



Economics of Hydrogen Refueling Stations

CaFCP Bus Team Meeting
August 30, 2016



Delivering Excellence Through Innovation & Technology

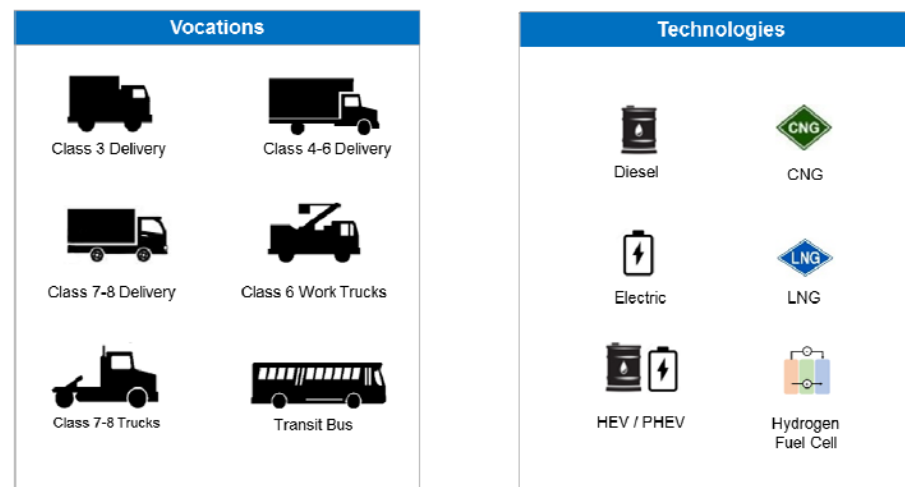
www.ricardo.com

Ricardo will provide versions of its Truck TCO and Hydrogen Refueling Station models for use by CaFCP staff and members



Background

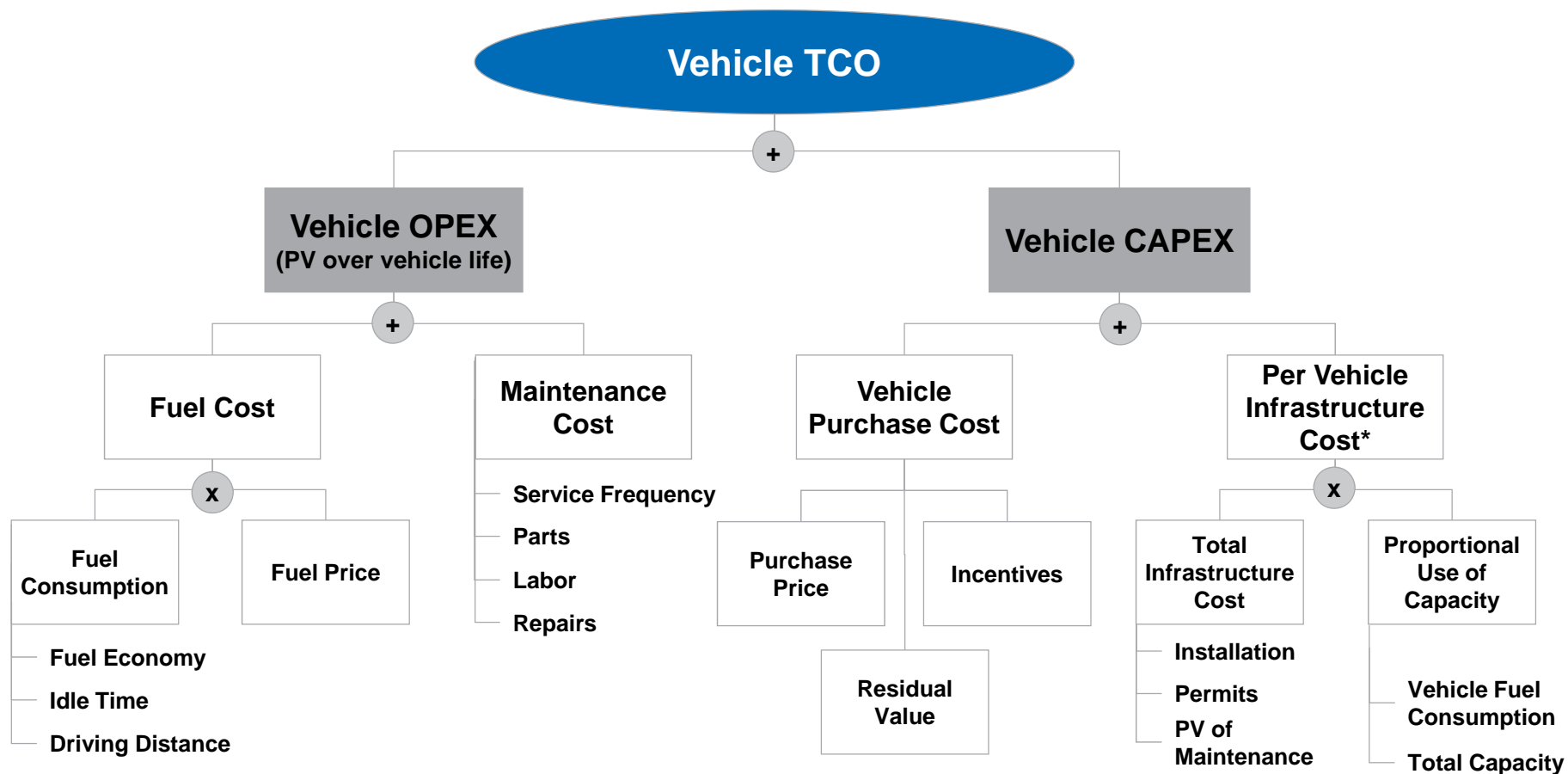
- Ricardo created a Total Cost of Ownership model for evaluating economics of different alternative powertrain technologies in various commercial vocations
- The model leverages Ricardo's technology roadmaps to provide insights on economics of alternative powertrains today and in future



