EVs at about $5,000 each. India expects over 1000 hydrogen powered vehicles on the road. It is unlikely. Several hundreds of thousands of vacuum cleaning robots will be sold in 2005 and cumulatively 700,000 domestic robots of all types in 2002 through to start of 2005 (UN Economic Commission for Europe). It will not happen.
Other	Sanyo Electric expect sales of 50 billion Yen (about $392 million) of vehicle batteries in 2005. Electricité de France plan to have doubled its EV on-road fleet over 2002. Japanese Government planned to have purchased 7,000 low polluting vehicles since 2002.

Table 18 Major EV launches, markets and other developments

Year – 2006

EV launches	Shell and DaimlerChrysler once expected to launch, jointly, a commercially viable hydrogen fuel cell EV. DaimlerChrysler diesel electric sport wagon GM launch hybrid EV Equinox pick-up truck. Fuel cell vehicles become viable in the view of Mark Mittleman, CEO PlugPower. We disagree. Formosa Plastics of Taiwan expect to make 0.5 million on-road EVs yearly. Most of the new hybrids offer better performance not just better fuel economy and emissions but prices remain high vs conventional vehicles. Example – Honda Accord hybrid has fuel economy of a Civic, far more power but price $30,000. Modec pure electric delivery van with Zebra NiNaCl battery, expecting to sell 1500 in the year and reach breakeven. Honda expects to sell 50,000 hybrids. Nissan Altima hybrid launch.
Markets	Large battery/fuel cell market exceeds $2.4 billion (BCC). $87 million market for non-lead materials for lead acid batteries (BCC). $936 million market for materials for batteries excluding lead acid types (BCC). Other battery and fuel cell materials are a $167 million market (BCC). Dyson expected to sell one million robot vacuum cleaners yearly at $3.2 billion retail value. It will not happen. 500,000 Americans will have purchased HEVs by 2006 (JD Power & Associates). Not likely. The Japanese continue to launch the most new EV models and the largest number of road EVs offering unusual consumer benefits. The 15 largest car manufacturers of 1999 have become 6 or 7 (Retail Motor Industry Federation).

Other	20 countries have laws banning ICE vehicles from city centres, or punitively taxing them. US tightens laws on pollution of inland waters, often banning ICE boats. The California Air Resource Board (CARB), which monitors air quality, has made electric fork lifts and other heavy industrial vehicles mandatory in certain environments with a six-year implementation period beginning in 2006.

Table 19 Major EV launches, markets and other developments

Year – 2007

EV launches	Peugeot Citroen launch mild hybrid mini cars and full hybrid cars. 2007 is earliest date Toyota expect profit from road EV cars. New models every year. Electrically-assisted bicycles available in the West for under $400 retail. Renault originally hoped to launch their first generally available fuel cell car. We consider this unlikely now. GM has launched five to twelve models of hybrid EV on-road vehicles 2003 to 2007. In 2007 it launches hybrid Chevrolet Malibu. Vectrix large 2 wheel scooter is selling in the US and Europe. It is an "electric hybrid" of fuel cell and battery with no ICE.
Markets	Inland boats with solar or wind power charging traction batteries are common. ICE boats banned on many inland waterways worldwide. Installed industrial EVs in US rises to 1,055,000 vs 830,000 in 1998, mainly lift trucks for non-durables and wholesale. Total lift trucks, including ICE is 1.4 million, up from 1.1 million in 1996 (EPRI). Clarence Ellers of World Electric Transportation Newsletter saw almost all passenger road vehicles electric from 2007 onwards. We do not agree. Four million on-road EVs in use globally, market becoming one million in one year, $24.2 billion, but this is only 1.5 per cent of global vehicle sales. Most will be cars and light trucks but with buses, sanitation trucks etc, becoming significant. EVs are only 0.5 per cent of all self-powered vehicles in use globally. (Freedonia Group). Europe still the largest market for heavy and light industrial EVs. Fuel cells will be viable in fork lift trucks: Michael Routtenberg, president and CEO of General Hydrogen Corporation
Other	Electric road vehicles use $2.3 billion of batteries in 2007. (Industry) World consumption of batteries $77.5 billion vs $37.5 billion in 1997. (Freedonia Group) US National Highway Traffic Safety Administration raises federal fuel economy standards by seven percent.

Table 20 Major EV launches, markets and other developments

Year – 2008

EV launches	2008 earliest date for large scale production of fuel cell EVs (Freedonia Group). We agree but 2015 is a more likely date. Conventional and hybrid cars and trucks very often sold with a folding two-wheeler EV on board, clipped into a charging point. China hosts the Olympic Games and showcases many EV bicycles, cars and transportation at the Games. More than 12,000 electric buses will be available. East Asia, notably China, still the largest market for 2 wheelers.
Markets	"Considerable growth in fuel cell vehicle market" (ABI). Ford/Freedom CAR expects "thousands" of fuel cell vehicles on the road. China's leading auto maker FAW will make about 1000 diesel electric parallel hybrid 10-12 meter buses for the Beijing Olympics and World Expo Shanghai 2010. 500,000 hybrids will have been sold; J D Power Associates
Other	2008 EU regulation requires average fuel consumption of new cars sold to be 50 mpg vs 35 mpg in 1998. 2008 European car makers pledged to reduce total carbon dioxide emissions from new cars by a quarter vs 1998.

Table 21 Major EV launches, markets and other developments

Year – 2009

EV launches	Many new hybrid EV motorcycles sold in volume.
Markets	EVs for the disabled and military EVs continue to be among the few recession proof EV markets.
Other	Many more countries have laws constraining ICE vehicles. Europe prohibits use of NiCd batteries.

Table 22 Major EV launches, markets and other developments

Year – 2010

EV launches	The first electric road cars and commercial vehicles sold profitably in high volume – these will be hybrids. Many new types of leisure EV creating new markets. Viable hybrid EV motorcycles in volume. Many new types of home and other service robots. Several new military EV boats, miniature submarines, airships, aircraft, mobile robots, remote controlled and manned attack vehicles. Most will be hybrids. Mobile robots the size of people are widely sold. They can do most simple chores and have the brain of a lizard (5,000 MIPS) according to Hans Moravec of the Robotics Institute, Carnegie Mellon University.
Markets	1.1 million on-road EVs in use in USA (EPRI). 5 million electrically-assisted bicycles bought yearly and at least one million 2 wheel scooters and motorcycles. Most sales still in East Asia. The number of motorcycles and motor scooters in East Asia (ICE + EV) has doubled over 1995 (EPRI). "Due to their conventional vehicle platform, mild hybrid technology will be a significant sales reality by the end of the decade".. (Ricardo, UK). 20 per cent of cars being made by Ford may be hybrid (Clay Ford, Chairman). IC based hybrid vehicles achieve 6 per cent market penetration (on road), (Ricardo, UK). Fuel cell vehicles take 10 per cent of German car market (OPEL, GM subsidiary). We doubt it. Fuel cell vehicles will be 10 per cent of car output of Vauxhall, the General Motors UK subsidiary, they say. We doubt it. Only 20,000 fuel cell EVs sold in 2010 (Donald Macarthur). Toyota licence of hybrid patents to Nissan calls for Nissan to make 100,000 hybrids by end of 2010. China's leading auto maker FAW will make about 1000 diesel electric parallel hybrid 10-12 meter buses for the Beijing Olympics in 2008 and the World's Expo in Shanghai 2010.
Markets/ continued	Fuel cell vehicles will take at least 4 per cent, or 608,000 vehicles of the total US automotive market. The market for these vehicles could even reach as high as 7.6 per cent, or 1,215,000 vehicles. 80 per cent of all fuel cell vehicles sold will be proton exchange membrane (PEM) fuel cells by 2010. (Source: Allied Business Intelligence). We doubt the 2010 sales figure. Tae Won Lim of Hyundai/ Kia says his company will have 3000 fuel cell vehicles sold by 2010. Korea overtakes Japan as number one supplier of hybrid vehicle batteries. Japan's Ministry of Economy, Trade and Industry plans 3.22 million environmentally friendly vehicles in use in Japan. "50,000 fuel cell vehicles on Japanese roads." National plan.
Other	US airports would have 43 per cent more emissions, vs 1997 if nothing is done about ground support vehicles etc. (CALSTART). Newcomer to the on-road car and commercial vehicle scene becomes a threat to traditional manufacturers by concentrating on pure and hybrid EVs and offering new, multi-faceted consumer propositions. Duke University Fuqua Business School training and research project for hydrogen fuel cell vehicles is completed

Table 23 Major EV launches, markets and other developments

Year – 2011

EV launches	Toyota promises hybrid versions of "almost all" models.
Markets	Up to 2.4 million fuel cell vehicles could be in service (ABI).
Other	Pollution laws continue to tighten.

Table 24 Major EV launches, markets and other developments

Year –2012

EV launches	Toyota promises hybrid versions of "almost all" models.
Markets	Up to 2.4 million fuel cell vehicles could be in service (ABI). Ford/Freedom CAR expects commercially viable fuel cell vehicles on the road in "large numbers" in 2012. "More than 3000 fuel cell vehicles on Korean roads" National plan. Some time between 2012 and 2015, lift trucks will only run on fuel cells: Michael Routtenberg, president and CEO of General Hydrogen Corporation
Other	Pollution laws continue to tighten. The decade of the hybrid EV begins to see the end with fuel cell vehicles beginning to sell in modest volumes but hybrids will be sold in large numbers for at least ten more years.

Table 25 Major EV launches, markets and other developments

Year – 2013

EV launches	Earliest date for volume sales of fuel cell vehicles (EPRI). Hybrid outdoor heavy vehicles such as cranes and earthmovers are common.
Markets	US the largest EV market by value. China the largest market by numbers. Military and cars dominate the market by value. Two wheel still has the biggest numbers. GM will have sold 1 million fuel cell vehicles at a profit – statement by Larry Burns, GM VP of research and development.
Other	PEM fuel cells sold in vehicles in volume.

Table 26 Major EV launches, markets and other developments

Year – 2014

EV launches	Most car, truck and bus models are offered with hybrid options.
Markets	870,000 hybrids will have been sold – nearly 5% of the market : J D Power Associates
Other	

Table 27 Major EV launches, markets and other developments

Year – 2015

EV launches	
Markets	"The average Japanese family will be driving a hybrid" Chuck Heine, Dana Corp. He does not see the majority of families in the West driving an on-road EV however. "5% of Toyota's worldwide sales will be hybrids." Dr Takehisa Yaegashi Toyota "My feeling is that we won't see significant numbers of fuel cell vehicles until 2015-2020. If you look at the history of these things, you often need a significant external impetus for change, the classic example being the oil shock of the 1970s. The problem is that it is difficult enough to see where a stimulus is going to come from that's strong enough and uniform enough across all markets to really make a difference. And look at something as practical as vehicle design cycles: a car takes around three years to develop and will be in production for another eight – that makes 11 years. So unless they're designing cars around the fuel cell concept right now in Detroit or Tokyo, it's going to take awhile." Dr Peter Wells, research fellow at the Centre for Automotive Industry Research UK.
Other	

Table 28 Major EV launches, markets and other developments

Year – 2020

EV launches	Many new EV boats and robots.
Markets	Hybrids have 20% penetration of new on road vehicles. (Ricardo UK).
Other	A study by the Laboratory for Energy and the Environment at the Massachusetts Institute of Technology has predicted that, in 2020, diesel hybrids could achieve the same energy efficiency and greenhouse gas emissions as fuel cell vehicles powered by hydrogen made from natural gas.

Table 29 Major EV launches, markets and other developments
Year – 2030

EV launches	
Markets	"Fuel cell technology is likely to become a factor in light vehicle power trains." Dr Takehisa Yaegashi Toyota
Other	

Table 30 Major EV launches, markets and other developments
Year – 2050

EV launches	
Markets	Iceland becomes a completely hydrogen economy, with the gas generated by geothermal power. Icelandic Government plan
Other	

1. Introduction

1.1. Definitions and scope of the report

The commonly accepted definition of an electric vehicle "EV" is a free-running electrically driven vehicle that carries its own power supply. Trains and trams picking up power as they go along do not therefore come within this definition, nor do warehouse vehicles that are tethered by a power line. However, pedestrian-operated loaders, stackers, carriers, golf caddies, floor polishers and stair-climbers do come within the definition when their power of movement is electric. The portable power source may be solar cells, fuel cells, rechargeable or dry batteries or even flywheels or capacitors. The vehicle may be an aircraft or a boat, though most of the business is concerned with land vehicles. Electric toys (free running) and mobile robots including ones that climb buildings, trees etc. are included. We do not include large diesel electric locomotives or large diesel-electric submarines as these are mature technologies well documented elsewhere.

1.1.1. Case study: The improved Toyota fuel cell FCHV Bus2 in 2005

The Toyota FCHV Bus2 shown in figure 1.1 is a fuel cell hybrid bus that operates on motors powered by high-pressure hydrogen-supplied fuel cells and a nickel-metal hydride secondary battery. Unlike gasoline- and diesel-fuelled vehicles, it does not emit carbon dioxide or other toxic substances during operation and is highly energy-efficient, as well as quiet, according to Toyota.

Fig. 1.1 **The Toyota FCHV Bus2**

Source: Toyota

An improved version is operating to September 2005 at EXPO 2005 Aichi, Japan. These fuel cell hybrid buses represent an improved version of the FCHV-BUS2-a large low-floor commuter bus that features a hybrid system powered by high-pressure hydrogen, that TMC and Hino Motors Ltd have been jointly developing since 2000.

The FCHV-BUS2, equipped with two units of TMC's high-performance Toyota FC Stack and incorporating the hybrid technologies found in the Toyota Prius hybrid passenger sedan and Hino's HIMR System, achieves high running efficiency by recovering energy during deceleration and delicately alternating between its fuel cells and secondary battery for power supply to the motor according to running conditions.

The FCHV-BUS2 was the first fuel cell-powered bus officially approved by Japan's Ministry of Land, Infrastructure and Transportation. Issued a license plate in 2002, the vehicle has been carrying out trial runs on public roads. It is also expected to run on regular Tokyo metropolitan bus routes this summer as part of a fuel cell bus pilot project promoted by the Tokyo Metropolitan Government.

1.1.2. Technical features

The main specifications of the current FCHV-BUS2 are as follows:

Vehicle
Base platform
Blue Ribbon City (Hino low-floor commuter bus)

Overall length / width / height
10,515 / 2,490 / 3,360 mm

Maximum speed

80 km/h

Occupant capacity

60 people

Fuel cell stack

Type

Polymer electrolyte fuel cell

Output

90 kW x 2

Motor

Type

Permanent magnet

Maximum output

80 kW x 2

Maximum torque

260 Nm x 2

Fuel

Type

Pure hydrogen

Storage method

High-pressure hydrogen storage tank

Maximum storage pressure

35 Mpa (350 atmospheres)

Secondary battery

Type

Nickel-metal hydride

At EXPO 2005 Aichi, Japan, the improved fuel cell hybrid buses operate as a shuttle from March 25 – Sept. 25 (185 days).

1.1.3. History of EVs

The first commercially sold EVs were developed in the nineteenth century. Several hundred companies offered road cars and buses in the early twentieth century but the gasoline engine usurped the electric motor because of superior performance, refuelling time and range. However, the early technical developments in electrical vehicles were employed in starter motors for gasoline engines, in electric vehicles for indoor industrial use and in small commercial on-road vehicles that have been sold successfully ever since. Several manufacturers of electric vehicles have been in production for fifty years as have their suppliers of motors, batteries and controls.

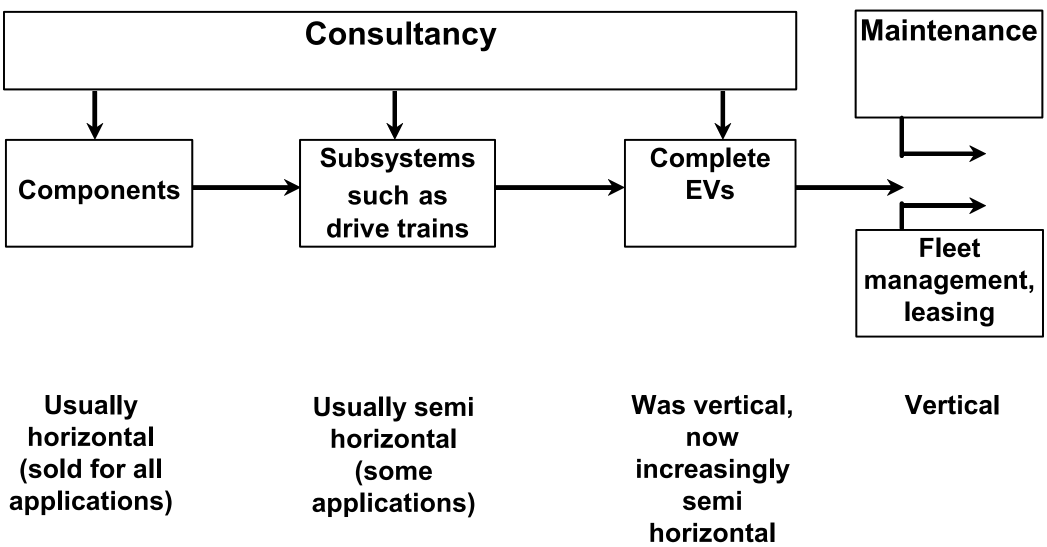
1.1.4. Organisations involved in the EV industry

Participants in the EV industry include media, journalists, analysts, management consultants, design engineers and suppliers of components and subsystems as well as manufacturers and sales organisations dealing in new and used complete vehicles. Some operate horizontally, selling their product or service to many applicational types of vehicles from those for warehouses to military versions. Others operate vertically. For instance, those making vehicles for the disabled often see themselves as in the healthcare sector alone and they may make vehicle parts for their own vehicles and customise each one, though this has usually proved to be a fragile strategy.

1.1.5. The EV value chain

The EV value chain is shown in figure 1.2.

Fig. 1.2 **Electric vehicle value chain**



Source: IDTechEx

1.1.6. Benefit of a broad definition

The benefit of the broad definition of an EV is that it reveals the great commonality between these various vehicles. They require similar technical and support skills and employ similar components and production technology. Modular design can mean one type converts to another. Many companies sell a range of EVs into different applications to exploit economies of scale. The old attitudes are breaking down where, say, the maker of fork lift EVs felt he had nothing to learn from makers of light industrial or military EVs. It is no longer valid to presume that those in other applicational sectors offer no competitive threat or relevant technical or marketing knowledge.

Indeed, the applicational segmentation is itself breaking down. For example, EVs for the disabled used to mean medical aids for the registered severely disabled but 3 and 4 wheel scooters are for people who have some difficulties but can still go out alone. This totally new market is now the fastest-growing part and it replaces nothing. Robots are usually like this as well – creating a new market and replacing nothing.

1.1.7. On-road vs off-road – not a clear distinction

Other segmentations are breaking down as well. Many major car manufacturers have decided that "on road" is the only worthwhile category of EV to explore. This is often based on the narrow premise that the engine of a conventional family car can be improved, notably to reduce pollution and keep the legislators at bay. However, golf cars are now legal on the roads of many US and European cities and 3 and 4 wheel mobility aids for the disabled, "microcars" and "neighbourhood electric vehicles (NEVs)" (small multi-person cars used locally) are even more widely accepted on roads as are certain commercial vehicles. Two wheelers are used both on and off-road.

1.2. Pure electric vehicles

Over 90 per cent of EVs by number and gross sales value have been "pure" EVs. By this we mean that they have no other engine on board that can be used to boost or, in certain situations replace the power of their electric motor or charge its batteries. Pure EVs can be powered by batteries, fuel cells, solar power, flywheels or combinations but only batteries are important today and the only major contender for traction batteries within ten years is expected to be fuel cells for most applications, and this is speculative, despite the huge investment in fuel cells. Nearly all fuel cell systems employ large batteries as well for start-up power, regenerative braking and power balancing. We call these pure EVs because no internal combustion engine ICE is involved.

1.3. Hybrid electric vehicles

Hybrid electric vehicles have a non-electric motor on board, usually an internal combustion engine, (ICE). There are various reasons for doing this. In a military main battle tank it may be used to recharge the batteries at times when there is not a danger of attack from missiles that will detect the heat or gaseous emission. In a road car, it may provide the extra range for inter-city motoring where pollution is permitted. However, in reality hybrids are more usually conceived as improved gasoline engines - less pollution, more miles per gallon and hopefully lower cost over life because the electric motor helps the ICE to run optimally. Some of the latest ones have acceleration that is superior to that achievable with ICE alone. In airport ground support equipment it may boost performance when high power delivery is needed. Hybrid engine combinations may be series or parallel connected, or sophisticated combinations of both, or as with the tank mentioned, totally separate with the ICE never providing traction. Hybrids are gaining market share but improved pure ICE engines are sometimes keeping up with them in both fuel economy and reduction of pollution. In the pollution stakes, they have competition from liquefied natural gas (LNG) and liquefied petroleum gas (LPG) powered ICE and other clean power sources for ICE engines such as hydrogen which are also being trialled. However, it is significant in 2005 that Ford has abandoned its gas powered car range to concentrate on fuel cell and hybrid EVs.

1.3.1. Pros and cons

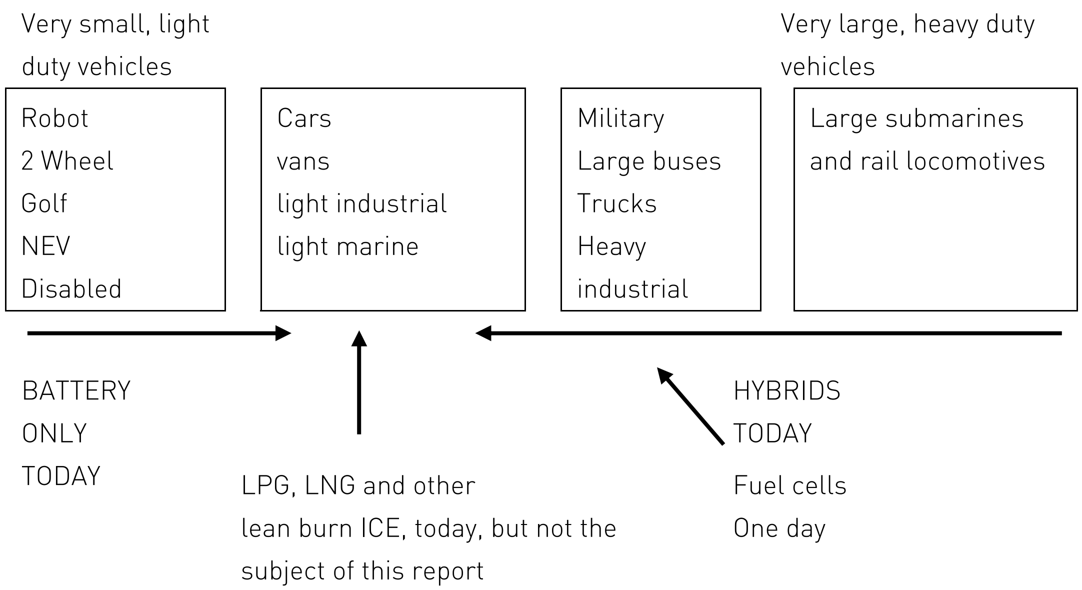
Most hybrid engine combinations permit the ICE and the electric motor(s) to run under optimum load and revolutions improving life, reliability and fuel consumption. Hybrids have been used as sources of standby electricity for radar and postal depots. However, hybrids usually cost more and have more parts to go wrong. Hybrids may only exceed the usage of pure EVs in transportation and large industrial and commercial vehicles i.e. cars, buses, taxis, trucks etc. Within 15 years, viable fuel cells may result in even these hybrids being replaced by pure EVs again.

One problem of semantics remains. Series hybrids such as the new Honda Insight and most hybrid buses have the ICE engine on all the time and some might say they are not EVs at all. However, we include them in our statistics in line with current practice in the industry.

1.4. Competing technologies and their targets

The competing technologies and their targets are shown in figure 1.3.

Fig. 1.3 **Competing electric drive train technologies and their targets by market sector**



Source: IDTechEx

1.5. Applicational sectors

In this report we prioritise applicational sectors rather than less-safe distinctions such as "on road" vs "off road". However, that still leaves some problems even beyond the breakdown of the category "disabled" that we discussed earlier. It is not enough to stick to "industrial", "leisure" etc. As an instance, an electric bicycle or car may be leased or sold to a company ("commercial") or sold to an individual or be for "leisure". There is no totally safe compartmentalisation but we have settled for:

- Heavy industrial
- Light industrial/commercial
- Disabled
- 2 wheel
- Golf car and caddy
- Cars
- Marine
- Military
- Mobile robots
- Other

It is not practical to completely separate commercial because of the excessive overlap with industrial. For instance, a people mover may be used by a factory or a bus company. Golf cars are mainly leased (commercially) and some are sold (leisure) but the category is particularly large and important with three companies specialising in global sales of golf cars. It therefore merits a section of its own.

1.5.1. Robots in many forms

Mobile robots perform operations such as photography and vacuum cleaning. Simple fetching and carrying is done by Automatic Guided Vehicles (AGVs) which are part of light industrial. Toys have something in common with some other electric vehicles in that they often employ the newer rechargeable batteries and efficient, though small, traction motors. They meet our definition of EVs. The newer home robots bridge the motive technology of toys and bicycles, disabled vehicles etc. They are sold for a few hundred to a few thousand dollars each. They often employ sophisticated electronics.

1.6. Reasons for adoption of EVs

In understanding EV markets and trends it is absolutely vital to realise that their adoption is not usually for the popularly understood reasons. It is commonly understood that successful electric vehicles are essentially conventional ICE four-wheel vehicles with an electric motor substituted for the ICE to control pollution. Not so.

In fact, so far, electric vehicles are usually financially successful where are bought because they:

- Replace human effort.
- Make new things possible.
- Save cost against alternative procedures.

and, less often

- Directly replace internal combustion engines on cost over life/pollution.

Frequently, the successes combine two or three of the first three attributes. Pollution legislation is rarely the primary reason why someone buys an EV.

Replacements of ICE vehicles with EVs with almost exactly the same functionality and appearance is not common beyond cars, trucks and buses. It is usually done to reduce cost over life or pollution of the air or water.

- Golf cars (cost over life).
- Tow tractors (cost over life, pollution).
- 2 wheel scooters (pollution, convenience, reliability).

- Some cars, vans, people carriers, buses (pollution, cost over life).

Golf cars, to explain one example, are mainly electric nowadays and the platform is virtually the same. The primary reason in cost reduction - no more expensive storage of gasoline at the club house, less maintenance, longer life.

1.6.1. Replacing ICE for reasons other than pollution

Usually, where EVs replace ICE vehicles, the reason is not pollution. Examples are given in table 1.1.

Table 1.1 **Some reasons why ICE vehicles are replaced with EVs**

ICE VEHICLE	REASON FOR REPLACEMENT WITH EV
Mining	Safety, reliability
Fork Lift	Manoeuvrability, cost over life.
Disabled	Silence, ease of control, reliability.
Military	No noise or heat signature Leaner, more responsive fuel supply chain.
Golf car	Cost over life
Car	Fuel economy

Source: IDTechEx

There is no reason to believe that this formula for success will change in the next ten years. Some EVs will continue to be purchased because governments ban or greatly deter alternatives, on pollution grounds, in particular applications, – 2 stroke scooters in China, ICE fork lifts in enclosed buildings and ICE boats on certain European lakes. However, most EV purchases will be freely made decisions. People rarely buy something simply because it does not pollute, particularly if it costs more, as is often the case with EVs. Table 1.2 shows wants well satisfied by EVs.

Table 1.2 **Wants well satisfied by EVs**

	Smaller, more manoeuvrable	Silence, low vibration	Acceleration	No pollution (air, noise) Fuel logistics easier – Outdoor	No pollution (air, noise) Fuel logistics easier – Indoor	Lowest cost over life	Lack of heat trail (missile attack)	Tolerant of frequent stop - start	Battery weight used for low centre of gravity or counter-weight	Safer e.g. no sparks or hot parts
Military, Police		A	A				A	A	A	
Industrial/Commercial										
Trash Collection				A				A		
Deliveries				A				A		
People-mover					A			A		
Warehouse, logistics	A				A	A		A	A	
Airside at airports	A			A		A		A	A	
Inside at airports					A			A		
Mining										A
Disabled	A	A			A			A	A	A
Leisure		A	A		A				A	A

Source: IDTechEx

1.6.2. Replacing human effort

Let us now look at these market drivers in more detail.

Examples of replacing human effort are:

- Fork lifts inside enclosed factories.
- Access platforms (also saves labour cost over scaffolding, for example).
- Bicycles.
- Pedestrian-operated load carriers, stair climbers, stackers, fork lifts, golf caddies.
- Folding golf buggies (car trunk).
- Golf cars for disabled in airports.
- Rickshaws.
- Bomb disposal robots.
- Neighbourhood vehicles.
- Electric skateboards.

1.6.3. Making new things possible

Examples of making new things possible are:

- Go karts (indoor use, safety, acceleration).
- Electric wheelchairs and 3/4 wheel "scooters" (independence).
- Home robots monitoring the elderly (safety, independence).
- Supermarket vehicles on loan so the infirm can shop (independence).
- Military disposable reconnaissance aircraft (information).
- Leisure submarines (fun, independence).
- Remote-controlled toy boats and cars (fun).
- Silent airships (undisturbed study of the top of the rain forest).
- Dragsters (record-breaking performance).
- Boats (undisturbed study of wild life).
- Golf course mowers (silence).

1.6.4. Electric fork lifts are not what they seem

Electric fork lift trucks look like ICE versions and sell very profitably in volume but appearances are misleading. They have created a new market for indoor lifting without human effort, in constricted spaces if necessary. Pure electric fork lifts are:

- Smaller.
- More manoeuvrable, controllable.
- Lower maintenance cost.
- Lower refuelling cost.
- Battery weight saves cost of counterbalance iron.
- Practicable/legal in enclosed spaces.
- Longer life.
- Much quieter

Soon, new hybrids will partly replace conventional, largely outdoor, fork lifts, tugs and other heavy industrial equipment. This does not impact the above "new" markets. It replaces ICE where pure EV cannot yet cope. This will be done primarily to save cost over life, not permit new functions. Hybrids will almost never replace pure EVs.

Conversions of vehicles to electric are very rarely done because the full benefits can only be created by a complete redesign. That boosts the markets for EVs. However, the exceptionally long life of EVs can reduce the numbers sold vs ICE.

1.6.5. Do not major on pollution if you want to succeed

The moral of the story is that those dedicated to reduction of pollution should design vehicles that replace human effort, make new things possible and save cost over alternative procedures. That way people will want to buy them and the pollution - reduction objective will be achieved. It is whimsical that the attitudes of the former Soviet Union of "It does not matter how I design my product. The government must be persuaded to force people to buy it" are still prevalent in parts of the transport sector. It will end in tears - again.

1.6.6. Cost over life

That said, we are now entering an era when many heavy and light industrial and commercial vehicles, and leisure vehicles (though not usually mainstream transportation such as cars, buses, taxis) are gradually going electric for simple reasons such as cost over life, which is typically 30-35 per cent lower.

Later, we may enter an era when cars, buses etc. are mainly hybrid or pure electric without being smaller, more manoeuvrable, lighter, easier to park, more fun or offering other multi-faceted marketing propositions. However, the unimaginative approach is likely to be more expensive and protracted, more difficult to forecast and less certain of success.

1.7. Profitability of EV businesses by type – results of our major survey

Profitability of EV companies varies widely. It gives some indication of future market strength at least in mature and maturing sectors (new market ventures tend to be more generally unprofitable). We have surveyed over 3,000 companies for the profit of their EV manufacturing activity in the period 1999 to 2005. The figures we give below relate to "normal" years 1999 – 2001. In 2002/2003 there have been anomalously lower numbers of profitable companies in saturated sectors because they were hostage to poor national or manufacturing economies. 2004/5 saw reversion to trend.

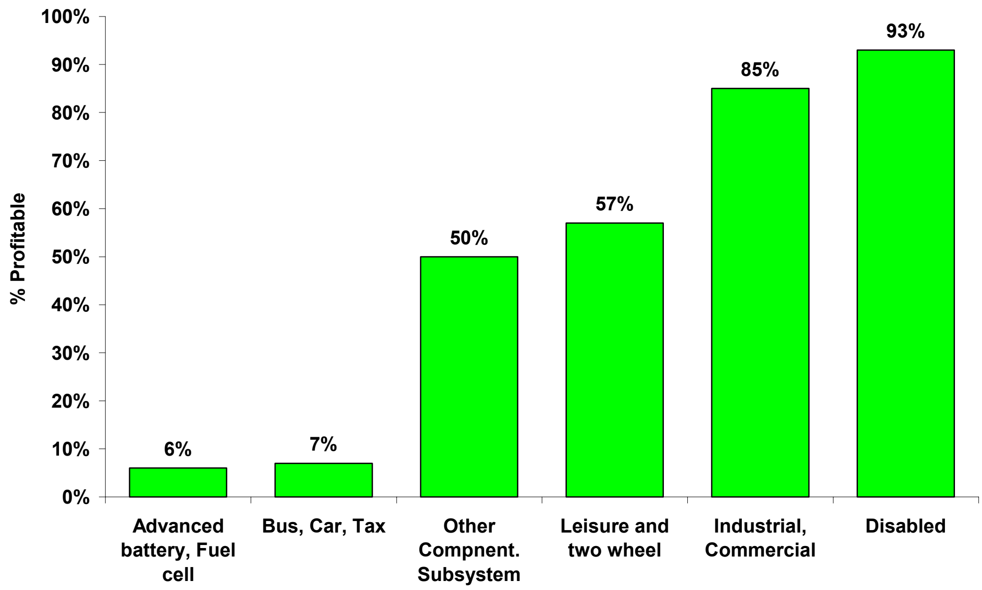
1.7.1. Applicational sector and product positioning are key

There is a very marked correlation of EV profit with applicational sector. Choice of applicational sector is probably the single most important decision of anyone in or entering, the EV industry, according to these results. Most industrial, commercial and disabled EV manufacturers and sales operations make a profit from this as do most service providers to the EV industry. Of the services, vehicle maintenance is exceptionally successful. This was shown to be the case from our market sample of independent maintenance businesses. In addition, over 30 sellers of disabled and industrial EVs said maintenance was a major contributor to profit. None said it was an impediment.

1.7.2. Profitability of EV manufacture by sector

The profitability by manufacturing sector is given in figure 1.4.

Fig. 1.4 **Percent of EV manufacturing operations that are profitable by sector**



Source: IDTechEx

Nearly all makers of advanced batteries, advanced fuel cells and drive trains lose money on this activity as do almost all manufacturers of on-road multi-person EVs. No one has ever made money out of pedestrian-operated EV domestic lawn mowers. (Large commercial lawn mowers for golf courses, hotels etc, are very different products, first launched in 1998 – 2000. Textron claim theirs is profitable). These differences are extreme enough to be meaningful. Contrast vehicles for the disabled which are often sold at prices treble the already highly profitable price charged to the intermediary by the manufacturer. No other EV selling in volume has these mark-ups. It is so price insensitive that mail order prices are often much higher than shop sale.

57 per cent of the manufacturers of leisure and two wheel EVs prosper but the other half is heavily biased towards very new participants. New manufacturers of 2 wheelers are appearing at a frenetic rate. This means that the percentage that are profitable will be slow to improve even though the business is booming in East Asia.

Less than half the manufacturers of conventional components and sub-systems made money in our survey, partly because many only have them designed into EVs that are commercial failures such as most EV road cars. That still leaves many successes and several with EV component sales of at least $100 million yearly.

1.7.3. Profitability vs barriers to entry

There is no correlation between barriers to entry to a given applicational sector and profit. For instance, vehicles for the disabled, such as EV wheelchairs and 4 wheelers are relatively easy to make, there are few if any approvals to obtain and they are easy to ship. A new entrant can therefore arrive very quickly, yet this sector has one of the highest percentages of profitable manufacturers. Disabled EVs are sometimes made by not-for-profit organisations or hired free in cities, deterring individual purchases, yet the businesses manufacturing, selling and renting them are still booming.

1.7.4. Profitability vs strength of consumer proposition

The primary reason why most participants make money in manufacturing certain EVs and not others seems to be in the strength of the consumer proposition which is typically multi-faceted and powerful in sectors where profits seem "easy", and the opposite where profits are rare. Consumer wants particularly well satisfied by EVs, and leading many participants to profit, differ radically between the applicational sectors.

By contrast, the consumer proposition presented by most manufacturers of multi-person EV road vehicles is weak and lacking in breadth. This is why model after model has failed to sell in volume over recent decades. Others in our survey have yet to offer their product commercially and so they lose money for this reason alone. Similarly, most of the manufacturers of advanced batteries and fuel cells in our survey are either not trading or are barely trading. They neither expect nor obtain a profit at this stage. However, all this is changing with the rapid introduction of hybrids, where vehicle and component makers are near to making good returns.

1.7.5. EVs as an enabling technology

The most powerful business cases are where EVs are the means to an end not the end in itself. Many successful categories of EV are absent from EV magazines, conferences and exhibitions, most of which could be re-titled "The Unprofitable Part of the EV Industry". You would look hard to find a vehicle for the disabled or a fork lift truck in most of them, for instance.

Another way of putting this is that EV capability is best seen as an enabling technology not a product.

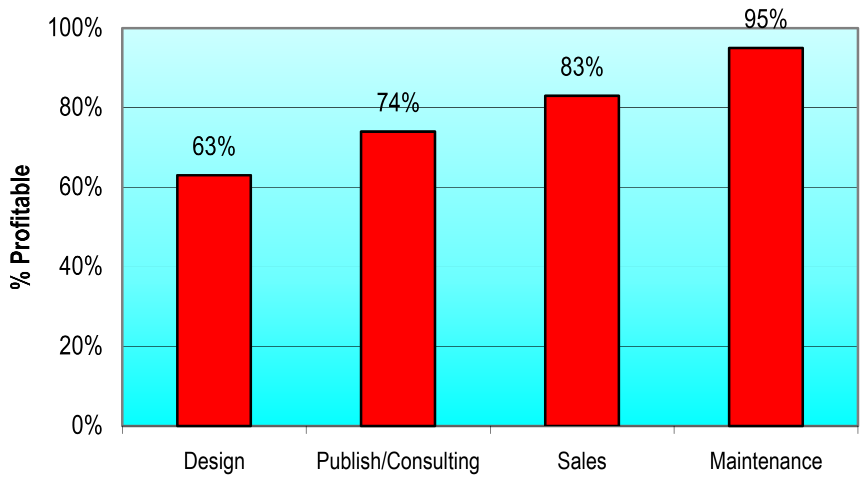
1.7.6. Profitability of EVs

Service sectors

It is easier to make money out of EV services than from manufacture. For instance, that is why Smiths Electric Vehicles in the UK has built their EV fleet management and fork lift maintenance divisions to be larger than their EV manufacturing activity, where they started. It is why Tennant, in the saturated market for EV floor care machines offers floor care services based on the machines. In 2003, it is why Textron, in the saturated market for golf cars, broadened its appeal by offering turnkey facilities management of all turf care and transportation in golf clubs.

In the service sector, maintenance of EVs is an area where most make money as is publishing, consultancy, analysis, public relations, show organisers, conference organisers and so on. This may seem surprising since this sector sees a lot of competition from not-for-profit organisations, from retired people seeking something to amuse them, to academia and government-private consortia. However, like vehicles for the disabled, it appears that the market demand and the close matching of supply to requirement, totally outweighs the negative factors. Training is a less forgiving sub-sector partly because many trainers concentrate on the unsuccessful on-road vehicles. Figure 1.5 gives service profitability by sector.

Fig. 1.5 **Percent of EV service operations that are profitable by sector**



Source: IDTechEx

Design, development, contract engineering, testing and prototyping sees a more mixed profit picture probably because most of it is in support of the (so far) mainly unsuccessful multi-person road vehicle arena and some is on long timescales. Production equipment is profitably sold to the EV manufacturers that are trading strongly (disabled, industrial, commercial) and the manufacturers of EV components sold in volume.

Of all the service sectors, sales and maintenance are served by most companies and most of these tackle fork lifts or disabled EVs. The reason is that these have very local requirements: size and geographic reach bring few extra benefits to the customer. The result is a plethora of very small, usually profitable, sales and/or service companies.

1.7.7. Profitability as a function of business size

Overall, we found no correlation between profit and size of EV operation in new markets. Within given applicational sectors there was correlation in some cases showing the sectors represent some barriers to entry. The newer application sectors for EVs such as most leisure EVs show little trend of profit with size as yet 2004 saw stronger signs of a shakeout in disabled EV manufacture with the largest, such as Pride, Invacare and Pihsiang strengthening their position and new niche operators thriving.

More mature applicational sectors show a particularly strong shakeout into very large and very small, the most progressed in this respect being manufacture of warehouse and allied EVs, notably fork lifts, where some very large players dominate such as Toyota (including year 2000 acquisition BT Industries), Nissan, Jungheinrich, NACCO, and Linde. Very small niche operators also do well but companies in the middle collapsed financially.

Services to the EV industry show no correlation of profit with size. Most operate internationally, from book publishing to design engineering and vary from individuals to operations with tens of millions of dollars of EV related sales yearly. Percentage profitability varies randomly with size.

Car manufacturers cannot always control the EV business

This illustrates that even where big becomes beautiful it is not the established car makers that always win. The same can be said of the winners in golf cars - Textron, Ingersoll Rand and Yamaha, where none are major car manufacturers, though all are quite large businesses because of other activities. In addition, we must note that being a leader does not prevent losses. Even companies with optimal market positioning can be wastefully managed.

1.7.8. Profitability of EV component manufacturers

Components manufacturers make or lose money at all sizes though there is a trend towards most traction batteries being made by volume producers because they are such a big business. The situation is summarised in table 1.3 showing dominance of Japanese companies, though, in 2005, there is evidence of a Korean challenge to this. As we noted, several EV components manufacturers are larger than most EV manufacturing operations because they differ in selling internationally and across many applicational sectors i.e. their batteries, motors, electronics, chargers etc. may be seen on vehicles for the disabled, industrial, leisure and other EVs.

