FC Backup Power
Case Study Norway

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Contents

- Introduction to IFE
- Fuel Cell Backup Power Case Study

Annual turnover:

1

BNOK

Annual scientific publications:

280

1948: IFA

1980: IFE

No. of employees:

650

Nationalities: 37

Researchers: 218

PhDs: 105

14000

Visitors a year

Advanced Laboratories:

24

National Centres for Environment-friendly Energy Research

2

International projects:

> 120

Digital Systems

- Control Room and Operations Centres
- Virtual and Augmented Reality
- Intelligent Systems
- Automation and User Monitoring
- Risk, Safety and Security
- Human and Organizational Factors

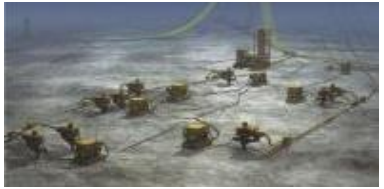
Material and Process Technology

- Solar Energy
- Battery Technology
- Renewable Energy Systems
- Neutron Material Characterization
- Material Processes
- Sustainable Industry

Flow Technology and Environmental Analysis

- Flow Technology
- Wind Technology
- Corrosion
- Tracer Technology
- Environmental Analysis

Li-ion Battery Value Chain



Li-on Battery Life Time Testing

- Accelerated Testing using
  - Fireproof storage
  - Temperature controlled cells
  - 104 test channels (0-5V, 0-50A)
- Characterization of Degradation with:
  - High precision Coulombic efficiency measurements
  - Differential capacity (dQ/dV) cycling measurements
  - Entropy spectroscopy (thermal characterization)
  - Electrochemical impedance
- Battery Lifetime Modeling
- Key Projects:
  - SafeLiLife → BattMarine

Hydrogen Systems

Hynor Hydrogen Technology Center

NORWEGIAN FUEL CELL AND HYDROGEN CENTRE
FUEL CELL & ELECTROLYSER SYSTEMS

Focus Areas

- Fuel Cell Systems
  - Hybrid PEMFC / Li-ion Battery Systems
- Water Electrolysis
  - Small-scale PEM (high pressure)
  - Large scale Alkaline
- System Modelling: Matlab Simulink, EES
- System Testing: IFE Hynor

Key Projects

- FME MoZEES
- Norwegian FCH Centre
- Contract Research

MOZEES
Mobility Zero Emission Energy Systems

Research Infrastructure

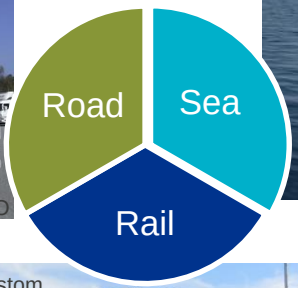
Clients & Partners

- Energy & Power Companies
- System Integrators
- Technology Companies

Research Center on Zero Emission Mobility

1 of 8 National Research Centers

Heavy Duty Transport
– New Areas for Innovation & Value Creation



Battery & Hydrogen – Technology Value Chains

CENTRE FOR ENVIRONMENT-FRIENDLY ENERGY RESEARCH
The Research Council of Norway

Materials → Components → Batteries & Fuel Cells → Modules → Systems

MOZEES
Mobility Zero Emission Energy Systems

Hynor Hydrogen Technology Center

NORWEGIAN FUEL CELL AND HYDROGEN CENTRE
FUEL CELL & ELECTROLYSER SYSTEMS

New Research Infrastructure (2016 –)

- Fuel Cell / Battery Laboratory System
- Water Electrolyzer Laboratory System




New Key Projects (2017 –)

MOZEES
Mobility Zero Emission Energy Systems

METROLOGY for HYDROGEN VEHICLES

EMPIR MetroHyVe-project

Contents

- Introduction to IFE
- Fuel Cell Backup Power Case Study

Source: DoE, USA

Telecom Backup Power Market in Norway

- Technology Options
  - Lead-acid Batteries – most commonly used (largest market share)
  - **Diesel** Generators – relatively few installations (small market share)
  - Hydrogen Fuel Cells – a few demonstration systems installed
- System Specifications
  - Most common power requirements today: ca. 5 kW
  - Future power requirement with 5G: **ca. 10 -15 kW**
  - Stand-alone power (legislative) requirement today: 2-4 hours
  - Stand-alone power requirement at some specific sites: **72 hours**

Sources: Nkom, Telia, Telenor

Case Study – Assumptions

- System Design Parameters*
  - Batteries – 5 kWh/h +70% extra capacity → 17 kWh battery per 2 hours
  - Fuel Cell Systems – 2 hydrogen bottles per 2 hour
- Economic Parameters
  - Cost data from literature (reports), suppliers, users, and IFE (data base)
  - Sensitivity analysis wrt. specific costs, lifetime, etc.
- Method
  - Net Present Value (NPV) calculations; i = 3 %, n = 10 and 15 years
  - Excel Spreadsheets

