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OFF-GRID ENERGY SYSTEM WITH SEASONAL STORAGE

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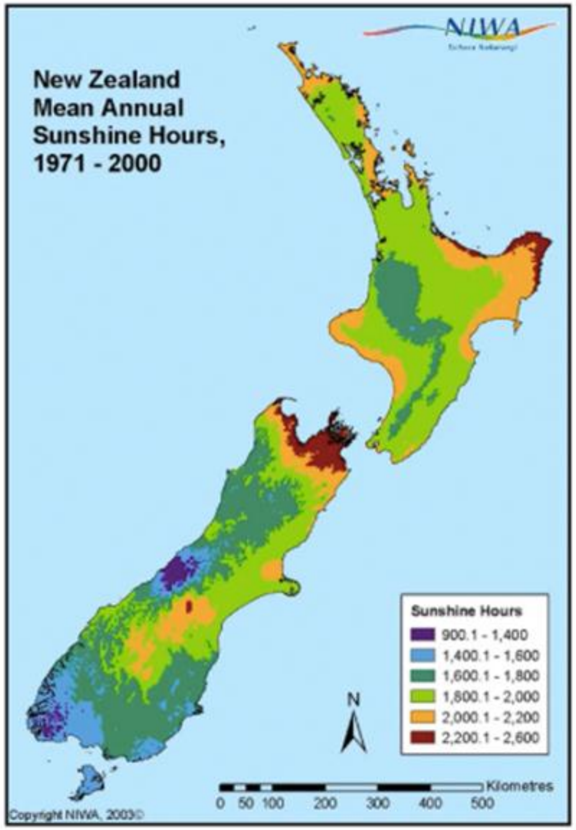
CONTENTS

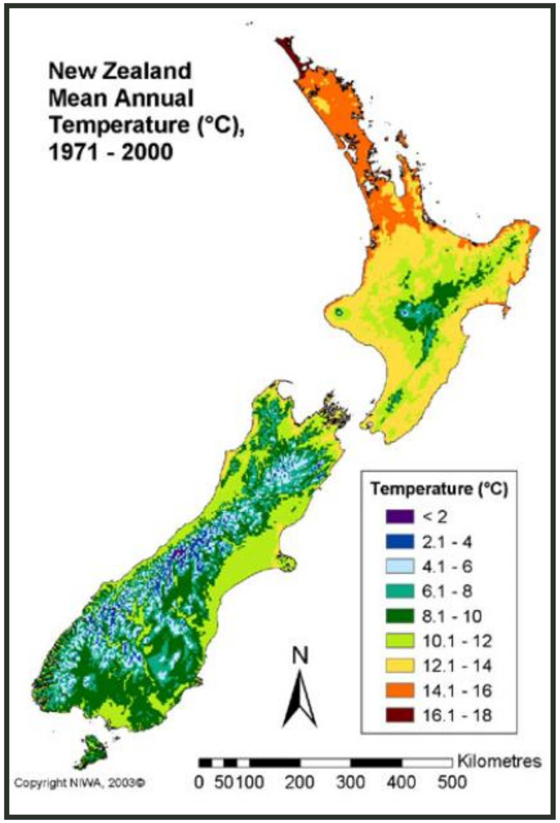
ENERGY SELF SUFFICIENT HOUSE

- ☐ Inter-seasonal energy self sufficient house for remote rural areas
  - Avoid high energy delivery costs
    - LPG, diesel
    - Electricity de-regulation
  - Sustainability with style - convenience
  - Elegant inter-seasonal storage - engineering challenge
  - Unmet demand - a market opportunity

NZ CLIMATE

- Longitude and altitude influence solar insolation, HDD and CDD





Seasonal variations:

