Flexibility with Renewable Energy

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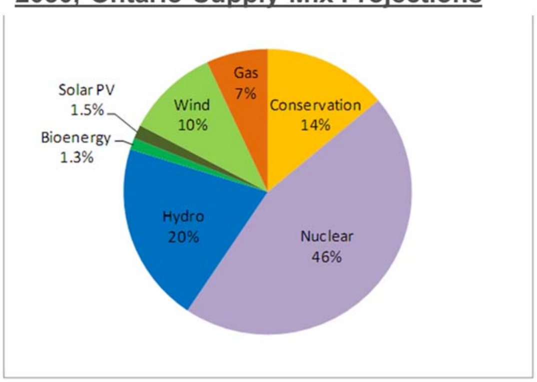
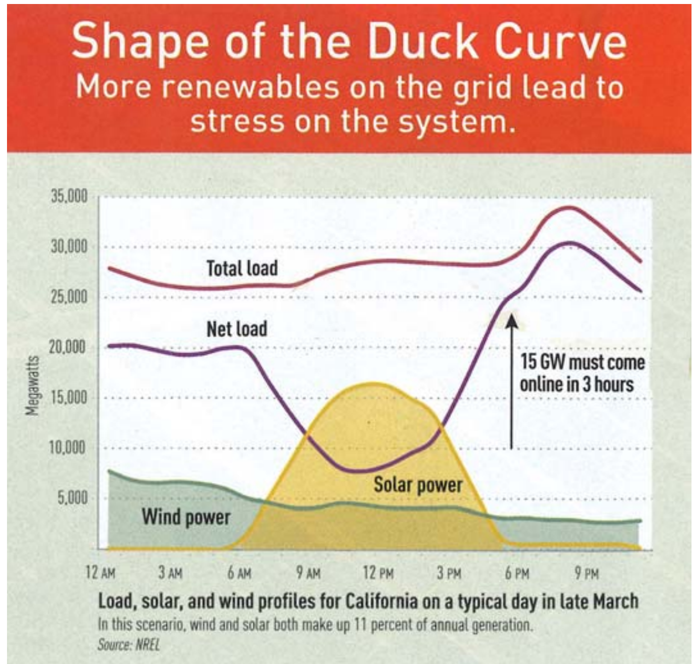
Renewable Energy

2030, Ontario Supply Mix Projections

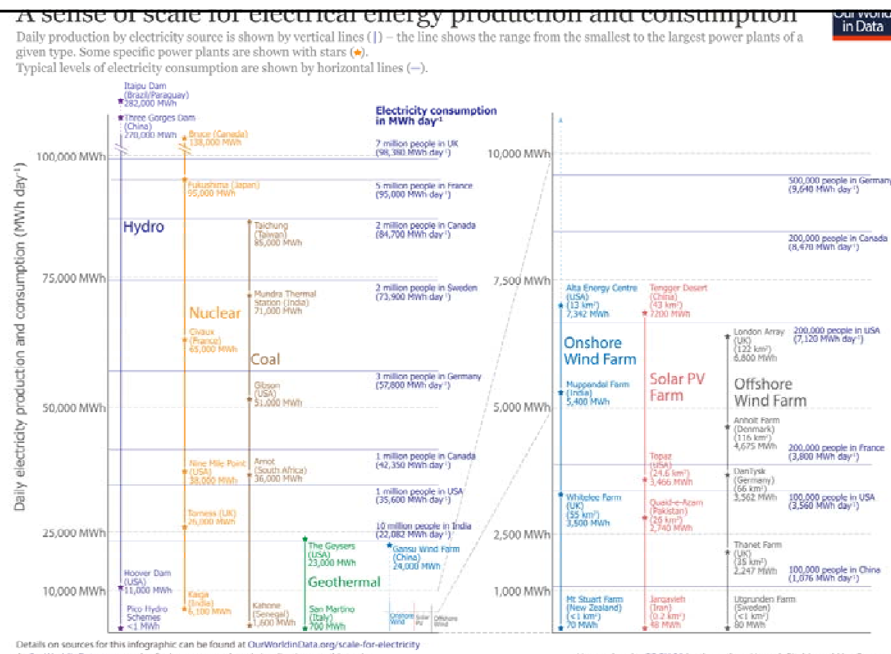


Source: Ministry of Energy, Long-Term Energy Plan

The Duck Curve



Caterpillar: Confidential Green



Now, what?

