

Manufacturing Competitiveness Analysis for Hydrogen Refueling Stations



Department of Energy Annual Merit Review
for Fuel Cell Research

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National Renewable Energy Laboratory

Project ID #
MN017

Overview



Timeline

- Project start date: April 2015
- Project end date: March 2018
- Percent complete: 75%

Budget

- Total project funding
 - DOE share: \$719 K
 - Contractor share: n.a.
- Funding received in FY16: \$519 K
- Planned Funding for FY17: \$0

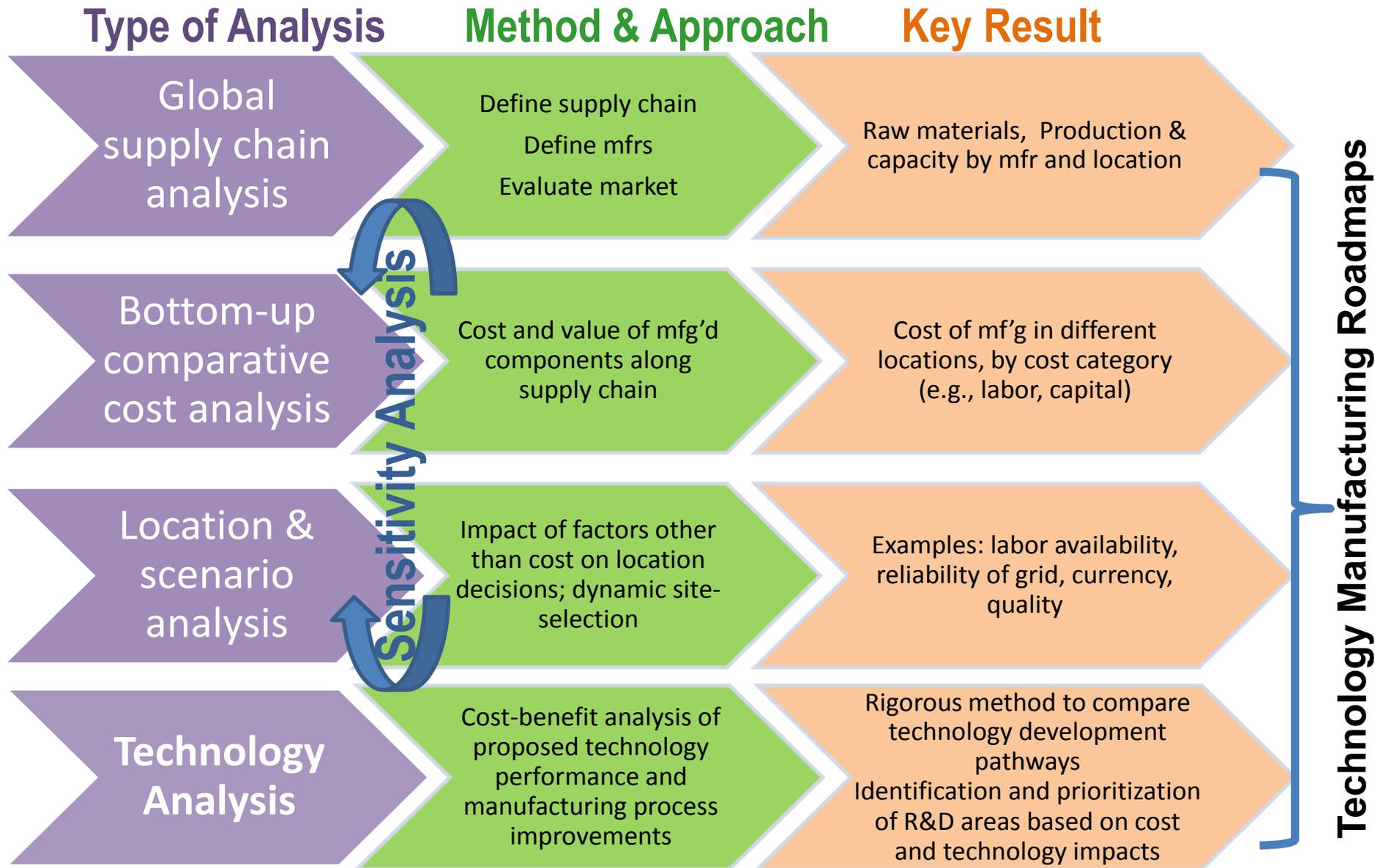
Technical Barriers

- A: Lack of hydrogen/carrier and infrastructure options analysis
- B: Reliability and costs of gaseous hydrogen compression
- E: Gaseous Hydrogen Storage and Tube Trailer Delivery Costs

Collaborators

- Argonne National Laboratory
- Sandia National Laboratories
- Pacific Northwest National Laboratory
- Other Industry Advisors and Experts

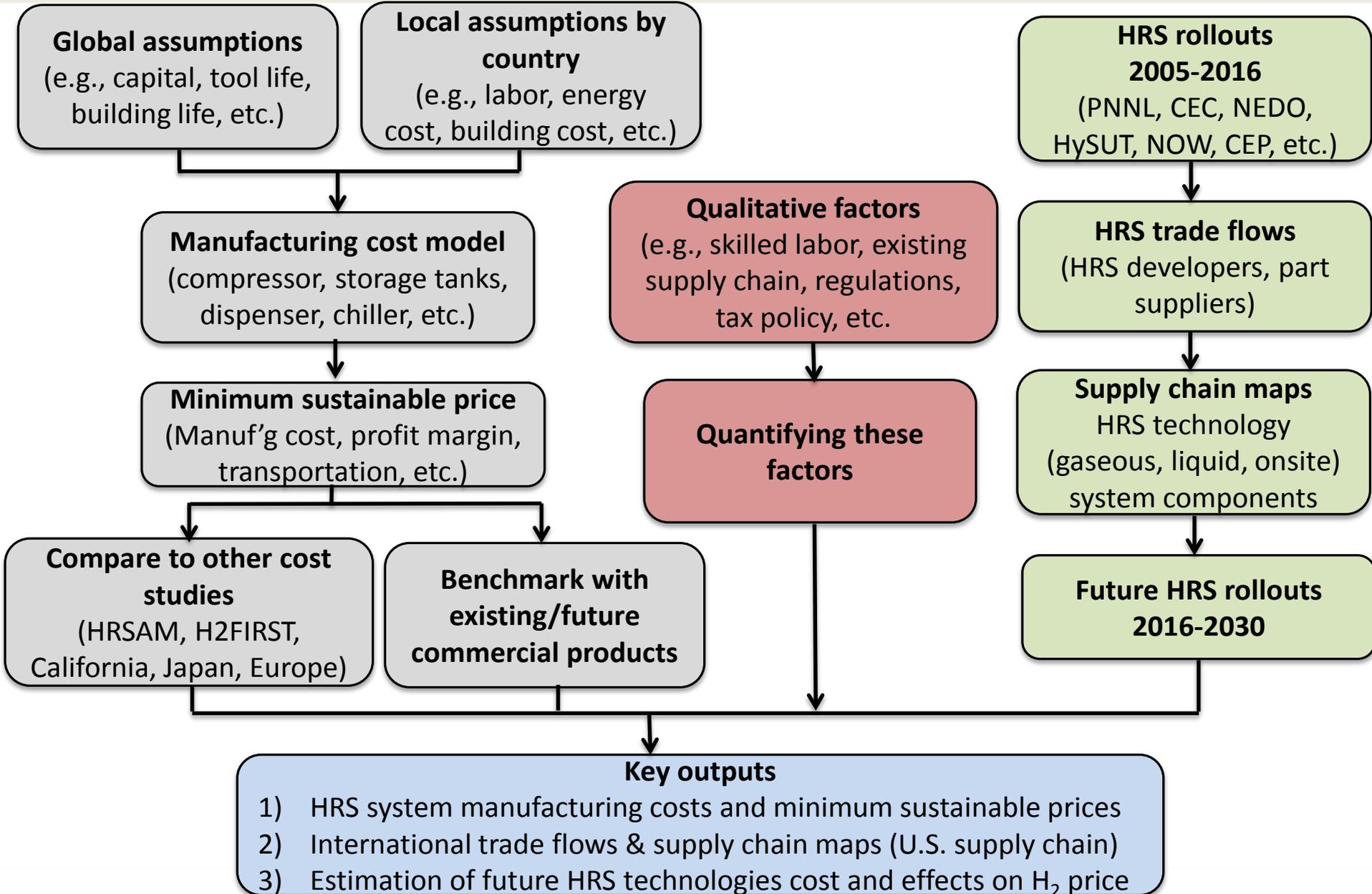
CEMAC Methodology & Key Results



Relevance & Goals

- Provide a platform for manufacturing cost analysis for major hydrogen refueling station (HRS) systems
 - Identify cost drivers of hydrogen compressor (40-60% of total HRS capital cost)
 - Identify cost drivers of various storage tank technologies and configurations
 - Investigate effect of learning experience and availability of part suppliers on the chiller, heat exchanger and dispenser costs
- Work with FCTO to establish manufacturing cost models for HRSs
 - Establish a manufacturing cost framework to study cost of HRS systems (compressor, storage tanks, chiller & heat exchanger, and dispenser)
 - Highlight potential cost reductions in manufacturing phase for future R&D projects

