# Pressure Consolidation Method for Low Cost $H_2$ Refueling

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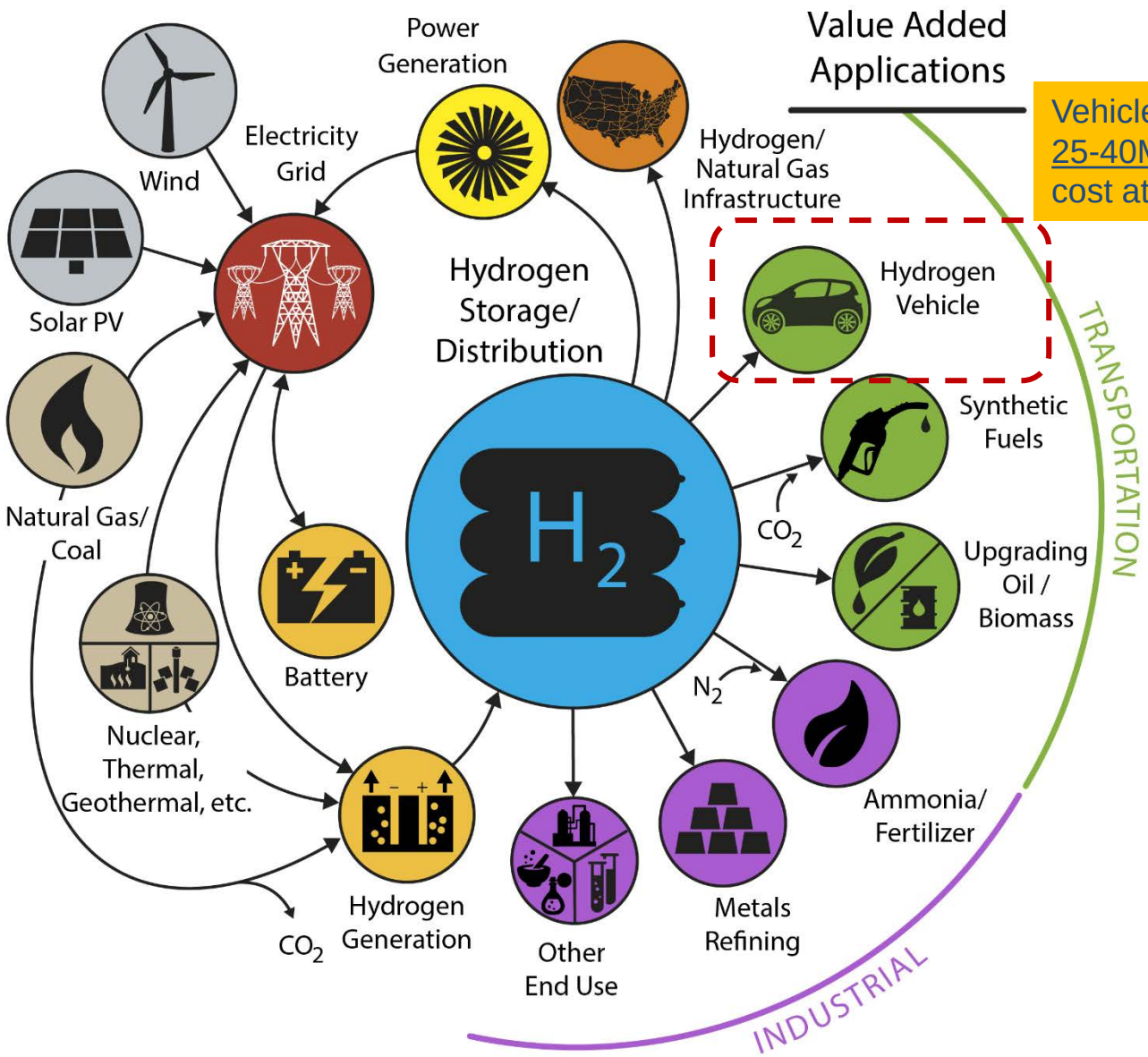
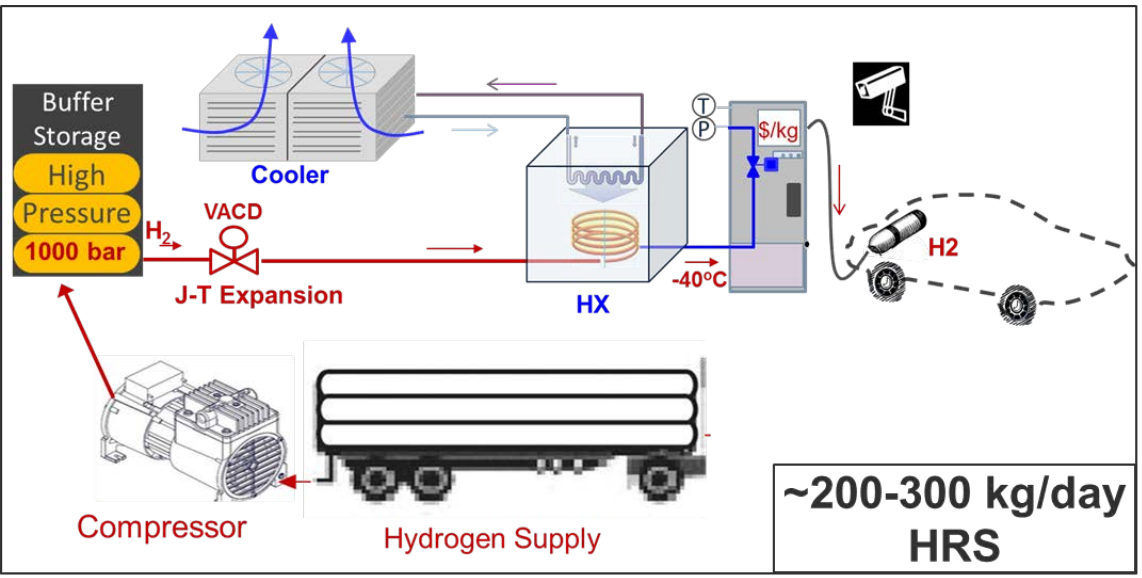
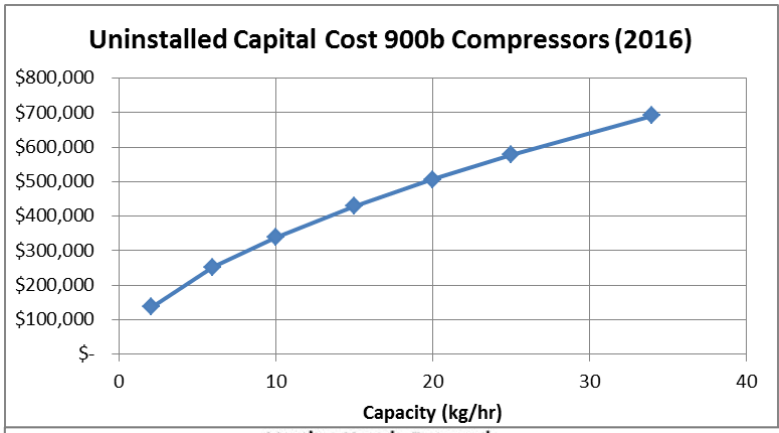
# Relevance to H2@Scale Energy System

