Energy Storage

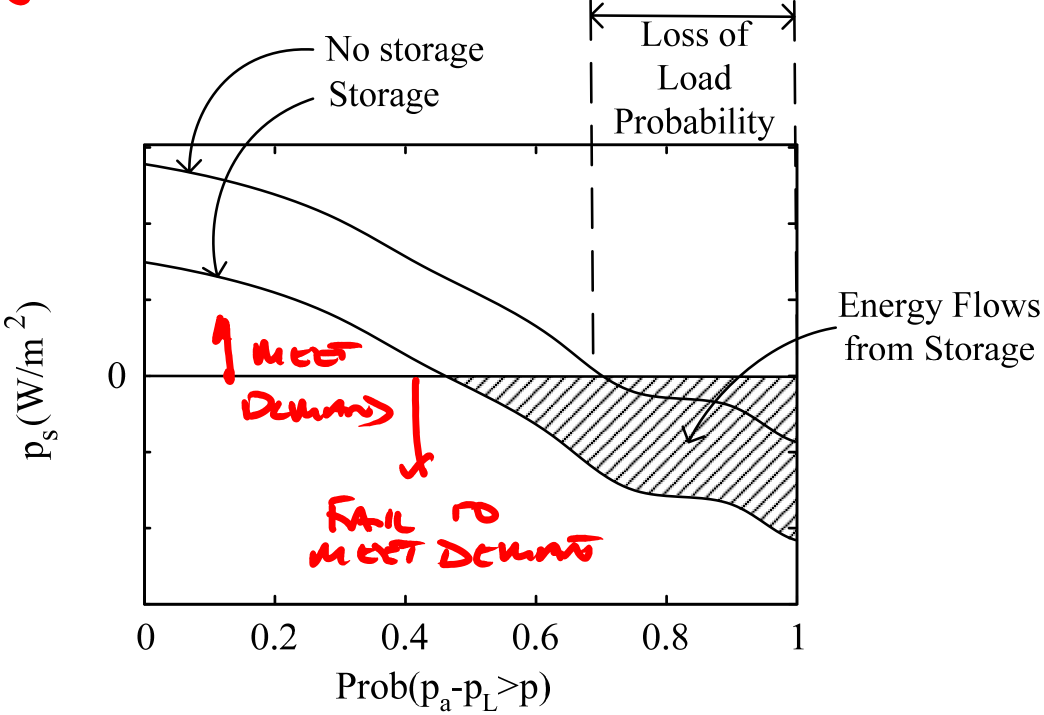
A. Introduction

3. Load Management

DEMAND VARIES WITH TIME

SYSTEM MUST BE ABLE TO SUPPLY MAXIMUM LOAD

↳ LEADS TO EXCESS CAPACITY THAT DOES NOT RUN OFTEN



STORAGE CAN HELP

- INSTALLED CAPACITY CAN BE REDUCED SIGNIFICANTLY

Energy Storage

B. Storage System Features

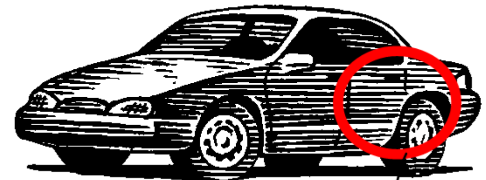
A GOOD STORAGE SYSTEM EXHIBIT SEVERAL CHARACTERISTICS

1. HIGH RATE OF ENERGY SUPPLY & RETRIEVAL
   POWER TO & FROM STORAGE MEETS REQUIREMENTS
2. HIGH TRANSFER EFFICIENCIES
   LOW-LOSS
3. LONG & LOSS FREE STORAGE
4. HIGH ENERGY CONTENT
   KEEPS SYSTEM OF REASONABLE MASS/SIZE
5. NO CHANGE IN ENERGY QUALITY
6. MODEST CONTAINMENT & ENERGY TRANSFER REQUIREMENTS
   ROOM P&T
   NO CORROSION