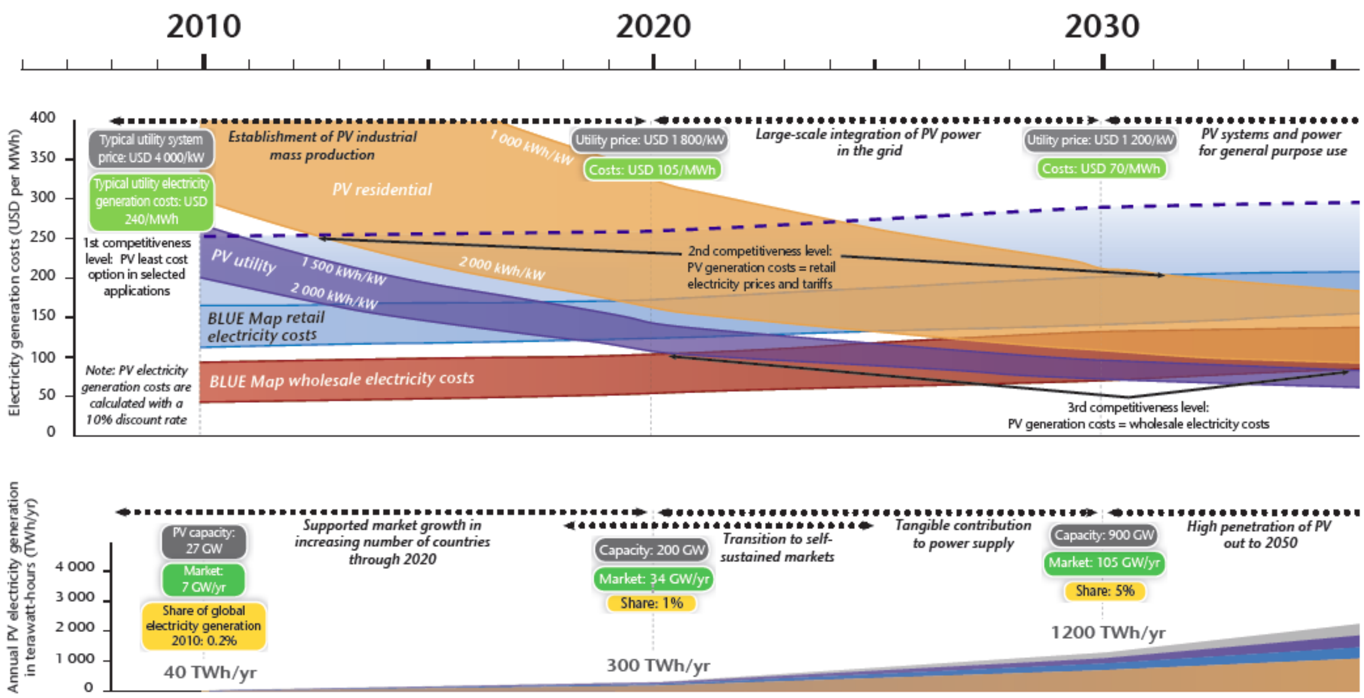
North has more Insolation overall and requires more cooling in the summer.

South has low insolation in the winter and requires more heating.

Alpine and high country regions have greater extremes.

PV COST TRENDS

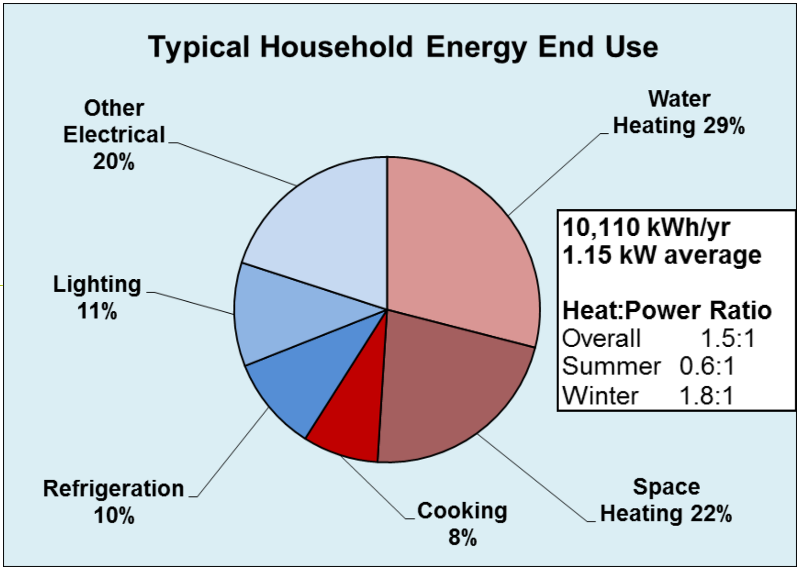
- IEA view of future solar PV cost trends – the impact of technology learning



Assumptions: Interest rate 10%, technical lifetime 25 years (2008), 30 years (2020), 35 years (2030) and 40 years (2050); O&M costs 1%.