Models for CaFCP

- A **Truck TCO Model** will be provided with two example vocations:
 - Class 8 Short Haul Daycab
 - Class 6 Parcel Delivery
- A **Hydrogen Refueling Station Model** will be provided which covers few scenarios of hydrogen procurement and station capacities and builds up the resulting price
- Both models are in MS Excel format with comments and layout to ease use and can be adapted by users to their own applications

TCO model is a detailed build up of capital expenditures and operating costs over an agreed ownership period



* Infrastructure costs assumed to be \$0 for diesel

The TCO model leverages Ricardo's technology roadmaps to evaluate economics of alternative fuel vehicles in future



Cost roadmap of alternative powertrain components



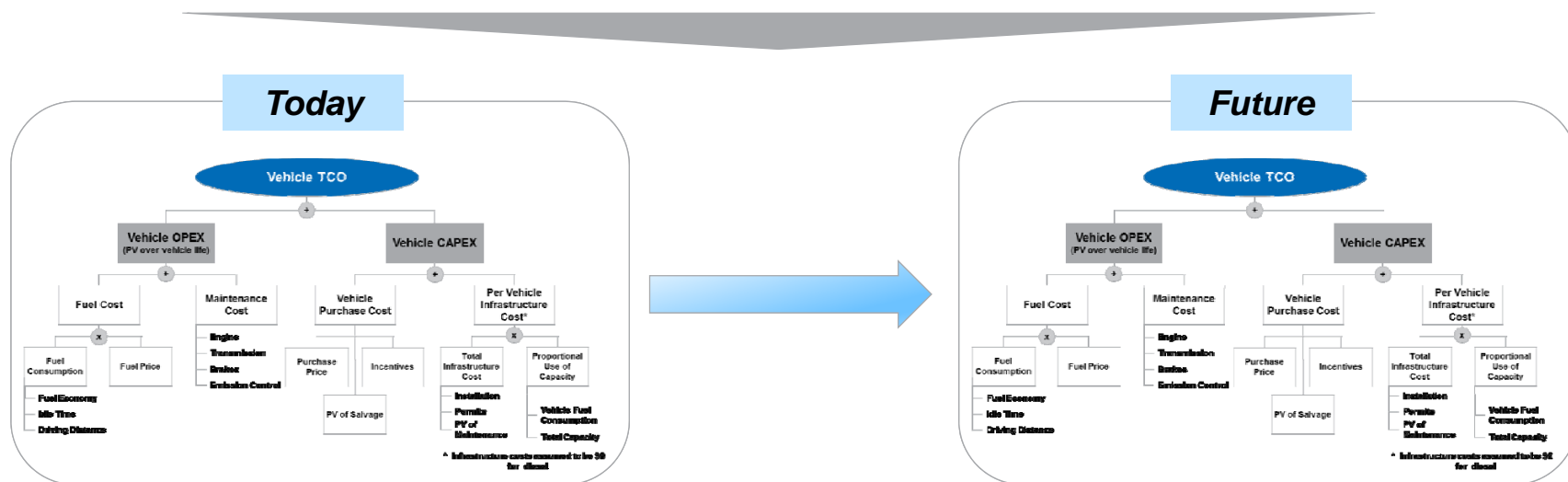
Fuel economy improvement driven by mandates and technology improvements



