DOE Hydrogen Composite Tank Program

Dr. Neel Sirosh
DIRECTOR, FUEL STORAGE

Goals

- Optimize and validate commercially viable high performance pressure storage systems for transportation applications, in line with DOE targets

Objectives:

- Develop and validate 5,000 psi storage tanks
  - Tank efficiency: 7.5 – 8.5 wt%
- Validate 5,000 psi in-tank-pressure regulators
  - Total storage system efficiency: 5.7 wt%
- Develop and validate 10,000 psi storage tanks
  - Tank efficiency: 6 - 6.5 wt%
- Develop and validate 10,000 psi storage systems
  - Quantum Internal Program; total system efficiency: 4.5 wt%
- Optimize designs and processes to achieve the DOE cost targets

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DOE Storage Targets

Parameter	2005	2010	2015
Usable Specific Energy (kw hr / kg)	1.5	2	3
Usable Energy Density (kw hr / L)	1.2	1.5	2.7
Cost ($ / kw hr)	$6	$4	$2
Cycle Life (1/4 tank to full)	500	1,000	1,500
Refueling Rate (kg H_2 / min)	0.5	1.5	2
Loss of Usable Hydrogen (grams)	1	0.1	0.05

Approach

- Learn from the successful 100 yr history of pressure vessels (industrial, aerospace, CNG)
- Optimize materials, design, process to improve weight efficiency (5,000 psi tanks)
- Develop & validate volumetrically efficient storage systems (10,000 psi tanks)
- Improve system efficiency (In-tank Regulator, Balance of Plant Components)
- Validate and certify components (Codes & Standards, Regulatory approvals)
- Work towards cost reduction (Technology, Economies of Scale

