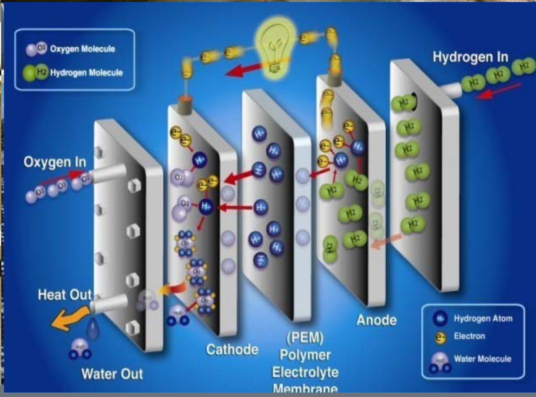
Fuel Cell Technologies Office Webinar

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy





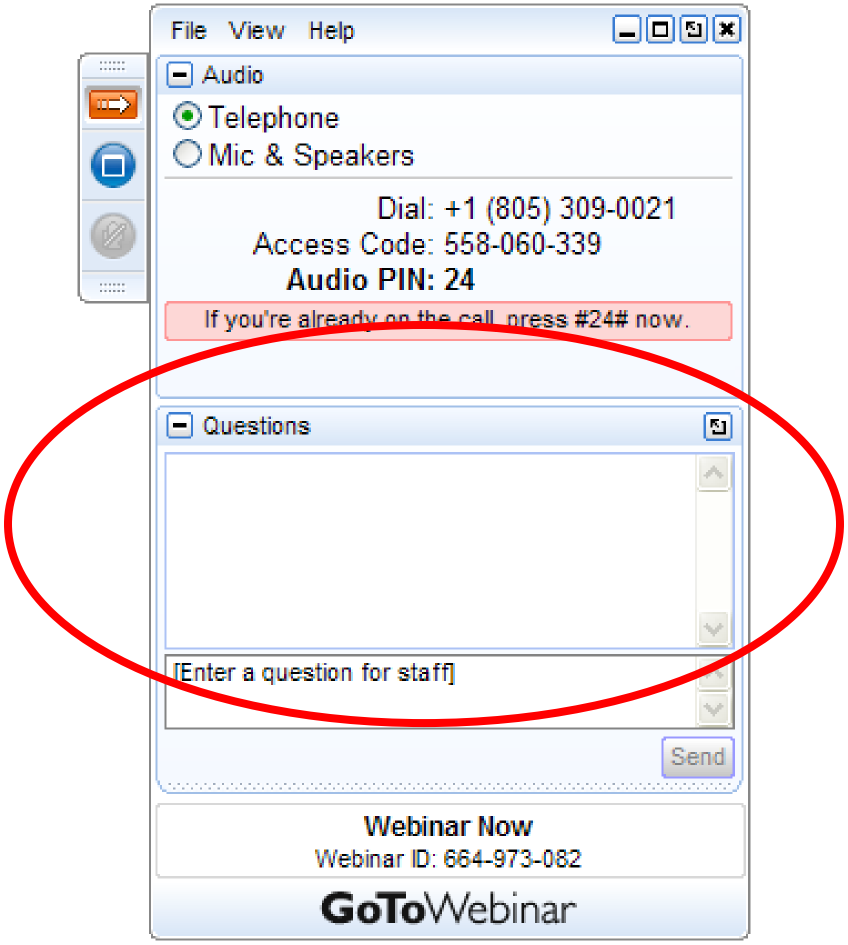
Manufacturing Competitiveness and Supply Chain Analyses for Hydrogen Refueling Stations

05/011/2017

Presenter: Ahmad Mayyas
Analyst - Clean Energy Systems
National Renewable Energy Laboratory

Question and Answer

- Please type your questions into the question box



CEMAC Clean Energy Manufacturing Analysis Center

Manufacturing Competitiveness and Supply Chain Analyses for Hydrogen Refueling Stations

Ahmad Mayyas

National Renewable Energy Laboratory

Agenda

I. Introduction

II. International HRS Status

III. Analysis of HRS Capital Cost

IV. Manufacturing of HRS components

V. Concluding Remarks

I Introduction

Relevance & Goals

- Provide a platform for manufacturing cost analysis for major hydrogen refueling station (HRS) systems
  - Identify cost drivers of major parts in the HRS
  - Investigate effect of *learning experience* and *availability of part suppliers* on the cost of some HRS systems
- Study supply chain and evaluate U.S. manufacturing competitiveness in the international market

Approach

Global Assumptions
(e.g. capital, tool life, building life)

Local Assumptions by Country
(e.g. labor, energy cost, building cost)

Manufacturing Cost Model
(compressor, storage tanks, dispenser, chiller, and heat exchanger)

Minimum Sustainable Price
(manufacturing cost, profit margin, transportation)

Compare to Other Cost Studies
(HRSAM, H2FIRST, California, Japan, Europe)

Benchmark with Existing/Future Commercial Products

Qualitative Factors
(e.g. skilled labor, existing supply chain, regulations, tax policy)

Quantifying These Factors

HRS Rollouts 2005-2016
(PNNL, CEC, NEDO, HySUT, NOW, CEP)

HRS Trade Flows
(HRS developers, part suppliers)

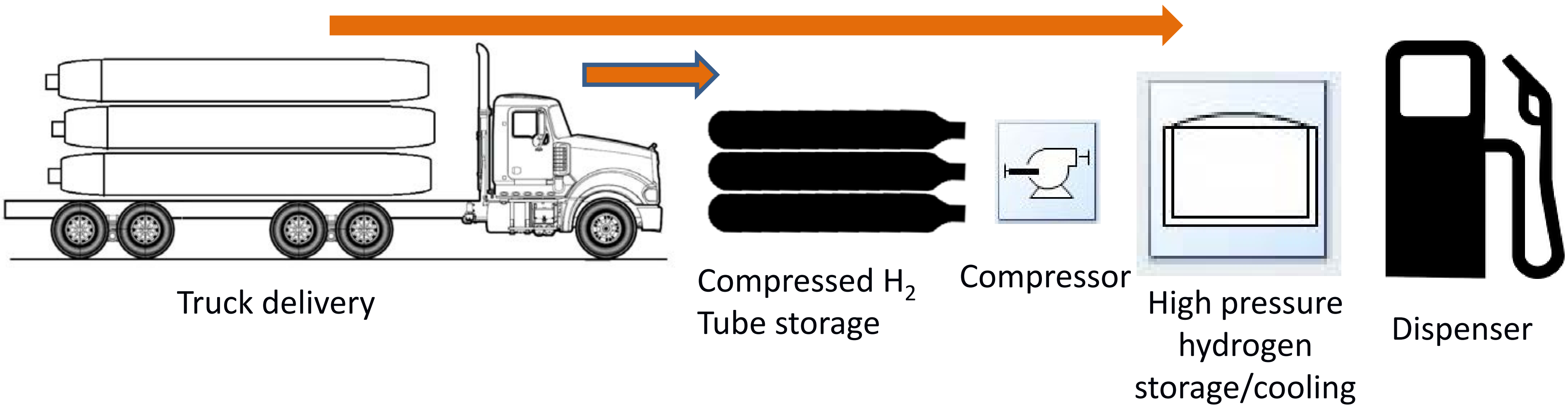
Supply Chain Maps
HRS technology (gaseous, liquid, onsite) system components

Future HRS Rollouts 2016-2030

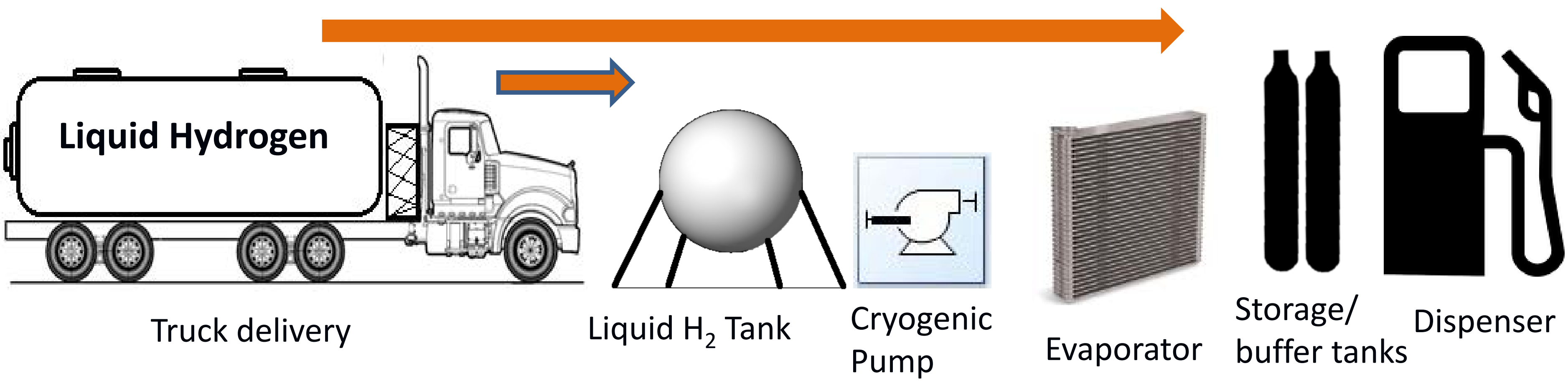
Key Outputs

1) HRS system manufacturing costs and minimum sustainable prices
2) International trade flows and supply chain maps (U.S. supply chain)
3) Estimation of future HRS technologies cost and effects on H_2 price