- Distributed PV achieves grid parity by 2020, domination by 2030

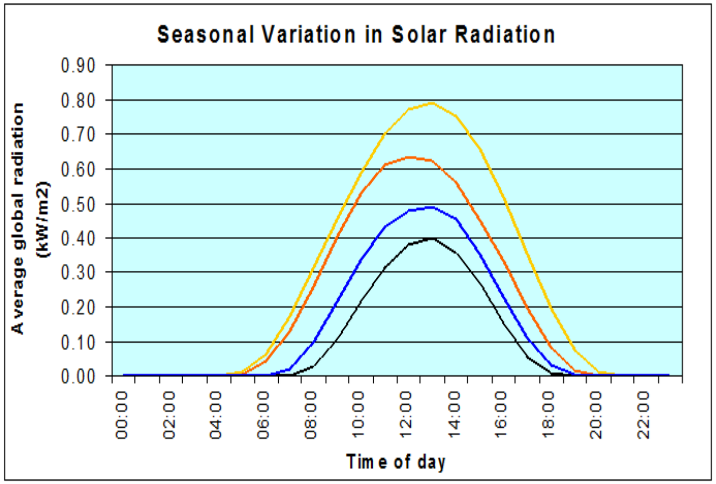
BASELINE ANNUAL DEMAND

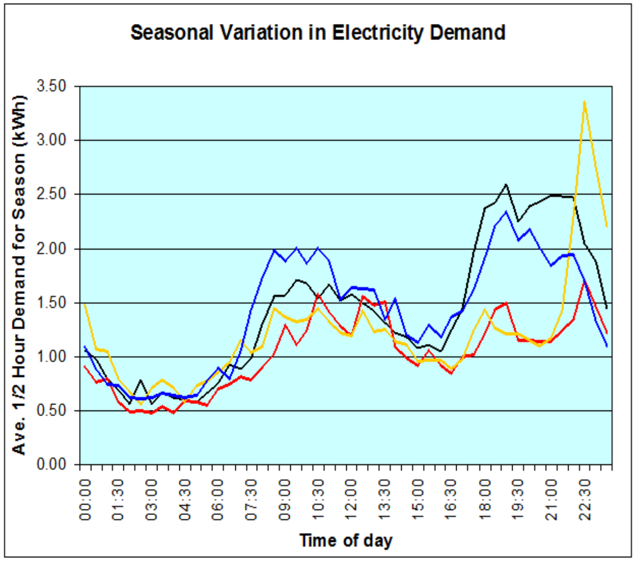


- ☐ Hot water, cooking, and space heating consume over 60% of the total
- ☐ Can be delivered via a thermal fuel

Energy Use	Annual kWh	%	Notes
Electricity (average power =384W)	2360	36.5	From PV direct and from battery.
Lights and miscellaneous intermittently used appliances.	2000	31	Combined monthly demand assumed to be relatively constant.
Heat pump – summer cooling	360 nominal	5.5	Proportional to cooling degree days.
Hydrogen (average power = 470W)	4120	63.5	From hydrogen store.
Cooking	420	6.5	Monthly demand assumed constant.
Water heating	2000	31	Monthly demand assumed constant.
Space heating	1700 nominal	26	Proportional to heating degree days.
Total annual energy use	**6480**	100	Depends on climate (degree-days).

ENERGY SUPPLY-DEMAND MISMATCH





Electrical demand from an on-grid rural community

- Electrical
  - Supply is highest in summer
  - Seasonal demand is relatively constant
  - Daily fluctuations smoothed by a “small” battery store of electricity
- Thermal
  - Seasonal demand is highly variable
  - Daily and seasonal fluctuations smoothed by a “large” store of fuel
  - Hydrogen is an efficient fuel – produced on-site from water

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HYDROGEN AS A STORAGE OPTION