Approach



Accomplishment and Progress

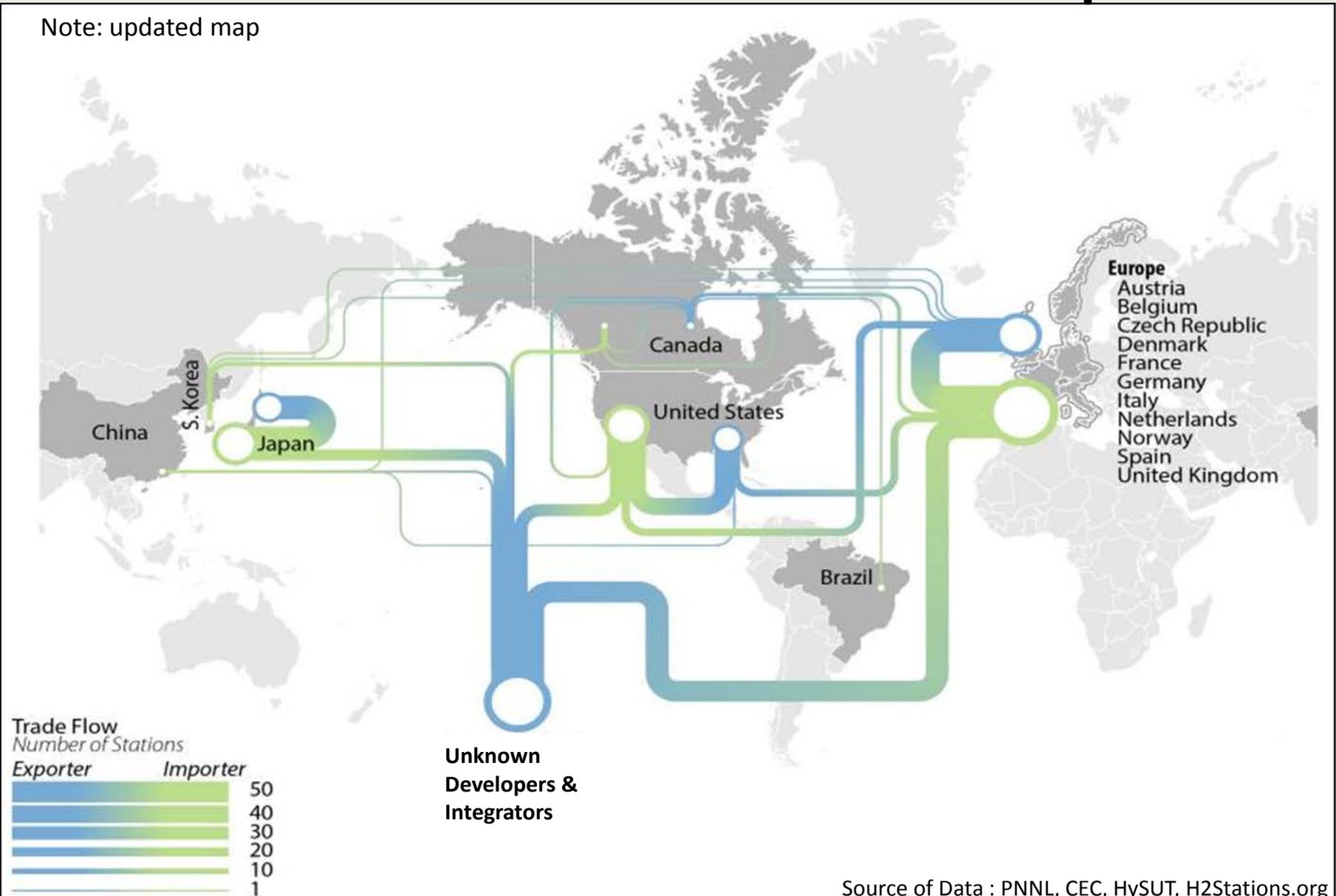
International Manufacturers



			
HRS Provider	Pressure Vessels Manufacturer	Compressor Manufacturer	Dispenser Manufacturer

HRS International Trade Flows Map

Note: updated map

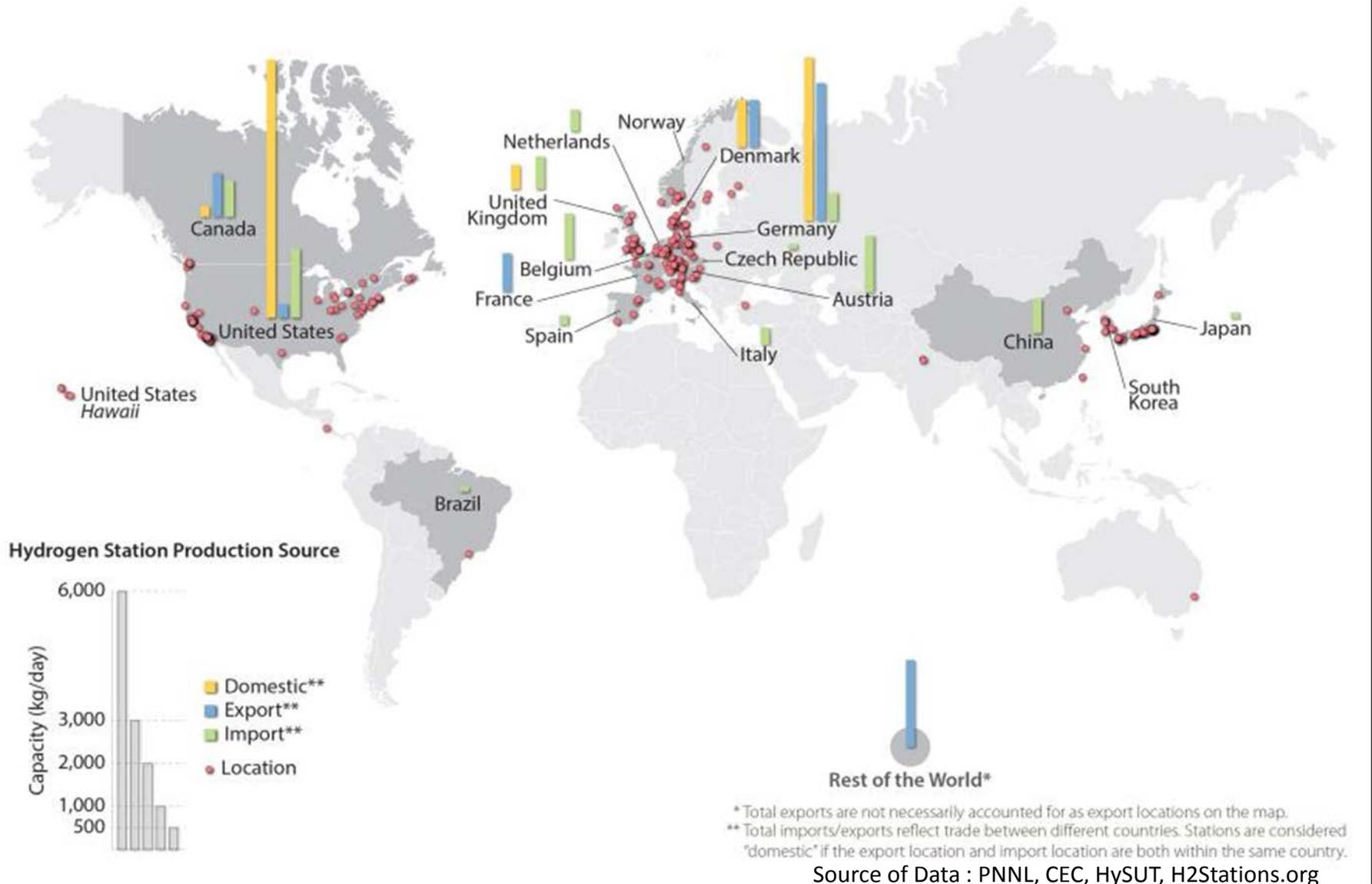


Source of Data : PNNL, CEC, HysUT, H2Stations.org

Accomplishment and Progress

HRS Trade Flows Map

Note: updated map



Accomplishment and Progress

Dispenser Cost Analysis



Single Hose Dispenser H35				
Part No.	Part	Supplier 1	Required Units	Dispenser (\$)
1	SOLENOID VALVE	Omega	1	715
2	Flow Meter	Alicate	1	10000
3	Pressure checking/Regulating Valves	Tescom	1	4771
4	Pressure Relief Valve	High Pressure Equipment Company	1	658
5	Breakaway valve	Oasis	1	3953
6	Hydrogen Leak Sensor	SBS	1	695
7	IR flame detector		2	3000
8	Pressure sensors	Sensor Solutions	2	600
9	Temperature sensors	TempSensing	1	50
10	Hydrogen filter		1	1000
11	Piping (10 m required)	Zoro	10	250
12	Tubing and Fittings (10 units estimated)	Swagelok	15	750
13	Air Actuated valve	Valworx	1	160
14	Control Unit	Siemens	1	1000
15	Hose (single/double)	NanoSonic	1	100
16	Nozzle	OPW	1	4531
17	Nozzle Boot		1	200
18	Power Supply	iGem	1	275
19	Digital Display	Wayne	1	347
20	Card Reader	Ovation	1	149
21	Console/keypad	Wayne	1	580
22	Console printer	Wayne	1	385
23	Fuses (3A; 5A; 10A)	Mersen	3	60
24	Relays (3A; 5A; 10A)	Releco	3	75
25	k-type thermocouples	Autocalve	2	204
26	Enclosure	n/a	1	500
27	Shut-down emergency Button	VanTech	1	40
	Total			35,048