Hydrogen Delivery to the HRS

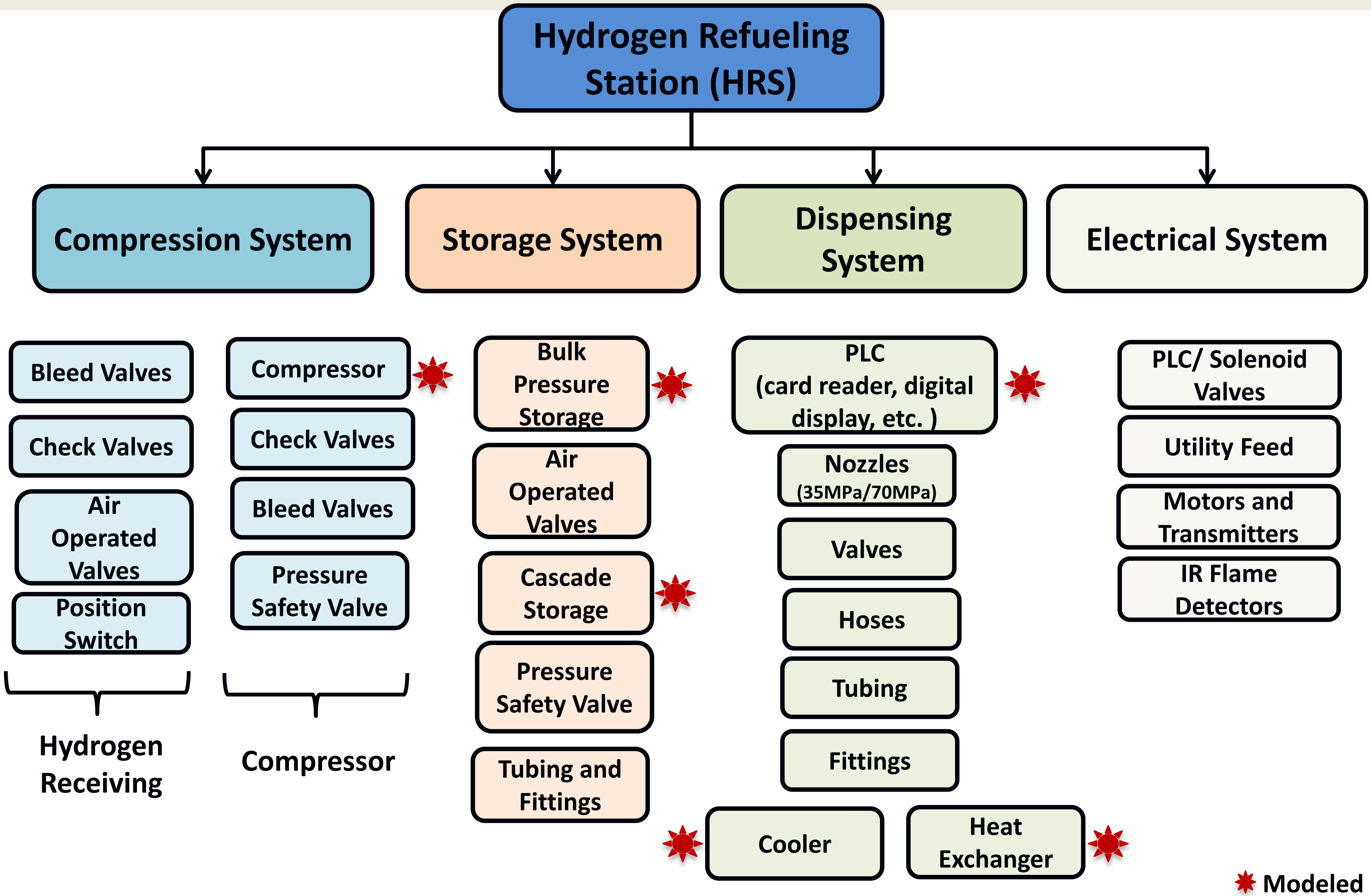


A configuration of a hydrogen station with gaseous hydrogen delivery

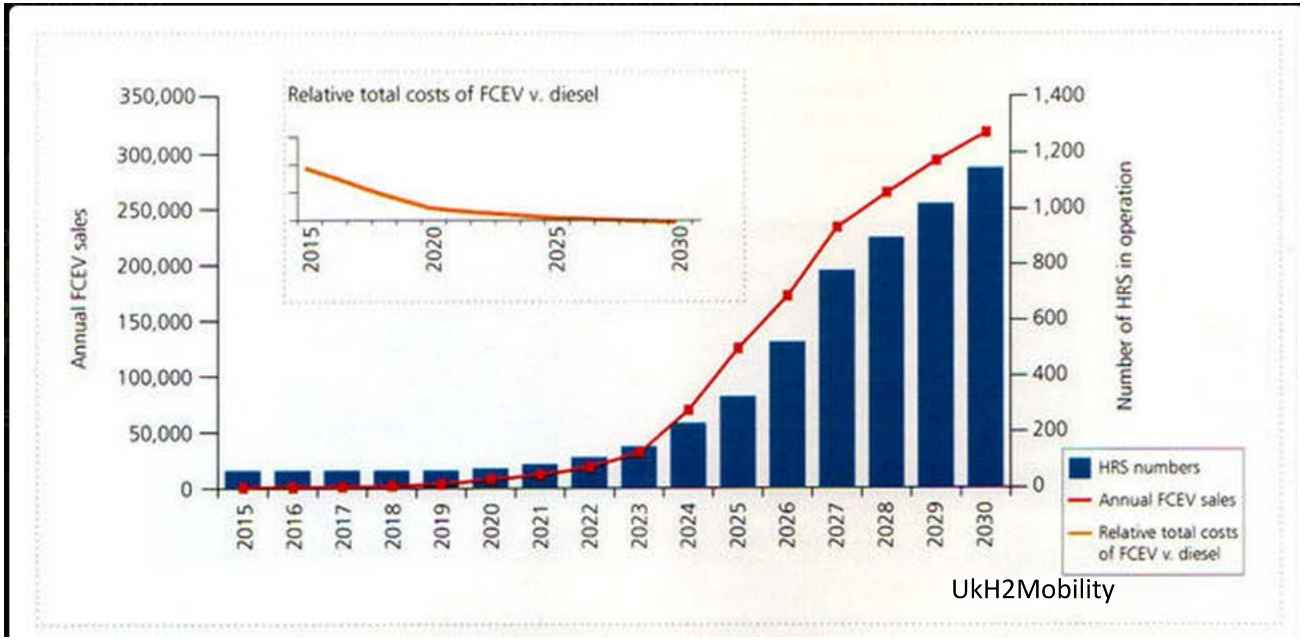


A configuration of a hydrogen station with Liquid hydrogen delivery

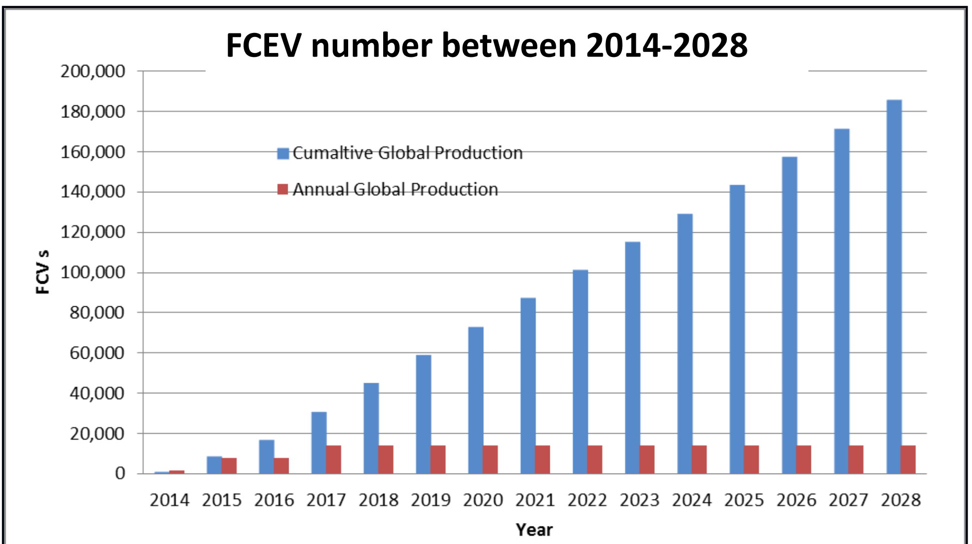
Gaseous HRS Components

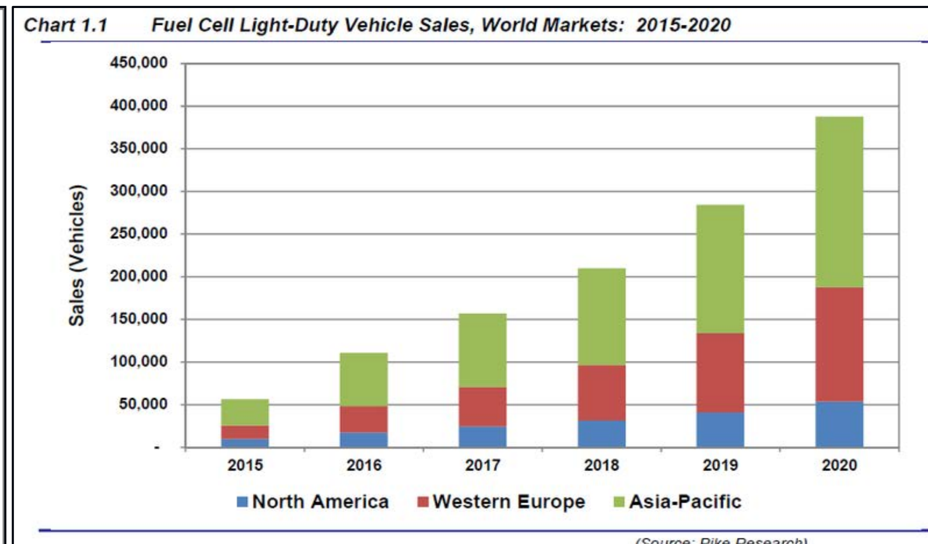


FCEV Sales 2015-2030



- 2020 sales/production estimate >30,000 FCEVs
- 2030 sales/production estimates >250,000 FCEVs on roads
- Is hydrogen infrastructure ready to support this number of FCEVs?