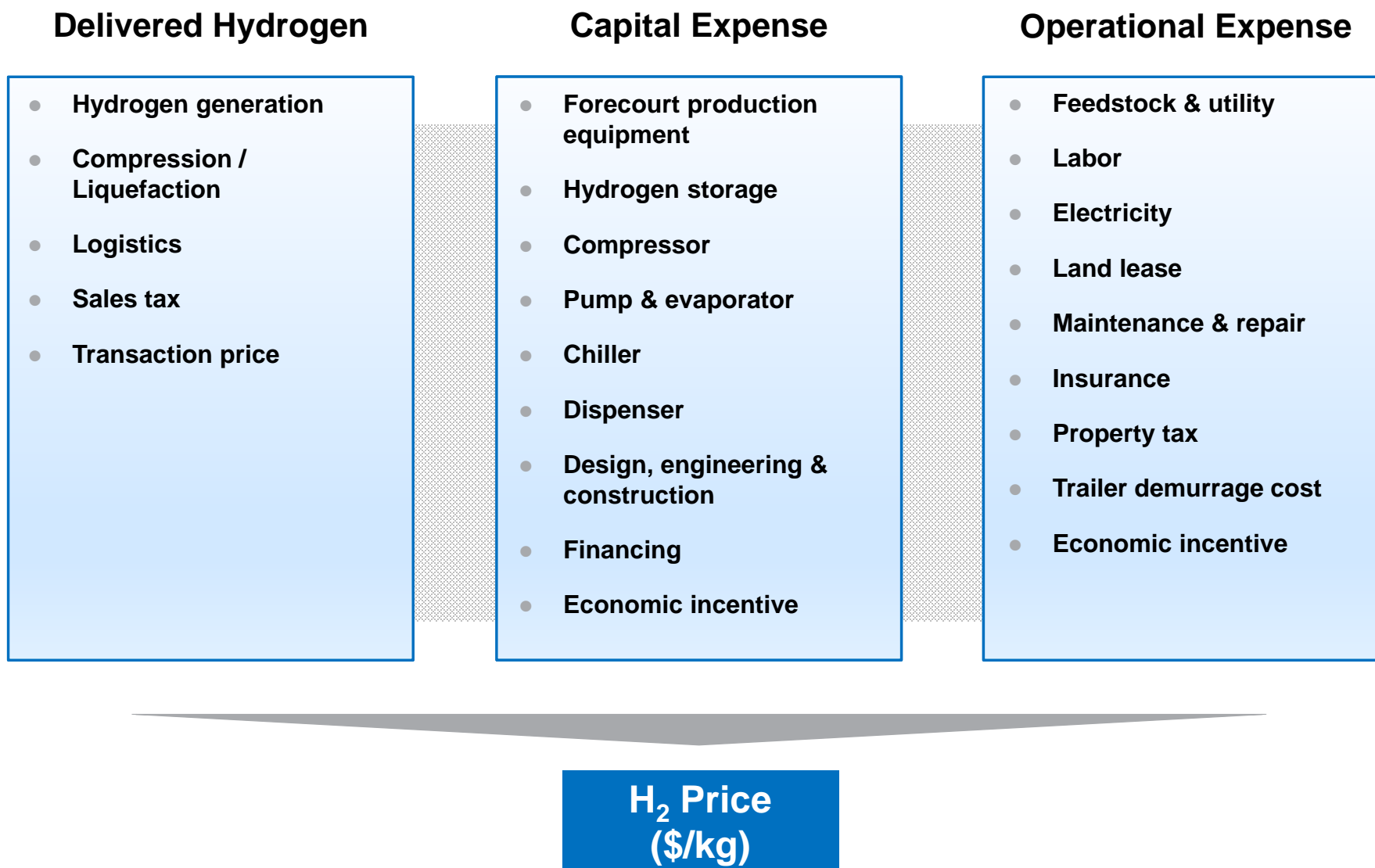
Maintenance cost decline with technology maturity