*Sources: Battery, Hydrogen, and Fuel Cell Technology suppliers

Hydrogen Fuel Cell System – Parameters

System category *FC Rated Power (kW)*		**System 1** *5 kW*				
Hours of back-up		2	4	24	48	72
# of H2 bottles necessary		2	3	8	14	21
Bundles if necessary (16 bottles)					1	1 + 5 bot
CAPEX	**NOK/kW or % of FC**					
Fuel cell stack (10000-30000)	20,000					
Power electronics + cables + rack	50%					
Supercap	50%					
H2 bottles	0					
H2 storage cabinet and other equipment	10,000					
Sum CAPEX	*NOK*					
OPEX						
Standby power (NOK/kW)	286					
Hydrogen (rent + test usage) (NOK/bottle) +-50%	1000					
Service every 5th year (NOK)	5000					
Sum yearly OPEX	*NOK*					
Sum year 5 OPEX	*NOK*					

Battery System – Parameters

System category *Battery Rated Power (kW)*		**System 1** *5 kW*				
Hours of back-up		2	4	24	48	72
Capacity needed (kWh)						
# of batteries (battery capacity = 1.8 kWh)						
# of strings (4 batteries in each string)						
# of battery racks needed						
CAPEX						
Battery (1000-4000 NOK/kWh)	2,000					
Battery racks (max 4 strings)	7,000					
Rectifier module	3,000					
Rectifier controller + casing + rack	50%					
Cables (per string)	1,000					
Installation	30%					
Sum CAPEX	*NOK*					
OPEX						
Standby power	7,000					
Floating charge per string	1,000					
Service (twice a year, total is shown)	6,000					
Installation & removal of batteries (every 5th year)	30,000					
New batteries (every 5th year)	2,000					
Battery swap admin costs (every 5th year)	7,000					
Sum yearly OPEX	*NOK*					
Sum year 5 OPEX	*NOK*					

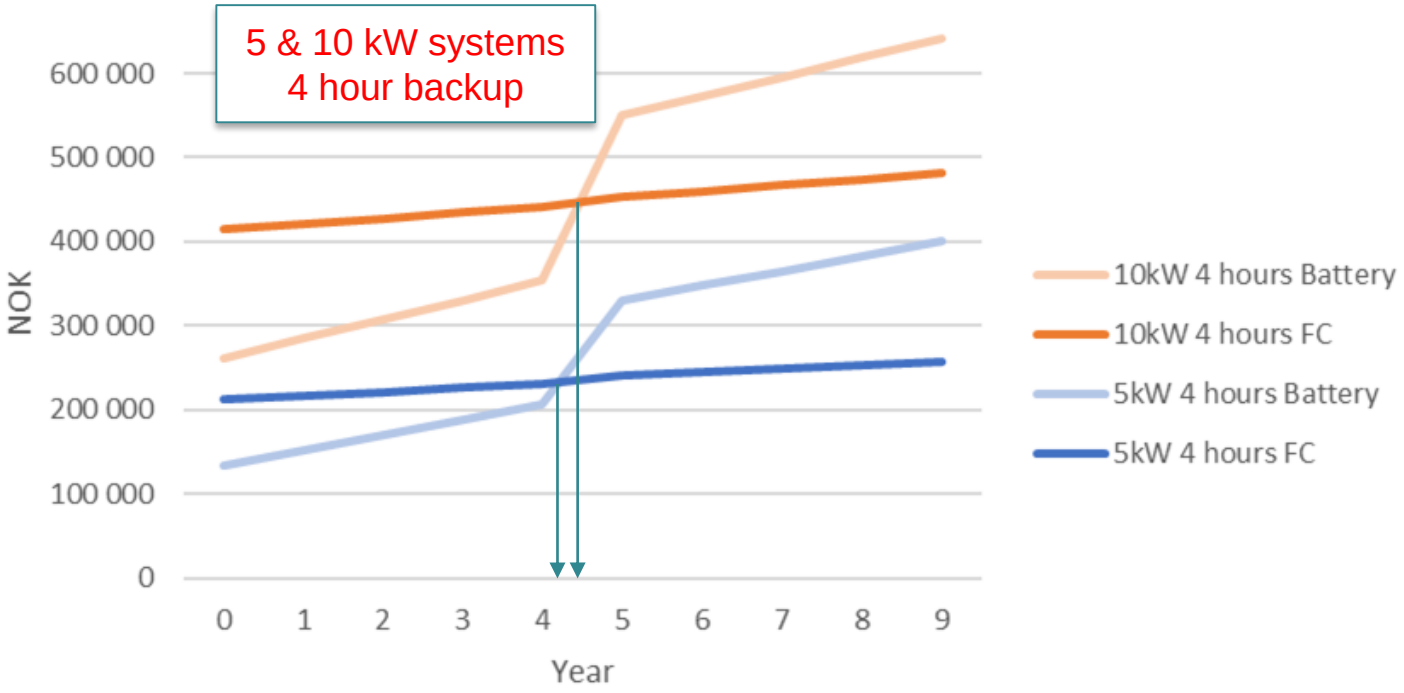
Fuel Cell & Battery System Cost Calculations