Table 1.3 **Study shows Japanese battery dominance**

Cause	Japanese aggressive commercialisation of HEVs has also put the Japanese automotive battery industry in the lead with development and marketing.
Trend	Trend likely to intensify especially in the areas of nickel metal hydride (NiMH) and lithium ion (Li Ion).
Scope	Also improving lead acid battery chemistries, once where Europe and US held strong positions.
Examples	Key manufacturers include: Sanyo Matsushita (Panasonic)

Source: After 2002 Advanced Automotive Battery Industry Report, EVAA

1.7.9. Size bias of profitability analysis

In general, companies were more willing to indicate whether they were EV profitable than to give the size of their EV-related sales. However, we believe that no more than twenty of the thousands of profit-seeking participants in the global EV industry are responsible for at least half of the money the industry is earning ex factory. Most have production of other EVs as well. Toyota, by far the world's largest EV manufacturer, has more than double the EV sales of its nearest competitors and is rapidly widening the gap. This is partly because Toyota is not sitting almost exclusively in heavy industrial, like these companies, but already makes EV cars, vans, buses, disabled vehicles etc.

We believe that the industry, and our sample in the profitability surveys, are heavily biased towards companies of a few million dollars sales down to none. All this conspires to limit our ability to identify trends of profit with size and it is evidence of a emerging rather than mature industry with the exception of fork lifts and golf cars and one or two mature niches.

1.8. Basis of forecasts of market value

All forecasts in this report that are value based use figures that are ex factory. They are "manufacturing" market figures and rankings are also on this basis. Thus companies largely selling other people's EVs are not ranked highly in this report.

2. Heavy industrial EVs

2.1. Definition

Trade associations of the industry concerned with fork lift trucks, stackers and similar off road vehicles choose to refer to them as "Heavy Industrial". The term "Heavy" can be something of a misnomer. For instance, a road truck can be far heavier than a fork lift truck but it is not included in the definition. As we said in the Introduction, "heavy" refers to heavy lifting or towing usually with onerous duty cycles.

We try to respect the convention in this report. In doing this, we acknowledge the appreciable number of companies that specialise exclusively in this sector. Their design skills relate to use of counterbalances for heavy loads and delivering high levels of traction often in small spaces. Their vehicles usually position products over short distances in factories, warehouses and docks by towing or lifting. For the future, we should also include earthmoving equipment because that is now becoming a target for EV technology as well – hybrid followed by fuel cell technology will offer many advantages.

2.2. Market drivers

Leaders in heavy industrial EVs produce many tens of thousands yearly and sell them globally, earning a similar amount from parts and maintenance as from sale of the original equipment. The industry has seen major consolidation in the last ten years with Toyota and Linde growing to respectively over $1.5 billion and over $1 billion in sales and support of heavy industrial EVs. The market size now depends on the size and growth of national economies and manufacturing industry, because it is quite large and saturating.

2.3. The major players shakeout

There were eight major players in heavy industrial EVs a few years ago but one entered receivership. There are now about six major players in heavy industrial vehicles in the world and the number may drop to four or so in the next few years, driven by the need to purchase parts in volume, promote global brands, support major customers worldwide and ride out recessions. The recession in manufacturing industry in the West and Japan in 2001/2003 caused even some of the leaders to make losses though others managed better. However, 2004 was a good year for nearly all of them. Success calls for manufacturing or assembly near to the major markets and support centres that are even more widespread. That usually means acquisitions. Those specialising in EVs seem to have done particularly well, notably Crown Equipment and BT Industries, now owned by Toyota. As predicted by marketing theory, as the market saturated, those with neither niche nor volume operations, but sitting between, have done particularly badly.

Some innovation

After exhibiting all the features of a maturing industry in recent years - profit and cash generation, consolidation, modest innovation, there is now a little more innovation being employed in the battle for the end game. Examples are new ergonomic concepts such as general purpose vehicles for positioning people at different heights, modules converting machines to perform different functions and the use of brushless motors for reliability and silence. Cosmetic design is being changed more frequently as well.

2.4. Profiles of some leaders and potential leaders

2.4.1. Linde, Germany 2004 report, 2005-7 plans

Linde AG is a large German company that is the world's largest manufacturer of non-road industrial trucks. The 2004 Linde Annual Report said:

"The year 2004 was a record year for the entire industrial truck industry, so it is expected that the markets will be somewhat quieter in the current fiscal year. However, we anticipate that 2005 will see an increase in sales in our Material Handling business segment and a significant improvement in earnings based on TRIM.100, our program for process optimization.

In 2004, the overall market conditions for the Material Handling business segment improved considerably. Demand for industrial trucks has increased across the world. Most of the growth in the year was generated in the regions of America and Asia.

Our Material Handling business segment also performed well during the year, supported by the dynamic growth in the world market for industrial trucks. Sales reached €3.372 billion, which represents a 10.1 percent increase over the previous year (2003: €3.063 billion). Operating profit rose 22.4 percent to €191 million (2003: €156 million).

In Europe, the most important sales market for Linde, the business segment achieved double-digit growth rates, with the good performance due mainly to above-average growth in Eastern Europe.

The service business is becoming increasingly important and now accounts for around 40 percent of total sales.

In order to benefit even more from dynamic market trends, especially in China, we are planning to launch a second brand of forklift trucks there."

Table 2.1 **Financial results of Linde Material Handling Division for financial year 2004**

MATERIAL HANDLING (€ MILLION)	2004	2003
Sales	3,372	3,063
Incoming orders	3,442	3,116
EBITA before special items	191	156
EBITA	191	96
Capital expenditure (excluding financial assets)	428	411
Number of employees	18,878	17,932

Source: Linde

"Our internal optimization program TRIM.100 was successful in 2004. We will continue to devote our efforts towards achieving further improvements in our processes and cost structures.

In fiscal 2005, therefore, we plan to launch a follow-up program to develop the Material Handling business segment, foster its growth and increase its efficiency. The aim of this program is to identify additional opportunities for synergies across the brands at the same time as achieving further cost reductions. Our strategic objectives include the expansion of our activities in Asia and of our service business. The program should lead to cost savings of €150 million by 2007."

2.4.2. Toyota Industrial, Japan/Europe 2005

Toyota is world leader in Heavy Industrial EVs with strong manufacturing in Japan and Europe. It does not split out its figures for industrial vehicles let alone electrical ones but in tables 7.6 and 7.7 in the Cars chapter we estimate the EV figures. 2005 is seeing about 200,000 EVs sold by Toyota. Figure 2.1 shows a typical Toyota industrial EV in 2005.

Fig. 2.1 **A typical Toyota industrial EV in 2005.**

Source: Toyota

2.5. Listing of manufacturers

The following table 2.2 gives examples of manufacturers of heavy industrial EV trucks:

Table 2.2 **Twenty examples of manufacturers of heavy industrial EVs by country**

COMPANY	COUNTRY
Caterpillar	US
Clark Material Handling Co	US
Crown Equipment Corp	US
Honda	Japan
Hyundai	Korea
Jungheinrich	Germany
Kelvin Engineering	UK
Komatsu Fork Lift Co	Japan
Linde	Germany
Lödige Fordertechnik	Germany
Mitsubishi	Japan
Nichiyo	Japan
Nacco Industries	US
Nissan Industrial	Japan
Partek (inc. Kalmar)	Finland
Schaeff	US
Southwark International Group	US
TCM Toyo	Japan
Toyota / BT Industries	Japan
Wilmat Handling	UK

Source: IDTechEx

2.6. Market size

“Powered industrial trucks” is a term used to describe off road equipment from heavy earth-moving machines to small fork lifts. The place of EVs within this has been as shown in table 2.3:

Table 2.3 **Percentage split of global manufacture of heavy industrial trucks**

INDUSTRIAL VEHICLE TYPES MANUFACTURED WORLDWIDE	PERCENTAGE OF TOTAL OUTPUT		
	1997	2005 FORECAST	2015 FORECAST
Combustion-engine trucks	44%	39%	9%
Other heavy electric industrial	-	-	30%
Electric fork lift trucks	19%	25%	25%
Electric pedestrian trucks	25%	25%	25%
High-level narrow-aisle lift trucks, electric	12%	11%	12%

Source: WRL and IDTechEx

The regional split across the world is shown in table 2.4.

Table 2.4 **Distribution of trade volume for heavy industrial EVs**

	1998	2001	2005 FORECAST	2015 FORECAST
Europe	41%	36%	33%	30%
North America	21%	21%	21%	18%
Asia and other	38%	43%	46%	52%

Source: WRL, Linde, IDTechEx

The league table of powered industrial trucks (EV and ICE) is shown in table 2.5.

Table 2.5 **Global league table of powered industrial truck manufacturers 2005 by value of sales**

	COMPANY	BASE	BRANDS
1	Linde	Germany	Linde, Still, Fiat OM, Baker Fenwick, Wagner, Saxby
2	Toyota	Japan	Toyota
3	Jungheinrich	Germany	Jungheinrich, MIC, Boss, Steinbock
4	Nacco	US	Hyco, Deca, Hyster, Yale, Sumitomo
5	Crown	US	Crown

Source: IDTechEx

Table 2.6 shows the ranking in 2005 for electric industrial vehicle sales

Table 2.6 **The ranking in 2005 for electric industrial vehicle sales**

RANK	COMPANY
1	Toyota
2	Linde
3	Crown

Source: IDTechEx

There are about 250 manufacturers of heavy industrial trucks worldwide but most do not make EVs. Between them they will make about 700,000 trucks in 2005. Most participants have under $20 million sales yearly. Mid-sized companies are becoming rarer. This industry is characterised by a dash for market leadership as the market matures, with frequent purchases of competitors. Many participants seek global reach with manufacturing in major markets. Some promote a global brand to support this. Others diffuse their image over many brand names and even have competing subsidiaries. Some specialise in the largest or the smallest machines, in ICE or EV power.

2.7. Market forecasts by technology 2005 to 2015

Tables 2.7, 2.8, 2.9, 2.10 give our projections.

Table 2.7 **Heavy industrial EV global market at ex factory prices 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number '000	275	340	355	370	385	400	453	507	560	621	703
$ Unit value	14,053	14,435	14,630	14,105	13,882	13,325	14,047	14,611	15,073	15,532	16,143
$ billion value	3.15	4.91	5.19	5.22	5.34	5.33	6.36	7.41	8.44	9.65	11.35

Source: IDTechEx

Table 2.8 **Heavy industrial pure EV (battery-only) manufacturing market projection 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number '000	270	280	285	290	295	300	303	307	310	316	323
$ Unit value	11,100	11,100	11,100	11,100	11,100	11,100	11,100	11,100	11,100	11,100	11,100
$ billion value	3.00	3.11	3.16	3.22	3.27	3.33	3.36	3.41	3.44	3.51	3.59

Source: IDTechEx

Average prices hold up because erosion of the price of today's models is offset by larger vehicles becoming EVs. These will include some used in earthmoving and some towing aircraft plus very heavy duty open air lifters.

Short term recovery from economic setbacks occurs in the West then medium term growth largely happens in East Asia at lower prices.

Hybrid EVs became available in 2003, mainly into cars. Later fuel cell pure EVs may also succeed in replacing ICE. This is speculative as yet. These trends are given in tables 2.9 and 2.10

Table 2.9 **Hybrid heavy industrial EVs 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number '000	5	60	70	80	90	100	150	200	250	300	350
$ Unit value	30,000	30,000	29,000	25,000	23,000	20,000	20,000	20,000	20,000	20,000	20,000
$ billion value	0.15	1.8	2.03	2.0	2.07	2.0	3.0	4.0	5.0	6.0	7.0

Source: IDTechEx

Table 2.10 **Fuel cell heavy industrial EVs 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number '000	-	-	-	-	-	1.0	1.5	2.5	2.7	3.0	5.0
$ Unit value	-	-	-	-	-	30,000	30,000	29,000	28,000	27,000	25,000
$ billion value	-	-	-	-	-	0.03	0.045	0.073	0.756	0.81	0.123

Source: IDTechEx

Technological trends

We can expect at least 70 per cent of fork lifts to be pure EVs in the rest of the world soon, just as they are in Europe today. Fleet management software is becoming very important in optimising maintenance, downtime and utilisation. Better utilisation of space is key in future:

- Increase of manufacturing space.
- Decrease in warehousing space.

That means EVs because they are much more space-efficient. Indeed, even smaller indoor material handling EVs have been developed by Crown.

Space and safety

In the US, space and safety are the primary retail and warehouse issues with more stand up riders, "walkies" and pallet trucks being adopted. There is no move to global practice in that the Europeans still favour sit down industrial trucks. However, one global trend is increased productivity from faster travel and lift speeds made practicable with EVs.

The new Crown ST/SX 300 series walkie stacker is shown in figure 2.2.

Fig. 2.2 **The new Crown ST/SX 300 series walkie stacker**

Source: Crown

Sensors are increasingly fitted to recognise dangerous operator conditions or situations and trucks increasingly have electronics in them that automatically monitors, and if necessary "rewrites"

Radio Frequency Identification (RFID) tags on pallets or products carried. The more reliable brushless DC and AC traction motors are beginning to be seen in heavy industrial trucks.

Batteries improve

Batteries are improving and, in the next few years we shall see the $2.2 billion 1999 market for traction batteries for all EVs growing slower than the vehicle market because fork lifts dominate that battery market and it will no longer be necessary to have 3 sets per fork lift for intensive usage (one in use, one cooling, one charging).

2.8. Future challenges and opportunities

The future industry challenges include:

- Reducing need and frequency of charging and changing batteries.
- Reduction of accidents through training and product development.
- Load wheel and tyre life.
- Continued development of sensors/microprocessor technology.
- Alternative energy sources such as fuel cells, now being trialled.

But the future is bright for the electric lift truck industry because of:

- Environmental concerns.
- More efficient use of energy.
- Operator friendly (less noise, vibration).
- Cost of use/ownership is less.
- More effective with space utilisation.
- Future electronic componentry advances will widen the gap against internal combustion.
- Legal push. More and more countries and states are making the environmental benefits of electric heavy industrial vehicles such as fork lifts a legal requirement. Europe is ahead of the US and most of the rest of the world in this respect. Nonetheless, California is the first state to mandate the use of electric and reduced-emissions lift trucks. The California Air Resource Board (CARB), which monitors air quality, adopted such a measure in 2004. The board proposed a six-year implementation period beginning in 2006. The current version of the plan actually is a melding of two proposals, LSI-2 and LSI-3

Potential sales growth of heavy industrial vehicles mainly lies outside fork lifts and today's candidates for electrification. This is because hybrid technology is of great relevance to heavy outdoor vehicles and it is likely to be eagerly adopted by manufacturers such as caterpillar that currently have no electric vehicles in their range because of the need for high power delivery for long periods of time and long range.

3. Light industrial and commercial EVs

3.1. Vehicles covered in this chapter

Light industrial and commercial EVs is a very diverse and poorly documented sector. That is why its size and potential are grossly underestimated. There are hundreds of manufacturers in this sector. Some more join every year while a few disappear. However, consolidation of the industry continues, with large players buying small ones, so the overall number of independent players has stabilised. For example, Taylor Dunn bought United Tractor and Tiger Manufacturing in 2002.
Light industrial EVs do not have large counterweights or position very heavy loads. Commercial EVs include buses and other vehicles that are the basis of a business in their own right, notably transportation.

3.1.1. Light industrial and commercial

We lump together our statistics for light industrial and commercial because there is a grey area between them. For instance a people carrier may be used in a company campus or to ply for trade in a city. Some commercial vehicles are used intensively however. Light industrial versions are light duty in being used less-intensively. Light industrial and commercial EVs include both on and off road vehicles typically owned or leased by companies rather than private individuals but we exclude leased cars as all cars are dealt with separately. We also separately discuss leisure EVs owned or leased by companies such as go karts and golf cars.

Figure 3.1 shows the new E150 battery driven pure EV delivery vehicle from VXL Automotive in the UK.

Fig. 3.1 **The new E150 battery driven pure EV delivery vehicle from VXL Automotive in the UK.**

Source: VXL Automotive

3.1.2. Examples

Examples of light industrial and commercial EVs discussed here are:

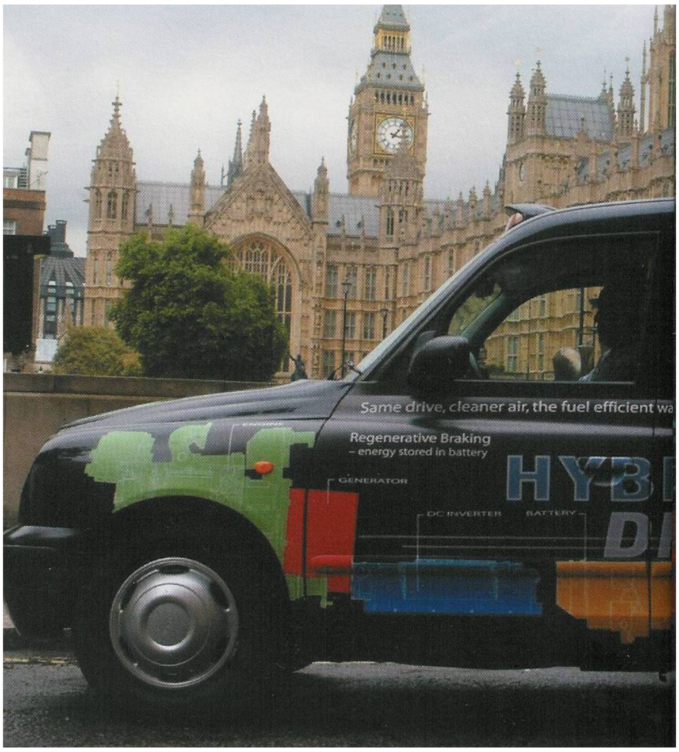
- Pedestrian-operated stair climbers and light load carriers such as those used for postal delivery on foot.
- Automatic guided vehicles (e.g. serving production lines).
- Trash bin collectors.
- Light duty tugs.
- Mobile powered access platforms, light cranes etc.
- Workmen's vehicles indoor and outdoor.
- Floor cleaners, wet scrubbers, polishers.
- Ice rink preparation machines.
- Airport ground support equipment from aircraft pushback tugs to mobile weather protection, steps, bridges, liquid removal/replacement, people movers, baggage trains etc.
- Vans, pick up trucks and larger on-road trucks.
- On-road delivery vehicles for factories and shops.
- Taxis, buses, trams, road trains

Of course, only those vehicles with electric traction power and carrying their power supply are included. Light industrial and commercial EVs are used both on and off road, indoors and out. Most of the EVs in this sector are either light duty off-road industrial vehicles or intensively used on-road commercial vehicles.
They can be divided by price. Most are under $10,000 ex factory but airport electric vehicles, buses and later road trucks, most of which are at higher prices, will drive market growth.

3.1.3. Case study: eMercury taxis in 2005

Figure 3.2 shows the new TXII hybrid London taxi developed by LTI with Canadian control software specialist Azure Dynamics. It is in concept stage but promises 35-40% fuel saving. It employs a 1.4 litre PSA-Ford common rail diesel with an electric combined starter-generator which is initially lead acid but will be NiMH in production. The traction motor is 67 kW.

Fig. 3.2 **The new TXII hybrid London taxi developed by LTI**



Source: LTI

Modec Ltd has bought the rights to a pure electric delivery van developed by LTI. It uses Azure Dynamics control software and Zebra nickel sodium chloride batteries. It was launched in 2005 and 1000 are expected to be sold by year end with 1500 sold in 2006, representing breakeven.

3.1.4. Heavy and light

Most of the heavy industrial EV companies usually make, or at least sell some light industrial EVs. Those making golf cars do variants for light industrial and commercial tasks such as moving the disabled in airport terminals and these are in our definition. Then there are the large number of companies specialising in light industrial and commercial vehicles.

In 2005, small EV trucks for 1 to 1.5 tonnes are a hot sector, with several new product launches.

The US military is said to be the world's largest owner of electric vehicles but most of these are standard airport ground support equipment and standard off road people movers etc. so they come in this light industrial and commercial EV section.

3.1.5. Major subcategories

To make sense of this diversity, we highlight the following sub-categories as particularly important.

- Pedestrian-operated EVs.

Pedestrian-operated EVs are extremely varied in type, manufacture and application. We deal with the lighter ones here. Some take loads up stairs or move tools in production between machining centres. Others are access platforms, cranes etc. Zap have a pedestrian-operated "silent backup power supply" that retails for $3,500 to the general public. This is a heavy bank of batteries that has battery traction power for a pedestrian to take it to where it is needed.

- Small tugs, workmen's vehicles, AGVs.

Small tugs and workmen's vehicles are also made by a significant number of companies. Some are variants of golf cars, others variants of supermarket vehicles for the disabled but most are custom made. Many are used in airports earlier but here we consider all other applications, varying from railway and bus stations to hotels, educational campuses, museums, theme parks, hospitals and large buildings notably in the US.

- Automatic guided vehicles (AGVs).

Automatic guided vehicles fetch and carry in factories and warehouses and about ten companies make most of these in the world. Their unit prices are $2-5,000 rather like the small tugs and workmen's vehicles, so this subcategory, with about 10,000 made yearly worldwide may be a $35 million market at ex factory prices.

- Floor preparation.

There is a potential US demand for battery powered floor care machines of $250 million yearly according to Tennant, the leader in this market sector. A D Little, in a study commissioned by EPRI, found electric floor sweepers/cleaners already to be the third biggest EV market in the US after heavy industrial and golf cars. Traction powered grinders and polishers for the construction industry also come in this sector as do ice rink preparation machines (a few hundred sold yearly). We believe that 5-10,000 floor preparation EVs are made worldwide and sold at an average price of $4,000. About 6 companies make the bulk of these. Some are pedestrian-operated.

- Rider-driven light industrial.

These are used in an immense variety of locations such as hospitals, railway stations, parks and leisure complexes. The driver travels on the vehicle. With an access platform it may be the driver who is lifted high to carry out the work. Most rider-driven light industrial vehicles are used off road.

3.1.6. Automatic Guided Vehicles (AGVs)

AGVs are not a large or rapidly growing market: there are other ways to automate factories and use in offices, postal sorting etc. is limited. They can last at least ten years before needing replacement. The number of factories in the world is not growing strongly anyway.

3.1.7. AGV people movers

However, AGV people movers that are EVs are starting to appear. The magazine Industrial Utility Vehicle reports as follows:

"Frog Navigation Systems has created People Movers, fully automated minibuses. Excellent for short distances, they offer transport on demand, eliminating long waiting times at areas such as Amsterdam Airport, where People Movers are in operation.

The electrically driven minibuses without driver and physical guidance are computer controlled and ideally suited as short distance feeders for public transportation networks.

Automated people mover systems like the Park Shuttle system have many advantages over manual controlled systems and over non-free ranging systems like conventional rail bound applications, these applications are shown in figures 3.3 and figure 3.4:

- Simple infrastructure.
- No drivers required.
- System flexibility: easy to expand.
- No air pollution: Electrically driven vehicles.
- Flexible vehicle routing: vehicles are not rail bound.

The FROG Navigation Kit can be integrated in virtually any vehicle and can transform it into an intelligent Free Ranging AGV, so companies are free to stick to their own vehicle supplier.

Project Rivium's FROG powered vehicle

To illustrate Frog Navigation Systems equipment comes Project Rivium, a new way to travel quickly and conveniently to and from Rotterdam's business park Rivium. Traffic jams near Rivium have long been a problem in Rotterdam, but now travel in and out of the business park is possible in five minutes.

Fig. 3.3 **Frog AGV people mover EV**

Source: FROG

To transport people in and out of the park, as well as transport them in from the parking lot to the terminal in Amsterdam's Schiphol airport, Frog re-designed their transport-toting automated guided vehicle (AGV) with the ability to haul people as well.

Project Rivium's AGV can transport anywhere from 20 kilos to 50 tonnes. The vehicles travel at 25kph and are electronically powered by the FROG system (Free Ranging on Grid), which consists of transponders which are embedded below the road surface 3.2 – 4.8 metres apart from one another".

Other low growth or no growth sectors include trams, milk delivery vehicles (UK, Japan) and battery-operated small road trains.

3.1.8. Airport EVs - the largest category in light industrial

Airport EVs include Ground Support Equipment dealing with aircraft services and transporting passengers on the "airside" plus vehicles used in the terminals and to serve the terminals such as adapted golf carts to deliver disabled passengers and special workmen's vehicles for use inside or outside buildings. There are special EV buses for both landside and airside. Airport EVs are mostly off road and are mainly mid-priced, so we discuss them further in section 3.4.

3.1.9. Commercial on-road vehicles

These are buses, taxis, trams, people movers, road trains, and other transport that is usually on road, though some operate both on and off road. However, the numbers in operation are small, though unit price is usually large and the sector is growing steadily. Many hybrid EV or fuel cell EV buses cost $250,000 or more.

US Federal Transit Administration program manager Shang Hsiung said in 2002 that, "There are approximately 316 battery electric and hybrid buses and trolleys in operation throughout the US."

Figure 3.4 shows two buses in Brazil using the locally made Eletra hybrid power trains. www.eletrabus.com.

Fig. 3.4 **Two buses in Brazil using the locally made Eletra hybrid power trains.**

Source: Eletra

3.2. Market drivers

Light industrial EVs typically replace human effort (and often associated non-vehicle aids) or make new things possible. Commercial EVs often directly replace ICE. For example powered access platforms replace scaffolding and ladders with something safer and quicker to use indoors, usually where ICE was never an option, and usually save cost as well.

Sometimes EVs in this sector replace ICE vehicles because of pollution laws or the desire of a company to be "green". Frequently cost is saved as with postal deliveries in New York, where electric vans are much cheaper to own than ICE vans.

The fact that electric motors can be stopped and started very frequently without wearing out or failing is often a benefit. No idling is needed : that means a saving in power consumption, noise and pollution. However, it is difficult to generalise across a sector with the greatest fragmentation and largest variety of existing and new applications and reasons for adoption.

3.2.1. Light duty

Unlike the heavy industrial sector, many light industrial and commercial EVs are not used intensively - not the continuous two or three shift working of many heavy industrial vehicles with high power delivery and duty cycles. Where long range is required, hybrid technology is used, notably with many commercial vehicles. This means that manufacturers of "light" vehicles do not usually match their income from sale of vehicles with income from (frequently needed) spare parts, maintenance and other services. Light industrial vehicles never need one set of batteries cooling down and another recharging while the third set is in use. Customisation is much more common in light industrial vs heavy, though this is often carried to excess, with high costs and sub optimal reliability resulting.

3.2.2. Heavy duty

Heavier duty cycles are experienced by buses and trucks. Here the market drivers are better fuel economy and cost over life and need for reduced pollution. Some credibility is coming to hybrid technology in powering this change because innovation is rapid and well funded.

For example, in 2002, Japan's Nissan Diesel Motor Company introduced a commercially available hybrid EV with a diesel engine paired with an electric motor and a capacitor. The 'Capacitor Hybrid Truck' is a hybrid version of the company's Condor truck. Its 'Super Power Capacitor' stores twice as much power as a conventional capacitor, storing energy when the truck slows down, improving the efficiency of the vehicle's regenerative braking system. The electric motor powers the truck during start-up : the diesel engine takes over when the vehicle reaches constant speed. Nissan Diesel claim that the Capacitor Hybrid Truck reduces nitrogen oxide emissions by 50 per cent and carbon dioxide emissions by one third.

The hybrid truck was available in two models from 2003 but is more expensive than conventional diesel trucks, costing nearly $120,000. The automaker expected to sell only 30 Capacitor Hybrid Trucks annually.

On the other side of the world, the Paice Corporation hybrid EV powertrain technology known as the 'Hyperdrive' system, is expected to be cost-competitive with conventional powertrain technology, providing significant gains in fuel efficiency and vehicle performance, as well as reductions in emissions of harmful air pollutants.

"Unlike hybrids on the market today, the Hyperdrive powertrain is well-suited for the large cars, sport-utility vehicles, minivans, and light trucks that many Americans want," said Paice director Bob Templin. "We believe it is only the hybrid drive system available today that can be commercially produced in large volumes and be successful in the marketplace. That is because it can deliver high fuel efficiency and also meet the needs and desires of consumers and automakers for performance and cost."

Paice plans to make the technology available to automakers worldwide.

We now segment the light industrial and commercial sector in a way that is more amenable to forecasting – by unit price.

3.3. Low cost light industrial and commercial EVs

These are priced at $1,000 to $12,000 in the main. They include pedestrian-operated vehicles, workmen's runabouts, trash bin collectors, light duty tugs for collecting supermarket trolleys, air baggage etc., floor care machines, automatic guided vehicles and simple mobile platforms. However, car-sized buses for developing countries can be in this category.

3.3.1. Very small buses

In the West and East Asia, small pure EV buses have some modest success. In Vietnam, for example, manufacturer Dang The Minh produced five low speed 12 seat electric vehicles and they are making 50 in 2005 The pleasure of electric motoring is readily available and affordable in Nepal, where hundreds of battery-operated vehicles are purring around Kathmandu. These three-wheelers are mainly used as mini-buses which seat ten passengers in the rear and one beside the driver. Six-seater models suitable for private use are also available as a cost of around $7,000. They have a range of around 65 to 70 kilometers per charge and their maximum speed is 25 mph (40 kph), which can reduce with a heavy load on a steep incline to 15 mph (25 kph). The 72 Volt electric drive, including batteries is all imported from the USA except for the locally made forward/reverse switch, the vehicle is shown in figure 3.5.

Fig. 3.5 **Electric bus in Nepal**

There is steady growth in demand for EVs for local services, whether delivery by open road or estate management in leisure parks, hotels, university or other campuses where laundry must be delivered, grass mown, repair materials assembled and so on, preferably without noise or pollution. Postal deliveries are made using pedestrian EVs in parts of the UK, seated EVs in Finland and US: all just a beginning. However, these new applications are only a lesser part of the low cost EV market and the larger part – "wheelies" for factories is levelling then probably dropping in demand.

Market projections are given in table 3.1. They show saturation of the market because the end uses are growing modestly, if at all and the vehicles have very long life. Fairly robust growth in 2005 is really recovery after the setbacks in global manufacturing industry (a major user) in 2000/2001/2002.

Table 3.1 **Global market for low-cost light industrial EVs 2005 to 2015 by numbers, value and technology**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	120	130	140	150	150	150	150	150	150	150	150
$ Unit value ('000)	7	7	7	7	7	7	7	7	7	7	7
$ million value	840	910	980	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050
% hybrid	2	3	5	10	20	30	40	45	50	53	58
% battery-only	98	97	95	90	80	70	59	54	48	43	35
% fuel cell	–	–	–	–	–	–	1	1	2	4	7

Source: IDTechEx

3.4. Mid-priced light industrial EVs

These are priced at $12,000 to $100,000 in the main. Most airport EVs are in this category as are delivery vans and trucks. For example, Daihatsu of Japan is making a mild hybrid version of its Hijet Cargo. This delivery vehicle is designed to serve local delivery markets as a higher performance, lower emission counterpart to the gasoline version. Figure 3.6 shows the new pure electric delivery vehicle from Q Electric vehicles in the UK that runs on lead acid batteries.

3.4.1. QEV70 delivery vehicle

Fig. 3.6 **The new QEV70 delivery vehicle**

Source: Q Electric

The specification is given in table 3.2.

Table 3.2 **Specification of the new QEV70 delivery vehicle**

POWER	1.5 TO 120 KW
Load	1.5-3.5 tonnes
Wheel separation	Long or short
Battery voltage	72-288V
Top speed	65 mph or governed

Source: Q Electric

3.4.2. Airport EVs

EVs at airports include terminal vehicles used by workmen and to ferry the disabled and Ground Support Equipment (GSE) serving the aircraft on "airside". GSE is the largest category. They span our low and medium cost categories but most of the value is in the medium cost versions.

GSE by airline and airport

The top six airlines in the world each have 25,000 to 35,000 ground support vehicles. Airports and specialist ground handling companies also own GSE and hire it to airlines or drive it for airlines. 17 airports handle 50 per cent of world passenger traffic. There are 2000 airports worldwide with significant passenger traffic. However, GSE is needed at freight, industrial and military airports as well. Chicago O'Hare Airport has over 600 EVs for GSE just serving United and American Airlines.

US incentives

The US, which has most of the world's civil and military airports, has a strong incentive programme in place plus pressure under local pollution statutes. In addition, some airports such as Austin Texas are going electric to reduce cost over life.

For example the HR1000 FAAR reauthorisation allows ten civil airports to each obtain up to $2 million towards low emission vehicles. The HR1035 Airport Air Quality Improvement Act allows ten more to do the same.

Overall market

There are about 300,000 GSE vehicles in the world's airports today, including non-passenger airports such as military, freight and oil industry. Over $2 billion is spent yearly on GSE in normal years. In 2001 to 2003 it has been less, due to collapse in profits and diversion of funds to fight the new terrorism and tougher economic conditions. In 2005, a minority are EV, perhaps 100,000, up from 60,000 in 1999. These are replaced every seven to ten years. Therefore, with growth in base numbers and adding terminal (non GSE) applications, the sale of EVs to airport applications is about 15,000 units in 2005, up from 12,000 in 1999, constituting the largest single end use of light industrial/commercial EVs. However, stronger sales are resuming as the air industry recovers.

Airport applications widen

For the future, not only are a higher proportion of tugs etc. becoming electric but applications are widening from large pushbacks to passenger delivery buses on the apron beginning to go electric as well.

Two impediments

However, there are two impediments. These EVs cost more than ICE equivalents though they are cheaper over life and often outperform (smaller, more manoeuvrable etc). Also, gate electrification costs $50,000 to 130,000 per gate so up front costs are high. Therefore, although the case is well made that they cost less over life, purchasers can be tardy because of limited up front cash availability.

Market drivers

New York Kennedy and Newark airports in the New York area will no longer be given concessions on local pollution bylaws and must go all electric within a few years to conform. Twenty US airports have government support to go electric as we mentioned. Up to 10 per cent of airport air pollution is caused by airside vehicles and in public areas there is now far less tolerance of ICE surface cleaners etc.

At Sky Harbor Airport Phoenix Arizona USA, SouthWest Airlines has switched entirely to electric ground support vehicles. This is just one of many recent examples. For instance, United Airlines announced two years ago that it will go all electric for GSE at John Wayne Airport USA.

In addition, IATA forecast that the world will handle about 120 per cent more air passengers and 140 per cent more air freight in 15 years yet only 2 per cent more airports will be built in that time. The 17 airports that handle over 50 per cent of the world's air passenger movements today will have a particularly acute problem but all airports will have to move passengers several times faster with less space per operation. A part of this will be positioning staff and passengers more rapidly inside the airport buildings, where vehicles must be electric because noise and pollution make the gasoline engine impractical or illegal. Far more EV people movers will be needed.

Big cost savings

Meanwhile, as with fork lifts and golf cars, airports are often convinced that cost of ownership of their EV people movers, tugs, lifters, load carriers, runway pavement testers etc. is around 30 per cent lower than the ICE versions. Indeed, CALSTART point to lower fuel costs, no fuel used during idling time, one third the maintenance of conventional GSE and typical life of over 30 years.

Austin Texas International Airport is going all electric on this basis alone. Gatwick Airport, London is 55 per cent gasoline for airport airside vehicles because of reservations about performance but in 1999 they were told that they would not get the new terminal they want unless pollution is sharply reduced. An urgent meeting of EV suppliers was called. The new Hong Kong airport is all electric to control pollution from the beginning.

EPRI's work has shown that most of the existing vehicles at US civil airports could be economically electrified - with an average saving of $1,000 every year per vehicle. 53 per cent could be directly replaced, 24 per cent indirectly and 19 per cent converted. Only 4 per cent had no potential for electrification. Emissions from airside internal-combustion vehicles can be reduced by 90 per cent. The figures are even more compelling today.

3.4.3. Military demand

Military airfields also need EVs. Global demand for both together may grow to exceed 50,000 electric vehicles yearly (we exclude light rail systems etc. because these are outside our definition) and even approach $1 billion yearly in due course, about half the money spent on all forms of GSE. This may be 2010, airports then constituting 40 per cent of the $2.5 billion light industrial and commercial sector, on road commercial transport being much of the rest.

Due to the specialist nature of some airport EVs, such as those towing jumbo jets, the EV market value is higher than the numbers imply. Honda and less well known names make some airport EVs sold for $1 million each. There are about 40,000 GSEs in the world's major civil airports with one billion dollars spent replacing and extending this fleet every year. The airport sector could be moving from 10 per cent electric to 90 per cent. That means most of the 300,000 GSEs now in existence, plus the growth of at least 6 per cent yearly.

3.4.4. Sub-optimal supply

Many of the specialist vehicles will remain the province of specialist suppliers. However, overall, the airport EV industry is well behind most other major suppliers of EVs in three respects:

- Globalisation: The leaders in fork lifts, golf cars and disabled EVs sell globally. Airport EV companies mainly supply nationally.

- Standardisation: Those supplying fork lifts, buses, trucks, golf cars, disabled EVs and so on generally supply virtually the same product worldwide. Although all airports are much the same across the world and handle the same limited variety of aircraft, completely different designs of support vehicles are seen in different countries and even different airports to perform the same tasks. Even building major variants on a standard platform/chassis is rare.

- Consolidation: Whereas the market leaders in fork lifts, golf cars and disabled EVs have acquired many competitors and grown organically to the point where two to five companies supply 50 per cent of global demand, the airside airport vehicle industry is highly fragmented and a few minor mergers are only now being seen.

Putting this right will not be easy, but inevitably it will happen in order to improve quality and price (we project price reductions) and make radical design improvements cost-justify over appropriate volume runs. Inutsuka Manufacturing Co of Japan are one of the largest suppliers of Ground Support Equipment in East Asia, though their products are virtually unknown in the West. Managing Director, Akira Inutsuka says that it is tough to sell standard products to Asia in the current economic circumstances but they are now trying hard to achieve this.

3.4.5. Small orders

Sales of EV buses, trams and other large commercial transport vehicles have been in ones or tens at a time though US orders from government departments have recently been in hundreds in some cases. For example, the US Postal Service ordered 500 EV vans for delivery in 2000 at $21,000 each. Its board of governors approved a further order of 5,500 over a few years subject to certain conditions but there were delays. From 2003, Renault has been offering both hybrid and pure EV minivans branded Kangaroo but no large orders have yet been received. However, in 2004, China's leading auto maker FAW revealed plans for about 1000 diesel electric parallel hybrid 10-12 meter buses for the Beijing Olympics in 2008 and the World's Expo in Shanghai 2010. Enova Systems of the US is involved in a development agreement to supply the parallel hybrid drive system for test and demo buses after which the Chinese are likely to make everything.

3.4.6. Future trends

The easiest vehicles to substitute as EVs, in terms of design and cost-justification, are the lightest and smallest tugs, carriers etc. It as encouraged by some evidence of lower cost over life of the EV despite higher upfront cost. The financial problems of airlines put this on hold in 2001-2002 with the new terrorism diverting funds to security anyway, but the change resumed strongly in 2003. Small pure electric and various sizes of hybrid electric buses (mainly diesel) continue to grow from a tiny base.

Table 3.3 and 3.4 give our market projections of airport and other mid-priced EVs.

Table 3.3 **Global market for medium cost light industrial EVs 2005 to 2015 by numbers and value**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	10	11	12	13	14	15	16	18	20	22	25
$ Unit value ('000)	20	21	22	23	24	25	25	25	25	26	26
$ million value	200	231	264	299	336	375	400	450	500	572	650

Source: IDTechEx

Table 3.4 **Global market for medium cost light industrial EVs 2005 to 2015 by technology**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
% hybrid	10	15	20	25	30	35	40	45	50	53	58
% battery-only	90	85	80	75	69	64	59	54	48	43	35
% fuel cell	–	–	–	–	1	1	1	1	2	4	7

Source: IDTechEx

Delivery vans and trucks

The US Department of Energy (DOE) has provided up to $2 million for the US Postal Service's (USPS) efforts to deploy electric delivery vehicles. The agency said the funds will be used for testing, validation and information sharing. USPS hoped to purchase 500 light-duty delivery vehicles based on the Ford Ranger pure EV. That might have been followed by an order for 5,000 if all goes well but the program was put on hold. USPS has more than 207,000 vehicles in its fleet – the largest fleet in the nation. Many of these vehicles operate on alternative fuels such as electricity, compressed natural gas, ethanol and propane. USPS had more than 30,000 alternative fuel vehicles in its fleet by the end of 2001.

Peugeot Citroen, Europe's largest on road EV manufacturer, sold little more than 1600 EV vans and small trucks in France and Britain between early 1998 and mid 1999 though they had capacity for 10,000. In 2000, they celebrated making their 5,000th on-road EV but in 2005, sales had yet to take off..

3.5. High priced industrial and commercial EVs

The high-priced category is dominated by buses at $100,000 to $1.3 million.

To give some examples from the past, Orion Bus Industries built 125 hybrid EV buses for New York Metropolitan Transport Authority in 2000. In 2002 to 2003, nine European cities together took delivery of a $38 million order for 30 Mercedes Citaro fuel cell driven buses at around $1.25 million each – five times the cost of conventional buses. Similar things are happening in Japan.

US Federal Transit Administration program manager Shang Hsuing said in 2002 that, "There are approximately 316 battery electric and hybrid buses and trolleys in operation throughout the US". In 2003 this figure is passing 400 and the global figure will be around 800. They continue to include relatively small, lower-cost battery-only buses for short range and light duty plus large buses, which are hybrid or trials of fuel cells. Market growth by value is now concentrated on hybrids.

3.5.1. Large buses in the US and China

The market for EV buses in value terms is, and will continue to be, dominated by large hybrid buses. Led by the US, orders for these are increasing in number and size.

New York

In 2002, the largest order ever for EV buses was 300 buses at $340,000 each, the$102 million order being delivered to New York in 2003/2004. However, a major city typically has 2,000 to 6,000 buses, so one can see the potential. In 2004, that order was roughly matched by the value of one for 1000 lower cost hybrid buses in China.

Los Angeles
Los Angeles Mass Transit Authority bought 19 electric buses in 1999. In 2003, it purchased 72 compressed natural gas (CNG) hybrid electric buses. These were articulated 60 foot vehicles and they will be used on the San Fernando BRT line. Orders of this typical size continue.

China
In China in 2003, the government voted $106 million for development of electric and other alternative fuel vehicles, buses being a significant part of this.

"Developing electric vehicles is significant in the effort to save oil energy, minimise air pollution and to give an impetus to the development of the country's auto industry", said Ministry of Science and Technology official Li Jian.

Li noted that the government plans to use EVs for "transport services" when Beijing hosts the Olympic Games in 2008.

One report said "More than 12,000 electric buses will be available" but we heavily discount this figure in our forecasting. Another report has put the figure at 8000, in the form of hybrids.