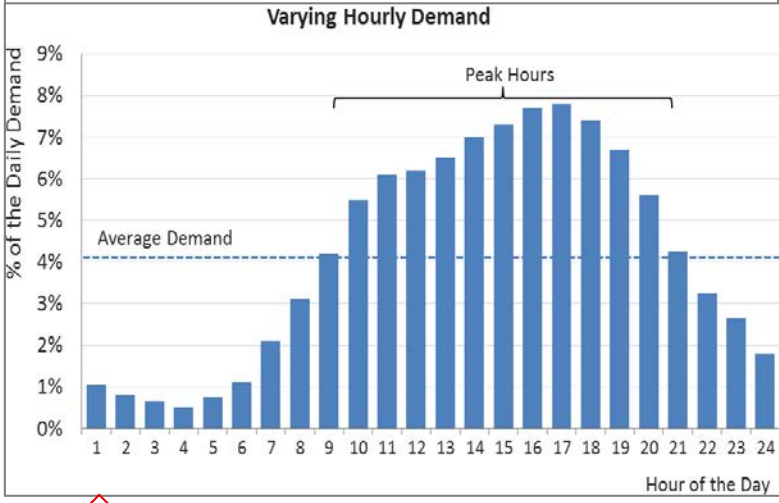


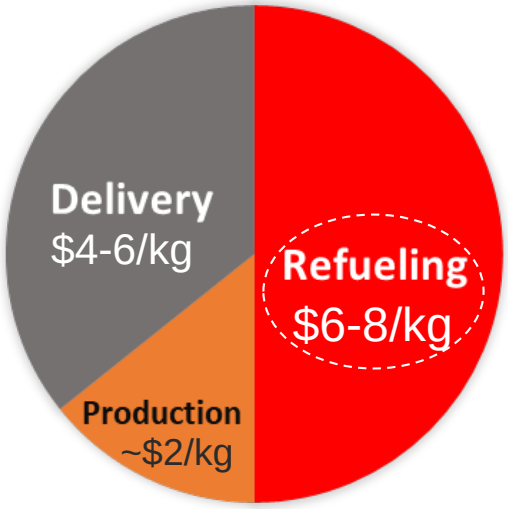

Vehicle choice models show potential of 25-40M FCEVs at **$5/kg** cost at the pump by 2050

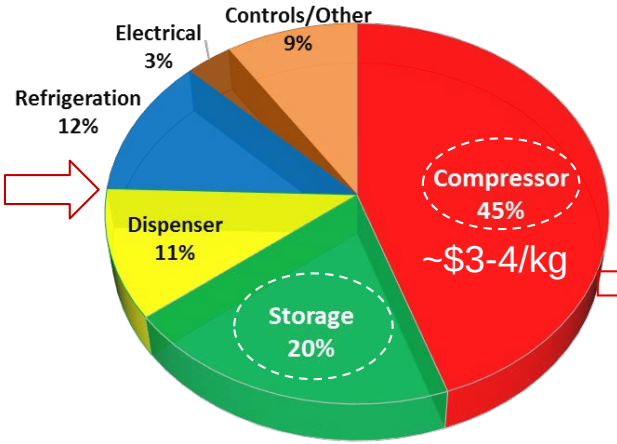
# Today, hydrogen cost at the dispenser in CA is $13-$16/kg