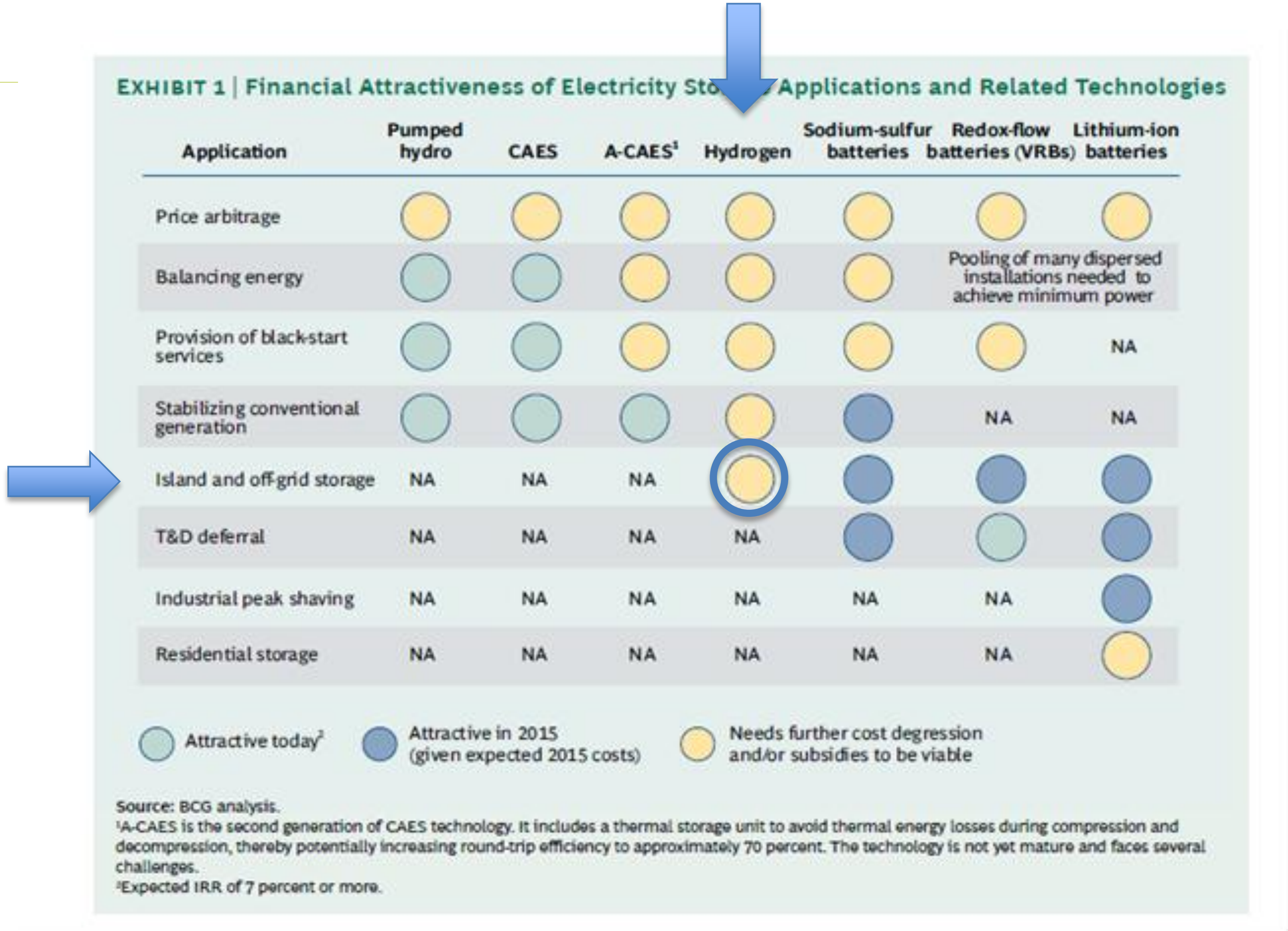


EXHIBIT 1 | Financial Attractiveness of Electricity Sto Applications and Related Technologies

Application	Pumped hydro	CAES	A-CAES[1]	Hydrogen	Sodium-sulfur batteries	Redox-flow batteries (VRBs)	Lithium-ion batteries
Price arbitrage	🟡	🟡	🟡	🟡	🟡	🟡	🟡
Balancing energy	🟢	🟢	🟡	🟡	🟡	Pooling of many dispersed installations needed to achieve minimum power	
Provision of black-start services	🟢	🟢	🟡	🟡	🟡	🟡	NA
Stabilizing conventional generation	🟢	🟢	🟢	🟡	🔵	NA	NA
Island and off-grid storage	NA	NA	NA	🟡	🔵	🔵	🔵
T&D deferral	NA	NA	NA	NA	🔵	🟢	🔵
Industrial peak shaving	NA	NA	NA	NA	NA	NA	🔵
Residential storage	NA	NA	NA	NA	NA	NA	🟡