Compressed Gases Have Been Around for Over 100 Years

Industrial

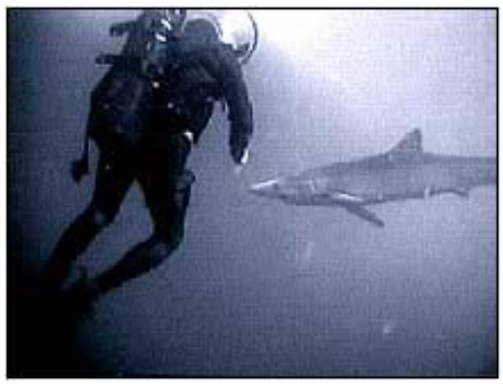
Fire Extinguishers

Life Support

Automotive

1900 1910 1920 1930 1940 1950 1960 1970 1980 1990 2000 2010

Pressures Up To 6,000 psi



SCUBA

Aircraft

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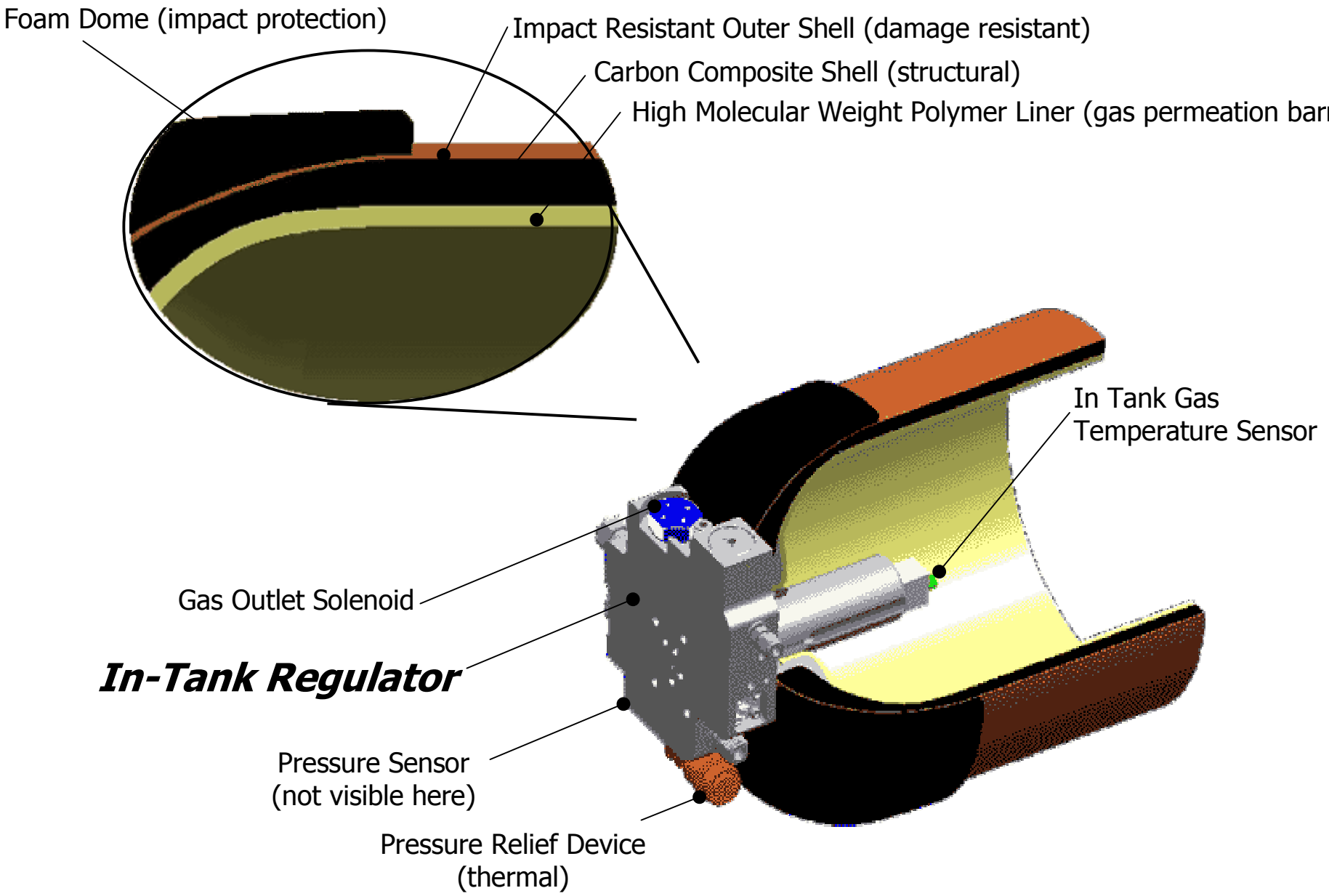
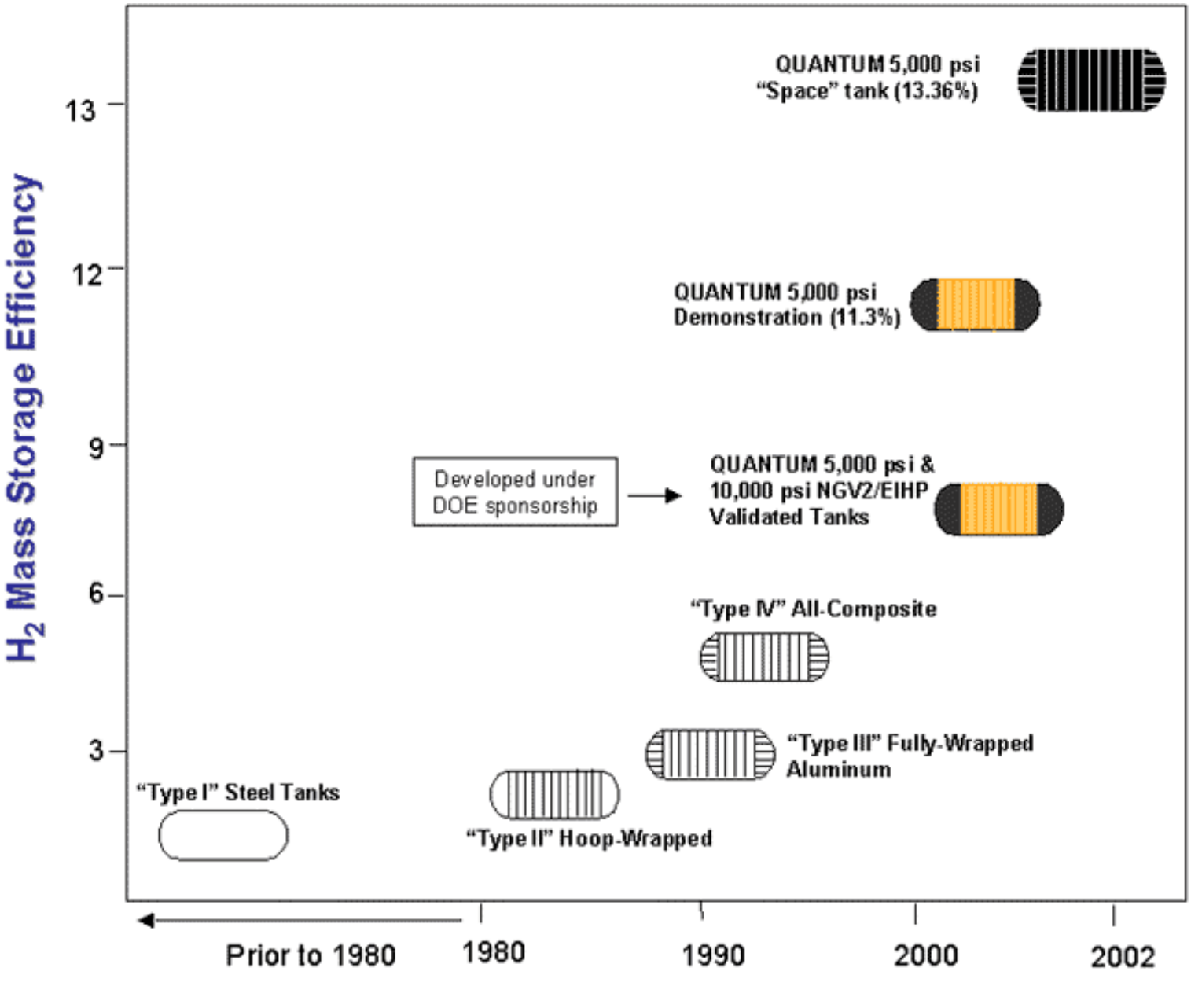
QUANTUM Compressed Hydrogen Storage