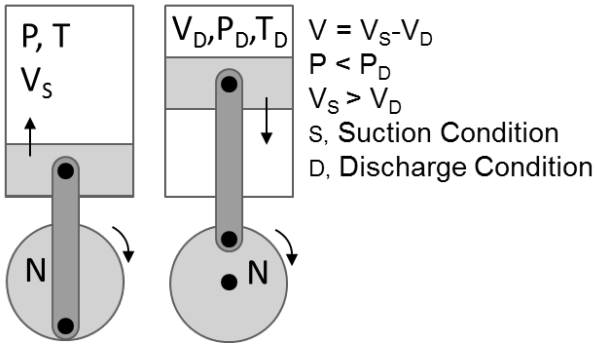



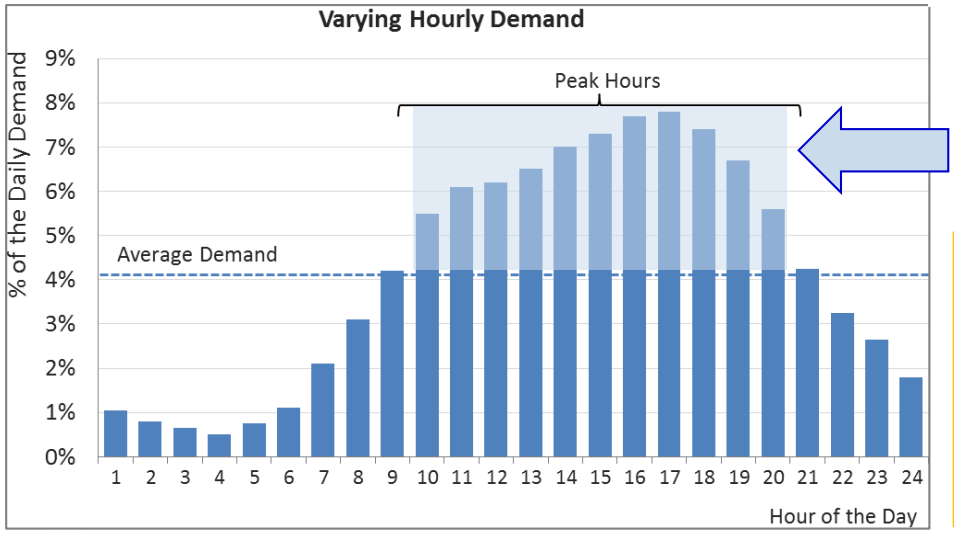
# *Compressor is the most costly refueling component but is oversized and underutilized*