Year	SYSTEM 1: 5 kW & 4 hours				SYSTEM 2: 10 kW & 4 hours				SYSTEM 2: 10 kW & 72 hours			
	Fuel cell		Battery		Fuel cell		Battery		Fuel cell		Battery	
	Yearly Costs	Total Costs	Yearly Costs	Total Costs	Yearly Costs	Total Costs	Yearly Costs	Total Costs	Yearly Costs	Total Costs	Yearly Costs	Total Costs
0	213 000	213 000	134 400	134 400	414 000	414 000	261 800	261 800	494 000	494 000	4 571 400	4 571 400
1	4 430	217 430	18 000	152 400	6 860	420 860	23 000	284 800	46 860	540 860	183 000	4 754 400
2	4 430	221 860	18 000	170 400	6 860	427 720	23 000	307 800	46 860	587 720	183 000	4 937 400
3	4 430	226 290	18 000	188 400	6 860	434 580	23 000	330 800	46 860	634 580	183 000	5 120 400
4	4 430	230 720	18 000	206 400	6 860	441 440	23 000	353 800	46 860	681 440	183 000	5 303 400
5	9 430	240 150	123 000	329 400	11 860	453 300	196 000	549 800	51 860	733 300	2 668 000	7 971 400
6	4 430	244 580	18 000	347 400	6 860	460 160	23 000	572 800	46 860	780 160	183 000	8 154 400
7	4 430	249 010	18 000	365 400	6 860	467 020	23 000	595 800	46 860	827 020	183 000	8 337 400
8	4 430	253 440	18 000	383 400	6 860	473 880	23 000	618 800	46 860	873 880	183 000	8 520 400
9	4 430	257 870	18 000	401 400	6 860	480 740	23 000	641 800	46 860	920 740	183 000	8 703 400
10	9 430	267 300	123 000	524 400	11 860	492 600	196 000	837 800	51 860	972 600	2 668 000	11 371 400
11	4 430	271 730	18 000	542 400	6 860	499 460	23 000	860 800	46 860	1 019 460	183 000	11 554 400
12	4 430	276 160	18 000	560 400	6 860	506 320	23 000	883 800	46 860	1 066 320	183 000	11 737 400
13	4 430	280 590	18 000	578 400	6 860	513 180	23 000	906 800	46 860	1 113 180	183 000	11 920 400
14	4 430	285 020	18 000	596 400	6 860	520 040	23 000	929 800	46 860	1 160 040	183 000	12 103 400
15	214 430	499 450	123 000	719 400	416 860	936 900	196 000	1 125 800	496 860	1 656 900	2 668 000	14 771 400
NPV		kr 396 805		kr 568 332		kr 744 749		kr 898 422		kr 1 310 954		kr 11 984 199

