Building industrial supply chains for fuel cells - where will the value be created?

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EVS30 – Session F6 - The role of hydrogen and fuel cells in the energy economy

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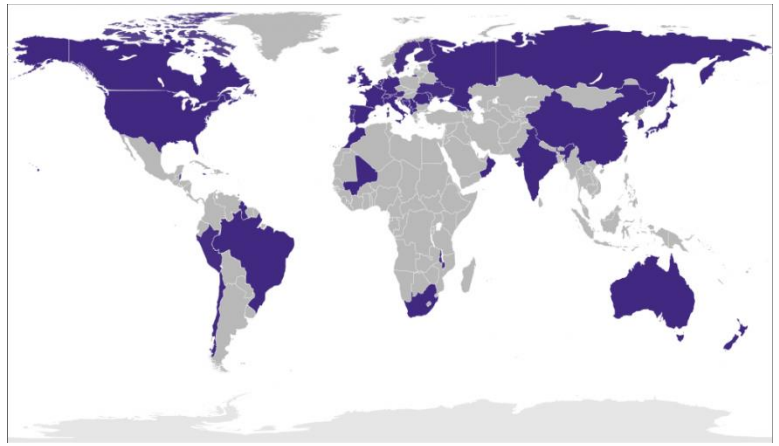
Today

- Introduction to E4tech and the Fuel Cell Industry Review
- Drivers behind future fuel cell adoption
- Status and development of global supply chain for automotive fuel cell systems

E4tech perspective:
Strategic thinking in sustainable energy

- International consulting firm, offices in UK and Switzerland
- Focus on sustainable energy
- Established 1997, always independent
- Deep expertise in technology, business and strategy, market assessment, techno-economic modelling, policy support…
- Spectrum of clients from start-ups to global corporations



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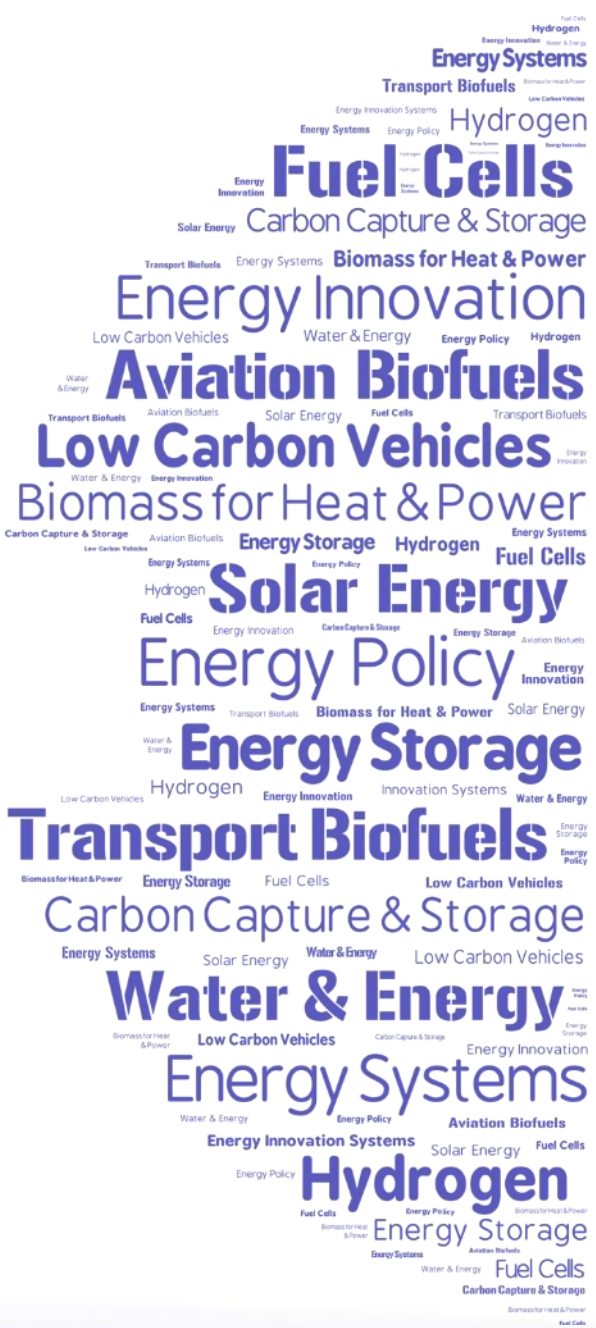
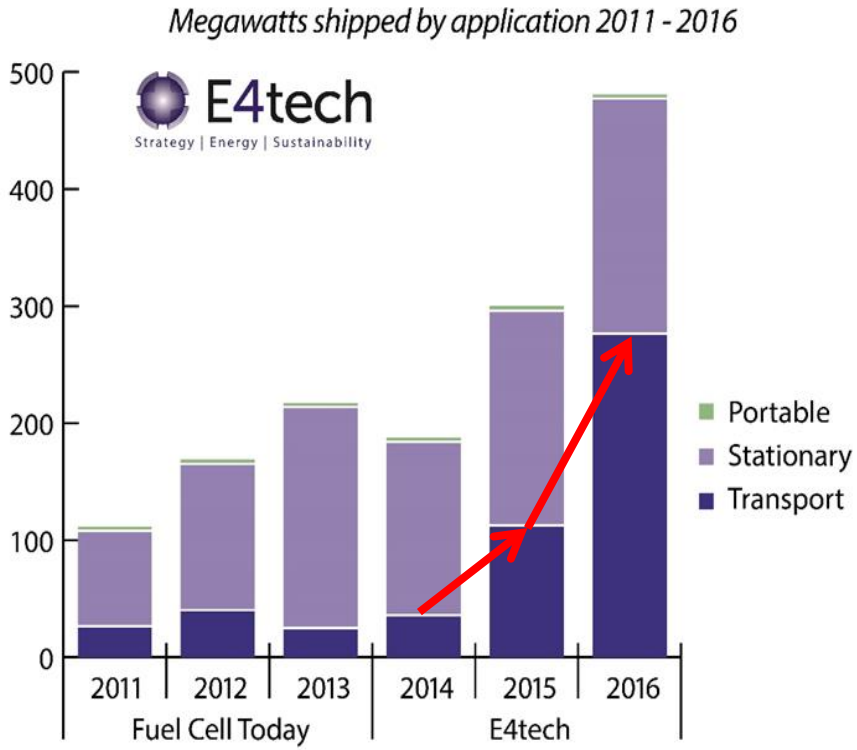


