Economic assessment of energy storage systems.

GAZEY, R., ALI, D., AKLIL, D. and FINNEY, S.

2011

ECONOMIC ASSESSMENT OF ENERGY STORAGE SYSTEMS

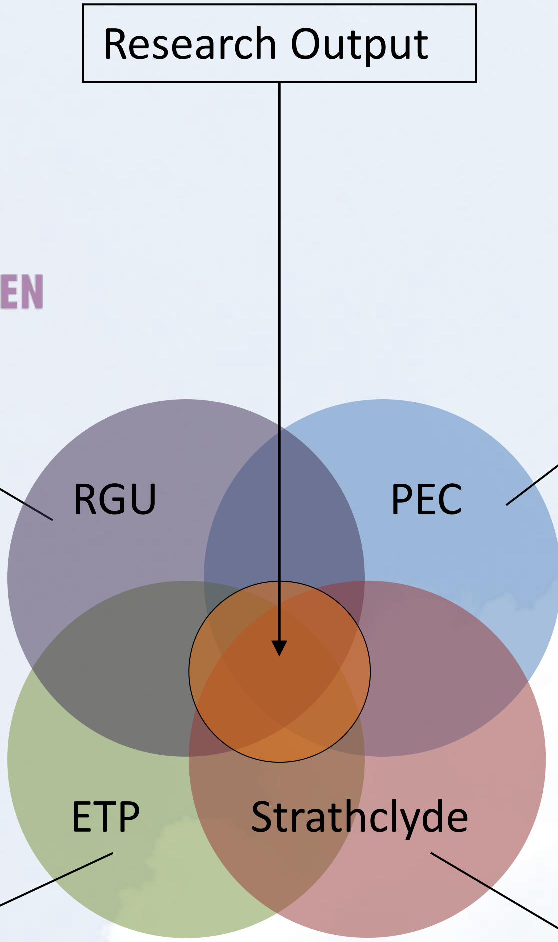
Ross Gazey, BSc(Eng)Hons., MPhil, MIET
PhD Research Student, Robert Gordon University

Overview

- Introduction
- Background
- Energy Storage System (ESS) Summary
- Hydrogen ESS
- Modelling
- Results.

Introduction

Research Partners



Introduction

- Supervisory Team:
  - Dr. Dallia Ali (RGU)
  - Dr. Daniel Aklil (PEC)
  - Dr. Stephen Finney (Strathclyde)

  - Ross Gazey (RGU - PhD Research)

- Acknowledgements to Energy Technology Partnership (ETP), Strathclyde University, Pure Energy Centre, and the Robert Gordon University IDEAS research centre