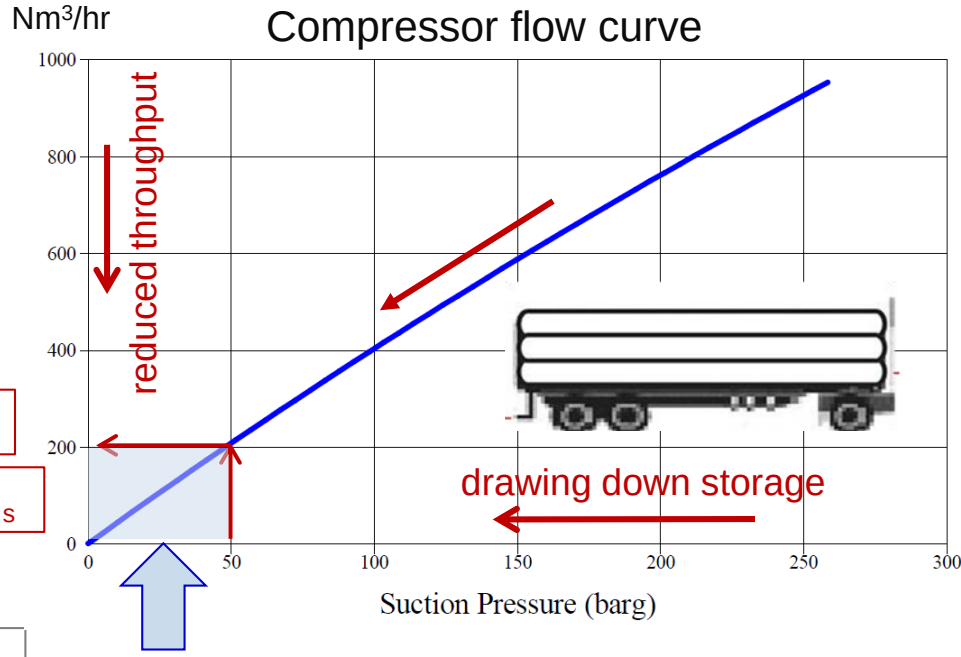



Mass flow rate = volume displacement x r.p.m. x density

Mass flow rate = volume displacement x r.p.m. x $[P/ZRT]_S$

Mass flow rate ~ suction pressure

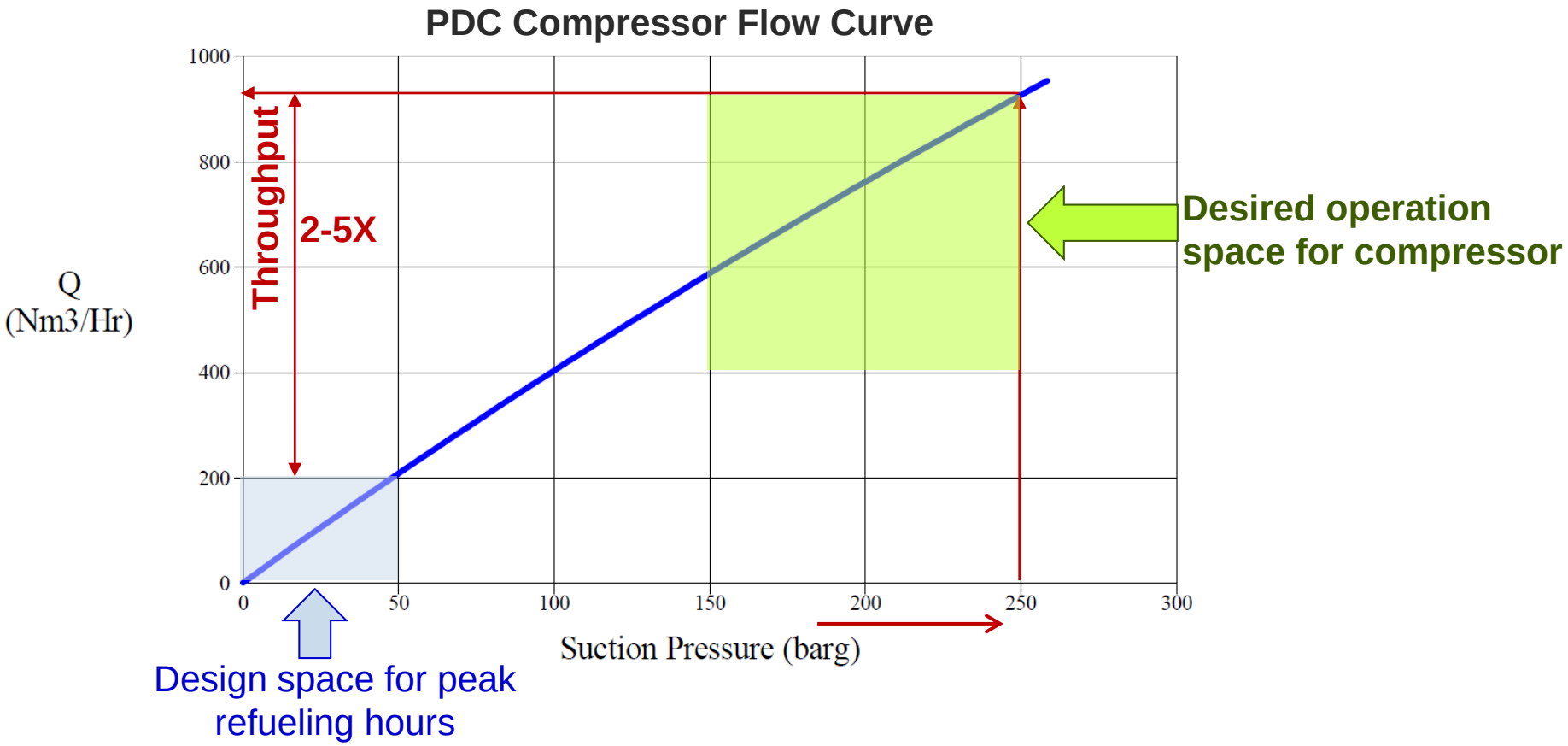


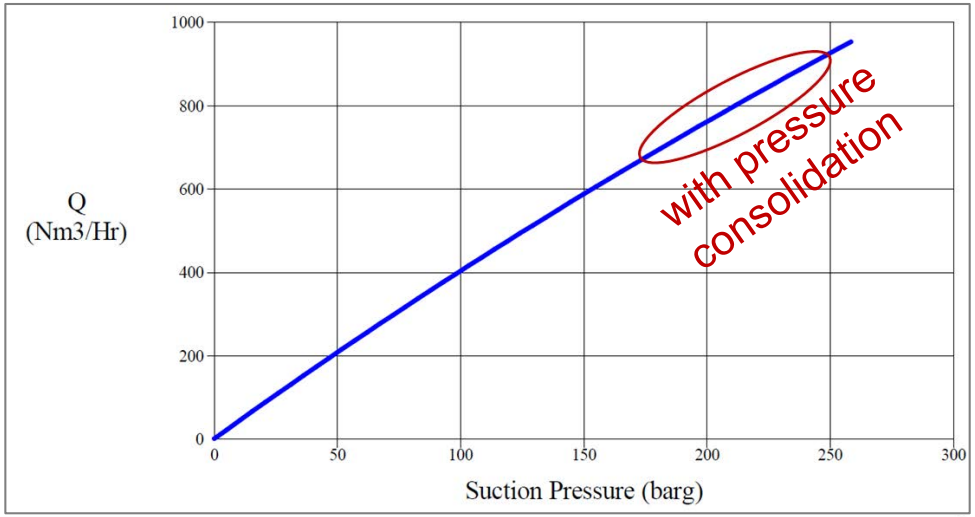

Design space for peak refueling hours

- Oversized → for better utilization of hydrogen supply storage
- But underutilized during off peak hours