Product Benchmarking



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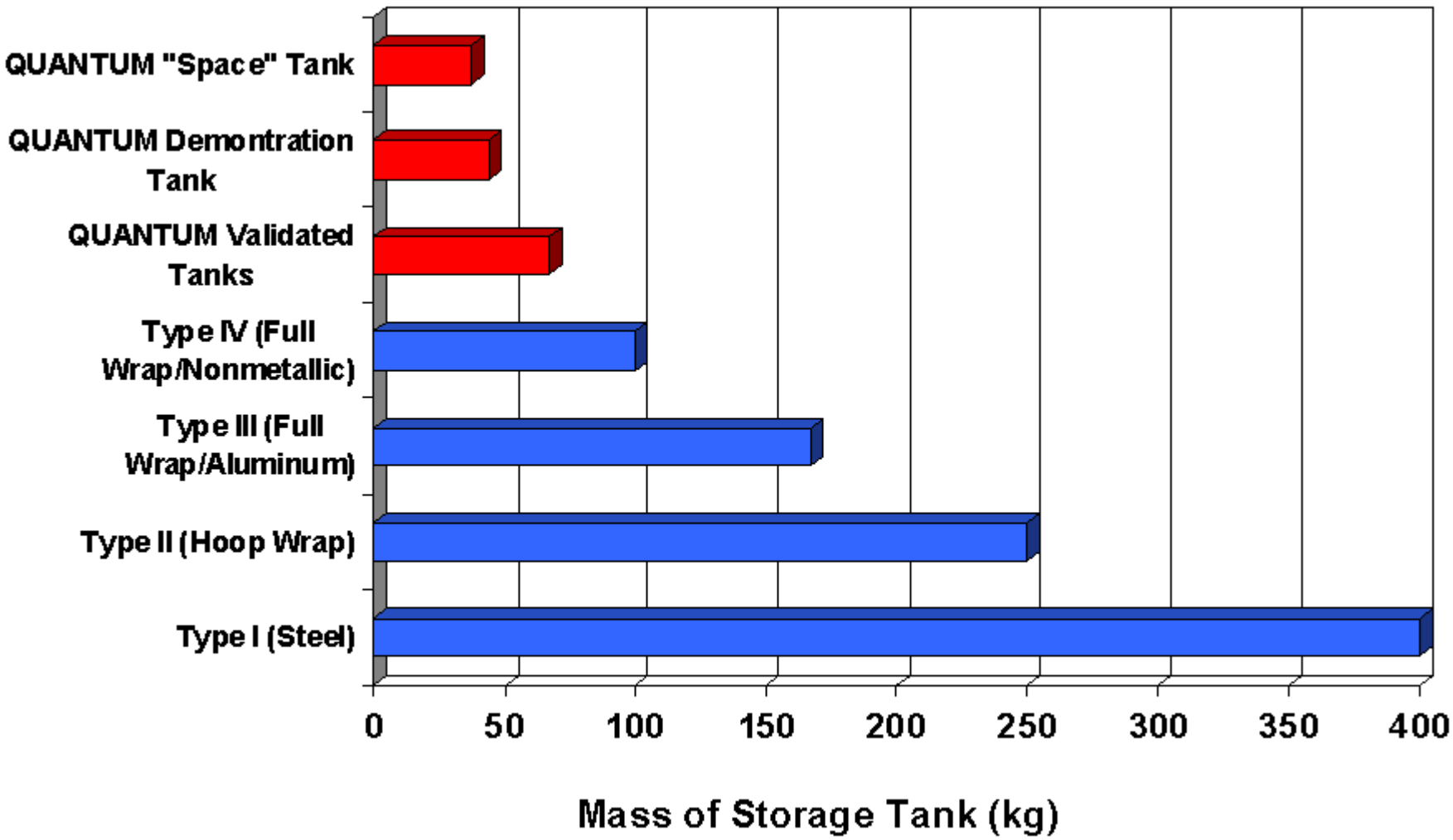
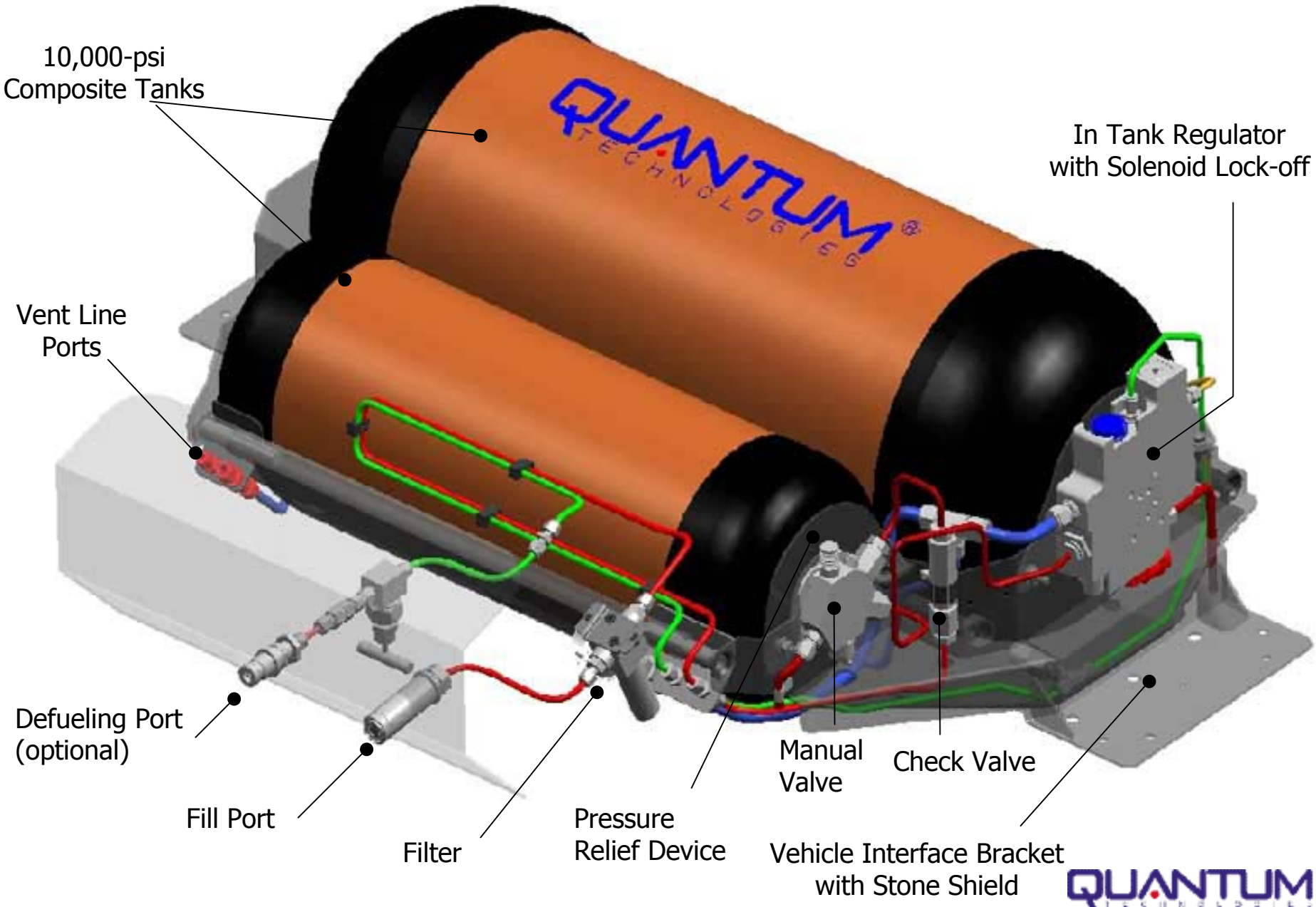
Mass of Tank to Store 5 Kg of Hydrogen Gas