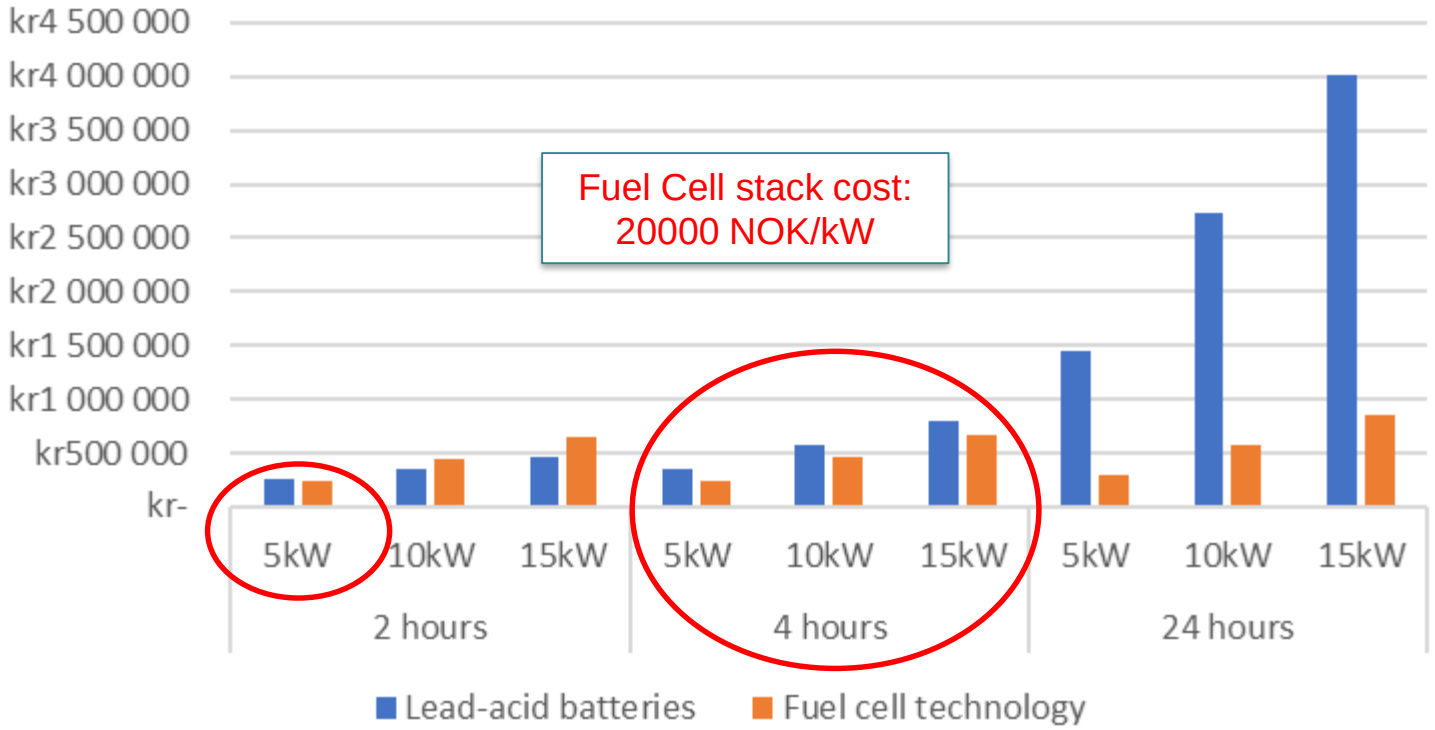
Fuel Cells

Batteries

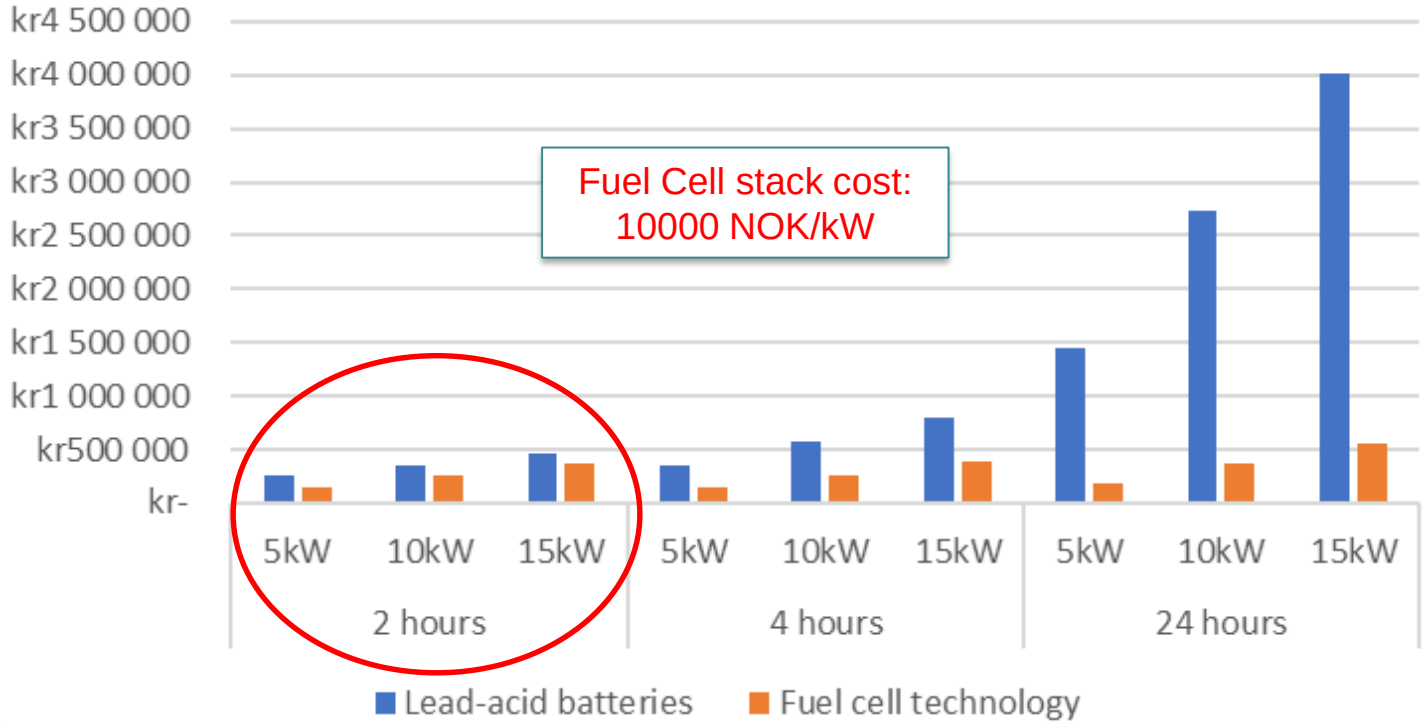
Fuel Cells vs. Batteries – Break-Even Points