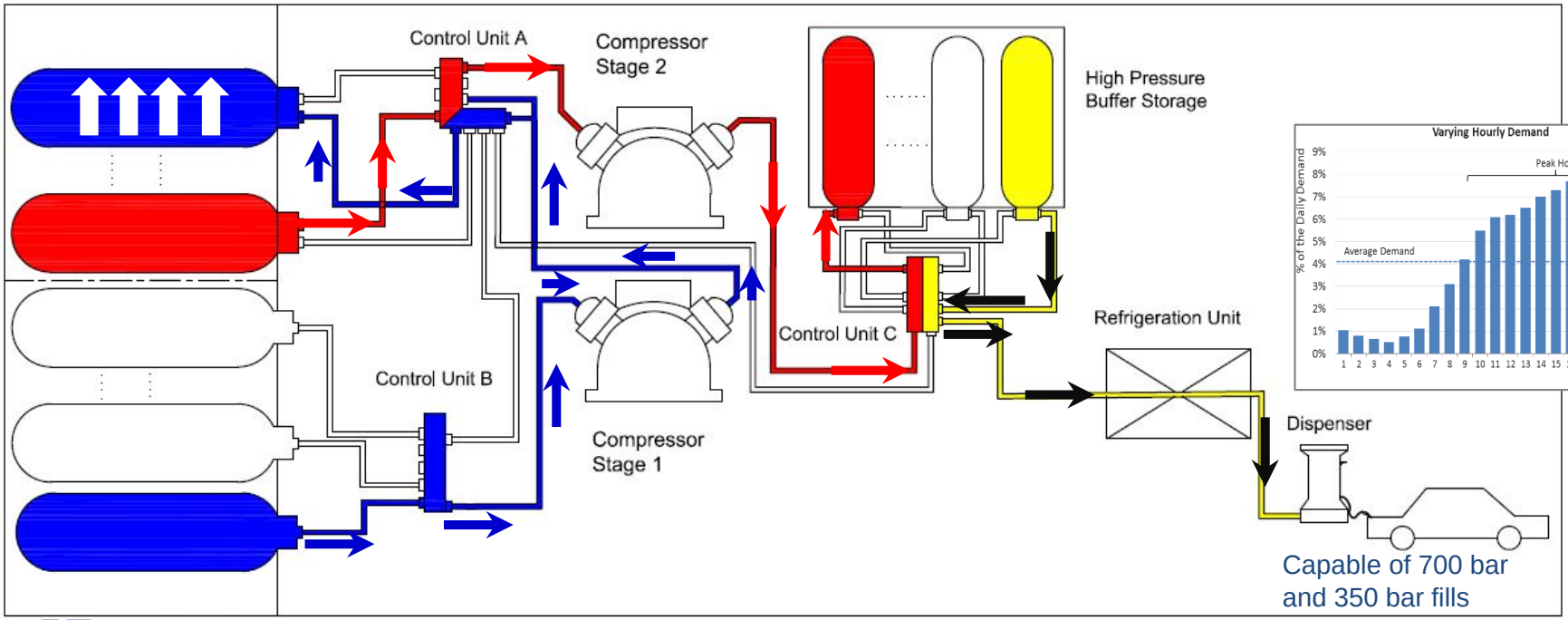
# *Pressure consolidation exploits the relationship between suction pressure and compressor throughput*