Our annual Fuel Cell Industry Review is a reference point for the fuel cell sector with commentary on its development: www.FuelCellIndustryReview.com

- E4tech leads the team, Bob Rose and Jonathan Lewis integral and essential
- Provides objective annual statistics of global fuel cell system shipments and commentary on industry and market trends
- Shows development and gives a reference point to actors within and outside the industry
- Around 100 companies contacted directly each year
- Data are aggregated and anonymised where possible and necessary
- Free for download

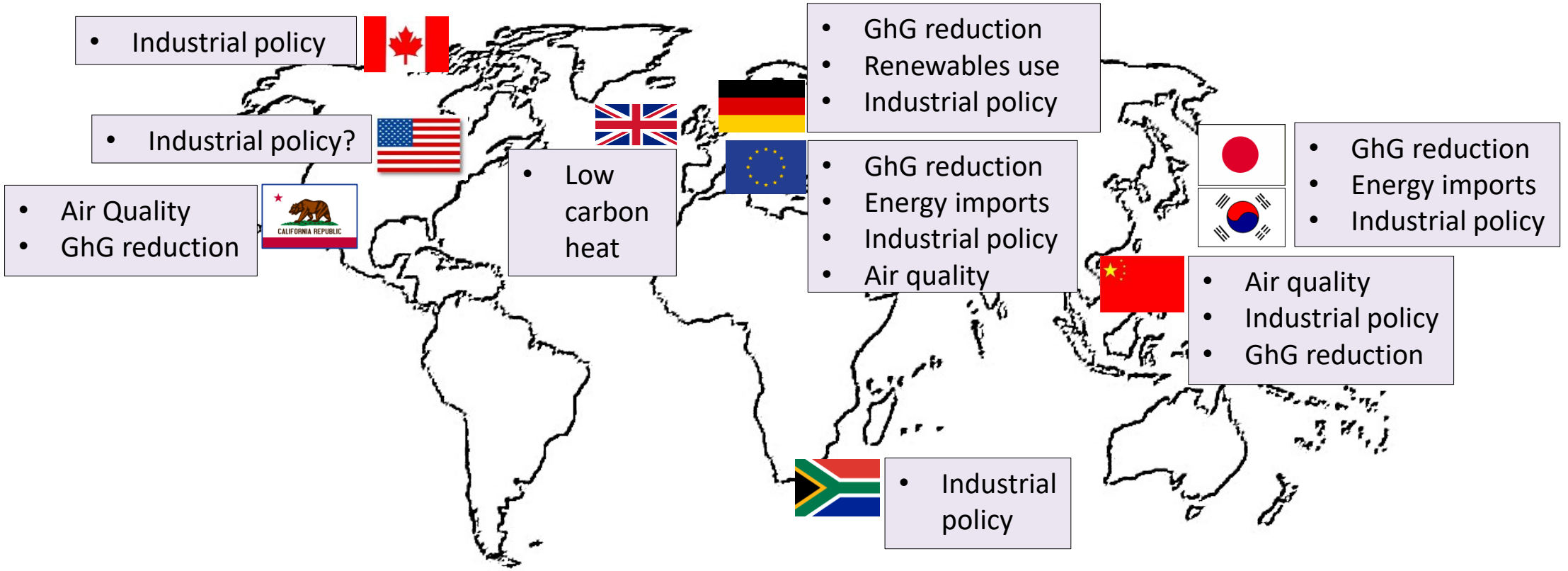
Next edition: November 2017

- Fuel cell deployments in transport are growing fast[1]
- Supply chains need to grow too