Flexibility

	Start Time to Full Power	Ramp rate (%power /min)
• Gas Turbine Plants	Minutes	20 - 50 (incl. Block Loads)
• GT Combined Cycle	Minutes/Hour	5-10
• Steam Plants (Coal)	Hours	1-5
• Nuclear Plants	Days	1-5

Note: Quick Cycles/ Fast Starts/ Fast Shutdowns negatively impact maintenance requirements

Table 11.1: Capability of different power generating technologies to provide flexibility

	Start-up time	Maximal change in 30 sec (%)	Maximum ramp rate (%/min)
Open-cycle gas turbine (OCGT)	10-20 min	20-30	20
Combined-cycle gas turbine (CCGT)	30-60 min	10-20	5-10
Coal plant	1-10 hours	5-10	1-5
Nuclear power plant	2 hours – 2 days	Up to 5	1-5

Source: NEA, 2012, p. 79.

Note on Efficiency

- Efficiency is usually Best at Full Load
  - Simple Cycle GT 45-42%
  - Combined Cycle 45-60%
- Part Load Efficiency is Lower

Energy Storage

- Safety
- Cost
- Round Trip Efficiency

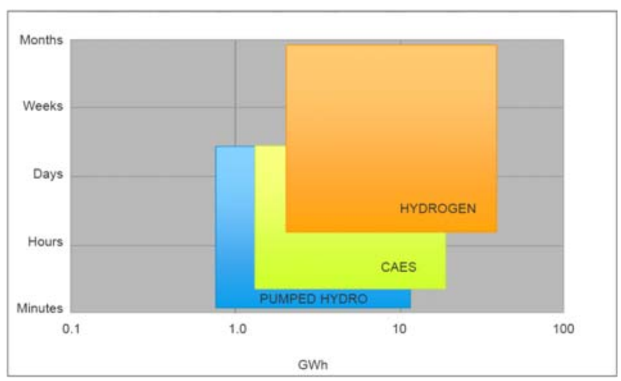
In this order!

Safety

- Power delivered to a large Metropolitan Area (say Los Angels or New York): 1.4×10^{10}W (14 GW)
- Storing the power needed for just one hour is 5×10^{13} J – that's about the energy of the Hiroshima Bomb
- It has to be **physically impossible** that this energy is released explosively !

Energy Density is Key to Bulk Storage Potential

- Pumped Hydro limited by geography
- Compressed Air Energy Storage (CAES) limited by:
  - energy density
  - competition for underground caverns
  - Common storage/injection point
- Blending H_2 with methane pipelines could remove geographic limits
  - Round trip efficiencies improve
  - Flexible storage / injection points
  - H2 energy density a competitive advantage



Source: D. Teichroeb, Alternative & Emerging Technology, Enbridge Inc. Oct 11 &12, 2011

