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Innovation Pathways in Energy Technology: The Case of Low-Carbon Vehicles

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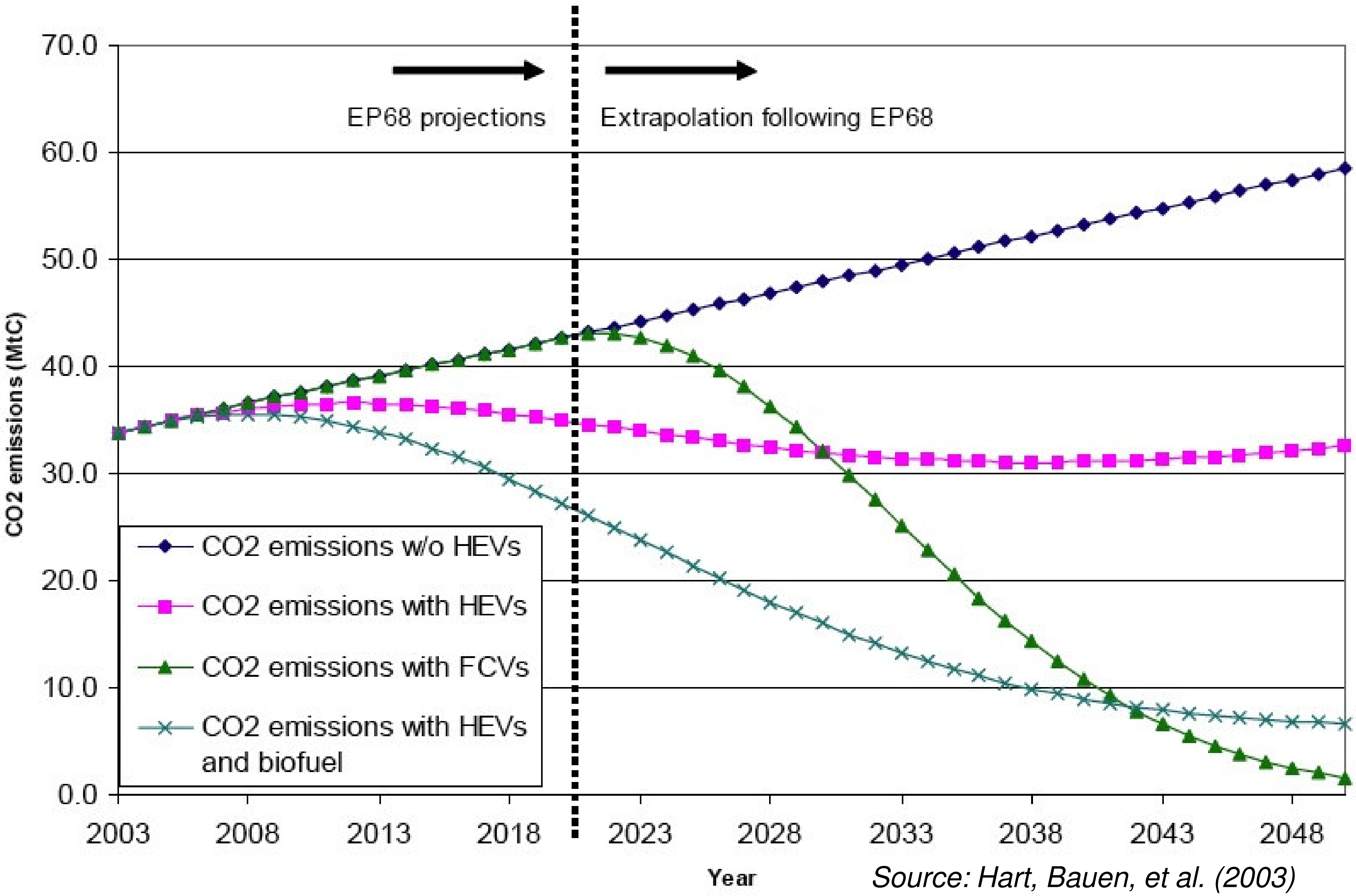
Presentation contents

1. Why EVs?
2. EVs as competing technological systems
3. Relevant market & technology dynamics

HEVs (and diesels) not enough



Source: Hart, Bauen, et al. (2003)

Decarbonisation options

(1) FCVs (+ decarbonised hydrogen)

(2) BEVs (+ decarbonised electricity)

(3) PHEVs (+ decarbonised electricity + carbon-neutral biofuels)