🟢 Attractive today[2]
🔵 Attractive in 2015 (given expected 2015 costs)
🟡 Needs further cost degression and/or subsidies to be viable

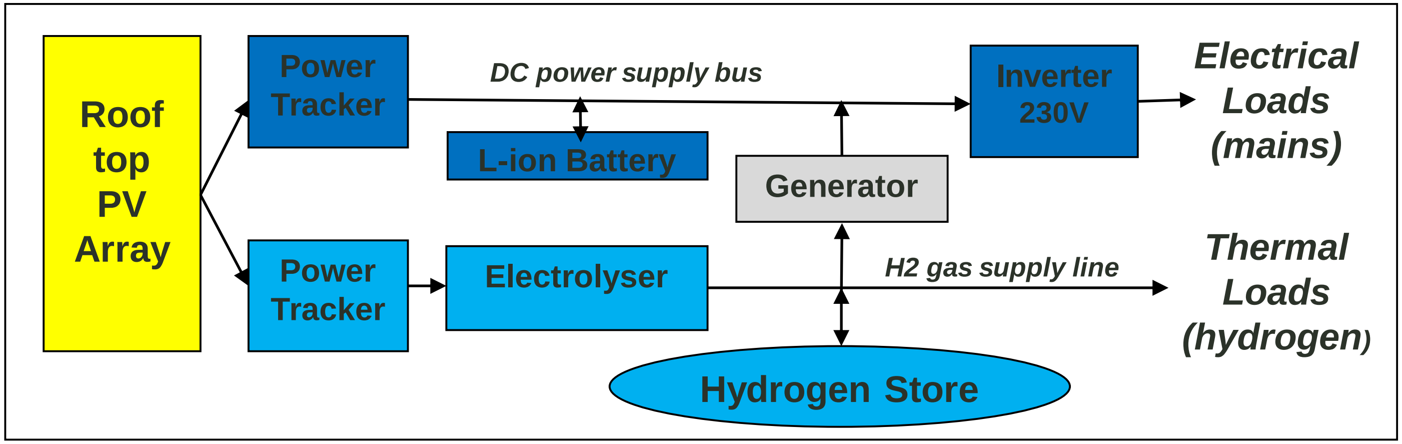
Source: BCG analysis.

[1] A-CAES is the second generation of CAES technology. It includes a thermal storage unit to avoid thermal energy losses during compression and decompression, thereby potentially increasing round-trip efficiency to approximately 70 percent. The technology is not yet mature and faces several challenges.

[2] Expected IRR of 7 percent or more.

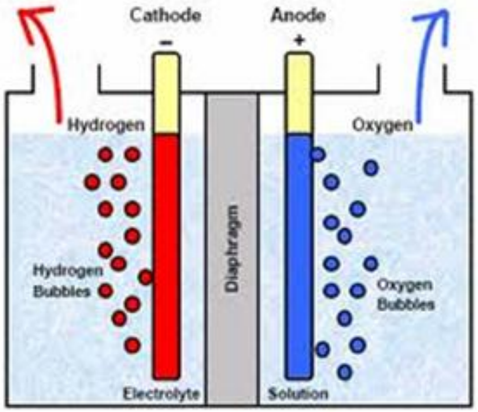
MODELLING: TECHNOLOGY MODEL

- Assumptions
  - Battery size is sufficient for at least a day of storage
  - Serve electrical load first, then charge battery, then produce and store hydrogen
  - If the battery charge is too low, re-generate from H2 store (these occasional transfers are not accounted for in the current model)