[1] "Fuel Cell Industry Review 2016, www.fuelcellindustryreview.com

National and regional policy remain a primary driver going forward. Fuel cells are one of very few options for clean transport



Is the fuel cell industry ready?

Meeting automotive OEM requirements AND understanding fuel cells is tough

OEMs require:

- Almost faultless part provision and exceptional QA rigour
- Just-in-time delivery
- More or less open book accounting and very small profit margins
- Production scale flexibility
- Secure supply chains

Fuel cell specialists often have:

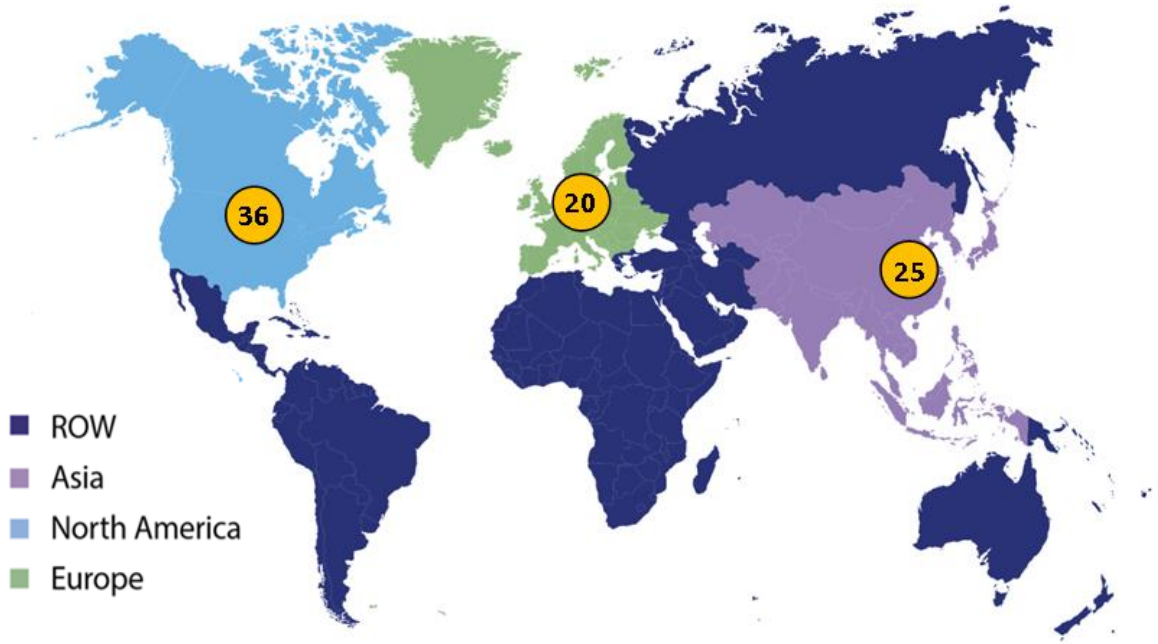
- Not yet frozen technology
- Limited production flexibility
- Entire staff smaller than Tier 1 QA teams
- A need for decent margins
- Evolving production processes
- Fragile suppliers