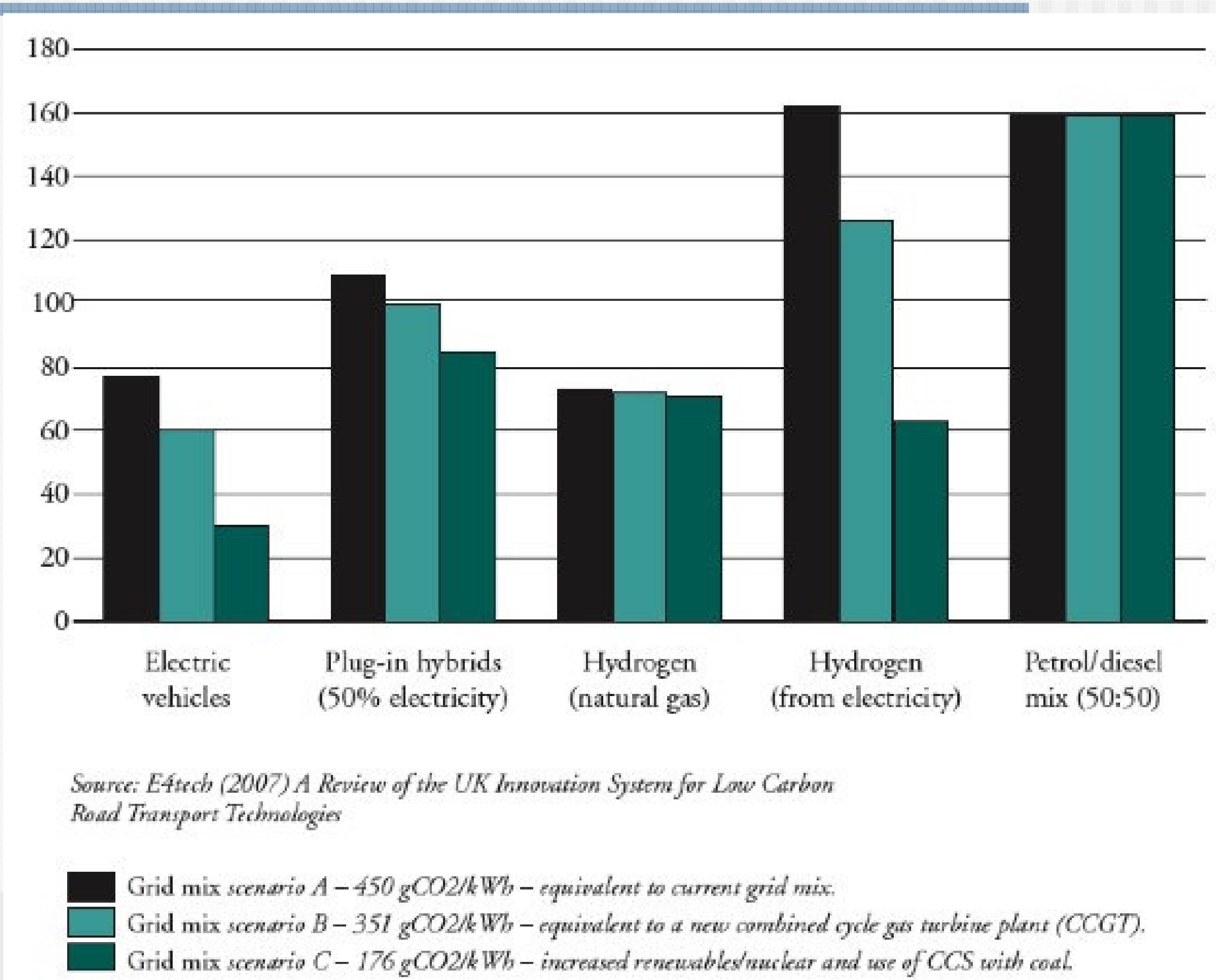
Recent industry & policy trends

- FCVs: Still moving forward
  - EU moving toward JTI, Japan and US continuing with demonstrations, roadmap
  - But concerns over lack of progress on H2 storage, infrastructure…
- BEVs: Comeback
  - New generation of vehicles (Subaru, MMC, Tesla, Think, etc.) and batteries (A123, NEC, Hitachi, etc.)
  - Tier 1 suppliers getting involved (JCI, Conti, etc.)
  - Policy support (UK/King Review, METI, DOE etc.)
  - PHEVs: A new paradigm? (GM, Toyota etc.)
- Biofuels
  - Mounting uncertainties over real decarbonisation impact, competition with food production…

Comparing options

- Energy security impact
  - Regional variations
- Environmental impact
  - Well-to-wheel analysis
  - LCA including manufacturing and end-of-life recycling/disposal
- Technology status
  - Vehicle and lifecycle cost
  - Performance, functionality, durability (under duress…)
  - Fuel availability
- Development potential
  - Technology & infrastructures
  - Decarbonisation

Well-to-wheel emissions



Competing technological systems

Component	**Petrol/ICEV**	**Petrol/HEV**	**Petrol-Electricity/ PHEV**	**Electricity/ BEV**	**Hydrogen/ FCV**
Propulsion	IC engine Fuel tank Controls	Power-assist batteries Electric motor Controls (+ same as ICEV)	Traction batteries Electric motor Controls (+ same as ICEV)	Traction batteries Electric motor Controls	Fuel cell Hydrogen tank Power-assist batteries Electric motor Controls
Energy production	Oil extraction & refining	(same as ICEV)	Electricity generation (+ same as ICEV)	Electricity generation (fossil, renewables, nuclear/CCS)	Hydrogen generation (small-scale SMR, electrolysis, renewables, CCS, nuclear)
Energy distribution	Pipeline, sea and road delivery Refuelling station network	(same as ICEV)	Electricity grid Home charger (+ same as ICEV)	Electricity grid Home charging Street/commer cial charging Smart chargers	Pipeline or road delivery (if produced off-site) Refuelling station network
Key industrial actors	Auto OEMs Auto parts suppliers Oil companies Oil service suppliers	Battery suppliers (+ same as ICEV)	Battery suppliers Electricity generators & suppliers (+ same as ICEV)	Auto OEMs Battery suppliers Electricity generators & suppliers	Auto OEMs Fuel cell suppliers Hydrogen suppliers (?) Battery OEMs