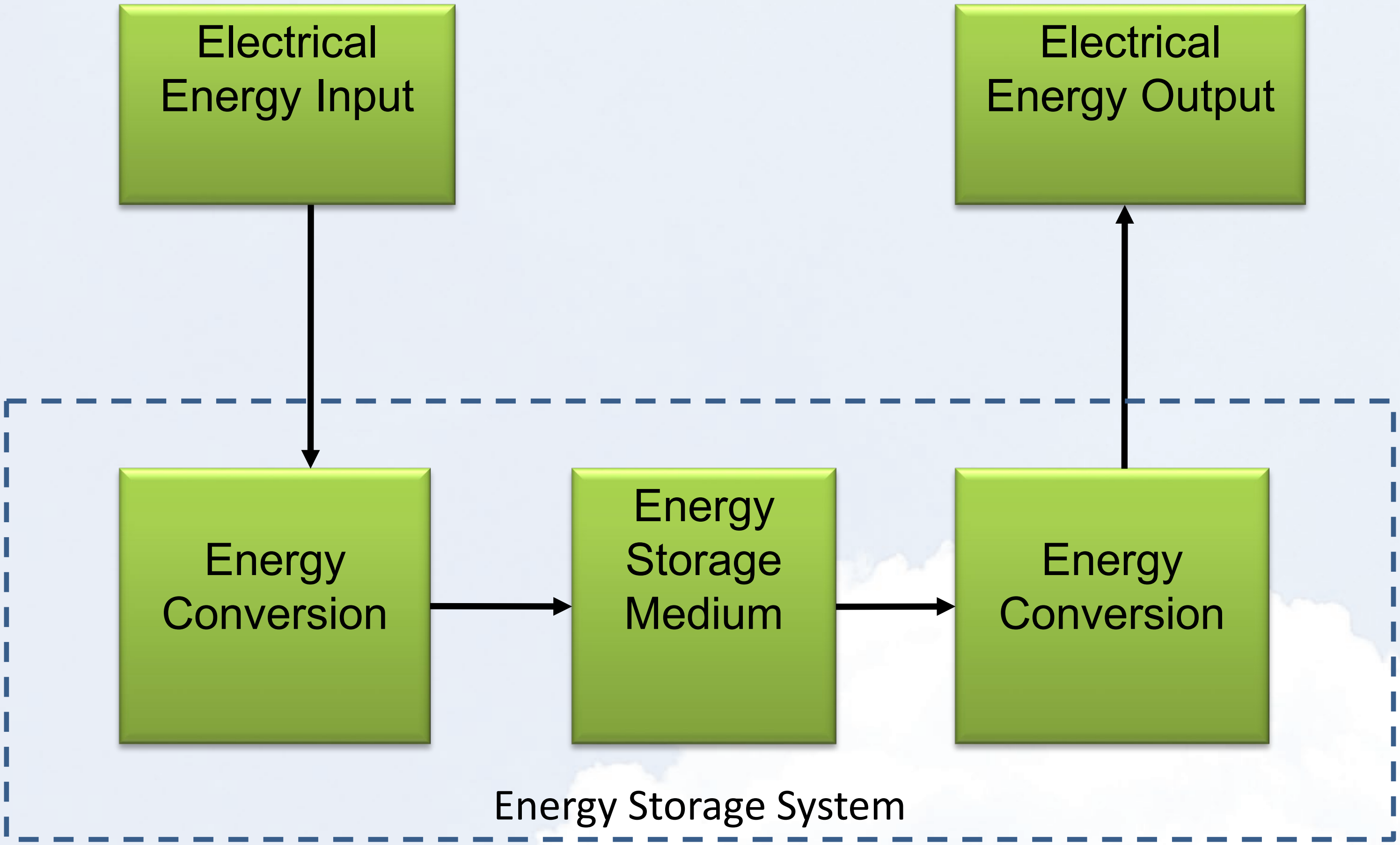
Background

- Within Scotland ambitious national targets are focused on achieving renewable generation of 80% by the year 2020
- Existing electrical infrastructure is becoming increasingly constrained
- Department of Energy & Climate Change announced:

> "In future we need greater electrical energy storage facilities and greater interconnection with our EU neighbours so that excess energy supplies can be sold or bought where required"

Energy Storage Systems (ESS)

Typical Elements of Energy Storage Systems



ESS Characteristics

- Depth of Discharge (DoD)

  How much energy can we take out
- Duration – Storage Capacity (kWh)

  How much can we store and for how long
- Charge/Discharge rates

  How fast can we replenish or remove energy
- Turn Around Efficiency

  How much is lost on the journey through
- How much does it cost
  - Capex
  - Opex

Summary of ESS costs*

Technology	€/kWh	€/kW	Life Time (years)	Efficiency (%)
Pumped Hydro	10-20	500-1500	40-80	65-80
Fuel Cell	2-15	300-1000	10-20	35-45
Battery	210-250	125-150	10-15	75-85
Flywheel	150-200	200-250	20	90
CAES	3-5	300-600	20-40	80-85