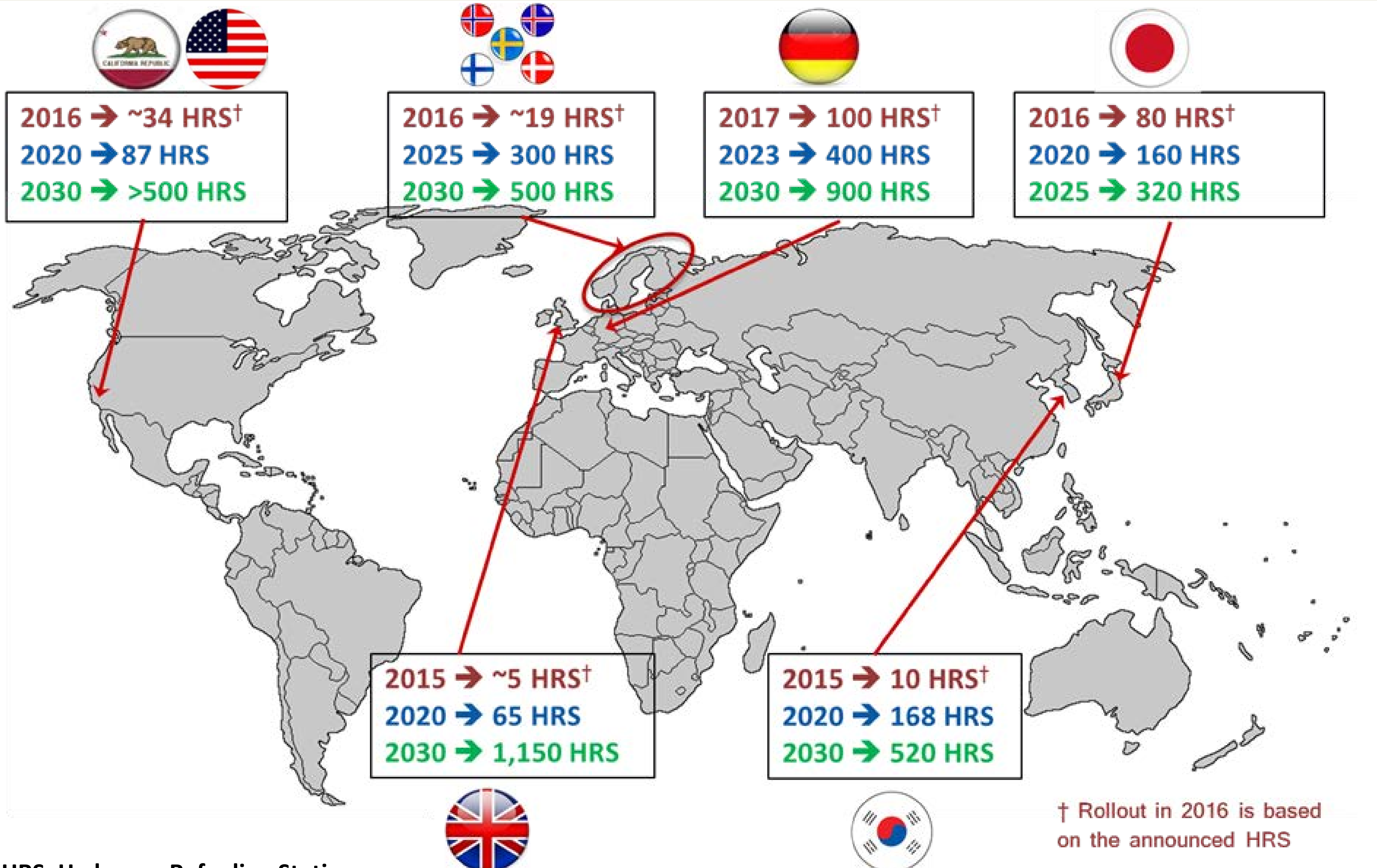




II

International HRS Status

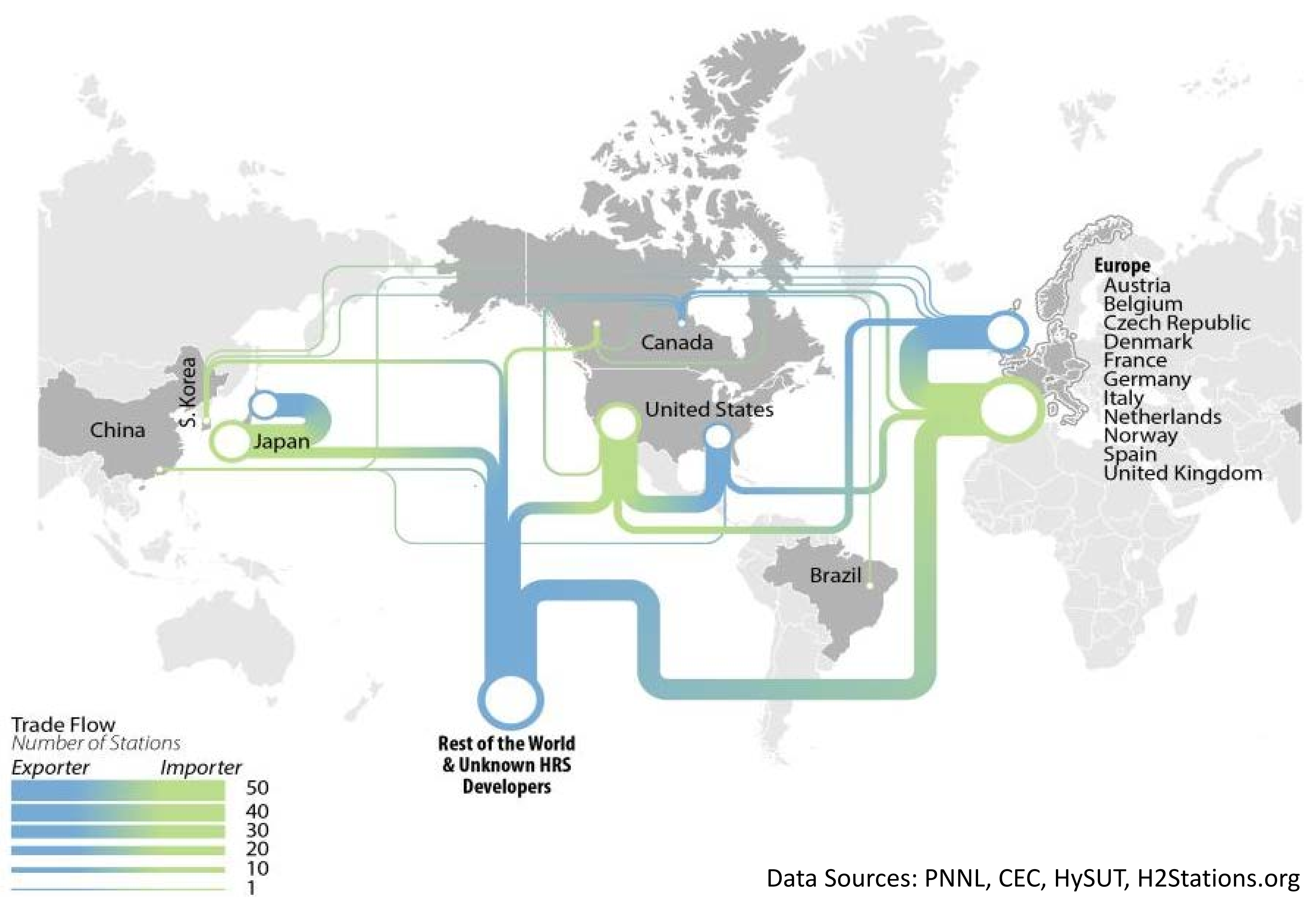
International HRS Rollouts



HRS: Hydrogen Refueling Station

Data Sources: PNNL, CEC, NEDO, HySUT, NOW, CEP

HRS Trade Flows Map



Data Sources: PNNL, CEC, HySUT, H2Stations.org

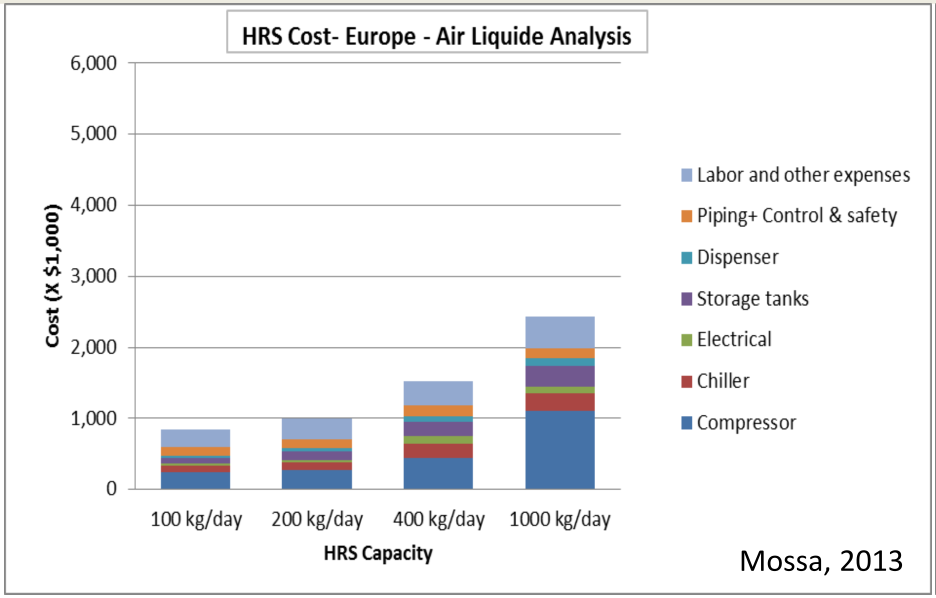
International Manufacturers

HRS Provider	Pressure Vessels Manufacturer	Compressor Manufacturer	Dispenser Manufacturer

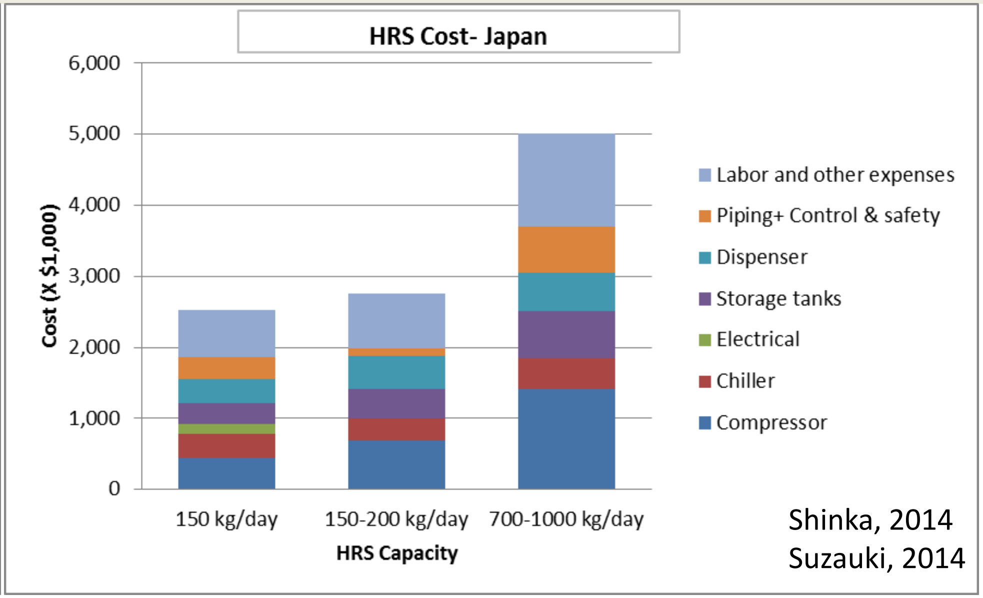
This map can be accessed from: https://maphub.net/mayyas111/HRS

III Analysis of HRS Capital Cost

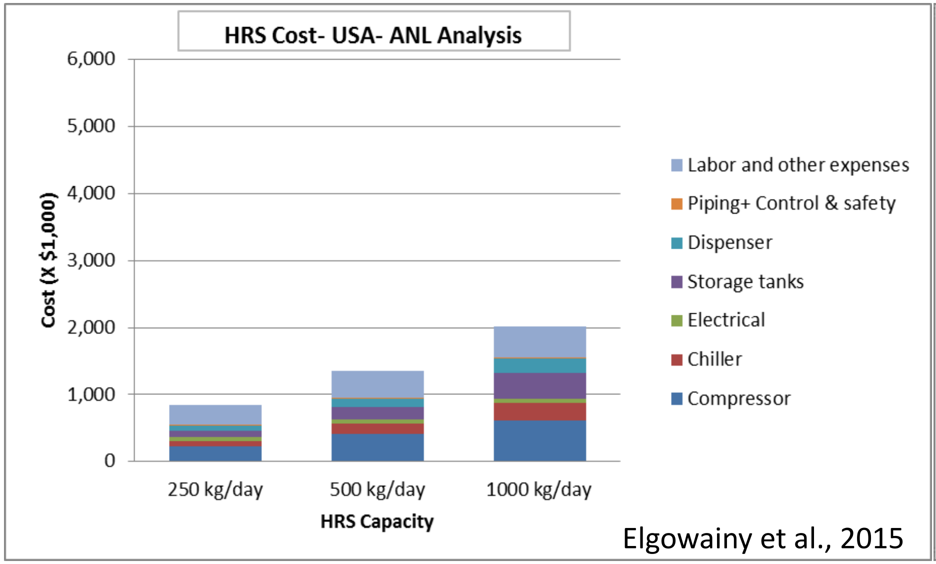
HRS Capital Cost



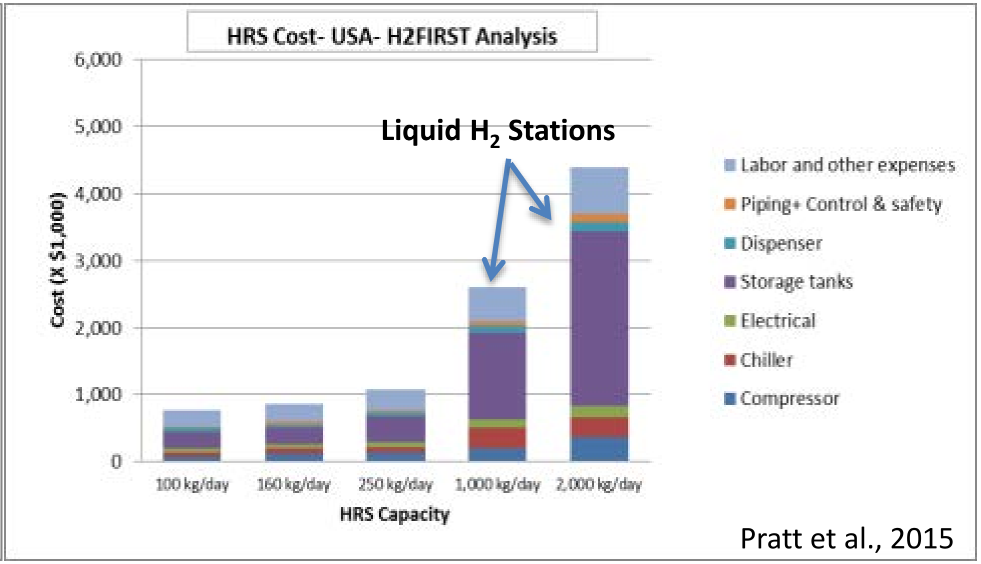
Mossa, 2013



Shinka, 2014
Suzauki, 2014



Elgowainy et al., 2015



Pratt et al., 2015

Other Expenses include site engineering, permitting, commissioning, and construction

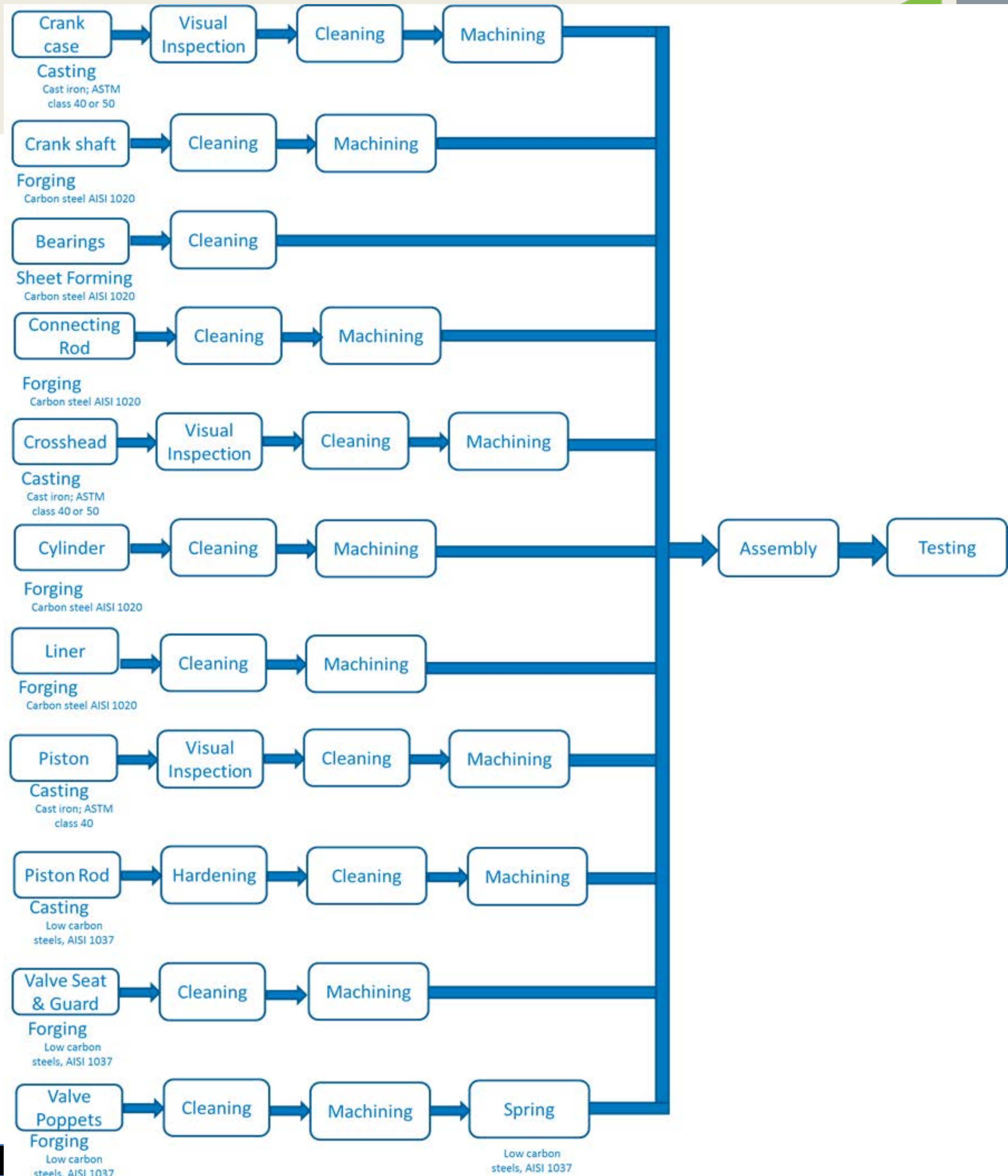
IV

Manufacturing of HRS components

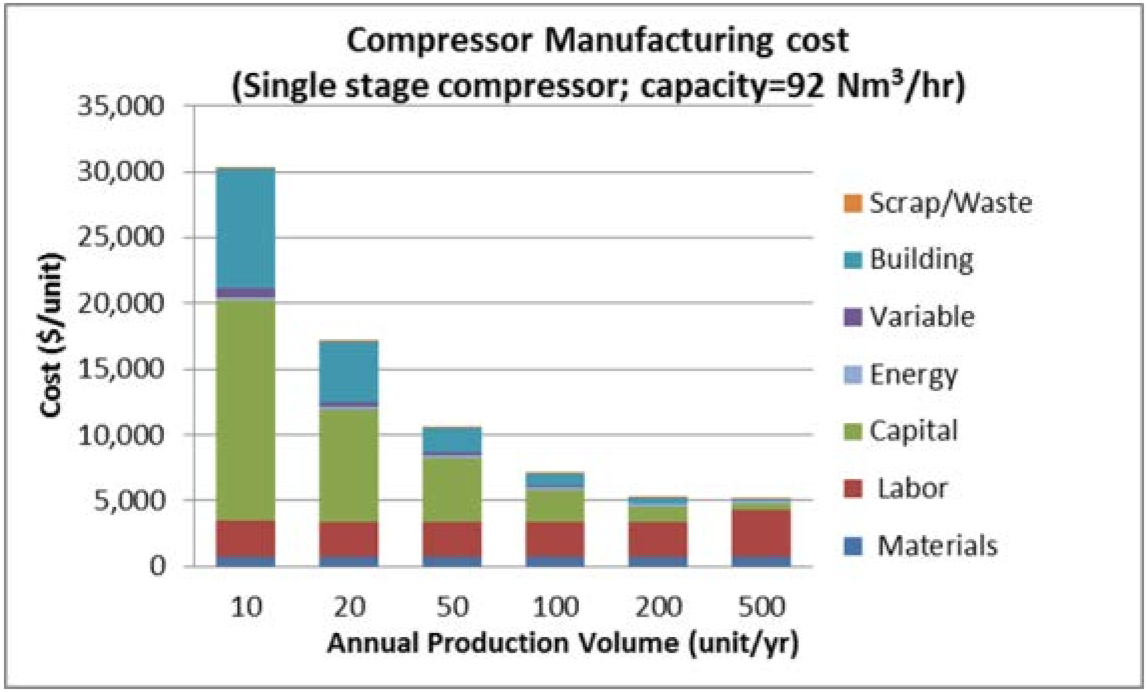
Assumptions- Compressor Manufacturing

- 1 stage compressor
- Compression ratio < 6:1
- P_{in}= 150-200 bar, P_{out}= 350-420 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
- 70 MPa HRS might need a hydrogen booster besides the compressor to increase the pressure from 350-420 bar (35-42 MPa) to about 700-900 bar for direct filling or storage in the cascade/buffer system