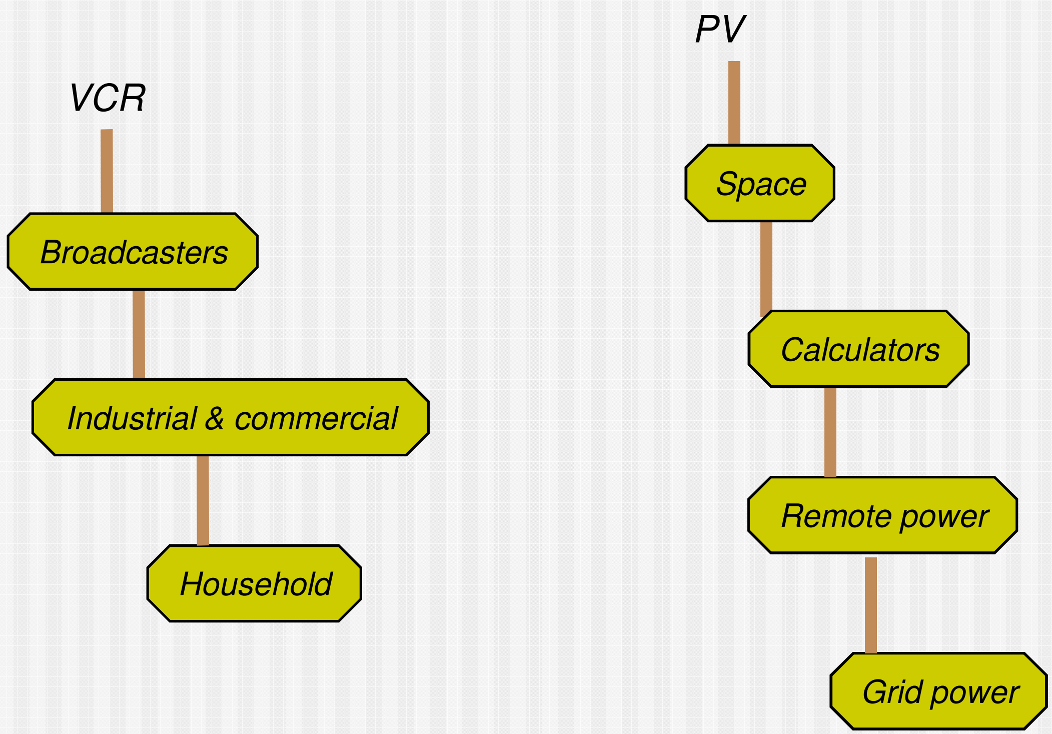
Innovation pathways

- Technologies & infrastructures (‘components’)
  - What/who will drive long-run cost/performance improvements in electrochemical storage, hydrogen tech, etc.?
  - What/who will drive investments in energy distribution infrastructures?
  - What/who will drive long-run decarbonisation?
  - Role of R&D vs. technological learning & migration (‘technology-push’ vs. ‘market-driven’ innovation)
- Systems
  - Step-change vs. gradual transitions (‘revolutionary’ vs. ‘evolutionary’ change)
  - Role of demonstrations, niche segments, etc.

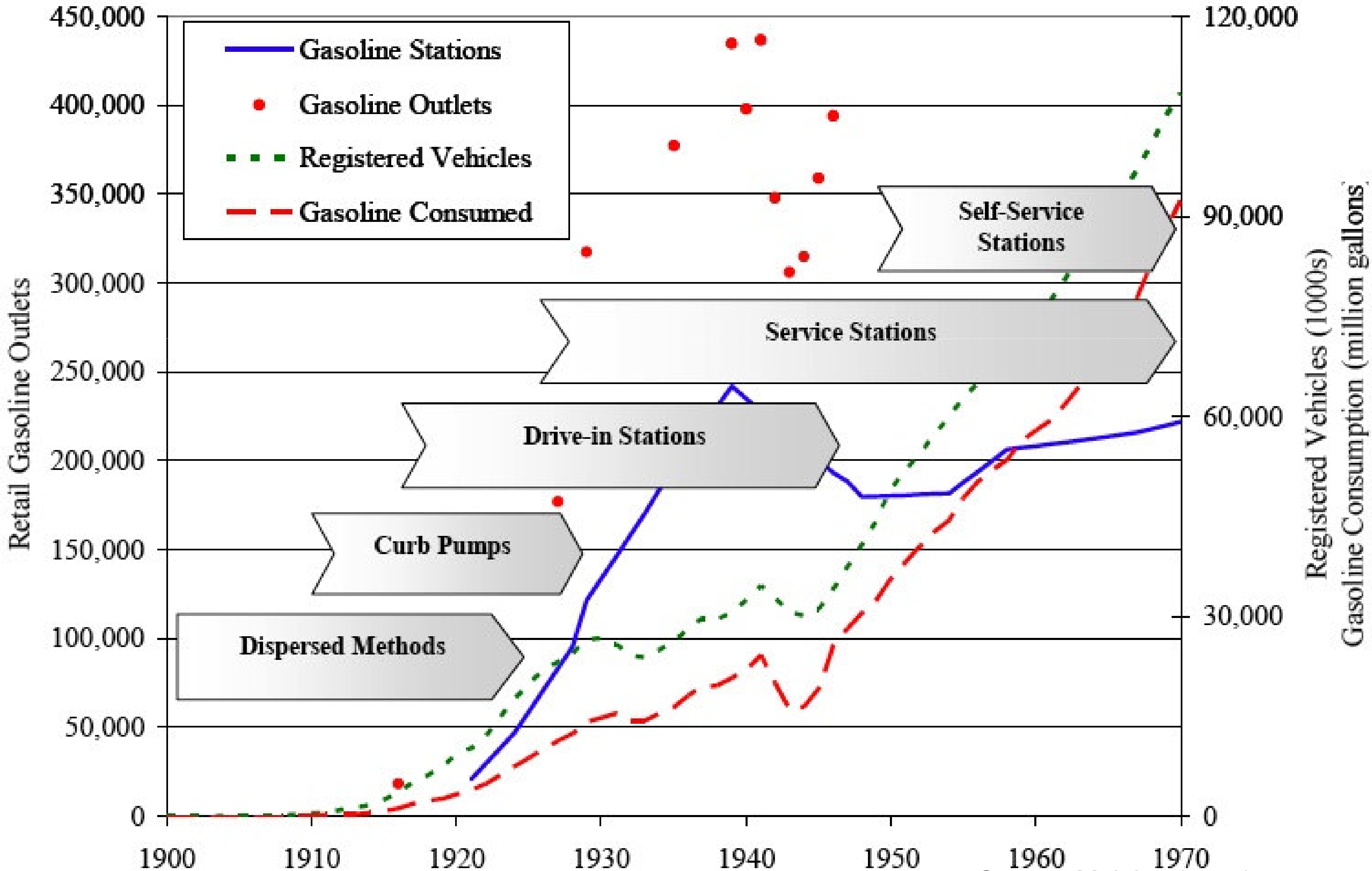
Lessons from history

- Component development
  - Technology-push R&D
    - Nuclear power
  - Technological migration (Basalla, 1988; Levinthal, 1998)
    - Steam & IC engines, wireless communications, PV
- System transitions
  - Piggybacking/hybridisation
    - Diesel-electric trains, Internet, ICEVs
  - System building
    - Light & power (Edison), cellular phones