Dual Hose Dispenser H35/H70				
Part No.	Part	Supplier 1	Required Units	Cost per Dispenser (\$)
1	SOLENOID VALVE	Omega	2	1430
2	Flow Meter	Alicate	2	20000
3	Pressure checking/Regulating Valves	Tescom	2	9542
4	Pressure Relief Valve	High Pressure Equipment Company	2	1316
5	Breakaway valve	Oasis	2	7906
6	Hydrogen Leak Sensor	SBS	1	695
7	IR flame detector		2	3000
8	Pressure sensors	Sensor Solutions	4	1200
9	Temperature sensors	TempSensing	2	100
10	Hydrogen filter		2	2000
11	Piping (20 m required)	Zoro	20	500
12	Tubing and Fittings (20 units estimated)	Swagelok	20	1000
13	Air Actuated valve	Valworx	1	160
14	Control Unit	Siemens	1	1000
15	Hose (single/double)	NanoSonic	2	200
16	Nozzle	OPW	2	14531
17	Nozzle Boot		2	400
18	Power Supply	iGem	1	275
19	Digital Display	Wayne	1	347
20	Card Reader	Ovation	1	149
21	Console/keypad	Wayne	1	580
22	Console printer	Wayne	1	385
23	Fuses (3A; 5A; 10A)	Mersen	3	60
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25	k-type thermocouples	Autocalve	2	204
26	Enclosure	n/a	1	500
27	Shut-down emergency Button	VanTech	1	40
	Total			67,595

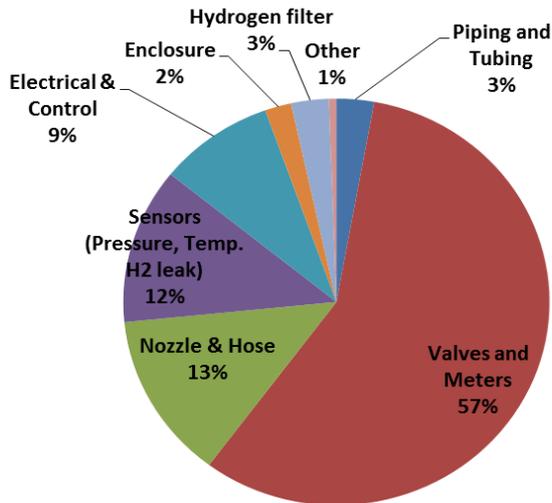
Accomplishment and Progress

Dispenser Cost Analysis

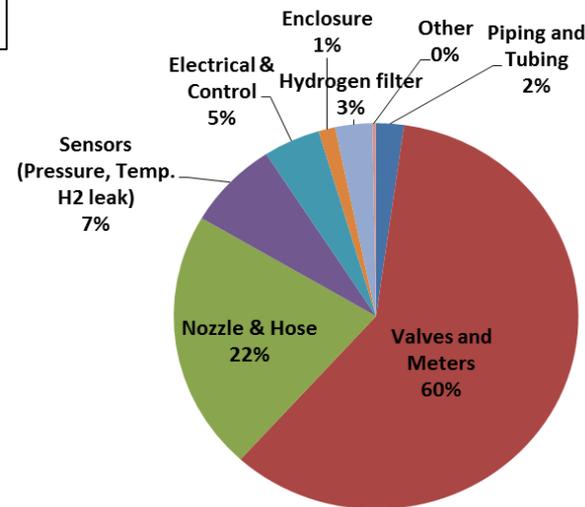


Parts Only

H35 Dispenser Parts Cost=\$35,048

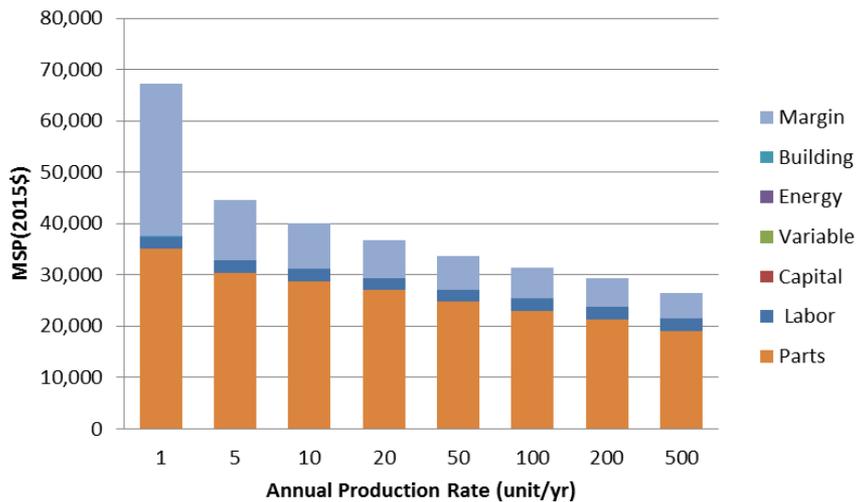


H35/H70 Dispenser Parts Cost=\$67,595

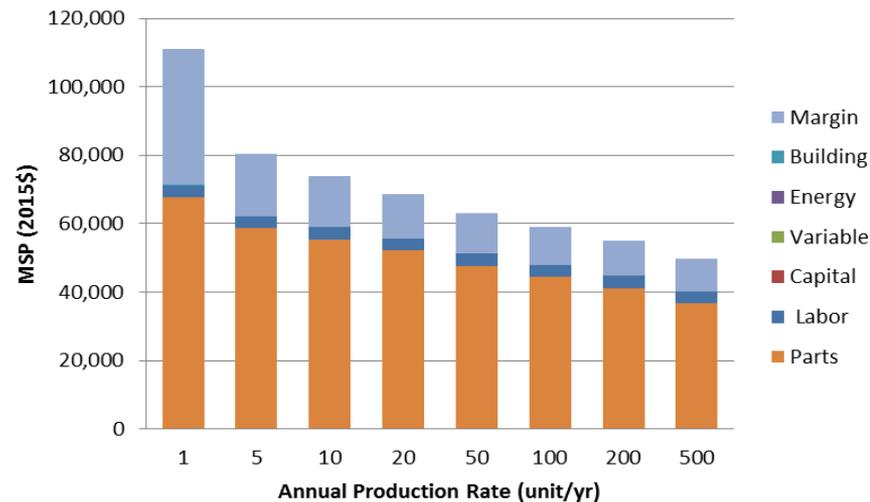


Parts & Assembly Cost (assuming 20% discount per 10x increase in purchased quantity)

MSP- Single Hose Dispenser (H35)



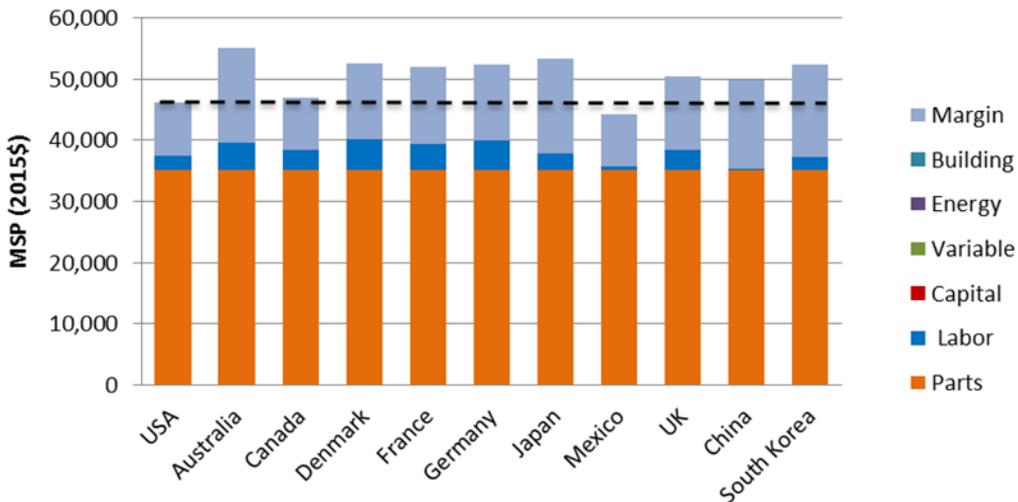
MSP- Dual Hose Dispenser (H35/H70)