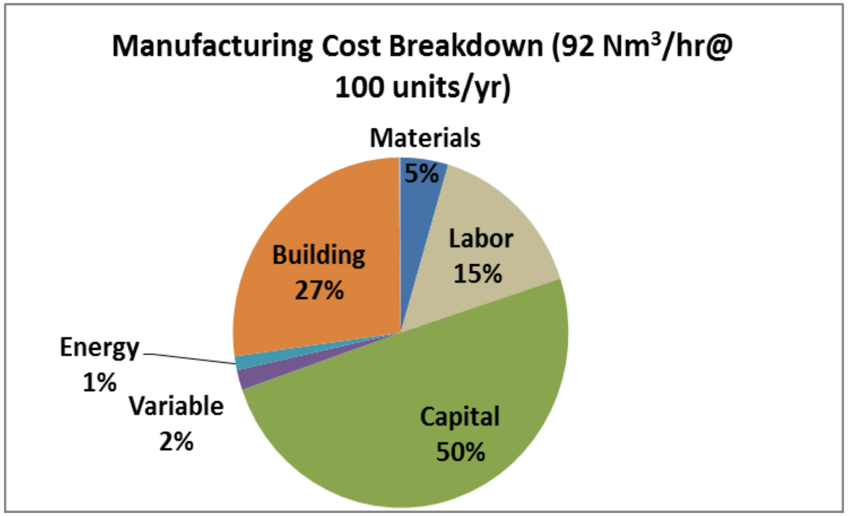
Process Flow Diagram- Piston Compressor

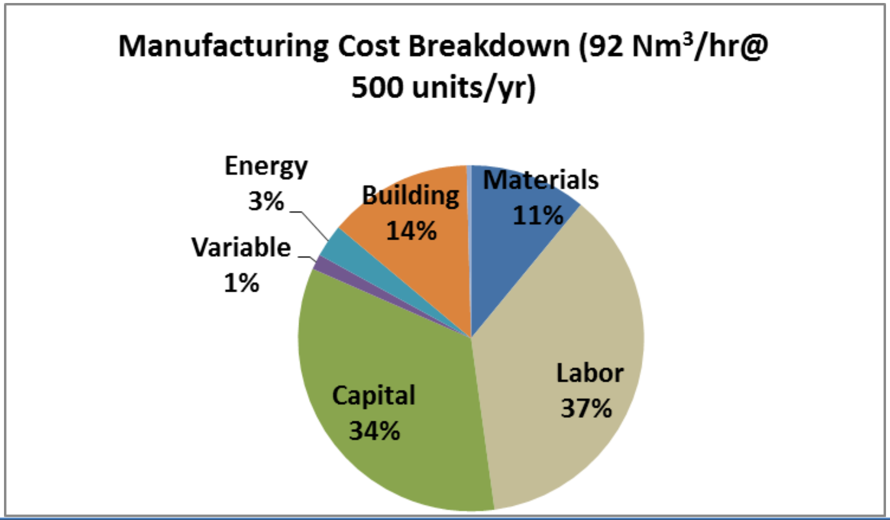


Manufacturing Cost Analysis

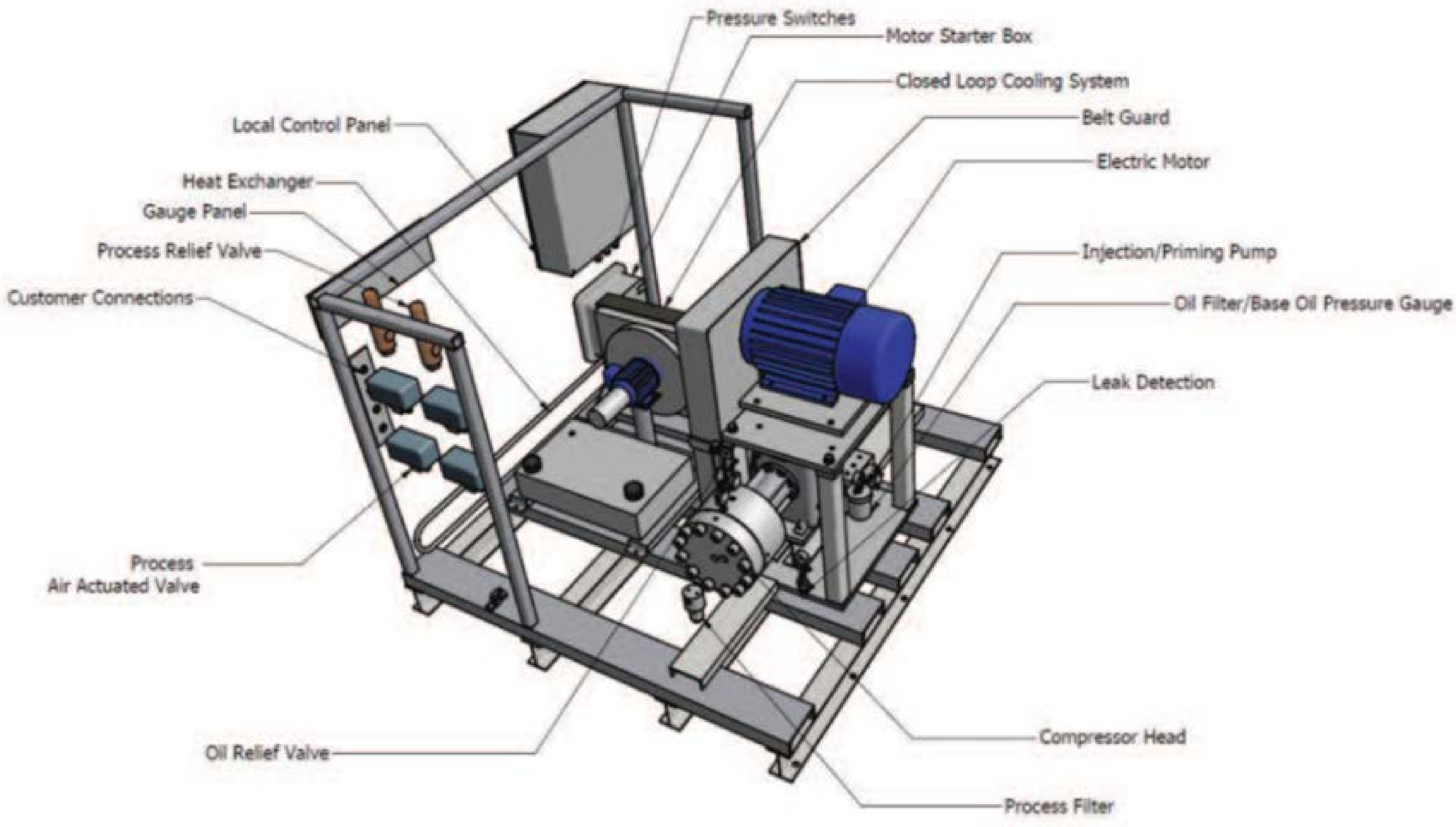


- Compressor frame and internal parts
- Not including balance of system



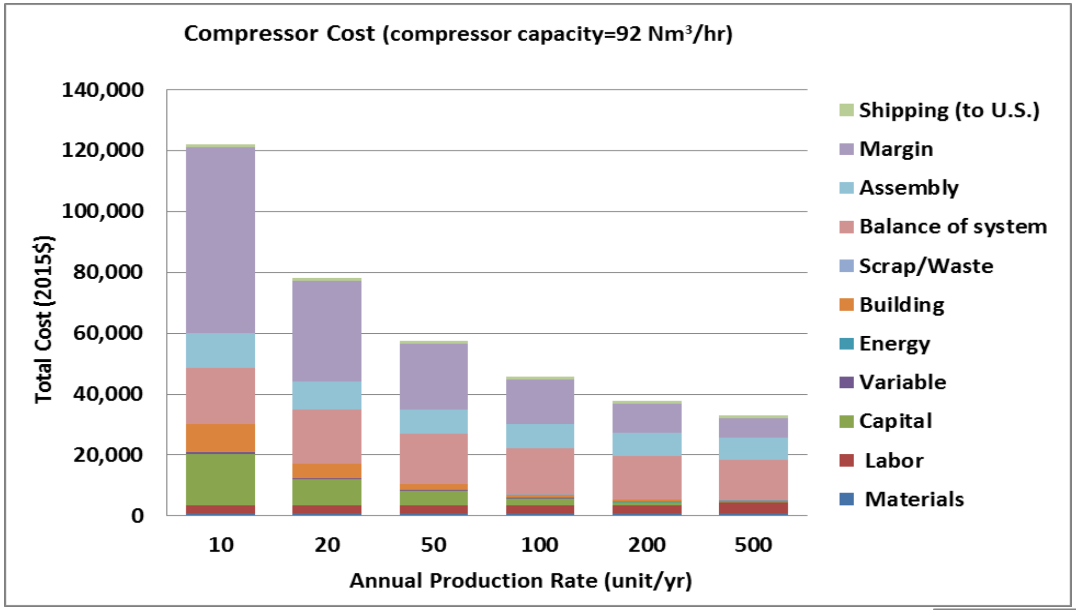


H_2 Compressor -Balance of System

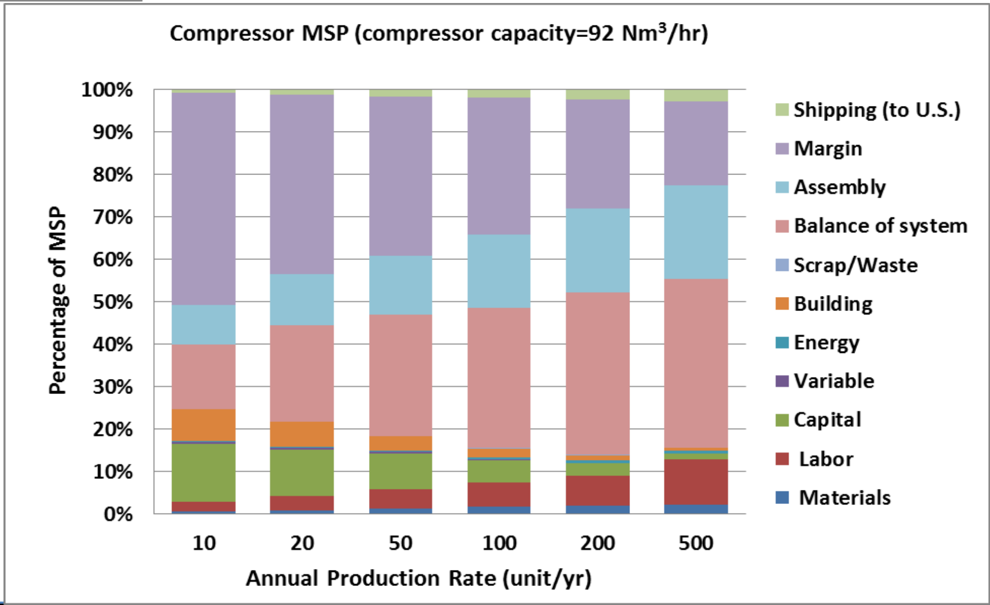


www.PDCMachines.com

Minimum Sustainable Price - Compressor

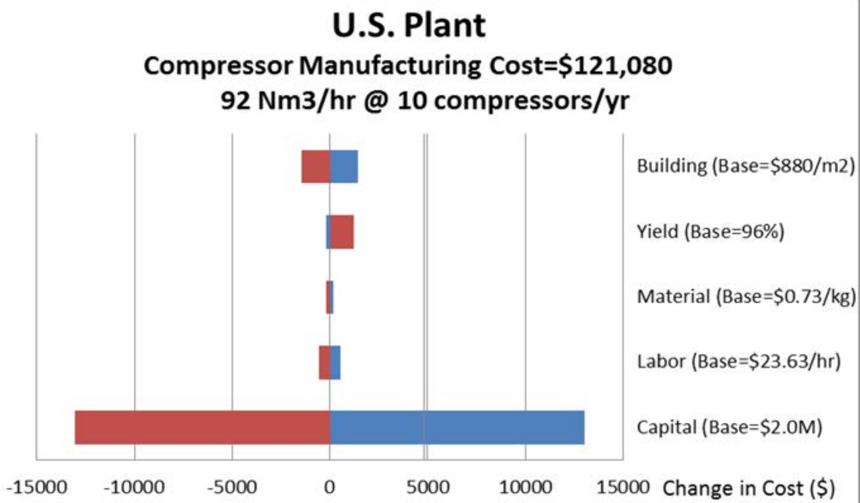


- Compressor capacity= 92 Nm^3/hr or 200 kg/day (1 stage)
- P_{in}= 150-200 bar, P_{out}= 350-420 bar
- Shipping cost is assumed for shipping compressors from East Coast to West Coast in this example
- Margin was calculated using WACC