Technology evolution as speciation



Evolutionary system development

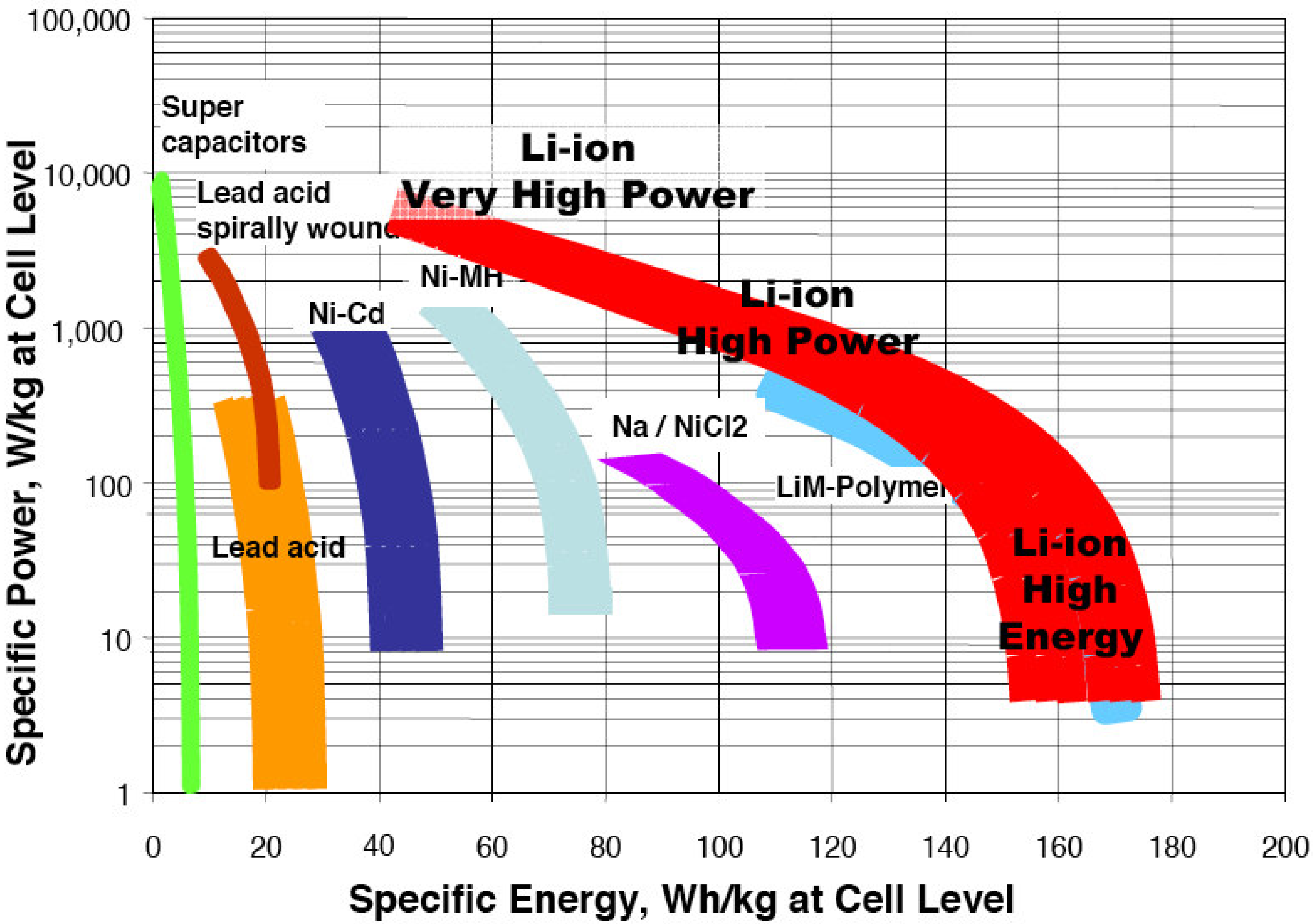


Source: Melaina (2005)

Technological learning opportunities

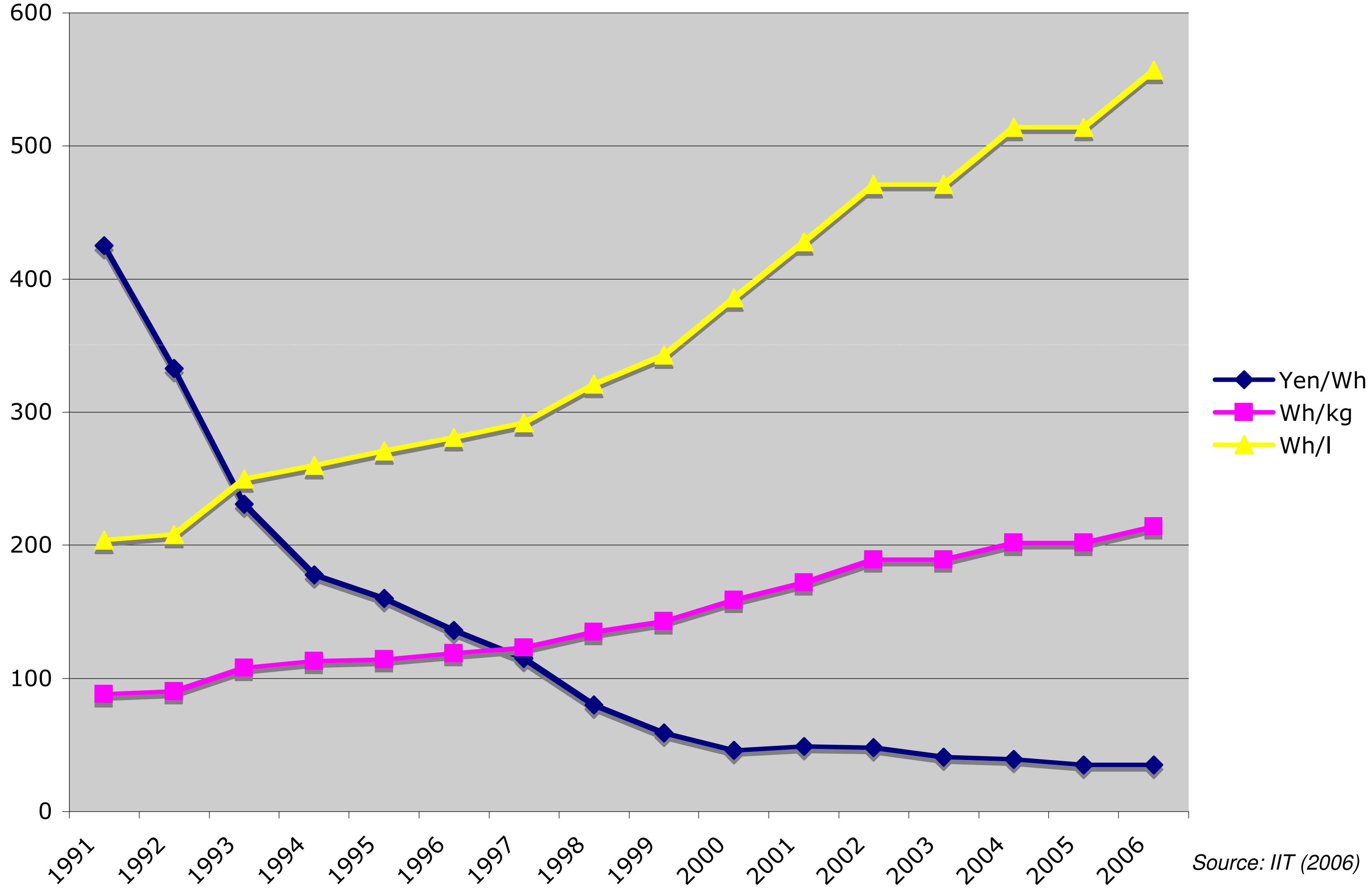
	Components (vehicles)	Components (energy production)	Components (energy distribution)	System (hybrid)	System (integral)
BEVs	Batteries: • **Space & military** • **Portable electronics** • **Backup power** • **Power tools** • **HEVs**	• **CCGT** • **CHP** • Clean coal • **Hydro, Nuclear** • **Renewables** • CCS	• **Electricity grids** • **Smart metering** • **Home chargers** • Street/commercial chargers • Rapid chargers	• PHEV	Niche: • **Forklift trucks** • **People movers** • **Neighborhood electric vehicles** Mainstream • Demonstrations • **Micro/urban vehicles**
FCVs	Fuel cells: • Space & military • Backup power • Portable power • Stationary power H2 storage: ???	• **Industrial gas** • By-product hydrogen ???	• **CNG**	• Hydrogen ICEV • Gasoline FCV • FC APU	Niche: • Forklift trucks • Submarines Hybrid Mainstream • Demonstrations