MODELLING - APPROACH

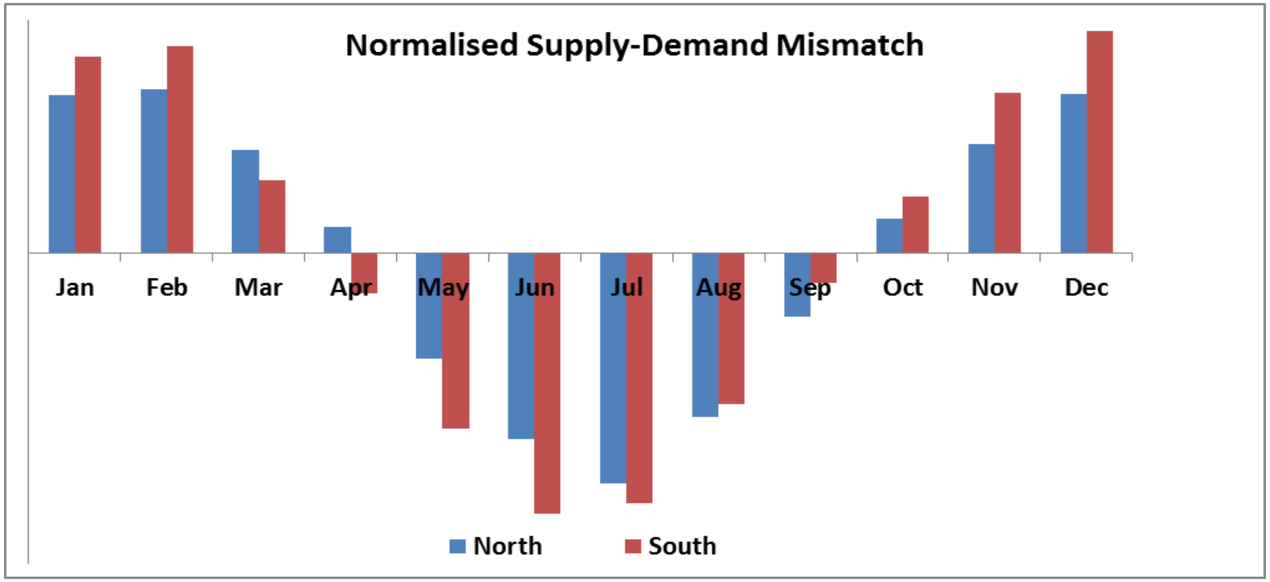
- Assume house design is energy efficient and the household observes conservative energy use practices
- For different scenarios
  - Develop realistic monthly demand profile variations from an annual baseline - using Heating Degree Days and Cooling Degree Days
  - Calculate solar PV supply capacity requirements
  - Calculate seasonal energy storage requirements
- Hydrogen
  - Produced on site by electrolysis
  - 80% average production efficiency
  - CHP not utilised
  - Appliance efficiency similar to LPG



Single electrolysis cell

MODELLING: 2 SCENARIOS

- Northern/warm and a southern/cool locations chosen
  - Estimate monthly variation from average for demand and supply
  - Northern solar energy is 15% higher than southern
  - Southern thermal demand is 79% higher than northern



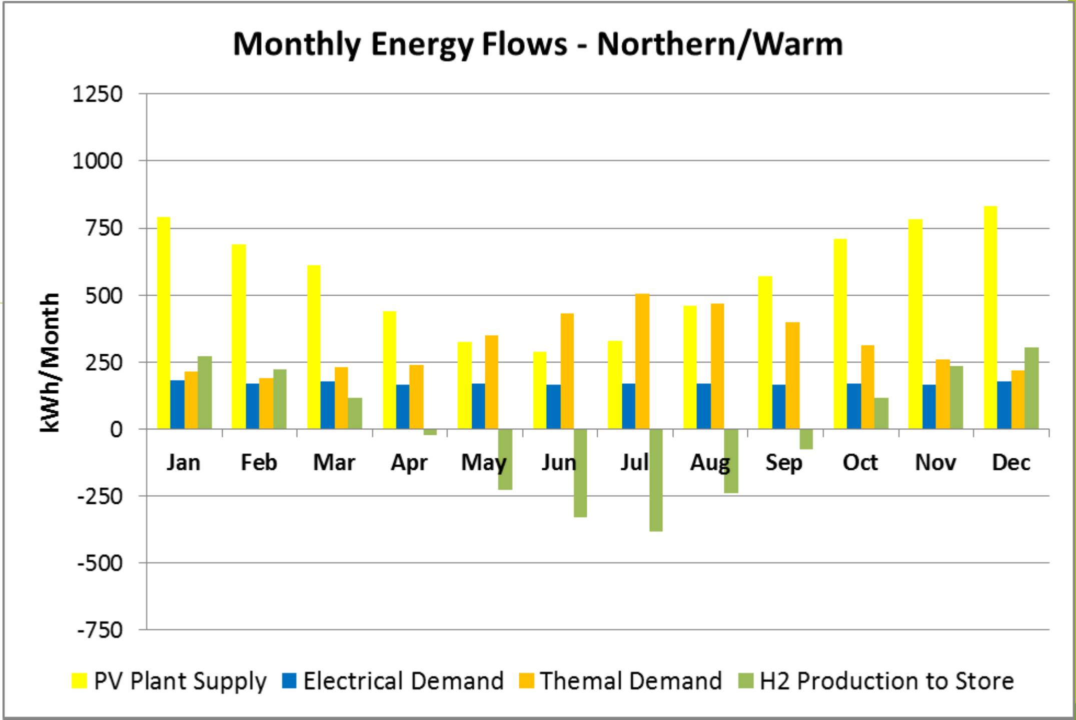
  - Calculate monthly storage transfers
  - Determine size of store