Minimum Sustainable Price - Dispenser

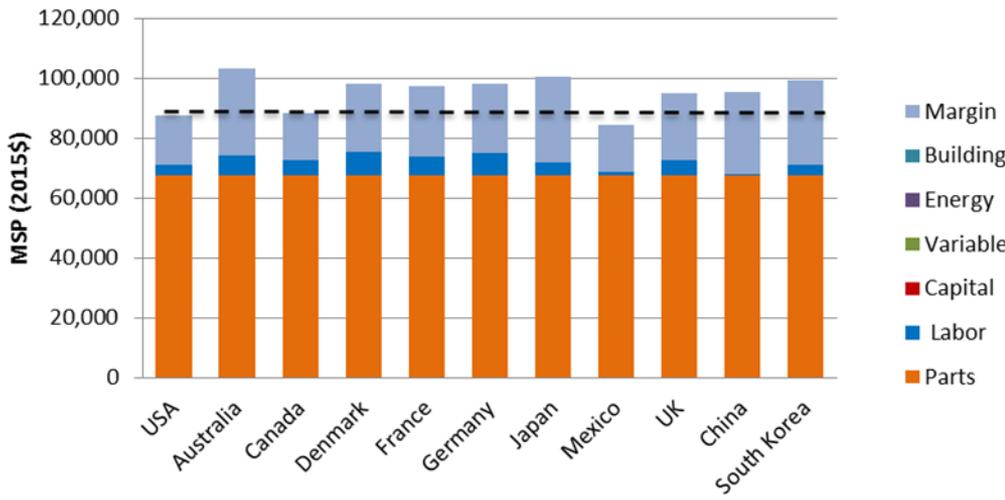


MSP - Single Hose Dispenser (H35)



- United States advantages are: lower shipping and interest rates and longer experience in this field
- Mexico's advantage relative to the U.S. is driven by lower labor and building costs

MSP - Dual Hose Dispenser (H35/H70)



Advance Heat Exchanging Technology



DCHE: Diffusion Bonded Compact Heat Exchanger

HysUT
Ebina Chuo Hydrogen Station

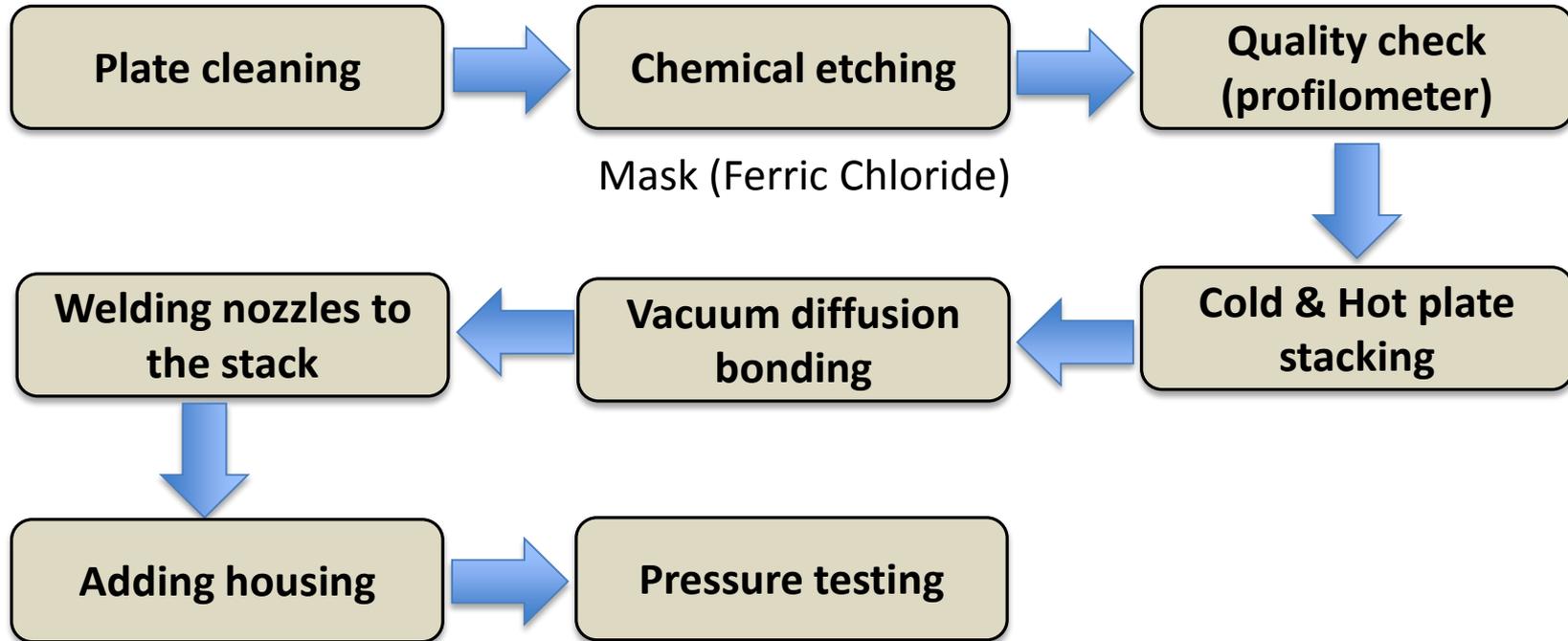


Photo Credit: JX Nippon Oil & Energy Co.

Example of integration with dispenser

Images for: NREL HRS and Kobelco DCHE

Microchannel Heat Exchanger - Process Flow

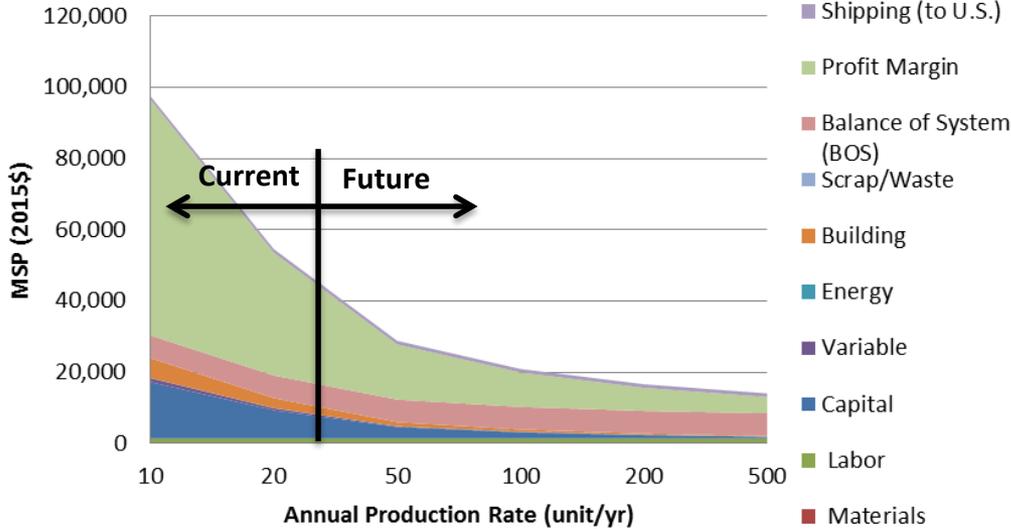


- Chemical etching can be replaced by laser grooving.
- Laser grooving speed= 300 mm/min

Minimum Sustainable Price - MCHE

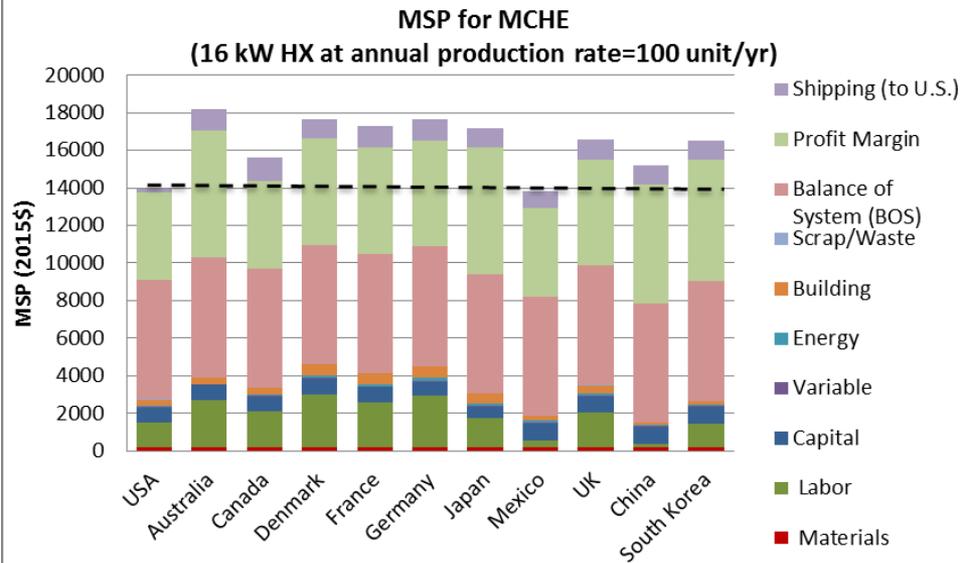


MSP for MCHE (16 kW)