Fuel price forecasts



Economic model of H₂ station is based on detailed CAPEX, OPEX and procurement cost from gas suppliers



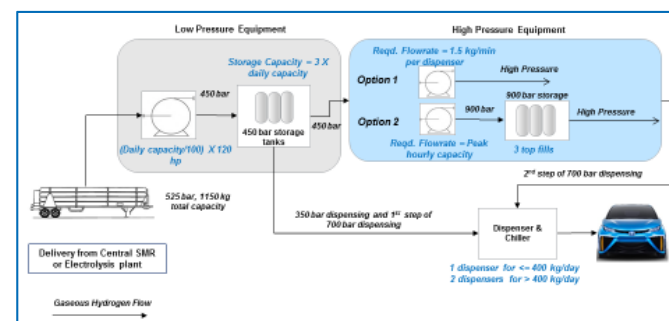
The model is configured for different station capacities and hydrogen generation and dispensing pathways



Parameters that can be manipulated to create different H₂ refueling scenarios

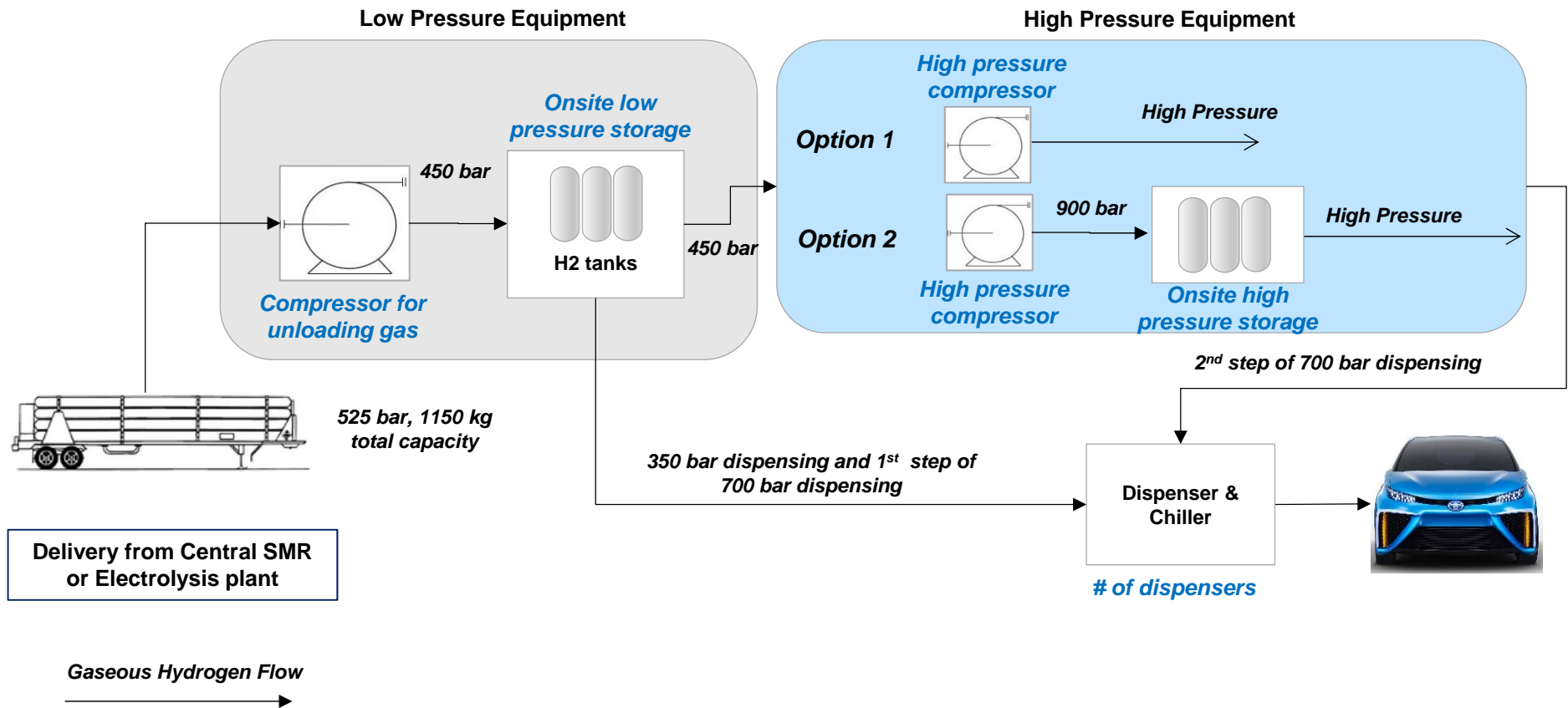
- Station capacity (kg/day)
- Capacity utilization
- H₂ generation location (Central / Forecourt)
- H₂ generation method (SMR / Electrolysis)
- H₂ delivery method (Gaseous / Liquid)
- Onsite storage method
- Dispensing pressure (35 MPa / 35 & 70 MPa)
- Subsidies (Capital, Operational)