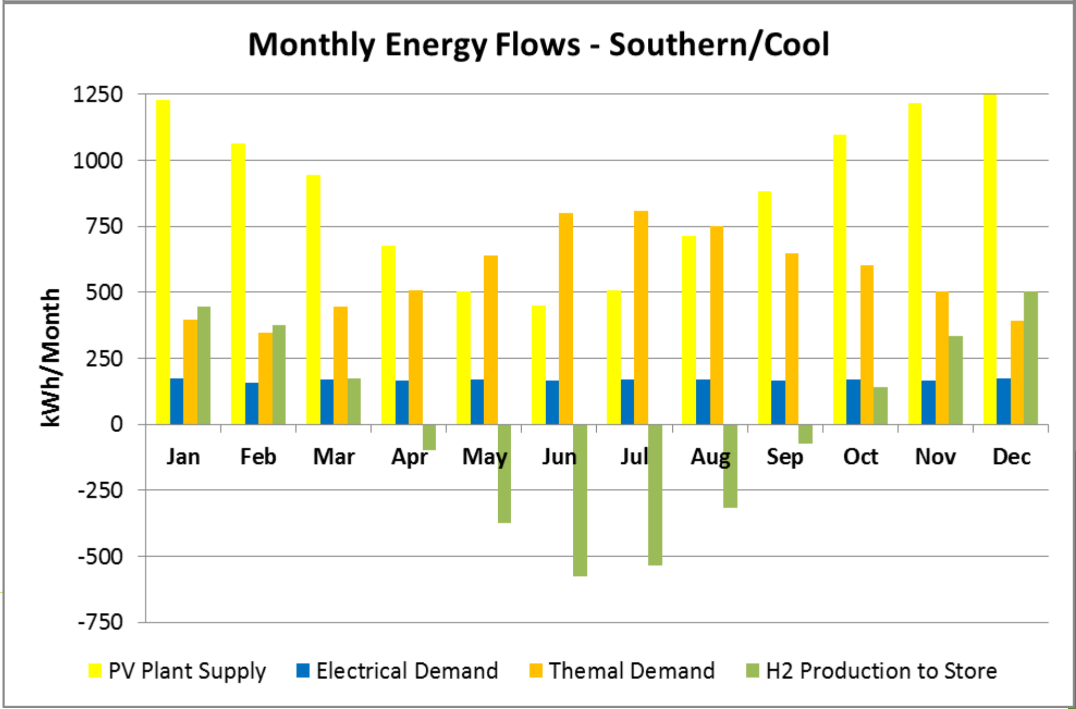
MODELLING RESULTS

- Northern/Warm:
  Summer air conditioning based on degree days contributes very little to electrical demand

- Southern/Cool:
  Larger PV array captures more energy, even in winter.

- Both scenarios:
  Sufficient electricity is generated in the winter to meet electrical demand





MODELLING RESULTS

- Annual demands and storage requirements for the two scenarios

Energy (kWh)	Northern/Warm Scenario	Southern/Cool Scenario
Ave. solar/day/m^2 at tilt	4.34	3.78
Electrical supply/yr (after losses)	6,832	10,571
Electrical demand/yr	2,048	2,014
Thermal demand (H_2 prodn.)/yr	3,827	6,845
Total end use demand/yr	**5,875**	**8,859**
Hydrogen store capacity (HHV)	**1,270 (22% of total)**	**1,974 (22% of total)**

Southern/cool requires 51% more energy than northern/warm, and thermal storage needs are 55% greater.