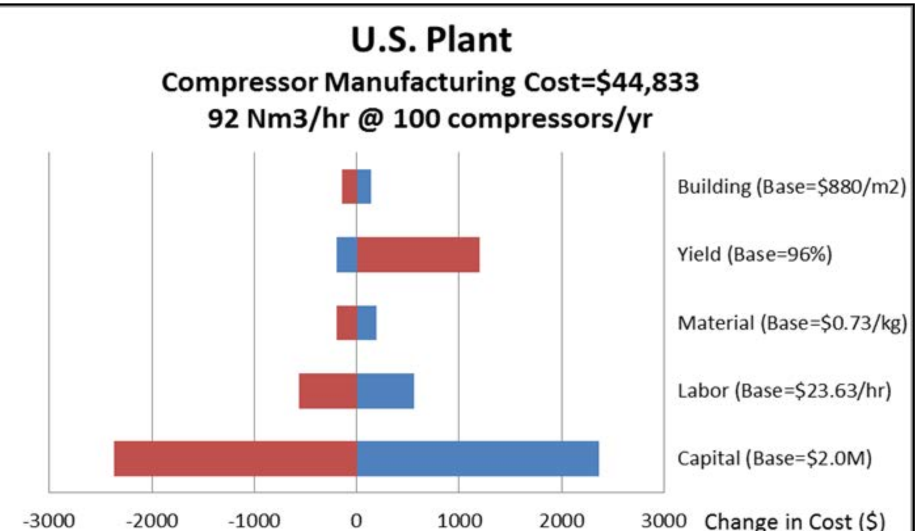


Sensitivity Analysis

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

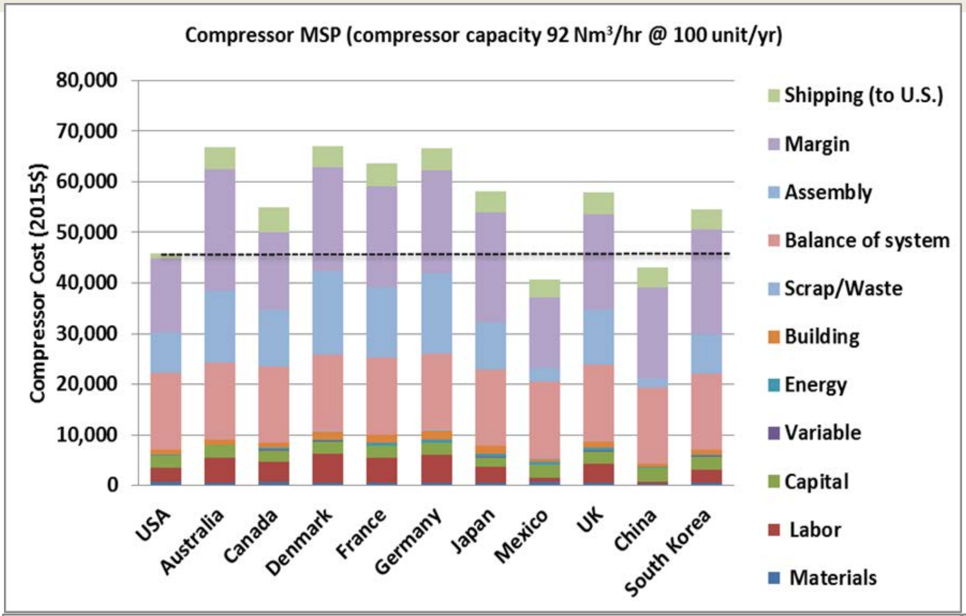


	Capital (Base=$2.0M)	Labor (Base=$23.63/hr)	Material (Base=$0.73/kg)	Yield (Base=96%)	Building (Base=$880/m2)
+20%	$13,047	$567	$196	-$180	$1,438
-20%	-$13,047	-$567	-$196	$1,205	-$1,438

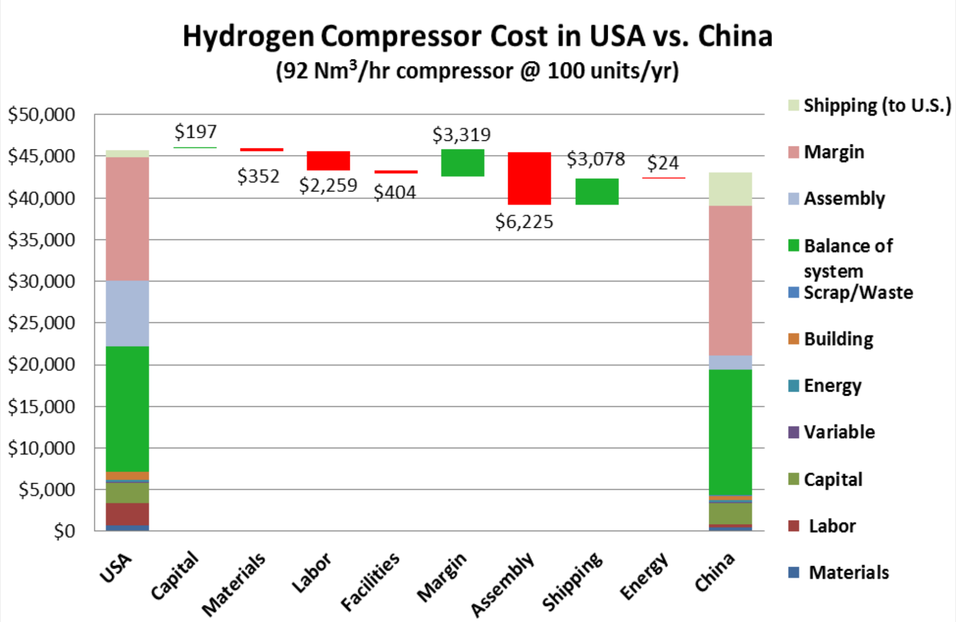


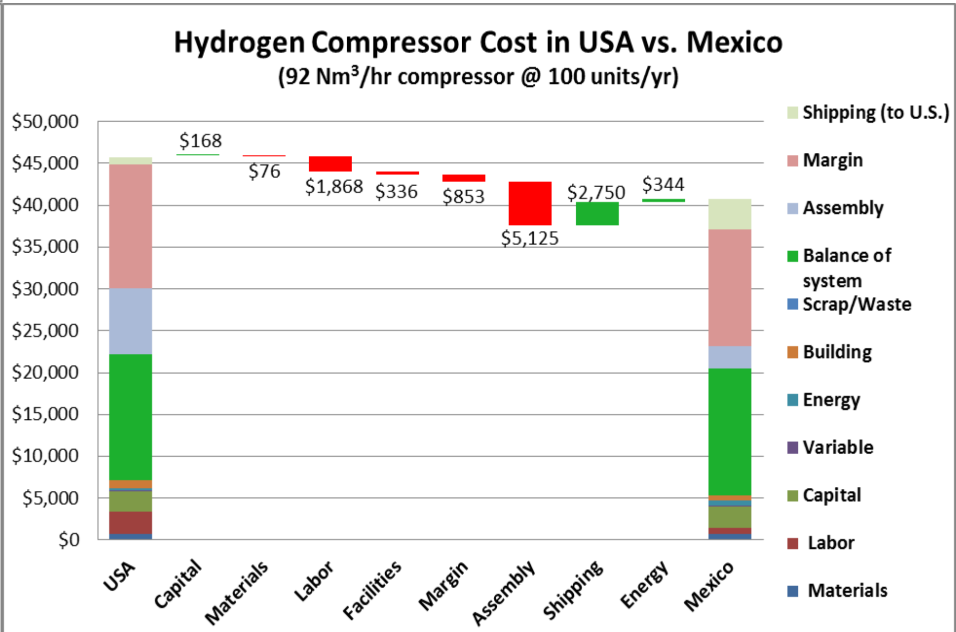
	Capital (Base=$2.0M)	Labor (Base=$23.63/hr)	Material (Base=$0.73/kg)	Yield (Base=96%)	Building (Base=$880/m2)
+20%	$2,368	$559	$196	-$193	$144
-20%	-$2,368	-$559	-$196	$1,201	-$144

Minimum Sustainable Price - Compressor

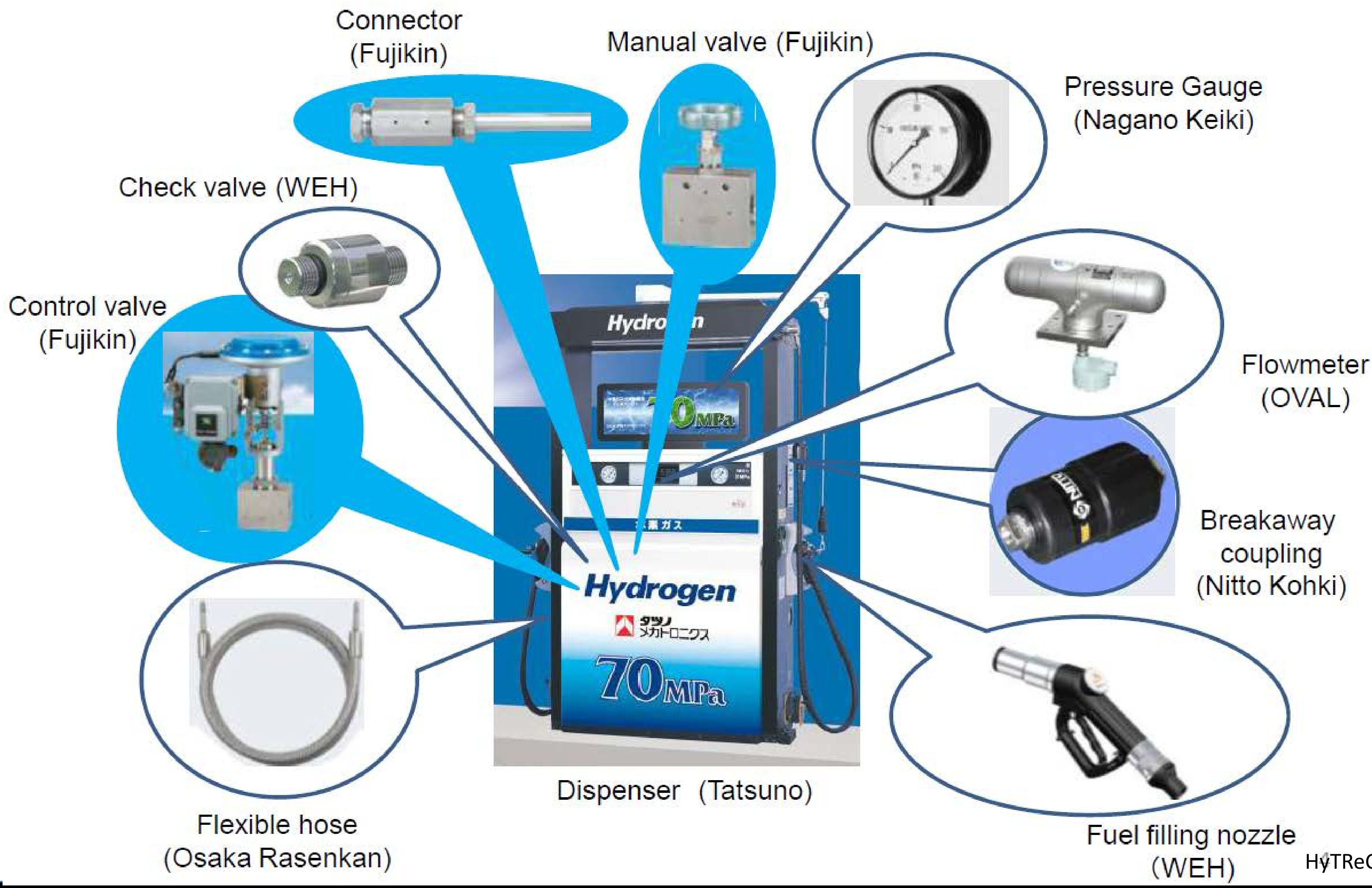


- United States advantages are lower shipping and interest rates and longer experience in this field
- China's advantage relative to the U.S. is driven by lower labor (including assembly), low material cost, building and energy costs
- Mexico's advantage relative to the U.S. is driven by lower labor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