MCHE: Microchannel Heat Exchanger

- United States advantages are lower shipping and interest rates and longer experience in this field
- Mexico's advantage relative to the U.S. is driven by lower labor and building costs
- China's advantage relative to the U.S. is driven by lower labor, low material cost, building and energy costs



Accomplishment and Progress

HRS Capital Cost and H₂ Price



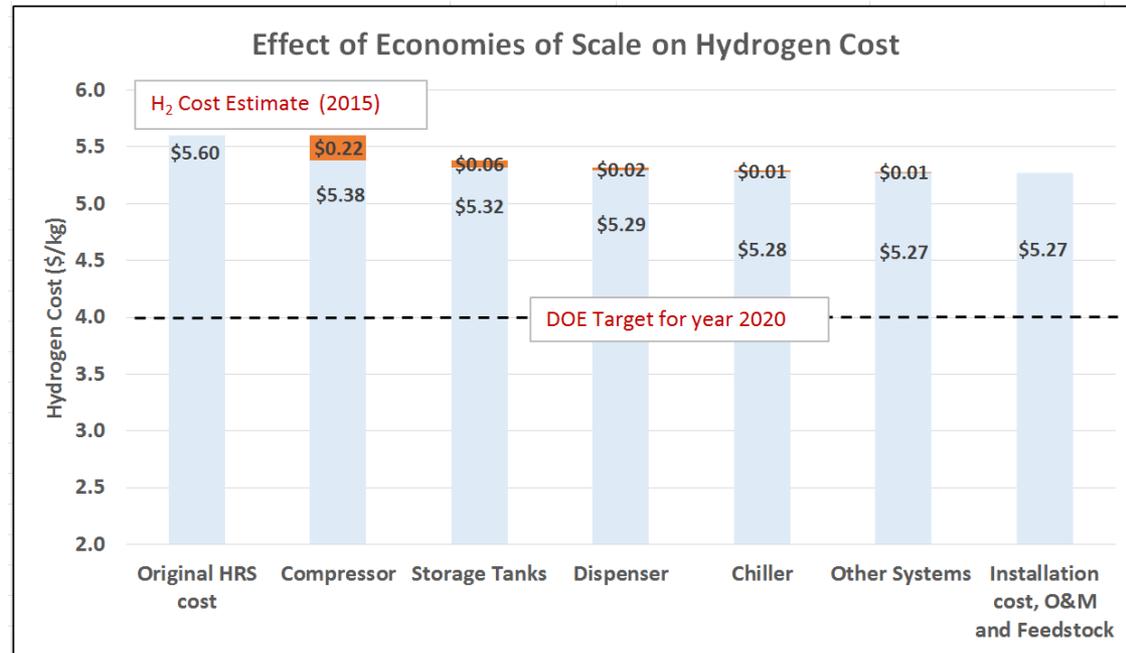
1 kg H₂ ≈ 1 gallon of gasoline equivalent (gge)

	Actual Cost (X\$1,000)	Future Cost (X\$1,000) @ 10 units/yr	Future Cost (X\$1,000) @ 100 units/yr
Capital Cost			
FirstElement HRS in California	2,050		
Installation cost, O&M and Feedstock	n/a	n/a	n/a
Compressor	121	55	45
Storage Tanks	166	117	56
Dispenser	270	75	55
Chiller	150	100	80
Other Systems	900	450	400
Installation cost	408	408	408
Future HRS Installed Cost	2,015	1,205	1,044

	2016 Hyundai Tucson Fuel Cell			2016 Toyota Mirai		
						
	Fuel Economy and Related Estimates					
Fuel Economy (mi/kg)	50	49	51	66	66	66
	comb	city	hwy	comb	city	hwy
Range (miles)	265			312		
Annual Fuel Cost *	\$1,700			\$1,250		

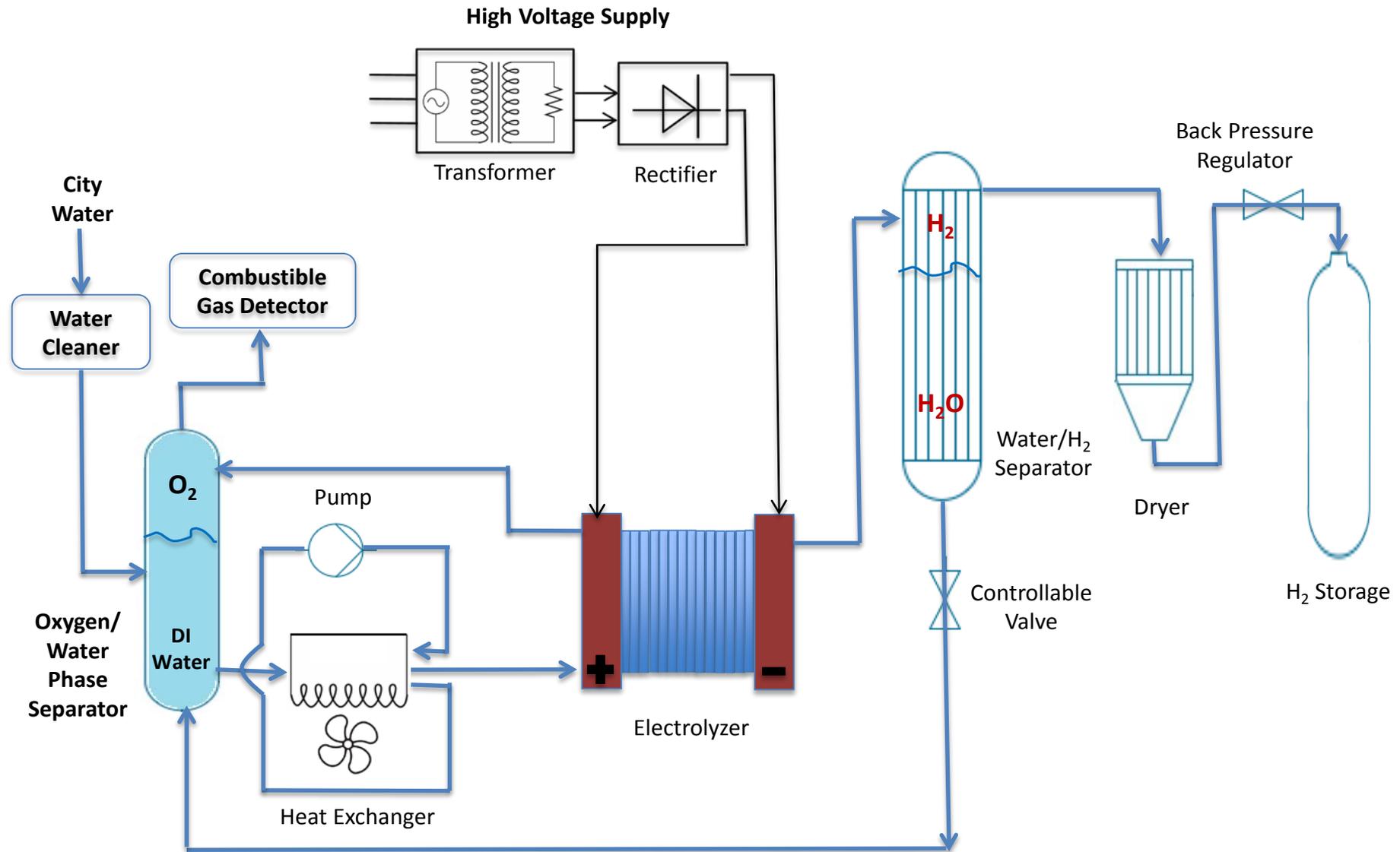
Ways of reducing hydrogen cost

- Economies of scale for HRS systems can reduce hydrogen cost more than 5-10% (~20 of CSD cost)
- Standardization can do similar thing (e.g., compressors, chillers, heat exchangers, etc.)
- Installing liquid hydrogen station. Depends on number of FCEV and utilizations of HRS