Energy Storage/Cycle Efficiency

X. Luo et al. / Applied Energy 137 (2015) 511–536

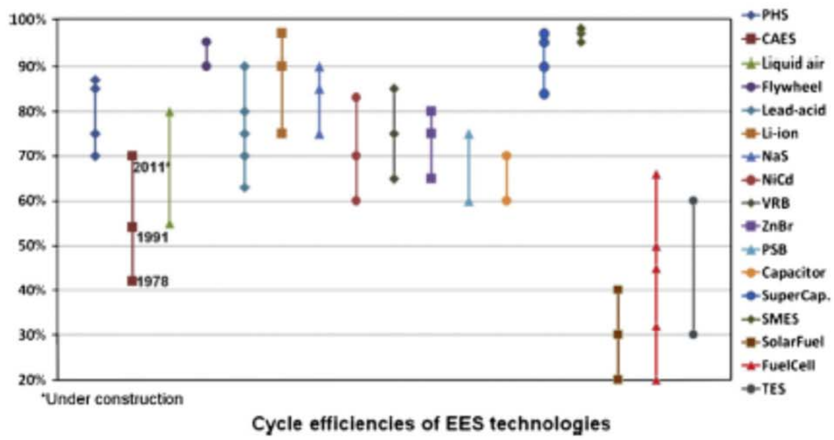


Fig. 17. Comparison of cycle efficiencies of EES technologies.

Capital Cost and O&M Cost

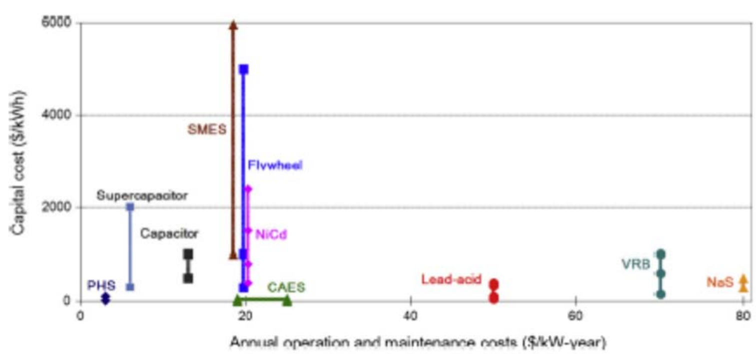


Fig. 18. Comparison of energy capital cost and annual operating & maintenance cost.

Power and Energy Capacity

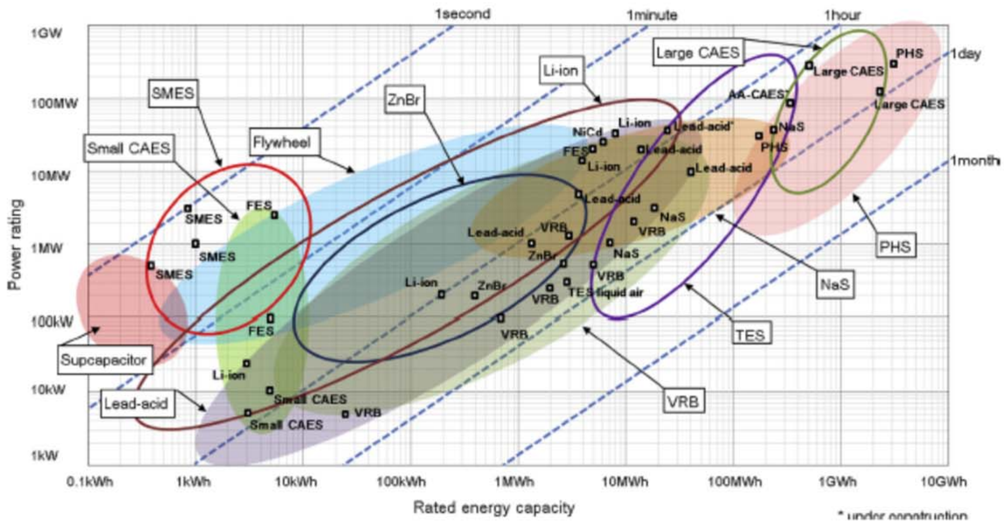
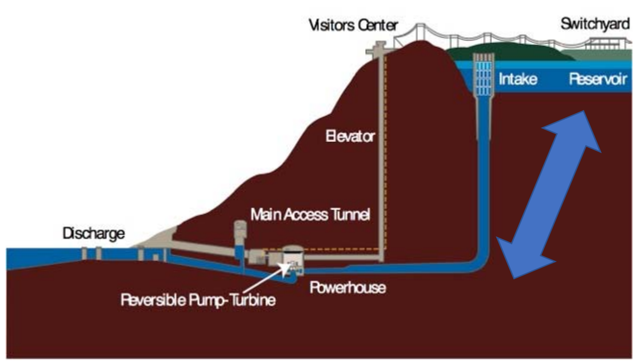