Tier 1s who can also do fuel cells exist, but are few

As part of a larger team we analysed the global supply chain of key components going into an automotive fuel cell system

- Cost analysis shows highest contributing components
- Structured interview process to gather data on development status
- Interviews and plant visits in the most important regions

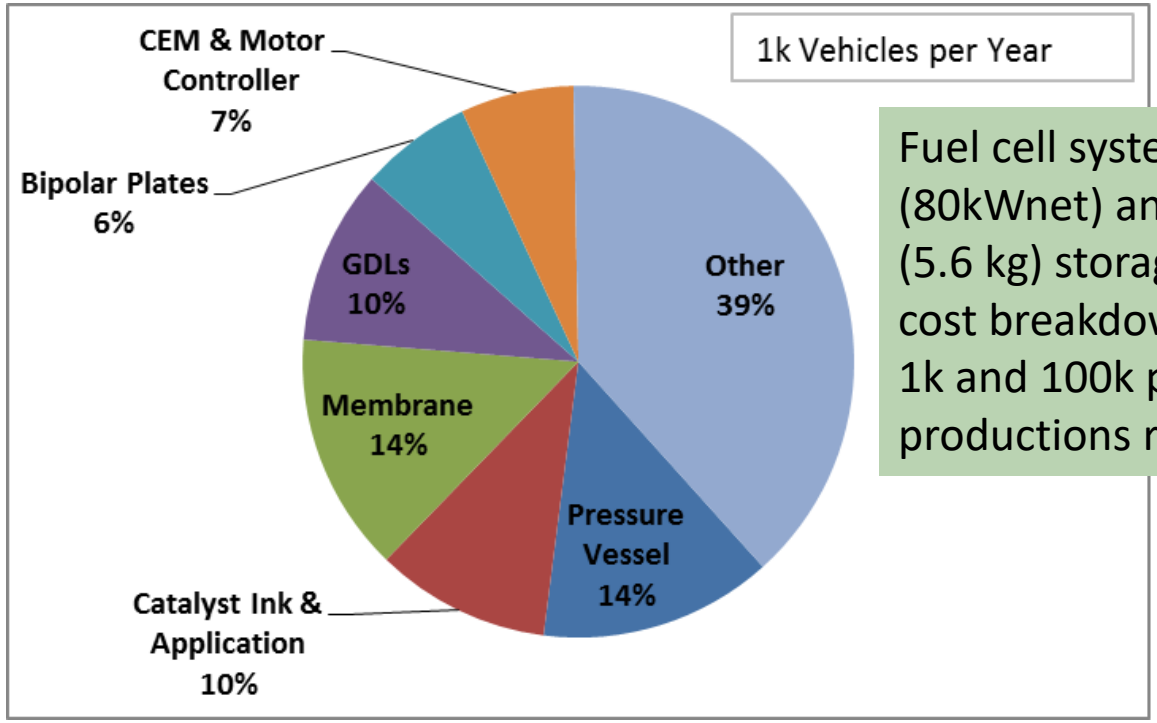
COMPONENT	USA	Asia	Europe
Bipolar Plates	2	2	2
Membrane	1	2	1
Gas Diffusion Layer	1	1	2
Catalyst Ink	1	1	2
Pressure Vessels	1	1	1