The lithium leap



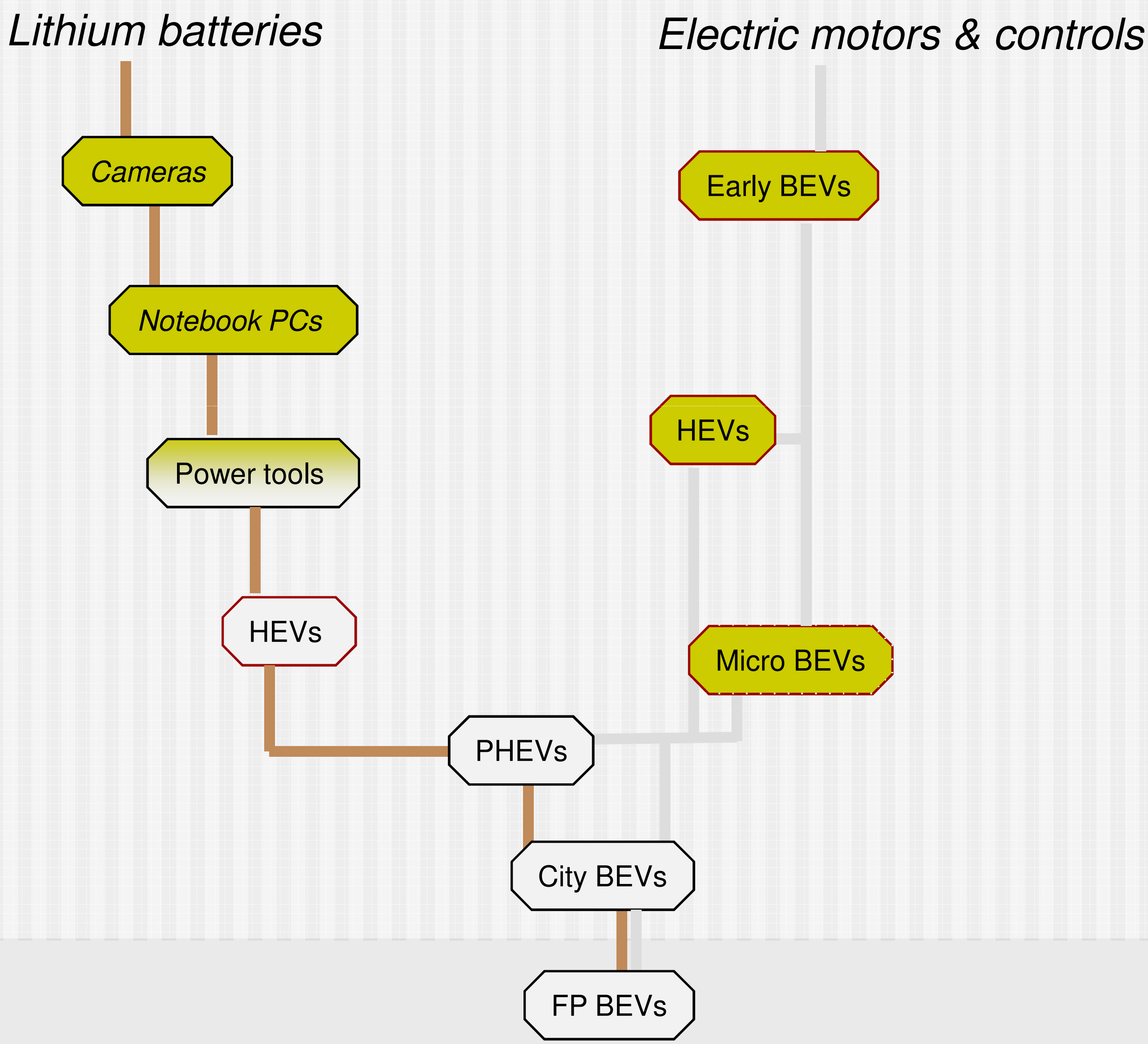
Source: Johnson Controls - SAFT Advanced Power Solutions