# *Pressure consolidation ensures high throughput fueling during peak hours*

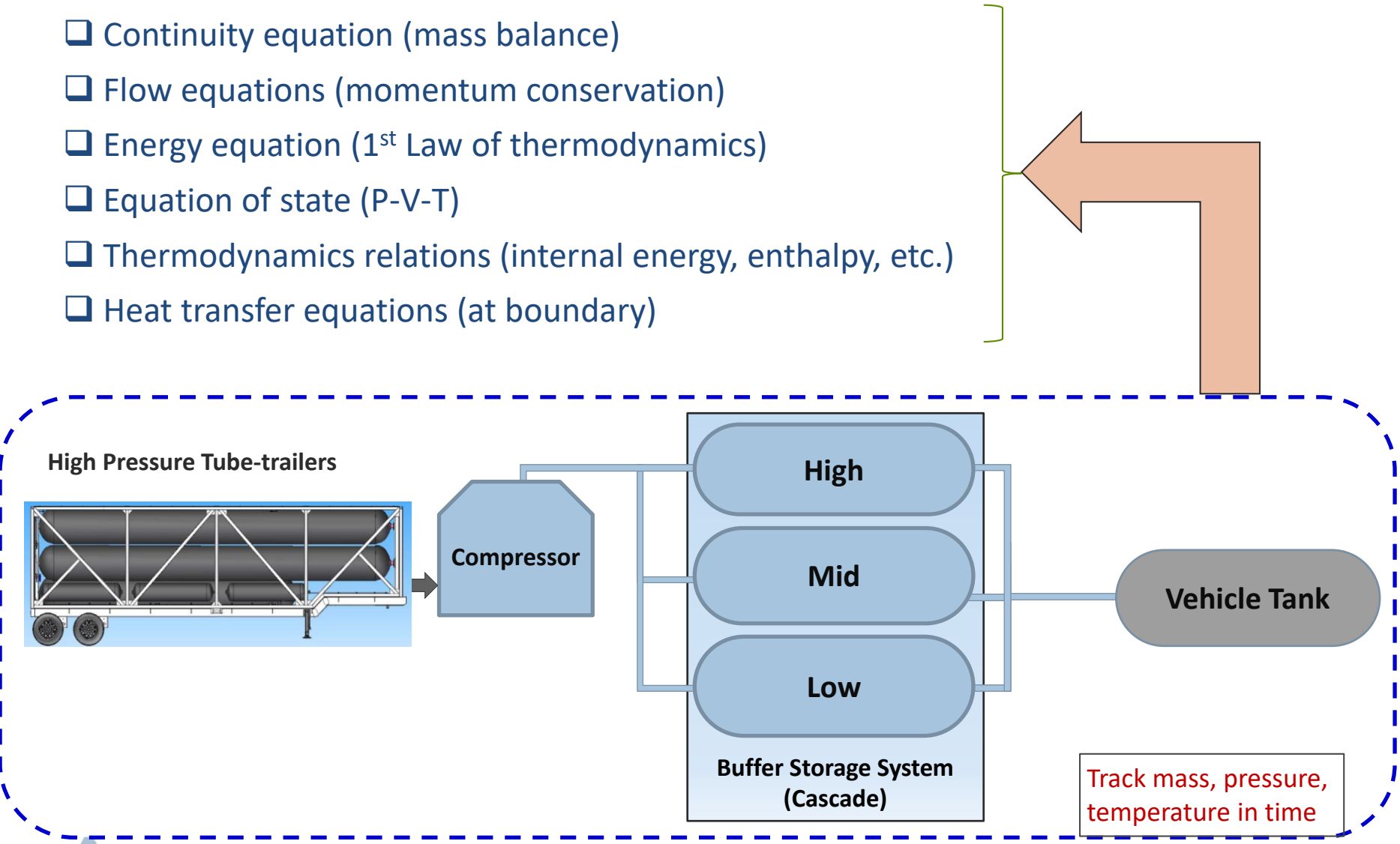



**Tube trailer or ground storage**

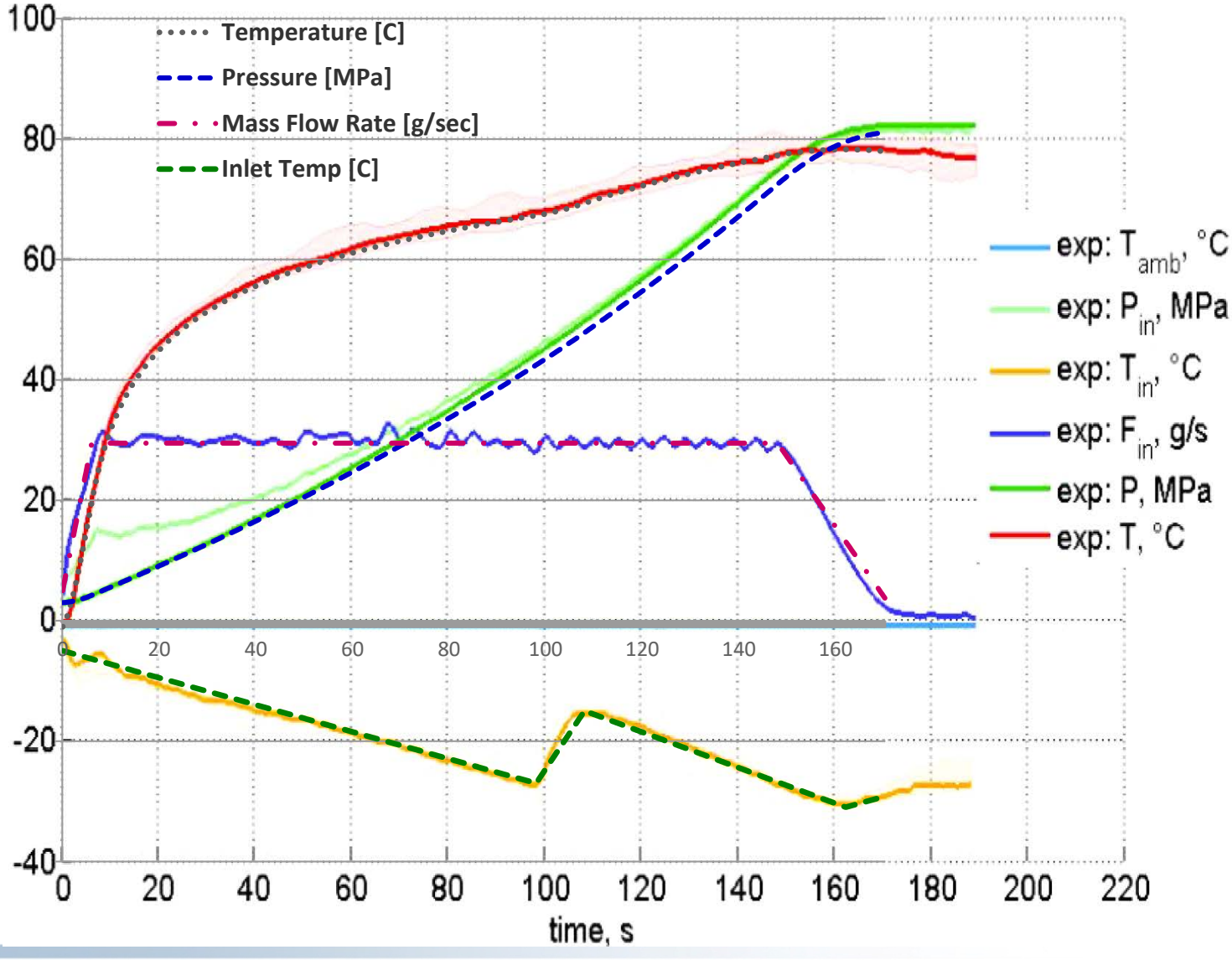


# *Solving physical laws – H2SCOPE Model*

- ❑ Continuity equation (mass balance)
- ❑ Flow equations (momentum conservation)
- ❑ Energy equation (1st Law of thermodynamics)
- ❑ Equation of state (P-V-T)
- ❑ Thermodynamics relations (internal energy, enthalpy, etc.)
- ❑ Heat transfer equations (at boundary)