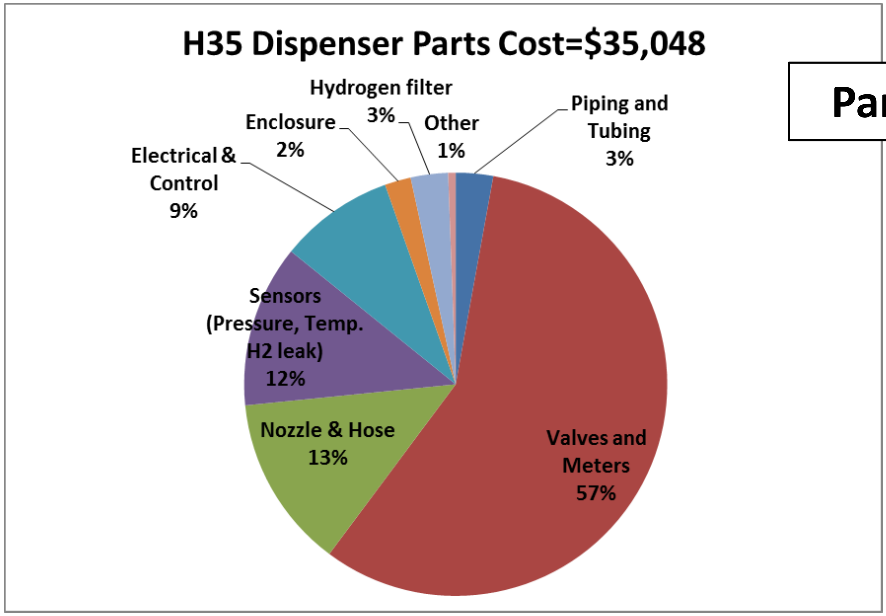


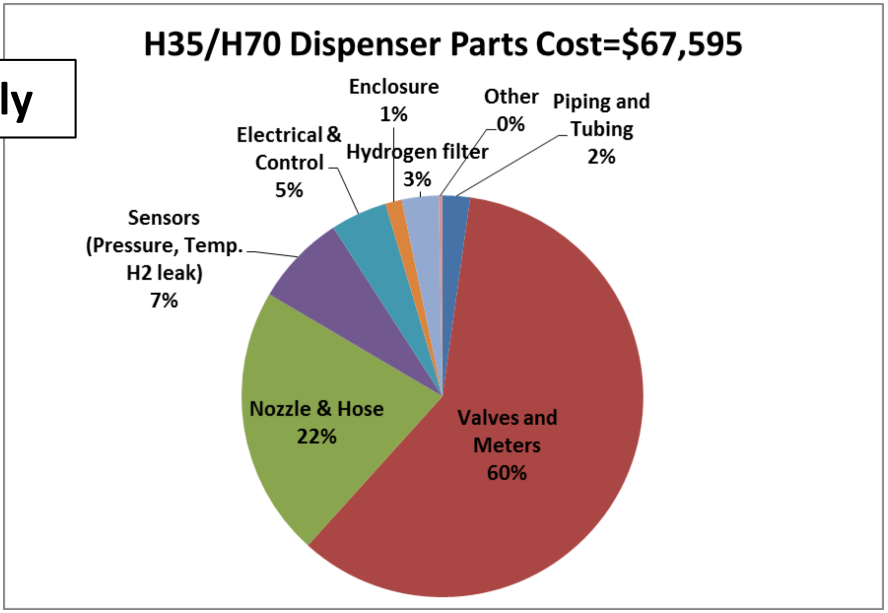
Hydrogen Dispenser



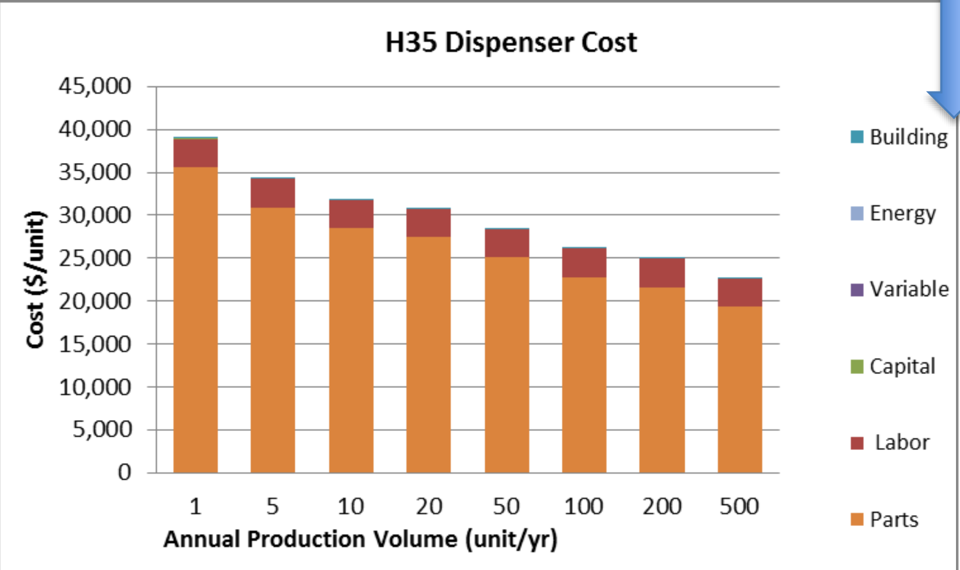
Dispenser Cost Analysis

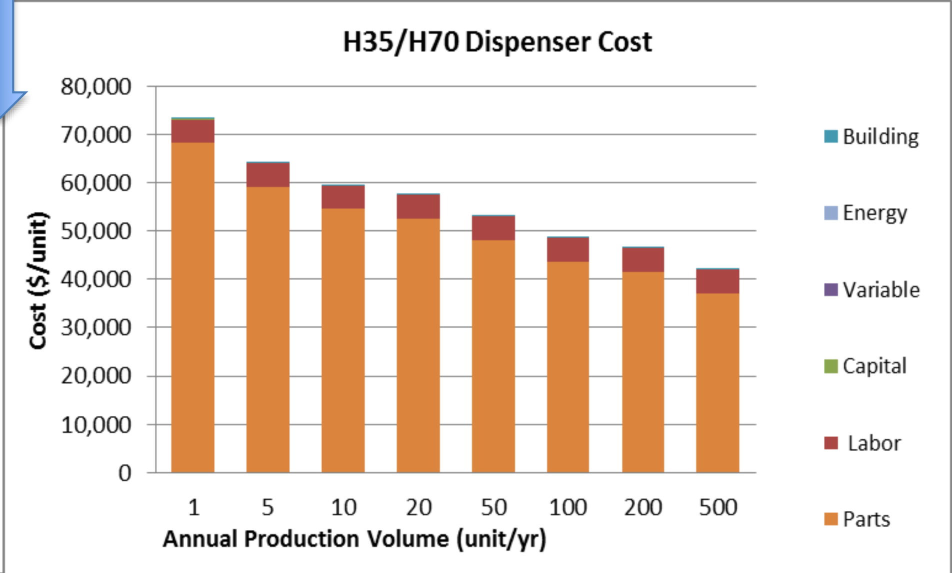
Parts Only



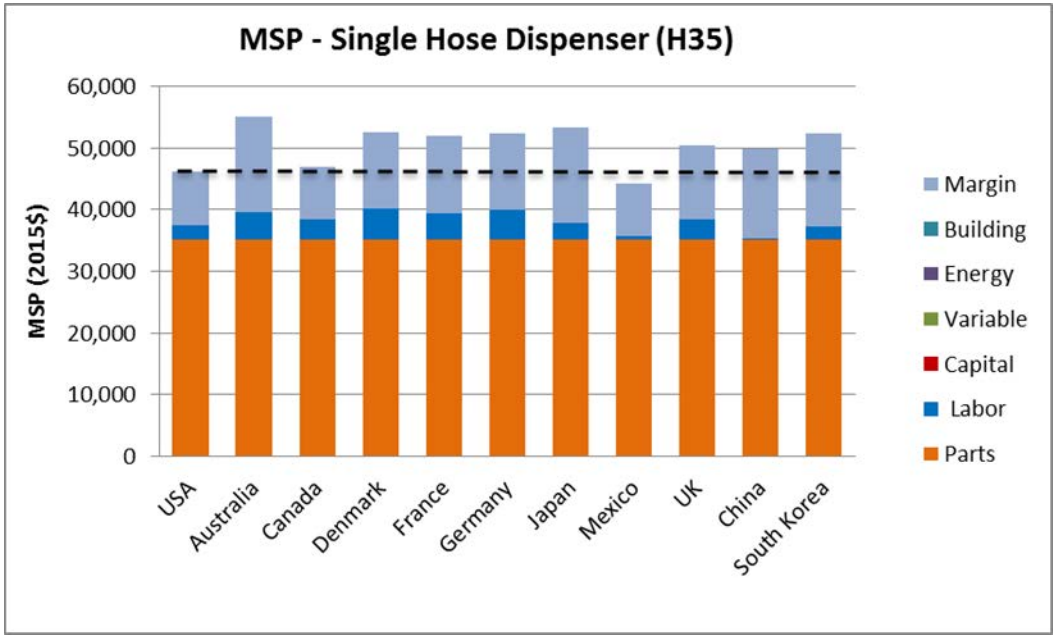


Parts & Assembly Cost (assuming 20% discount per 10X increase in purchased quantity)





Minimum Sustainable Price - Dispenser



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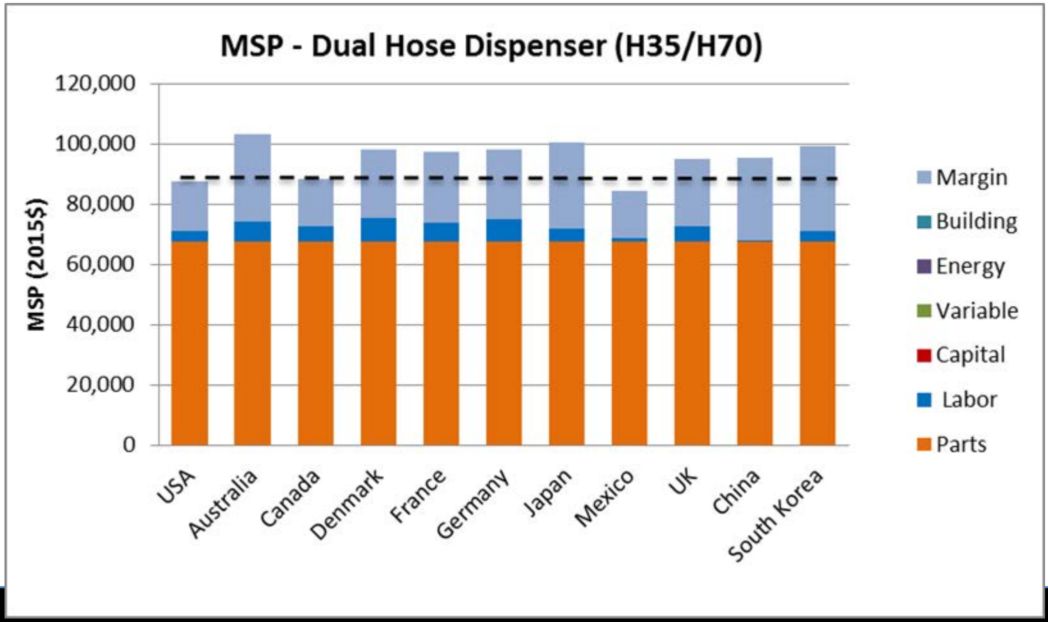


Advance Heat Exchanging Technology

DCHE: **D**iffusion Bonded **C**ompact **H**eat **E**xchanger

Images for: NREL HRS and Kobelco DCHE

Microchannel Heat Exchanger - Process Flow

Plate cleaning → Chemical etching → Quality check (profilometer)

Mask (Ferric Chloride)

→ Cold & Hot plate stacking → Vacuum diffusion bonding → Welding nozzles to the stack → Adding housing → Pressure testing

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

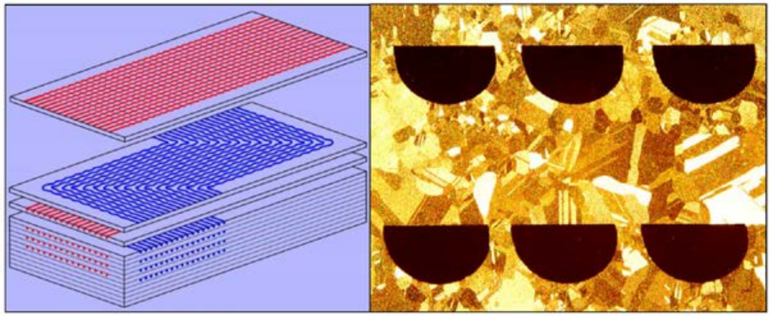
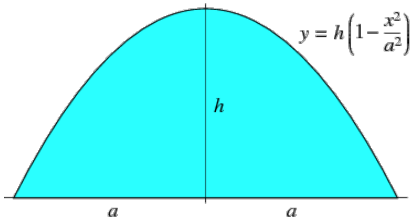
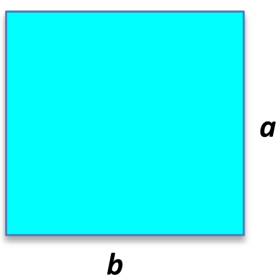