Lithium ion: key to BEVs

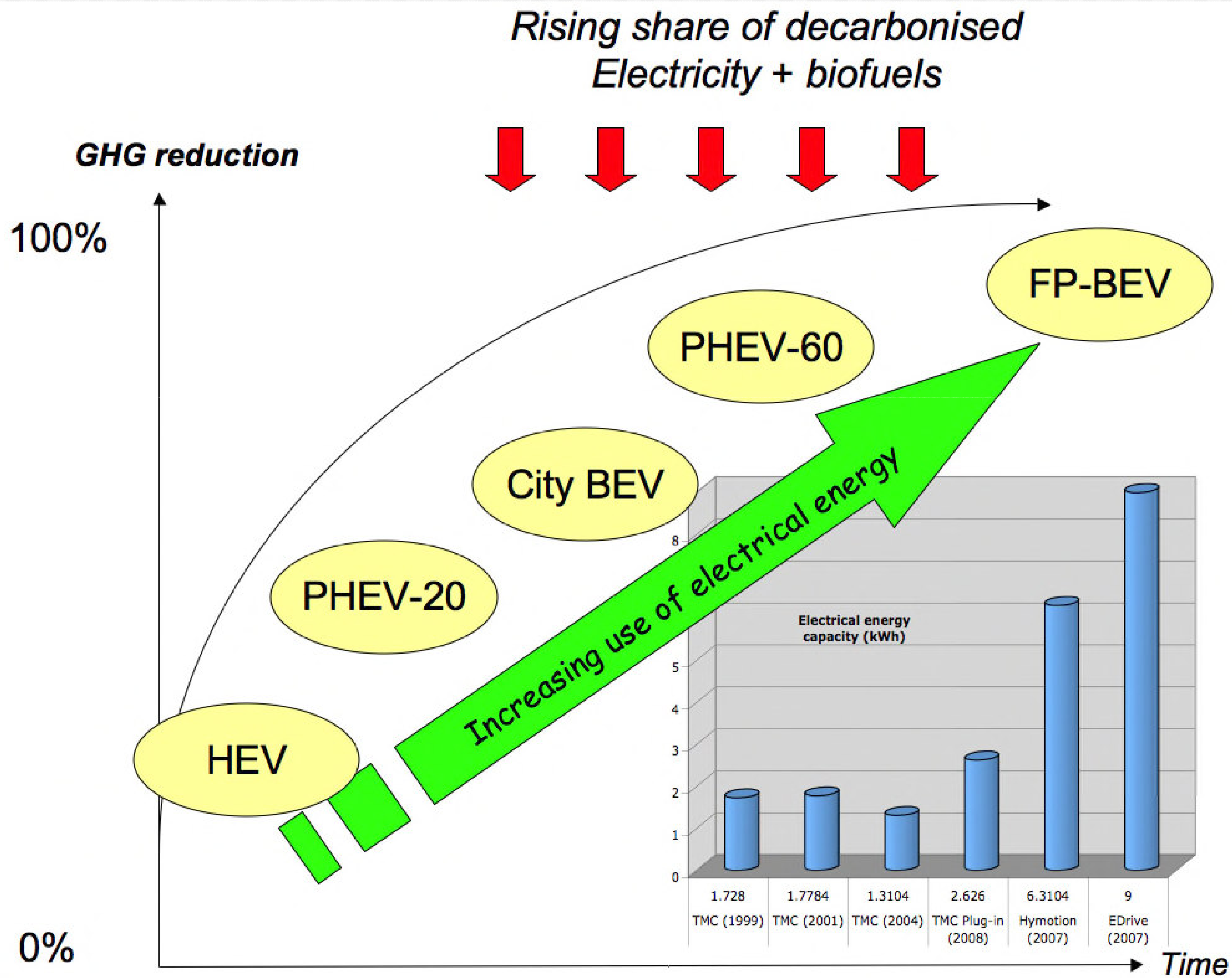


Source: IIT (2006)