3.5.2. ISE Research in 2005

ISE Research-Thunderbolt, Inc designs and makes EV drive trains. It has fulfilled a $3.1 million contract with New Jersey Transit to 'deploy a new generation' of hybrid electric transit buses. The buses are operated under the supervision of NJ Transit and ISE maintenance.

In 2005, New Flyer Industries delivered the first new gasoline hybrid 40-foot urban transit bus in Southern California to Long Beach Transit. The pilot bus delivery is the first of 76 in the initial production run to be delivered to Long Beach and other Southern California transit agencies. More than 100 transit buses using these quiet, ultra low emission drive systems will be operating in California cities from Sacramento to San Diego by the end of 2005.

Figures 3.7 and 3.8 show these vehicles.

Fig. 3.7 **Gasoline hybrid buses being sold using ISE drive trains.**

Source: ISE

Fig. 3.8 **The first new gasoline hybrid 40-foot urban transit bus in Southern California delivered by New Flyer Industries**

Source: ISE

In 2005, ISE Corporation (ISE) achieved another historical first by delivering the world's first transit bus using a Hybrid Hydrogen Internal Combustion Engine (HHICE) drive system. The HHICE system uses a variant of ISE's proven ThunderVolt® hybrid-electric drive system that generates power with a Ford hydrogen-burning internal combustion engine.

In 2005, another project for ISE is providing the drive train for the Entwistle MB4 tow tractor powered by a Lynntech PEM fuel cell.

3.6. Market projections 2005-2015 for commercial and high cost light industrial EVs

Our market projections include any other high-cost light industrial or commercial EVs that may emerge in later years. The largest segment after buses is likely to be large trucks but, for now, there is little being done to introduce hybrid trucks (pure EVs do not have the range).

The Natural Gas Fuel 2002 Fleet Survey found that the US Fleet sector is unwilling to transition to any alternative fuel vehicles (AFVs). AFV use had dropped from a high of 5.3 per cent in 1997 to 3.7 per cent in 2002. The barriers cited were cheap gasoline, lack of access to alternative fuels, cost of AFVs, distrust of technology and limited vehicle availability. Fleet managers outside government rarely show much will to pay extra to pioneer or do a public good. Future intention was to purchase 6 per cent AFVs however. Set against this, we note that hybrid EVs use conventional fuel. They are not AFVs and are therefore more acceptable.

Our forecasts for large buses and other high priced industrial and commercial EVs are given in tables 3.5 and 3.6.

The main sale will be in the USA, Europe, Japan and China, with the US dominant for several years.

Table 3.5 **Global market for commercial and high cost light industrial vehicles by value and numbers, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number	400	1,000	1,000	1,000	1,000	1,200	1,500	2,000	3,000	3,400	3,800
$ Unit value ('000)	350	330	330	330	330	325	300	250	300	300	300
$ million value	140	330	330	330	330	390	450	500	900	1,000	1,100

Source: IDTechEx

Table 3.6 **Global market for commercial and high cost light industrial vehicles by technology percentage split, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
% hybrid	90	84	84	84	84	83	82	81	80	79	77
% battery-only	9	10	10	10	10	10	8	7	7	7	6
% fuel cell	1	5	5	5	6	7	10	12	13	14	17

Source: IDTechEx

The reason why fuel cells are so slow to take off despite sales today is because sales for many years consist of highly uneconomic trials by bus companies and government. Adequate infrastructure and cost reduction is not well progressed. However, buses will be an early candidate for fuel cells partly because they have their own fuelling infrastructure. See the Appendix for more on fuel cells.

3.7. Listing of manufacturers

There are at least 380 companies worldwide making light industrial and commercial vehicles in 2005. Some are given in table 3.7 . Entries and exits from the transportation sector of this business are frequent. Giants Allison and Siemens have strongly invested in hybrid electric powertrains for buses etc, making market growth more credible. Some of the following companies are not currently trading but are preparing product for market.

Table 3.7 **132 manufacturers of light industrial and commercial EVs by country and examples of their products**

COMPANY	COUNTRY	EXAMPLES OF PRODUCTS
AAI Corp / ACL Technologies	USA	Buses
AGV products	USA	AGVs
Alstom	France	Buses
APS	USA	Buses
Advanced Vehicle Systems	USA	Buses
Alternative Vehicles Technology	UK	Buses
American Lincoln	USA	Floor cleaners
Assembled Products Corp	USA	Supermarket mobility aid
Anseldo Transport	Italy	Vans
Araco	Japan	Truck
Asquith	UK	Factory vehicles
Associated Engineers	China	Factory vehicles
Audi	Germany	Commercial
Aviogei	Italy	GSE
Bajaj	India	3 wheel taxis
Beijing Fullstar	China	People carriers, tugs
Boyertown Manufacturing	USA	Battery train
Blue Giant	USA	Buses, industrial
Boschung	Germany	GSE
BT Industries	Sweden	Pedestrian load movers
Cantone	China	Buses
Carre Galopin	France	3 wheel wheelie bin collector, street sweeper Platform lifts
Caterpillar	USA	Buses
Champion	China	GSE
Charlatte	France	Load carriers
Clark Material Handling	USA	Airport GSE etc
Columbia ParCar	USA	GSE
Contrac	Germany	Vans
DaimlerChrysler	Germany	People movers
Daktari Engineering	Australia	Industrial
Davco Industries	USA	Buses
Design Line	New Zealand	AGV
Digitron	Sweden	Industrial
Douglas Equipment	UK	Buses
Ebus	USA	Vans
Elcat Electric Vehicles	Finland	Buses
El Dorado	USA	Commercial
Electricars	UK	Multipurpose tractor mower
Electric Tractor Corp	USA	Vans
Electric Vehicles International	USA	Buses
Electric Vehicles Worldwide	USA	Buses
Elgin Sweeper Co	USA	3 wheel single person industrial
Empower	USA	Buses
Enova	Italy	GSE, commercial
Eurocar	UK	Vans, trucks
FAAM	Italy	Workmen's vehicles
FAR	Italy	GSE
FHM	USA	Vans, trucks
Ford	USA	Ice resurfacing
Frank J Zamboni	USA	People movers
Frazer Nash Research	UK	Battery trains
Garmendale Engineering	UK	Vans
General Motors	USA	Scissor Lift
Genie North America	USA	GSE
Giliberti	USA	People movers
Gillig	USA	Battery trains
Golf Car Utility Systems	USA	Motorised food vendors
Graf Carello	Italy	GSE
HakoWerke	Germany	Industrial
Harlan Corp	USA	GSE
Hewden Stuart	UK	Buses
HIL Technologies	UK	Vans, trucks
Hino Motors	Japan	GSE, people movers

COMPANY	COUNTRY	EXAMPLES OF PRODUCTS
Honda	Japan	Buses
Ibedrola	Spain	Buses
Imatron Voima	Finland	Buses
Intelligent Motors	China	Trucks
Isuzu	Japan	GSE
Inutsuka	Japan	Scissor lift
Ivy Hilift	USA	Vans, trucks
JC Andruet	France	GSE
Jenbacker Werke	Germany	Load carriers, people movers
John Bradshaw	UK	Utility vehicle
John Deere	USA	GSE
Kalmar	Sweden	Factory vehicles
Komatsu Fork Lift Co	Japan	Factory vehicles
Lavendon	UK	Light Aircraft pushbacks
Lektro	USA	Mobile platforms
Lift Dynamics	USA	Large pallet handlers
Lodige Fordertechnik	Germany	Industrial
McGrath Industries	USA	Industrial
MAN	Germany	Scissor lift
Mayville Engineering	USA	Industrial
Methode Network Business Products	USA	
Micro Vett		Small tugs etc.
Mitsubishi	Italy	Industrial
Mondragon	Japan	Buses
Moto Barrow	Spain	EV wheelbarrows
Motor Coach Industries	UK	Buses
Mulag	Canada	Buses
Multicar Spezialfahzeuge	Germany	Commercial
Nifty Lift	Germany	Access platform
Nilfisk Advance	UK	Floor cleaners
Nissan Industrial	UK	Commercial and industrial, inc trucks
	Japan	GSE
Northwestern Motor Co		Buses
Nova Bus	USA	Buses
Orion Bus Industries	USA	Commercial & Industrial
POEM	USA	Buses, vans
PSA Peugeot Citroen	Malaysia	Buses
Ponticelli	France	Buses
PTP	Italy	Industrial
Rabbit Tool	UK	Commercial
Renault	USA	Remanufacture
Ross Electric Vehicles	France	Taxis, rickshaws
Scooters	UK	GSE, industrial
Sinai	India	Industrial
SK International	Italy	Vans, light trucks, etc.
Smiths Electric Vehicles	USA	Vans, bus drive trains, trucks, ice resurfacing
Solectria	UK	Buses
	USA	Buses
Southworth International Group		GSE
Speciality Vehicles	USA	GSE
Spijkstaal Elektro	USA	Vans, trucks
Stewart & Stevenson	Netherlands	GSE
Suzuki	USA	Buses
Taylor Dunn	Japan	AGV
Technobus	USA	Floor care
Telelift	Italy	GSE
Tennant	Germany	Mowers, industrial
Tesco HiLift	USA	Buses
Textron	USA	Mowers
Thomas Built	USA	Buses, vans, trucks, also many industrial
Toro	USA	Buses
Toyota	USA	Buses
	Japan	Buses
Transport Energy Systems		Vans
TransTeq	Australia	GSE
Trolley Enterprises	USA	GSE
Unique Mobility Europa	USA	Stackers, tool movers
United Tractor	Germany	People movers

COMPANY	COUNTRY	EXAMPLES OF PRODUCTS
W & E Electric Vehicles Wilmat Handling Yamaha Zap	USA UK UK Japan USA	Battery module EV

Source: IDTechEx

3.8. Overall market projections for light industrial and commercial EVs

3.8.1. Overall market by unit cost

Our overall market projections are given in tables 3.8 and 3.9.

Table 3.8 **Overall market projection for global sales of light industrial and commercial EVs by numbers by price range, 2005 to 2015**

NUMBER ('000)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	120	130	140	150	150	150	150	150	150	150	150
Medium-cost	10	11	12	13	14	15	16	18	20	22	24
High-cost	0.40	1.0	1.0	1.0	1.0	1.2	1.5	2.0	3.0	4.0	5.0
Total	130	142	153	164	165	166	167	170	173	176	179

Source: IDTechEx

Table 3.9 **Overall market projection for global sales of light industrial and commercial EVs by value by price range, 2005 to 2015**

$ MILLION VALUE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	840	910	980	1,050	1,050	1,050	1,050	1,050	1,050	1,050	1,050
Medium-cost	200	231	264	299	336	375	400	450	500	550	600
High-cost	140	330	330	330	330	390	450	500	900	1,100	1,300
Total	1,180	1,471	1,574	1,679	1,716	1,815	1,900	1,900	2,450	2,700	2,950

Source: IDTechEx

The light industrial and commercial EV manufacturing market is one of the toughest to estimate because of the wide variety of applications and participants. We believe it was around $550 million globally in 2000 and has grown since then, but levelling in 2002/2003 due to recession in much of manufacturing industry.. Although others report lower figures we do not believe they have taken into account more than a minority of participants. We are encouraged by the fact that our figure represents little more than $3 million per participant and we have listed details of a large number of participants in our report "Over 600 Electric Vehicle Manufacturers and Their Future".

The largest category "self-propelled operator-riding industrial" is in trade-association parlance "8709-11030". B. Samra VP Worldwide Marketing of Taylor Dunn put this at $90 million for the US and multiplies by three to get the world market - $270 million in 2001, not far from our $300 million.

We believe this category breaks down into a large airport-related sector (Ground Support and Terminal equipment) and a miscellaneous sector, where these vehicles are used, mainly off road, for load and people carrying, floor care etc. in industry, hotels, theme parks, large office and industrial buildings and many other locations.

3.8.2. Markets by technology 2005 to 2015

Our forecasts by technology are given in tables 3.10, 3.11 and 3.12.

Table 3.10 **Global unit numbers ('000) of hybrid light industrial and commercial EVs by price range, 2005 to 2015**

NUMBER ('000)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	2.40	3.90	7.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Medium-cost	1.00	1.65	2.40	3.25	4.20	5.25	6.40	8.10	10.00	12.00	14.00
High-cost	0.36	0.84	0.84	0.84	0.84	0.99	1.23	1.62	2.40	3.00	3.75
Total	3.76	6.39	10.24	19.09	20.04	21.24	22.63	24.72	27.40	30.00	33.00

Source: IDTechEx

Note the jump in sales of high cost versions (notably buses) from 2006 in preparation for the 2008 Olympics in China, and other initiatives.

Table 3.11 **Global unit numbers ('000) of battery-only light industrial and commercial EVs by price range, 2005 to 2015**

NUMBER ('000)	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	117.6	126.1	133.0	135.0	135.0	135.0	133.5	133.5	132.0	132.0	132.0
Medium-cost	9.0	9.4	9.6	9.8	9.7	9.6	9.6	9.6	9.6	9.6	9.6
High-cost	0.14	1.0	1.0	1.0	1.0	1.2	1.2	1.4	2.1	2.6	3.2
Total	127.0	136.5	143.6	145.8	145.9	145.8	144.3	144.3	143.7	144.2	144.8

Source: IDTechEx

Table 3.12 **Global unit numbers (000) of fuel cell light industrial and commercial EVs by price range, 2005 to 2015**

NUMBER	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	–	–	–	–	–	–	1,500	1,500	3,000	4,750	6,200
Medium-cost	–	–	–	–	-	-	160	180	400	900	1,500
High-cost	-	-	-	-	-	-	150	240	390	500	620
Total	-	-	-	-	-	-	1,8	1,9	3,7	6.2	8.3

Source: IDTechEx

Note that the fuel cell program is bold for buses etc. compared to most other EVs. This is because they can tolerate shortcomings of fuel cells such as long start-up time and cost. Also cities and governments subsidise such antipollution measures with buses in particular. Our market value forecasts by technology are given in tables 3.13 to 3.15.

Table 3.13 **Global value ($ millions) of hybrid light industrial and commercial EVs by price range, 2005 to 2015**

$ MILLION VALUE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	16.8	27.3	49.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0
Medium-cost	20.0	41.25	52.8	74.8	101.0	131.0	160.0	203.0	250.0	305.0	270.0
High-cost	126.0	227.2	227.2	227.2	227.2	321.8	369.0	486.0	720.0	1000.0	1400.0
Total	162.8	295.8	329.0	407.0	483.2	557.8	634.0	688.0	1,075.0	1410.0	1775.0

Source: IDTechEx

Table 3.14 **Global value ($ million) of battery-only light industrial and commercial EVs by price range, 2005 to 2015**

$ BILLION VALUE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	823	882	931	945	945	945	934	934	924	914	904
Medium-cost	180	197	211	225	232	240	240	240	240	242	242
High-cost	14	33	33	33	33	39	36	35	63	98	130
Total	1,017	1,112	1,175	1,203	1,190	1,224	1,210	1,209	1,227	1,254	1,276

Source: IDTechEx

Table 3.15 **Global value ($ million) of fuel cell light industrial and commercial EVs by price range, 2005 to 2015**

$ BILLION VALUE	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Low-cost	–	–	–	–	–	–	10.5	10.5	10.5	10.5	10.5
Medium-cost	–	–	–	–	-	-	4.0	4.5	10.0	15.0	21.0
High-cost	-	-	-	-	-	-	45.0	60.0	117.0	189.0	275.0
Total	-	-	-	-	-	-	59.5	75.0	137.5	214.5	306.5

Source: IDTechEx

Note that the largest growth in market value is hybrids followed by battery-only vehicles. Hybrids at high unit costs grow particularly strongly. This means buses but with trucks also important in later years. Figure 3.9 shows a pure EV bus in Italy using fast charge batteries

Fig. 3.9 **A pure EV bus in Italy using fast charge batteries**

Source: Wanfler

4. EVs for the disabled

4.1. The sector with the most compelling and enduring need

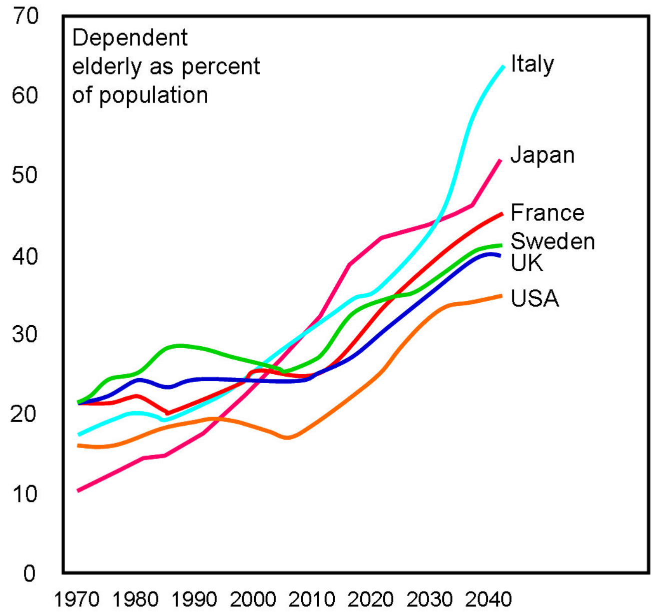
There are many reasons why vehicles for the disabled have been are and will be a booming business. The elderly –by no means the only section of society needing mobility aids –are more wealthy, more demanding and, through better medicine and diet, better able to look after themselves to some extent, provided they are given a few aids where necessary. Indeed, current and future generations of elderly have been mobile all their lives and they will be far less tolerant of immobilisation than past generations were.

4.2. The demographic time-bomb

Most dramatically of all, the so-called "demographic time-bomb" shown in figure 4.1, by which the number of dependent elderly is growing exponentially as a percentage of the population is meaning that more and more people have to be enabled to look after themselves whether they want to or not, because carers will be in increasingly short supply.

4.2.1. Ageing population and the dependent elderly

Fig. 4.1 **Percentage of dependent elderly 1970 to 2040**



Source: National statistics.

Table 4.1 gives some relevant statistics.

Table 4.1 **Statistics relevant to the challenge to society caused by ageing population**

EVIDENCE	REPORT	DATE
By 2050, 15% of Japanese will be over 80. In 2005, fertility rates in Tokyo are down to 0.99 children per woman of child bearing age meaning that there will be fewer people to look after the elderly and disabled in future.	UN Department of Economic and Social Affairs report	2005
The percentage of the Japanese population that are over 65 years old is rising from under 22% in 2000 to 32% in 2015	National Social Security Bureau	2005
From 2000 to 2030, the population of Japan and Italy drops by over 10 million and they become nations of relatively unsupported elderly	National statistics	Various
Already, in the US, 80% of the people requiring care receive it from family and friends.	Survey	2004
The population of people of working age in Europe will drop by 1% from 2005-2030, but the elderly will sharply increase	European Union	2005
The US had a nursing shortage of over 168,000 in 2003 and 62% of hospitals have significant diversion issues. The US will have a healthcare facility bed shortage of 24% in 2010.	AHA US GAO	2002 2003
People are living longer but not costing much more because they are active longer and their decline is more sudden	Financial Times	2004

Source: IDTechEx

There simply will not be enough doctors, nurses and carers to go round and governments and charities will not be able to bear the crippling burden of providing institutional care to so many people, nor should they if technology can come to the rescue. Institutional care is a poor option if the disabled person can spend at least some of their time being more independent and particularly more mobile.

4.2.2. Laws make mobility easier

Coincident with this, more and more countries are making it a legal requirement to have ramps and other access for the disabled in public places and buildings and in the workplace and they are even providing single seat vehicles for the slightly disabled to borrow in these places. In our research for this report, we even met an elderly lady who has difficulty in walking but nevertheless possessed a quad bike, a power chair and a mobility scooter for different aspects of her life and she used them intensively. This is a glimpse of the future – independence and entertainment for such people and an eagerness to buy what is new and useful, not as a replacement but as an additional possession.

4.3. Types of mobility vehicle

In the industry of vehicles for the disabled, the main distinction is between:

Those who can get into and operate a standard vehicle unassisted. The "impeded" include those with MS or Parkinson's disease that can still walk albeit slowly. It can include pregnant women and the mobile elderly who nevertheless may not be able to walk fast enough or far enough for the task in hand or in the company of younger people. It may also include a young person with a temporary injury such as a sprain. They are usually provided with a vehicle with three or four equal-sized thick pneumatic wheels, (variously called personal assist vehicles, runabouts, scooters, scootas, power chairs and buggies). Such a vehicle can usually mount road curbing and cope with rough country paths. It is usually allowed on the road with the driver unlicensed, with no road tax and no statutory requirement for a helmet. Maximum speed is typically no more than 8 mph. Such vehicles are on free loan at the Louvre, in Paris, in theme parks, city centres, and in most major supermarkets, for example. Usually, no carer is present when they are used. Most of these vehicles are bought unmodified. They retail at about $1,500 and some are even bought by mail order. There are two basic types – power chairs or scooters. The power chairs have central big wheels so they can turn in their own length and be used indoors and outdoors. They are usually steered by a small joystick. The scooters are three or four wheel and driven by handlebars. They are usually cheaper but not usually suitable for indoor use. Some "microscooters" fold to go into a car trunk Some users buy one of each type – the power chair for comfort and indoors and the microscooter for use when out in the car. All these vehicles last for many years and need little maintenance. They are a booming, relatively price insensitive market and the most profitable type of EV. Most are bought by the owner except in countries such as Norway and the Netherlands where the government usually pays. Some are an impulse buy.

By contrast, the "seriously disabled", such as paraplegics, need lifting into and out of their mobility vehicle and usually need highly customised supports and controls on the vehicle. They use these vehicles intensively so they are more expensive and may need replacing every two years. Unlike the above vehicles, they are ugly and functional, as would be expected by something the purchaser, such as a government official, never uses themselves. They are usually called motorised wheelchairs or electric wheelchairs but some are variants on power chairs. They are almost always bought by the government or an institution, not an individual, and a carer is often nearby when they are used. This market is growing only slowly – about 1% yearly - and does not have the gross value of the first market despite unit prices being many times higher.

In addition there are cars, vans, SUVs etc that are either adapted for the disabled or designed from scratch for such people.

4.3.1. Growth by new market segments

The above descriptions portray two very different market needs, typically with very different suppliers and three basic types of vehicle but this is only the beginning. We now look closer. To understand how the overall market has defied recession and continues to grow strongly, one must understand how great creativity in addressing new needs and compromises is growing the market. First let us look at the power chair. This is an apt description. It is a luxury, well-padded chair, made mobile with, usually, two large wheels and four small ones. This makes it something intermediate between a scooter and a powered wheelchair, being intermediate in price – at around $4,000 – and performance. It can turn in its own length, so, unlike a scooter, it can be used in the average home or small shop as well as on the street or sidewalk. It is usually bought unmodified as a standard product though some accessories are offered.

Too expensive to be provided by cities, theme parks and supermarkets on free loan, it is usually bought by the independent disabled. Lacking motorised limb movement, motorised recline etc or extensive customisation it is not usually bought for the severely disabled. However, power chairs usually have joystick control like a wheelchair, whereas scooters usually have handlebars.

Table 4.2 shows the chronology of launch of these three families of products, for that is what they are. New variants add new sub-markets all the time, as the examples in tables 4.3 through 4.5 testify. We even have some people owning two vehicles – for example, a folding low-cost version ("microscooter") put in the car by the owner without assistance and used indoors at, say, the shopping mall, and a heavy outdoor version (scooter or power chair) to go from home down the road into the local town.

Mobility scooters and power chairs last many years because they are only used intermittently and they have little to go wrong. People change these because something more attractive comes along not because they wear out. For example, someone with a three wheel scooter may upgrade to the more stable four wheel scooter.

However, most new segments get new users buying the products where those people did not previously have anything because they felt their needs were not met by what was previously on offer.

Table 4.2 **Evolution of three families of powered vehicles for the disabled**

	STATUS	1980		1990		2000		2010
1	Severely disabled with carer usually nearby. Indoor/outdoor.	Powered wheelchair						
2	Disabled without carer nearby. Indoor/outdoor.		Powered chair					
3	Moderately disabled/impeded. Outdoor Indoor only in large spaces			Scooter				

Source: IDTechEx

Table 4.3 **Evolution of powered wheelchairs for the severely disabled, usually with carer nearby, 1980 to 2010**

1980		1990		2000		2010	EXAMPLE	COUNTRY
Powered wheelchair							DMA	UK
		Powered wheels to convert wheelchair					Yamaha	Japan
		Powered individual movement of limbs, recline etc					Redman	US
		As above with heavy wheels for rough terrain					Adaptachair Balder Permobil	UK US/Norway US/Denmark
		Custom advanced designs					RGK	US
				Very rough terrain			Kili-Kart	US
				Obese			ConvaQuip	US
				High speed			21st Century Scientific	US

Source: IDTechEx

Table 4.4 **Evolution of power chairs 1980 to 2010**

1980		1990		2000		2010	EXAMPLE	COUNTRY
		Powered chair					Pride Mobility	US
				House-chair, small footprint			Stannah	UK
				Power raise or stand up			Levo	Switzerland
				High speed			Bounder	US
					Stair climb (gyro)		iBot	US
					Very long range (fuel cell)		Not available yet	

Source: IDTechEx

Table 4.5 **Evolution of scooters for the disabled 1980 to 2010**

1980	1990	2000	2010	EXAMPLE	COUNTRY
	Three wheel			Sunrise	US
	Four wheel			Pihsiang	Taiwan
	Public use in buildings – anti-collision			Assembled Products	US
		Rough terrain		Electric Mobility	UK
		Very rough terrain		Magic Mobility	Australia
		Microcar		Sunrise	US
		Minicar		Toyota	Japan
		Lightweight microscooter (liftable by one person, folding)		Pihsiang	Taiwan
		Two seat		Pihsiang	Taiwan
		Paediatric		Pihsiang	Taiwan

Source: IDTechEx

The above segments for the three families of vehicle are by no means comprehensive, but we make the point that the overall market grows partly by suppliers meeting extra needs. That helps it defy recession.

4.4. Market drivers

Since there are far more impeded/disadvantaged people than severely disabled, the market for power chairs together with scooters is bigger, in both volume and value, than the market for motorised wheelchairs despite their lower price.

4.4.1. Geographical distribution

The US is the largest market for mobility vehicles for the disabled by value and numbers. The continental split is shown in table 4.6. Existing geographical markets ease in growth by 2010 as there is some saturation in the highly dominant markets of the US, UK, France, Germany, Italy and the Netherlands. However, other countries adopt the vehicles in a big way, including China and Japan, both with rapidly growing percentages of elderly people.

Table 4.6 **The continental percentage split of markets for vehicles for the disabled by value in 2005**

US	EUROPE	OTHER
60	30	10

Source: IDTechEx

Table 4.7 gives the split by country within Europe

Table 4.7 **The percentage split of market for vehicles for the disabled by country within Europe**

UK	GERMANY	THE NETHERLANDS	OTHER
50	15	15	20

Source: IDTechEx

Table 4.8 gives the numbers in thousands of scooters plus power chairs that will be sold in Europe 2005 to 2015.

Table 4.8 **The numbers in thousands of scooters plus power chairs that will be sold in Europe 2005 to 2015.**

YEAR	NUMBER K YEARLY
2005	192
2006	215
2007	238
2008	260
2009	283
2010	311
2011	356
2012	399
2013	435
2014	463
2015	483

Source: IDTechEx

4.4.2. Needs creating new segments

Some of the new sub-markets created out of fresh air are substantial. Versions for supermarkets have proximity detectors which stop them automatically to prevent the user hitting displays or other customers, fixed very low speed (e.g. 1.5 mph) and industrial parts for safety and reliability in congested areas where utilisation is high. They also have special large baskets, so they are substantially different from standard scooters and cost 50 per cent or so more despite being bought in bulk. Over 100,000 of these are in use today. Other versions are covered for bad weather and sometimes called microcars and yet others are miniaturised for use in the home with very small wheels for congested areas and they may electrically raise the user on command. Some may be made available in airports etc. in future to help even fit people "disabled" by heavy loads and long corridors. They may need auto relocation after use.

In summary, this is a vibrant, innovative sector replacing human effort and making new things possible. The internal combustion engine (ICE) is irrelevant because of indoor use and frequent stop start. The sector even includes multipurpose on-road/off-road and off-road alone. It also includes commercially bought free issue or free use vehicles and privately purchased vehicles.

Financial

For the registered disabled, there are strong tax incentives in most countries. For example, in the UK, value added tax of 17.5 per cent is waived. The very severely disabled can often get the total cost of the vehicle from government. Financial incentives strongly affect purchase of vehicles for the very severely disabled. In many countries lack of such incentives can prevent the EV market existing at all. By contrast, incentives only have a second order effect on sales of powered wheelchairs and scooters because these are more usually bought by people of independent means and unit prices are far lower. Demographics and disposable income are far more important here.

Price stabilisers/ enhancers

The market for electric vehicles for the disabled is relatively price insensitive because the purchasers of the most popular types are the users themselves who decide they have a need and often impulse buy or at least fail to shop around. There are price stabilisers/ enhancers in this market too. It is not all about intense competition and selling the basic, stripped down product. We have also noted that people often buy both a scooter and a power chair. Features that may hold up the price by offering more in the years to come include those in table 4.9

Table 4.9 **Features of mobility vehicles that may hold up the price by offering more in future**

FEATURE	COMMENT
Long range e.g. fuel cell powered	Fuel cell two wheel vehicles and cars are already being trialled
High speed versions	Off road, leisure etc
Radio	Typical car accessories
Anti-theft locators	As in cars today
Heated seats	As in cars today
Heated handlebars	As in motorcycles today
Rag tops or hard tops	As in motorcycles today
Emergency call out phones	Need for disabled
Improved battery status reporting	Weakness today causes a worry
Emergency battery charge e.g. with fuel cell	Small fuel cells becoming available soon for laptops etc
In use charge with e.g. solar panels	Improved flexible printed solar panel sheet available soon
Greater adjustments to accommodate the obese etc	Currently only expensive special versions do this
Adjustment for lumbar support	Only on some top of the market power chairs
Longer life	Need but not a strong one
More rugged	Need for off road use
Stair climbing ability	Available from one model but expensive
Rough terrain tolerance	Available from three suppliers but special expensive vehicles not a capability of normal vehicles
Four wheel drive	Useful for off road and difficult kerbs etc
Lights etc for night use	Needed by some. Available only as an extra on a minority of models at present
Ultra light weight eh titanium/ graphite/ advanced batteries	Needed if the big wheel, rough terrain versions are to be easily lifted into cars
Advanced fast chargers in the vehicle	Need. Losing charge is a great fear
Lockable storage as in a car or a motorcycle pannier	Security
Upgradeability	Fashion and useful features.

Source: IDTechEx

4.4.3. What is driving regional differences?

There are country by country variations in quantity and mix. This is caused by personal preference and disposable income in the main but the nature of accommodation, sidewalks etc also comes into it. For example, there are relatively few scooters in Japan or Germany and almost no disabled vehicles of any type in the poorer countries of Europe, let alone the third world.

4.4.4. Case study: Pride Mobility, USA

Fig. 4.2 **Pride Jazzy – making new things possible**

Source: IDTechEx

Pride Mobility manufactures electric vehicles for the disabled in the US but it has also put its brand on some scooters made in Taiwan etc. Together, the sales of these may have a monetary value higher than those of any competitor, though various Taiwanese manufacturers, selling under many brands, rival Pride in sales value and exceed it in numbers. It specialises solely in vehicles for the disabled but it only had a small market share and so little economy of scale. Intelligently, the company went for excellence of design and premium pricing. It worked. In 1998, in the UK alone, they sold about $19 million of product, say 10,000 EVs virtually from a standing start. Their power chairs and four wheelers had style and quality and their "Jazzy" design, shown in figure 4.2, for the first time combined the best of both worlds – a disabled EV with luxury styling that can turn in its own length yet had thick large wheels that give a good ride on rough terrain. Its reclinable chair is exceptionally lush and comfortable and price is at the top of the range. It is extremely popular. Pride may be selling over 100,000 EVs yearly now, largely premium priced and all for the disabled. It is particularly successful in the US and Europe.

4.5. Listing of manufacturers

The number of suppliers has doubled over the last few years as new market segments calling for very different products which have been created. However, although the vehicles are made in Israel, Korea, mainland China and elsewhere nowadays, 70% of output is from Taiwan. Table 4.10 shows how we see the trend of manufacturing location.

Table 4.10 **The percentage distribution of manufacture between Taiwan and Mainland China by value of vehicles for the disabled 2005 and 2015**

	2005	2015
Taiwan	70	5
Mainland China	2	60

Source: IDTechEx

Table 4.11 gives the market by geographical region, ex works pricing and percentage split in 2005 and 2015

Table 4.11 **Market for EVs for the disabled by geographical region, ex works pricing and percentage split in 2005 and 2015**

	VALUE $ MILLIONS	% SPLIT IN 2005	% SPLIT IN 2015
US	354	60	55
Europe	177	30	30
Other	59	10	15
Total	590	100	100

Source: IDTechEx

Table 4.12 gives examples of manufacturers of EVs for the disabled.

Table 4.12 **Eighty examples of manufacturers of EVs for the disabled by country**

COMPANY	COUNTRY
Adaptachair	UK
Aldersley Battery Chairs	UK
APC	USA
Assembled Products Corp	USA
Aviation Mobility	USA
BalderPower Wheelchairs	Norway
Booster	UK
Bridgestone	Japan
ConvaQuip	USA
CTM l	Israel
Denton	UK
DMA	UK
Electric Bike	UK
Electric Mobility	USA
Euroflex	Sweden
Everest & Jennings	USA
EV Meltec	Japan
FAAM	Italy
Falcon Rehabilitation Products	USA
Freerider	Taiwan
Friedrich Albrecht	Germany
FEE	Japan
Genus	Canada
Giraldin	Italy
Glory Mountain	China
Good Pace	USA
Graf Cavello	Italy

COMPANY	COUNTRY
Horizon Mobility	UK
Hot Shot Products	USA
Hoveround	USA
Independence Technology	USA
Invacare	USA
John Bradshaw	UK
Karelma	Various
Kili-Kart	USA
Kou Mu Industrial	Taiwan
Kymco	Taiwan
Levo	Switzerland
Ligier	France
Lion Industries	UK
Line Industries	Canada
Long Yin Enterprises	Taiwan
Maclaren	UK
Magic Mobility	Australia
Merits	Taiwan
Mevee	Spain
Meyra	Germany
Montis	Germany
Newton Products	UK
Nimble	Canada
Optiway	Canada
Otto Bock	Germany
Pacesaver	USA
Permobil	USA/Denmark
Pihsiang	Taiwan
Pride	USA
Radakadd	Chile
Redman	USA
REV	Taiwan
Revatak	Holland
RGK	USA
R J Mobility	UK
Scandinavian Mobility (Invacare)	UK
Shih Li Ho	Taiwan
Stannah	UK
Sungift	UK
Sunrise Medical	USA
Teftec	USA
Taiwan Mobility	Taiwan
Toyota	Japan
Travelite	Israel
21st Century	USA
Ulrich Alber	Germany
Vassilli	Italy
Welzorg	Holland
Wheelcare	USA
Wheelchairs of Kansas	USA
Winmed	East Asia
Yamaha	Japan
Zi Yu Enterprises	Taiwan

Source: IDTechEx

Note that we include a few heavily modified golf cars and special road cars, people movers etc, designed specifically for the disabled. Although, as noted, 70% of all vehicles for the disabled were made in Taiwan in 2005, most appeared in the European and US market branded by various local companies. Many of the vehicles made in the West employ drive trains made in Taiwan.

4.6. Market forecasts by technology and region, 2005 to 2015

EPRI reported over 100,000 electric wheelchairs and 195,000 three wheel EV scooters and other EV aid-to-walking vehicles in the US in 1995. Today the figure is much higher, and the vehicles are more reliable (in 1994, 75 per cent of US users reported a battery-related problem).

Worldwide consumption in 2005 is 800,000 yearly, including about 10,000 radically new EVs and rising strongly. It will reach 1.2 million in 2010. As part of the growth by fragmentation of this market described earlier, there will be large new sub sectors such as EVs for the disabled that can mount steps to be stored in a house and ones that can be even more easily dismantled or folded for carrying in a car trunk.

Prices will drop for the identical product as these EVs are mass-produced for the first time and more companies use the same platform for light industrial and leisure variants. Today's average ex factory price is being eroded by the great success of the lowest cost product, the microscooter, but as this growth eases, the upmarket products will drive average prices upwards.

4.6.1. Growth by creating new markets

Fig. 4.3 **Stair climbing function of the iBOT**

Source: Independence Now

The market for electric vehicles for the disabled will continue to grow by adding new sectors, usually dominated by companies that are not the big players in traditional versions. In the past Invacare was largest in electric for the severely disabled but Pride largely created the market for power chairs. Pihsiang and others largely created the market for scooters. So it is now that golf cars heavily modified for the disabled come from Ingersoll Rand and special electric cars for the disabled from Toyota in recent times. We believe that there will be electric boats for the disabled and we note that the new Segway two wheeled vehicle is recommended for the mildly disabled – there may be special versions for such people. A company in the UK makes bicycles into tricycles for the disabled. The radically new all-terrain wheelchairs should be selling fairly well in 2003/2004. The gyro stabilised stair climbers (figures 4.3 and 4.4) may gain approval and sell well. Specialised vehicles for the deaf and robotically guided vehicles for the blind will also emerge. Indeed some of the latter exist in Japan today. In this way, the market grows.

Fig. 4.4 **Balance function of the iBOT**

Source: Independence Now

Traditionally, it is mature markets that are affected by recession An example is heavy industrial in 2001/2002. By contrast, the disabled sector is not mature, with the exception of vehicles for the very severely disabled. Even here, there will be little economising in spend because it would be political dynamite. Power chairs and scooters may be impacted by recession eventually but that is probably at least ten years away. Table 4.4 gives our forecasts for the existing and new markets for electric vehicles for the disabled, and shows the important contribution of radically new designs.

In table 4.13 we show the new markets saturating more severely than existing markets because these mainly address small niches and there may even be an element of fashion in some of them. However, more robust new markets may well emerge.

Table 4.13 **Number projections for global sales of existing vs radically new types of design and use of disabled EVs 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Conventional ('000)	761	835	903	942	982	984	1,075	1,218	1,360	1,420	1,530
Radically new ('000)	39	45	57	98	138	216	225	232	240	247	258
Total number ('000)	800	880	960	1,040	1,120	1,200	1,300	1,450	1,600	1,667	1,788

Source: IDTechEx

One cross check on the magnitude of the market in 2003 is to say that the 130 or so manufacturers average only 4,000 of so vehicles yearly on average

4.6.2. Markets by region

The global manufacturing market projections are given in table 4.6:

Table 4.14 **Global manufacturing market by number and value in 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	800	880	960	1,040	1,120	1,200	1,300	1,450	1,600	1,800	2,050
$ Unit value	688	717	746	775	804	833	850	860	860	860	860
$ billion value	0.550	0.631	0.716	0.806	0.900	0.965	1.105	1.247	1.370	1.548	1.763

Source: IDTechEx

A substantial part of this growth will be caused by geographical expansion and more governments and commercial organisations buying these EVs for free use on their premises but also by their use being extended to fit people with loads to carry and other applications. For instance, in 2000, Magic Mobility Australia and Kili-Kart of the USA launched the world's first all-terrain wheelchairs.

Microscooters now constitute the largest new market in recent years for electric vehicles the disabled. Figures 4.8 to 4.12 show Roma Medical's microscooters, manufactured by Pihsiang, their range includes the Shoprider microscooter which can easily be taken apart for storage and folded up and easily transported by one person and also the larger Milan and Sunrunner models.

4.6.3. Markets by technology

From 2005 to 2007 we expect mobility vehicles for the disabled to be almost entirely battery operated but at the end of that time a few fuel cell powered vehicles may be on the market.

Fig. 4.5 **Shoprider microscooter fully**

Source: Roma Medical

Fig. 4.6 **Shoprider dismantled for storage**

Source: Roma Medical

Fig. 4.7 **Shoprider transport and storage**

Source: Roma Medical

Fig. 4.8 **Shoprider Milan**

Source: Roma Medical

Fig. 4.9 **Shoprider Sunrunner**

Source: Roma Medical

5. Two wheeled EVs and allied vehicles

5.1. Definition

This category mainly concerns EV bicycles. In some countries, these evade insurance, tax, registration and the need for a driver's licence provided they are electronically gated to a maximum speed of 15 mph or so depending on country. However, the later-emerging market for 2 wheel scooters (usually seated) and motorcycles, including quad bikes and allied single seater machines are also included. These are a form of 'All Terrain Vehicle' (ATV) and they have retail prices in a similar range to EV motorcycles at $2,500 to $7,000. Their uses overlap those of two wheelers but add more, notably:

- Home and professional utility use.
- Police and local law enforcement needs.
- National, regional and local government security.
- Private and public border patrol and regulation.
- Outdoor sports – ideal for sportsmen and campers who want to travel quietly.
- Public and private parks management.
- Transportation and utility in areas with no gasoline.
- Airport tarmacs and large industrial facilities.
- And many other uses ...

5.1.1. Case study: Dana Corporation Willy scooter

Scooters, with their two stroke engines, emit a disproportionate amount of pollution – 500 more amount of harmful substances than a car - so several developers are prioritising them for the pure EV or hybrid treatment. Dana Corporation has teamed with MZ Engineering of Germany and ZSW a government owned non-profit organisation in Germany to make the Willy scooter named after Sir William Groves, the inventor of the fuel cell in the early 1800s. This technology demonstrator is based on a commercially available battery powered scooter from MZ Engineering. It is an "electric hybrid" in the that the fuel cell recharges the battery which provides motive power. It is still a pure EV. No ICE is involved. The fuel cell is modular and uses compressed hydrogen. The machine is shown in figure 5.1.

Fig. 5.1 **The Dana Corporation Willy scooter powered by fuel cell and battery.**

Source: Dana Corporation

5.1.2. Case study: Peugeot Quark quad bike

Peugeot, the French car company, has offered a number of two wheel electric scooters over the years without significant commercial success but it continues to evolve very stylish designs. Latest is the prototype Quark pure EV quad bike shown in figure 5.2

Fig. 5.2 **The new prototype Peugeot Quark pure EV quad bike**

Source: Peugeot

The specification is shown in table 5.1.