Resulting costs incurred at the refueling station



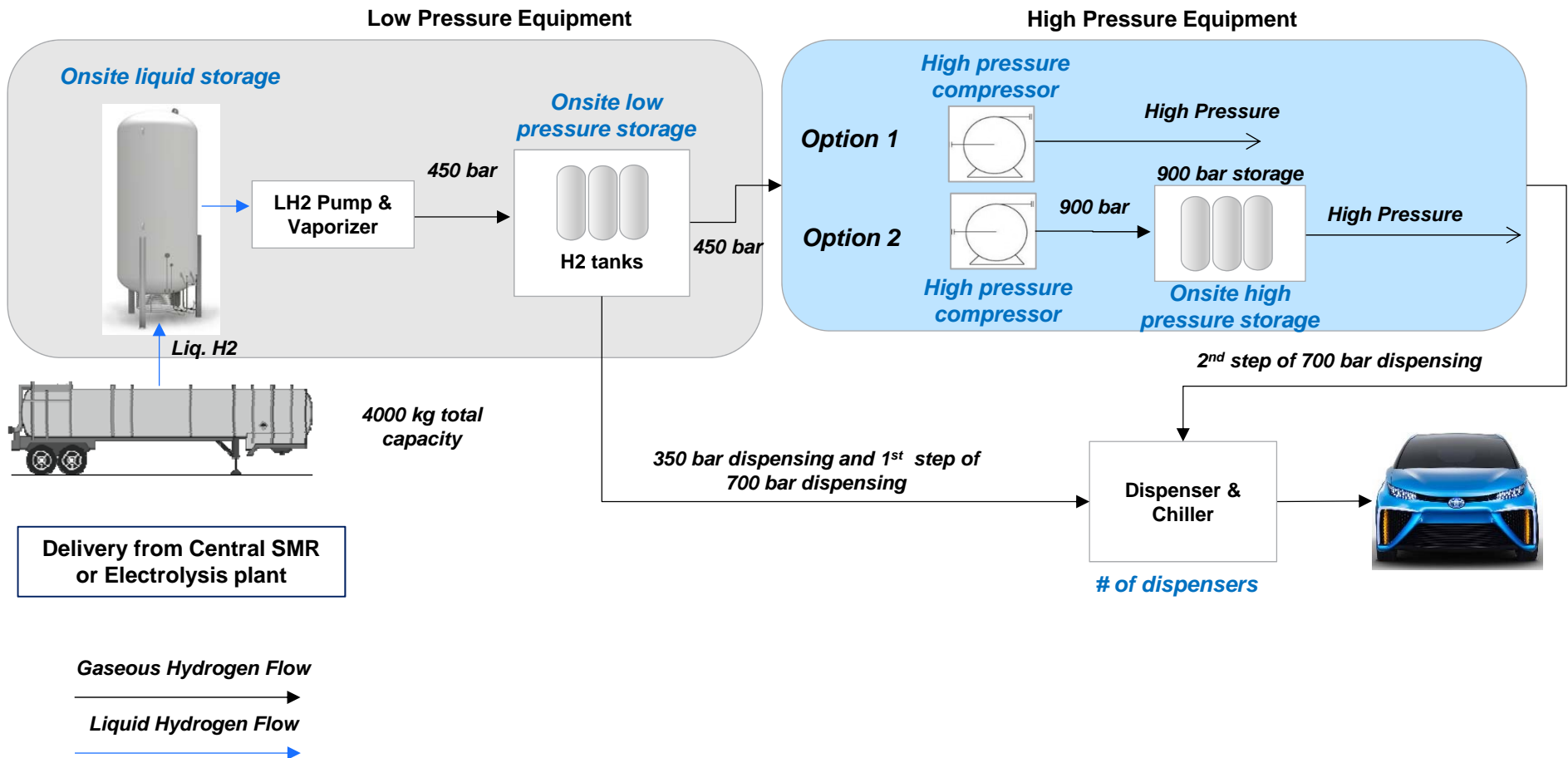
- Hydrogen Price
- Capital Expenditure
- Operational Expense
- Equipment footprint