Speciation & BEV development



BEV transition scenario



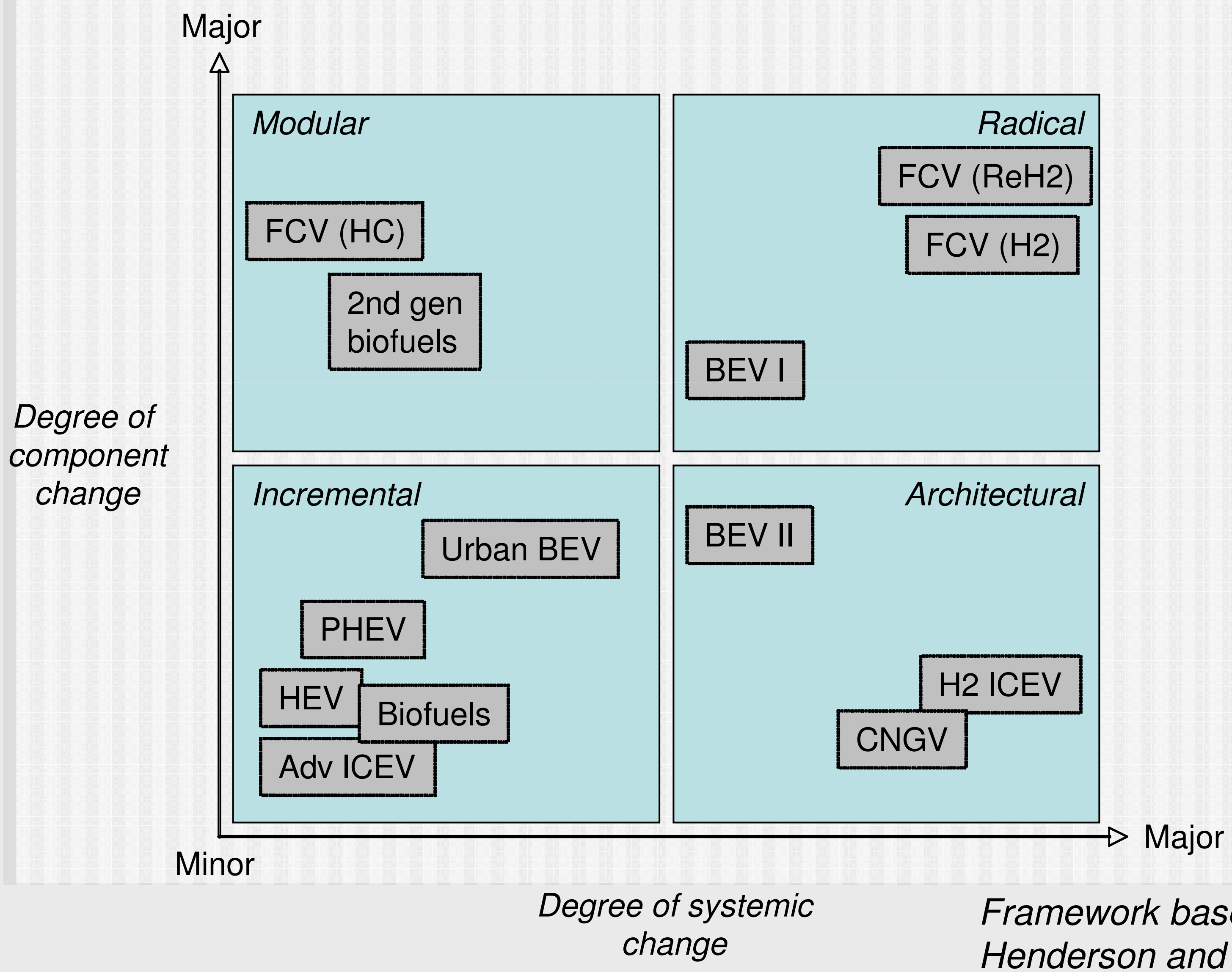
Question marks

- Technology migrations
  - What app's/developments are really relevant to BEVs/PHEVs?
  - Issues with scaling up, durability (under duress), etc.
- Infrastructures
  - How many EVs can current grids accomodate?
  - Regional variations (China, etc.)
- R&D
  - Potential 'game-changing' breakthroughs
  - Technical limits to lithium batteries
- Incumbents
  - How will Big Oil respond?
  - How will the IC engine industry respond?

Summary

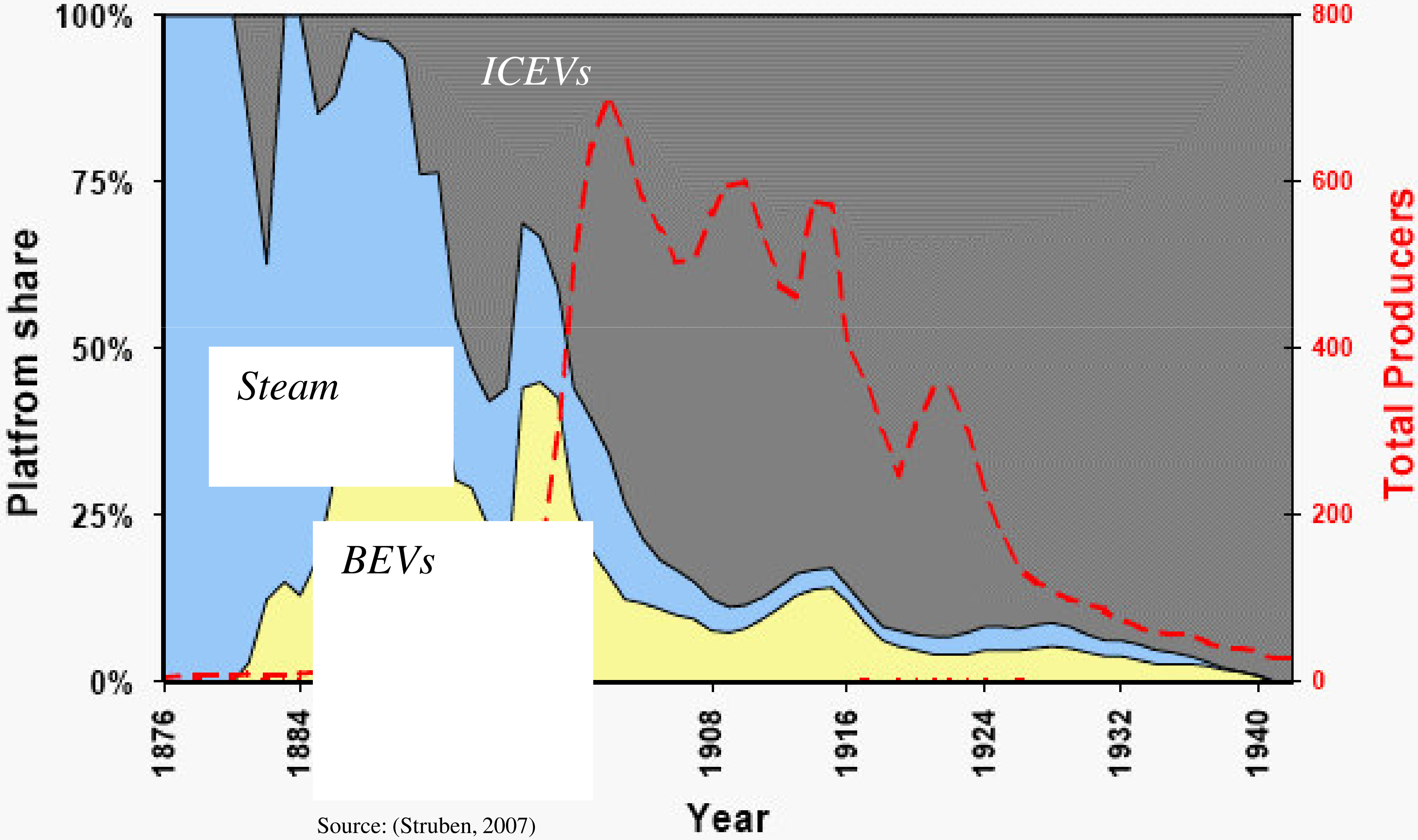
	PHEV & BEV	FCV
Technology	Largely market-driven (migration)	Largely R&D driven
Energy	Decarbonisation under way	Sparse (universities)
Infrastructure	Basic infra already in place	Sparse (industrial)
Innovation pathway	Architectural	Radical
Transition pathway	Evolutionary	Revolutionary
Potential for new entrants	High	Low

Innovation pathways compared



Framework based on Henderson and Clark (1990)

Back to the future?