Table 5.1 **Specification of the experimental Peugeot Quark fuel cell quad bike.**

Chassis	Aluminium and carbon fibre
Fuel cell	MES-DEA air cooled
Battery	40 cell NiMH 288V
Tank	9 liters
Motors	4@TM4
Max power torque	28 kW
Max speed	110 kph (68 mph)
Acceleration 1-50 kmph (31 mph)	6.5 secs
Range	100 km (62 miles) – 130 km(81 mls in eco mode
Kerb weight	425 kg

Source: Peugeot

5.1.3. Case study: Systrel, Eberli and Associates – Mobilec moped

Systrel, Eberli and Associates has designed an electric moped that is made for them in China by Jinan Tech. The design was done in the village of Colombier near the Swiss City of Neuchatel. The CEO of the company and principal designer of MOBILEC-EV is Mr. Peter Eberli, who formerly was a senior engineer at one of Switzerland's largest battery companies and who is a specialist on low-cost battery, motor and drive control systems for two-wheel electric vehicles.

The Swiss Department of Energy has helped support the initial design and development work of the MOBILEC-EV. The product also enjoys the attention and respect of pro-environment groups around the world including China's own environment protection agency. It is a deliberately low technology affair.

The electric moped went on the market in late 2004 at around $1200 which is less than its ICE equivalent and one third of the cost of a highly powered electric scooter. Specification is:

- Battery: lead acid
- Range: 25 miles
- Cost of use: 25 cents per 100 Km (60 miles)

Adviser to the company David Dichter says, "No amount of public sentiment in favour of pollution free vehicles will win consumers over unless the price is right."

Founder Pierre Eberli thinks he can sell 100 in Switzerland alone and Brazilian investors have been found to back production of 1-2000, starting in Brazil.

5.2. Market drivers

5.2.1. Bicycles and electric bicycles

The global population of pedal bicycles in 2003 is shown in table 5.2

Table 5.2 **Global population of bicycles, in billions, by region**

REGION	NUMBER OF PEDAL BICYCLES (BILLIONS)
China	0.45
India	0.30
European Union	0.14
USA	0.12
Japan	0.07
Brazil	0.04
Total	1.12

Source: CycleElectric

Annual bicycle production has declined in most years since 1995. China is key to electric bicycle sales and production just as it is key to bicycle sales and production. In 2000 it took its rightful place as world leader in production and use of electric bicycles, overtaking Japan which did the pioneering of both manufacture and use, with sales peaking in 1997 and only partly recovering by 2003. EV bicycle sales in Japan were as in table 5.3:

Table 5.3 **Sales of electric bicycles in Japan 1994 to 2005**

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Sales in '000	90	225	200	150	160	170	180	200	180	180

Source: IDTechEx

Sales in China have burgeoned upward without a pause, driven largely by draconian anti-pollution laws. See table 5.4.

Table 5.4 **Sales of electric bicycles in China 1998 to 2003**

	2001	2002	2003	2004	2005
Sales in '000	800	1,000	1,300	1400	1700

Source: IDTechEx

Expert Frank Jamerson sees global sales as in table 5.5.

Table 5.5 **Global sales of electric bicycles 2001 to 2005**

	2001	2002	2003	2004	2005
Sales in '000	800	1,000	1,200	1,500	1,800

Source: Frank Jamerson

Industry expert Ed Benjamin of CycleElectric can provide more detail on global trends in electric bicycles both by technology and by market. He monitored 2002 sales by region as in table 5.6. Contact Edbike@aol.com.

Table 5.6 **Global sales of electric bicycles 2002 by region**

SALES IN '000	2002	AVERAGE PRICE ($)
USA	20	1,500
European Union	55	1,000
Japan	200	750
China PRC	1,000	300
Rest of World	5	N/A
Total	1,280	

Source: CycleElectric

CycleElectric expect China to grow to about 4 – 10 million units per year, Japan to 500,000 units per year and the USA and European Union to 1.5 million units per year. Chief obstacles are performance and price, but Europe also needs to improve its dealer network, says CycleElectric.

5.2.2. Massive boost to 2 wheelers in China

In 2000, the Chinese government announced the world's largest government intervention to introduce 2 wheel EVs. The so called Electric Vehicle Development of the National Technology Industrialisation Project puts large human and material resources into the research and development of the electric vehicle.

This includes research of the electric vehicle (concept vehicle) and key technology; development and manufacture of the electric vehicle (refit vehicle); establishment of an electric vehicle demonstration zone in Nan Pio of Gruengdong Province, acceleration of the creation of relevant standards and social protection systems.

The government of China hopes its electric vehicle colleagues will communicate through various channels with foreign counterparts, thus establishing multiple co-operation on various aspects of EV research and manufacturing. Especially in Shanghai, a series of favourable policies have been made to industrialise EV products : replacement of the existing 500,000 petroleum-driven scooters has effectively been banned and substituted by electric ones; battery charging stations are under construction; electric buses will be the major form of community transportation : quality batteries applicable to EV products are in demand.

The total stock of conventional motorcycles in China is several tens of millions, up from 4.2 million in 1989 and 8.5 million in 1993.

Beyond Shanghai

Even beyond Shanghai, the Chinese government is preparing regulations to restrict the use of fuel-powered motorcycles and encourage people to buy electric bicycles and scooters. Zhou Hiang, chief engineer of the State Administration of Machinery Industry said, at a press conference, in late 1999,

"With the new laws in place, the production of electric bicycles will be greatly expanded and become a new hot spot of China's economic development. Evs are expected to become more popular as people's living standards increase and urban traffic is improved. Electric bicycles and motorcycles are more easily accepted in China than cars, given the present income level".

He believes electric bicycles are the best substitute for fuel-powered motorcycles, which are a cause of serious air pollution in large cities.

5.2.3. Boost for 2 wheelers in Taiwan

As a result of the severe pollution problems in Taiwan from 2 wheel vehicles – mainly small two stroke motorcycles and scooters – the Government of Taiwan mandated, in 1998, that 2 per cent of motorcycle sales must be for electrically powered vehicles. There are about 1.5 million motorcycles sold per year in Taiwan. The total stock of conventional motorcycles is around 8 million, in a small country packed with 20 million people.

5.2.4. The big potential- bicycles

The largest number of transport equipments in the world is bicycles. The fastest-growing transport sector is motorcycles/2 wheel scooters.

Yamaha report that Japan alone has 70 million push bicycles, about one for every two people. China has hundreds of millions of them.

5.2.5. Weak market drivers in the West but some changes

While several countries in East Asia have been encouraging electric bicycles, the West has done the opposite, with full motorcycle legislation applied in most countries. That means insurance tax and even a hard hat in most cases. Roads must be used not sidewalks. While Europe seems to be doing little to change this situation, the US eased its laws in late 2002 according to ZAP, who report,

"According to legislative reports, the United States Senate has approved HR727 and President Bush has signed it into law. The bill, introduced by Cliff Stearns (Republican – Ocala, Florida), passed the house in 2001. Currently, low-speed electric bikes are regulated by the national Highway Traffic Safety Administration (NHTSA), which subjects these bicycles to the same standards as motor vehicles.

Low-speed electric bicycles offer consumers the convenience of assisted power," explains Stearns. "These bikes give their riders, often seniors, the disabled and law enforcement officers, some extra help in pedalling long distances and uphill. These are bicycles and should be regulated as bicycles. Under NHTSA's jurisdiction, electric bikes will be required to have additional equipment such as those on trucks and cars. These requirements would upset the weight and balance of the bicycles, as well as increase their prices. However, sales of electric bicycles remain at pitiful levels in all western countries.

HR727 will transfer jurisdiction over low-speed electric bicycles from NHTSA to the Consumer Product Safety Commission, which regulates consumer products such as bicycles. The legislation applies to low-speed electric bicycles with less than one horse-power and a maximum of 20 miles per hour."

5.2.6. Hybrid motorcycles

Hybrid motorcycles and, later, fuel cell motorcycles should prove a success because they will eventually give lower cost over life, less pollution and fewer refilling stops. Like hybrid cars, later models will offer superior acceleration etc to the pure ICE equivalent.

5.2.7. Case study: Segway

The Segway, "Human Transporter" has been causing a stir since its introduction in 2002. Amazon made the first few deliveries late in 2002/early 2003.

It claims to be the answer to vehicle congestion in modern cities. The much-hyped scooter, the creation of US inventor Dean Kamen, has a top speed of 12.5 mph and can carry a single person, with baggage.

To overcome instability, it is equipped with a system of gyroscopes and tilt sensors. These monitor the user's centre of gravity about 100 times a second and tilt the scooter in order to compensate for the user's movements. When the rider leans forward, the Segway moves forward but retains its stability. Lean back and it goes backwards. See figures 5.3, 5.4 and 5.5.

Fig. 5.3 **Segway Human Transporter**

Source: Segway

Fig. 5.4 **Segway Human Transporter at rest**

Source: Segway

Fig. 5.5 **Segway Human Transporter with carriers**

Source : Segway

Source: Segway

This allows the Segway to dispense with brakes, accelerators and normal steering; instead, the rider moves forward to go faster, pulls back to stop and sways into bends.

The scooter is powered by a battery.

Steve Jobs, the head of Apple, hailed the product as the answer to traffic and pollution but it remains a niche product, constrained by the weather, legal constraints on wheeled vehicles on sidewalks and the dangers of use in vehicular traffic.

5.2.8. Case study Rietti undercuts Segway

To overcome the high price of a Segway, Rietti now offers a similar, but in some ways inferior, product for $699.95 retail in the US. Figure 5.6 illustrates this product, which pushes back when you break to avoid the driver falling forward. It uses two extra wheels for stability rather than the gyros of the Segway but sales have been modest so far.

Fig. 5.6 **Rietti two wheel scooter**

Source: Gadget Universe

Listing of manufacturers

The following are examples of manufacturers of EV two wheelers and EV quad bikes. There are a large number of very small companies making very small numbers. Indeed the largest EV conference in the world moved to Beijing in 1999, when the associated exhibition was packed with companies newly making two-wheel EVs – over 30 in all. At the Belgian Motor Show in January 2000 there were 24 makes of EV bicycle. See table 5.7.

Table 5.7 **70 examples of manufacturers of two wheel Evs and electric quad bikes**

COMPANY	COUNTRY
AdEl	Europe
Badsey Electric Group	USA
Barlic	China
BikeElectric	UK
Bridgestone	Japan
Celco Profil	Italy
Charger Bicycles	USA
Condor Industry	USA
Currie Technologies	Australia
Dana Corporation	USA
Denali Cycles	USA
eCycle	USA
Electric Motorbike	USA
Electric Transportation Co	USA
Electric Vehicle Company of Thailand	Thailand
Electric Vehicle Technologies	USA
Electrobike	USA
Eserati Electric Tech	USA
ETC	USA
EV Global Motors/Fairly	USA/Taiwan
EV Max	USA
EV Rider	USA
FAAM	Italy
FAR	Italy
Fenghua Yongwang	China
Garmendale Engineers	UK
GDF	Czech Republic
Giant Bicycles	USA
HCF	Taiwan
Heinzmann	Germany
Honda	Japan
Ideation	Taiwan
Jayanth Chadra	India
Kynest	China
Long Reach	UK
Mase Generators	Italy
Mechatronics	Russia
Mercedes Benz	Germany
Merida	Japan
Miyata	Japan
Mobilec	Brazil, China
Montague	China
MBK	Japan
MZ Engineering	Germany
Ningbo	China
Nova Cruz	Australia
Panasonic	Japan

COMPANY	COUNTRY
Pedal Power LLC	USA
Power Assisted Products	USA
Pro Audio Elite	Italy
Prima Ricerca	Italy
PSA Peugeot Citroen	France
Raleigh	China
REVI	USA
SABAT	China/USA
Sanyo	Japan
Segway	USA
Shanghai Elite	China
SMH	China
Suzuki	Japan
Sunpex	Taiwan
Suzhou Small Antelope	China
T&DI	China
Tiaoku	Taiwan
Tokyo R&D	Japan
Trek Bicycles	China
Vectrix	Poland/Ireland
USA-Bikes	USA
Yamaha	Japan
Zap	USA

Source: IDTechEx

Table 5.8 gives the largest suppliers of electric bicycles by number.

Table 5.8 **Largest suppliers of electric bicycles by number (not in order)**

COMPANY	COUNTRY
Hero	India
Shanghai Forever	China
Phoenix	China
Suzhou Small Antelope	China
Giant	Taiwan/China
Merida	Taiwan/China

Source: IDTechEx

CycleElectric put the largest by number as Suzhou Small Antelope.

The following tables 5.9 to 5.15 give detailed listings, prepared by CycleElectric International Consulting Group and reproduced with their permission, the information in these tables was correct at 21 August 2001 for Pedelec and E-Bike manufacturers and system makers, country breakdowns, type of propulsion systems and battery used and estimates of numbers of units sold.

5.2.9. Europe

CycleElectric estimates that the total units sold to European dealers in 2000 were 53,380. In 2001 it was about 65,000. The numbers in table 5.9 are estimates given by the manufacturers in July 2002.

In 2005, sales of two wheel electric vehicles remain lacklustre in most countries but hybrid and later fuel cell motorcycles should have a great future.

Table 5.9 **Supply of electric bicycles in Europe 2000/2001 by number, maker and battery chemistry**

MANUFACTURER – BRAND NAME	COUNTRY OF FINAL ASSEMBLY	ESTIMATES OF UNITS SOLD		SYSTEM MAKER	BATTERY CHEMISTRY
		2000	2001		
Sparta	The Netherlands	7,000	13,000	Yamaha	NiMH & NiCd
Sachs	Germany	4,500	2,200	Sanyo	NiCd & NiMH
Powabyke (Shanghai Elite)	China	4,500	4,500	Elite	Lead
Piaggio	Italy	4,000	1,500	Prima-ABB	Lead
Yamaha-MBK	France	4,000	7,000	Yamaha	NiMH & NiCd
Merida	Taiwan	3,000	3,000	Merida	NiMH
Prima	Italy	3,000	500	Heinzmann	NiCd & Lead
Heinzmann	Germany	3,000	400	Heinzmann	NiCd
Sinclair	UK	3,000	3,000	Sinclair	Lead
Renault	Taiwan	2,000	500	Giant	Lead
BKTech/Biketec	Switzerland	1,500	1,600	BKTech Biketec	NiCd
Lafree	Taiwan – The Netherlands	1,500	4,000	Giant Panasonic	Lead NiMH
Aprilia	Italy – Taiwan	1,500	2,000	Merida	NiMH
Kynast	Germany	1,000	2,000		NiCd
Otto	Italy	1,000	n/a	Adel	Lead
Antec	The Netherlands	1,000	1,000	Antec	Lead & NiCd
Mercedes-Benz	Germany	1,000	3,000	Sanyo	NiCd
BiKit	Germany	1,000	2,500	BiKit	Lead
KTM	Austria	800	1,000	Egston	NiCd
Velocity	Switzerland	500	150	Velocity	NiCd
Rex	Sweden – Austria	400	n/a	Schachner	NiCd
Thun	Germany	300		Sanyo	NiCd
Peugeot Velectron	France	300		Panasonic	NiCd
Epple	Germany	100	See SRAM	SRAM	Lead
AC-Power Bike	Austria	45		Kasbauer	NiMH
Una-E	Germany	35	40	Heinzmann	NiCd
SRAM	Germany		5,500	SRAM	Lead
Schachner	Germany		2,000	Schachner	NiCd
Roll-Tech	Germany		600	Heinzmann Schachner	Li-Ion & Lead
Hean Cyclen	Denmark		500	Heinzmann	Lead
Hoening	Germany		350	Sanyo Heinzmann	Lead & NiCd
Draisin	Germany		150	Heinzmann	NiCd
Panasonic	Japan		100	Panasonic	NiMH
Lohmeier	Germany		60	SRAM Heinzmann Lohmeier	Lead, NiCd, NiMH
Kleinebenne	Germany		60	Egston	NiCd
Others		5,400	590	Many small makers and importers	Lead, NiCd, NiMH

Source: CycleElectric

Table 5.10 gives major electric 2 wheel scooter makers in Europe.

Table 5.10 **Listing of major light electric scooter makers and importers in Europe**

COMPANY	COUNTRY	COUNTRY OF MANUFACTURE
ADEL	Italy	Italy
Tante Paula	Germany	Taiwan
MZ	Germany	Germany
Glider	The Netherlands	Taiwan
GDF	Czech Republic	Czech Republic
Heinzmann	Germany	Taiwan (by HCF)
Barth	Germany	Germany
Sachs	Germany	China
EZ-Rider	The Netherlands	Taiwan
ISD	Italy	China

Source: CycleElectric

5.2.10. USA

USA sales shown in table 5.11 include small stand-up scooters

Table 5.11 **Sales of two wheelers in USA by number, maker and battery chemistry (12 months to 21/8/2001)**

BRAND OR MANUFACTURER	FINAL ASSEMBLY	QUANTITY	SYSTEM MAKER	BATTERY CHEMISTRY
EV Global	Taiwan	17,000	Heinzmann	Lead
Giant Bicycle Co.	Taiwan	20,000	Giant	Lead
Merida	Taiwan	3,000	Merida	Lead/NiMH
Currie Technologies	Taiwan/Thailand	39,000	Currie	Lead
Zapworld.com	USA/ Taiwan	33,000	Zap	Lead
BiKit	China	2,500	BiKit	Lead
ETC	Taiwan	10,000	ETC	Lead
Rabbitt	USA	25		NiMH
Heinzmann	Germany	400	Heinzmann	NiCd
Mercedes	Germany	165	Sanyo	NiCd
Condor	Taiwan	25	Condor	Lead
Various Chinese	China	500	Hub Motors	Lead/NiMH
HCF	Taiwan	2,500	HCF	Lead
Various Chinese scooters	China	3,000	Various	Lead
JD Components	Taiwan	6,000	JD Components	Lead
Babsey	USA	500	Babsey	Lead
Moterrad	Germany	100	MZ	Lead
Electricbike Factory	USA	100	Proprietary	Lead
Think Mobility	Taiwan	250	Giant	Lead
EV Rider	Taiwan	62,000	JD Components	Lead
SRAM	Germany	300	SRAM	NiCd
Schwinn	Taiwan	800	Currie	Lead
Trek	USA	500	Yamaha	NiCd
Charger/GT	USA	1,000	Aerovironment	Lead
Denali	USA	200	Denali	NiMH
Worksman	USA	10	Heinzmann	NiCd
Industrivel	Canada	n/a	n/a	n/a
EGo	USA	35	EGo	Lead
EPS	Canada	20	EPS Hub	Lead
Diamond Firefly	China	200	Hub	Lead
Master Shine	China	15,000		Lead
Sunpex	Taiwan	3,500	Sunpex	Lead

Source: CycleElectric

5.2.11. Japan

The Japanese Pedelec market has been the main market for Pedelecs in the 6 years 1996 to 2001. The average sales volume in these years was about 200,000 units in the domestic market according to CycleElectric.

Table 5.12 **The two wheeler brands offered on the Japanese domestic market by market share and battery chemistry**

BRAND NAME	SYSTEM MAKER	BATTERY CHEMISTRY
National Panasonic	National Panasonic	NiCd/NiMH
Yamaha	Yamaha	NiCd/NiMH
BMI / Bridgestone	Yamaha	NiCd/NiMH
Honda	Honda	NiCd/NiMH
Miyata	Yamaha / National Panasonic	NiCd/NiMH
Marsushi	Yamaha	NiCd/NiMH
Sanyo	Sanyo	NiCd/NiMH
Suzuki	Suzuki / National Panasonic	NiCd/NiMH
Others		NiCd/NiMH/Lead

Source: CycleElectric

5.2.12. China

The Chinese market was estimated by CycleElectric International in 2001 as being about 1 million units annually. Due to aggressive incentives by local and central government, this is expected to grow rapidly to 10 – 13 million units annually.

There are about 250 companies in China that are involved in some way with supplying electric bikes or electric bike components.

Table 5.13 **34 sources of two wheelers in China by brand, region and battery chemistry**

COMPANY	PROVINCE	BATTERY CHEMISTRY
Cranes Battery – Powered Bicycle	Shanghai	Lead
Shanghai Unison Electodynamics, Ltd	Shanghai	NiMH
Shanghai Kefeng Electric Bicycle Company	Shanghai	Lead
Shanghai Shangda Technology Co. Ltd	Shanghai	Lead
Chengdu Beite Electric Bicycle Company	Sichuan	Lead
Sunbird Electric Bicycle	Sichuan	Lead
Min Sida Electric Bicycle Company	Sichuan	Lead
Huafeng Electric Bicycle Company	Sichuan	Lead
Jianshe Industry Co. Ltd	Sichuan	Lead
Ningbo Xunlu Deer Motor Vehicle Co. Ltd	Zhejiang	Lead
Zhe Jiang Wolong Group Co. Ltd	Zhejiang	Lead
Ningbo Huajia Industry Company	Zhejiang	Lead
Zhe Jiang Libahuang Group Corp	Zhejiang	Lead
Eleshine Electric Vehicle Co. Ltd	Jiangsu	Lead
Sunway Group Co. Ltd	Jiangsu	Lead

COMPANY	PROVINCE	BATTERY CHEMISTRY
Suzhou Small Antelope Electromobile Co. Ltd	Jiangsu	Lead
Tianxing Electric Bicycle Company	Jiangsu	Lead
Toprun Electric Bicycle Co., Ltd	Jiangsu	Lead
T & Di Continental Dove Electric Motor-Driven Bicycle	Jiangsu	Lead
Chi Tuma Electric Bicycle Company	Jiangsu	Lead
Beijing Tsinghua Electric Vehicle Co. Ltd	Beijing	Lead
Anyang Feying Group Co. Ltd	Henan	Lead
Shenyang Wangda Vehicle Spare Parts Co. Ltd	Lianning	Lead
Suppo Battery Co. Ltd	Lianning	Lead
Shijiazhuang Kangjia Electric Company	Hebei	Lead
Yizhou Chunfeng Electric Bicycle Company	Hebei	Lead
Zhaocheng Electric Bicycle Company	Anhui	Lead
Mai Ge Wei Electric Bicycle Company	Guangxi	Lead
Tianjin Teda Electric Vehicle Co. Ltd	Tianjin	Lead
Newtimes Motor Holdings Co. Ltd	Tianjin	Lead
Yi Te Electric Bicycle Company	Tianjin	Lead
Fege Bicycle Group	Tianjin	Lead
Wuhau Yunghe Electric Company	Wuhan	Lead
Yunnan Hongta Electric Bicycle Company	Yunnan	Lead

Source: CycleElectric

Table 5.14 **Listing of light electric scooter makers in China (all presently use lead-acid battery chemistry)**

RANK	COMPANY
1.	Buyang Group (China) Feishen Folding Pulley Industrial Co. Ltd
2.	Zhejiang Xingyue Power Machinery Co. Ltd
3.	Technopark Tower Co. Ltd
4.	Fujian Fortune Jet Mechanical & Electrical Technology, Ltd
5.	Guangdong Yorkpoint Electric Vehicle Group Co, Ltd
6.	Macat Bike Company, Macat Group
7.	Chang Zhou City Jonson Sport-bicycle Co, Ltd
8.	Taiwan Zhaori Electric Co. Ltd
9.	Zhejiang Qunsheng Group
10.	Zhejiang Yuankang Four Star Co. Ltd
11.	Dongguan Glorious Company
12.	Dongguan Yuandong Scooter Company
13.	Zhejiang Huangyan Chaoqian Electrical Vehicle Co. Ltd
14.	Zhejiang Xingxing Electric Vehicle Co. Ltd
15.	Taizhou Xingyuan Electric Machinery Instrument Co. Ltd
16.	Zhejiang Hengi Power Supply Co. Ltd
17.	Zhongxing Electric Vehicle Co. Ltd
18.	Zhejiang Wuyi Dongfeng Machinery Company
19.	Yongwang Vehicle Accessories Factory
20.	Pangyu Welltruth Motor Company
21.	Zhejiang Yongkang Feipeng Electromotion Vehicle Factory
22.	Zhejiang Yongkang Lingying Motor Accessories Factory
23.	Zhejiang Yongkang Shuangmen Electric Factory
24.	Zhejiang Yongkang Yiyun Electro Co. Ltd
25.	Jifa Co., Ltd
26.	Hongda Industrial Company Co. Ltd
27.	Shanghai Yilida Enterprises Development Co. Ltd
28.	Shanghai Kefeng Electric-Vehicle Development Co. Ltd
29.	Shanghai Xiande Trade and Industrial Co. Ltd

Source: CycleElectric

5.2.13. Power system makers for electric bikes, pedelecs and small E-scooters

System makers are suppliers to the light electric cycle industry. Worldwide there are just about fifty key power system makers that are dominating the market volume, according to CycleElectric who are foreseeing that this trend of less and less system makers will continue because of the higher and higher pressure on quality and price for these products. To meet customer expectations more and more pedelec and e-bike makers will use power systems offered by large system makers. The key system makers are listed in table 5.15.

Table 5.15 **Two wheeler EV system makers by battery chemistry**

SYSTEM MAKER	BATTERY CHEMISTRY
National Panasonic	NiCd / NiMH
Yamaha	NiCd / NiMH
Merida	NiCd / NiMH
Honda	NiCd / NiMH
Giant	Lead
Heinzmann	NiCd
Sanyo	NiCd / NiMH
Suzuki	NiCd
BiKit	Lead
ETC	Lead
Currie / MAC BMC	Lead
Zap	Lead
SRAM	Lead
Shanghai Elite	Lead / NiCd
Zhongxing	Lead
EleShine	Lead
Keda EBM	Lead
Suzuhou Small Antelope	Lead
Shanghai KeFeng	Lead
Zhe Jiang Wolong Motor	Lead
BGB	Lead
Marsahl	Lead
T & Di	Lead
Elebike	Lead
ADEL	Lead
Prima	Lead
LuYuan	Lead

Source: CycleElectric

5.3. Market forecasts, 2005 to 2015

5.3.1. Overall market

Table 5.16 gives our market projections for two wheel EVs.

Table 5.16 **Manufacturing market projections for two wheel EVs at ex works prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	2,650	3,500	4,600	5,300	6,000	6,800	7,000	8,200	9,000	10,000	11,300
$ Unit value	566	608	652	707	750	800	862	828	869	905	976
$ billion value	1.50	2.13	3.00	3.75	4.5	5.44	6.04	6.79	7.82	9.05	11.03

Source: IDTechEx

There are no trade associations collating figures for all electric bicycles and the task is compounded by the rapidly increasing number of manufacturers and the addition of EV two wheel scooters and the Segway Human Transporter in future years. Also compounding the problem will be electric motorcycles, notably hybrids and fuel cell driven versions. Average prices rise in future primarily because of scooters and motorcycles not because of the Segway and clones becoming significant.

However, over 70 per cent of the market will be in China for several more years. Some may therefore question our implication that sales of two wheelers and allied vehicles in the West will remain modest for several more years. However, the glamour and publicity surrounding these vehicles in the West has yet to be reflected in sales performance. FAAM seem to have taken ten years to sell 500 seated two wheel scooters. Excellent publicists Zap entered US Chapter 11 Bankruptcy Protection in 2002. Many participants continue to go under or lose money heavily, though some will strike it rich by innovating correctly.

5.3.2. Fuel cells important one day?

A weakness of battery two wheelers is range. For large two wheelers such as motorcycles a weakness can be lack of sustained high power delivery. Fuel cells promise to solve both problems.

Time Magazine named a prototype fuel cell-powered bicycle designed by Aprilia, SpA as an "Invention of the Year 2001". The fuel cell was provided by the NovArs unit of Manhattan Scientifics, Inc.

"Fuel cell technology, which uses pollution-free hydrogen gas to generate an electric current, could ignite electric bike sales," said Time. "The first prototype, from Italian bike maker Aprilia, stores compressed hydrogen in a two-liter canister housed in the frame. With a top speed of 20 miles per hour. the bike won't win the Tour de France. But it weighs 20 per cent less than regular electrics and travels twice as far .... Now that's cool."

Manhattan Scientifics announced in 2000 that it had entered into an agreement to develop a fuel cell-powered concept bicycle with Aprilia, a leading manufacturer of motor scooters and motorcycles. The fuel cell bicycle was demonstrated as part of the Aprilia exhibit at the Bologna Motor Show in 1999. The company said the bicycle has approximately a 50 mile range, and the bicycle's hydrogen storage container can be re-fuelled in "a minute".

Motorola and others have worked on fuel cells for laptop computers for many years so small fuel cells are by no means a new concept. In 2003 it was possible to buy palm sized fuel cells to recharge mobile phones but no fuel cell powered vehicles of any type are on open sale even in 2005. With two wheelers fuel cells face problems of lack of fuelling infrastructure. If they are to be recharged by cartridges (like mobile phones) there will be a problem of cost and safety. Figures 5.1, 5.15, 5.17 and 5.18 show latest prototypes and concept vehicles.

5.3.3. Fast growth in China

Li Zheng, an expert on EVs in her native China puts Chinese demand for electric bicycles alone at several million a year within a few years. She notes that air pollution in Chinese cities has become very severe not least because of small gasoline engines. Electric bicycles will become the most common form of motorised transportation replacing mopeds, gasoline motor assisted bicycles, and motor scooters, in her opinion.

5.3.4. Massive pollution in China

Only 1 per cent of the cities in China can qualify for the desired standards of air quality (there are over 600 major cities in China). Shanghai and Beijing are the most polluted cities in the world according to the World Health Organisation.

Shanghai, Beijing, Tanjing, Guangzhou and other cities in China already forbid the sales of gasoline powered bicycles, a far more draconian move than any contemplated elsewhere in the world other than perhaps Nepal.

Zheng notes that congestion means it takes about 1 – 2 hours to go to work by public transportation in China but an electric bicycle typically halves this time, so there is more incentive to buy these bicycles than simply legal coercion.

The increase of living standards and wages now makes it possible for many Chinese to buy electric bicycles. The income of ordinary people has increased more than ten times in recent years, so they can afford electric bicycles though not yet motorcycles or cars on average.

When the e-bike first emerged in Shanghai in 1985, 10,000 electric bicycles were sold immediately. If there had not been the problems of quality of the bicycles, the market would have rocketed at once but it shows that the demand already existed.

The number of bicycles which are owned by people in Shanghai is four million. From surveys, 20 per cent of bicycle riders wish to own an electric bicycle. A similar number wish to buy gasoline powered bicycles. As sales of gasoline powered bicycles are strictly limited, the percent of bicycle riders who wish to but electric bicycles will exceed 20 per cent argues Li Zheng. Two million could certainly be sold in five major cities. However, the number of bicycles in China is 2 billion, so replacing only a small percentage could create a business of several million EVs yearly, certainly by 2010. This and the advent of hybrid EV motorcycles and two wheel scooters drives our forecast of sales rising to 10.9 million two wheel EVs in 2015.

5.3.5. Fundamentals are good

Benjamin argues that increasing prices for gasoline and automobiles will impose a larger burden on family finances and encourage a move to electric bicycles. Legislation and regulation designed to combat air pollution will also help to foster the electric bicycle business. Benjamin says bicycle retailers must realise that electric bicycles will appeal to a much wider audience. In the West, he feels that the industry is focusing its efforts on the much smaller sport bicycle market, when a potential transit market would be much larger.

“The electric bicycle is the first of an explosion in transportation products that are going to change often,” says Benjamin. “The public has never had a lot of choices in transit technology. That’s about to change.”

Figures 5.7 to 5.13 show various two wheel electric scooters and bikes.

Fig. 5.7 **Electricmoto motorcross motorcycle by blade**

Source: Blade

Fig. 5.8 **Two wheel electric scooter by Electric Vehicle Technologies**

Source: Electric Vehicle Technologies

Fig. 5.9 **Two wheel electric scooter by Electric Vehicle Technologies**

Source: Esarati

Fig. 5.10 **EVT "Survivor" MD70EMT bike**

Source: Electric Vehicle Technologies

Fig. 5.11 **EVT Scooter**

Source: Electric Vehicle Technologies

Fig. 5.12 **Viento Scooter by Electric Cycle Company**

Source: Electric Cycle Company

Fig. 5.13 **Lepton Scooter**

Source: Lepton

5.3.6. Battery projections

Battery two wheel EV sales are projected in table 5.17.

Table 5.17 **Global market for battery driven two wheel vehicles, at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	2,500	3,100	4,000	4,500	5,000	5,500	6,000	6,500	7,000	7,500	8,000
$ Unit value	300	300	300	300	300	280	270	260	260	260	260
$ billion value	0.75	0.93	1.20	1.35	1.50	1.54	1.62	1.69	1.82	1.95	2.08

Source: IDTechEx

5.3.7. Hybrid projections

Table 5.18 **Global market for hybrid two wheel vehicles, at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	-	400	600	799	988	1,295	1,490	1,680	1,950	2,300	2,750
$ Unit value	-	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
$ billion value	-	1.20	1.80	2.40	3.00	3.88	4.47	5.04	5.85	6.90	8.25

Source: IDTechEx

5.3.8. Fuel Cell projections

Table 5.19 **Global market for fuel cell two wheel vehicles, at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	–	–	–	1	2	5	10	20	50	85	140
$ Unit value	–	–	–	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
$ billion value	–	–	–	0.003	0.006	0.015	0.03	0.06	0.15	0.26	0.42

Source: IDTechEx

Fig. 5.14 **Electric Vehicle Technologies' All Terrain Vehicle (ATV)**

Source: Electric Vehicle Technologies

The Electric Vehicle Technologies ATV quad bike shown in figure 5.14 is a battery-only vehicle at present. We believe hybrid versions will also be popular.

5.3.9. Case study: ENV fuel cell motorcycle 2005

The company describes its 2005 product as follows:

The ENV (Emissions Neutral Vehicle) bike was designed to Intelligent Energy's brief by a British team, led by multi-award-winning designers Seymourpowell (last year cited as Britain's 6th most important cultural movers and shakers in a BBC poll). Figure 5.15 shows the bike.

Fig. 5.15 **The ENV fuel cell motorcycle**

Source: EN

The ENV bike is fully-functioning and has been engineered and purpose-built (based around Intelligent Energy's world-beating Core fuel cell) from the ground up, demonstrating the real, everyday applicability of fuel cell technology. The Core, which is completely detachable from the bike, is a radically compact and efficient fuel cell, capable of powering anything from a motorboat to a small domestic property.

Fig. 5.16 **The ENV removable 1 KW PEM fuel cell**

Source: ENV

ENV is lightweight, streamlined and aerodynamic. It boasts a performance that outreaches any existing electrical bike. In an urban or off-road environment, it can reach speeds of 50 mph.

It is also virtually silent (with noise equivalent to an everyday home computer) and its emissions are almost completely clean.

On a full tank, the ENV bike could be used continually for up to four hours without any need for re-fuelling. The bike can also be used by riders of any skill level with simple controls, via a throttle directly linked to the applied power. The bike has no gears and is strictly defined as a motorbike, although it feels to riders more like a very quick and responsive mountain bike. 'ENV is light, fast and fun', commented Seymourpowell director Nick Talbot. 'It has good ground clearance, great off-road suspension travel and a very carefully considered power to weight ratio. I have ridden motorbikes for years', he added, ' and, in the process of designing the bike, I have become a convert to fuel cell technology. The bike is usable, useful and great-looking. It was important on this project to demonstrate that new technologies don't have to be wrapped up in a dull product – engaging public imagination and enthusiasm is key.'

ENV has been produced in two monochromatic colourways: black supergloss and iridescent white. 'This was to express the bike's parallel natures', explained Nick Talbot. 'On the one hand, it expresses a utopian future vision of 'clean power, anywhere' - and on the other, it's an exciting, hard-edged bike and fun to ride.'

The bike's primary frame and swinging arm are made from hollow-cast aircraft grade aluminium. At its heart is a fully-integrated 1kW fuel cell generator providing power on demand directly to the drive-train. To enhance performance during peak power demand (i.e. when accelerating), the fuel cell is hybridised with a battery pack to provide a 6kW peak load to the motor. The result is a balanced hybrid concept which combines the main advantages of Intelligent Energy's Core fuel cell, hydrogen storage and battery technology.

www.envbike.com

5.3.10. Honda FC Stack fuel cell motorcycle

Figure 5.17 shows an alternative approach – the experimental Honda fuel cell powered scooter that can start in sub-zero temperatures

Fig. 5.17 **Experimental Honda fuel cell powered scooter**

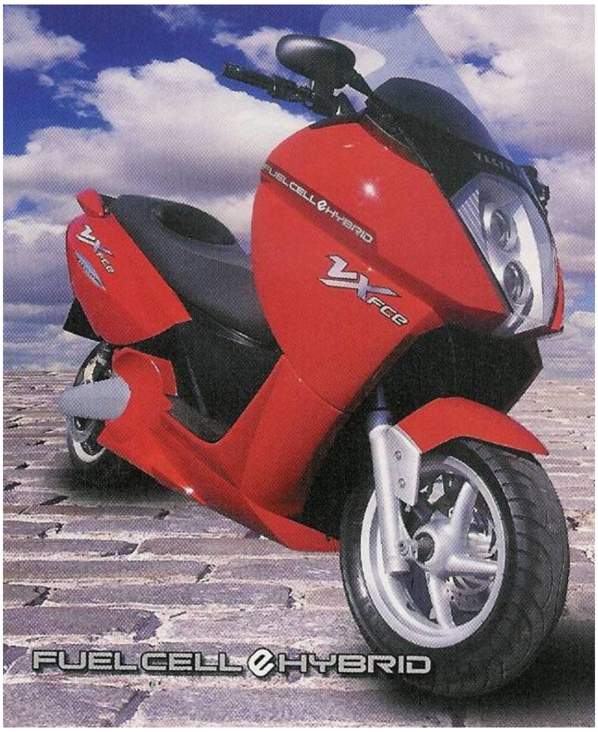
Source: Honda

The high-efficiency next-generation Honda FC Stack has been made even lighter and smaller, and redesigned for use in scooters. Honda has applied their expertise gained in the development of fuel cells for automobiles, and further miniaturized the system, optimizing it for application to scooters.

5.3.11. Case study: Vectrix fuel cell "electric hybrid" scooter in 2005

The new Vectrix scooter is not a hybrid in the sense of combining batteries or battery/ fuel cell combinations with an ICE. Rather, it is an "electric hybrid" meaning that the fuel cell boosts what is a pure battery powered EV by continuously charging the battery. It is shown in figure 5.18.

Fig. 5.18 **The new Vectrix "electric hybrid" fuel cell scooter 2005**



Source: Vectrix

The specification is

- 62 mph top speed
- 1-50 mph in 6.8 seconds
- Up to 150 mile range

The model VX-FCe will be launched in Europe and the US in 2007.

The claimed benefits are environmental friendliness, low operating costs, longer battery life and minimal maintenance. It was jointly developed with Parker Hannefin Corporation www.parker.com/fuelcells which has skills in motion and control systems and Protonex a manufacturer of power solutions for small and portable equipment. For Vectrix, which specialises in zero emission vehicles see www.vectrixusa.com

Battery-only Vectrix

Vectrix has a new Maxi-Scooter, for which £30 million ($60 million) was sought by floating about 60 per cent of Vectrix shares on Aim, the London junior market, in June 2005.

'The European attitude to the environment changes as you go north. It is important in northern Europe. In the south of Italy environmental consciousness is zero,' says Carlo Di Biagio, Chief Executive elect at Vectrix. 'But I was captivated by the performance of this bike. That's what will sell it there. It has the riding experience and the acceleration of an 800cc machine. It's like being launched into space.

'It's a revolution in bike travel. There is no pollution and it handles like a big bike. It satisfies your riding needs. It's truly unique. Scooters are very much used for commuting, and it's that market that we're in,' he says. Few European commuters travel further than 30km and the bike lasts around 80 minutes. According to the prospectus, it recharges a totally flat battery in two and a half hours.

Currently, 35 per cent of two-wheeled motor vehicles in the UK are mopeds of less than 50cc. Some 35 per cent of the UK two-wheeled market is motorbikes, and the scooter accounts for the remaining 30 per cent. However, the UK market is relatively immature: half a million two-wheelers go into Rome every day, compared to 35,000 that go into London.

The vehicle was designed in the company's Rhode Island offices by Andrew MacGowan, its chairman and founder.

Di Biagio argues that there are a lot of machines to be sold in the UK and that the City understands the type of company that Vectrix is. He says: 'In the UK the scooter market is growing fantastically – it was up 26 per cent by unit sales last year. It's a function of more traffic and congestion on the roads and public transport becoming more unpopular.'

The cash raised by the share sales is going to go into financing a factory and a couple of Vectrix shops, one in Rome and one in London. So now Di Biagio has a unique product and a detailed plan to sell it in his favourite markets across Europe. The object is to sell 6,000 machines in the first year of production. They will cost about £5,500 ($9,000) and there are good tax breaks for such machines in Italy, apparently.

Fig. 5.19 **Electric bicycle by OVO of France**

Source: OVO

Fig. 5.20 **TAMI Rhino EV skateboard from Australia**

Source: TAMI

6. Golf EVs

6.1. Definition

This section is concerned with people-carrying golf cars, including those that are used for non-golf purposes provided they are unmodified. It includes single seat golf buggies, some of which fold to go in a car trunk though these are in a minority. Excluded are golf-cars heavily modified for industrial or commercial use, ones carrying six to ten people being an example. These are in the Light Industrial and Commercial section. Large pedestrian-operated electric golf caddies for the clubs of several players are included : these are very widely used in Japan. Small individual motorised caddies are also included. However, by far the dominant product by gross sales value is the two-seat golf car so popular in the US and most of the rest of the world. Some are four-seat.

6.2. Market drivers

6.2.1. Golf course creation

The primary market driver of growth is the number of golf courses being built. This peaked some years ago in the most important location, the USA. Secondarily there is the trend to personal ownership of golf cars, the increased use of unmodified golf cars for personal transportation in local communities notably in the US and the replacement market, which grows as the population of golf cars increases across the world. For example, leader Textron saw a 15 per cent increase in golf cars sold to individuals in 2002. There is also a small contribution from the increase in the percentage of vehicles sold that are electric - around 60 to 70 per cent today – and from the increase in the number of open roads outside golf courses where their use is becoming legal. Some cities in the US now permit golf cars on open roads, for example.

One difficulty in establishing unit prices is the fact that most golf cars are leased and the notional equivalent value is rather arbitrary. Currently the industry pitches this low at around $3,000 in the US depressing the evaluated market size by value. We use ex factory prices.

In the last few years, the growth rate of the golf car market has eased primarily due to the saturation of need on golf courses, as few new courses are now being built.

6.2.2. Secondary market - golf cars not used for golf

In the US in 2005, there are over 500,000 golf cars modified for on road use, where they can be less than half the price of an Neighbourhood Electric Vehicle NEV but more primitive. The majority are used throughout the sunbelt in gated communities. Around 150,000 golf cars are sold every year in the US for on road use but there is no equivalent market anywhere else in the world. A smaller opportunity has been golf cars adapted for use in airports, land management etc.