***Values taken from literature:**

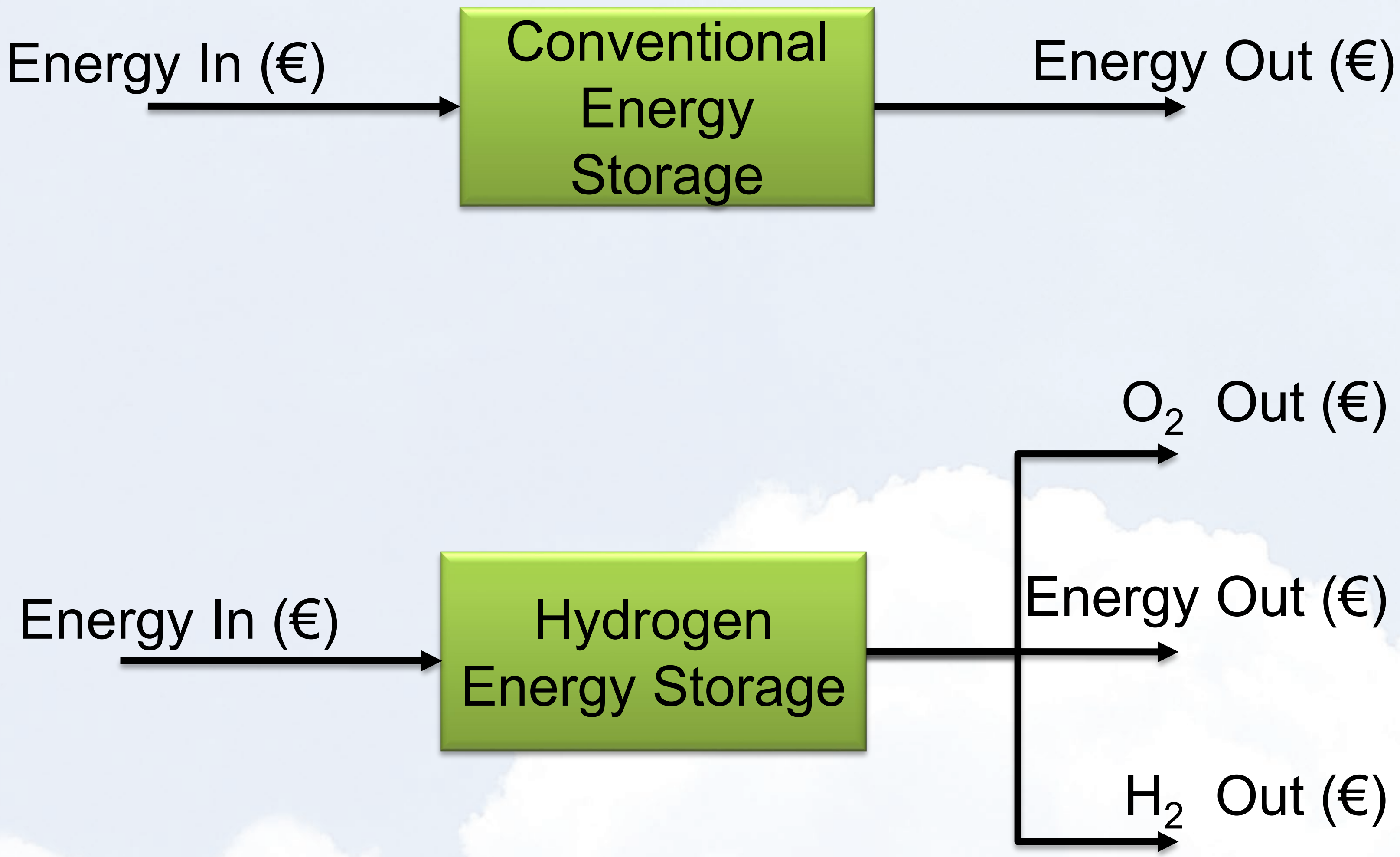
- A. Marshall, "Electricity Storage Struggles to add up", Ends Report 435, April 2011.
- D. Connolly, "A Review of Energy Storage Technologies For the integration of fluctuating renewable energy", University of Limerick, August 2009
- D.Lumb, "Energy Storage & Renewables, is it an uphill struggle?", Edison Mission Energy.
- J.K Kaldellis etall, "Techno-economic comparison of energy storage systems for islands autonomous electrical networks" Renewable & sustainable energy reviews 13 (2009).