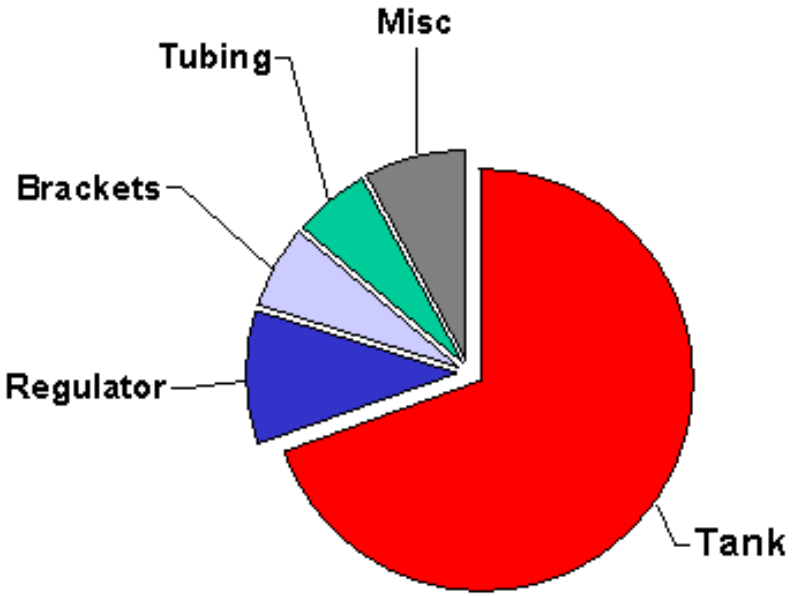
Compressed Hydrogen Storage System



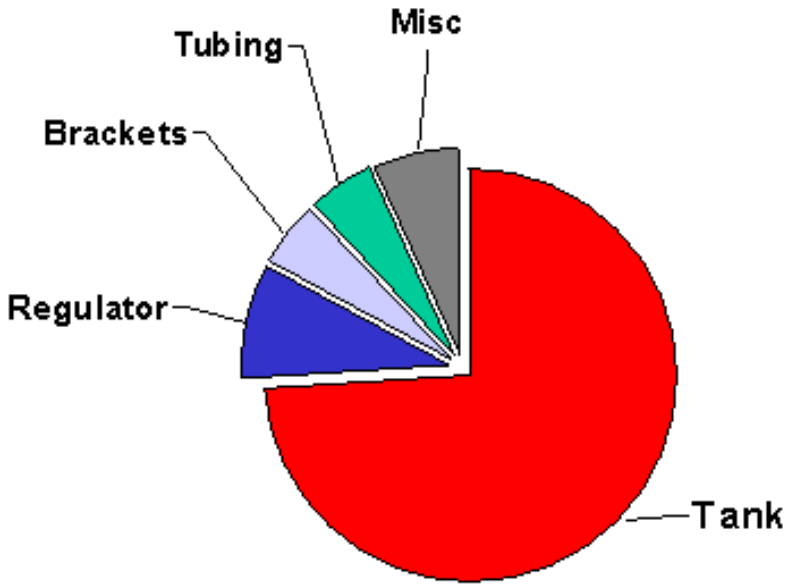
System Level Weight Efficiency

Storage of 5 kg of Hydrogen Gas (Using One Tank)

5,000 psi



10,000 psi



Usable Specific Energy (kw hr / kg)	2005	2010	Status
5,000 psi Technology	1.5	2	1.9
10,000 psi Technology	1.5	2	1.6