6.3. Listing of manufacturers

Table 6.1 gives some examples of the rather modest numbers of golf EV manufacturers following the shakeout ten years ago. Only niche players and volume players remain. However, there are now several new entrants each year. New entrants stay as niche players. Table 6.1 gives examples of manufacturers making golf EVs.

Table 6.1 **15 examples of golf EV manufacturers**

COMPANY	COUNTRY	VEHICLE
American Chariot/Planet Electric	USA	Golf car
J C Andruet	France	Golf car
Beijing Fullstar	China	Golf car
Columbia ParCar	USA	Golf car
Electric Mobility	USA/Poland	Golf car
FAR	Italy	Single seat golf vehicle
Gorilla	USA	Golf car
Ingersoll Rand	USA	Golf car
Kangaroo Motorcaddies	USA	Golf caddy
Melex	Poland	Golf car
Panasonic	Japan	Golf caddy
Pihsiang	Taiwan	Golf caddy and car
PowaKaddy	USA	Golf caddy
Textron	USA	Golf car
Yamaha	Germany	Golf car

Source: IDTechEx

6.4. Market forecasts by technology and region 2005 to 2015

6.4.1. Golf EV market

The global golf EV market is shown in table 6.2. All are pure, battery-only, EVs. The ex factory average price is depressed by exclusion of industrial and commercial variants and the inclusion of motorised golf caddies. In later years there may be a few hybrids replacing the remaining ICE vehicles used for golf.

Table 6.2 **Manufacturing market projection for golf EVs, all are battery-only vehicles (cars plus caddies), 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	265	265	265	265	265	265	265	265	265	265	265
$ Unit value ('000)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000
$ billion value	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53

Source: IDTechEx

We reiterate that this is not the total of sales of golf car operations. It excludes industrial and commercial variants, spare parts and service.

Table 6.3 gives the geographical split in 1999, 2003 and 2013 by percentage.

Table 6.3 **Geographical split of golf EV sales by value 2000, 2005 and 2015**

	2000	2005	2015
US	60%	65%	60%
Rest of World	40%	35%	40%
Total	100%	100%	100%

Source: IDTechEx

6.4.2. No more growth

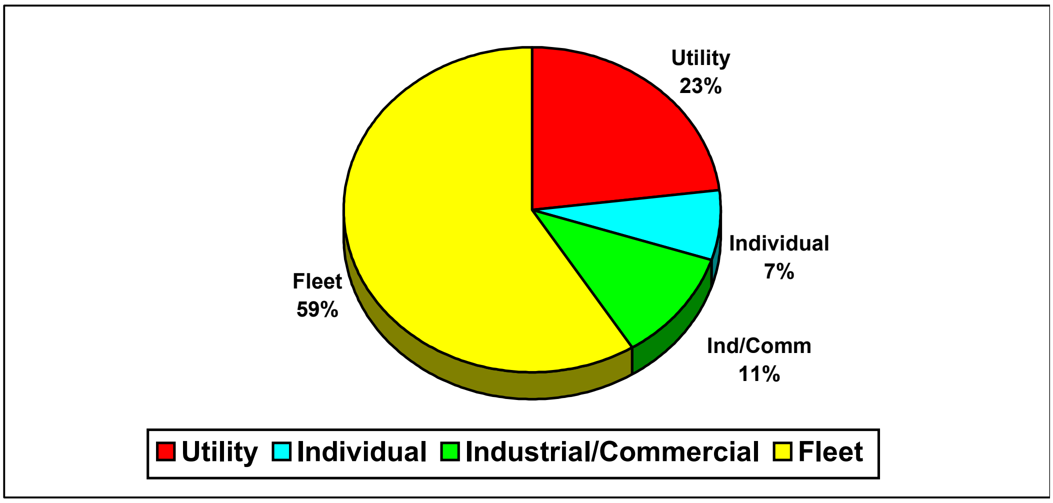
As a senior executive of another golf EV company put it to us "Just about everyone in this industry knows the party is now over". Fast growth and strong prices have gone for ever, because the US has built most of the golf courses needed, electric golf cars last longer and there are fewer and fewer ICE vehicles to replace.

6.4.3. Low prices

Unit pricing of golf cars varies from $800 for used models to $20,000 for specials. In the US a typical golf car is around $2500 ex factory or into lease and $3500 on the street to an individual but prices are sometimes higher in the rest of the world. Motorised golf caddies can cost only a few hundred dollars ex factory. Golf cars are relatively unusual in that electric versions are often cheaper than ICE versions. This is far from true for road cars, for instance.

The split of the market by application is shown in figure 6.1.

Fig. 6.1 **Global golf car market and allied light industrial vehicle market in 2003**



Source: Textron

The market trends as:

- Niche opportunities
- Growth in individual owner
- Emergence of China / South East Asia.
- European "Street Legal" vehicles
- Regulatory mandates and incentives

No great incentive or funding to make hybrid or fuel cell versions.

However, in 2005 we believe that the rest of the world is barely providing market growth in golf cars to compensate for easing in growth of the US market. This is partly because of global economic shakeout but it is also due to few countries emulating the US love affair with golf. Hybrids or better battery golf cars may replace the yearly sale of ICE golf cars. ICE golf cars are needed on hilly large courses, at least in the opinion of golfers in Japan.

Figures 6.2 and 6.3 shows two vehicles from Ingersoll Rand Club Car, number two in the business after Textron. It illustrates how allied vehicles can be made on a basic golf car chassis.

Fig. 6.2 **Latest pure electric golf car from Ingersoll Rand**

Source: Ingersoll Rand

Fig. 6.3 **Latest and all terrain vehicle from Ingersoll Rand**

Source: Ingersoll Rand

6.4.4. Turnkey success

In a classic marketing move, for the last seven years, Textron has been reacting to market saturation by selling turnkey services rather than just vehicles.

Textron Golf, Turf and Specialty Products is leading the golf industry as the only provider to offer a single, turnkey, fully-integrated package – golf cars, turf products, maintenance vehicles and in-house financing. For example, it was awarded a multi-year, exclusive contract with Meadowbrook Golf Inc to provide E-Z-GO golf cars, Jacobsen turf equipment and Cushman specialty vehicles – all financed by Textron Financial.

7. Cars

7.1. Types of electric car 2005-2015

In this category we include cars for the open road and vehicles that carry more than one person in closed communities, or at restricted speeds, where full crash - proofing and other approvals are not needed. Of course golf cars are also used in neighbourhoods, on and off-road but these are dealt with under Golf Cars. Microcars and other electric cars designed or adapted in a major way for the disabled are dealt with under Disabled when they are based on an EV scooter for the disabled. However, single person, covered microcars not aimed at the disabled are included here, ones from Honda and a $100,000 high performance version from Commuter Cars Inc being examples. The main types of EV car in 2005 and 2015 divide into the categories given in tables 7.1 and 7.2.

Table 7.1 **Types of EV car and technology 2005**

TYPE OF CAR	USUAL EV TECHNOLOGY TODAY
Intercity car (including SUV)	Hybrid ICE/ battery. Mainly gasoline, some diesel. None can be plugged in to charge and none can run mainly on the battery alone.
Neighbourhood Electric Vehicle (NEV)	Pure EV Battery-only
City car	Pure EV Battery only

Source: IDTechEx

Table 7.2 **Types of EV car and technology 2015**

TYPE OF CAR	USUAL EV TECHNOLOGY TODAY
Intercity car (including SUV)	Hybrid ICE/ battery, some pure EV fuel cell. Gasoline and diesel are popular in hybrids.
Neighbourhood Electric Vehicle (NEV)	Pure EV Battery-only, some pure EV fuel cell, but still needing a battery.
City car	Pure EV Battery only, some pure EV fuel cell but still needing a battery.

Source: IDTechEx

7.2. Plug in hybrids and fuel cells are coming.

Figure 7.1 shows an experimental pure EV fuel cell car from Hyundai

Fig. 7.1 **An experimental pure EV fuel cell car from Hyundai**

Source: Hyundai

It may seem surreal that the Sports Utility Vehicle (SUV) is so often the object of trials of hybrid or fuel cell EV technology but ICE SUVs account for 60 per cent of the US motor industry's earnings. General Motors, Ford and DaimlerChrysler certainly want to hold on to them for as long as possible. There is something of a runaway situation in most developed countries by which the tax on SUVs is so affordable and they are so safe when they hit a small car – but do so much damage to it – that owners of small cars are increasingly tempted to buy the SUV. Indeed, SUVs are also seen as a way of navigating the many new speed bumps and other hazards without discomfort. This rates progress of increasing fuel consumption as vehicles get bigger is illustrated in figure 7.2. However, the figure also shows the benefits of today's hybrids and the planned hybrids that can be topped up by being plugged into an electricity supply. Both Valence Technology and California Cars Initiative showed concept plug-in hybrid cars in Spring 2005 that were based on the Toyota Prius.

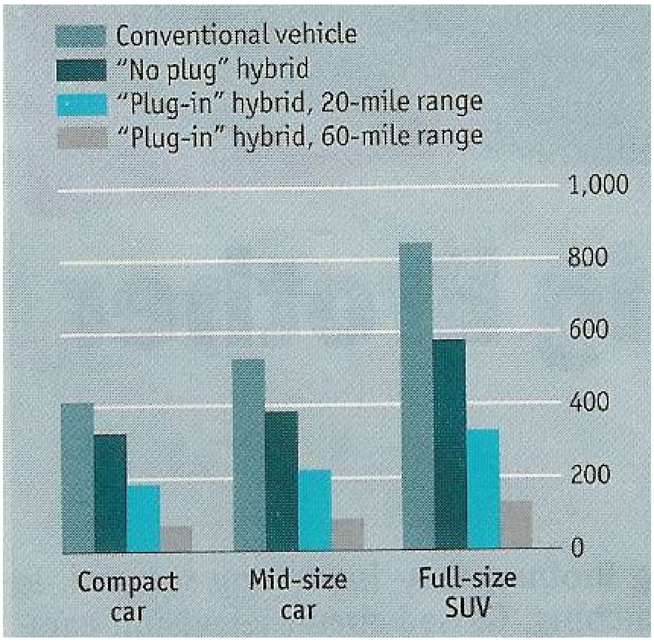
The success of the SUVs made by US companies may turn out to be a pyrrhic victory against the steady penetration of the US automotive market by the Japanese. The highly regarded US analyst Scott Sprinzen of Standard and Poors said, in spring 2005:

"Recently, sales of [GM's] mid-size and large SUVs have plummeted and industry wide demand has stalled, partly because of high gas prices. What we have is a decline in the product segment that represents one of the most substantial sources of earnings for these companies [GM and Ford]. Although GM has substantial cash reserves, its ability to withstand persistent poor financial performance is not unlimited."

However, Paul Ballew of General Motors said, "There is no substantial secular decline in SUVs..." and Bill Ford of Ford Motor Company said, "We don't share anyone's pessimism. It is our job to prove our critics wrong."

Nevertheless, the debt of GM, Ford and Chrysler has downgraded to high risk recently and the head of Toyota has cautioned Japanese companies against taking US market share too quickly because major factory closures in the US could become a political issue. Clearly, US motor companies must bet correctly on hybrids and other new models. Rightly or wrongly, the financial markets see a significant possibility of GM or Ford going under within ten years. Standard and Poors say there is a one in eight chance.

Fig. 7.2 **Average annual fuel consumption in US gallons by vehicle type**



Source: EPRI, DaimlerChrysler, Economist

Figure 7.3 shows the Ford Escape hybrid SUV now in production

Fig. 7.3 **The Ford Escape hybrid SUV now in production**

Source: Ford

However, the Europeans are laggards, because they favour pure diesel for reducing fuel consumption, even though it is less beneficial than gasoline hybrids, and emits nitrogen oxides which cause smog and are detrimental to health and the particulates are a respiratory health hazard. However, Ricardo in the UK is teamed with Qinetiq in the UK to build a diesel electric hybrid – something of a half way house, and particulate filters for diesel engines are improving. The objectives vs the existing Prius are shown in table 7.2. However, by the time it gets there, if it ever does, the Prius and its contemporaries will have moved on. Nonetheless, others believe in the concept.

7.3. Ultra environmental diesel hybrids in 2020?

A study by the Laboratory for Energy and the Environment at the Massachusetts Institute of Technology has predicted that, in 2020, diesel hybrids could even achieve the same energy efficiency and greenhouse gas emissions as fuel cell vehicles powered by hydrogen made from natural gas. It is a long way off because, for now, a diesel engine costs about $2000 more than a gasoline engine and it needs systems to treat the exhaust. Indeed Californian laws require diesels to be as clean as gasoline vehicles yet filtering nitrogen oxides remains a problem and particulate filters only remove 90% at present.

Table 7.3 **Objectives of the Ricardo Qinetiq diesel hybrid being designed in 2005 vs today's Prius gasoline hybrid**

TYPE	FUEL ECONOMY MILES PER US GALLON	CARBON DIOXIDE EMISSION GRAMS PER KILOMETER
Today's Prius	55	104
Planned diesel hybrid	70	90

Source: Toyota, Qinetiq

7.4. Nissan hybrids 2005

Figure 7.4 shows the Nissan Altima hybrid car. Nissan has collaborated with Toyota on hybrids since 2002, licensing Toyota intellectual property with the long term objective of becoming more independent. In 2002, the agreement guaranteed delivery of 100,000 in a five year period but Nissan entered 2005 having sold very few.

Fig. 7.4 **The Nissan Altima hybrid car.**

Source: Nissan

7.5. Market drivers

7.5.1. Artificial pricing makes volumes uncertain

In any sector where profits are rare, the forecasting of sales is hazardous because they will be affected by more than consumer demand. Companies may decide to abandon a model simply because it has lost too much money or suddenly impose a massive price hike. This is not true of any of the other major categories of EV as represented by the other chapters of this report. That said, in 2005, we are probably within three years of the eleven or so hybrid models currently on offer, and their immediate successors, making money.

7.5.2. Factors correlating with profit

Of the 60 plus companies making or preparing EV cars only four claimed to be profitable in their EV activity when we surveyed them from 1999 to 2002 and even here the profits were on the back of other more-successful products they sell such as commercial or industrial electric vehicles or selling EV designs, sub-systems and licenses. In 2005, we have reason to believe that much the same situation pertains. Most of the EV car "successes" in profit terms relate to small cars that do not replace the family car. They include bubble cars and pedal-assisted enclosed 3 wheelers.

7.5.3. Problems with pure EV cars will be overcome

Pure EV cars continue to be strongly rejected by nearly all consumers.

Table 7.4 gives the evidence gathered by Nissan to explain this.

Table 7.4 **Nissan ranking of reasons for rejecting pure EV cars**

1.	Price
2.	Range
3.	Recharge time
4.	Availability of public recharge points

Source: Nissan

For most, the problem with battery-only EV cars remains a reluctance to buy, at any price, something with "a two gallon tank that takes eight hours to refill". Most offerings have been of this nature. Most EV cars look like clones of conventional cars pitched as direct replacements that are somewhat more green but much more expensive. Some experts such as Bill Dahlberg, chief executive of Ford Th!nk says this is always doomed to failure.

"You must make the connection between the consumer and the technology", he said at the NAEVI conference in Atlanta, in late 1999. Ford failed to do so, however, abandoning their Th!nk pure EV car in late 2002 after selling only 1,600 or so.

7.5.4. New Mitsubishi pure EV car 2008-2010

In May 2005, Mitsubishi Motors Corp. of Japan announced that it will start selling electric cars in 2010. The Tokyo-based automaker, showed off a small test vehicle equipped with motors embedded in the rear wheels that run on lithium-ion batteries.

"For a company with small sales like ours, this is a way we can assert a meaningful presence," Tetsuro Aikawa, who oversees product development and environmental research, told reporters at the company's headquarters. The company is undecided on overseas sales for the car. Aikawa said the planned mini-electric car, which will be available for test fleets in 2006, has a cruising range of 150 kilometres on a single charge and can be recharged in a regular home.

Mitsubishi is targeting housewives who drive to pick up children from school, go grocery shopping and won't need to travel long distances, Aikawa said, adding that they are expected to enjoy owning a car that never needs to fill up at a gas station.

Officials said the electric car will cost slightly more than a comparable gas-engine vehicle but they hope to keep prices down through government aid available for buyers of ecological cars. Although the price isn't decided, it may sell for under two million yen ($19,000 US), according to Mitsubishi Motors.

There are many technical innovations that can assist innovative stylish design of pure EVs whether fuel cell or battery driven. In 2004, Michelin unveiled an "active wheel" which bypasses the need for clutch, gearbox or transmission shaft or anti-roll bar says the company. This is because the wheel incorporates an electric traction engine so drivers can even switch between two and four wheel drive. It even includes an active suspension system.

7.5.5. Imaginative market positioning

Consumers buy pure EV cars for "green" or leisure reasons, for fun, to be different, for use where normal cars are impossible to park - and so on. They may be a "third" car, not a replacement for the family car. In future, in certain places they may be forced on consumers because conventional vehicles are banned. The profitable successes in cars so far therefore replace or augment human effort or make something new possible like parking in a few square metres : they rarely directly replace ICE vehicles. Accordingly, we should expect that shrewd market positioning will be a major key to success in the future as well. In the end, only the profitable vehicles survive.

7.6. Companies and launch programs

7.6.1. Hybrids

The beauty of hybrids, which combine ICE and electric power delivery, is that they require no change in driver behaviour (no finding an electric point) and they do not call for a special fuelling infrastructure (as fuel cell and pure EVs do). Recently, Joseph Romm, director of the Center for Energy and Climate Solutions, a non-profit US institution said, "Hybrids are almost certainly the platform from which all future clean vehicles will evolve."

Little wonder then that, in sharp contrast to pure EV cars, hybrid electric vehicles are showing strong growth and innovation and we are now in the decade (or more) of the hybrid. This is because they are reliable, affordable – particularly with the available government grants - and more fuel efficient than virtually all pure ICE vehicles. People feel good about their environmental credentials vs ICE, because they have up to 90% reduction in emissions.

7.6.2. Exponential growth of hybrids

For example, in 2005 it was announced that DaimlerChrysler and General Motors have agreed to work together on a more fuel-efficient dual mode hybrid propulsion system for all types of vehicle. Following Ford Escape and Honda Accord hybrids launched in 2004, GM already announced a hybrid version of the Chevrolet Tahoe and GMC Yukon vehicles for late 2007 and Chrysler will have a hybrid Dodge Durango in early 2008. Following the eleven or so models we have today, CSM Worldwide, an automotive research company, forecasts that 20 new hybrid models will appear in the US by 2007. Current hybrids in the market or made in small numbers are shown in table 7.4. Examples of hybrid launches 2006-2015 are shown in table 7.5.

Table 7.5 **Examples of hybrids in the market or made in small numbers 2005**

COMPANY	MODEL
Toyota	Prius, MR2 sports, Civic, small bus, Lexus SUV, RX400H SUV, Crown sedan,
Daihatsu	Hijet cargo
Mazda	MX5 Miata
General Motors	Chevrolet Silverado, Chevrolet Sierra, Saturn Vue, Dodge pickup truck, diesel hybrid bus,
Ford	Escape
Optare	Solo bus
LYI/ Azure Dynamics	London black cab
Hino	Ranger
Hyundai	Click compact

Source: IDTechEx

Table 7.6 **Examples of hybrid launches 2006- 2009**

2006-2007	2008	2009
Chevrolet Tahoe GMC Yukon Toyota Camry Chevrolet Malibu DaimlerChrysler sport wagon GM Equinox pickup Nissan Altima Peugeot Citroen mini and family cars	Dodge Durango	Mercedes cars

Source: IDTechEx

7.6.3. Case study: Toyota Motor Co., Japan

Toyota is one of the best run companies in the world. It has the most consistent, comprehensive and intelligent EV program of any company. The market capitalisation of Toyota is over$105 billion. It is not weighed down by debt like several Western competitors. It makes six million vehicles every year. Figure 7.5 shows the Toyota CS&S sports car concept of a high performance hybrid.

Fig. 7.5 **Toyota CS&S concept of a high performance hybrid sports car.**

Source: Toyota

Total Toyota EV sales

We estimate that Toyota achieved the EV sales for 1999 to 2003, shown in table 7.6 and we estimate the sales for 2004 to 2007 in table 7.7.

Table 7.7 **Toyota sales of EVs, 1999 to 2003**

	SALES							
	1999		2000		2001		2003	
	NO K	VALUE $M	NO K	VALUE $M	NO K	VALUE $M	NO K	VALUE $M
Industrial / commercial	30,000	300	35,000	300	34,000	250	38,000	320
Cars	15,255	300	19,026	500	36,928	950	80,000	1,600
Associated parts and service	–	200	–	300	–	320	–	400
Total	45,255	800	54,026	1,100	70,928	1,520	118,000	3,320

Source: IDTechEx

Table 7.8 **Estimated Toyota sales of EVs 2004-2007**

	SALES							
	2004		2005		2006		2007	
	NOK:	VALUE $M	NK:	VALUE $M	NOK:	VALUE $M	NOK:	VALUE $M
Industrial / commercial	39	320	40	330	41	360	42	370
Cars	100	2000	160	2800	250	3500	350	4000
Associated parts and service	-	500	-	600	-	700	-	800
Total	139	2820	200	3730	291	4560	392	5170

Source: IDTechEx

Toyota hybrids

In August 2005, Toyota confirmed that it will launch hybrid versions of ten more models in the next five years and sales of about one million extra hybrid cars yearly will result. Toyota leads the world in hybrid vehicles. Its Prius, at once the most sophisticate (series parallel) and the best selling hybrid car has won many awards including, in 2004 alone:

- North American Car of the Year
- European Car of the Year
- International Engine of the Year

Sales of 90,000 in 2004 will rise to 140,000 in 2005 but other hybrids will also be sold. The relative success of the Prius prompted Toyota to develop of a range of hybrids, including Prius sports car, a version of the Yaris City car, the Previa multi-purpose vehicle, and, launched as a hybrid in 2002 the Crown luxury model. There will be a hybrid Harrier SUV and Alphard van. The official stance of

Toyota is that ICE-electric hybrids will be the main low-emission vehicles for the next few years and the company intends to have hybrid versions of all its models eventually..

Toyota – global leader in industrial EVs

The largest EV manufacturing operation of Toyota is heavy industrial vehicles where it is global leader. We profiled the heavy vehicles in Chapter 2. However, Toyota also make an EV floor cleaner, high washer and high sweeper, and battery powered towing tractors.

In 2000 Toyota probably achieved $2 billion dollars in EVs and associated services and they probably held at least this figure in 2001/2002 by increased sales of hybrid cars, buses etc, offsetting a drop in the market for industrial EVs. In 2003, Toyota EV sales including service were probably $3.3 to 3.5 billion, more than treble the nearest competitor.

International manufacturing centres and outside sourcing

Toyota manufactures fork-lift trucks in Japan, the USA and France through its subsidiary TMC (Toyota Motor Corporation). In-fill of the product range is achieved by the Toyota brand on certain competitor's products. Wheel loaders, regarded as construction machinery, are also produced in the Toyota factories.

Even before the BT Industries acquisition, Rödig and Scherr reported "In spite of the difficult economic climate in Asia there can be no doubting Toyota's important position among the leaders of industrial vehicles." Subsequently, the economic position in Asia has improved. Indeed, in 2005, the Chinese economy is now growing at twice the rate of the USA.

Leverage

Toyota tell us they make good use of their industrial EV skills to leverage their other EV activities. Such leverage is not available to their car-making Western competitors as they no longer have industrial vehicle divisions.

Toyota light industrial and commercial vehicles – the most product launches?

In 2001, Toyota launched the first four-wheel drive hybrid-electric minivan, the Estima. The 6-passenger vehicle has a 2.4-litre, four-cylinder gasoline engine, batteries, a pair of electric motors, and a continuously variable transmission. The minivan primarily runs on battery electric power, and when more power is needed, the gasoline motor kicks in. In 2001 sales of 1,000 per month were announced. Toyota has committed $481 million to alternative and improved engines.

Toyota also makes buses, on-road trucks, airport ground support equipment and other light industrial and commercial EVs and neighbourhood cars all in modest quantities.

Toyota fuel cell vehicles

Toyota has been testing fuel cell cars since 2003. These are heavily loss-making trials. The company thinks fuel cell vehicles are some way away, but it is heavily investing in them for many types of vehicle. Toyota is marketing just a few of a fuel cell SUV in Japan and the US much earlier than originally planned. The earlier launch reflects the successful results of a year of testing in the US and Japan of the FCHV-4 prototype, and it is Toyota's response to society's expectations for cleaner mobility solutions.

The SUV, based on the Kluger-V in Japan and the Highlander in the US, newly developed, featuring conventional vehicle-like performance based on improvements to the FCHV-4's reliability, cruising distance, functionality and other aspects. Reducing cost, cold temperature performance and other issues remain. Therefore leases are offered only to select private sectors, technology related companies, institutional organisations and research facilities. Toyota is leasing a total of approximately 20 vehicles during the first year to entities that have access to hydrogen-supply infrastructure and after-sales service.

In 2005, Toyota has about half the global EV car market by value and about 20 per cent of the industrial/commercial EV market.

The one to beat

We believe that Toyota will remain the world's largest EV manufacturer by value until at least 2008. Toyota has 90 per cent of the global market for hybrid on-road vehicles at present. It may have at least 20 per cent of global industrial and commercial EV sales. It has the greatest commitment and consistency of purpose. Its plethora of new product launches should reinforce its leadership. Its rate of launching new EV products is about double that of most competitors. At meetings we have often heard Western competitors admit that Toyota is "2 years ahead" and "the one to beat". However, we have not found any evidence that Toyota are serious about 2 wheelers, EVs for the disabled or other small EVs such as home robots and AGVs. It does not make EV air- or watercraft. More surprisingly, as yet, the company is not particularly active in light industrial EVs in growth markets such as airports.

7.6.4. Case study: ZAP

The following press release describes the current activity of ZAP.

SANTA ROSA, California (September 23, 2004) - The small, Northern California Company that made a name for itself by 'zapping' bicycles, scooters, and cars, celebrated its tenth anniversary today. ZAP (OTC BB:ZAPZ) of Santa Rosa, California has been working for the past decade to commercialize the growing demand for more energy efficient and environmentally friendly forms of transportation and energy.

Fig. 7.6 **ZAP Worldcar made in China**

Source: ZAP

Today ZAP is on the verge of becoming America's newest automotive manufacturing company. This week, ZAP announced that its new Chinese-assembled electric WORLDCAR™ has been certified by the State of California Environmental Protection Agency as a "Zero-Emission Vehicle" and is one of the first full-performance production electric cars. ZAP is also waiting for EPA approval of the new Smart Car Americanized by ZAP, a 60-MPG micro-car imported from Europe. With these cars soon to be available to consumers, ZAP is working on establishing a ZAP automotive dealer network that will become the distribution portal for a variety of advanced automotive technologies that follow ZAP's philosophy of 'Zero Air Pollution.'

ZAP has restructured in the past few years with the addition of its recent automobiles as well as other new products to create divisions underneath the corporate umbrella and brand of ZAP. In addition to its automotive division, ZAP is retaining its consumer products division to further develop its line of electric bikes, scooters and similar vehicles. ZAP also recently announced the establishment of ZAP Energy Division with the introduction of its new ZAP Portable Energy, a lithium-ion battery system that can be used as a power source for mobile electronics, like cell phones and handheld computers. ZAP says technology like this produced in larger formats has the ability to power electric cars for hundreds of miles per charge.

ZAP has come a long way since its humble beginnings in 1994 in Alameda, California where it manufactured its patented ZAP electric motor kit for bicycles. ZAP moved to Sebastopol, California in 1995 and expanded to make electric bicycles for law enforcement, commuting and recreation. ZAP went public in 1996 to keep the company moving ahead and growing with an innovative Direct Initial Public Offering on its website. ZAP parleyed its entry into the stock market to introduce its ZAPPY® folding electric scooter, which catapulted the relatively unknown company around the world, with shipments of the ZAPPY to more than 60 different countries. To this day, ZAP's patented ZAPPY is still known as one of the best electric scooters on the market.

ZAP's success with the ZAPPY was short-lived as it came to grips with increasing low-cost competition for scooters and bicycles. In the period following 1999, ZAP sought to diversify its product lines with such items as electric motorcycles, underwater scooters, neighbourhood electric cars and more. The costs in R&D to develop new products was further hindered by the stock market crash of 2000, which left ZAP with few choices but to seek protection under a Chapter 11 Reorganization in 2002. During this four-month period, ZAP reorganized to reduce its operating costs and brokered a merger with two automotive marketing companies, which resulted with the entry of Steve Schneider as Chief Executive Officer for ZAP.

Schneider dreamed that the timing was ripe to establish a new car company focused on advanced transportation technologies that are socially responsible and friendly to the environment. By combining ZAP's resources and brand recognition with his 20 years experience in the automotive business, over the past two years Schneider has charted an aggressive new strategy of creating an auto dealer network that caters to environmentally friendly consumers.

"As a pioneer in this industry ZAP has taken a number of risks, but we now feel that ZAP is positioned to be involved in a major shift taking place in the transportation and energy markets," said ZAP CEO Steve Schneider. "In an era when industry and government are debating about the future of transportation, ZAP is forging ahead with new technologies, new products and an aggressive new business plan. We like to say that ZAP stands for Zero Air Pollution, which is a new kind of philosophy that we feel is important for the industry of tomorrow. In the end, we think that a good business is a business that is good for the environment and is socially responsible."

Schneider's dream came one step closer to reality last month when ZAP and technology partner Apollo Energy Systems unveiled a new hydrogen fuel cell technology powered by liquid ammonia and an advanced lead-cobalt battery system. This patented innovation of a fuel cell system used by NASA could also bring America one step closer to President Bush's dream of a hydrogen economy. ZAP and Apollo say that they could put a fuel cell powered ZAP car on the road by next year, years ahead of the forecasts for other hydrogen fuel cell designs

7.7. Listing of manufacturers

Table 7.9 gives some of the companies that are either manufacturing or intending to manufacture EV cars including hybrids.

Table 7.9 **57 examples of manufacturers and intending manufacturers of EV cars**

COMPANY	COUNTRY
AC Propulsion	USA
Araco	Japan
Bajaj Auto	India
Beijing Fullstar	China
BigMan EV	USA
BMW	Germany
CityCom	Germany
City El	Germany
Commuter Cars	USA
Corbin Pacific	USA

COMPANY	COUNTRY
Daihatsu Motor	Japan
DaimlerChrysler	Germany/USA
Dixon Engineering	USA
Dynasty Electric Car Corp	Canada
Elcat	Finland
Electric Auto	USA
Euro Automobiles Heuliez	France
EV Global Motors	USA
Feel Good Cars	Canada
Fiat	Italy
Ford	USA
Frazer Nash	UK
Garmendale Engineers	UK
General Motors	USA
Global Electric Motorcars	USA
Hino Motors	Japan
Honda	Japan
Hyundai	Korea
Isuzu	Japan
Kia Motors	Korea
Lada	Russia
MAN	Germany
Mazda	Japan
Mitsubishi	Japan
Nevco	USA
Nissan	Japan
Otomobil	Malaysia
Piaggio	Italy
Pihsiang	Taiwan
Proton	Malaysia
PSA	France
Reliant	UK
Renault	France
Reva Electric Car Company	India
Scholl SunPower	Switzerland
Solectria	USA
Sparrow	USA
Subaru	Japan
Suzuki	Japan
Svenska ElFordan	Sweden
Swatch	Switzerland/France
Transit Innovations	USA
TWIKE	Switzerland
Unique Mobility/Pininfarina	USA/Italy
Volkswagen	Germany
ZAP	USA
ZEV Technologies	USA

Source: IDTechEx

7.8. Market size and trends 2005-2015

7.8.1. Manufacturing market projection

Table 7.10 gives our forecast for the next decade.

Table 7.10 **Manufacturing market projection for EV cars, prices ex factory, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number (000)	300	400	601	801	1,012	1,255	1,510	2,015	2,420	2,895	3,150
$ K unit value	20	20	20	20	20	20	18	18	18	18	17
$ billion value	6.0	8.0	12.0	16.0	20.2	25.1	27.2	38.7	46.8	52.1	60.4

Source: IDTechEx

Prices are actually very unpredictable because being below cost in most cases, at least in early years, they are arbitrary. Government subsidies are also volatile. The above volumes could be halved and average prices double or vice versa. In later years, as fuel cell versions start to sell, they will be priced at a heavy and uncertain loss.

7.8.2. Breakdown by type and manufacturer

Evolution not revolution

From 2005-2010, new batteries and fuel cells start to make the EV family car affordable and practicable for far more people. That implies making a small but significant dent in the 60 million or so ICE cars made world-wide every year. We see a most likely figure of 1.25 million EV cars sold in 2010. The long timescale represents evolution not revolution and it depends on battery cars and hybrids. Fuel cells will be making a very slow start.

7.8.3. Neighbourhood vehicles

A neighbourhood electric vehicle (NEV) is a car used for going short distances in gated communities, on small islands and so on. About 10,000 to 15,000 neighbourhood cars have been sold worldwide by various companies, but Bombardier of Canada backed out of the business after disappointing sales of its neighbourhood vehicle, Global Electric Motorcars remained important. Global Electric Motorcars, had sales of $12.5 million in 1999 and probably at least that in 2000, when it was acquired by DaimlerChrysler. In the US, there are over 50,000 vehicles yearly are put to use for this purpose but most of them are second-hand golf cars.

Prices

Second-hand golf cars cost about $1,000. A new golf car bought for this purpose is no more than $4,000. The cars designed as NEVs are $6,000 to $15,000 in the main but they are easier to park, weatherproof and sometimes crash proof.

LSV definition

Low-speed vehicles (LSV) as defined by NHTSA and Transport Canada are vehicles that are commonly referred to as NEVs or neighbourhood electric vehicles, and are identified in the marketplace under brand names like GEM, Feel Good Cars ZENN, Dynasty IT and others. Maximum speed is often only 25 mph and they can be operated on streets with 35 mph speed limits.

Neighbourhood vehicles are usually limited to two seats which is unattractive to most people as is their price which is well above a golf car. The New York Times has also said they were "tough to sell (at $6,000 or more) where much cheaper golf cars ($3,500) are accepted".

Numbers

We believe in 2005 the US is taking only a few tens of thousand ZEVs yearly at most from all manufacturers put together, though the figure is growing. NEVs are considered appropriate for college campuses and retirement communities as well as restricted city centres. There is reason for optimism. The California Air Resources board(CARB) told us in 2003 that the cumulative sale of NEVs in California, the leading purchasing region, are between 7,500 and 16,000. They have eased their requirement that motor manufacturers sell a certain percentage of ZEVs. This would have meant 25,000 battery-only EV cars sold in California in 2003. However, the curiously named Partial ZEVs (PZEVs) are accepted in place of these and seven models had been approved by 2003. Some are lean burn pure ICE. Some are hybrid.

Laws planned

There is increasing legislative pressure to ban ICE cars from city centres and other sensitive areas but allow EVs. This is soon to be true in many European cities and San José-Costa Rica, Beijing-China, Mexico City-Mexico, New Delhi-India and Tokyo-Japan, to name just a few. In most of these cities air pollution is becoming very dangerous. Indeed, in an effort to battle air pollution, congestion and the impact of vehicles, some 35 French cities have banned conventional cars from their downtown areas during certain times as of 1999. All this may benefit neighbourhood vehicles as much as adoption in closed residential areas but the laws can be met in other ways - with travelators, walking, pedal power and sometimes even LPG, LNG or other low emission engines.

Table 7.11 gives our projections of global NEV sales 2005 and 2015.

Table 7.11 **Global sales of Neighbourhood Electric Vehicles (NEVs) and new or used golf cars serving that purpose in 2005 and 2015**

	2005	2015
New NEV	8,000	300,000
New and used golf cars	50,000	80,000
Total NEVs	58,000	380,000
Percentage in USA	70%	50%

Source: IDTechEx

Nearly all will be pure battery-only EVs because range is not an issue. Some may be called city cars. Companies selling over 50,000 three and four wheel scooters for the disabled yearly, such as Pihsiang, may soon be in a better position to make these NEVs than most of today's NEV manufacturers, for whom volume is a distant dream.

7.8.4. Taiwan tries to leapfrog - but not yet

Continuing the tradition of the last hundred years, we still hear of grandiose plans for production of electric cars. In mid 1999, Taiwan's Formosa Plastics Group, the country's largest business conglomerate, announced that it will spend $2 billion to manufacture EV cars and auto parts, primarily for export markets.

Company chairman Wang Young-ching said Formosa Plastics decided on EVs because Taiwan's conventional automobile production capacity is well behind that of other nations. Wang said tariffs on vehicles manufactured in Taiwan are expected to fall once the nation is admitted into the World Trade Organisation.

"In the past few years, we have focused on chemical products, but our next target will be electric cars" said Wang at the 1999 shareholders meeting.

The company's production plant became operational in 2003. Once full production capacity is reached in 2006, the plant is expected to turn out about 500,000 EVs annually. Formosa officials negotiated with the French automaker Renault for a possible technology transfer agreement. In the meantime, Pihsiang Machinery makes a few microcars on its production line capable of 200,000 vehicles yearly but most of its output of 60,000 vehicles in 2002 and around 100,000 in 2005 is vehicles for the disabled.

7.8.5. Forecasts

Virtually all forecasts of EV cars sales have been over-optimistic for decades. Forecasting can only derive from a tenuous base with on road EV transportation. At best 300,000 EV cars are in existence in 2005. The replacement market is therefore minuscule. So when will there be millions? There are 40 to 60 serious manufacturers of EV cars but every year or so one goes under. Large car manufacturers such as Toyota and Honda will obviously be successful with hybrids but there may be successful new entrants from countries such as Taiwan. The small players are more likely to run out of finance and/or be gobbled up by major automotive groups.

7.8.6. What will not happen

The only confident forecast of numbers and value is, in our opinion, the date before which the high volumes will not be achieved. As Freedonia Group points out, referring solely to on road transportation and pure EVs.

"Large scale deployment of electric vehicles will not occur until the range limitations of the current generation of vehicles are overcome, mass production of EVs results in sufficient economies of scale to make electric vehicles price competitive with conventional internal combustion vehicles, and the establishment of a recharging infrastructure occurs.

Fuel cell vehicles, which may potentially overcome many of the drawbacks that have inhibited EV sales to this point, particularly the limited range (usually less than 100 miles) between charges, will not see large scale production until after 2007."

Very significantly, at the CITELEC conference in Belgium in early 2000, a Toyota representative said that it is currently misguided to urge them to scale up volume of their best-performing pure EV cars such as the RAV4 because volume cannot lower its cost enough. New designs are needed. The same must be true of the excellent Nissan Altra.

Battery development are key

We feel that viable new batteries will be just as important as viable fuel cells, notably for local area car use, as with city centre cars, pooled "station" cars only used to get to the bus or train, or neighbourhood vehicles. These new batteries are also slated for 2005 or later for volume production. However, we disagree with other forecasters who argue that success with cars is all about pollution control, notably by new laws forcing people to buy EVs or better publicity persuading people to be "good citizens". Recent surveys have shown that people will pay very little more for "green" cars on average. Trendy, fun EV cars are appearing. Sometimes three fit in one parking lot. New uniques are being offered such as the tilting three wheeler. New markets will be created. These are examples of "making something new possible", a traditionally successful consumer proposition that several manufacturers of EV cars have ignored at their cost.

Nonetheless, we agree that the first one million EV cars made in one year will be in the year 2007 at the earliest (we say 2010). Freedonia call that a $24.2 billion industry in 2009 but today's evidence is that the down-market pure EV and the hybrid cars are the first to succeed. If down-market products represent most of the EV car market in 2007, a distinct possibility, particularly if most are purchased in East Asia, then the dollar sales may be less impressive than current forecasters believe. EV cars may be a $25 billion business in 2010, in our view. In value, it will be almost entirely a matter of hybrids replacing existing models of family car, SUV etc.

7.8.7. Forecasts by technology

J D Power LMC issued the following interesting press release on February 3, 2005.

WESTLAKE VILLAGE, California—Despite rapid growth in hybrid-electric vehicle sales forecasted over the next few years, hybrid market share is expected to top out at 3 percent of the U.S. automotive market by 2010, according to the J.D. Power-LMC Automotive Forecasting Services Hybrid-Electric Vehicle OutlookSM released today.

Nearly 88,000 hybrid-electric vehicles were sold in the United States in 2004, comprising 0.52 percent of the total U.S. light-vehicle market. With the number of vehicle models utilizing a hybrid-electric power train in the U.S. market expected to increase from 8 to 11 in 2005, J.D. Power-LMC anticipates hybrid sales will surge to more than 200,000 units this year, resulting in a market share increase to 1.19 percent.

Seventeen hybrid-electric models will be available in the U.S. market by 2006, when sales are expected to climb to more than 260,000 units and market share to reach 1.53 percent. J.D. Power-LMC anticipates that number to grow to 38 hybrid models—17 cars and 21 light trucks—by 2011, with sales reaching 535,000 units, or 3 percent of U.S. sales.

"Despite the significant growth in the number of models and annual sales over the next five years, we anticipate hybrid market share to reach a plateau of approximately 3 percent near the end of the decade," said Anthony Pratt, senior manager of global powertrain forecasting at J.D. Power-LMC

"This is related primarily to the price premium of $3,000 to $4,000 that consumers must pay for a hybrid vehicle, compared with a comparable non-hybrid option, and to competing technologies such as more fuel-efficient gasoline and diesel options that will be available after 2006."

Among automotive nameplates, Toyota—which currently holds more than 60 percent of the hybrid market in the United States—is expected to maintain the greatest hybrid share through 2011, when it likely will hold 40 percent of the hybrid market. Honda currently holds 31 percent of the hybrid market share but is expected to see its share slip to 20 percent by 2011. Chevrolet is expected to be the largest domestic brand in the hybrid market, growing its market share to nearly 15 percent by the end of the decade.

Released quarterly, the Hybrid-Electric Vehicle Outlook examines the sales and market share forecast for hybrid vehicles in the U.S. market. J.D. Power-LMC Automotive Forecasting Services is a division of J.D. Power and Associates.