Hydrogen ESS cost

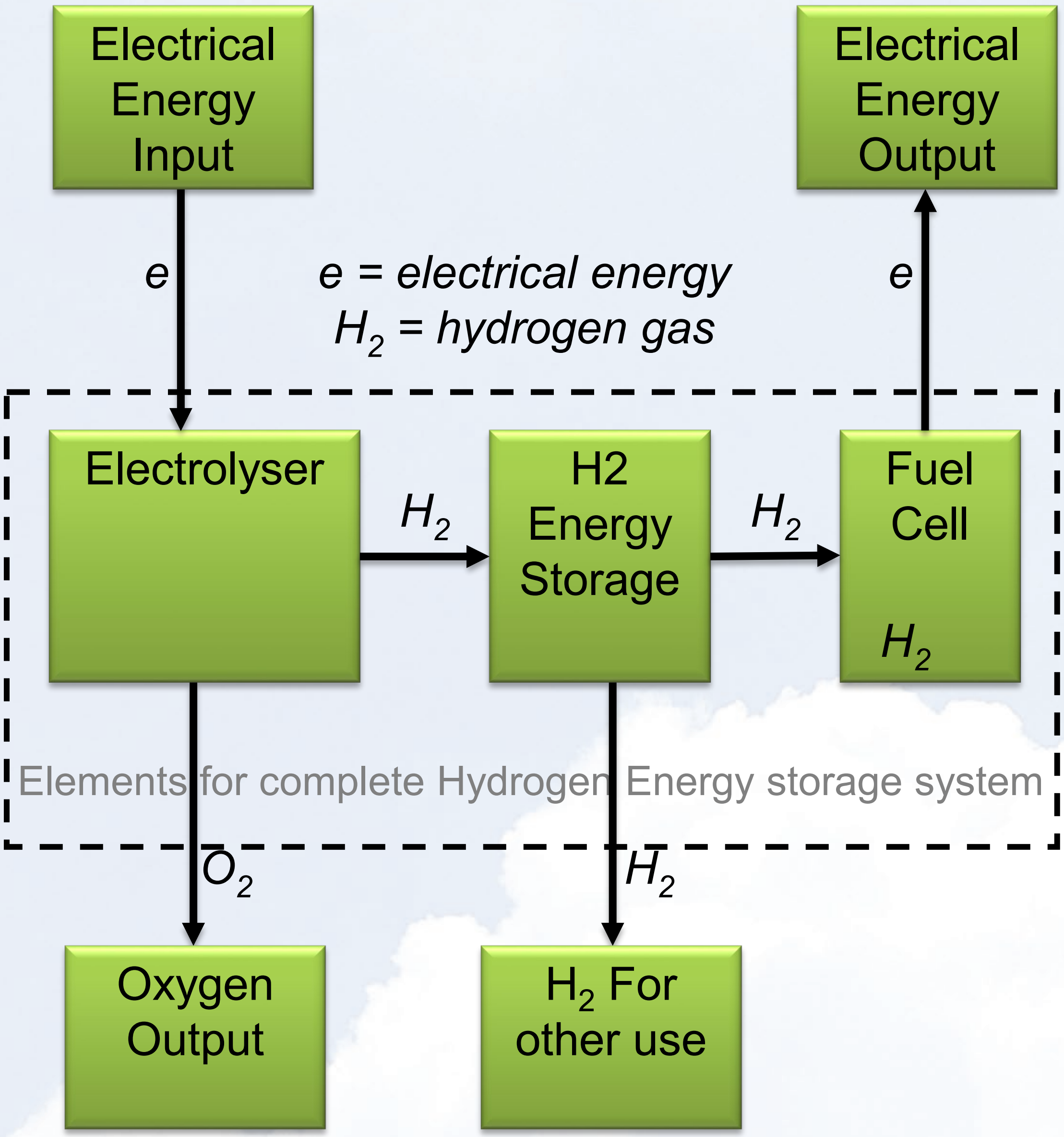
Economic Costs Data*		
Hydrogen ESS Capex		
Electrolyser (€/kW)	€	2,500.00
Storage (€/kWh)	€	77.00
Fuel Cell (€/kW)	€	4,000.00
Annual Hydrogen ESS Opex		
Electrolyser (€/kW)	€	50.00
Storage (€/kWh)	€	2.00
Fuel Cell (€/kW)	€	100.00
Energy cost (€/kWh)	€	0.06
Energy Costs		
Constrained cost (€/MWh)	€	238.89
Generation value (€/MWh)	€	61.11
cost differential (€/MWh)	€	177.78