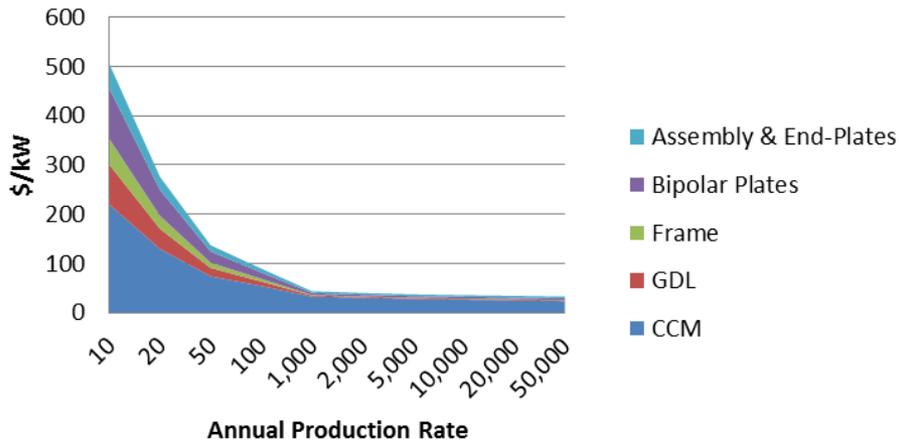
Accomplishment and Progress

Schematic of PEM Electrolysis System

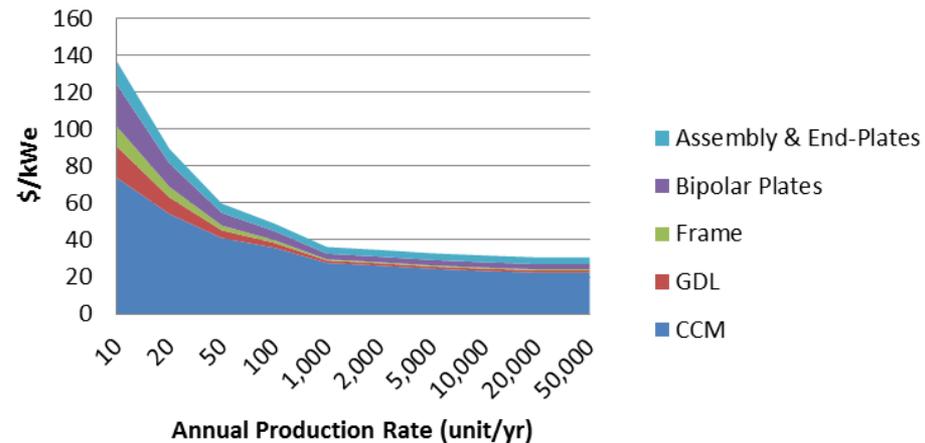


PEM Electrolyzer Stack Cost – Preliminary

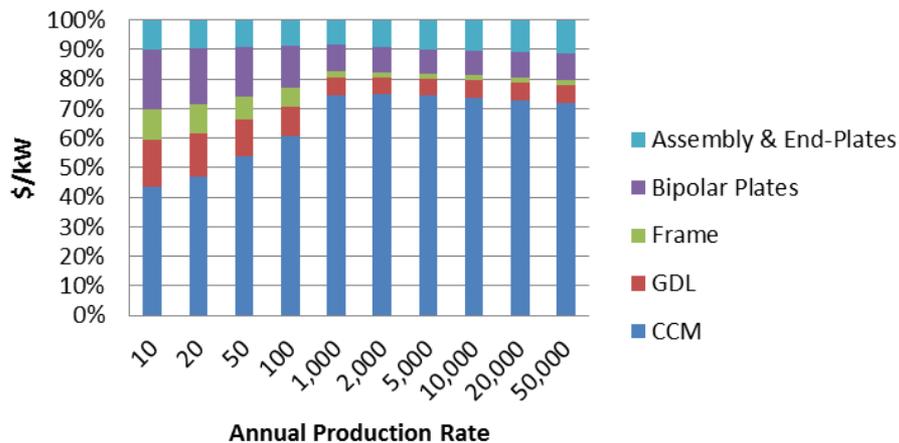
Stack Cost (\$/kW) - 200 kW



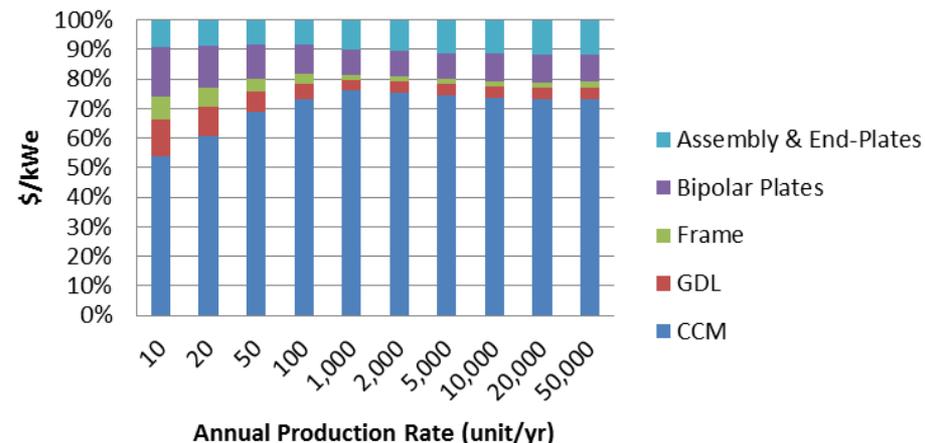
Stack Cost (\$/kW) - 1 MW



Stack Cost (\$/kW) - 200 kW



Stack Cost (\$/kW) - 1 MW



65 kg H₂/day

325 kg H₂/day

Remaining Challenges and Barriers



Challenges we face in this study:

- Involve more organizations (industry, part suppliers, regulation agencies, etc.) in the hydrogen refueling station study
- Establish new collaboration with industry for the ongoing project (manufacturing competitiveness of the onsite hydrogen production equipment)
- Lack of competition between part suppliers (e.g. nozzles and hoses) make it hard to study potential cost reductions

Proposed Future Work

- Complete manufacturing cost analysis for other HRS's systems (e.g., onsite hydrogen production systems)
 - PEM electrolyzers
 - Alkaline electrolyzers
 - Small size steam methane reformers
- Study effect of future technologies and economies of scale on the HRS capital cost and hydrogen prices

Responses to 2016 AMR Reviewer Comments

- NREL should discuss how the researchers will transfer this information to industry.
- The project should reach out to existing manufacturers and developers to review the results and the assumptions that drive the models.

In addition to the continuous work we do with industry, we got the chance to work with California Energy Commission (CEC) and ZEV office at the California Governor's office.

- The project should bring in companies that are innovating away from the traditional and mature systems and components—technology readiness levels 6 and 7.

Our team is trying hard to collaborate with researchers and manufacturers in such area, for example we recently started to work with some manufacturers of new microchannel heat exchanger technology that has been proven to reduce the cost at the long run and have better heat exchanging capabilities than classical double tube heat exchangers

- It would have been interesting if some effort was spent on durability and operating expenditures (OPEX).

While this project focuses on manufacturing cost and supply chain analyses, we agree that OPEX is important area that needs further investigation. We will work with FCTO to propose some ideas of optimizing manufacturing and operation cost of some technologies used in the hydrogen stations.

- It is not clear whether the models are used only for helping DOE assess status. Impact could be larger if these models are shared and used by the developers.

We already established sort of collaboration with industry and hope to expand this network. We will also work with FCTO and CEC to publicize our findings and insights. We are also planning to attend some conferences in Europe and Asia to publicize and promote the importance of this work.

Collaborations

- Kriston Brooks, Pacific Northwest National Lab (PNNL)
 - Provided critical inputs for manufacturing cost analysis for heat exchangers
- Amgad Elgowainy, Argonne National Lab (ANL)
 - Help in validating manufacturing cost model results & effect of qualitative factors (e.g., number of jobs created)
- Daryl Brown, Pacific Northwest National Lab (PNNL)
 - Provided data on HRS capital costs (HRSAM)
- Tetsufumi Ikeda, HySTU program, Japan
 - HRS installations in Japan
- Kareem Afzal and Osama Al-Qasem, PDC Machines
 - Provided critical inputs for manufacturing cost analysis for compressors
- Tetsuya Tanaka, Hitachi compressors, Japan
 - Provided some specifications for H₂ compressors for Japanese market
- Sean Shunsuke Chigusa, Kobelco Compressors, Japan/USA
 - Provided some inputs for hydrogen compressor
- Industry stakeholders: provided estimates for dispenser cost (SunDyne, Tescom, Swagelok, HyDAC, High Pressure Equipment, Rust Automation & Control, SBS, MyDax, Welcon, Russels Technical, Thermofin, etc.)