Headquartered in Westlake Village, California, J.D. Power and Associates is an ISO 9001-registered global marketing information services firm operating in key business sectors including market research, forecasting, consulting, training and customer satisfaction. The firm's quality and satisfaction measurements are based on responses from millions of consumers annually. Media e-mail contact: michael.greywitt@jdpa.com or john.tews@jdpa.com

The IDTechEx forecasts of car sales by technology are given in tables 7.12, 7.13, 7.14. The hybrid figures imply about 6% of road vehicles made in 2015 will be hybrid – hardly a revolution. Frost & Sullivan predicts that nine out of ten European automakers are likely to turn to hybrid technology, and that by end of this decade HEVs will have reached an estimated penetration of about 2.7 percent in the European market. Indeed, ABI Research, with its own projections, forecasts that globally "less than 5%" will be hybrids in 2010 "provided present petrol (gasoline) prices persist." And there is the key point. It is quite possible that gasoline shortages and/ or price hikes and/ or tougher pollution controlling legislation could lead to at least 10% of vehicles made in 2015 being hybrid.

Table 7.12 **Global hybrid EV car sales at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	285	380	570	712	879	1,088	1,305	1,740	2,088	2,500	3,080
$ Unit value ('000)	20	20	20	20	20	20	18	18	18	18	17
$ billion value	5.70	7.40	11.4	14.2	17.6	21.8	23.5	31.3	37.6	45.0	52.4

Source: IDTechEx

Table 7.13 **Global battery-only EV car sales at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	15	20	30	88	131	162	195	260	312	370	440
$ Unit value ('000)	20	20	20	20	20	20	18	18	18	18	17
$ billion value	0.30	0.40	0.60	1.76	2.62	3.24	3.51	4.68	5.62	6.66	7.48

Source: IDTechEx

Table 7.14 **Global fuel cell EV car sales at ex factory prices, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	–	–	1	1	2	5	10	15	20	25	30
$ Unit value ('000)	–	–	20	20	20	20	18	18	18	18	17
$ billion value	–	–	0.02	0.02	0.04	0.10	0.18	0.27	0.36	0.45	0.51

Source: IDTechEx

Fuel cell car sales are modest and, compared with some other EVs analysed in this report, slow in growth. This is because of the many challenges in creating acceptable and affordable fuel cell cars. All the above sales will be heavily loss-making. Those, like EPRI, that anticipate even more modest sales in the decade to come may be right. However, we are encouraged by the proposed $1.2 billion US Freedom Fuel government package in 2003, $720 million being earmarked for infrastructure. Nonetheless, this money will only buy pilot studies. The cost of changing most gasoline stations to serve fuel cell fuel such as hydrogen runs to tens of billions of dollars in North America alone. Of course, this can be done gradually, as old equipment comes up for replacement but that delays things.

Claimed to be the world's first fuel cell powered sports car, this LIFECar is based on the Morgan Aero Eight. Starting August 2005, it is being developed in the UK over two years with a QinetiQ 24 KW PEM fuel cell and ultracapacitor regenerative braking. The UK Government is partly funding the $3.5 million cost. The platform is Ford, electronics is by Cranfield University, motors by Oxford University, system design by OSCar and refuelling facility by BOC.

The LIFECar is claimed to be the world's first fuel cell powered sports car,

Source: LIFECar

8. Marine

The US market for leisure boats alone is worth $14 billion in 2005 and it is growing. Just a small EV slice of that market can be big business and electric boats are used for much more than just leisure.

8.1. History

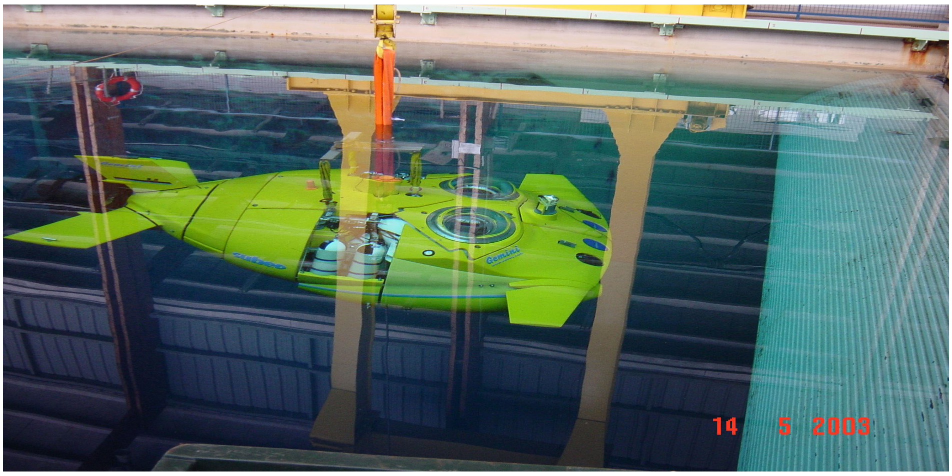
Electric surface boats have been made for 100 years. The first outboard motor was electric. However, the suitability of the electric motor is one thing: the imagination of designers is another. The marine EV sector is one of the few sectors where designers are very imaginative and constantly generate excitement and attention. This is a major factor in driving sales, notably of versions for leisure and for research, military use and ocean, oilrig and undersea cable monitoring.

8.1.1. Case study: Subeo Gemini submarine

Gemini is a recreational vehicle and has a depth range of 50 meters. Even at this depth the pressure on the hatches is about 14 tonnes, and the total pressure on the pressure vessel itself is about 125 tonnes. It has all the components of a large submersible, namely – surface buoyancy tanks, trim tanks, lead trim, lead acid batteries, life support systems, front and rear hydroplanes, a rudder and a very sophisticated control system consisting of a PLC (Programmable Logic Controller) and many electrically operated solenoid valves, pneumatic actuators, stepper motors, encoders and several electrical power systems. Its forward speed is 4-6 knots and when the surface buoyancy tanks are fully blown, it has a freeboard of 300-400mm. The design and control of the submersible combines just about every engineering discipline i.e. structural, electrical, mechanical, life support, physics, hydrodynamics and naval architecture. Gemini sells for about $900.000. Director David Harvey said, "Gemini is a prototype designed for mass production. We wanted to discover if there was a market for a submarine with this specification plus looks, and based on the interest to date, there most certainly is".

Marine

Fig. 8.1 **A Subeo Gemini submarine**



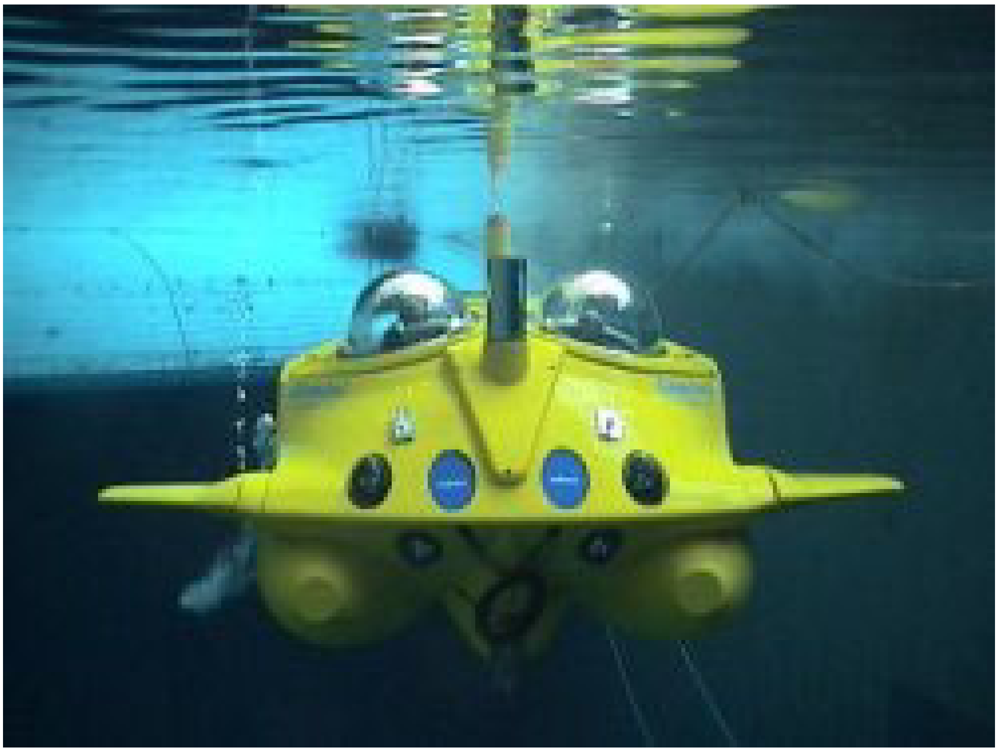
Source: Subeo

SUBEO Ltd., a UK company was formed in 1993 to develop small state-of-the- art underwater vehicles. The managing director and founder of the company Robert Leeds, designed the first concept vehicle Gemini. Robert Leeds has a background in Structural Engineering and Marine Work.

Other members of the development team used their expertise in system engineering, GRP fabrication, hydraulics, pressure vessel fabrication, life support engineering and general mechanical engineering to manufacture the vehicle, which was launched in August 2001.

The ceremony of the launching and naming of Gemini, was performed by Commodore David Russell, Deputy Flag Officer of the Royal Navy. Commodore Russell had a few days earlier returned from Russia where he had been leading the Royal Navy rescue team to the KIRSK disaster. Since the launch the Gemini sub has undergone exhaustive testing both in the UK and France.

Fig. 8.2 **The Subeo Gemini front view**



Source: Subeo

From the development of Gemini and the evaluation of all the systems, SUBEO Ltd has developed its Aquarius Vehicle. These vehicles are now available for purchase in various specifications depending upon customer requirements and budget.

SUBEO also designs specialist vehicles such as the 500m-research vehicle illustrated below .

Fig. 8.3 **Subeo specialist underwater vehicle**

Source: Subeo

8.2. Sales by region

8.2.1. Total market

Most electric boat builders are in the US and most sales are there. Several companies claim to be market leader. In Europe, Ruban Bleu of France is a market leader and in the USA it may be US Submarines. Much depends on who landed the last big order.

8.2.2. Underwater

Electric submarines and underwater diving tugs ("scooters") have been made in several countries since they were first sold steadily about ten years ago. Most underwater EV manufacturers are in the US and that is the main market for these. Only in the US is there a lively market for Remotely Operated underwater Vehicles (ROVs) and personal and tourist submarines, for example.

8.2.3. Large military submarines excluded

All the surface and undersea vehicles in our survey are very different from diesel electric military submarines that we exclude. Most of the types we consider are battery only and all are much lower in price. All subsea vehicles are battery only when used below the waves but the big tourist submarines may use other power sources when on the surface. Some are boat shaped and diesels may power them at up to 15 knots on the surface.

We illustrate various electric marine craft in figures 8.1 to 8.15.

Fig. 8.4 **Electric deck boat by Leisure Life**

Source: Duffy Electric Boat Co

Fig. 8.5 **Electric launch**

Source: Leisure Life Limited

8.3. Commonality with land EVs

Electric boats come within our definition of an EV and this is far from being an academic observation. Those making land-based EVs and their components should take an interest in marine applications because the same or similar motors, batteries and controls are used. National electric vehicle associations have boat manufacturers as members.

8.3.1. Grants for land and water

The massive European Union Fifth Framework of subsidies and grants for new technology provides backing for EVs. 40 per cent is land, 40 per cent marine and 20 per cent for work applicable to both land and marine EVs synergistically in one programme. EV boats include small electric submarines for leisure, research and military use but the largest sector is surface boats (sometimes charged by solar power, at least in part – see figure 8.4) for leisure and commercial use, mainly on inland waterways.

8.3.2. Effect of land EV manufacturers entering marine

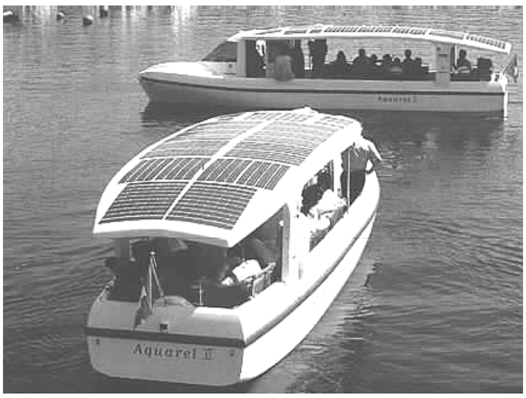
Even before European land EV manufacturers enter marine with EC assistance, US EV car makers Global Electric Transport and ZEV have started to make boats and ZAP, Pro Audio Elite and others make scuba power assisters, otherwise known as sea scooters, see figure 8.14. Yamaha and Honda make EV outboard motors and Yamaha may soon do EV boats. These and other companies with similar synergies may lower the price and increase the reliability of EV boats leading to volume sales and production automation to match.

8.4. Market drivers

8.4.1. History

In the US, at least 12 companies offered electric surface boats in 1995 according to EPRI. A similar number of companies in the US do so today. What has changed is the considerable number of companies offering undersea electric craft and the new companies offering various EV craft outside the USA. This illustrates the market drivers of evolving needs, prosperity and global spreading of the message.

Fig. 8.6 **Solar powered boats for tourism cruising at 12 kph on Lake Geneva**



8.4.2. Pollution laws

Already, ICEs have been banned from all lakes in Austria and certain lakes in Switzerland, Germany, Denmark, Holland and several fisheries in the UK. There are hundreds of solar boats operating in Europe and Australia. Tourist boats in India are frequently electric even today.

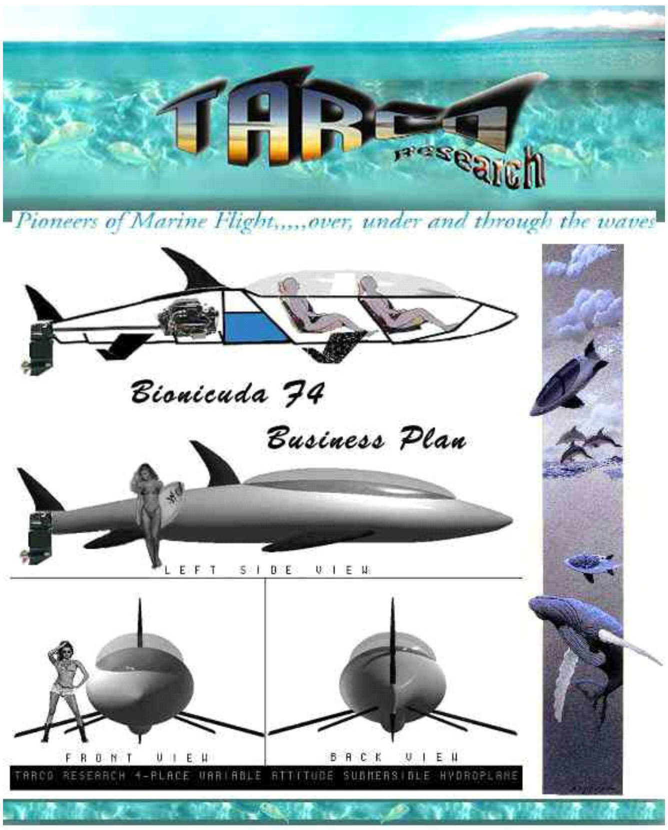
EPRI is optimistic that increased restrictions on pollution in US inland lakes could lead to a significant percentage of the million or more inland surface boats in the US being switched to electric ones. They felt this could grow the market by tens to hundreds of thousands of boats yearly.

Pollution laws also generate niche markets. For example, one Swiss company is designing high power EV boats so water skiing can return to European lakes where ICE boats are banned.

8.4.3. Bionic Dolphin – the power of imaginative design

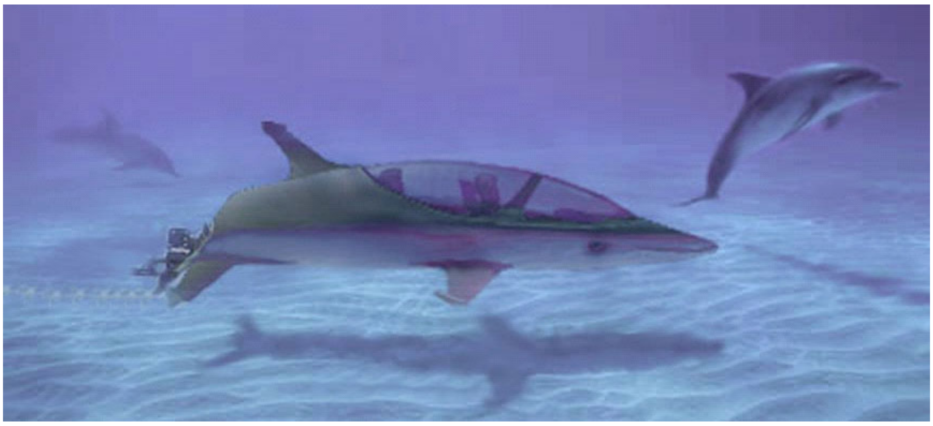
Quite separately, we are seeing many exciting new concepts and trials of "extreme" craft for over, in and under water use such as the "bionic dolphins" of Tarco Research, see figures 8.6 and 8.7. The prototype could jump thirty feet out of the sea and then dive and act as a submarine. These will create new markets.

Fig. 8.7 **Bionic Dolphin craft from Tarco Research**



Source: Tarco Research

Fig. 8.8 **Bionic Dolphin two-person electric submarine**



Source: Tarco Research

8.4.4. Autonomous Underwater Vehicles (AUVs)

AUVs will sell in modest volumes but at high prices. AUVs first swam close to a decade ago. The Autonomous Benthic Explorer (ABE), a deep-diving craft created at the Woods Hole Oceanographic Institution in Massachusetts, conducts geophysical surveys. The torpedo-shaped Hugin 3000, made by Norway's Kongsberg-Simrad, monitors oil rigs, pipelines and transoceanic cables up to 2 miles deep. As oceanographers tackle ambitious plans to build the first undersea observatories – permanent unmanned lookout stations on the ocean floor outfitted with moored sensors and buoys – a new generation of AUVs will act as the key moving parts, roaming and monitoring the deep and sending real-time data to shore.

Fig. 8.9 **The British Scorpio remote controlled rescue vehicle that released the trapped Russian submarine in August 2005.**

Serving underwater research stations

Underwater research stations (their first full-scale field test is scheduled for 2005) will reveal the workings of the oceans. "AUVs linked to observatories are going to be the 24-by-7 presence in the ocean that we never had," says Alexandra Isern, program director for ocean technology at the National Science Foundation, which is funding one of the observatories. "They'll provide continuous monitoring of even the most deeply hidden ocean processes, the way satellite systems already do on land." Underwater docking stations at the observatories will enable AUVs to stay out for months at a time.

Holistic, non-stop ocean monitoring

Underwater observatories will make it possible for the ocean to be seen whole, its complicated physical and biological interconnections unravelled. This has become a matter of some urgency, for in the sea the planet's climate is shaped. You cannot make any predictions about the health of the planet without understanding the oceans.

AUV swimmers

The latest AUV from MBARI, named Dorado, a torpedo-shaped 17-foot by 21-inch vehicle, has 10 to 15 pounds of positive buoyancy. If disabled underwater, it will rise to the surface. Dorado has sonar to measure Arctic ice depths and sensors that, by detecting nitrates, oxygen, the amount of suspended matter and other parameters, identify how the properties of ocean water varies depending on the location, time of year and other factors. A conductivity-temperature-depth (CTD) instrument provides data to calculate salinity and density, currents and sound velocity.

Popular Science reports that, "The Dorado is one of a class of AUVs known as Swimmers because they are fitted with huge batteries that power propellers. Swimmers can travel moderate distances and carry sizeable payloads. Another more recently introduced type of AUV, the Glider, uses shifts in its buoyancy and centre of gravity to dive and rise. Gliders tend to be smaller than swimmers and be focused on specific, limited tasks. They move slowly – about 0.5 mph – but they have great endurance".

AUV gliders

A typical glider is the University of Washington's Seaglider, a needle-nosed vehicle about 6-feet long and 114 pounds, with very short fixed wings and a fixed tail. An electric motor moves the battery pack – and the Seaglider's centre of gravity – fore and aft, to control the pitch of the nose. Roll control, which allows the Seaglider to bank like an airplane, comes from shifting the batteries from side to side.

Surfacing to recharge automatically

Engineers at the Autonomous Undersea Systems Institute in Lee, New Hampshire, USA, for example, are developing AUV-appropriate solar panels; by periodically rising to the surface to bask in the sun while uploading their data, solar-powered gliders will be able to stay out on an environmental reconnaissance mission for a year or more.

The AUV developed by Virginia Institute of Marine Science, Gloucester Point, USA has a long sonar antenna at the front making it look like a swordfish. It can identify and count different types of fish and it is used to monitor the size of fish stocks for conservation. They can travel 100 kilometers before recharging and they radio back the information at intervals.

8.4.5. Case study: AUVs at the Florida Atlantic University

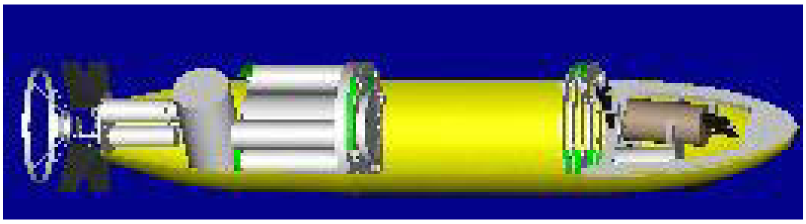
The AUV program is an ever expanding field of study in the Ocean Engineering department of Florida Atlantic University. Small, low cost, long range vehicles have been developed as sensor platforms for educational, scientific, and military applications.

Currently, two separate vehicles are under construction/development/refinement: the Ocean Voyager II and the Ocean Explorer series. Several projects directly related to the vehicles themselves are underway here at the F.A.U. Ocean Engineering Department and at the University of South Florida Marine Science Department. Some of these include CHIRP sidescan and sub-bottom sonar, passive imaging sonar, long baseline sonar, acoustic modems, exotic batteries, ocean small-scale turbulence sensors, and various suites of water quality packages.

The Ocean Explorer is not just a single AUV but rather the name for the next generation of several vehicles currently being built. This is a new family of AUV's of modular construction, with hull, sensors and software easily convertible for different payloads. One uses an extensive intelligent distributed control system called LonWorks (Neuron) for communications between numerous sensors and actuators. It is presently undergoing tests in the local waters around F.A.U.

The docking system allows an Ocean Explorer AUV to rendezvous and dock with its base station using fuzzy logic control. Figure 8.9 shows the vehicle.

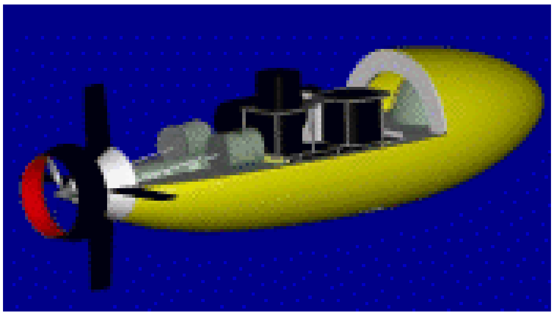
Fig. 8.10 **The Ocean Explorer AUV**



Source: Florida Atlantic University

This is the 3-foot parallel mid-body version, containing approximately 7.5 cubic feet of payload volume. This version is about 10 1/2 feet long. The base vehicle is about 7 1/2 feet in length. Figure 8.10 shows the Ocean Voyager II, an earlier project. On 7 August 2005 a British Scorpio remote controlled underwater rescue vessel rescued Russian submarine Priz which was trapped in fishing nets at a depth of 190 meters.

Fig. 8.11 **Ocean Voyager II AUV**



Source: Florida Atlantic University

Figure 8.11 shows a British Remote Controlled Mine Destruction Vehicle RCMDV being lowered into the water. This is a battery powered electric vehicle.

Fig. 8.12 **A British Remote Controlled Mine Destruction Vehicle being lowered into the water.**

Source: Library picture

8.4.6. Hybrid ships after 2010

The warships of the future will differ from conventional vessels. They will run on electric motors and their power sources - diesel or gas turbine engines - will be designed so that they can be placed anywhere on the ship and duplicated elsewhere. This will allow flexibility if one part of the ship is damaged and save space over direct-drive conventional vessels. Merchant ships will follow the trend. Professor Scott Sudhoff is working on this at Purdue University in the US.

One of the first fruits of such work will be a next-generation destroyer. The efficiency of an all-electric propulsion system will allow the Navy to trim the crew size for the ship from 300 to 95. It is being developed as part of a contract of $250 million over six years to develop electric propulsion technology for the DD-21 class ships. The new DD-21 ships will feature the same gas turbines or diesel engines used on current ships, but will use generators and electric motors to replace reduction gears used to control the ship's drive shaft. Reduction gears take up a large amount of space on ships : they are difficult to maintain. Electric motors will control ship propellers independently of the turbines/diesel, which will eliminate the need for long drive shafts. The new systems are promised to be more efficient and will require less manpower to maintain. The Navy also notes that the electric propulsion systems will make ships quieter, and thus less vulnerable to attack. Navy Secretary Richard Danzig says other ship classes could eventually be powered by electricity.

However, just as we do not include large diesel electric submarines in our forecasts, we do not include these planned hybrid ships as their very high prices and small volumes would be a distortion.

A total of 32 electric-powered DD-21 class destroyers will be built for about $25 billion. The first is expected to be ready around 2010. We exclude these ships from our market statistics.

8.5. Leisure and tourist submarines

Small submarines for leisure, recovery, research etc, number about 500 yearly, sold for around $150,000 average, though one version for 64 people (246 feet maximum depth) is $4.3 million and the Seattle 1000 (1,000 feet maximum depth) is nearly $20 million. The Seattle 1000 can stay down for three weeks. At the other extreme there are assembly kits for as little as $1,500.

Leisure submarines and divers tugs are one of the most vibrant sectors of electric boating partly because they are new and exciting. They replace nothing. They are often glamorous and achieve new things whereas electric surface boats look much like the manual or ICE boats they replace and are used for the same purpose. Figures 8.12 to 8.19 give some examples. The market and manufacture is again mostly in the US. There are at least as many manufacturers of electric undersea boats as surface boats and the value of the two markets is similar, despite the smaller number of submarines sold.

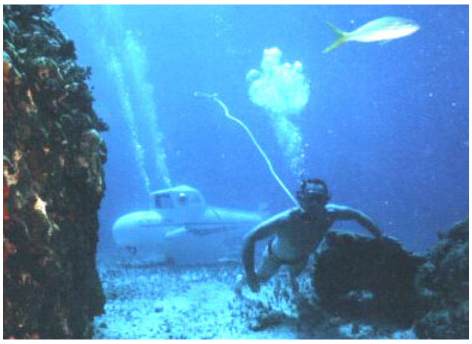
Fig. 8.13 **Personal submarine**

Source: Kitterdge

Fig. 8.14 **Wet submarine**

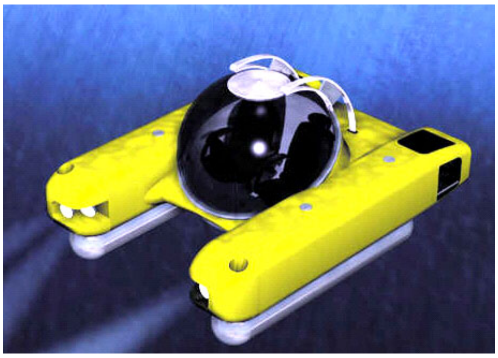
Source: Odyssea

Fig. 8.15 **Two-person SportSub submarine**



Source: International Venture Craft

Fig. 8.16 **Triton personal submarine**



Source: US Submarines

Fig. 8.17 **Deep Flight Aviator two-person leisure submarine**

Source: Hawkes Ocean Technologies

Fig. 8.18 **Seattle personal luxury submarine by US Submarines**

Source: US Submarines

Fig. 8.19 **US Submarine's main tourist submarine**

Source: US Submarines

Fig. 8.20 **Sea Scooter by Pro Audio Elite of Italy**

Source: Pro Audio Elite

8.6. Manufacturers by country and product

Table 8.1 gives some examples of companies making electric water craft.

Table 8.1 **43 examples of manufacturers of EV electric water craft**

COMPANY	COUNTRY	TYPE
AquaSub	USA	Personal submarine kit
Aquawatt	UK	Open boats
Autonomous Undersea Systems Institute	USA	AUV
Beckman Electric Boats	USA	Open boats
Black River Boats	USA	Open personal boats
Bobcat Boats	USA	Open boats
Budsin Wood Craft	USA	Open boats
Canadian Electric Boats	Canada	Leisure boats
Caribbean Submarines	USA	Tourist submarines
Cobalt Marine	USA	Leisure boats
Cquestor	USA	Personal submarine
Curtis Marine	USA	Open boat
Deep Star	USA	Tourist submarine
Duffy Electric Boats	USA	Leisure and tourist boats
Electracraft	USA	Leisure boats
Electric Marine Industries	USA	Launches
Electro Cruise Boats	USA	Runabout boat
Florida Atlantic University	USA	AUV

COMPANY	COUNTRY	TYPE
Hawkes Ocean Technologies	USA	Prototype and hired submarines
Hyco	Canada	Small submarines
International Venture Craft	USA	Personal submarines
Kittredge Industries	USA	Small submarines
Kongsberg Simrad	Norway	AUV
Leisure Life	USA	Paddle boats
MBARI	USA	AUV
Mergo	USA	Tourist submarines
Neptune Sea Technologies	Finland	Small submarines
Odyssea	USA	Personal submarines
Pro Audio Elite	Italy	Scuba scooter tug
Ruban Bleu	France	Small boats
SeaMagine Hydrospace	USA	Submersibles
Secret Mountain Boats	USA	Kayak
Spincraft Electric Boats	USA	Open leisure boats
Subeo	UK	Submarines
Submersible Systems Technology	USA	Small submarines
SubSea Submersibles	USA	Submersibles
Tarco Research	USA	Personal submarine prototypes
Underwater Vehicles	Canada	Tourist submarines
University of South Florida	USA	AUV
US Submarines	USA	Personal and leisure submarines
Venture Craft	Canada	3-person wet submarine
Winborn Electric Sailboat	USA	Sailboat
Woods Hole Oceanography Institute	USA	AUV

Source: IDTechEx

Figure 8.20 shows small battery only boats for hire made by Ruban Bleu of France which had supplied 500 by 2002. This company does many other EV boats including a passenger catamaran, and eight, seven and five person electric boats.

Fig. 8.21 **Small electric boats for hire**

Source: Ruban Bleu

8.7. Selling prices

Selling prices of marine EVs vary widely.

US Submarines
So far, US Submarines has sold several two-man submarines, called the Triton 650, which costs $620,000, fits aboard a megayacht and can be moved around by trailer. A recent order was for a $3 million Marlin 1000, a 57 foot submarine with an interior the size of a luxury jet which dives to 1,000 feet.

US Submarines may be the biggest in the world in non-military submarines and it has interest in models priced up to $80 million each. Its gross sales value may be $100 million yearly soon.

Underwater Vehicles, Inc
Alan Whitfield, of Silvercrest Submarines a UK firm with a sister company, UVI, in Canada, says business in private submarines, new and secondhand, is growing. "We do best with the small two-person submarines such as the K350 for $200,000, perfect for cruising around wrecks. They sit on the water, and you climb into the top with your champagne and your picnic and off you go."

Table 8.2 **Indicative prices for marine EVs in 2005**

COMPANY	TYPE	PRICE $ ('000)
US Submarines	Phoenix 1000 luxury submarine	80,000
US Submarines	Large Submarine Marlin 1000	3,000
US Submarines	Two-man deep dive submarine	620
Seascooter	Scuba tug	0.2
Seamagine	Professional Sea Mobile submarine	270 – 350
Venture Craft	Sportsub	40
Duffy	Ten-seater launch	18
Budsin Wood Craft	Wooden open boats	15 – 45
Spincraft	Two-seater open boat	3.5
Pro Audio Elite	Scuba tug	0.8

Source: IDTechEx

8.8. Marine EV sales projections, 2005 to 2015

8.8.1. Surface and subsurface boat markets

In numbers, the sales of marine EVs today are evenly divided between surface boats – mainly leisure – and subsurface – mainly divers' tugs. Many of the surface boats have been converted to electric for silence and reliability and sometimes to meet pollution statutes. Worldwide about 20,000 electric surface boats are sold yearly, of which, one or two thousand are large multiple-passenger commercial boats. Whereas Spincraft small 2 seaters retail at $3,500, Duffy make larger, quality boats retail for around $18,000 (Mr Duffy tells us he makes 500 yearly). Commercial surface boats retail at around $30 – 60,000.

While the above surface boats dominate the market numbers, the value of sales is inflated by small numbers of high priced electric surface and particularly subsurface craft because many of these sell for hundreds of thousands to tens of millions of dollars each. However, these sales are fairly static.

The figures for marine sales are given in table 8.3 and figure 8.16. The numbers are inflated by low priced items such as small boats and scuba diving tugs but the very high price of the other vehicles pushes up the average price of the whole. Boats made electric by fitting an electric outboard motor are excluded from these figures.

Table 8.3 **Marine EV manufacturing global market 2005 to 2015**

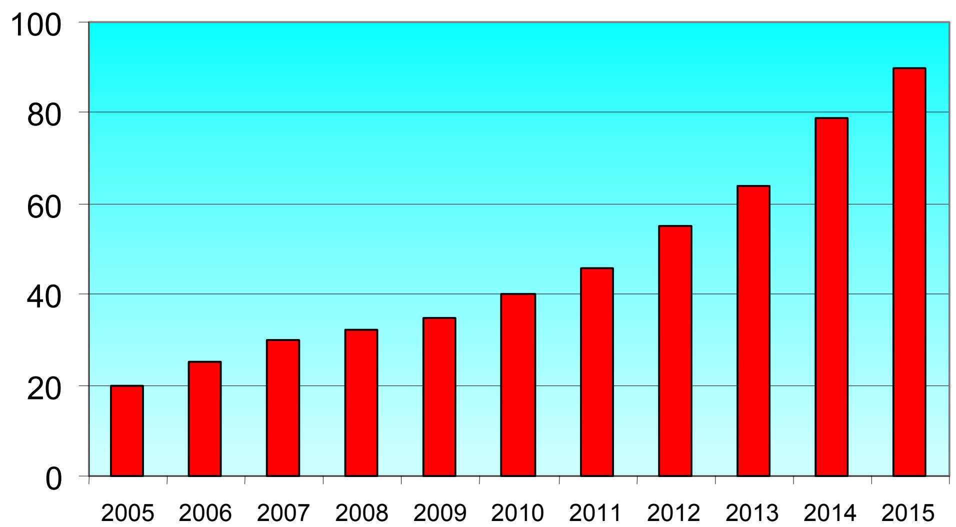
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	30	32	35	40	46	55	64	79	90	100	110
$ Unit value ('000)	50	48	48	47	46	36	36	36	36	35	47
$ billion value	1.50	1.53	1.68	1.88	2.12	2.31	2.59	3.24	3.99	3.45	5.21

Source: IDTechEx

The average prices in table 8.3 are therefore misleading. The vast majority of sales are for craft costing $5 - $1,500 but the average price is inflated by significant sales of craft costing $0.5 – 10 million.

There is upside potential in these figures, particularly if new pollution laws for inland waters really bite. They could lead to sales of hundreds of thousands of EV boats every year.

Fig. 8.22 **Global marine EV sales ('000) 2005 to 2015**



Source: IDTechEx

8.8.2. Projections by technology, 2005 to 2015

Today there are very few hybrid ICE-electric boats. We exclude the many people buying an auxiliary outboard motor for inland open boats, small seagoing sailboats etc because these motors do not form part of the craft and are not usually bought as part of a new boat. This will change. Existing ICE boat builders, particularly of seagoing boats will seek to provide the lower cost over life, higher reliability and fewer fuel stops that ICE can supply, even though pollution from the fuel of small craft is, sadly, not much of an issue at sea. Our projections by technology are given in tables 8.4, 8.5 and 8.6.

Table 8.4 **Global manufacturing market for hybrid water craft 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	-	7	9	15	18	25	32	44	49	55	62
$ Unit value ('000)	-	34	35	36	40	45	45	45	50	50	55
$ billion value	-	0.24	0.32	0.54	0.72	1.13	1.44	1.98	2.50	2.75	3.41

Source: IDTechEx

The average price shown here will vary sharply whenever top-of-the-range luxury and tourist submarines are sold.

Table 8.5 **Global manufacturing market for battery-only electric water craft 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	25	25	26	28	28	30	32	35	40	45	50
$ Unit value ('000)	32	34	35	36	36	36	36	36	36	36	36
$ billion value	0.80	0.85	0.91	1.01	1.01	1.08	1.15	1.26	1.44	1.62	1.80

Source: IDTechEx

Table 8.6 **Global manufacturing market for fuel cell electric water craft 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	–	–	–	–	–	–	–	–	1.0	1.5	2.0
$ Unit value ('000)	–	–	–	–	–	–	–	–	50	50	50
$ billion value	–	–	–	–	–	–	–	–	0.05	0.08	0.10

Source: IDTechEx

Fuel cells are not attractive for water craft because of the need for a distributed refuelling infrastructure and the cost. Iceland, in trying to create a hydrogen economy on the back of geothermal power, is an exception but only the fishing fleet is involved. Iceland has few leisure boats. The fuel cells on its fishing vessels will be few in number and experimental for many years.

8.8.3. Projections by under-over water craft, 2005 to 2015

Today the value market is dominated by underwater craft. Later, we see hybrid surface craft on lakes and at sea becoming available and popular, driven by cost, convenience and, inland, by new pollution laws.

See table 8.7 for percentages of sales.

Table 8.7 **Percentage of sales by value of underwater vs overwater EVs, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Overwater EVs	35	30	35	40	45	50	55	58	60	62	65
Underwater EVs	65	70	65	60	55	50	45	42	40	40	38

Source: IDTechEx

8.8.4. Projections by region

The USA is driving nearly all undersea research and leisure and the appropriate EVs. Surface EV craft are mainly made and bought in the USA, though less dominantly so. We see this situation largely continuing. See table 8.8.

Table 8.8 **Value of EV marine craft manufacturing market by region, 2005 to 2015, in percentages**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
North America	76	74	72	70	68	66	64	62	60	58	56
Other	24	26	28	30	32	34	36	38	40	42	44

Source: IDTechEx

9. Mobile robots, toys, leisure, research, hobbyist

9.1. Definition

This section covers EVs not included in other sections, including many fast growing if, as yet, small sectors. The same is true of police EVs. Leisure includes everything beyond golf cars, leisure versions of vehicles for the disabled and two wheelers. Go karts, dragsters and electric skate boards are examples. Mobile robots include those for bomb disposal, lawn mowing, etc. Toys are EVs that include remote-controlled cars and boats and imitation electric dogs and cats. We discuss toys but exclude them from the figures in the Executive Summary and Conclusions because their very low price and high volumes are a distortion. Other EVs include hobbyist kits, silent airships, unmanned aircraft and research vehicles, such is the variety of activity.

9.2. Market drivers

Here we have the most new markets being created. The pace of innovation is intense and the big sellers change from year to year. Fashion also comes into it, and also rapidly expanding functionality and thus product obsolescence notably with home robots, so forecasting is difficult. On rare occasions, legislation helps these innovations, recent banning of ICE go karts in many European indoor venues being an example but these EVs usually sell because they make something new possible such as a policeman patrolling an area at speed without residents being disturbed or criminals noticing.

Special situations are common with this sector. For example Iceland, with cheap geothermal power wishes to move to a hydrogen economy. It plans to convert its one thousand or so fishing boats to fuel cell propulsion, according to announcements in 2002.

9.2.1. Case study: Toyota at Expo 2005

"The Dream, Joy and Inspiration of Mobility in the 21st Century" is the theme of the massive Toyota pavilion at Expo 2005.

Through performances featuring the i-unit (a future concept vehicle) and the Toyota Partner Robots, visitors are introduced to the directions and technology of future society, along with the possibilities for the vehicles of the future. There are also easy-to-understand displays of the cutting-edge technology possessed by the different companies in the Toyota Group.

Fig. 9.1 **Image of the performance at Toyota Pavilion Expo 2005**

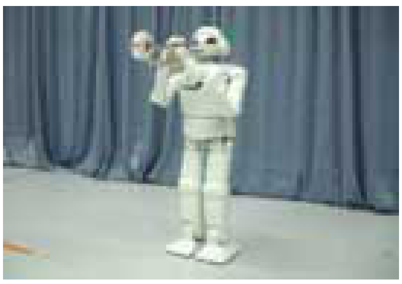
Source: Toyota

9.3. Contents of exhibition

Performances

There are two performances: a welcome show and the main show. The welcome show is a highly entertaining performance featuring robots that welcomes visitors to a future world. The main show performances involving the i-unit, robots and human performers. A fantastic spectacle unfolds on the stage by means of a giant 360-degree screen and stage props. Through the appearance onstage of elements of life, nature and future society, visitors will be introduced to the wonder of moving about freely and living, and also to a new kind of relationship between people and cars.

Fig. 9.2 **The Toyota Partner Robot (current development model - several types of robots, updated both in form and performance appear at EXPO 2005.**



Source: Toyota

Fig. 9.3 **The development concept is "Mobility Extending Human Ability" - a single-passenger, futuristic vehicle that represents further development and evolution of the PM exhibited at the 2003 Tokyo Motor Show.**

Source: Toyota

9.4. Listing of manufacturers by country and product

Table 9.1 gives examples of manufacturer's in this area of EV production and supply.

Table 9.1 **30 examples of manufacturers of mobile robots, toy, leisure, research or hobbyist EVs by country and product**

COMPANY	COUNTRY	PRODUCT
Advanced Technology Products	USA	Electric aircraft
Aerovironment	USA	Unmanned, portable military surveillance aircraft (miniature)
CityEl	Japan	Police
Cobra	Italy	Go karts
Dragon	China	Toys
Dyson Domestic Appliances	UK	Robot vacuum cleaner
Electrolux	Sweden	Home robots
EMR	UK	Go karts
Fisher Price	USA	Toys
Formula 5	UK	Go karts
Fujitsu	Japan	Two-legged robot
Honda	Japan	Robots
Inuktun	Canada	Pipe and duct robots and emergencies
iRobot	USA	Home & office robots, disaster recovery etc
Kango Electric Vehicles	USA	Go karts
Lindberg	China	Toys
Marui	Japan	Toys
Matsushita	Japan	Home robots
NEC	Japan	Home robots
Omron	Japan	Home robots
Pet Perengo	Japan	Toys
RoboScience	UK	Home robots
Roomba	USA	Home robots
Sanswire Networks	USA	Solar powered airship as alternative to communications satellites
Sanyo	Japan	Home robots
Sony	Japan	Toys, mobile robots
Tamiya	Japan	Toys
Toyota	Japan	Robots, toys

COMPANY	COUNTRY	PRODUCT
Xerox	USA	Robots
Zap	USA	Police
Zevco	UK	Go karts

Source: IDTechEx

9.5. Market size and trends

There is an enormous number of other EV products emerging that create new markets by making possible something new, including:

- Further “PIG” robot vehicles that do investigative work in pipes.
- Remote-controlled underwater investigative craft.
- Remote-controlled military surveillance vehicles on land, in the sea and in the air.