*Courtesy of the Pure Energy Centre

Hydrogen & Conventional Energy Storage



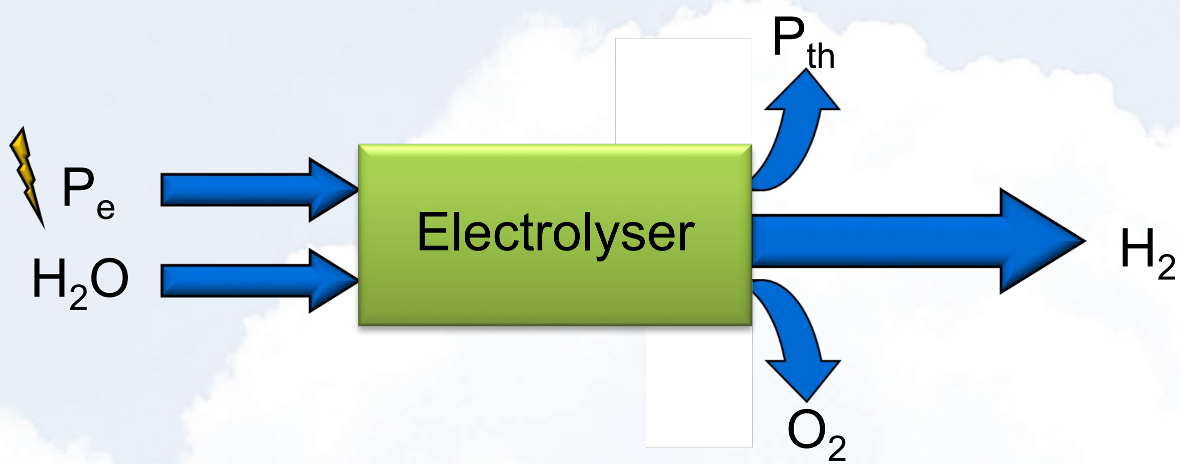
Hydrogen ESS



Hydrogen ESS

What is an Electrolyser?

- An Electrochemical device the converts electrical energy and pure water into hydrogen
- By-products are:
  - Oxygen (O_2)
  - Waste heat (P_{th})
- Typical Efficiency Range 55% to 90%