Fig. 16. Comparison of power rating and rated energy capacity with discharge time duration at power rating. The marked data of EES facilities from the cited references in Section 2 of the paper).

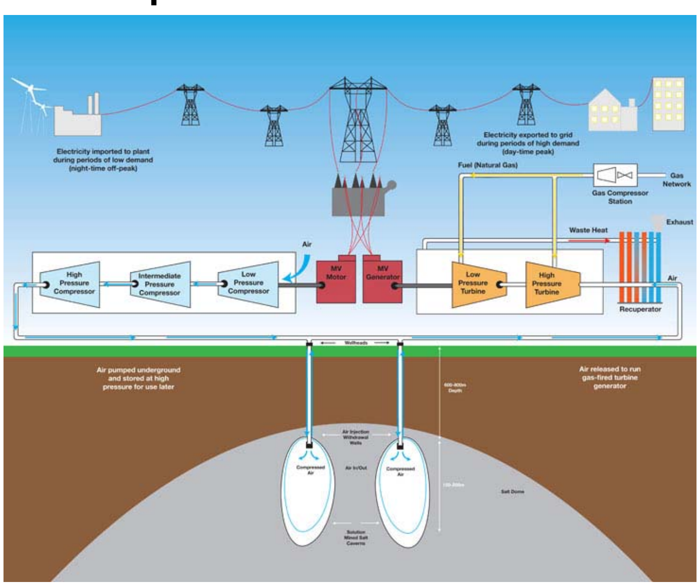
Tried and Proven: Hydroelectric Storage



Batteries

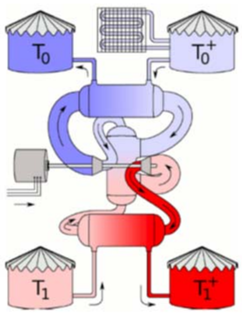
Readily available in the MW size range

Compressed Air Energy Storage



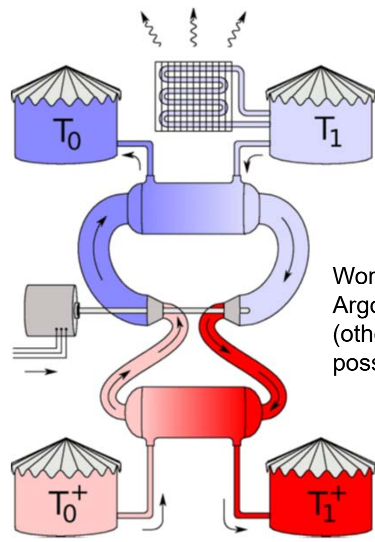
Two things need to be stored:
-Heat of Compression
-Pressurized Air

Pumped Thermal Storage with Heat Exchange (Laughlin)



and Regeneration

Charging phase



Hydrogen In Pipelines

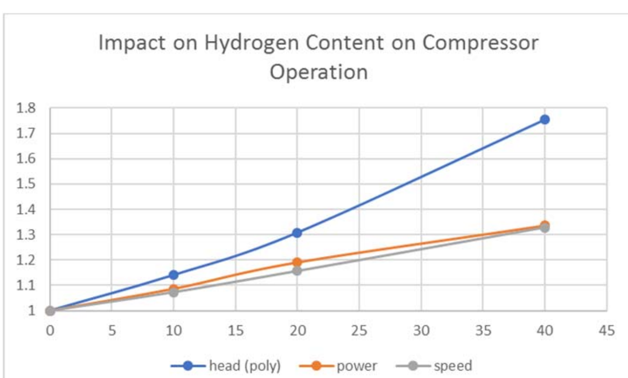
- Transportation Efficiency
- Combustion
- Safety