The mobile robot and leisure sector is becoming particularly important.

9.5.1. Mobile robots

The sale of home robots in Japan was of the order of the tens of thousands a year in 1999 from near-zero the year before, a market being created of $40 - 50 million at ex factory prices. However, it was driven by fashion and amusement and sales have been fitful since then. No other country has purchased these mobile robots in such large numbers.

EV robots for gardening, hospitals and elsewhere have started to follow. Many will be an impulse buy. We project 7 million being sold in 2015, most of them being robot vacuum cleaners and lawnmowers. This is a heavy discount on the projections of some participants. We are discounting numbers and value in case there is further severe price erosion or delay. However, unlike other categories in this report, the value projections are more secure than numbers because there are few robot applications that can lead to large numbers sold but there are many developments of high value robots. There are several hundred different families of mobile robots being sold or developed, from surveillance to lawn mowing. Examples include:

Spider-bot
A spider-shaped robot will be used to investigate hazardous materials in inhospitable environments, say its creators at NASA. The spider-bot was originally developed for exploring other planets and for maintenance and repairs on the international space station. Small enough to fit in the palm of a human hand, the robot has antennae that help it to detect obstacles and cameras that let it survey the surroundings. Unlike real spiders, this prototype robot has only six legs, giving it a curious gait, but future versions may have up to 50. NASA scientists are now working on ways to attach tools to the robot’s front legs.

Tetwalkers

In March 2005, it was announced that NASA is developing Autonomous Nanotechnology Swarms ANTS, basically collapsing tetrahedra that move by falling over due to four electric motors – one at each node – initiating a collapse in the desired direction. Future models will have motors measured in thousandths of a millimeter and eventually millionths, says NASA. They will form ad hoc networks, inter-communicating as needed and forming cooperative shapes if necessary. They may travel through space on solar wind and morph into landing and then terrestrial shapes such as snakes. If they found something they could form an antenna to radio earth and if they hit something they could morph back into the right shape. Damaged "cells" in a shape could be replaced using collective intelligence. "Tetwalkers move by toppling over," saysSteve Curtis of NASA," It's a very reliable way of moving around."

Cryobot

A cryobot is a vehicle which moves through ice by melting the ice wall directly in front of it taking measurements of the encountered environment, and sending the collected data or images to the surface of the ice. The US Jet Propulsion Laboratory is developing them during 2005-6.

Rescue robot

Recent severe earthquakes underline the risks faced by rescuers who search for survivors in collapsed buildings. Risks can be reduced by using a robot to carry out the initial search through the rubble. A prototype robot has been built by engineers at North Carolina State University in the USA. It crawls along pipes, which are often left intact when buildings collapse. "Moccasin II," can find its way through complicated piping, complete with right-angled turns and vertical climbs. It is fitted with a video camera, so that its location in the pipe can be seen. It also carries sensors that could sense vibrations caused by tapping on pipes.

Robotic camera

A robotic camera on wheels has been prototyped that can climb lamp-posts. It will be used by the media for filming and by the police for surveillance and was announced in 1999 by Brunel University, London, Tecsec and the University of Wales in the UK.

The CARER

The CARER (Companionable Autonomous Robot with Emotional Responsibility) "robo-pet". It is a robot on wheels to assist the elderly and acts as a pet but also monitors the health of the owner and can fetch medicine and call a doctor if needed. It is being designed by Salford University, UK.

Autonomous robot

The robot that can survive and work for a very long time is deeply significant though the first manifestations of such robots seem frivolous. An autonomous robot which seeks out slugs and draws power from their decomposing bodies is being developed by the University of the West of England in Bristol, UK. Called Slugbot, it uses a CMOS image sensor under red light to see the slugs at night. It uses optical shape recognition software to confirm that what it sees as a bright white object is indeed a slug, then removes it with its carbon-fibre arm which has a reach of 1.8

million. The robot uses a combination of differential GPS and an active IR localisation system to find its way back to its base, where slugs are put in a fermentation chamber. Bacteria convert them into gas which is used to fuel Slugbot's batteries. The project aims to develop robots with animal-like self-sufficiency. The researchers admit that they "did not expect to be able to match the speed and performance of a cheetah chasing a zebra within the time frame of this project, so we decided to chase something slightly slower .... slugs."

The robot, which is 2 ft (0.6m) high , is designed to operate at night, when slugs do most of their damage. The pests emit a different infra-red wavelength from earthworms, soil and snails. What began as a research project also promises to become a commercial success.

The Soil Association of the UK welcomed the robot as an invention that could rid farmers of slugs without the need for pellets. At present $16 million is spent each year on the chemical control of slugs in the UK, contrary to "organic" principles. The slugbots, developed over two years at a cost of $240,000 are expected eventually to work in teams and sell for about $1,600 each.

Walking robot

Honda Motor Company of Japan has an experimental human-like walking robot that can cope with stairs, sloping ground and opening doors. It cost several million dollars to build and has serious objectives. It is not a toy.

Robotic primitives

Researchers at the Xerox Palo Alto Research Centre in California are working towards producing a small number of a robotic primitives, or building blocks, that can combine with many others to create complex, active, forms automatically for the task in hand. This combination of low cost and flexibility means that individual elements can be entirely disposable : two broken robots, with the correct working components, can easily transform themselves into one 'healthy' machine. They can walk or use wheels as required by different tasks.

Areas where such modular robots could really come into their own include search and rescue in a bombed or earthquake damaged building. Here the environment is highly unstructured so it is uncertain what shape of robot would be most appropriate. Planetary exploration, deep sea mining, exploratory oil drilling, industrial or nuclear plant inspection, pipe maintenance in sewer systems and aid for the disabled are other possible applications.

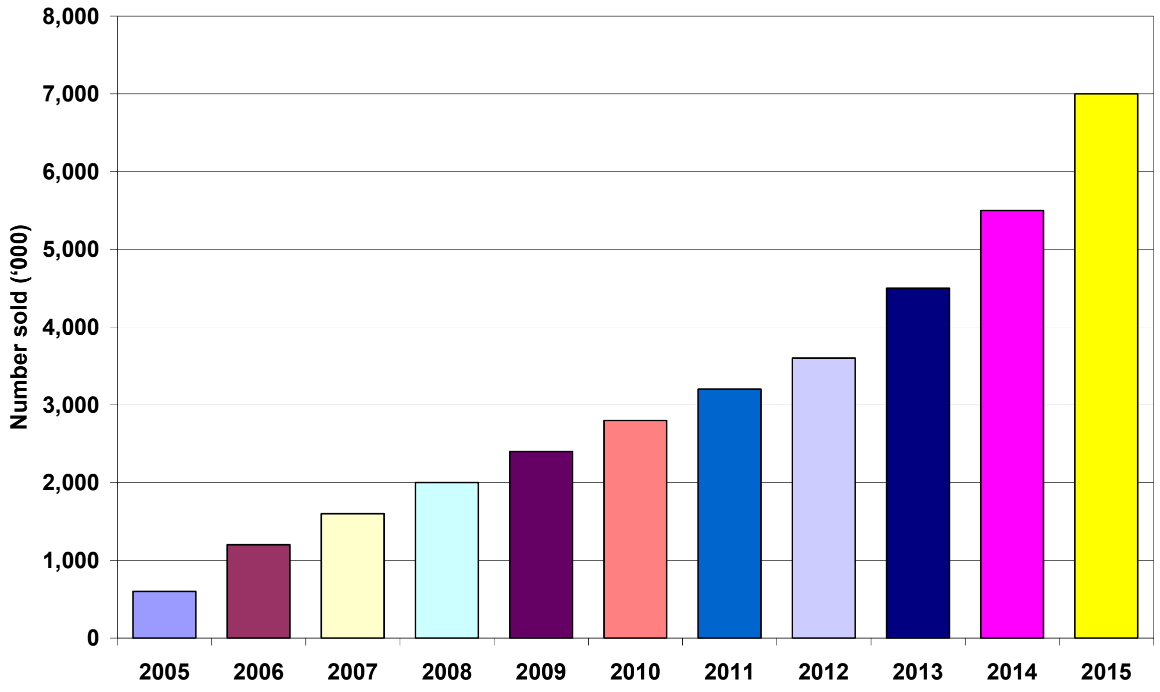
EV insects

The Japanese Ministry of Trade and Industry (MITI) is sponsoring several Japanese companies developing EV insects weighing less than half a gram and travelling at 15 cms per minute. They can inspect cabling and, it is hoped, even carry out repairs. An early use will be in nuclear reactors.

Increased sales are also predicted for specialised service robots for professional uses as varied as space exploration, sewer inspection and cleaning, surgery, building demolition, bomb disposal and fire-fighting.

See figure 9.4 for global mobile robot sales 2005 to 2015.

Fig. 9.4 **Global mobile robot sales ('000) 2005 to 2015**

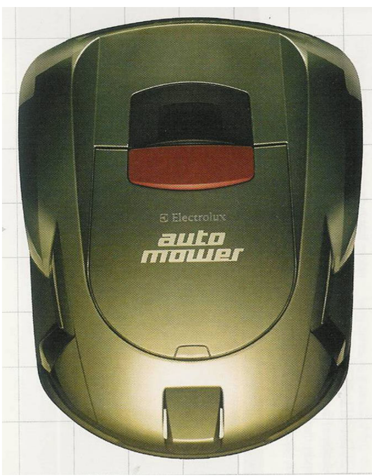


Source: IDTechEx

9.5.2. Case study: The Electrolux Automower

Electrolux followed its robot vacuum cleaner with the Electrolux Automower in 2004 as shown in figure 9.5.

Fig. 9.5 **The new Electrolux Automower**



Source: Electrolux

It mows the lawn taking about one hour to do 2 square meters but it is quiet and returns to its charger as necessary – every 90 minutes or so. It is constrained to the correct area by thin buried wires. Cost is around $2500. www.automower.com

9.5.3. Rescue robots in Germany

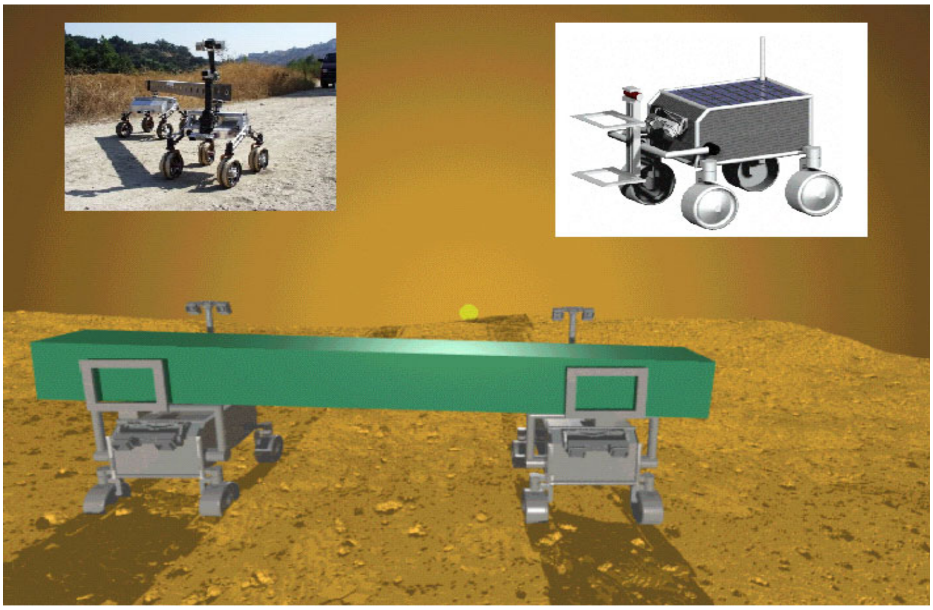
Researchers from the International University of Bremen (IUB) in Germany have built 'rescue robots', combing mechatronics with intelligent control programs that can help emergency services to identify victims and potential danger sources. The robots can be used to inspect collapsed buildings, assess the situation and search and locate victims in urban rescue missions. Quiet EV operation reduces danger.

The IUB robots contain thermal imaging cameras and specially developed sensors that can detect human breathing by measuring the amount of carbon dioxide. However, the most significant benefit is their ability to produce onsite maps autonomously so that rescue squads can speedily locate victims and identify trouble spots. Other attachments include smoke sensors and microphones that, together with the thermal imaging cameras, can be used to pinpoint an intruder.

9.5.4. Case study: Robots on Mars

The Jet Propulsion Laboratory is working on so-called Planetary Surface Robot Work Crews (RWCs). This is an illustration of how some electric vehicles in the form of mobile robots may employ small numbers but the value of these projects can be high and growing. The following description is issued by the laboratory.

Fig. 9.6 **Robots for Mars**



9.5.5. Technology and Mission Relevance

Technology:
Simultaneous multi-dimensional controlled application of force and movement by a team of robots in uncertain terrain to achieve goal-level coordinated behaviours. State of the art is currently limited to indoor lab demonstrations on a level floor.

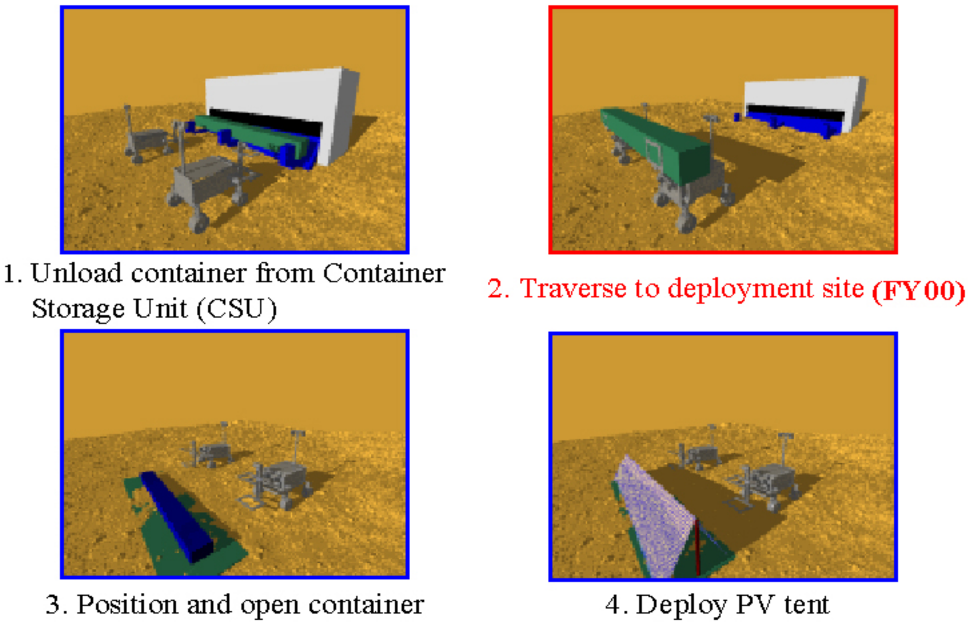
Enterprise Applications:
Space Science: Enables long duration, complex planetary surface science applications such as deep drilling, networked instrument activities (cf. recent JPL Team X studies).

HEDS: Enables robot colonies for precursor infrastructure missions such as site preparation, ISRU & power system deployment, (cf. NASA studies for robotic outposts, Mars Reference Mission).

Fundamental Problems being addressed
Multi-robot autonomous operational concepts, sensing, and control for the coordinated grasping, transport and placement of extended structures in uneven, natural terrain. State of the art is currently limited to indoor lab demonstrations on a level floor, and in most cases does not provide closed loop control of inter-robot kinematics and dynamics.

Extensible control architecture for a broad class of multi-robot coordinated tasks, wherein the fundamental sensor and control modules are re-usable, and sharable by multiple robotic agents. Functionality includes precision terminal guidance to a site over non-cooperative, uneven terrain, with visual-based cooperative obstacle avoidance and navigation during transport, also, the automated cooperative manipulation of payloads in all phases of operational activity. State of the art is limited to single rovers, of limited dexterity.

Fig. 9.7 **Mission Scenario To Aid Technology Development**



The mission scenario is based on a proposed robotic deployment of a modular solar photovoltaic (PV) tent array mission. In Colozza[8] the study demonstrated that a nearly constant power profile can be realized by a tent array of standard silicon PV cells. Such a PV tent array would be difficult to deploy using a solitary robot, since the modules are 5 meters long and would represent a considerable challenge for precision placement. Two cooperating robots can perform the task using the following sequence of steps (as shown above): 1. Unload the container from the container storage unit (CSU) (Pickup Phase), 2. Traverse to the deployment site (Transport Phase), 3. Position and open the container (Positioning Phase), and 4. Deploy the PV tent (Deployment Phase). These steps were chosen to be consistent with decided the mass and power constraints for a mobile robotic platform on the Martian surface.

Objectives

- Develop a scalable control architecture for the autonomous intelligent coordination of multiple, flight-relevant robots, enabling canonical grasp, lift, force, move operations in sloped and rocky natural terrain (acquire-transport-deploy).
- Provide a methodology for analysis, design, specification, and verification of specific implementations of the architecture.
- Develop infrastructure and tools to support implementation and evaluation.

Approach

- Leverage existing SRR/FIDO code at device driver level [Aghazarian, et al (2000)].
- Leverage existing behaviour fusion code [Pirjanian (2000)].
- Finite State Automata for transport sequence used in FY00 - collaboration with Stanford on planning layer (FY01 deliverable).

- Develop communication behaviour library for general coordination.
- Design templates for primitive and group behaviour development.
- Design and specification of behaviour hierarchy for coordinated transport.

FY00 Level 1 Milestone:

FY00 Level 1 Milestone: Develop and demonstrate a sensor-based control architecture for multiple robots performing coordinated transport of a rigid extended object over outdoor irregular terrain. Capabilities of this architecture for cooperative and coordinated robot work crew control will be evaluated in the JPL arroyo using two robots carrying a half-scale sized mock-up of a photo-voltaic (PV) tent container up to 50 meters.

Technical Approach

Technical Approach (FY00-02 planned effort which targets NASA TRL 3 at completion):

This multi-year task develops system architectures and technologies for autonomous multi-robot-based operations that will establish long term robotic colonies on Mars. The work is fundamentally enabling for precursor missions that anticipate a manned habitat on Mars, as well as supporting complementary networked science opportunities. The scope of work includes mechanization design, autonomous operation strategies, rover sensing and control techniques, terrestrial system models, and testing of resulting vehicle and operational concepts in simulated field trials.

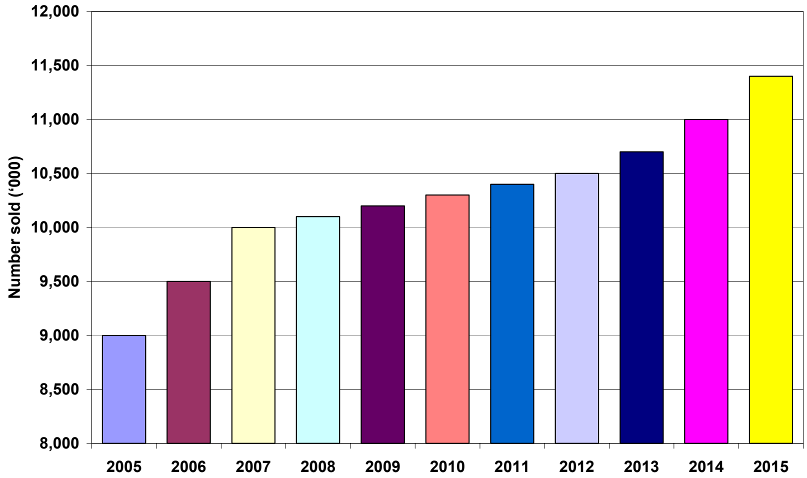
Fig. 9.8 **Robot Work Crew**

Source: JPL

9.5.6. Toys

EV toys, notably remote-controlled boats and cars but also including little cars the child sits in, are a substantial but slower growing business aside from flashes of demand. Most are made in Japan, China and Taiwan. The low unit price, at tens of dollars ex works make them atypical in the EV industry as does the very small size of the components. True, the NiCd and NiMH batteries have the same technology as some mainstream EVs but this can be a fashion business with very different dynamics. Robot cats, dogs and similar toys sell for up to $2,000 and have recently been very popular in the USA and Japan. Demand could reach many hundreds of millions of dollars yearly but at lower unit prices - perhaps down to $50 – and it may not last. See figure 9.9.

Fig. 9.9 **Global toy EV sales ('000) 2005 to 2015**



Source: IDTechEx

There have even been major product recalls with toy EVs. Fisher Price recalled up to ten million "Power Wheels" toy cars and trucks. Peg Perego recalled 0.274 million battery powered toy vehicles also on safety grounds.

Total numbers of non-robot EV toys sold globally today may be a few million yearly at the low average ex factory price of around $100. Including the new robot cats and dogs etc. The total toy EV demand may have been $400 million in 2000 rising to $800 million in 2003. Our projections maintain an average price of $1000 and show growth slowing – there is a strong element of fashion in these devices. These sales are heavily biased towards the Japanese market.

9.5.7. Other leisure

Go karts

Go karts are becoming electric for reasons of performance and pollution control. However, despite about 10 companies making them in Europe, under 1,000 a year are sold as yet because price is high, around $4,000 ex works, well above the price of an ICE version. Although electric go karts do make new things possible (no danger of heat or voltage, no pollution, controlled speed, exceptional acceleration) they are still in the unenviable position of replacing ICE i.e. they have (almost direct) competition. Also most are sold to operators not private individuals and these companies will not prematurely scrap their existing fleets.

Dragsters

Electric dragsters are called "amp suckers". They greatly outperform conventional dragsters and are now accepted as a separate class by the American National Hot Rod Association.

Skateboards

Fashion items like electric skateboards are of some interest to private individuals in California for example.

Land skiing

Zapworld.com, a manufacturer of electric vehicles including bikes and scooters started delivering its limited edition PowerSki in early 2000. The company was financially restructured in 2002, having suffered from the poor growth of the EV bicycle market in the West and it no longer makes the two wheelers.

The ZAP PowerSki are inline skates that use an electric drive system designed around a two-wheel chassis with two aluminium poles extending out the back. Users hold on to poles as the PowerSki tows them along at speeds up to 16 miles per hour.

The company said the PowerSki is cross country skiing on wheels, what ZAP refers to as "land skiing". One battery charge provides up to seven miles range on the street, rough terrain, or up and down hills. A second battery allows for even greater range. Sales of the various Zap leisure products are modest.

Rapid innovation

We shall see new EV innovations in leisure. Indeed many companies making EVs for the disabled see them being made available for allcomers in theme parks and other venues with or without modification.

Different ideas come alight in different places

This is a highly fragmented market, with local enthusiasms. For instance, push-and-stand two wheel EV scooters are popular in the US. They fold down to go in a car trunk and, with or without seat, are now sold inside some new Lincoln luxury cars. Electric dragster racing is popular in the US but electric go karts have taken hold in Europe.

9.5.8. Research and hobbyist

The most glamorous research EVs are those used to explore the moon and Mars but there are many others, including non-military unmanned aircraft such as the AeroVironment "perpetual" aircraft surveying in the upper atmosphere and silent airships that do not disturb rain-forest animals. Hobbyist EVs include self-build kits and specials plus miniature reproduction vehicles and conversions for old vehicles.

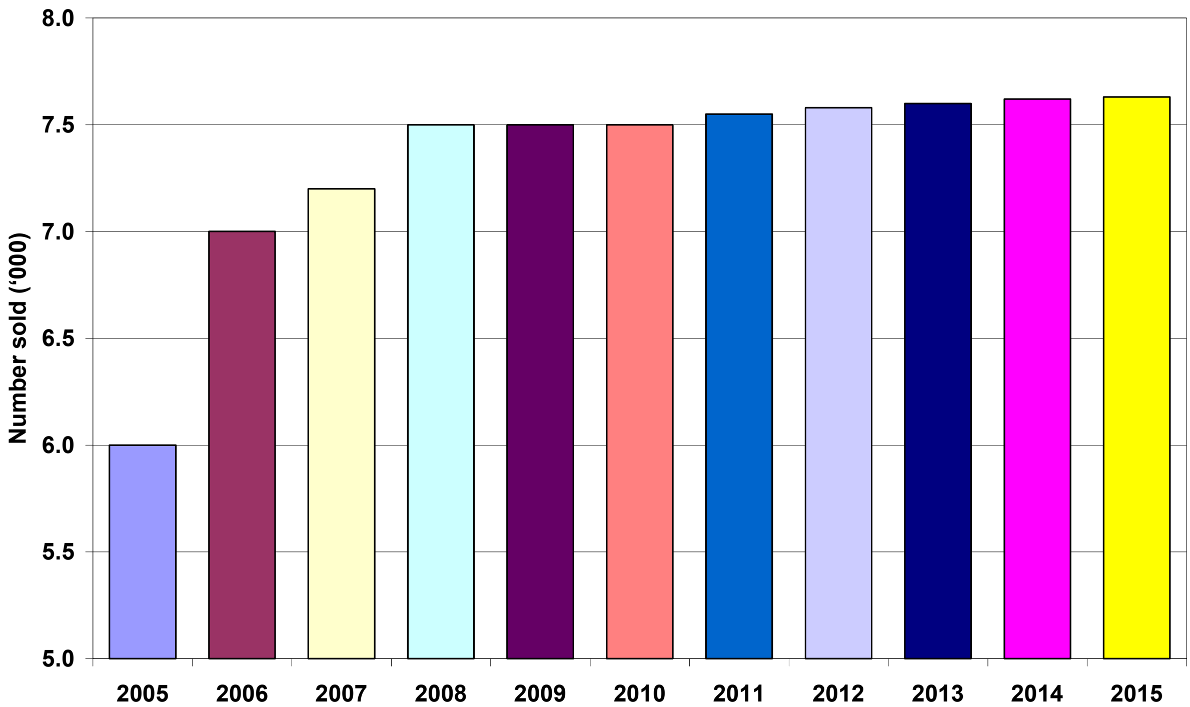
Electric aircraft

Several teams in the USA and Europe are attempting to adapt small, single-engined aircraft for battery or fuel cell powered flight. Furthest along in development is the E-Plane, by Advanced Technology Products of the USA. It is built around an modified all-carbon Lafayette III donated by American Ghiles Aircraft of Dijon, France. The plan is to power the E-Plane with a permanent magnet motor. Current comes from lithium batteries mounted in the wing. Electric motors would mean powerplants could log 10 times as many hours between costly overhauls. The E-Plane could be flying in 2005.

9.5.9. Mining

Underground vehicles used in mining are often diesel in order to deliver large amounts of power for long periods, locomotives being an example. However, these are very expensive as all parts must be cooled to below 150ºC. Safety is still a concern. For this reason, there are also battery versions and fuel cells are of interest. The total market for all mining vehicles carrying their own power is 10,000 yearly at an average price of $300,000 worldwide today. It is growing slowly if at all but penetration of electric is expected to increase. This may get prices down eventually but there will still be a market of about $2 to 3 billion to go for. See figure 9.9.

Fig. 9.10 **Global mining and other EV sales ('000) 2005 to 2015**



Source: IDTechEx

9.6. Market forecasts by sector and technology, 2005 to 2015

The next few years will see sudden jumps in the market as trials of totally new concepts succeed, including some of those mentioned above. For example, over 100,000 people have bought the Sony

AIBO robot dogs at around $1,300 each. Our projected price erosion for mobile robots may not occur if sophisticated two-legged robots sell well. Some are described in table 9.2. First sales were in 2004.

Table 9.2 **Specification and pricing of planned two-legged mobile robots**

	DR ROBOT	SONY SDR-4X	HONDA ASIMO	FUJITSU HOAP-1
Function	Assistant	Entertainment	Service	Research
Size	24 in	23 in	48 in	19 in
Weight	8 lbs	14 lbs	115 lbs	13 lbs
Command input	Voice/PC	Voice/PC	Joystick	Voice/PC
Sensors	11	32	4	34
Vision system	Mono	Stereo	Mono	Stereo
Degrees of freedom	27	38	26	20
Walking speed	1.2 kph	1 kph	1.6 kph	Programmable
Estimated cost	$1,500	$60,000	$100,000	n/a

Source: Popular Science

Our detailed forecasts are given in tables 9.3 to 9.8. EV robots and toys are all battery only pure EVs. We do not anticipate hybrid or fuel cell versions in any significant numbers up to 2015.

Table 9.3 **Global EV manufacturing market for mobile robots, battery-only, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	600	1,200	1,600	2,000	2,400	2,800	3,200	3,600	4,500	5,500	7,000
$ Unit value ('000)	1.6	1.4	1.2	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$ billion value	0.96	1.68	1.92	2.00	2.40	2.80	3.20	3.60	4.50	5.5	7.0

Source: IDTechEx

Table 9.4 **Global EV manufacturing market for mining and others, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	6.0	7.0	7.2	7.5	7.5	7.5	7.55	7.58	7.6	7.62	7.63
$ Unit value ('000)	250	250	250	250	250	250	250	250	250	250	250
$ billion value	1.50	1.75	1.80	1.88	1.88	1.88	1.89	1.90	1.91	1.91	1.91

Source: IDTechEx

Table 9.5 **Global EV manufacturing market for mining and others, battery-only EVs, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	6.0	7.0	7.2	7.4	7.5	7.5	7.5	7.5	7.5	7.5	7.5
$ Unit value ('000)	250	250	250	250	250	250	250	250	250	250	250
$ billion value	1.50	1.75	1.80	1.85	1.88	1.88	1.88	1.88	1.88	1.88	1.88

Source: IDTechEx

Table 9.6 **Global EV manufacturing market for mining and others, fuel cell EVs, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	–	–	–	0.01	0.01	0.03	0.05	0.08	0.1	0.13	0.17
$ Unit value ('000)	–	–	–	250	250	250	250	250	250	250	250
$ billion value	–	–	–	0.0025	0.0025	0.0075	0.0125	0.02	0.025	0.0325	0.0425

Source: IDTechEx

Table 9.7 **Global EV manufacturing market for toy EVs, 2005 to 2015, all pure electric**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	9,000	9,500	10,000	10,100	10,200	10,300	10,400	10,500	10,700	11,000	11,400
$ Unit value	100	100	100	100	100	100	100	100	100	100	100
$ billion value	0.90	0.95	1.00	1.01	1.02	1.03	1.04	1.05	1.06	1.10	1.14

Source: IDTechEx

10. Military

10.1. Overview

This section covers military EVs other than ones that are standard commercial products and marine types. Military forces are very interested in EVs because:

- Carrying less fuel (e.g. hybrids) means that previously impossible missions become possible, speed of advance is improved and cost is reduced
- In pure electric mode there are no heat or gas signatures for missiles to home in on.
- Acceleration and coping with rough terrain (low speed torque) are improved
- They can do tasks that humans should not do, such as bomb disposal. In March 2005 the Pentagon committed $12 million to the development of an unmanned EV that would approach wounded soldiers in action and operate on them.
- They make the vehicles less vulnerable to attack

10.1.1. Examples of military EVs

Figure 10.1 shows the Aggressor Alternative Mobility Vehicle (AMV) from Quantum Technologies in the US. It is a light duty military vehicle powered by a hydrogen fuel cell.

Fig. 10.1 **Fuel cell powered Aggressor AMV**

Source: Quantum Technologies

The terrorist attack of September 11, 2001 and other factors led to the US increasing its military budget by an amount equal to the total military budget of Italy. Now the US military budget exceeds that of all other countries combined. Development of EVs, particularly hybrid EV land vehicles has been boosted as a consequence. The Electric Power Institute (EPRI) tells us that they see very rapid growth in military EVs on land for many reasons.

Hybrids are seen by EPRI to be particularly relevant for military applications.

In the air

A market for hand-held disposable surveillance aircraft has yet to be established in the US but bids have been placed which are usually for electric versions and these are in the region of $1,000 each to meet the budgetary requirement. The first volume order placed may be for $100 million. If support is included, this market could become several hundred million dollars yearly worldwide. In addition, full size unmanned "perpetual" surveillance and other aircraft are being trialled to stay aloft for months on solar power and battery storage.

Most of the development and demand is in the US and is secret but some news items in the UK give an indication of the main direction of the thrust.

EV battle tank

A planned British main battle tank that is electric will be around $5 million in price and provide a company such as Vickers with over $500 million income yearly including spares and services if it is successful.

Hybrid armoured car

Alvis, UK the defence group, is in talks with the British Ministry of Defence to supply an environmentally friendly armoured car in a deal worth at least $1.5 billion. The vehicles Alvis's Swedish Hagglunds subsidiary has developed is a stealth weapon with a low radar profile. It runs on rubber tracks instead of steel to minimise noise. It has a top speed of 53 mph, and can run on its batteries for several hours for silent operation. Alvis claims the vehicle has environmental advantages such as:

- Considerably lower fuel consumption.
- The option to choose a diesel engine from the private car market which have lower emissions than larger truck engines.
- Production materials reduced by a half compared with traditional military transports.

In 2001, the Swedish army ordered three of the vehicles for evaluation purposes and the British army was expected to follow suit.

Electric light tank

Meanwhile, Singapore Automotive Technologies has made a "light tank" that is electric. It may provide them with at least tens of millions of dollars of sales yearly.

Battlefield taxis

Battlefield taxis such as the "Hummer", have a potential of $100 million yearly in 3-5 years, and Bradley armoured vehicles have a similar or larger potential. Global purchases of surveillance, combat and non-combat military EVs will total many hundreds of millions of dollars yearly within a few years and 2.1 million military electric vehicles could be made in 2013, implying most trucks and runabouts plus a great deal of large sophisticated equipment such as tanks. Most will be hybrids but fuel cells will start to have an impact as these are particularly attractive to the military. For small vehicles there will still be battery-only EVs in use.

Robotic combat vehicle

Unmanned aerial vehicles (UAVs) are a familiar part of the military's armoury, though not yet in electric form. Unmanned tanks have yet to advance much beyond the drawing board. "Air is much more forgiving because there's not much to hit," says John Bares, director of Carnegie Mellon's National Robotics Engineering Consortium. "But when you're slogging through a forest at 30 mph and you make a little mistake – Bam! You hit a tree."

The Department of Defense's Future Combat Systems program embraces the deployment of terrestrial robotic technology as soon as 2010. Unmanned ground combat vehicles UGCVs) like the Spinner could be used as motorised mules to ferry material to the front lines, but they can also conduct everything from armed reconnaissance to medical evacuation from the battlefield without risking soldiers' lives. "Our premise is to exploit the fact that it's an unmanned vehicle," Bares says. "Most vehicles are designed to support and protect the guys inside." The spinner employs a hybrid electric powertrain from PEI Electronics.

Electric cargo-hauler without batteries

The military's newest cargo-hauling hybrid-electric behemoth may be electric, but it does not use batteries. Developed by Oshkosh Truck, the 8x8 Heavy Expanded Mobility Tactical Truck with ProPulse hybrid-electric-drive technology uses a 40-kW diesel/generator set, which spins the AC motors that drive the wheels and also charges high-performance capacitors. When conditions call for an extra burst of power for acceleration, the capacitors discharge and deliver the juice. While capacitors do not hold a charge as long as batteries, they are lighter.

Other US military EV programs

The US military seeks a 75 per cent cut in fuel usage by 2020 and believes hybrids can contribute 25- 30 per cent. It is developing a land-based V22 hybrid reconnaissance surveillance and targeting vehicle "RSTV", a hybrid FMTV truck and a hybrid line hauler. The development budget granted by the US military for the projects is $43 million. In addition a HybriDrive™ hybrid electric drivetrain from Lockheed Martin has been installed in a Volvo VNL64 tractor as part of a big-rig project funded by the US Army's Tank-Automotive and Armaments Command.

The project employs a standard Class 8 Volvo tractor with a 460-horsepower Cummins engine powering a hybrid drive with two 250-hp motors. Fuel savings of 20 or 25 per cent are expected, but could reach 40 per cent during some duty cycles. At least one demonstration truck is to be delivered to TACOM by December 2000. Radian, Inc. is the prime contractor, with Lockheed Martin Control Systems and Volvo Trucks North America as subcontractors.

Non combat vehicles

There is a large military demand for non-combat EVs, and the US Airforce is thought to have the biggest EV fleet in the world. These are mostly airside airport vehicles that are largely the same as those used by civil airports so we covered these as "industrial". However, some are customised.

Combat vehicles

There are very few electric combat vehicles in use across the world today, presumably due to the inadequate range and slow recharging of yesterday's battery-powered vehicles. Nonetheless, high speed multipurpose personnel carriers and attack EVs have valuable advantages over their IC equivalents, such as low noise, lack of the heat and vapour trails that missiles home in on and superlative acceleration, active life and reliability. In the military, reliability is extremely important.

Israel

Unique Mobility reported has shipped electric propulsion system components to Technion - Israel Institute of Technology, in connection with a hybrid-electric powertrain for a heavy tracked military vehicle. The first shipment included a pair of SR286 waterproof traction motors rated at 75 kilowatts each, and a similarly sized generator unit rated at up to 100 kilowatts output to be mated to a diesel engine, and they supplied electronic controls.

The new military vehicle is operable in all-electric mode, giving a low thermal signature that makes it "virtually impossible to detect using infra-red sensor technology," UQM says. The company supplied similar parts for hybrid vehicles in development by the US military. "We believe there is tremendous opportunity to introduce hybrid-electric propulsion systems in combat class vehicles," UQM chairman and CEO Ray Geddes said.

Bomb disposal

Electric robot vehicles for inspecting, defusing and removing bombs are widely used. They replace human effort and make something new possible. ICE versions never were an option because their noise and vibration would detonate the bomb prematurely. If that is what is required, it is easier to throw a brick!

Disposable surveillance aircraft

Disposable surveillance aircraft mentioned earlier are small enough to be carried by individual soldiers and they are currently being developed and trialled. Some of these are battery powered and are required to fly for an hour or so. Of these, some use conventional aerofoil designs (such as the AeroVironment submissions).

Others are based on the way an insect flies. The electric insects are based on the work of Charles Ellington of Cambridge University UK who built a large slow-motion insect for wind tunnel tests in 1994. He showed how this form of flight depended on a micro-vortex. His research came to the attention of the Defence Advanced Research Projects Agency (DARPA) of the US Department of Defence, which has begun a $35 million programme to develop micro air vehicles, or MAVs. The concept was of equipping soldiers with tiny aircraft, including helicopters that would carry miniature remote sensing devices to observe enemy troops on their side of the battlefield. However, such devices, even if small, could not do well in urban combat - in narrow city canyons and inside buildings. They would be too noisy to remain undetected or they would fly too fast to manoeuvre. By contrast, insects can fly quietly in all directions, hit a wall at full speed and survive.

DARPA insects

To create such hardy reconnaissance bugs, DARPA began its Mesoscale Machines for Military Applications programme in 1998. $20 million was granted in initial funding. A three-year deadline was imposed on selected research institutions across the US. Ellington is working with Georgia Institute of Technology with Robert Michelson to develop the "reciprocating chemical muscle" - chemical power source that will energise the wings, navigation and steering instruments, and various payload accessories of his group's device, called an entomopter, for at least three minutes.

Vanderbilt University

Competitor Vanderbilt University is nearing sustained tethered flight with a five-gramme 15 centimetre-wingspan artificial insect. Actuators made from piezolectric material - a ceramic that strains when a voltage is applied to it - flap the insect's wings. Electric power currently comes from an external Source: a lithium battery. "With the amounts of lift that we are expecting, we can pretty much tweak it and get the thing to hover by itself autonomously", their Adam Cox asserts. Later it will become a true EV carrying its own power source. Vanderbilt and Georgia Tech teams are optimistic that they can bring their bugs to life. "By the end of the three years we'll have it flying in stable, trimmed flight," says Ellington. "I'll be able to walk out of my office and toss it down the hallway and have it fly away."

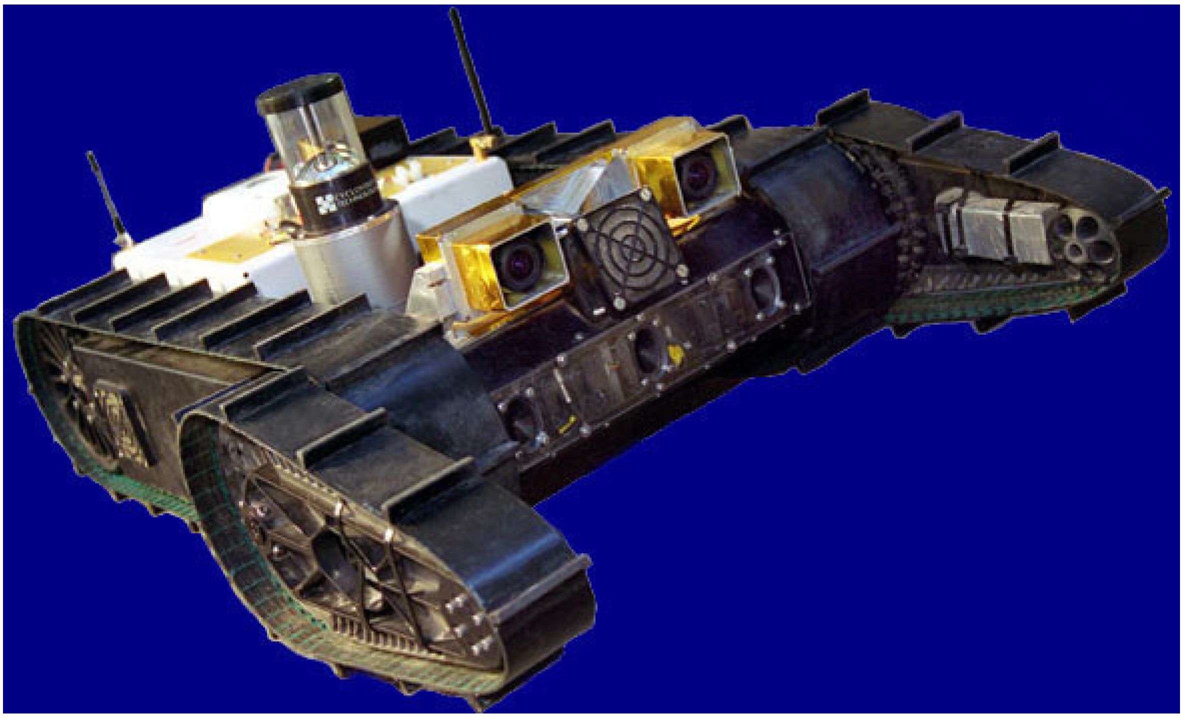
10.1.2. Case study: UQM unmanned combat vehicle

In 2005, UQM of the US is executing a $599,000 contract with the US Marine Corps to develop a hybrid propulsion system to propel a small, unmanned combat vehicle weighing between 227 and 1000 kilograms. The propulsion system that is under development includes a ten kilowatt propulsion motor, a planetary gear set, and a dual motor controller with an integrated 60 KHz inverter that will operate when the vehicle is stationary.