Project Summary



- **Relevance:** to provide a framework for technoeconomic and supply chain analyses for hydrogen refueling stations
- **Approach:** Bottom-up cost analysis cost models, detailed supply chain maps and investigation of qualitative factors effect on manufacturing competitiveness
- **Technical Accomplishments and Progress:**
 - Manufacturing cost models for hydrogen compressors, storage tanks, dispensers, chillers and heat exchangers, and onsite hydrogen production equipment
 - Trade flow maps for global HRSs
- **Collaboration:** Sandia, ANL and PNNL
- **Proposed Next-Year Research:**
 - Complete manufacturing cost models for onsite hydrogen production equipment
 - Complete supply chain analysis and trade flow mapping for onsite hydrogen production equipment
 - Investigate effect of qualitative factors in the manufacturing competitiveness

Technology Transfer Activities



- Not applicable for this cost analysis

Thank you

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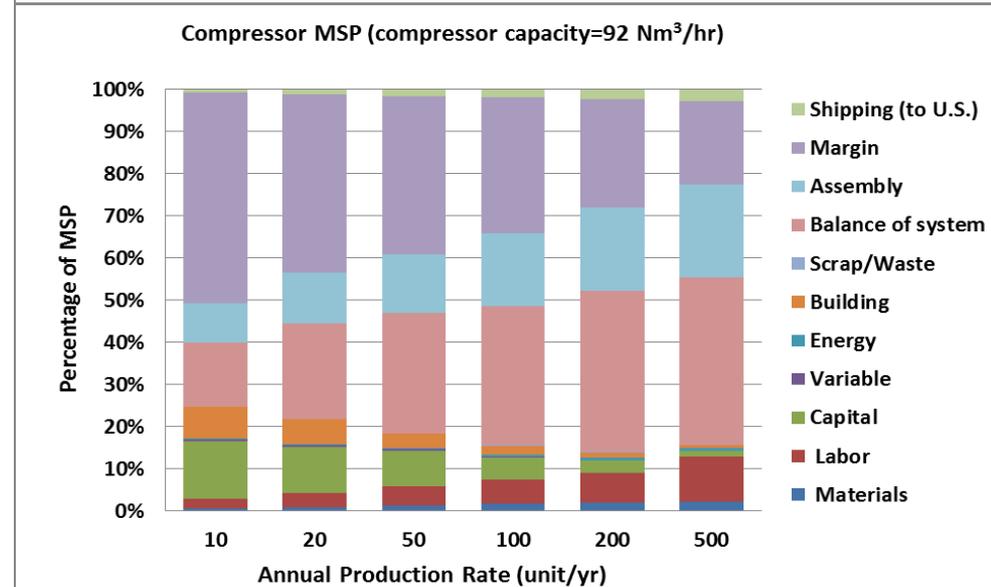
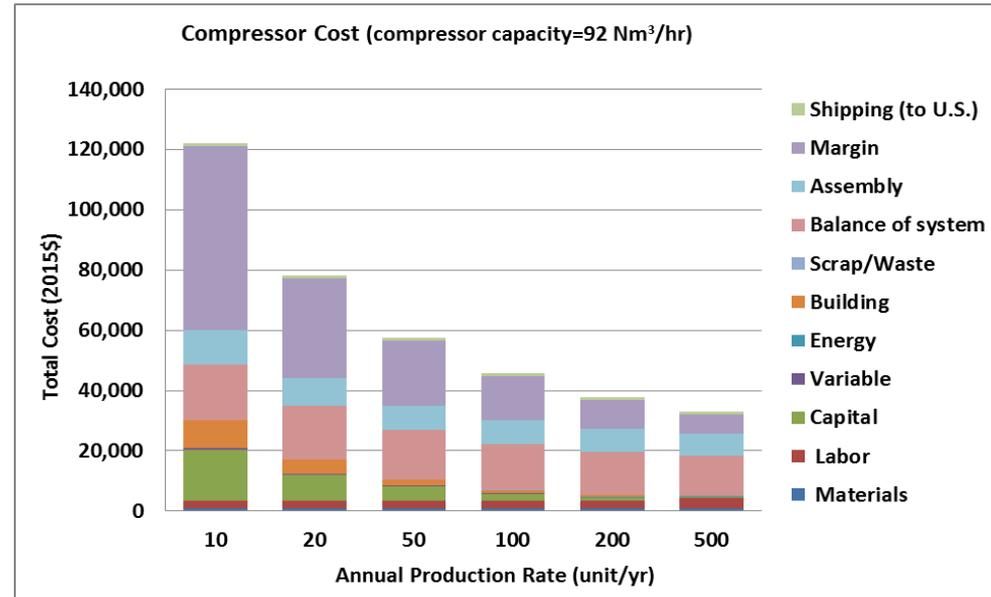
Backup Slides

Minimum Sustainable Price - Compressor



Assumptions

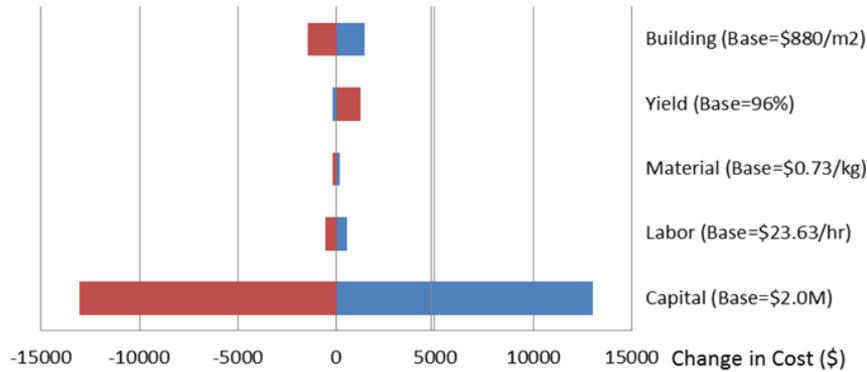
- 1 stage compressor
- Compression ratio < 7
- $P_{in} = 150\text{-}200$ bar, $P_{out} = 350\text{-}420$ bar (5,000-6,000 psi)
- Manufacturing cost model for compressor case and internal parts only
- Balance of system was added to the direct manufacturing cost of the compressor case & internal parts
- Profit margin was estimated using weighted average cost of capital (WACC) method
- Shipping cost is assumed for shipping compressors from East Coast to West Coast in this example



Sensitivity Analysis



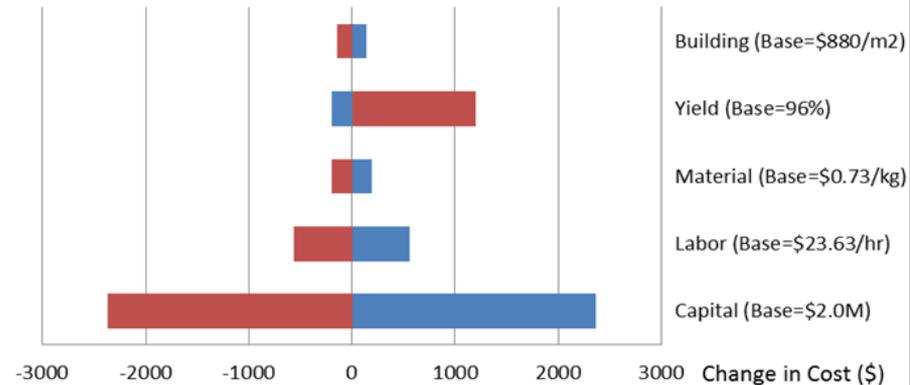
U.S. Plant
Compressor Manufacturing Cost=\$121,080
92 Nm3/hr @ 10 compressors/yr



Input parameters were varied by +/- 10% (relative) from base values to identify the modeled price sensitivities to various input assumptions

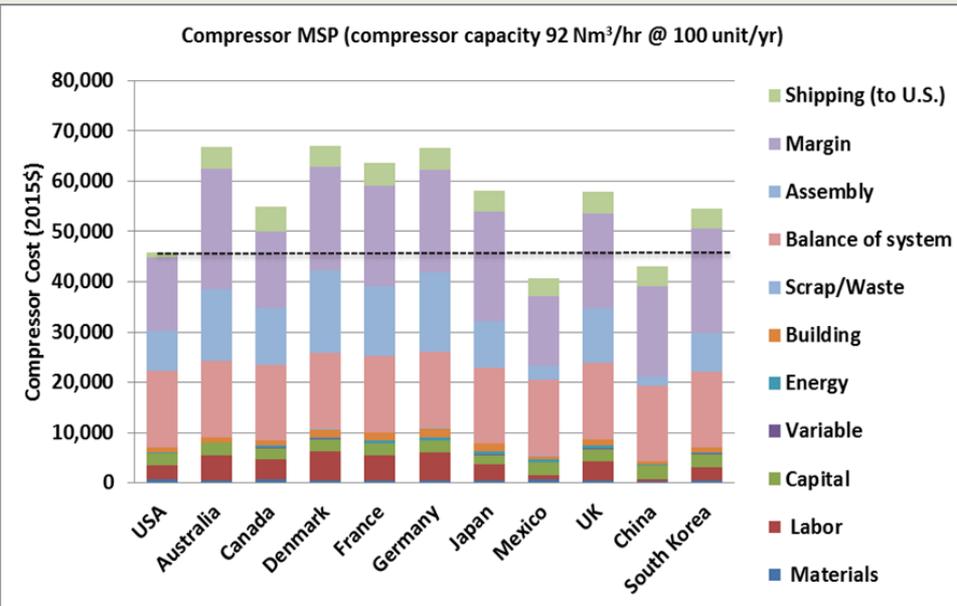
	Capital (Base=\$2.0M)	Labor (Base=\$23.63/hr)	Material (Base=\$0.73/kg)	Yield (Base=96%)	Building (Base=\$880/m2)
+20%	\$13,047	\$567	\$196	-\$180	\$1,438
-20%	-\$13,047	-\$567	-\$196	\$1,205	-\$1,438