Source: (Struben, 2007)

Policy implications

- Different innovation pathways/models: different needs
  - BEVs & PHEVs:
    - Need more ‘market-pull’ policies (biofuels obligation?)
    - R&D on high-energy batteries
  - FCVs
    - Need more support for niche markets, MUCH less for FCV & H2 station demonstrations
    - R&D on H2 storage, “advanced” H2 generation
- Transitions: Do we have the will for revolutionary/radical change?

Radical/revolutionary transitions?

"In no prior case has the government attempted to promote the replacement of an entire, mature, networked energy infrastructure before market forces did the job. The magnitude of the change required if a meaningful fraction of the US energy system is to shift to hydrogen exceeds by a wide margin that of previous transitions in which the government has intervened."

National Academy of Sciences (2004)

Extra slides

Uncertainties

- Technology: Breakthroughs in fuel cells, batteries, hydrogen, or other critical complementary technologies?
- Energy: Oil, natural gas, CCS, nuclear power, biomass… how much and at what prices?
- Infrastructures: H2 pipelines and/or refuelling stations, V2G networks… what costs and when?
- Policy: Carbon taxes, ZEV mandates… when and where?
- Consumers: Acceptance of sub-500 km ranges? Home charging? High-pressure gases?

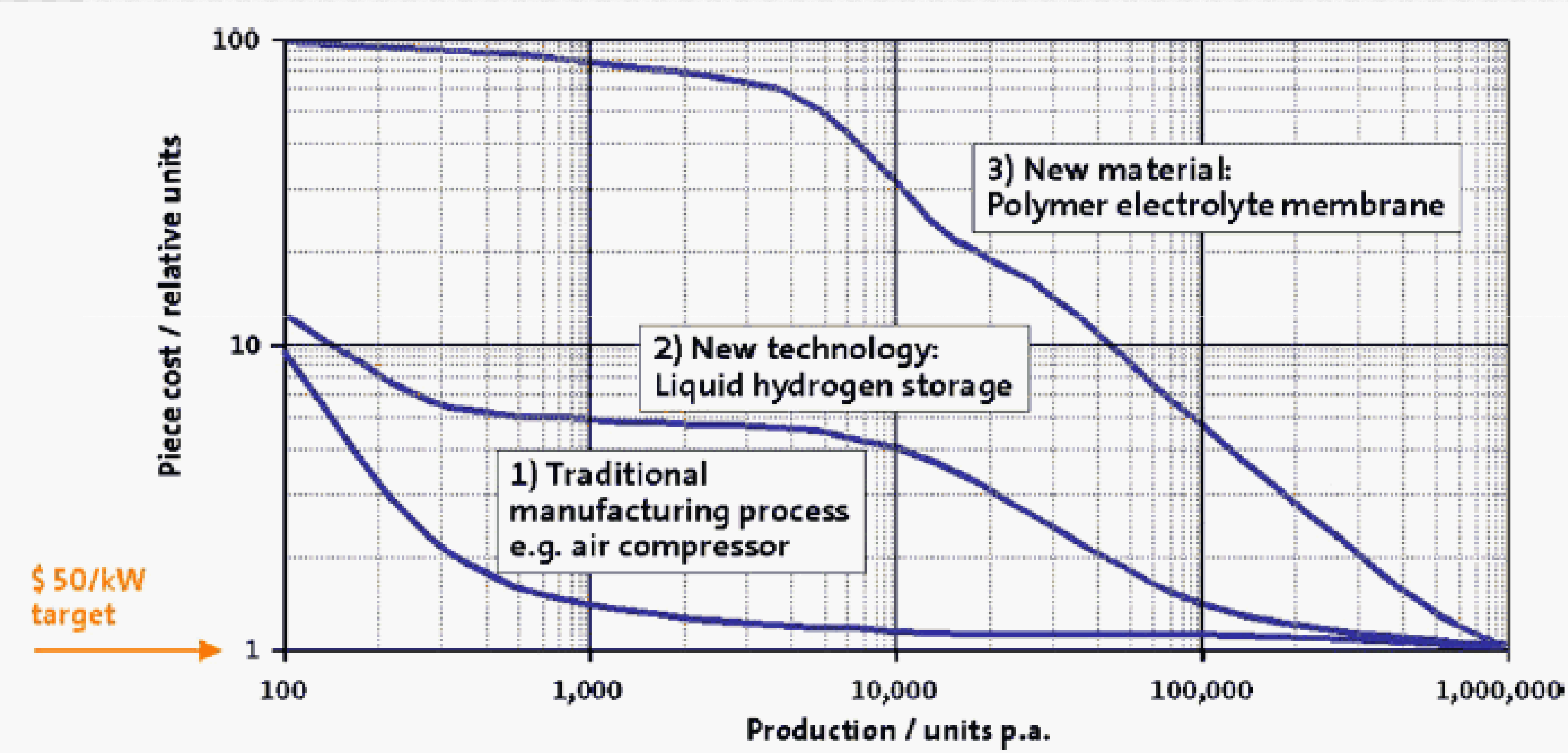
Why EVs?

- Increasing energy security risks and geopolitical tensions
- High and growing share of total greenhouse gas emissions (CO_2)
- Air pollution (PM, NO_x, SO_2, HCs, CO) and health impacts
- Huge markets and economic opportunities/threats

What changed for EVs?

- More drivers
  - Energy security
  - Air pollution
  - Climate change
- More possibilities
  - Spillovers from global lithium battery industry
  - Spillovers from HEVs
- More applications/options
  - HEVs
  - PHEVs
  - Micro BEVs
  - High-end BEVs

FCVs: The cost curve



Source: GM

	Energy security	Air quality impact	Climate impact	Techno status	Market dynamics	R&D and key actors
CNG	+	+	+	++	+	-
CTL	++	---	---	+	+++	++
Advanced diesels	+	-	+	+++	+++	+++
Biofuels	++	+	+	++	++	+++
Hybrids	+	+	++	+++	+++	++
BEVs (short-term)	+++	+++	++	-	+	++
BEVs (ideal cond.)	+++	+++	+++	?	?	?
FCVs (short-term)	+	+++	++	-	- -	+++
FCVs (ideal cond.)	+++	+++	+++	?	?	?
Plug-in hybrids	++	++	++	++	++	++