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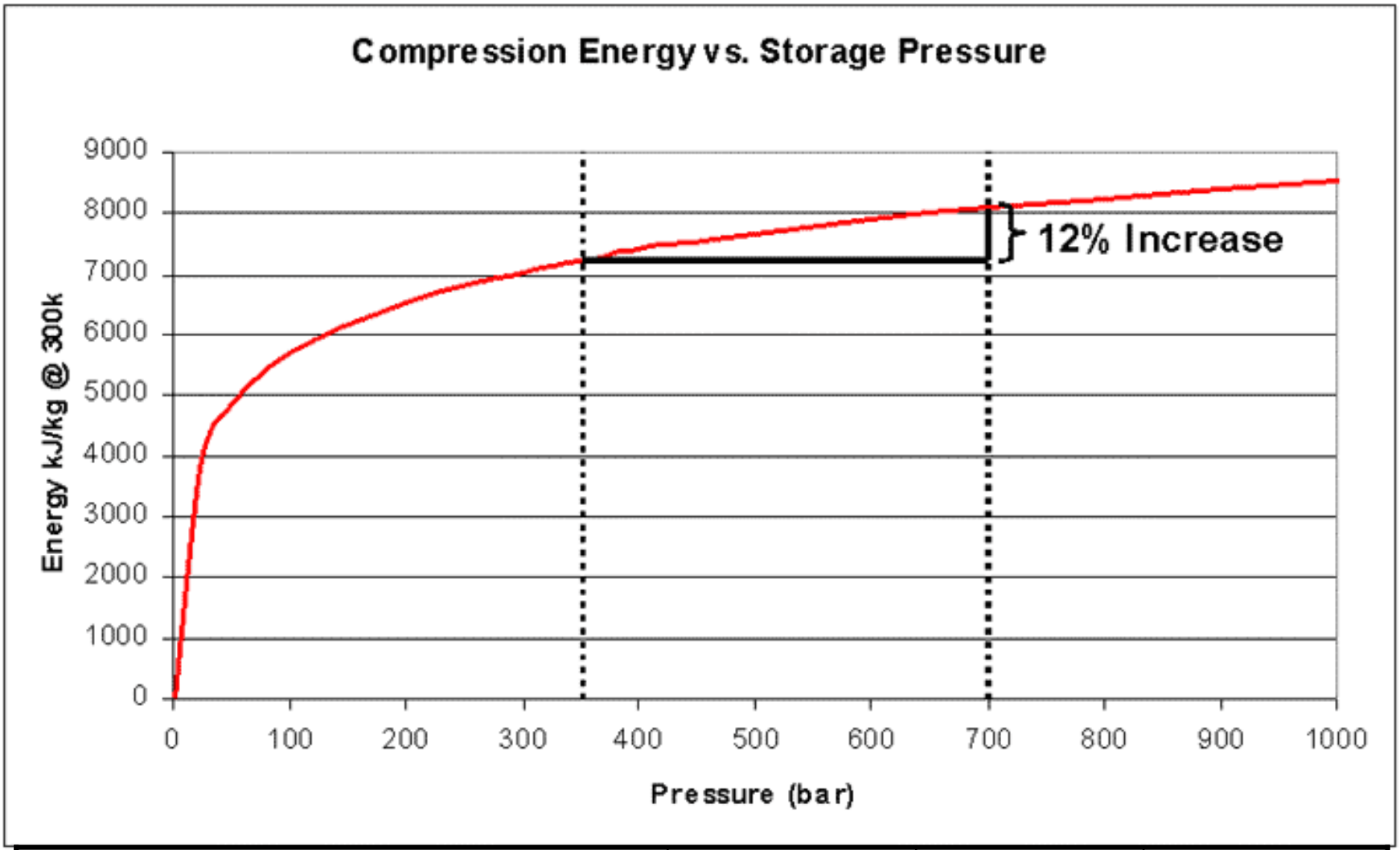
Volumetric Efficiency: 5,000 psi vs 10,000 psi Storage

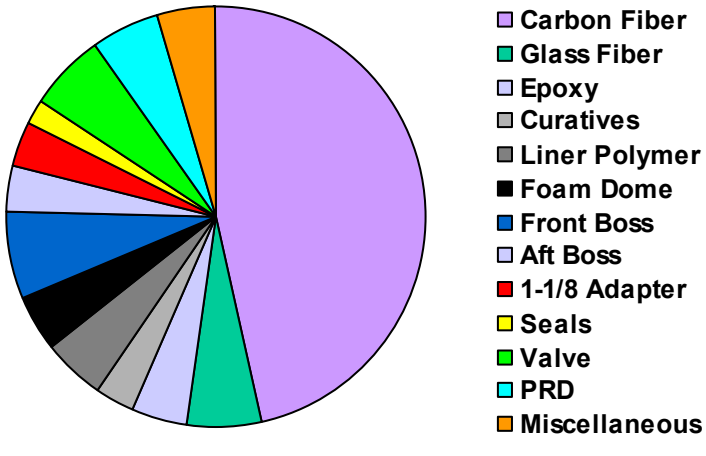


	2005	2010	Status
Usable Energy Density (kw hr / L)	1.2	1.5	1.3

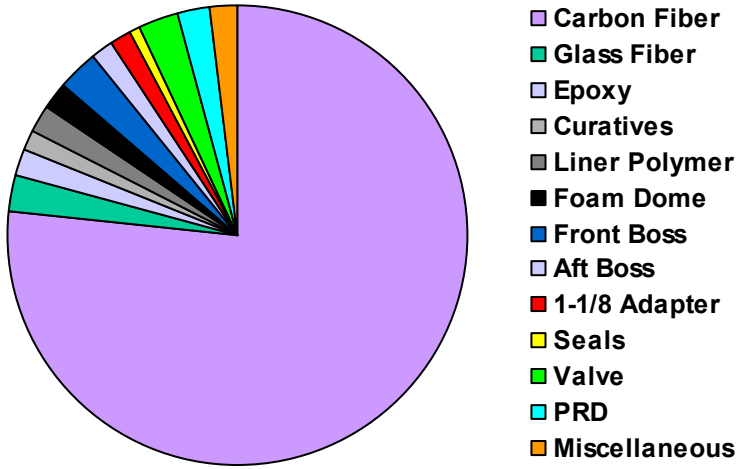
Cost Drivers

- Primary driver is material cost
  - 40 - 80% is carbon fiber cost
  - Significant opportunities for cost-reduction