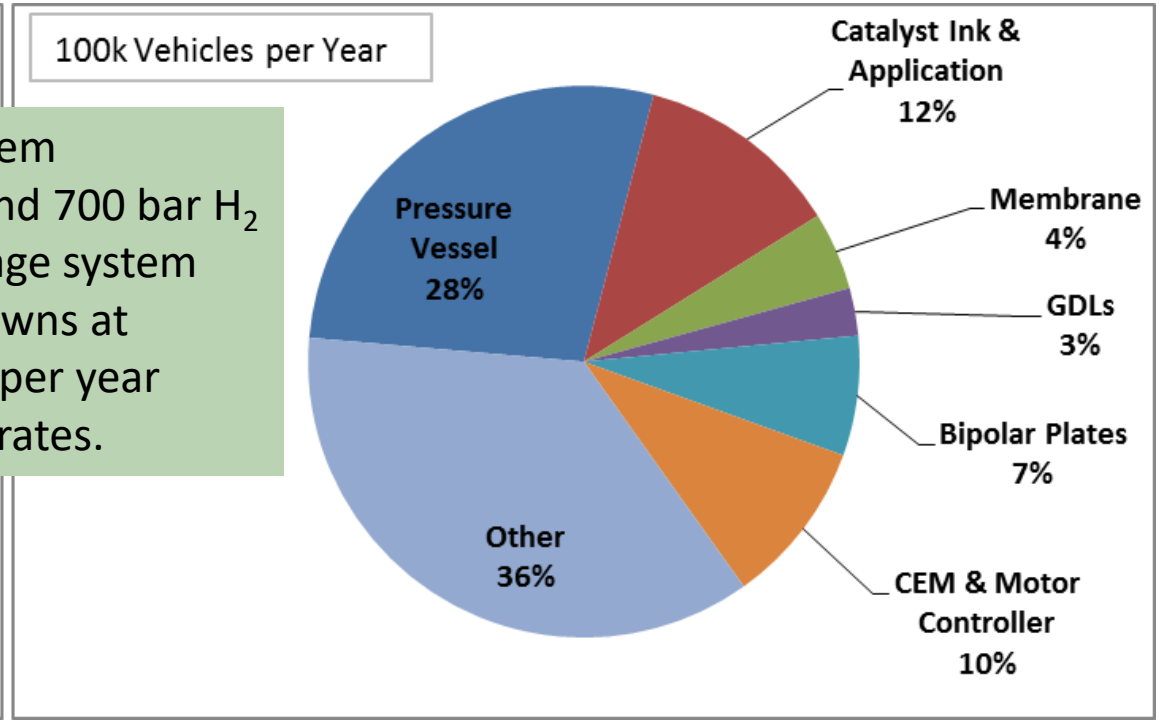
Of the ~80 companies identified, only a few are ready to supply OEMs today

Source: AMR presentation of "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis" GLWN et al, DE-EE-0006935

The study focused on the key components that together contribute more than 60% of total fuel cell system cost



Fuel cell system (80kWnet) and 700 bar H_2 (5.6 kg) storage system cost breakdowns at 1k and 100k per year productions rates.