Image Source: Heatric.com

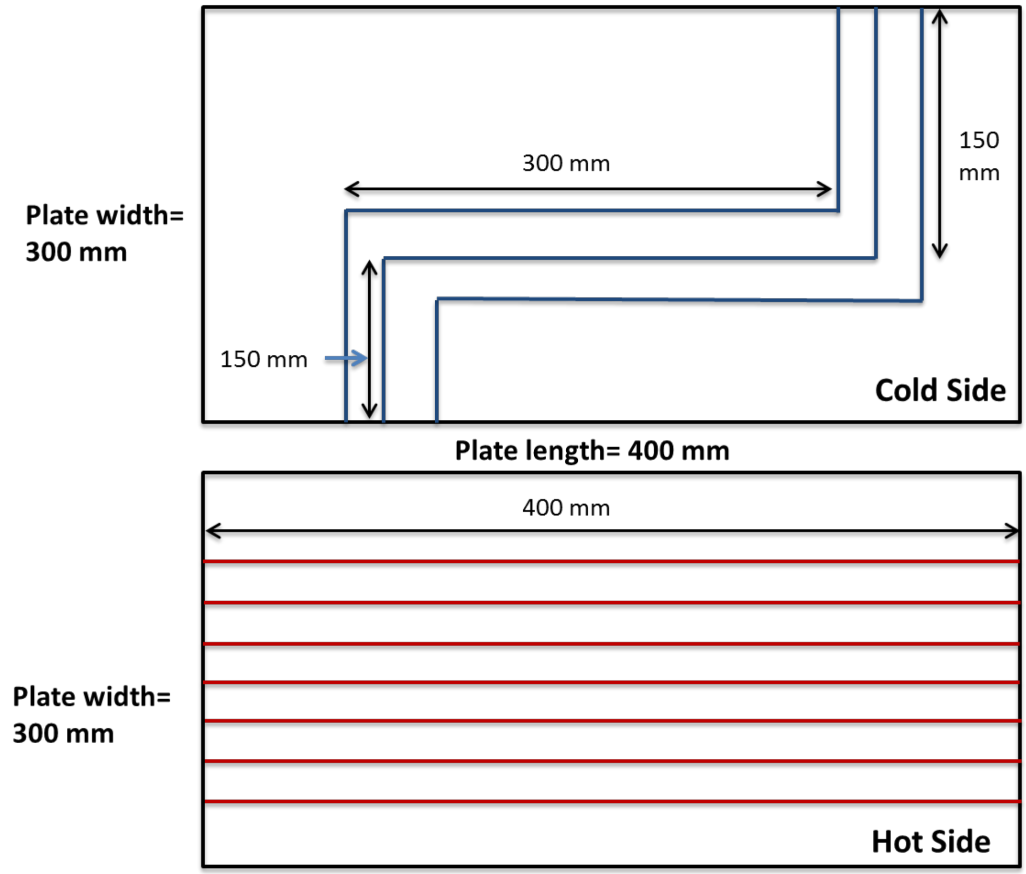
Plate Design Parameters



Parabolic Channels



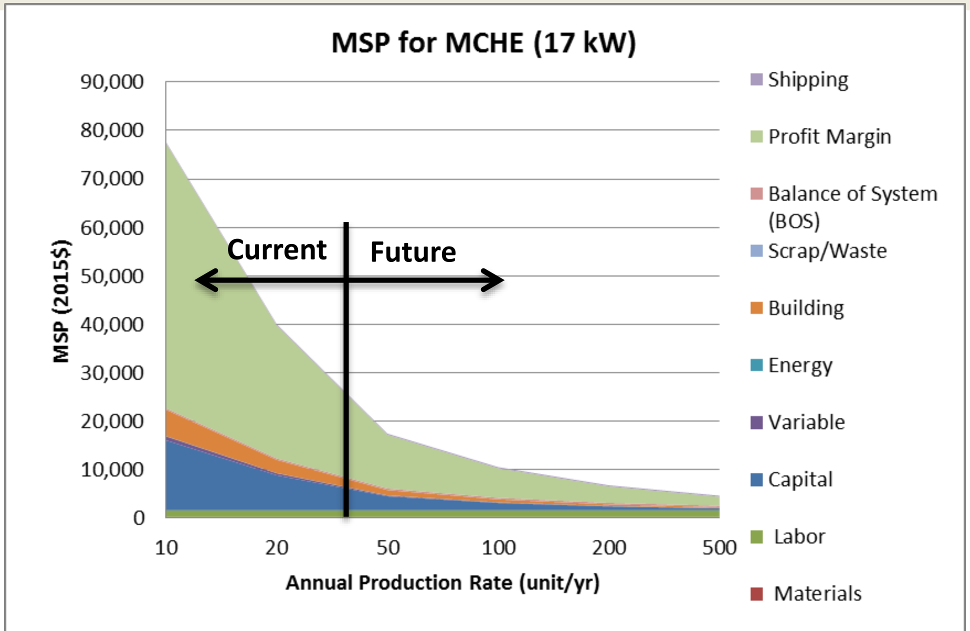
Square Channels



Chosen Design

Individual Plate Size= 400*300 mm^2=375,000 mm^2 Distance between Individual Channels= 750 µm								
Parabolic Channel Design Channel Parameters					Square Channel Design Channel Parameters			
a (mm)	h (mm)	Arc Length (mm)	Plate Thickness (mm)	Transfer Area of Individual Channel (mm2)	a (mm)	b (mm)	Plate Thickness (mm)	Square Channel-Transfer Area of Individual Channel (mm2)
0.125	0.20	0.897	0.500	458.97	0.25	0.25	0.500	400.00

Minimum Sustainable Price - MCHE



MCHE: Microchannel Heat Exchanger

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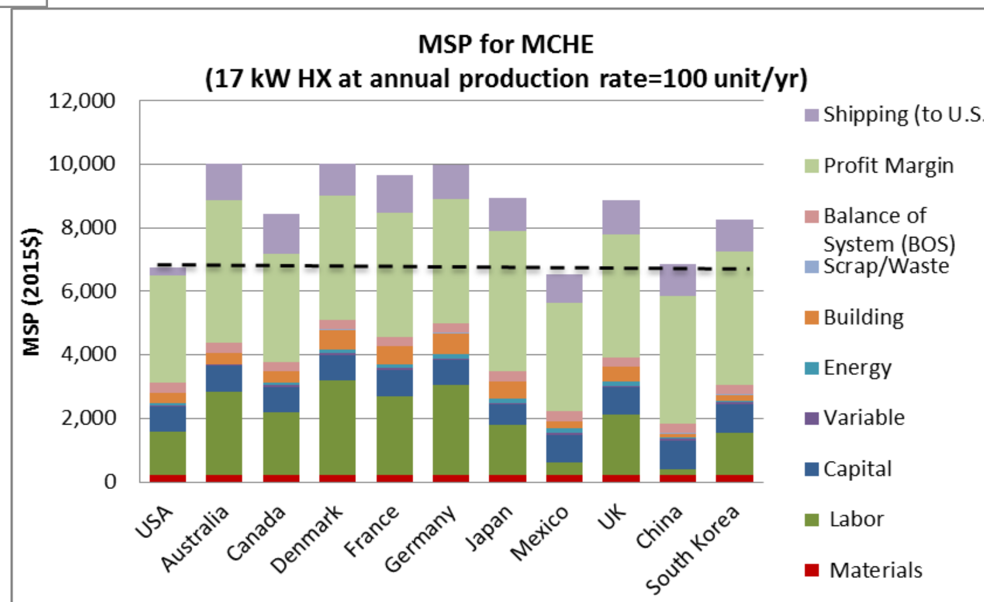


V Concluding Remarks

HRS Capital Cost and Hydrogen Price

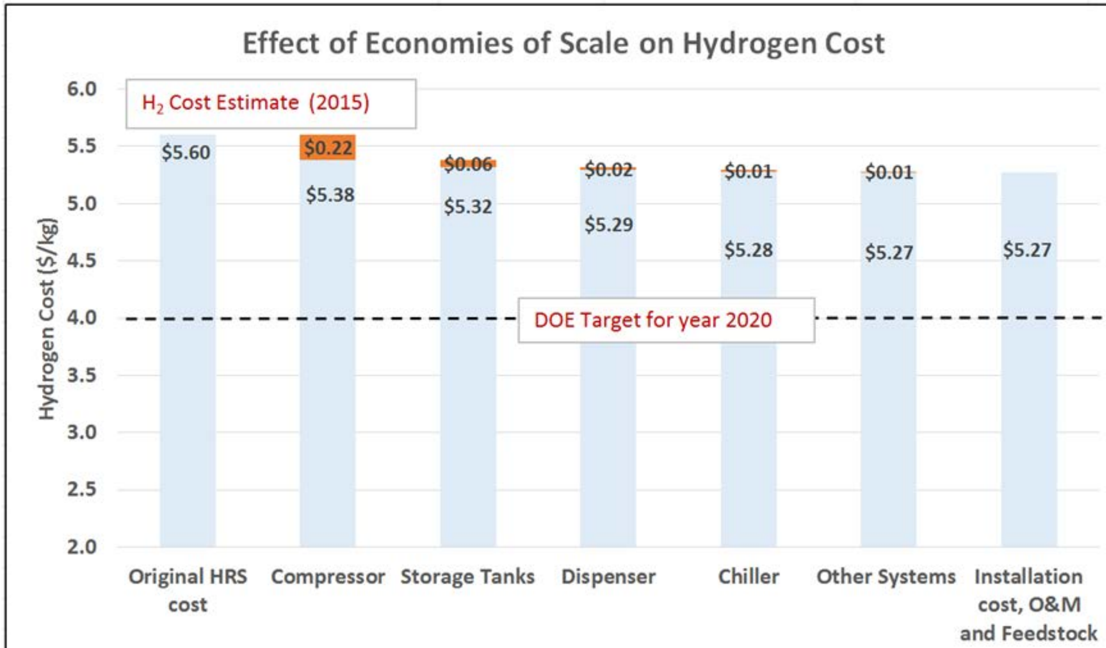
	Actual Cost (X$1,000) Capital Cost FirstElement HRS	Future Cost (X$1,000) @ 10 units/yr	Future Cost (X$1,000) @ 100 units/yr
Installation cost, O&M and Feedstock	n/a	n/a	n/a
Compressor	270	145	46
Ground Storage Tanks	370	320	176
Dispenser	270	87	82
Chiller	150	120	96
Other Systems	547	450	400
Installation Cost	408	408	408
HRS Installed Cost	**2,015**	**1,530**	**1,208**

1 kg H_2 ≈ 1 gallon of gasoline equivalent (gge)

	2016 Hyundai Tucson Fuel Cell	2016 Toyota Mirai
		
	Fuel Economy and Related Estimates	
Fuel Economy (mi/kg)	50 comb; 49 city; 51 hwy	66 comb; 66 city; 66 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



Conclusions

- Lack of standardization may result in higher manufacturing cost
- U.S.-based manufacturers have advantages of longer experience in the field and low energy cost
- Future technologies and economies of scale will have great impact on the HRS cost and H_2 prices