HYDROGEN STORAGE OPTIONS

- Volumes

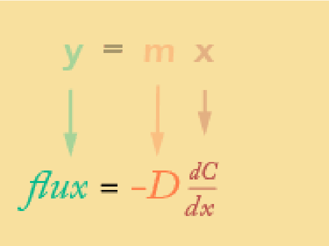
At NTP (Atmospheric)	Energy (kWh)	Volume (Nm^3)	Weight (kg)
Energy Density	3.2	1	0.0812
Northern	1270	397	32
Southern	1974	617	50

- Storage options (volume is inversely proportional to pressure)

Vessel	Pressure (bar)	Factors
Metal hydride	10	Heavy (M-H 20xH2wt), high cost
HP steel cylinders	200	Compression, energy, high cost
EHP composite tanks	700	Compression, energy, v high cost
LP plastic pipes	4	LP electrolyser, low cost
Flexible bag	1 (Atmospheric)	LP pumping, very low cost

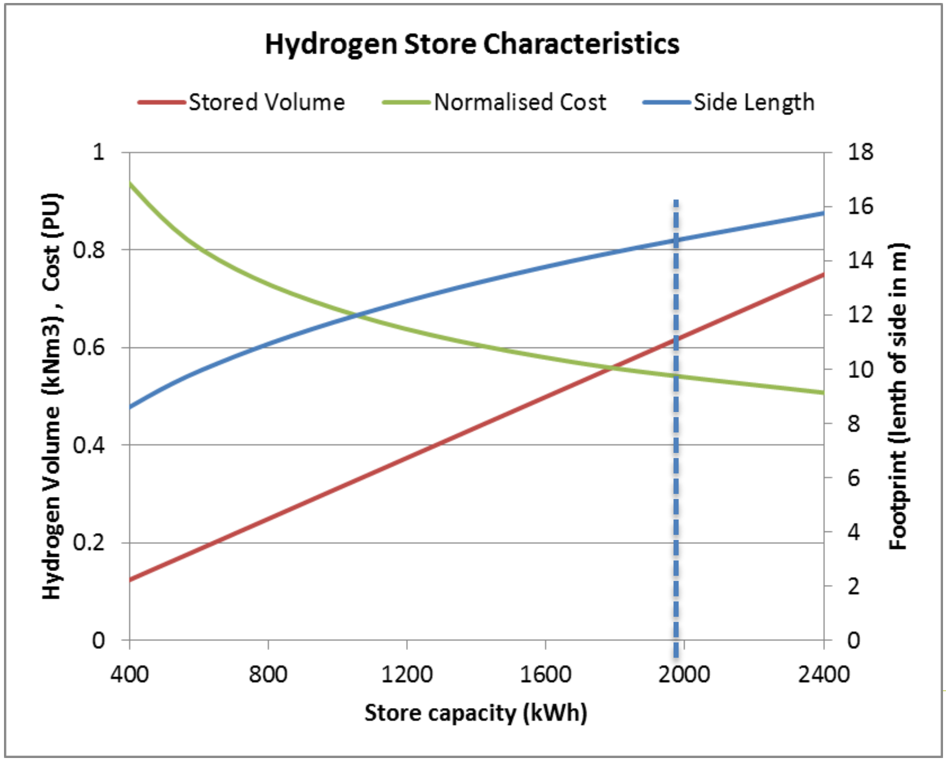
ATMOSPHERIC PRESSURE STORAGE

- Membrane permeability to gases
  - Hydrogen out – loss of efficiency
  - Oxygen in – explosion hazard (max O_2<1%)
- Gas diffusion is governed by Ficks law

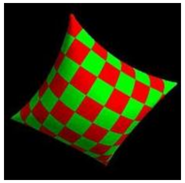


$$y = m\,x$$

$$flux = -D\frac{dC}{dx}$$



Volume - the tea bag problem:



$$V = w^3\left(h/\left(\pi w\right) - 0.142\left(1 - 10^{\left(-h/w\right)}\right)\right),$$

h = *w* = 15m provides ~ 2,000kWh

Plenty of room on many rural sites -

CONCLUSIONS

- ❑ Solar PV with low pressure hydrogen storage offers an opportunity to achieve year round energy off-grid supply from widely available intermittent renewable energy.
- ❑ Where space is available and the land cost is low, atmospheric pressure bladder storage may be a cost effective option.

THANK YOU FOR ATTENDING

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Matiu/Somes Island pilot system:

http://user.logicenergy.com/matiusomes/display.php