U.S. Plant
Compressor Manufacturing Cost=\$44,833
92 Nm3/hr @ 100 compressors/yr

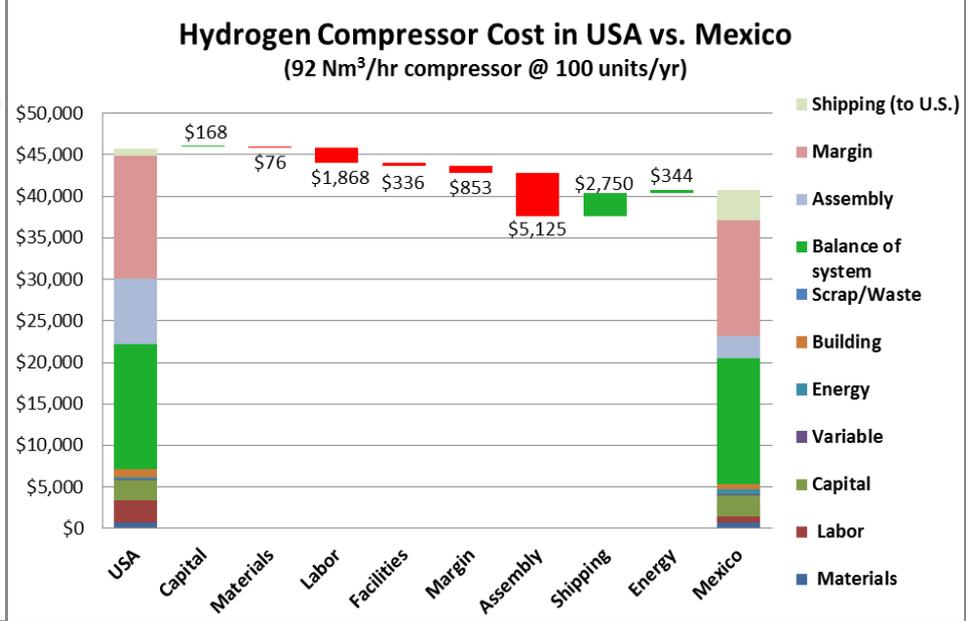
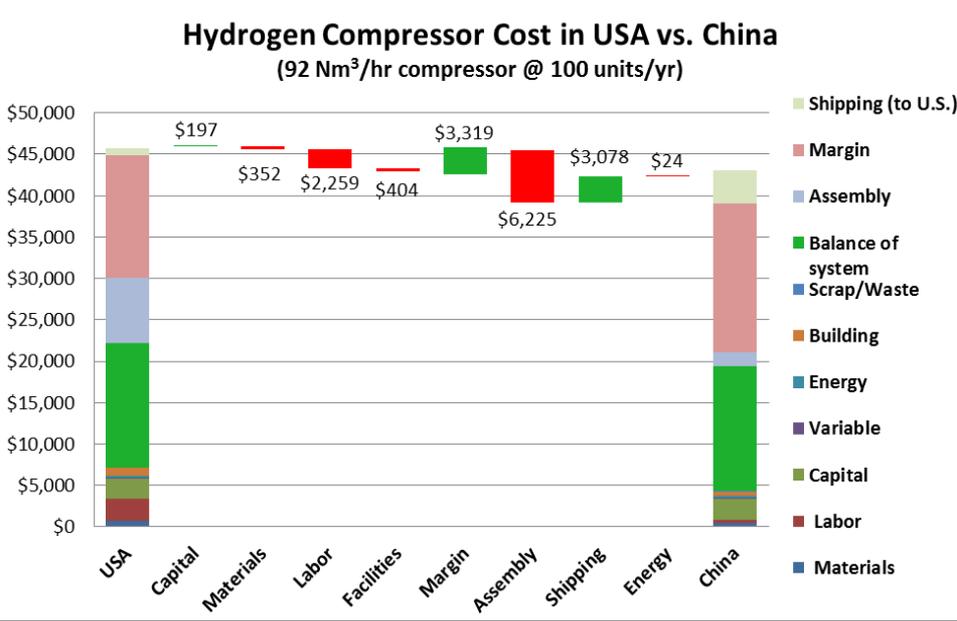


	Capital (Base=\$2.0M)	Labor (Base=\$23.63/hr)	Material (Base=\$0.73/kg)	Yield (Base=96%)	Building (Base=\$880/m2)
+20%	\$2,368	\$559	\$196	-\$193	\$144
-20%	-\$2,368	-\$559	-\$196	\$1,201	-\$144

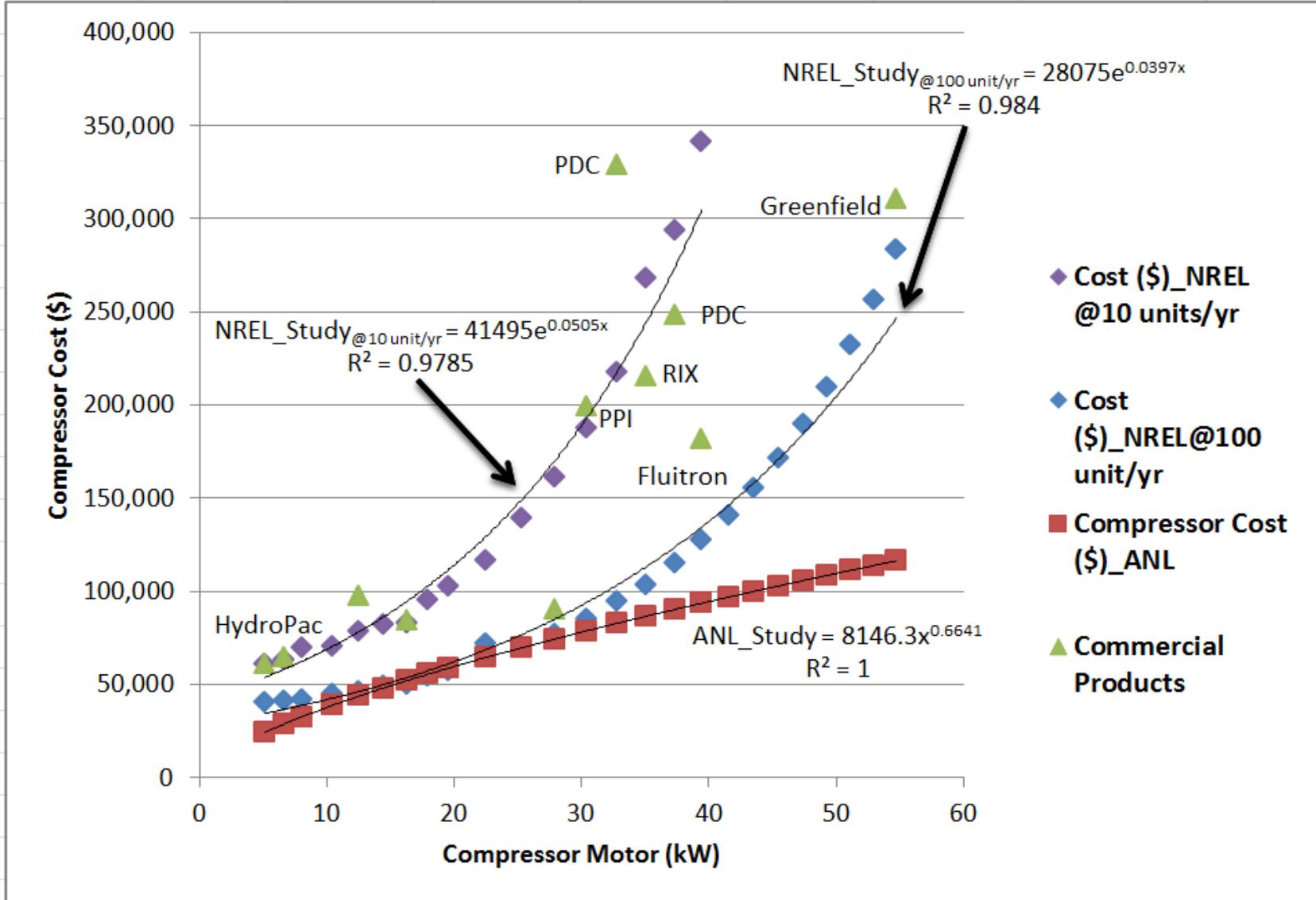
Minimum Sustainable Price - Compressor



- United States advantages are lower shipping and interest rates and longer experience in this field
- China's advantage relative to the U.S. is driven by lower labor, low material cost, building and energy costs
- Mexico's advantage relative to the U.S. is driven by lower labor and building costs



Estimation of Compressor Cost



Annual inflation rate= 2%

Elements of Manufacturing Analysis



- Innovation potential
- Manufacturing experience: *Learn by Doing*
- Intellectual property
- Cost of energy
- Cost of manufacturing
- Availability of investment capital
- Low-cost labor requirements & availability
- Product quality
- Skilled labor requirements & availability
- Tax policy
- Currency fluctuations
- Import and export policies
- Automation/advanced manufacturing
- Raw material availability
- Ease of transportation
- Existing supply chains
- Synergistic industries and clustering
- Existing or growing market
- Ease of doing business
- Safety
- Regulations
- Inventory costs and supply chain delays