10.1.3. Case study: URBIE reconnaissance robot

Figure 10.8 shows the URBIE reconnaissance robot being developed by JPL

Fig. 10.2 **The URBIE reconnaissance robot**



Source: JPL

The Tactical Mobile Robot program, in the DARPA Advanced Technology Office, has enlisted JPL's Machine Vision Group in leading the design and implementation of its perception urban robot. This urban robot (Urbie) is a joint effort of JPL, iRobot Corporation, the Robotics Institute of Carnegie Mellon University, and the University of Southern California Robotics Research Laboratory.

Urbie's initial purpose is mobile military reconnaissance in city terrain but many of its features will also make it useful to police, emergency, and rescue personnel. The robot is rugged and well-suited for hostile environments and its autonomy lends Urbie to many different applications. Such robots could investigate urban environments contaminated with radiation, biological warfare, or chemical spills. They could also be used for search and rescue in earthquake-struck buildings and other disaster zones.

10.1.4. Case study: Micro Robot Explorer – Spider Bot

The Micro Robot Explorer class of robots known as Spider Bots are insect-like and can walk, climb and even traverse a ceiling. It is intended that they can repair orbiting spacecraft, including radar and antenna arrays and come our at intervals to check equipment.

Fig. 10.3 **An example of a Spider Bot**

Source: JPL

10.1.5. Case study General Motors fuel cell Silverado truck

Press release :Apr 01, 2005

The modified Chevrolet Silverado is equipped with two 94 kW fuel cell stacks, capable of generating 188 kW and 317 foot-pounds of torque, or roughly the motor torque generated by GM's 5.3 liter V-8 engine. Range with three 10,000 psi tanks is 125 miles.

Honeoye Falls, NY - General Motors Corp. and the U.S. Army announced they are partnering to introduce the world's first fuel cell-powered truck into U.S. military service. The U.S. Army took delivery of the crew cab pickup at the GM research facility outside of Rochester, NY, where the vehicle's two fuel cell power modules were made. Marking the occasion was Sen. Hillary Rodham Clinton (D-NY), who was instrumental in securing the funds in the 2005 Department of Defense appropriations on behalf of GM's experimental truck."

"The work that GM is doing here in Honeoye Falls represents extraordinary promise for New York State and indeed the entire nation. Securing the funds to make this project possible was a critical step in the right direction. I'm thrilled to have helped and been able to play a role in today's announcement," said Senator Hillary Rodham Clinton.

The modified Chevrolet Silverado is equipped with two 94 kW fuel cell stacks, capable of generating 188 kW and 317 foot-pounds of torque, approximately that generated by GM's 5.3 liter V-8 engine.

"Fuel cell vehicles are a good match with U.S. Army goals," said Elizabeth A. Lowery, GM's vice president for Environment and Energy. "We are committed to the development of new technologies that will improve fuel consumption and reduce vehicle emissions. Fuel cell systems are both clean and quiet, and therefore, can provide a battlefield advantage.

"Our partnership with the U.S. Army will familiarize the military with the next-generation of commercially-developed fuel cell technology, will help us drive down costs, create potential for future joint development of fuel cells and promote the development of a hydrogen infrastructure."

The U.S. Army has the largest fleet of vehicles in the world. Improving fuel economy and reducing the logistics of the fuel supply chain could save millions of dollars. For example, it cost the U.S. Army up to $400 a gallon of gas to ship fuel to Iraq and Afghanistan.

GM has a history of working with the military on their transportation needs. The automaker produces more than half of the non-tactical military vehicles purchased each year. The U.S. Army will evaluate the experimental truck until July 2006 at an Army base in Ft. Belvoir, Va. The vehicle will be used to deliver packages but will not be used in combat. Rigorous testing is planned in different climates and locations around the U.S. to assess performance and give the military first-hand experience with hydrogen and fuel cells.

Despite weighing 7,500 pounds, the GMT800 accelerates in a similar fashion to a V-8 powered production truck, but produces no tailpipe emissions. Fuel cells chemically convert hydrogen into electricity and water. Three 10,000 psi compressed hydrogen storage tanks, provided by Quantum Technologies, will provide a range of 125 miles, even though the vehicle was not optimized for range.

Market forecasts

The projections for military vehicles omit disposable $1,000 surveillance aircraft carried by soldiers. If these succeed, the volumes will be much higher and market value somewhat higher, these are shown in tables 10.1, 10.2 and 10.3.

Table 10.1 **Global EV manufacturing market for military, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	6	20	50	101	205	210	210	220	250	250	250
$ Unit value ('000)	50	50	60	61	62	63	63	68	80	79	84
$ billion value	0.30	1.0	3.0	6.15	12.75	13.5	13.5	15.0	19.5	19.8	20.9

Source: IDTechEx

Table 10.2 **Global military hybrid EV sales 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	5	18	45	80	150	150	150	150	150	130	118
$ Unit value ('000)	50	50	60	60	60	60	60	60	60	60	60
$ million value	0.25	0.90	2.7	4.8	9.0	9.0	9.0	9.0	9.0	7.8	7.1

Source: IDTechEx

Table 10.3 **Global military battery-only EV market, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	1	2	5	20	50	50	50	50	50	50	50
$ Unit value ('000)	50	50	60	60	60	60	60	60	60	60	60
$ million value	005	0.1	0.3	1.20	3.00	3.00	3.00	3.00	3.00	3.00	3.00

Source: IDTechEx

Table 10.4 **Global military fuel cell EV market, 2005 to 2015**

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Number ('000)	–	–	–	1	5	10	10	20	50	60	72
$ Unit value ('000)	–	–	–	150	150	150	150	150	150	150	150
$ million value	–	–	–	0.15	0.75	1.5	1.5	3.0	7.5	9.0	10.8

Source: IDTechEx

To give a sense of proportion, the $19.5 billion spend in 2013 would be two per cent of the global military spend at that time. There is, however, an implication that most military trucks and armoured vehicles and even a lot of runabouts (Jeeps) would also be hybrid at that time, mainly to reduce cost and fuel logistics difficulties.

The total spend projected by the US military is $430 billion in every year from 2008 to 2014 according to the 2003 budget but, if all current commitments are met, that must rise by $100 billion each year.

Table 10.5 list some suppliers.

Table 10.5 **Suppliers of military EVs**

COMPANY	COUNTRY	TYPE
Advanced Technology Products	US	Aircraft
Aerovironment	US	Aircraft
Alvis	UK/Sweden	Land vehicles
DaimlerChrysler	US	Land vehicles
Ford	Germany	Land vehicles
General Dynamics Land Systems	US	Land vehicles
General Motors	US	Land vehicles
IDJ/PEI	US	Land vehicles
Ingersoll Rand	US	Land vehicles
Oshkosh Truck	US	Land vehicles
Singapore Automotive Technologies	US	Land vehicles
UKLP (formerly FMC)	US	Land vehicles
Vickers	UK	Land vehicles

Source: IDTechEx

Appendix 1

Fuel cell EVs

Appendix 1: Fuel cell EVs

The significance of fuel cells

Our forecasts after 2010 depend partly on whether fuel cells are a success. It is not just a matter of fuel cells replacing – or not replacing – some existing hybrid or pure battery EVs. They will indeed replace some ICE-battery EV hybrids and a few pure battery EVs within 10 - 15years. That would not affect our overall figures for sales of EVs of all sorts. More important is the fact that the characteristics of fuel cells favour replacement of existing ICE vehicles. That would grow the overall EV market, possibly substantially. That is certainly the intention of the main proponents. We therefore appraise fuel cells in this separate chapter.

The situation with fuel cells can be summarised as "Great wall of money meets great wall of problems". The result is great uncertainty about when fuel cells will have a major impact. We have been waiting since the fuel cell was invented in the UK by Sir Charles Groves in the 1840s. For the last fifty years, success has always been ten years away.....

The challenges of fuel cells

There are interim fuel cells that are being commercialised earlier than the ultimate fuel cells, at least in certain applications. Interim fuel cells may burn methanol, ethanol or (indirectly) gasoline or other hydrocarbons supplied to the vehicle. They may be refreshed with zinc or other materials. Ultimate fuel cells simply burn oxygen with hydrogen to make water. They are ultimate in that they should be the most efficient and least polluting. The various types of fuel cell technology have most of the following challenges when applied to vehicles. See table A1. We distinguish between the ultimate, notably, "Proton Exchange Membrane PEM" and interim types such as methanol.

Table A1 Challenges faced in developing satisfactory fuel cells for vehicles

CHALLENGES	TYPE
Start up time	Most
Pollution – air	Interim
Pollution – land	Interim
Noise	Most
Cost	Most
Size	Most
Weight	Most
Reliability	Most
Life	Most
Poisons	Interim
Precious metals	Some
Lack of infrastructure	Most
Sensitivity to contamination	Most
Lack of standards	Most
Water that freezes	Many
Safety	Most
Hydrogen storage	PEM

Source : IDTechEx

Table A2 gives a detailed view of the negatives and positives for some types of vehicle.

Table A2 Category of vehicle vs negatives and positives of fuel cells

CATEGORY		LIMITATIONS WHERE FUEL CELLS MAY HELP								
		Inadequate weight	Frequent maintenance	Pollution	Poor range	Stop Start	Poor start torque	Fire Risk	Difficult to provide charging	Frequent refills
Heavy warehouse, dock and factory vehicles such as forklifts	ICE	●	●	●		●	●	●		
	Battery		●							
Heavy tugs such as for aircraft and mining	ICE	●	●	●		●	●	●	●	
	Battery		●		●					
Light stackers, lifters etc.	Battery				●					
Light airport ground support equipment e.g. tugs, workmen's vehicles	Battery				●				●	
Seated floor sweepers, scrubbers, ice rink conditioners, floor grinders, mowers, mobile platforms (e.g. scissor)	Battery				●					
Neighbourhood vehicles	Battery				●					
Golf cars	ICE			●						
	Battery				●					
Cars	ICE		●	●		●				●
Buses	ICE		●	●	●	●				●

Source: IDTechEx

Let us explain further.

Weight

Counterbalanced vehicles and heavy tugs/locomotives tend to need weight in order to operate efficiently. It is expensive to do this with iron. Lead acid batteries serve well. The heavier fuel cell systems may have a similar benefit.

Maintenance

Frequent maintenance of ICE is due to their inherent complexity and lack of reliability, particularly gasoline versions. With battery vehicles it does not apply to the motor but to the battery itself where even a small forklift may need one set of batteries in use, one cooling down and one recharging. All three sets may last two years or less. That is for intensive work cycles : it does not apply to light or infrequent duty.

Pollution

Pollution is intolerable, even illegal indoors with ICE and now draconian regulations are being applied outdoors at such localities as airports and orchards in the West and cities in China and Taiwan. An overall summary is given in table A3.

TableA3 Potential benefits of fuel cells in vehicles

BENEFIT	TYPE
Lower cost of ownership	All
Lower pollution than ICE	All
Indoor use	PEM and a few others

Source: IDTechEx

Forecast penetration of fuel cells

Like most EV cars, up to 2008 or so, fuel cells will usually be sold on a loss-making basis. For fuel cells that may mean up to 2013. Therefore, as with cars, forecasting sales is as much a matter of forecasting subsidies as forecasting demand and that makes it very uncertain.

Our forecasts, 2005 to 2015

Table A4 gives an estimate of the percentage of fuel cell EVs by category 2003, 2013, 2015 for some of the most promising categories.

Table A4 Estimate of percentage of EVs that are fuel cell driven 2003 to 2015

%	2003	2013	2015
Mining	zero	15	25
Military	zero	near zero	30
Heavy industrial	zero	2	10
Light industrial,	zero	2	5
Commercial	zero	10	5
Car			

Source: IDTechEx

However, note that these percentages are of an inflated EV market caused by replacement of ICE with fuel cells. Virtually all previous forecasts by experts have been wildly over-optimistic. Within light industrial/commercial, large buses and trucks may be as much as 20 per cent fuel cell in year 2013 but all forecasts remain highly speculative at this stage.

All fuel cell vehicles need hefty batteries for start up, regenerative braking and for auxiliary power when shut down. Thus all EVs depend on progress in battery technology and economy of scale of battery production and fuel cell EVs are no exception.

Allied Business Intelligence

A new report from Allied Business Intelligence (ABI) anticipates that the fuel cell vehicle (FCV) industry will grow significantly by the end of the decade. Titled "U.S. and Global Automotive Fuel

Cell Markets : Markets, Technologies and Applications", it predicts that as many as 2.4 million FCVs could be in service by 2011. this is far more optimistic than our projections.

ABI said the prognosis depends on the ability of automakers to address existing technological challenges, including fuel distribution and the development of simpler processing technology.

"It is not the same industry it was even a year ago", said ABI vice president of energy research Atakan Ozbek, who authored the study. "The dynamics that are driving the fuel cell industry have been evolving rapidly and are setting the stage for a large market".

ABI said fuel cell availability in 2003 and 2004 is expected to be lower than earlier predicted by ABI, but the group noted that it believes the FCV market will grow considerably in 2007 and 2008. The report said fuel cells will become more affordable once economies of scale are reached, which could be after 100,000 automotive fuel cells have been produced.

The report pointed to bus fleets and state and federal government fleets as important early markets for fuel cell vehicles because central hydrogen fuelling facilities are "easier to build and maintain than passenger car fuelling stations across the U.S."
Some of the technical barriers to commercial FCV use discussed in the report include fuel cell fuel distribution and complex fuel cell processing technology.

"Despite all of this, almost all automotive manufacturers, even the once conservative (General Motors), are now investing in the potential hydrogen economy", said Ozbek.

Business Communications Company

A recent study from Business Communications Company, BCC says that the U.S. large battery and fuel cell material market dipped from $1.5 billion in 2000 to $1.4 billion at the wholesale level in 2001. However, the market should be worth more than $2.4 billion in 2006, rising at an average annual growth rate of 12 per cent during the next five years.

The study, "RGB-266A Materials for Large Size Batteries and Fuel Cells" found that while lead remains the most important large battery material, the value of lead materials sold in the U.S. fell between 2001 and 2002. BCC projects that shipments of lead materials, whose prices have fallen "significantly", aiding conventional EVs, will see an average increase of about 0.8 percent per year over the next five years.

BCC said other materials used in lead-acid batteries, such as tin, antimony, sulphuric acid, arsenic, bismuth, selenium, tellurium, silicon oxide, calcium, cadmium and phosphoric acid, could experience more significant growth, with value increasing from $80 million in 2001 to approximately $87 million in 2006, putting conventional EVs at a disadvantage.

Sales of non-lead battery materials, such as platinum group metals, titanium, zirconium and lithium, carbon, and rare earth compounds, are expected to grow at an AAGR of 66 per cent from $74 million in 2001 to $ 936 million in 2006.

Poor lead-acid battery sales will mean that the sale of such organic materials as plastic resins, organic electrolytes and many battery separators, will remain at approximately $40 million through the five-year scope of the report.

BCC calculates that other battery and fuel cell materials, which represented a $35 million market in 2001, should grow to a $167 million market by 2006.

Other forecasts

Roger Dettmer, writing in IEE Review says, "IC-based hybrids are a proven technology. The fuel cell – augmented by hybridisation or otherwise – suffers from high costs and problems of fuel supply. Ford envisages that, sometime after 2010, it will be able to offer fuel cell vehicles to customers at affordable prices and that hydrogen filling stations, if built in sufficient number, will produce fuel at a price comparable to existing petrol prices."

Nick Owen, Ricardo's senior manager in Ricardo Technology Group, takes a more qualified view of the fuel cell's prospects : "For the next twenty years, hybrid technology will achieve far greater sales volumes than fuel cell vehicles, as it is much more compatible with today's manufacturing and servicing infrastructure. For the longer term, fuel cells, as prime movers or auxiliary power units, remain an interesting, low-emission alternative to the IC engine."

Types of fuel cell

The main types of fuel cell are as in table A5.

Table A5 Types of fuel cell and characteristics

TYPE	FEATURES
Alkaline Fuel Cells (AFC)	Operate at approximately 80°C and have been extensively used in spacecraft and submarines. They have been tested to drive road vehicles such as minivans, using hydrogen as fuel.
Solid Polymer Fuel Cells (SPFC)	Also called Proton Exchange Membrane (PEM) Fuel Cell – the most important for vehicles in the longer term, and Direct Methanol Fuel Cells (DMFC). Operate in the range 60°C-130°C and are suitable for transport and portable applications and for cogeneration in buildings. SPFC could also find applications in power generation in providing peak power and avoiding grid-reinforcement. SPFC are currently tested at a 250 kW scale. They offer potential for significant cost reduction and are expected to be commercialised in 5-10 years.
Phosphoric Acid Fuel Cells (PAFC)	At approximately 40% electricity production efficiency and 200°C operating temperature. PAFC is suitable for commercial or light industry applications. Systems of 200 kWare presently commercially available. Pilot plants of 1.3 MW in Italy and of 11 MW in Japan have been built, but their cost is still high (2,500 EURO/kW). Not suitable for vehicles.
Molten Carbonate Fuel Cells (MCFC)	Have approximately 55% net electricity efficiently. Operate at 650°C and are appropriate for utilities and industrial applications requiring heat between 200°C and 600°C. A number of technical problems such as corrosion and reliability still have to be solved. It is expected that commercialisation will take 5-10 years. Systems up to 2 MW have been constructed and demonstrated but the reliability of such systems has not been encouraging. Not suitable for vehicles.
Solid Oxide Fuel Cells (SOFC)	Have a comparable efficiency and the same utilisation sectors as MCFC. Operating temperature is between 700°C and 1,000°C. A 100 kW plant is operated in Holland. Further materials research and cost reduction will be needed. Commercialisation is expected to take place in around 10 years. Not suitable for vehicles.

Source: IDTechEx

Strength and breadth of consumer propositions for fuel cells

The strength and breadth of consumer propositions for fuel cells in non-road applications where they replace EVs, hybrid or battery only go in the following order:

Table A6 Prioritisation of fuel cell applicability by type of EV

1	Heavy industrial battery vehicles, notably fork lifts.
2	Light industrial battery vehicles, such as seated mowers, floor cleaners, mobile platforms (boom, scissor, etc) and workmen's vehicles in the grounds of theme parks, hotels etc.
3	Neighbourhood cars and golf carts where long range or heavy duty such as hill climbing is required. An example is Japanese golf courses.

Source: IDTechEx

Airports use both heavy and light electric vehicles that would benefit from fuel cells.

PEM fuel cells are the ultimate, most elegant, least-polluting solution for most mobile fuel cell applications. The interviews with 44 global experts carried out by Northeast Advanced Vehicle Consortium in 2000 found that a large majority considered PEM to be the best solution for mobile use.

Fork lifts and tugs for mining and aircraft can benefit from fuel cell power even if the unit is heavy because of the need for large weight, small size, low cost over life and heavy usage. For fork lifts small size is valuable because manoeuvrability in congested warehouses etc is an issue and the weight will save cost of iron counterweights needed with ICE versions. (Lead – acid batteries do this today but not for the heaviest duty applications). With certain fork lifts and not many other applications, the batteries are today used so intensively that one set is in use, one cooling and one being recharged. That gives fuel cells an advantage not available in lighter-duty vehicles.

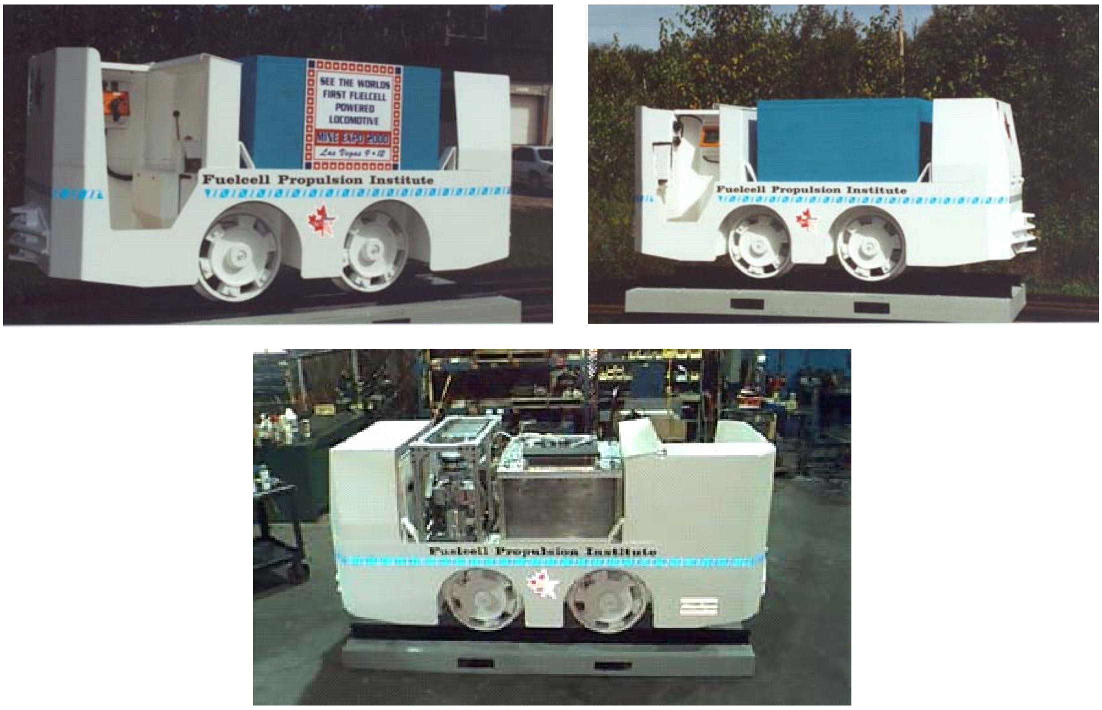
Many of these consumer propositions are likely to apply to some military vehicles and some boats as well. Neighbourhood vehicles need the range of a fuel cell and the small size of ECD storage but not the weight and sales are weak. Most golf carts are fine with batteries and the golf car market is not growing.

Given that the biggest opportunity for fuel cells in vehicles is to replace ICE vehicles, we list the softest targets below.

- Mining locomotives
- Earthmoving equipment
- Buses
- Heavy tugs
- Heavy trucks
- Heavy lifters
- Military vehicles

Two and three wheel vehicles can benefit from fuel cells in due course, particularly motorcycles, but almost all of them need very dispersed refuelling, so we give them lower priority.

Fig A1 Fuel cell mining locomotive at the Atlas Copco Wagner manufacturing facility in Oregon, USA



Source: Atlas Copco

Fuel cell developers

The following businesses, institutes and organizations are involved in research and development in the fuel cell industry (with links and technology focus, if available). A directory of almost 500 fuel cell related companies and organizations — featuring contact names, addresses, phone numbers and company descriptions — is available for $50.00 through Fuel Cells 2000. Table A8 gives examples of companies involved in commercialising fuel cells in vehicles.

Table A8 Over three hundred examples of companies involved in commercialising fuel cells in vehicles

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
3- Dimensional Services	Michigan	USA	General R&D
AC International Inc.	Ontario	CANADA	
Acurex Environmental	California	USA	PEM & PAFC
Advanced Power Sources	Leicestershire	UK	General R&D
AeroVironment Inc.	California	USA	General R&D
Alliance to Commercialise Carbonate Technology	Washington	USA	MCFC
AlliedSignal Aerospace Co.	California	USA	PEM & SOFC
Analytic Power Corporation	Massachusetts	USA	PEM
Ansaldo CLC s.r.l.		ITALY	PAFC
Argonne National Laboratory	Illinois	USA	PEM, MCFC & SOFC
Atlanta Gas Light Co.	Georgia	USA	
Avista Laboratories	Washington	USA	PEM
Balcke-Durr Inc.	Florida	USA	
Ball Aerospace & Technologies Corp.	Colorado	USA	
Ballard Generation Systems Inc.	New Jersey	USA	PEM
Ballard Power Systems Inc.	British Columbia	CANADA	PEM
Battelle	Ohio	USA	
BCS Technology Inc.	Texas	USA	PEM

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
Bechtel Corporation	California	USA	
BG Technology	Leicestershire	UK	
BHP Research	Victoria	AUSTRALIA	
BMW		GERMANY	PEM
Bosch Technologies Group	British Columbia	CANADA	
Brookhaven National Laboratory	New York	USA	
Bruderly Engineering Associates	Inc.	Florida	USA
Burnham Polymeric	New York	USA	
C2i Ltd.	California	USA	
Case Western Reserve University	Ernest B. Yeager Center, Ohio	USA	PEM
Catalytica	California	USA	
CdF Ingenierie	Freyming-Merlebach	FRANCE	
Central Research Institute of Electric Power Industry (CRIEPI)		JAPAN	MCFC & SOFC
Ceramatec	Utah	USA	SOFC
Ceramic Fuel Cells Ltd.	Victoria	AUSTRALIA	MCFC
Chrysler Corporation	Michigan	USA	PEM
Chubu Electric Power Company Inc.		JAPAN	
Cinergy Corporation	Ohio	USA	
City of Chula Vista	California	USA	
Colorado School of Mines	Colorado	USA	
Columbia Gas	Ohio	USA	
Cooper Industries	New York	USA	
Coval H2 Partners	California	USA	PEM
CSIRO Energy Technology	New South Wales	AUSTRALIA	
Daimler-Benz AG		GERMANY	PEM
DAIS Corporation	Florida	USA	PEM
Danish Energy Agency	Copenhagen	DENMARK	
dbb Fuel Cell Engines GmbH		GERMANY	PEM
DCH Technology Inc.	California	USA	PEM
DE NORA s.p.a.		ITALY	PEM
Defence Research Agency		UK	
Degussa AG		GERMANY	
Delco Propulsion Systems	Indiana	USA	
Delft University of Technology		NETHERLANDS	
Delphi Energy & Engine Management Systems	New York	USA	PEM
Desert Research Institute	Nevada	USA	
Detroit Edison	Michigan	USA	
Directed Technologies Inc.	Virginia	USA	PEM
Down Stream Systems Inc.	California	USA	
DTI Energy, Inc.	California	USA	PEM
Duke Power Company	North Carolina	USA	
DuPont Polymers & Automotive	Delaware	USA	PEM
Duke Energy	North Carolina	USA	
Duke University	North Carolina	USA	
Duquesne Light	Pennsylvania	USA	
Dutch Fuel Cell Corporation BCN		NETHERLANDS	
DynEco Corporation	Florida	USA	
E Source	Colorado	USA	
EA Technology		UK	
Ecole Polytechnique de Montreal		CANADA	PEM
Ecostar Electric Drive Systems Company	Michigan	USA	
Electric Auto Corporation	Florida	USA	
Electric Fuel Cells Inc.	Wisconsin	USA	
Electric Power Development Company		JAPAN	
Electric Power Research Institute	California	USA	PAFC & MCFC
Electrical Research Institute-USCAS		MEXICO	

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
Electricite De France (EDF)		FRANCE	
Electro-Chem-Technic		UK	PEM
ElectroChem Inc.	Massachusetts	USA	PEM
PEM			
Elkraft		DENMARK	MCFC
ENEA Casaccia Research Center		ITALY	
Eneco		UK	Alkaline
Energia Ltd.	Virginia	USA	
Energy Partners Inc.	Florida	USA	PEM
Energy Related Devices	New Mexico	USA	PEM
Energy Research Corporation	Connecticut	USA	DFC & MCFC
Energy Ventures Inc.		CANADA	AFC
Energy and Environmental Research	California	USA	
E-TEK Inc.	Massachusetts	USA	
ETSU		UK	
Exxon Research & Engineering	New Jersey	USA	
Fabrique Research		NETHERLANDS	SOFC
Factory Mutual Research Corp.	Massachusetts	USA	
FCP Engineering Inc.	Florida	USA	PEM
Federal Energy Technology Center	West Virginia	USA	MCFC & SOFC
Florida Institute of Technology	Florida	USA	
Florida Solar Energy Center	Florida	USA	
Ford Motor Company	Michigan	USA	PEM
Forschungszentrum Julich		GERMANY	DMFC, SOFC & PEM
Fritz-Haber-Institut der Max-Planck-Gesellschaft		GERMANY	
Fuel Cell Buyers Consortium	California	USA	PAFC & PEM
Fuel Cell Corporation of America	Pennsylvania	USA	PAFC
Fuel Cell Design & Development	Connecticut	USA	
Fuel Cell Group		DENMARK	PAFC, MCFC & SOFC
Fuel Cell Industries	Minnesota	USA	
Fuel Cell Institute of S.J.T.U.		CHINA	MCFC & PEM
Fuel Cell Manufacturing Corp.	Connecticut	USA	DFC
Fuel Cell Technologies	Connecticut	USA	
Fuel Cell Technologies Ltd.		CANADA	
Fuel Cells & Reformers Canada Ltd.		CANADA	
Fuelcell Propulsion Institute	Colorado	USA	PEM
Fuji Electric Corporate Research and Development Ltd.		JAPAN	PEM
Fujita Research	California	USA	
Gas Research Institute	Illinois	USA	SOFC
Gas Technology Canada		CANADA	
Gaskatel GmbH		GERMANY	AFC & PEM
Gaz De France		FRANCE	
General Motors - Advanced Technology Vehicles	California	USA	PEM
Georgetown University	Washington D.C.	USA	PAFC
Georgia Institute of Technology	Georgia	USA	
Giner Inc.	Massachusetts	USA	DFC
Global Thermoelectric Inc.		CANADA	PEM
GlobeTech Inc.	Texas	USA	PEM
GPU International Inc.	New Jersey	USA	PEM
H Power	New Jersey	USA	PEM
Haldor Topsoe Inc.	Texas	USA	
Hawaii Natural Energy Institute	Hawaii	USA	
Helsinki University of Technology		FINLAND	
Hitachi Works		JAPAN	MCFC
Honda R&D Co. Ltd.		JAPAN	PEM
Honda R&D North America Inc.	California	USA	PEM
Howaldtswerke-Deutsche Werft AG HDW)		GERMANY	PEM

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
H-Tec - Wasserstoff-Energie-Systeme GmbH		GERMANY	PEM
HTU Friedrichshafen GmbH		GERMANY	
Hydro Quebec Research Institute		CANADA	
Hydrofuel Industries	California	USA	
Hydrogen Research Institute		CANADA	
Hydrogenics Corporation		CANADA	
IBERINCO/Iberdrola		SPAIN	
Idaho National Engineering and Environmental Laboratory	Idaho	USA	
IGR Enterprises Inc.	Ohio	USA	SOFC
IIT Kharagpur		INDIA	MCFC
Illinois Institute of Technology	Illinois	USA	MCFC
Illinois Power Company	Illinois	USA	
Industrial Technology Research Institute		CHINA	
Information Technologies Inc.	Washington	USA	PEM
InnovaTek Inc.	Washington	USA	
Innovation Advantage		UK	PEM
Institute for Integrated Energy Systems	British Columbia	CANADA	
Institute of Applied Energy		JAPAN	
Institute of Gas Technology	Illinois	USA	PAFC, PEM, MCFC & SOFC
Institute of Technical Physics		RUSSIA	SOFC
Instituto CNR-TAE		ITALY	
Instituto De Quimica De Sao Carlos-USP		BRAZIL	
INTA		SPAIN	
Intercon Research	Illinois	USA	
International Fuel Cells	Connecticut	USA	PAFC & PEM
Intoximeters Inc.	Missouri	USA	PEM
Ishikawajima-Harima Heavy Industries (IHI)		JAPAN	MCFC
Isuzu Advanced Engineering Center Ltd.		JAPAN	
Jet Propulsion Laboratory	California	USA	PEM
Johnson-Matthey		UK	
King Abdulaziz City for Science and Technology		SAUDI ARABIA	
Korea Electric Power Research Institute (KEPRI)		KOREA	
Korea Institute of Energy Research		KOREA	
Korea Institute of Science and Technology (KIST)		KOREA	
Korea University		KOREA	
Lawrence Berkeley Laboratory	California	USA	PEM
Lawrence Livermore National Laboratory	California	USA	
Lockheed Martin Energy Research Corp.	Washington DC	USA	
Los Alamos National Laboratory	New Mexico	USA	PEM
Loughborough University	Leicestershire	UK	
Lucent Power Systems	Texas	USA	
Manhattan Scientifics Inc.	New Mexico	USA	PEM
Materials and Systems Research Inc.	Utah	USA	
Matsushita Battery Industrial Company Ltd.		JAPAN	
Mazda R&D of North America, Inc.	California	USA	PEM
M-C Power Corporation	Illinois	USA	MCFC
MCFC Research Association		JAPAN	MCFC
McDermott Technology Inc.	Ohio	USA	PEM
Meruit Inc.	California	USA	
Michael A. Cobb & Company	Ohio	USA	
Michigan Consolidated Gas Company	Michigan	USA	
MICROTRON/USR&D	New York	USA	SOFC
MINATOM		RUSSIA	
Mississippi Polymer Institute	Mississippi	USA	PEM
Mitsubishi Electric Corporation		JAPAN	PAFC
Mitsubishi Heavy Industries Inc.	New York	USA	PEM & SOFC
Mitsui Engineering and Shipbuilding Company		JAPAN	

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
Ltd.			
Mossgas		SOUTH AFRICA	
Motorola Inc.	Georgia	USA	
MPC Products Corp		USA	Hydrogen
MTU Friedrichshafen GmbH		GERMANY	MCFC
Murata Manufacturing Co. Ltd.		JAPAN	SOFC
Musashi Institute of Technology		JAPAN	
Nagoya Institute of Technology		JAPAN	
National Aeronautics and Space Administration	Ohio	USA	Regenerative FCs
National Aerospace Laboratory		JAPAN	PEM
National Draeger Inc.	Colorado	USA	PEM
National Fuel Cell Research Center	California	USA	
National Institute of Materials & Chemical Research		JAPAN	
National Renewable Energy Lab	Colorado	USA	PEM
National Taiwan University		TAIWAN	
Netherlands Agency for Energy and the Environment		NETHERLANDS	
Netherlands Energy Research Foundation		NETHERLANDS	PEM, MCFC & SOFC
New Energy and Industrial Technology Development Org.		JAPAN	
New York Power Authority	New York	USA	
NexTech Materials Ltd.	Ohio	USA	PEM & SOFC
Niagara Mohawk Gas	New York	USA	PAFC, PEM & MCFC
Niagara Mohawk Power Corp.	New York	USA	PAFC, PEM & MCFC
NKK Corporation		JAPAN	
Northeast Utilities Service Co.	Connecticut	USA	
Northwest Power Systems, LLC	Oregon	USA	
Novouralsk Electrochemical Plant		RUSSIA	
NUI Ventures	New Jersey	USA	
Oak Ridge National Laboratory	Tennessee	USA	
Oklahoma State University	Oklahoma	USA	
ONSI Corporation	Connecticut	USA	PAFC
Ontario Hydro Technologies		CANADA	
Osaka Gas Co. Ltd.		JAPAN	SOFC
Osaka National Research Institute		JAPAN	MCFC
Pacific Northwest National Laboratory	Washington	USA	PAFC, MCFC & SOFC
Parsons Power Group Inc.	Maryland	USA	
Patrick Grimes Associates	New Jersey	USA	
PEI Electronics	Alabama	USA	PEM
Pennsylvania Power & Light Company	Pennsylvania	USA	
Pennsylvania State University	Pennsylvania	USA	
People's Gas System Inc.	Florida	USA	
Phosphoric Acid Fuel Cell Technology Research Association		JAPAN	PAFC
Physical Sciences Inc. (PSI)	Massachusetts	USA	
Plug Power, LLC	New York	USA	PEM
Plum Street Enterprises Inc.	New York	USA	PAFC
Portland General Electric	Oregon	USA	
Power Technologies Corporation	California	USA	
PreussenElektra AG		GERMANY	
Princeton University	New Jersery	USA	PEM
Proton Energy Systems	Connecticut	USA	PEM
Riso National Laboratory		DENMARK	
Rocky Mountain Institute	Colorado	USA	PEM
Roke Manor Research		UK	
Rolls-Royce Aerospace Group		UK	
Rolls-Royce Industrial Power Group		UK	
Royal Institute of Technology		SWEDEN	AFC, PEM, MCFC & DMFC

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
Royal Military College of Canada		CANADA	
Russian Federal Nuclear Center		RUSSIA	MCFC
Sacramento Municipal Utility District (SMUD)	California	USA	PAFC & MCFC
Samsung Advanced Institute of Technology		KOREA	
Samsung Heavy Industries		KOREA	
San Diego Gas and Electric	California	USA	MCFC
Sandia National Labs	New Mexico	USA	
Santa Clara Demonstration Project	California	USA	MCFC
SANYO Electric Co. Ltd.		JAPAN	PAFC & SOFC
Schafer Corporation	California	USA	PEM
Schatz Energy Research Center (SERC)	California	USA	PEM
Shikoku Research Institute Inc.		JAPAN	
Siemens AG		GERMANY	PEM
Singapore Technologies Automotive		SINGAPORE	PEM
Small-Scale Fuel Cell Commercialization Group Inc.	Oklahoma	USA	
SOFCo	Utah	USA	SOFC
Solinnov		HUNGARY	
Southern California Edison	California	USA	
Southern California Gas	California	USA	PAFC, MCFC & SOFC
Southwest Research Institute	Texas	USA	PEM
SPIC Science Foundation		INDIA	PEM & DMFC
Spokane Intercollegiate Research & Technology Institute (SIRTI)	Washington	USA	PEM
Sulzer Hexis Ltd.		SWITZERLAND	SOFC
Sumitomo Heavy Industries Ltd.		JAPAN	
Supreme Council for Research Centers and Institutes		EGYPT	
Sustainable Power Systems Inc.	Florida	USA	PEM
Synthesechemie		GERMANY	MCFC
Taiwan Institute of Economic Research		TAIWAN	
TATA Energy and Resources Institute (TERI)		INDIA	MCFC
TDA Research	Colorado	USA	SOFC
Technical University Eindhoven		HOLLAND	
Technical University Graz		AUSTRIA	
Technische Universitat Darmstadt		GERMANY	
Technische Universitat Munchen		GERMANY	
Technology Management Inc.	Ohio	USA	SOFC
Technology Partnership Plc.		UK	
Technology Research Laboratories Inc.	North Carolina	USA	
Tennessee Valley Authority	Tennessee	USA	
Texas A&M University	Texas	USA	PEM
Thermo Power Corporation	Massachusetts	USA	
Thiokol Corporation	Utah	USA	
Three Bond Co. Ltd.		JAPAN	PEM
TNO Energy & Environment		NETHERLANDS	
Tokyo Institute of Technology		JAPAN	
Toshiba Corporation		JAPAN	PAFC & PEM
Total Design Management	Michigan	USA	PEM
Toyota Motor Corporation		JAPAN	PEM
United States Army Construction Engineering Research Labs	Illinois	USA	PAFC
United States Department of Energy (main)	Washington DC	USA	PAFC, PEM, MCFC & SOFC
United States Department of Energy (Office of Transportation Technologies)	Washington DC	USA	PAFC & PEM
United States Department of the Navy	Washington DC	USA	
United Technologies Research Center (UTRC)	Connecticut	USA	PAFC & PEM
Universiti Kebangsaan Malaysia		MALAYSIA	
University of California	California	USA	PEM

COMPANY	LOCATION	COUNTRY	FUEL CELL TYPE
University of California - Davis (Inst. for Transportation Studies)	California	USA	PEM
University of California - Davis (R&D)	California	USA	PEM
University of Florida	Florida	USA	
University of Kassel		GERMANY	
University of Malta		MALTA	
University of Michigan	Michigan	USA	
University of Missouri - Rolla	Missouri	USA	SOFC
University of Pennsylvania	Pennsylvania	USA	
University of Reading		UK	PEM
University of South Carolina	South Carolina	USA	PEM
University of Southern Mississippi	Mississippi	USA	PEM
University of Surrey		UK	PEM and SOFC
University of Technology		MALAYSIA	
University of Utah	Utah	USA	
University of Victoria		CANADA	
University of Waikato		NEW ZEALAND	
University of Washington	Washington	USA	
University of Western Sidney	Nepean	AUSTRALIA	
UtiliCorp United	Missouri	USA	
Warsitz Enterprises	California	USA	PEM
Wellman CJB Ltd.		UK	PEM
Westinghouse Electric Corporation/Siemens	Pennsylvania	USA	SOFC
Westinghouse Savannah River Company	South Carolina	USA	
Worchester Polytechnic Institute	Massachusetts	USA	PEM
Yamanashi University		JAPAN	
Zevco		UK	AFC
ZSW	Center for Solar Energy & Hydrogen Research	GERMANY	PEM, MCFC & SOFC
ZTEK Corporation	Massachusetts	USA	SOFC

Key:

AFC	Alkaline Fuel Cells
MCFC	Molten Carbonate Fuel Cells
PAFC	Phosphoric Acid Fuel Cells
PEM	Proton Exchange Membrane
SOFC	Solid Oxide Fuel Cells
SPFC	Solid Polymer Fuel Cells

Source: IDTechEx

Hydrogen sources

Hydrogen can be extracted fairly cheaply from abundant fossil fuels, such as coal, generating pollution. The US favours this route for fuel cell vehicles. Europe and Japan favour renewables but both routes can lead to sharp reductions in pollution. Table A9 gives values for the cost of producing hydrogen by various routes.

Table A9 The cost of producing hydrogen by source

	$ PER GIGAJOULE
Electricity from nuclear power	10 – 12
Electricity from coal/gas minus CO2	15 – 18
Hydrogen from coal/gas/oil	1 – 5
Hydrogen from natural gas minus CO2	8 – 10
Hydrogen from coal minus CO2	10 – 13
Hydrogen from biomass	12 – 18
Hydrogen from nuclear power	15 – 20
Hydrogen from onshore wind	15 – 25
Hydrogen from offshore wind	20 – 30
Hydrogen from solar cells	25 – 50

Source: International Energy Agency