Gaseous Hydrogen Delivery



Data for the model was obtained from suppliers, station owners, proposals to CEC grant solicitations, and other public domain sources

Liquid Hydrogen Delivery



Data for the model was obtained from suppliers, station owners, proposals to CEC grant solicitations, and other public domain sources

The version of the model created for fuel cell partnership provides a high level analysis of the refueling stations



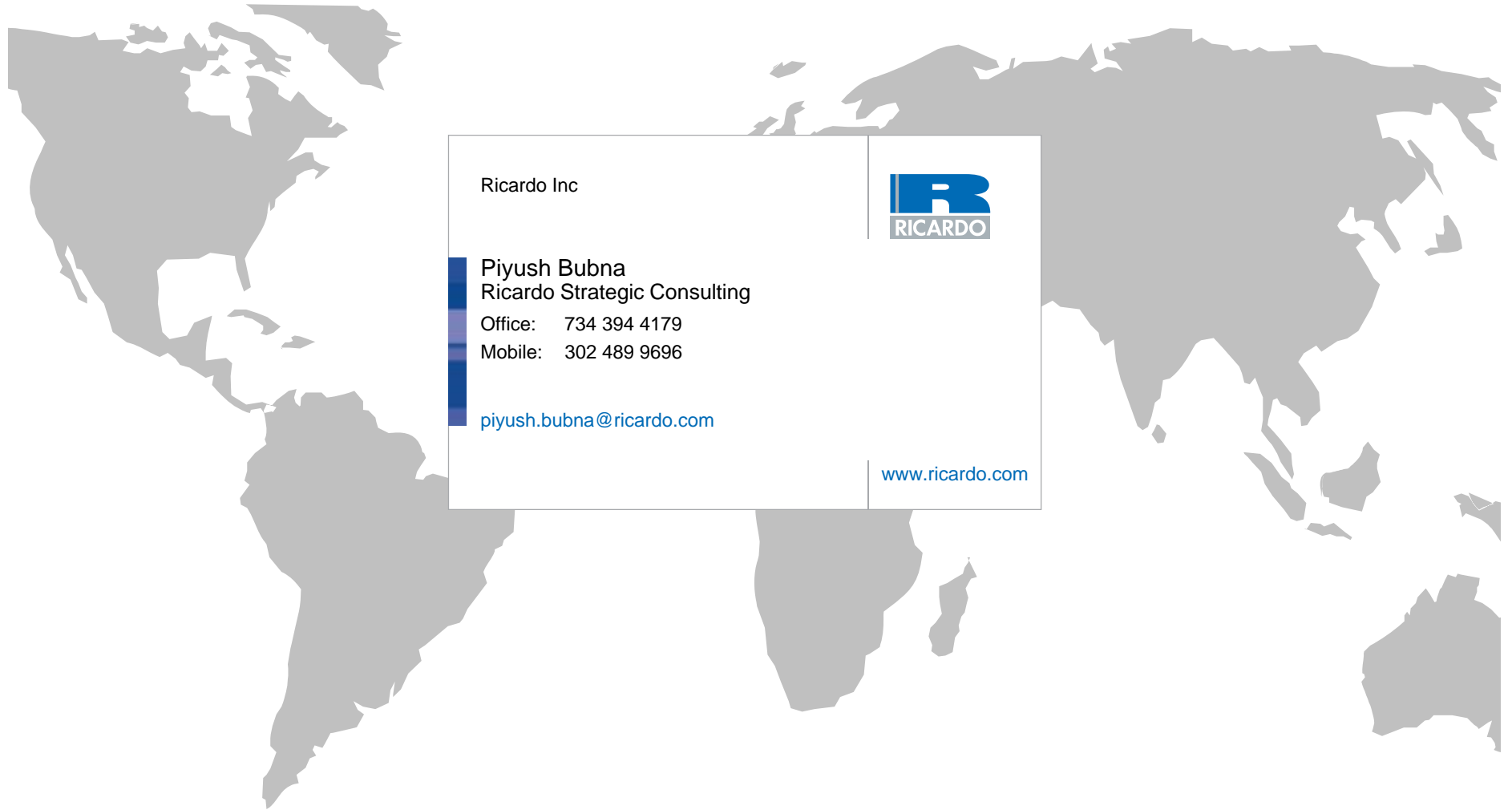
Legend	
	User Input
	Output
	Ricardo Data
	Calculations