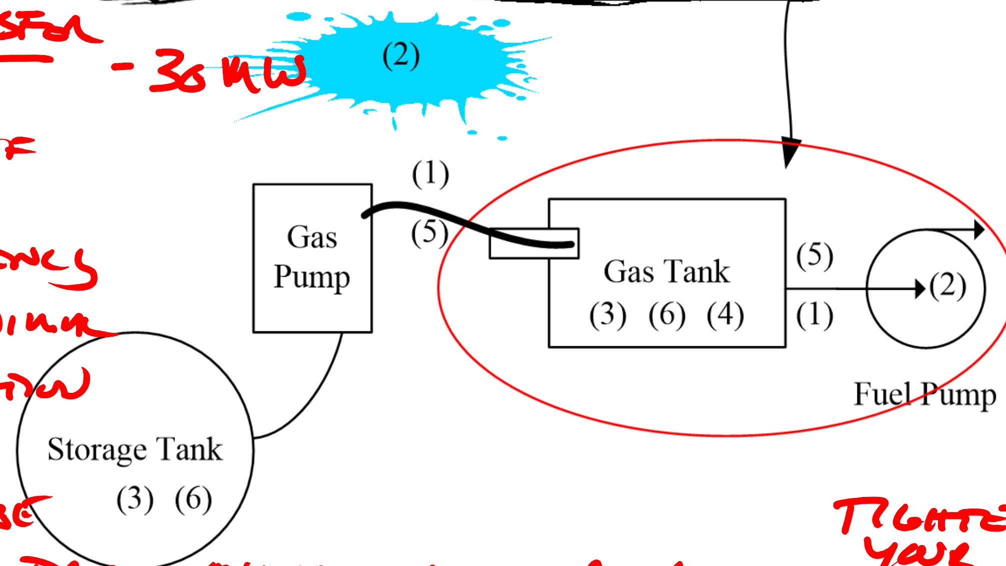
Energy Storage

B. Storage System Features

GASOLINE STORAGE SYSTEM



1. HIGH RATE OF ENERGY SUPPLY & DELIVERY
   - GAS PUMP – $\frac{\text{ENERGY TRANSFER}}{\text{SECOND}}$ – 30 MW
     – DEMAND OF ENGINE

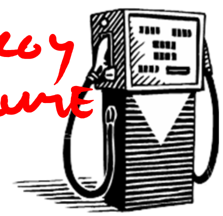


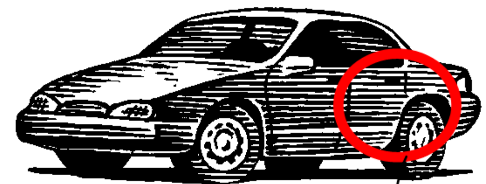
2. HIGH TRANSFER EFFICIENCY
   - LOSSES ARE MINIMAL SPILLS/EVAPORATION
3. LONG & LOSS FREE STORAGE
   - WELL SEALED GAS TANK INSURES MINIMAL LOSSES TIGHTEN YOUR GAS CAP!
   - GASOLINE IS STABLE → STORAGE TIME IN YEARS