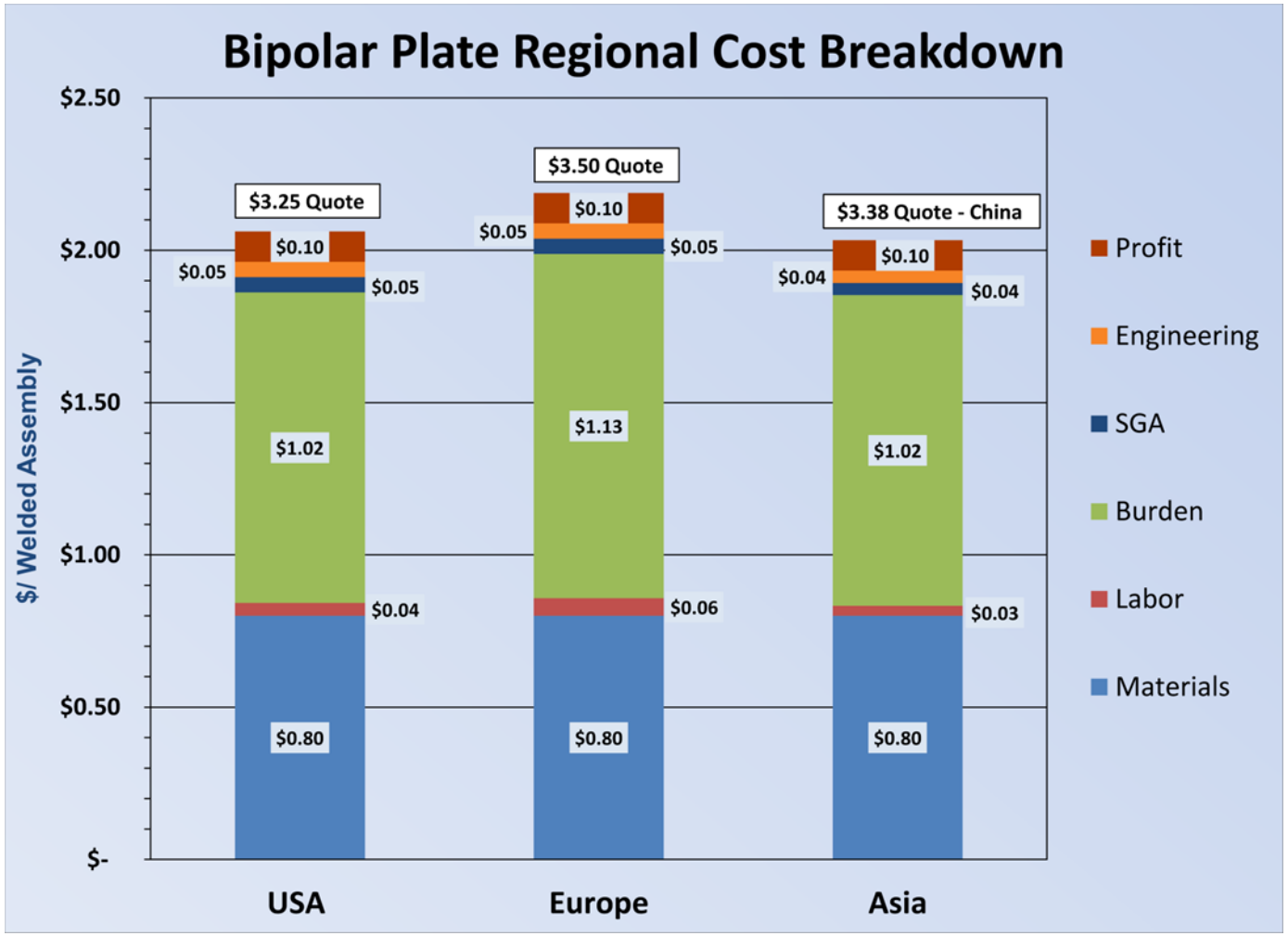
Cost breakdown assumptions based on Strategic Analysis (SA) cost models

Other items included in cost but not studied: **H_2 storage balance of system** (regulator, valve, tubing, fittings, system controller, and fill port); **fuel cell stack components** (gaskets, end plates, current collectors, compression bands, stack insulation housing, stack assembly, stack conditioning); **fuel cell balance of plant** (CEM & motor controller, H_2 sensors, coolant & air handling components, fuel system components, humidifier, system controller).

Source: AMR presentation of "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis" GLWN et al, DE-EE-0006935

Manufacturing costs vary only slightly by region and component – the supply chain is global, but specific regions are leading in individual components

- **Bipolar Plate**: Europe and Asia lead in bipolar plate technology
- **Catalyst**: Europe and Asia are currently the leaders in catalysts
- **GDL**: Four main companies predominate, in Europe, Asia, and the U.S.
- **Membrane**: The U.S. leads in membrane technology
- **Pressure Vessel**: Pressure vessel competitiveness is divided into carbon fiber production and vessel fabrication. Both areas are ripe for technology advancement



Example: Regional Cost Breakdown for Bipolar plate

Source: AMR presentation of "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis" GLWN et al, DE-EE-0006935

Our industry scorecard shows: The global industry ready for 10k systems per year, but high volume capabilities need further development