# *Simulation results were validated against published experimental data*



# Key Simulation Parameters

- Buffer storage and tube trailer (or ground storage) options

| Storage Type | Pmax [bar] | Pmin [bar] | Storage amount [kg] |
|---|---|---|---|
| Type II High pressure cascade pressure tank [bar] | 910 | 420 | 16 (per tank) |
| Titan V (type IV) 350 bar tube trailer (or ground storage) | 400 | 20 | 900 |

- Fueling parameters

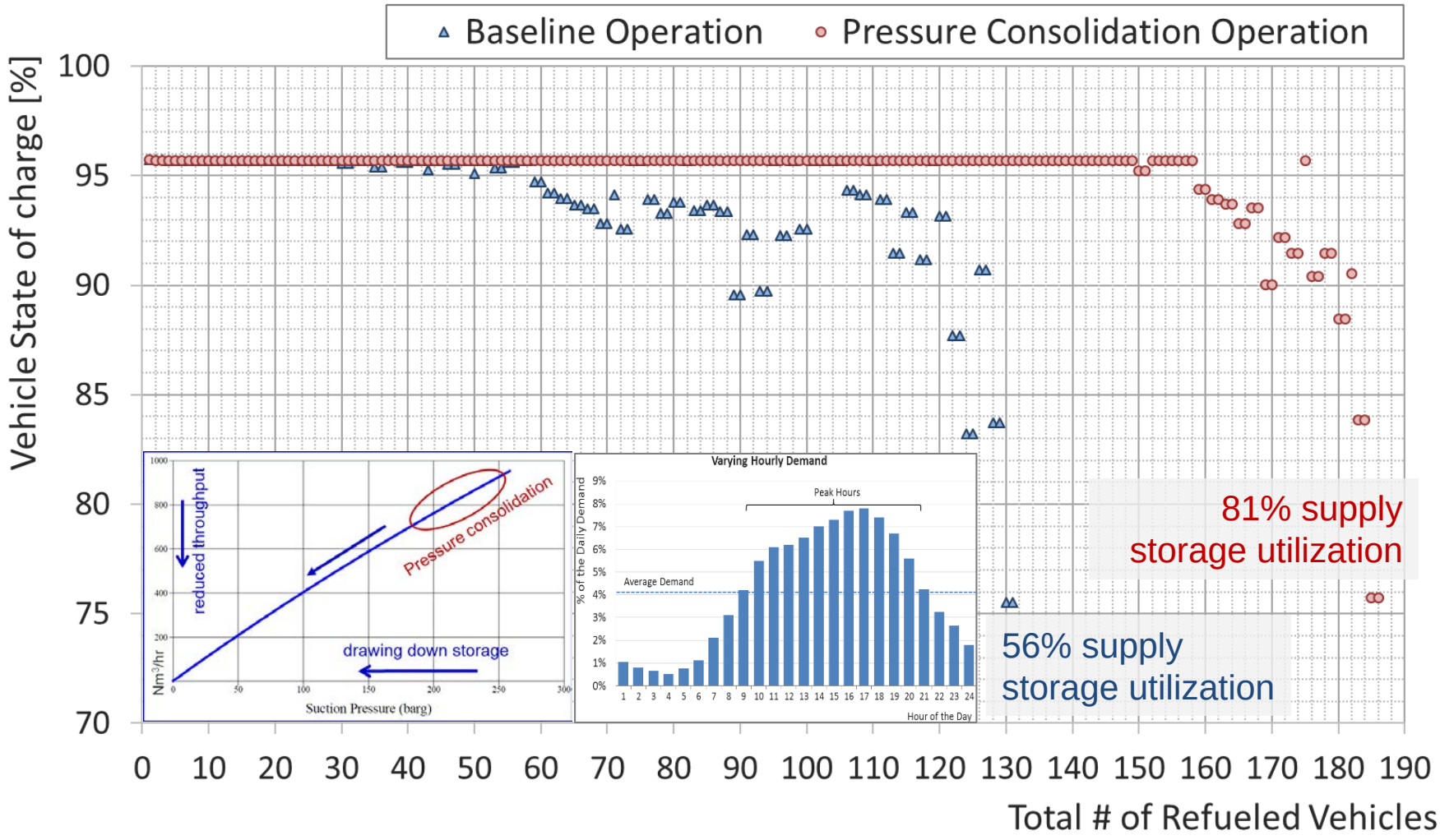
| Fueling Protocol | Value |
|---|---|
| SAE Fill Pressure Ramp Rate @25°C Ambient, for 4-7 kg Tank Capacity [MPa/min] | 18.5 |
| Initial Vehicle Tank Pressure [MPa] | 5 |
| Final Vehicle Tank Pressure [MPa] (Typical State Of Charge at 25°C ambient) | 81 (96%) |
| Leak Checks Duration for Every 200 bar Rise [sec] | 10 |
| Lingering Time Between Fills [sec] | 120 |