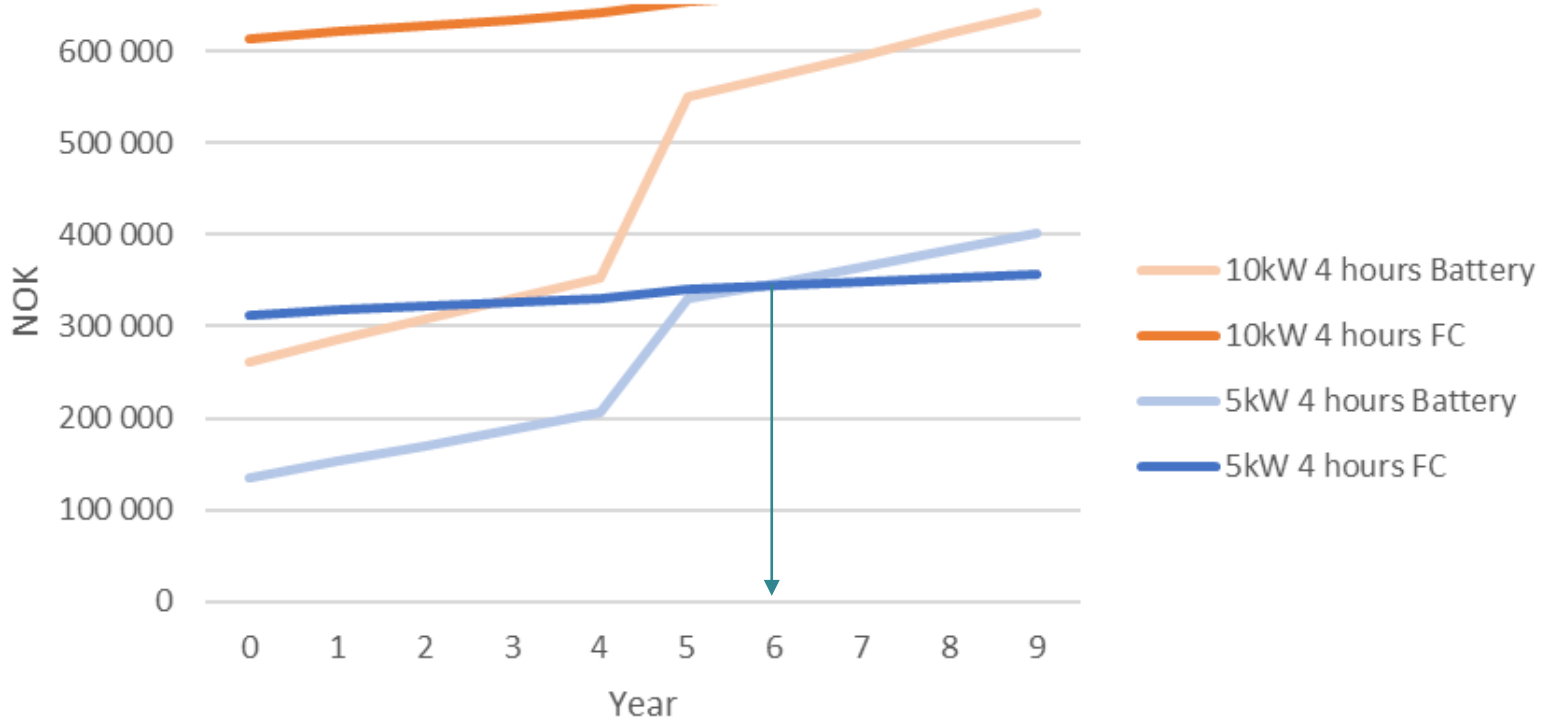
NPV Calculations with Default Parameters