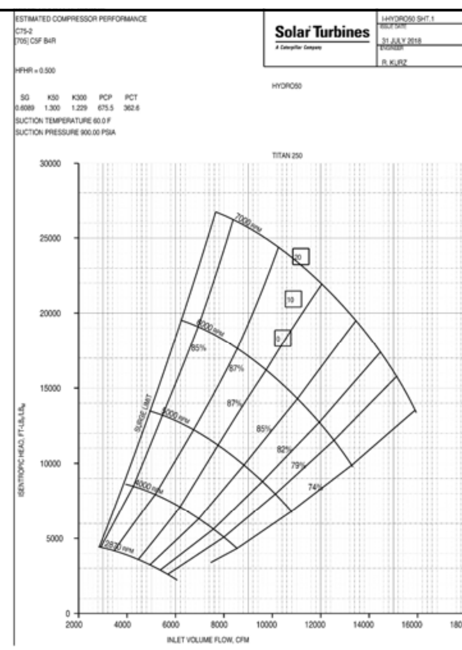
Hydrogen

- Very light, very small molecule (H_2)
  - Mole Weight =2 ,(example Natural gas is about 17 -18)
  - High Cost of Compression
  - Leakage issue
  - Heats up when expanded (most other gases cool down)
- Usually not naturally occurring, but can be created by electrolysis from Water.
  - Electrolysis consumes electricity
  - Conversion Efficiency between 20 and 60 %

Hydrogen In Pipelines

Power Demand for Compression (same Energy Content)



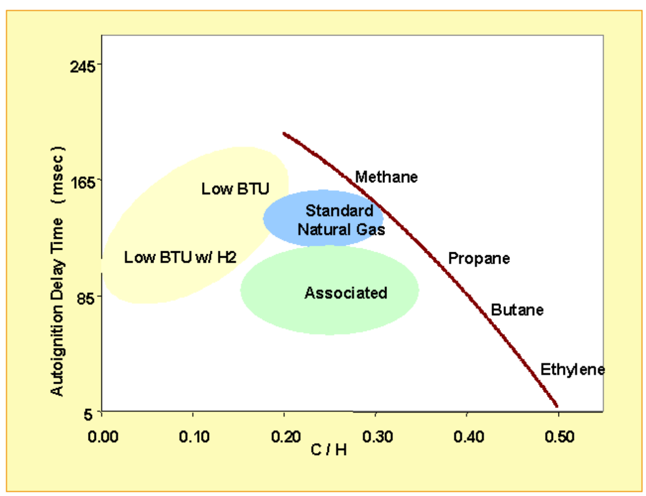


Combustion and Hydrogen

- Todays Lean Premix (Low Emission) combustion systems can accept some Hydrogen in the fuel gas