Technology Readiness	Bipolar Plate				Catalyst				Gas Diffusion layer				Membrane				H2 Vessel			
	US	EU	Asia		US	EU	Asia		US	EU	Asia		US	EU	Asia		US	EU	Asia	
			Japan	China			Japan	China			Japan	China			Japan	China			Japan	China
1-10k	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
100k	M-L	MOD	MOD	LOW	MOD	H-M	H-M	MOD	MOD	MOD	MOD	LOW	H-M	H-M	H-M	H-M	H-M	H-M	H-M	H-M

Manufacturing Readiness	Bipolar Plate				Catalyst				Gas Diffusion layer				Membrane				H2 Vessel			
	US	EU	Asia		US	EU	Asia		US	EU	Asia		US	EU	Asia		US	EU	Asia	
			Japan	China			Japan	China			Japan	China			Japan	China			Japan	China
1-10k	H-M	HIGH	HIGH	HIGH	H-M	HIGH	HIGH	HIGH	H-M	HIGH	HIGH	HIGH	H-M	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH	HIGH
100k	M-L	MOD	MOD	LOW	MOD	H-M	H-M	LOW	M-L	MOD	MOD	LOW	LOW	MOD	M-L	LOW	M-L	M-L	M-L	M-L

Readiness Legend:

HIGH	Currently sufficient to produce to stated demand
HIGH TO MODERATE	Capability and capacity exist, although no current production demonstrated at stated demand
MODERATE	Requires some advancements or capital investment to produce to stated demand
MODERATE TO LOW	Requires some advancements capital investment, and no current production demonstrated at stated demand
LOW	Requires major advancements or major capital investments to produced to stated demand

Source: AMR presentation of "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis" GLWN et al, DE-EE-0006935

Moving from 10k to 100k vehicles / year requires substantial investments, yet it does not support dedicated manufacturing for all components

- A line producing a welded bipolar plate assembly could be economically viable at around 10k vehicles per year
- GDL, membrane, and MEA lines could be economic for a vehicle market around 10k vehicles per year
- Catalyst cost is dominated by platinum cost. Skills and security needs make barriers to entry market extremely high
- PFSA and possibly carbon fibre require significantly larger markets to support dedicated manufacturing
  - At ~30k vehicles 50kg of PFSA is required. PFSA will likely be one component in a portfolio from a fluoropolymer manufacturer at an existing chemical plant
  - Carbon fibre supply is an oligopoly and high pressure tanks are much less important a market than aerospace