This version is still based on a public station model like the ones being built for fuel cell cars but with few changes:

- Hydrogen generated centrally and delivered
- Low pressure (35 Mpa) dispensing
- High stations capacities and utilization

Hydrogen Price Calculator				
Station Online Calendar Year	2015			2030
Hydrogen Procurement Method	Gaseous Delivered	Liquid Delivered	Liquid Delivered	Liquid Delivered
Station Capacity (kg/day)	200	400	800	800
Station Utilization	80%	80%	80%	80%
Capital Cost Recovery Period (years)	10	10	10	10
Capital Cost <i>includes equipment, engineering & consutruction</i>	\$ 1,250,000	\$ 1,970,000	\$ 2,100,000	\$ 1,260,000
Fixed Operating Cost (\$/year) <i>includes land lease, labor, maintenance & repair, insurance, taxes</i>	\$ 90,000	\$ 115,000	\$ 115,000	\$ 90,000
Variable Operating Cost (\$/kg) <i>includes feedstock and utilities</i>	\$ 0.09	\$ 0.05	\$ 0.05	\$ 0.05
Subsidy in Capital Cost	\$ -	\$ -	\$ -	\$ -
Hydrogen Price Breakdown (\$/kg)				
Cost of Delivered Hydrogen (\$/kg)	\$ 5.12	\$ 4.68	\$ 4.68	\$ 2.20
Station CAPEX (\$/kg)	\$ 2.14	\$ 1.69	\$ 0.90	\$ 0.54
Station OPEX (\$/kg)	\$ 1.63	\$ 1.03	\$ 0.54	\$ 0.44
Fee charged by operator (\$/kg)	\$ 1.00	\$ 0.50	\$ 0.25	\$ 0.25
Total Hydrogen Price				
Total Price of Hydrogen (\$/kg)	\$ 9.89	\$ 7.90	\$ 6.37	\$ 3.42
Total Price of Hydrogen (\$/DGE)	\$ 11.18	\$ 8.93	\$ 7.20	\$ 3.87

Questions



Ricardo Inc



Piyush Bubna
Ricardo Strategic Consulting

Office: 734 394 4179

Mobile: 302 489 9696

piyush.bubna@ricardo.com

www.ricardo.com