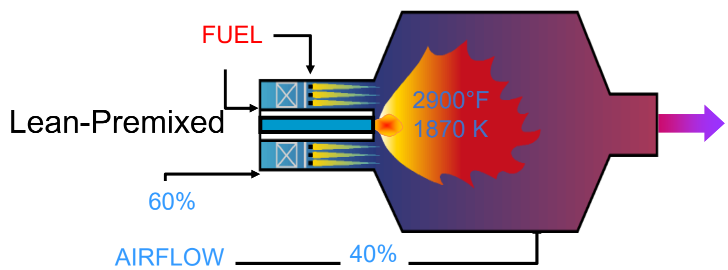
Hydrogen

- Much Higher Flame Velocity
- Higher Auto Ignition Delay Time

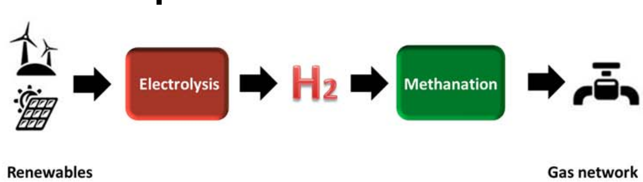


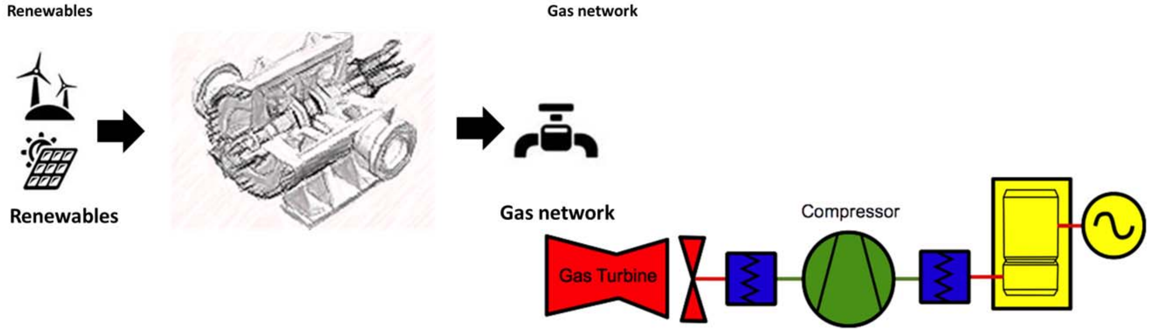
Auto Ignition and Flashback

- Autoignition Delay Time
  - Longer for lean mixtures
  - Shorter for higher pressure and temperature
- Flashback
  - Flame Speed vs Bulk Velocity
  - Flame speed higher for Propane or Hydrogen



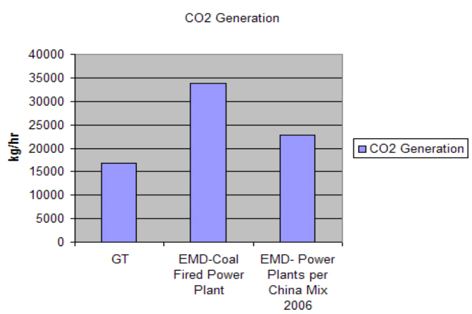
Power to Gas and Power to Compression

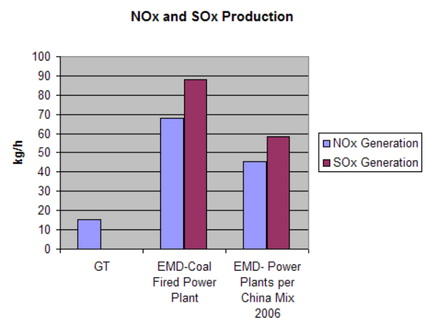




A Note On Emissions Footprint

Comparison for a 30MW Compressor Station with either
2 15MW Gas turbine Drivers or 2 15 MW Variable Speed EMDs





Assumptions: -Dry Low Nox Gas Turbine (Solar Titan 130S)
-Power plant Emissions per Klein et al, 2003.
-Efficiency for Electric Drive train: 93%
-Transmission Efficiency for Electric power: 95%
-Power Plant Mix: 65% Coal, 3% Gas, 2% Oil, 30% Nuclear and Hydro

GHG Emissions- Methane and all that

- GTCC's have significantly lower Methane emissions than other gas fired concepts
  - Lower UHC/VOC emissions
  - Lower seal leakage (typically less than 0.005% of gas flow for a pipeline compressor)
  - Fewer shutdowns requiring blowdowns

Macro System

- Integration with Gas User

  - Pipelines have storage capability
  - Electrical grids don't (except for batteries)
  - Smart cooperation between power plants and their pipelines

Renewable Energy Usage Requires:

- significant flexibility from Gas Fired Systems

and

-storage capability