# Simulated Performance for 350 bar consolidation pressure

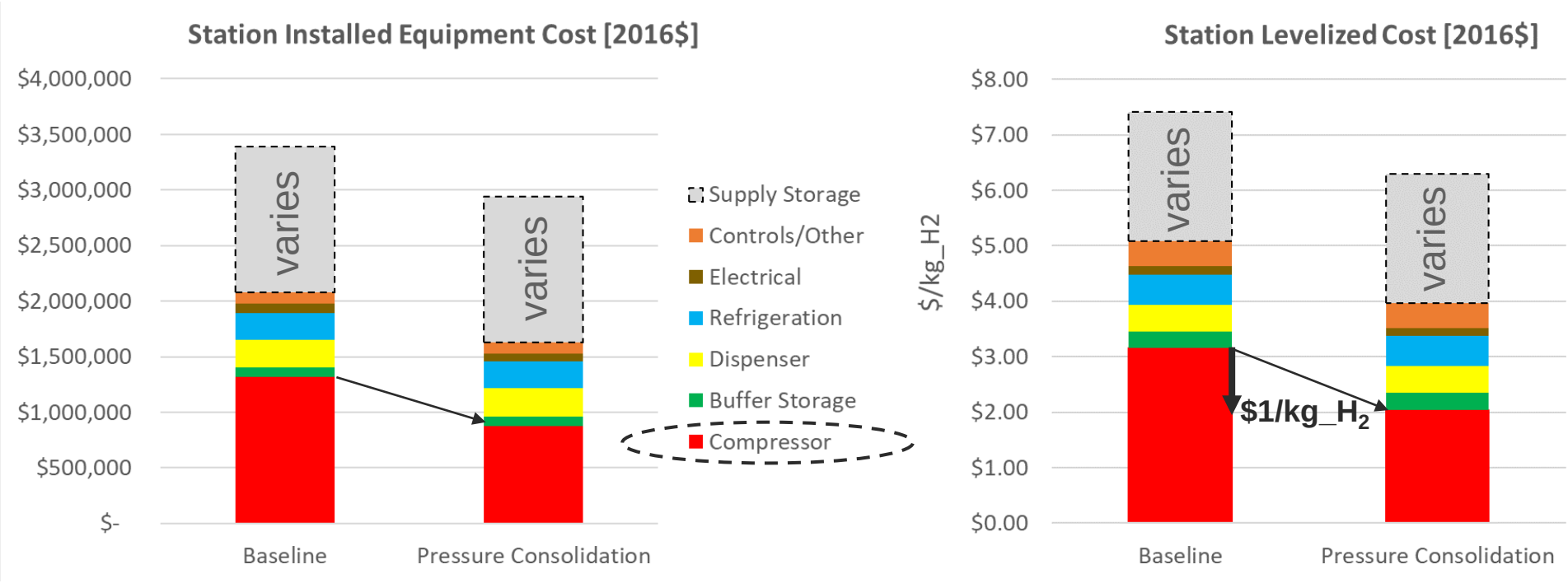
- Fill operation with 4.5 kg fills and 3-tank buffer storage (2-hose, 500 kg/day)

Supply Storage: 900 kg @350 bar

~100 FCVs/day @96% SOC



# Refueling Cost Evaluation for 500 kg/day Station (Today)



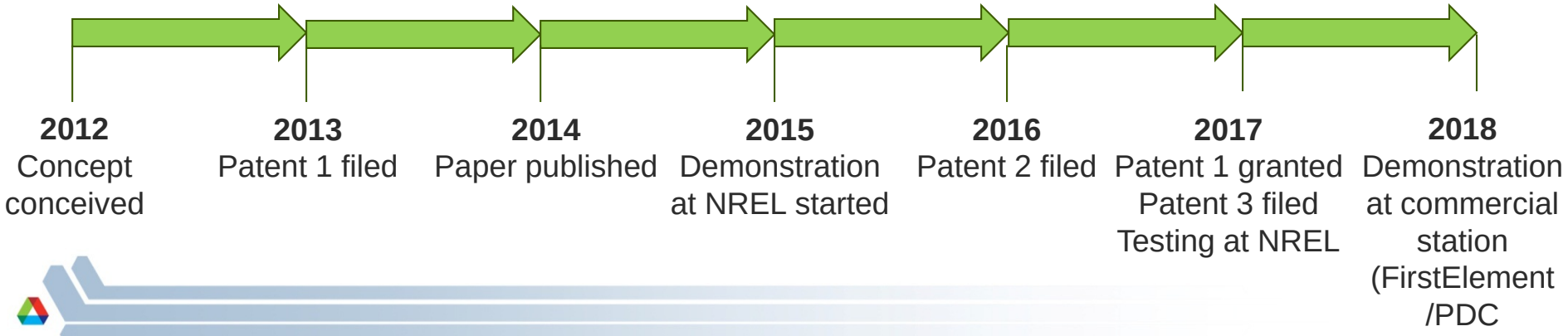

✓ Compressor cost can be reduced by 30-40%, resulting in saving of >$1/kg_$H_2$

# *Proof of concept testing is underway at NREL*

- **ANL/PDC/NREL H2FIRST Project funded by FCTO**


# Summary

- Argonne developed the pressure consolidation concept since 2012
- Pressure consolidation operation extends the capacity of HRS for full vehicle fills with consistent back-to-back capability (2X)
- Pressure consolidation significantly improves the utilization of the hydrogen supply storage
- Proof of concept under way at NREL
- Information documented in patent and journal articles, and disseminated to companies and in public forums
- Commercial demonstration with FirstElement / PDC Machines



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# *Thank You!*

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Link to Argonne's Hydrogen Delivery and Refueling models:

http://www.hydrogen.energy.gov/h2a_delivery.html