Energy Storage

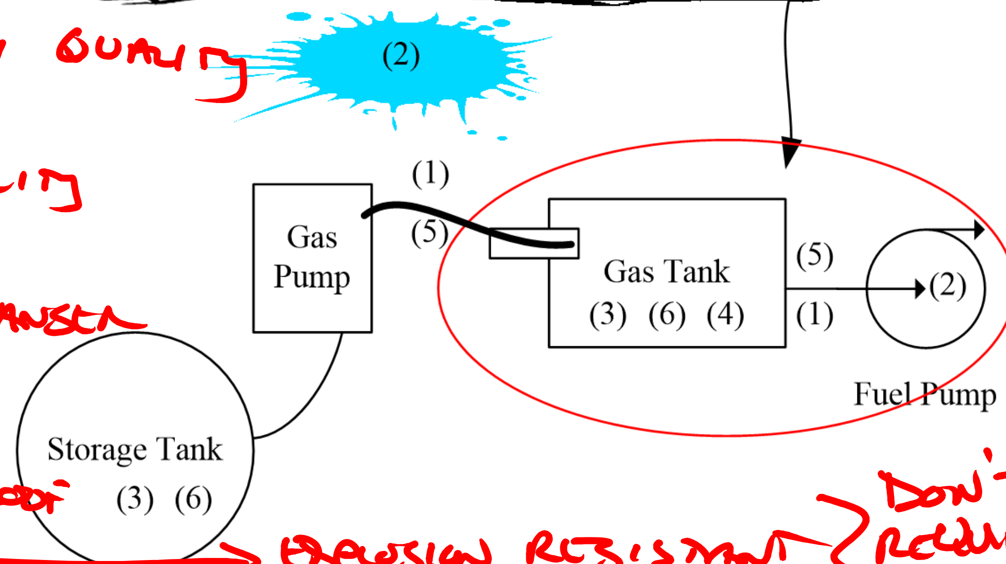
B. Storage System Features

4. HIGH ENERGY CONTENT
   GAS HAS HIGH ENERGY
   CONTENT BY MASS & VOLUME





5. NO CHANGE IN ENERGY QUALITY
   GAS IN → GAS OUT
   NO CHANGE IN QUALITY



6. MODEST CONTAINMENT & TRANSFER
   REQUIREMENTS

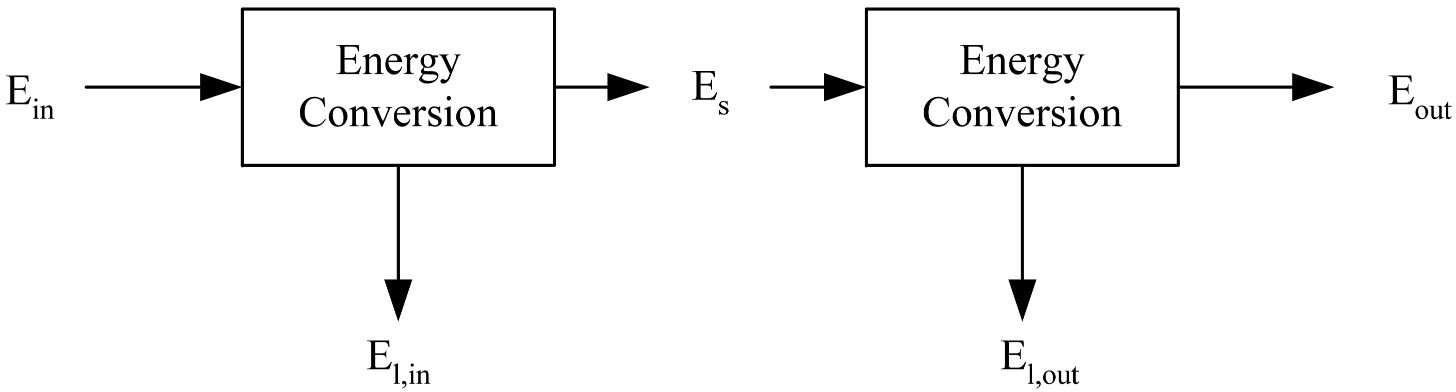
   GAS TANK – LEAK PROOF → EXPLOSION RESISTANT
   GAS TANK AT AMBIENT TEMPERATURE & PRESSURE

} DON'T REQUIRE EXOTIC CONTAINMENT

Energy Storage

C. Energy Storage Performance Metrics

1. Efficiency



FOR A STORAGE SYSTEM, ENERGY CONVERSION HAPPENS TWICE

→ ENERGY TO STORAGE $\qquad \eta_{in} = \dfrac{E_s}{E_{in}}$

→ ENERGY FROM STORAGE $\qquad \eta_{out} = \dfrac{E_{out}}{E_s}$

OVERALL EFFICIENCY $\eta = \eta_{in}\,\eta_{out}$

NEED HIGH EFFICIENCIES IN BOTH DIRECTIONS

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

ENERGY STORAGE BROKEN INTO 2 TYPES: PRIMARY STORAGE; SECONDARY STORAGE

PRIMARY STORAGE - ENERGY COMES IN STORED FORM

SECONDARY STORAGE - ENERGY CONVERTED TO STORED FORM

IMPORTANT TO ALL STORAGE

ENERGY DENSITY

$$e_m = \frac{E_S}{m} = \frac{\text{ENERGY STORED}}{\text{MASS USED FOR STORAGE}}$$ MASS ENERGY DENSITY

$$e_v = \frac{E_S}{\forall} = \frac{\text{ENERGY STORED}}{\text{VOLUME USED FOR STORAGE}}$$ VOLUME ENERGY DENSITY

$e_m \Rightarrow$ GOVERNS WEIGHT OF SYSTEM (TRANSPORTATION)

$e_v \Rightarrow$ GOVERNS VOLUME OF SYSTEM (TRANSPORTATION & FIXED APPLICATIONS)

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

POWER DENSITY – GOVERNS MASS & VOLUME ASSOCIATED WITH THE RATE AT WHICH ENERGY IS SUPPLIED

$$P_m = \frac{P_{out}}{m} = \frac{\text{OUTPUT POWER}}{\text{MASS OF STORAGE}}$$ MASS POWER DENSITY

$$P_v = \frac{P_{out}}{V} = \frac{\text{OUTPUT POWER}}{\text{VOLUME OF STORAGE}}$$ VOLUME POWER DENSITY

POWER DENSITIES DEPEND ON CONVERSION PROCESSES AS WELL AS STORAGE PROPERTIES

IT IS OFTEN DIFFICULT TO OPTIMIZE P_m & e_m IN THE SAME STORAGE/CONVERSION DEVICE

GASOLINE ENGINE – POWER SIZES THE VEHICLE

– ENGINE OVERSIZED FOR AVERAGE REQUIREMENT

P_m - HIGH

e_m - LOW-WEIGHT

HYBRID ENGINE – HIGH TORQUE MOTOR FOR STARTING

– SMALL ENGINE FOR CRUISE

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

Storage Form Storage Form	e_m kJ/kg	e_V MJ/m^3	cycle η
Crude Oil	42,000	37,000	
Coal	32,000	42,000	
Hydrogen Gas	120,000	10	0.4-0.6
Hydrogen Liquid	120,000	8700	
Hydrogen Metal Hydride	2000-9000	5000-15,000	
Ethanol	28,000	22,000	
Methanol	21,000	17,000	
Water 40-100° C	250	250	
Rocks 40-100° C	40-50	100-140	
Iron 40-100° C	30	230	

Energy Storage

C. Energy Storage Performance Metrics

2. Energy and Power Density

Storage Form Storage Form	e_m kJ/kg	e_V MJ/m^3	cycle η
Rocks 200-400° C	160	430	
Iron 200-400° C	100	800	
Salts (Phase Change)	>300	>300	
Pumped Hydro - 100 m head	1	1	0.65-0.80
Compressed Air		15	0.40-0.50
Flywheels, Steel	30-120	240-950	
Flywheels, Advanced	>200	>100	$\sim$ 0.95
Lead-Acid Battery	40-140	100-900	0.7-0.8
Nickel-Cadmium	350	350	
Advanced Battery	>400	>400	