Hydrogen ESS

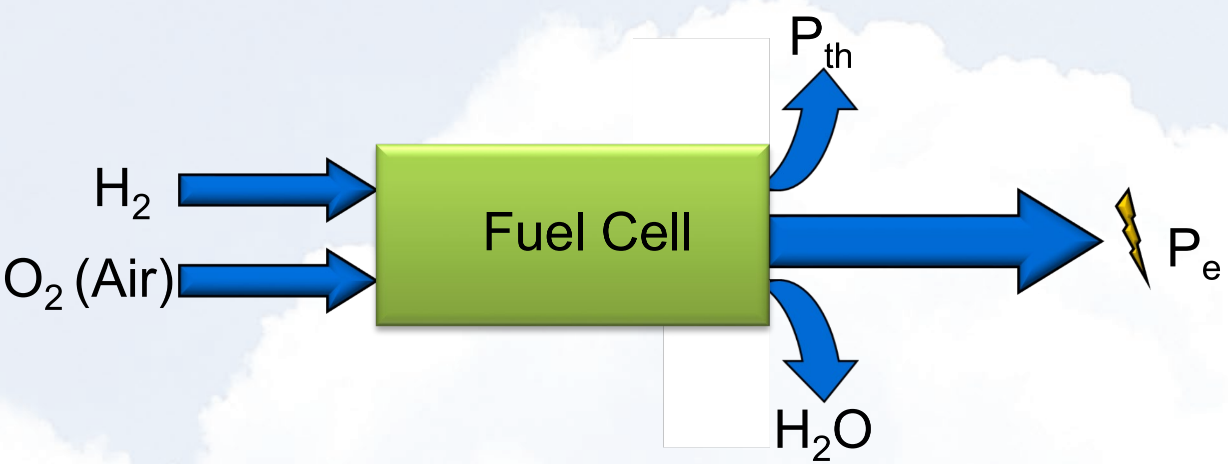
What is a Fuel Cell?

– An Electrochemical device the converts energy in hydrogen into electricity

– By-products are:

- Water vapour (H_2O)
- Waste heat (P_{th})

– Typical Efficiency Range 40% to 60%



Modelling ESS cost

The developed 'Levelised' ESS cost model considered:

- Total cost of ownership
  - ISC_t = Invested Storage Capital in year (t)
  - SOM_t = Storage Operation and Maintenance costs in year (t)
  - EC_t = input energy cost (t)
- Total value of output
  - EO_t = Value of sold energy in year (t)
  - $H2_t$ = Value of sold hydrogen gas year (t)
  - $O2_t$ = Value of sold Oxygen gas in year (t)
- Annual Discount rate of 10% considered (r)
- 20 year operation life considered for H_2 (n)

Modelling ESS cost

Levelised Cost of Storage (LSC)

$$LSC = \frac{\sum_{t=1}^{n} \frac{ISC_t + SOM_t + EC_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{EO_t + H2_t + O2_t}{(1+r)^t}}$$

ISC_t	= Invested Storage Capital in year (t)
SOM_t	= Storage Operation and Maintenance costs in year (t)
EC_t	= input energy cost (t)
EO_t	= Value of sold energy in year (t)
$H2_t$	=Value of sold hydrogen gas year (t)
$O2_t$	=Value of sold Oxygen gas in year (t)
r	=Annual Discount rate of 10%
n	=20 year operation life considered for H_2

Modelling ESS cost

Market Data*	
O2 Sale (€/Tonne)	€ 3,000.00
H2 Sale (€/Tonne)	€ 5,000.00
Electricity sale (€/MWh)	€ 177.78
Discount rate (r)	10%

*Courtesy of the Pure Energy Centre

Modelling ESS cost

Considered Scenarios:

A. No FC - (no energy sale), 100% 0_2 & H_2 gas sold

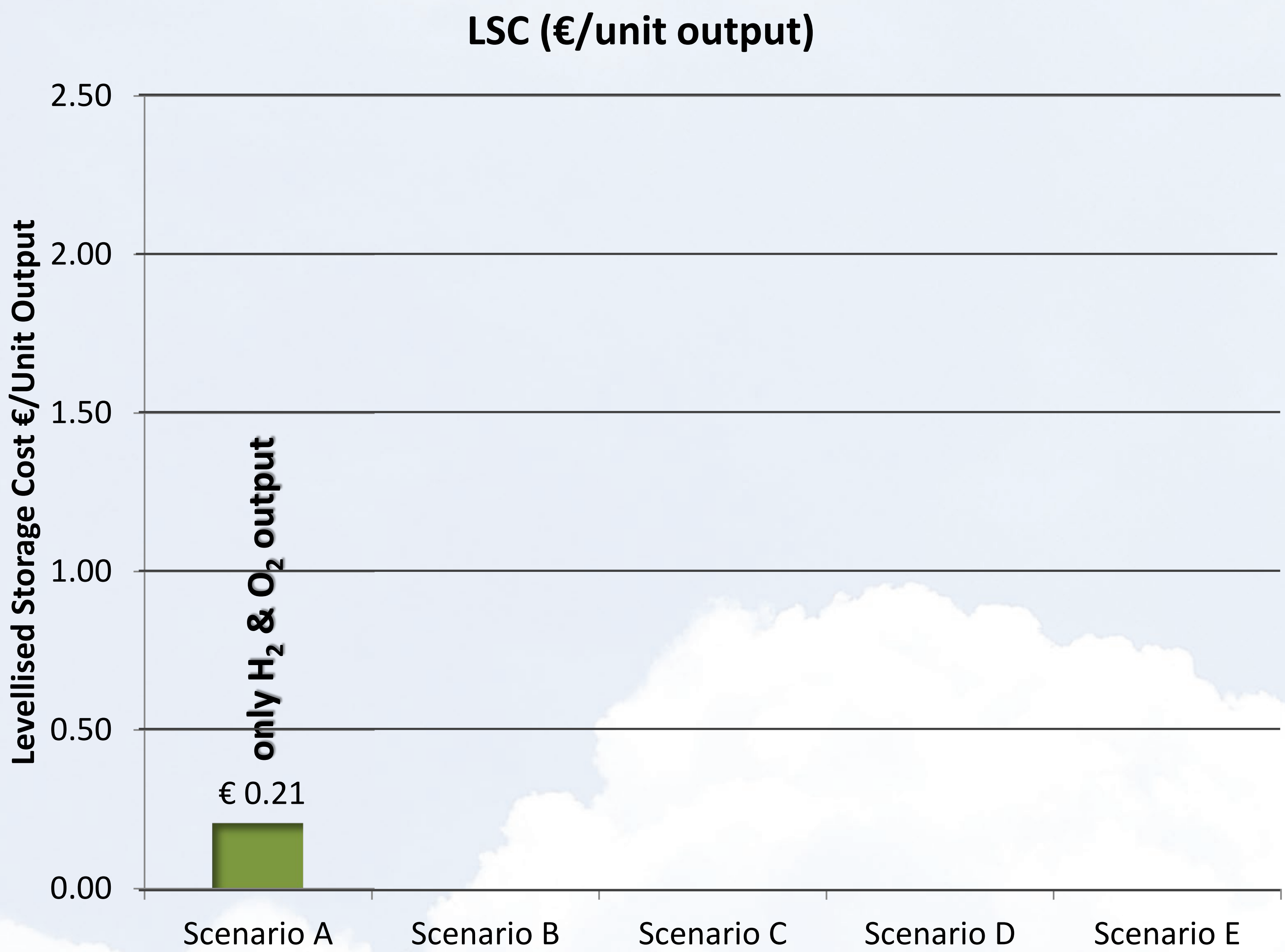
B. 100% energy sale - 3MW FC, 100% 0_2 sold, no H_2 sale