Jobs & Investment at 100k vehicles / year

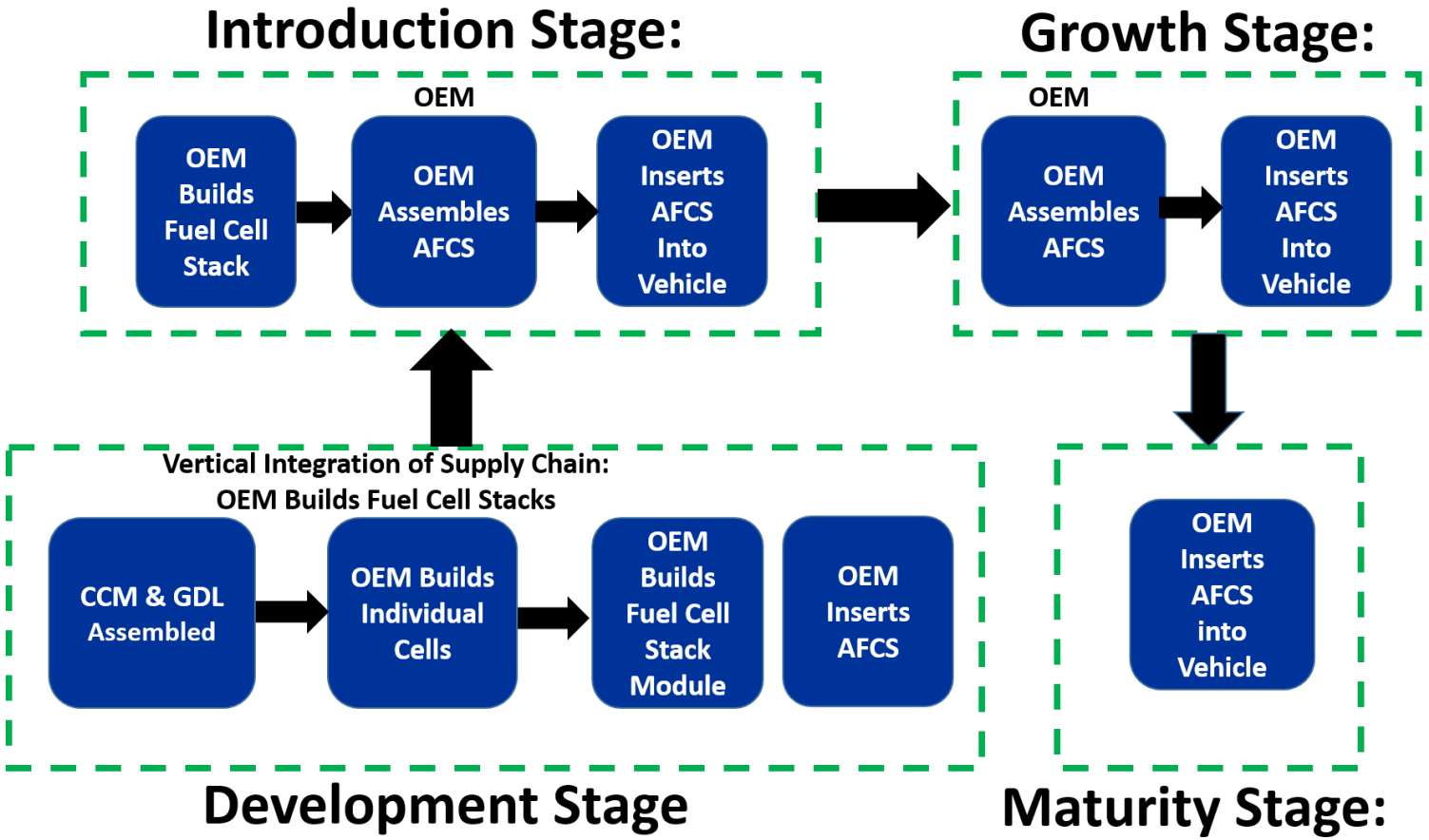
	Direct Labor Jobs	Investment	Units / year
Bipolar Plate (BPP)	30 - 40	$80M Capex $36M Facilities	37 million
Catalyst	20 - 40	$2.4M Capex $14M Facilities	1,800kg Pt
Gas Diffusion Layer (GDL)	35 - 50	$30M Capex $13M Facilities	2.4 million m2
Membrane	35 – 50	$7M Capex $5M Facilities	2.4 million m2
Pressure Vessel (PV)	160 – 190	$33M Capex $74M Facilities	100,000

Automotive Fuel Cell System: 80kW$_{net}$ and 700 bar H_2 (5.6 kg)

The OEM manufacturing transitions suggested in this slide are consistent with the transitions in the Product-Life-Cycle of an emerging technology; however, the Growth and Maturity stages will be strongly dependent on the manufacturing culture of the different OEMs.

Source: AMR presentation of "U.S. Clean Energy Hydrogen and Fuel Cell Technologies: A Competitiveness Analysis" GLWN et al, DE-EE-0006935

The current automotive fuel cell supply chain is immature. Many options for roles and partnerships are open



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*AFCS: Automotive Fuel Cell System

In summary: Fuel cells are getting serious, supply chains are growing – and the positioning is happening now

- Our study shows the need for international cooperation and supply chain development
  - **Japan** has strong national support and 'tentative certainty' around markets
  - **Chinese** fuel cell suppliers are comparatively immature, but a strong support exercise has begun
  - **N America** has surprisingly few suppliers for some components
  - **Europe** has pockets of strength, notably in Germany
- Overall ICE cars have more in common with FC cars than with BEVs
  - Currently leading FCEV OEMs 'own' their fuel cell technology, like they 'own' their ICE technology
  - Many ICE supply chain actors also have a place in the fuel cell supply chain
  - Fuel retailers and energy companies remain part of the bigger picture and hence support FCEV roll-outs

Supply chains are still evolving, but will lock down soon

Most of the serious future players are already in the game

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