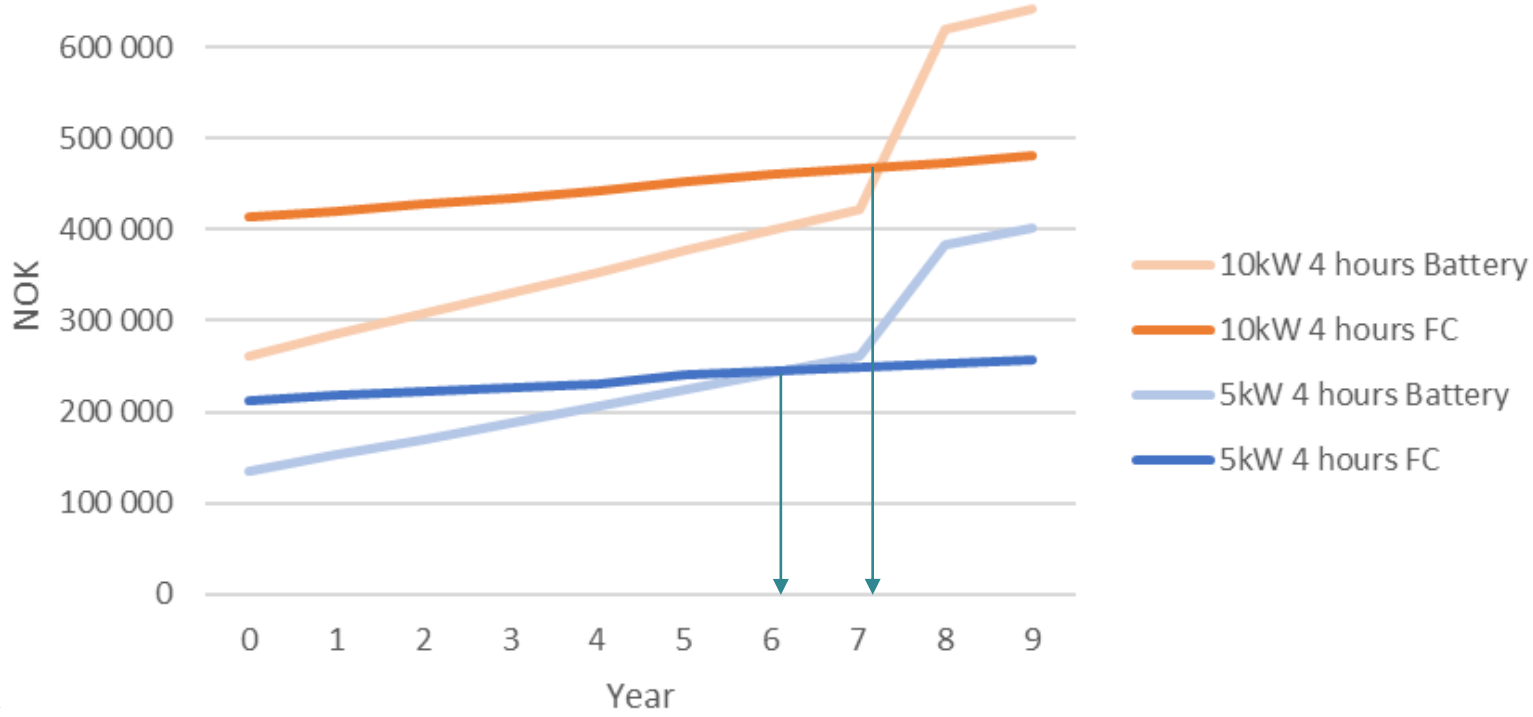
NPV when FC stack cost is Reduced by 50%



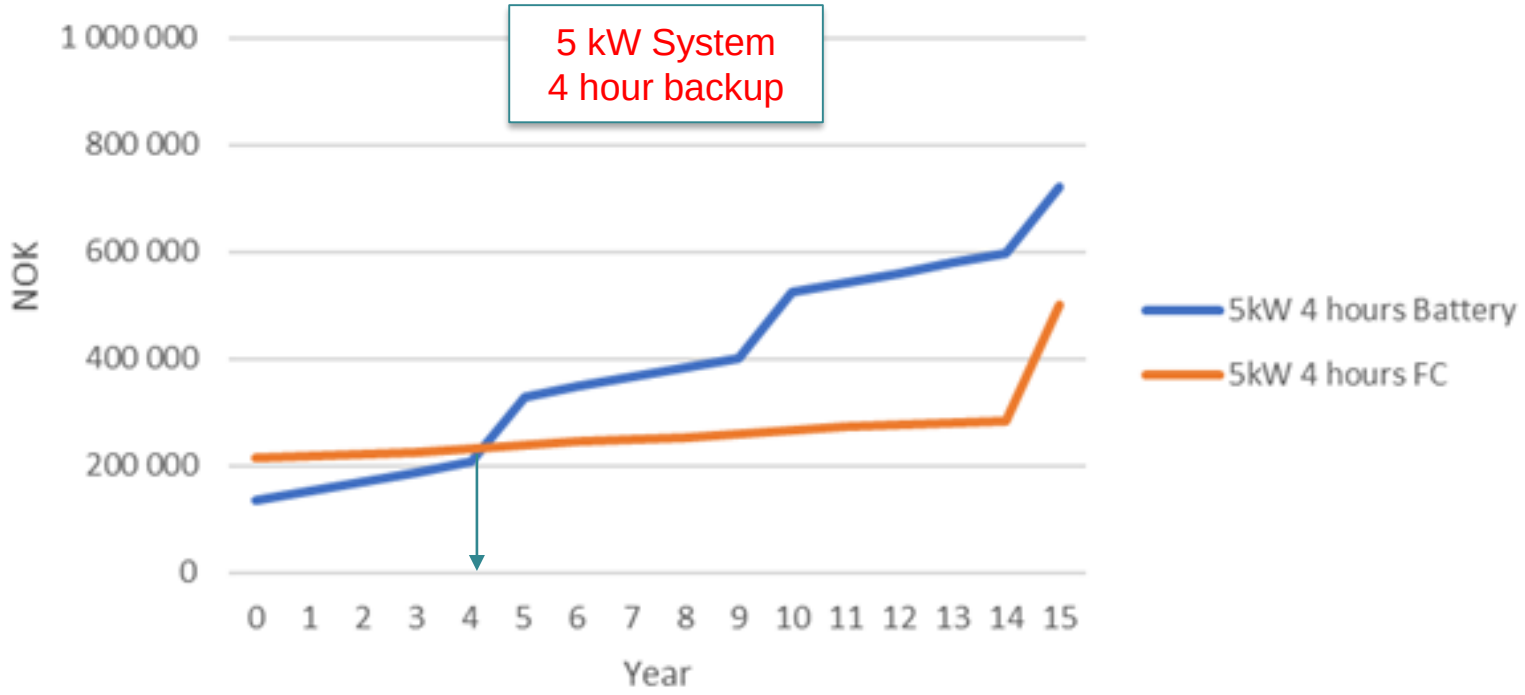
NPV when FC stack cost is Increased by 50%