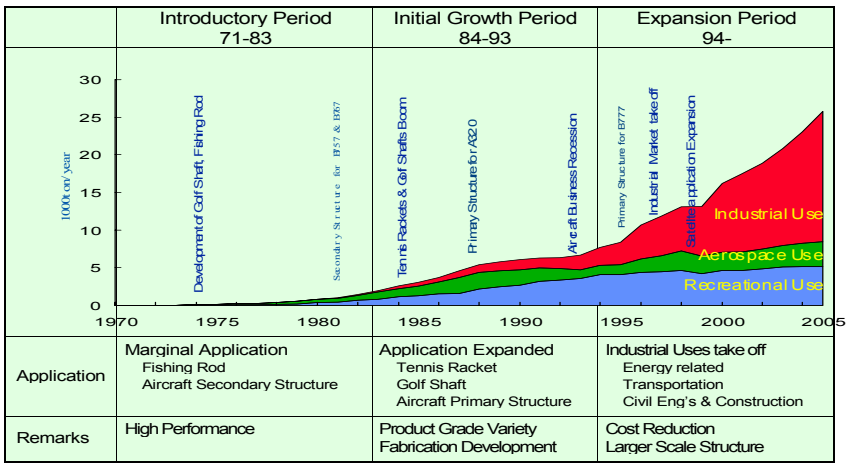
Cost Structure – Fiber A



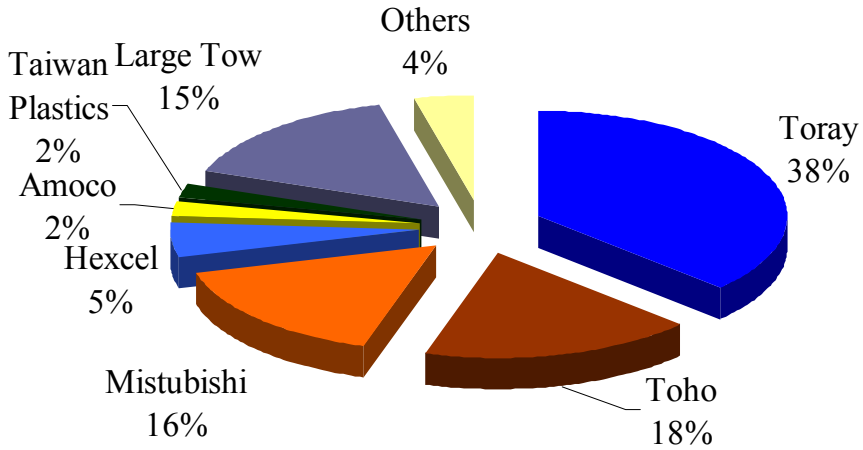
Cost Structure – Fiber B



Carbon Fiber Worldwide Supply



Carbon Fiber Market Share



Safety & Certification Status

Certification Status:

Storage Pressure	Approvals / Compliance
3,600 psi (250 bar)	NGV2-2000 (modified) DOT FMVSS 304 (modified)
5,000 psi (350 bar)	E.I.H.P. / German Pressure Vessel Code DBV P.18 NGV2-2000 (modified) FMVSS 304 (modified) KHK
10,000 psi (700 bar)	E.I.H.P. / German Pressure Vessel Code DBV P.18 FMVSS 304 (modified)

QUANTUM Participates in:

- E.I.H.P (European Integrated Hydrogen Project) Code Committee
- ISO Hydrogen Storage Standard Committee
- CSA – America NGV2 Hydrogen TAG

Regulatory Approvals

Regulatory Agency

- ISO 15869 - **International**
- NGV2 - **US/Japan/Mexico**
- FMVSS 304 - **United States**
- NFPA 52 - **United States**
- KHK - **Japan**
- CSA B51 - **Canada**
- TÜV - **Germany**

Validation Tests

- Hydrostatic Burst
- Extreme Temperature Cycle
- Ambient Cycle
- Acid Environment
- Bonfire
- Gunfire Penetration
- Flaw Tolerance
- Accelerated Stress
- Drop Test
- Permeation
- Hydrogen Cycle
- Softening Temperature
- Tensile Properties
- Resin Shear
- Boss End Material

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10,000 psi Components Availability

Component	Available	Approval
Tank	✓	EIHP / TÜV
Regulator	✓	EIHP / TÜV
Check Valves	✓	EIHP / TÜV
PRD (thermal)	✓	EIHP / TÜV
Manual Tank Valves	✓	EIHP / TÜV
Pressure Transducers	✓	EIHP / TÜV
Refueling Receptacle	✓	EIHP / TÜV
Fuel Lines	✓	EIHP / TÜV
Fittings	✓	EIHP / TÜV

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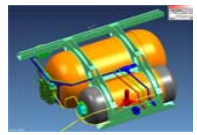
Project Timeline