C. 50% O_2 & H_2 gas sold, 50% H_2 sold as energy through a 3MW FC

D. No FC - (no energy sale), no 0_2 sold, 100% H_2 sold

E. 100% Energy sold (3MW FC), no O_2 nor H_2 sold

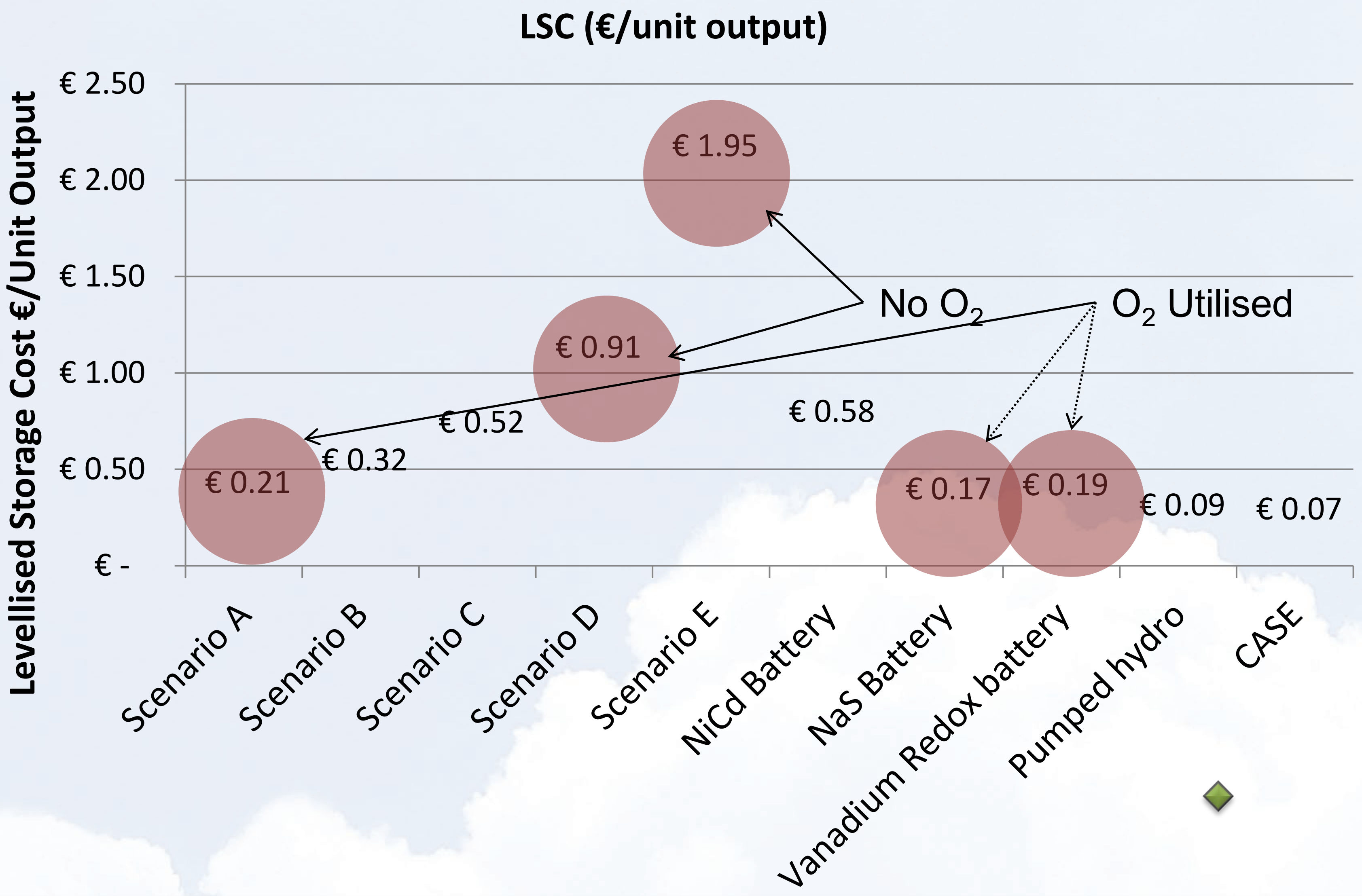
Results



LSC (€/unit output)
Levellised Storage Cost €/Unit Output
2.50
2.00
1.50
1.00
0.50
0.00
only H_2 & O_2 output
€ 0.21
Scenario A
Scenario B
Scenario C
Scenario D
Scenario E

Results

How does H2 Compare with other technologies



Conclusion

- Electrolysis as a network deferrable balancing load has the potential to offer a cost effective solution
- H_2 technology is getting close to other electrochemical energy storage technologies where otherwise 'vented' O_2 is utilised.
- When looking at electricity only, cost of H2 technology has to reduce to become as competitive with other ESS.