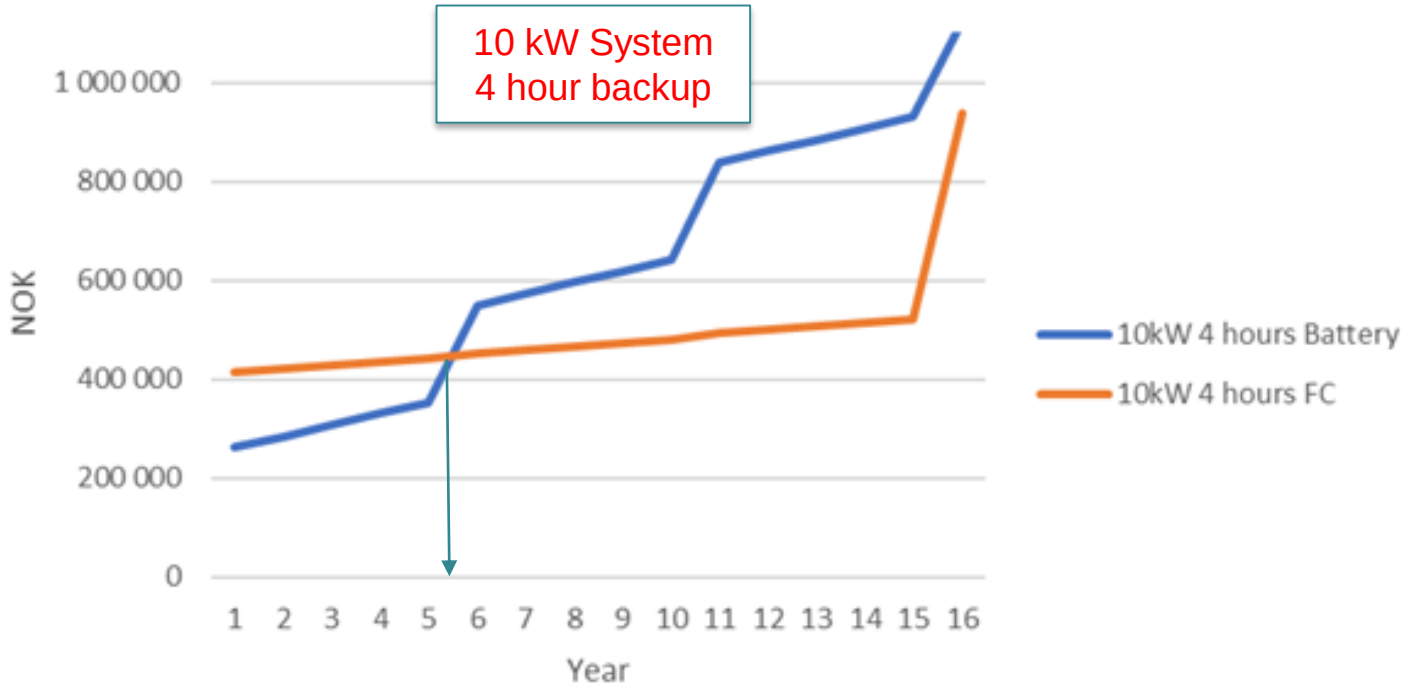
NPV when Battery Life is Increased to 8 years