Thank you

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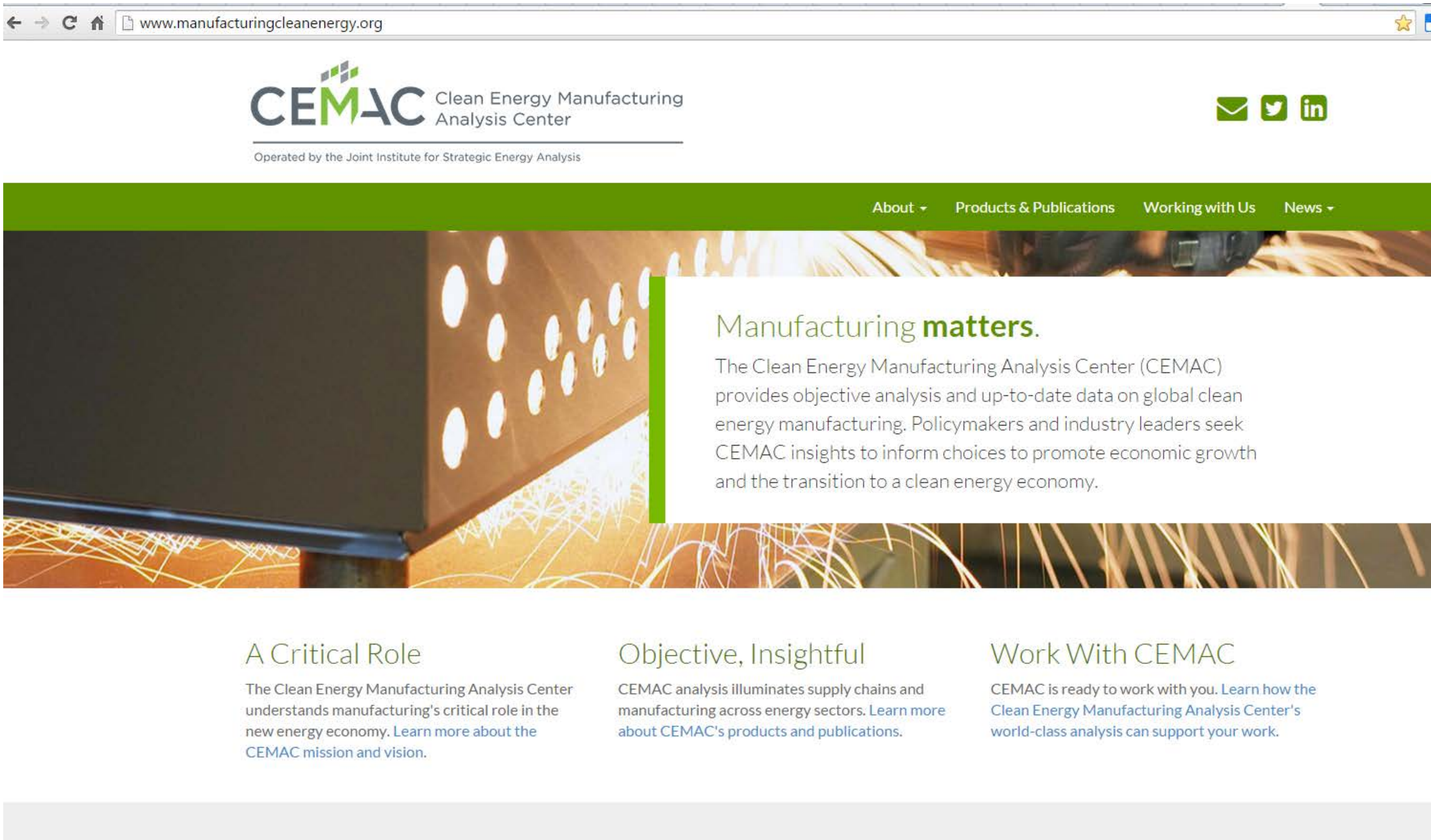
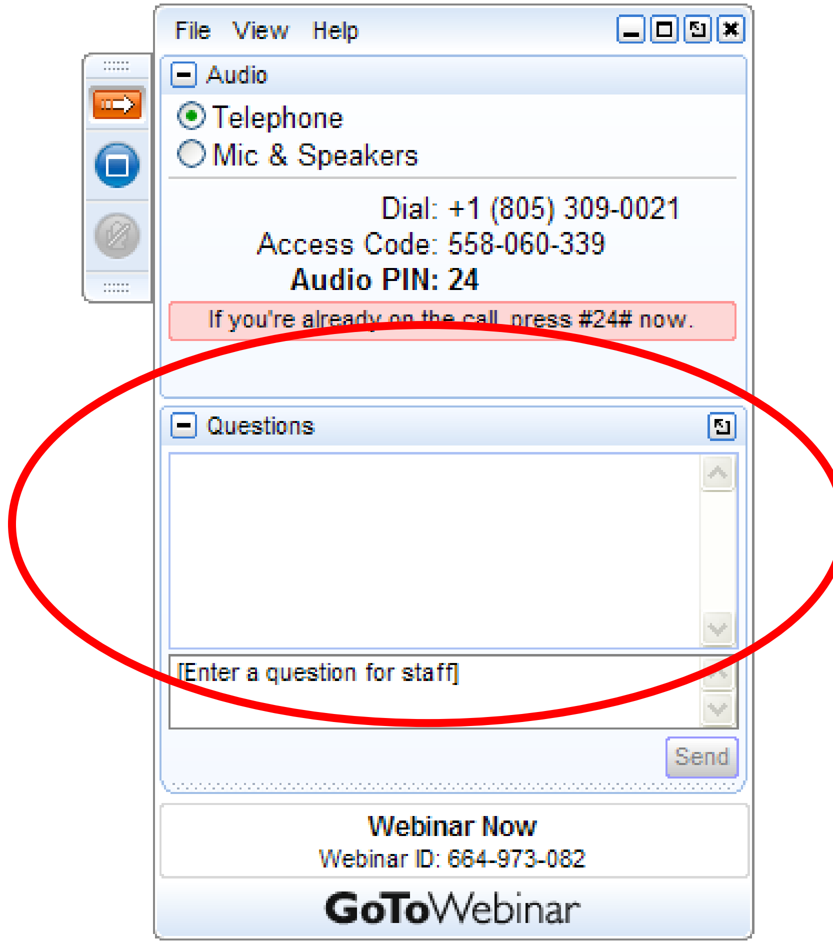


Question and Answer

- Please type your questions into the question box



Thank you

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hydrogenandfuelcells.energy.gov

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Backup Slides

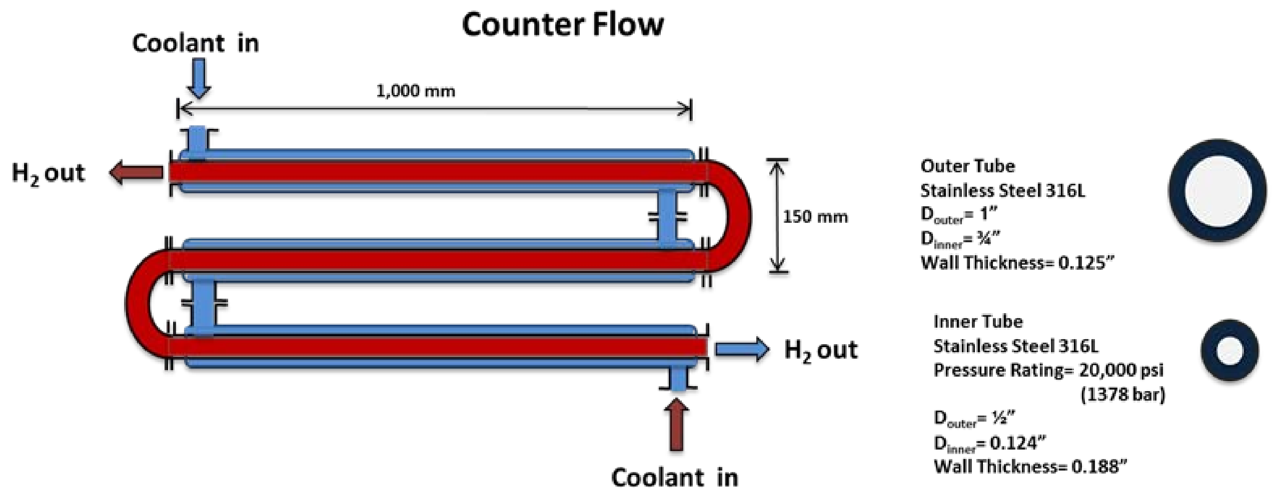
Dispenser Cost Analysis

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	Fueses (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**

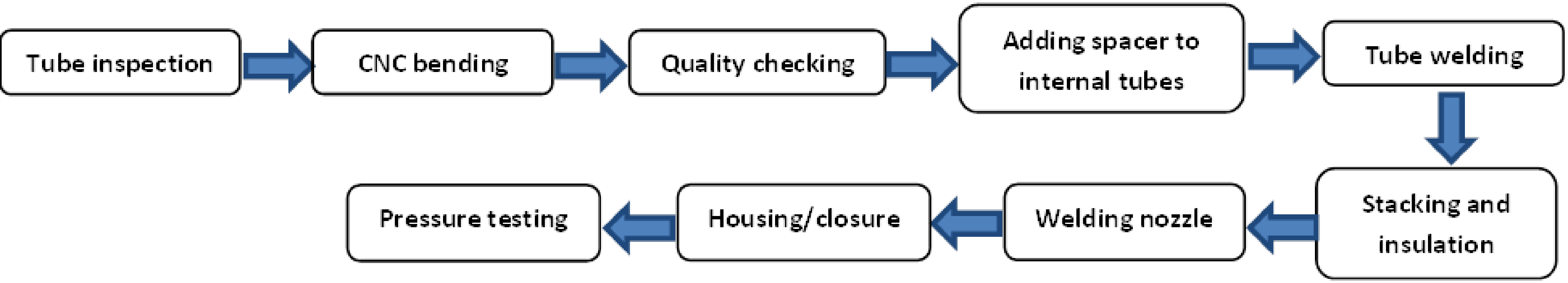
Dual Hose Dispenser H35/H70				
Part No.	Part	Supplier 1	Required Units	Cost per Dispenser ($)
1	SOLENOID VALVE	Omega	2	1430
2	Flow Meter	Alicate	2	20000
3	Pressure checking/Regulating Valves	Tescom	2	9542
4	Pressure Relief Valve	High Pressure Equipment	2	1316
5	Breakaway valve	Oasis	2	7906
6	Hydrogen 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	Fueses (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			**67,595**

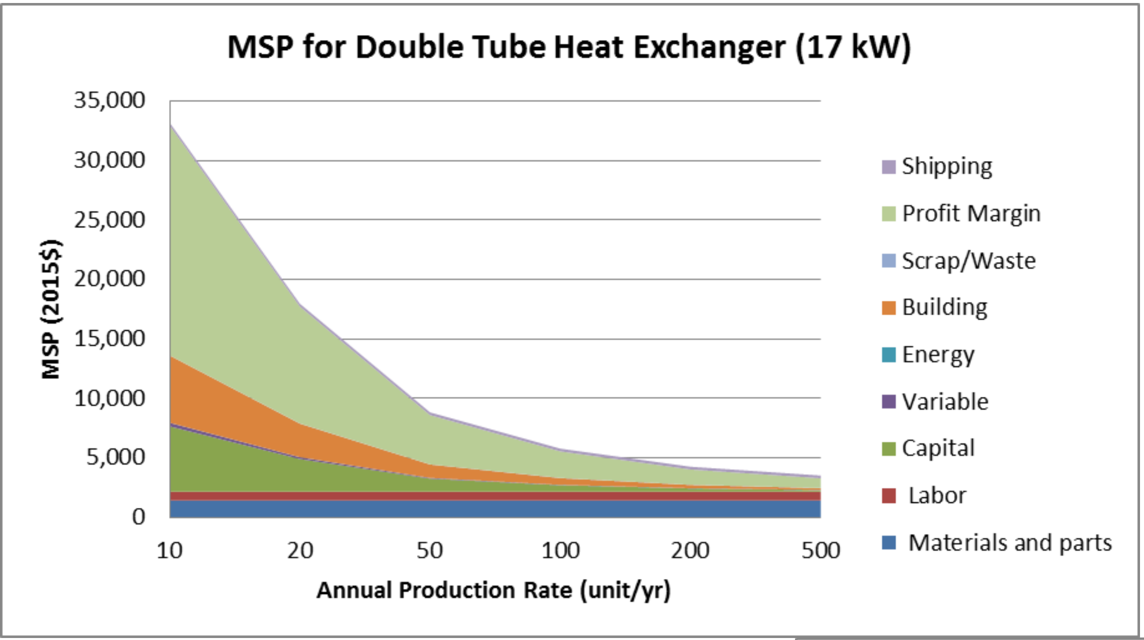
Double Tube Heat Exchanger

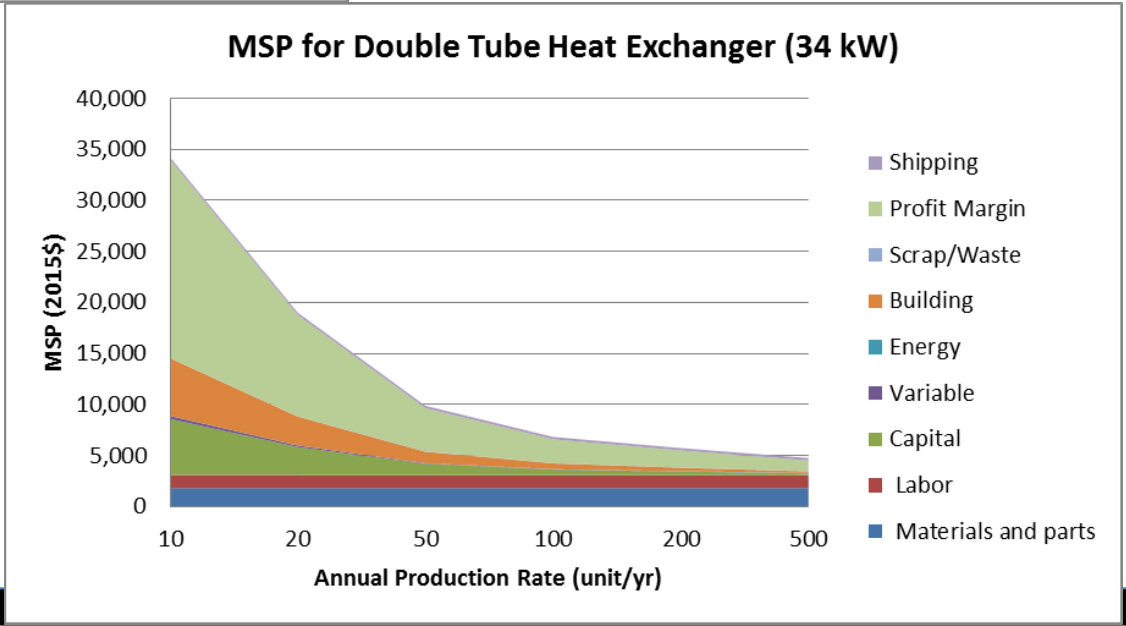
HX Design



Process Flow




MSP for Double Tube Heat Exchanger (17 kW)
MSP (2015$)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
10
20
50
100
200
500
Annual Production Rate (unit/yr)
Shipping
Profit Margin
Scrap/Waste
Building
Energy
Variable
Capital
Labor
Materials and parts


MSP for Double Tube Heat Exchanger (34 kW)
MSP (2015$)
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
10
20
50
100
200
500
Annual Production Rate (unit/yr)
Shipping
Profit Margin
Scrap/Waste
Building
Energy
Variable
Capital
Labor
Materials and parts