PRODUCTION

250 Bar CNG

350 Bar H_2

700 Bar H_2



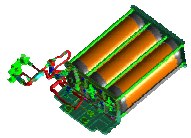
Up to 10X Cost Reduction Through Economies of Scale

PROTOTYPE

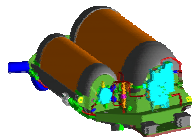
250 Bar H2

350 bar Conformable

350 Bar H_2



700 Bar H_2



Cost Reduced (30%)

700 Bar H_2

CONCEPT

250 Bar CNG

DOE Programs

350 Bar H_2

700 Bar H_2

Cost Reduced (30%)

700 Bar H_2

Cost Reduced (75%)

700 Bar H_2

Next Gen Storage

1998 2000 2002 2004 2006 2008

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Collaborative Work

- Alliance with Thiokol (Material, Design, Testing)
- Global alliance with GM (Fuel Cell Enabling Technologies)
- Development Program with NASA / Aerovironment (Advanced light weight systems)
- CRADA with Idaho National Labs (Enhanced Permeation Barriers)
- Collaboration with Oak Ridge National Labs (Monitoring Systems)

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Accomplishments – Technical Progress

2002

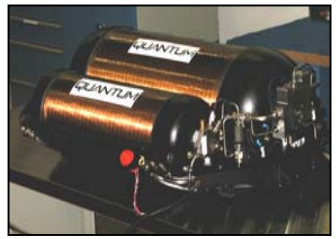
Validated & shipped 5,000psi tanks (NGV2, EIHP standards)

(7.5 & 8.5 wt %)

Validated & shipped 10,000 psi tanks (Worlds' first 10,000 psi tank; EIHP / TUV)

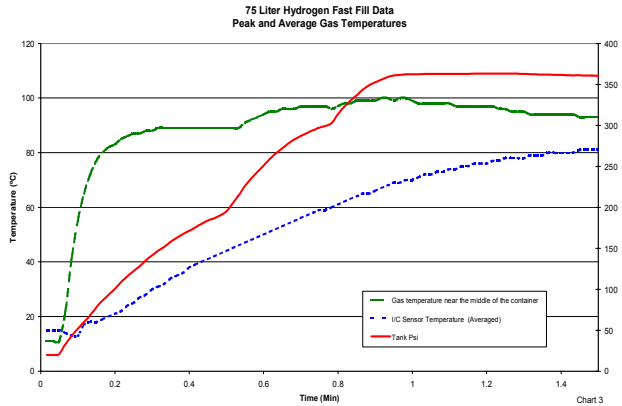
(6 wt %)

Certified complete 10,000 psi Storage System (EIHP / TUV)



(3 wt %)

Successfully demonstrated 10,000 psi fast-fill within 3 minutes



2003

Achieved 13.36 wt % tank efficiency (5,000 psi tank; aerospace)

Completed 5,000 psi tank & in-tank regulator production optimizations

Achieved >45,000 cycles fatigue life and 30% cost-reduction for 10,000 psi tanks (design, process)

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Accomplishments – Commercial Progress

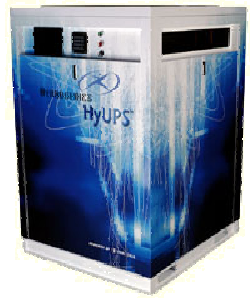
2002

Agreement with Hyundai to Jointly Develop Fuel Cell & Alt Fuel Vehicles

Texas Tech & Virginia Tech in Future Truck competition with Quantum tanks

GM's revolutionary Hy-Wire introduced with Quantum tanks

Quantum tanks used in stationary power application (NEXTEL, Hydrogenics)



2003

Ships Three Portable Refueling Systems

Production of Storage systems for Toyota

Supplies storage system to Suzuki

SUZUKI

Agreement with Sumitomo for storage systems Distribution

Sumitomo Corporation

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Future Plans / Milestones

- Refueling Strategy (Thermal Management with Fast-Fill) (’04)
- Structural Optimization of Tanks, Liners, Components (’04)
- Materials (Lower Cost Fibers, Strength & Cycle Life Trade-off, Liner Materials) (’05)
- Balance of Plant Components (Valves, Regulators, Filters, Relief Devices, Tubing, Fitting, Sensors, Mounting) (’05)
- Vehicle Hydrogen Safety (Impacts, Crash Statistics) (’05)
- Smart Tanks – Monitoring System to Support Lower Burst Ratio (’05)

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Conclusions

- 5,000 psi and 10,000 psi compressed storage systems are currently available and successfully deployed on fuel cell vehicles
- DOE 2005 performance targets are achievable
- Storage is a significant cost factor in overall fuel cell system cost
- Carbon Fiber and stainless steel hardware costs represent over 90% of the costs
- Design & process improvements to address storage tank costs are on-going

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