NPV with System Lifetime *n* = 15 years



NPV with System Lifetime *n* = 15 years



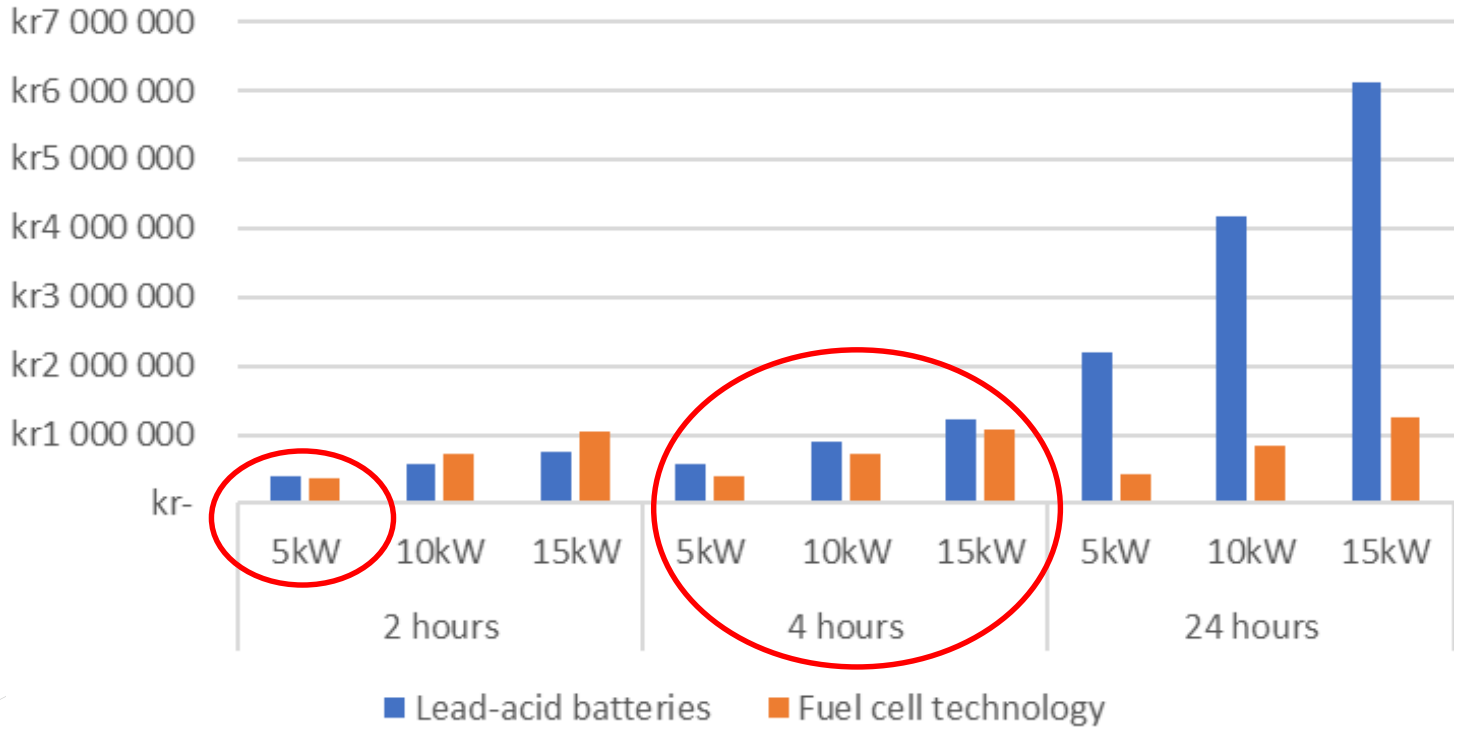
Hydrogen Storage – Renting vs. Owning?

- Renting
  - 300 bar steel bottles:
  - 1000 NOK/bottle (OPEX)
  - Bottle swaps included in price
- Owning
  - 350 bar composite cylinders:
  - 3500 NOK/cylinder (CAPEX)
  - 200 NOK/swap (OPEX)

NPV Calculations (NOK)

System	Renting	Owning
5 kW, 4 hours	396 805	383 396
10 kW, 4 hours	744 749	726 870
10 kW, 72 hours	1 310 954	1 114 286

NPV when owning H2 Storage Cylinders



Summary & Conclusions

- Technology & Systems
  - Hydrogen Fuel cells systems have long life and are highly scaleable
- Techno-Economic Study with Sensitivity Analysis
  - Batteries mostly suitable for system with short term backup < 2 hours
  - Hydrogen fuel cells suitable for medium to long term backup > 4 hours
- Business Case for Hydrogen Fuel Cells (versus Batteries)
  - Increased requirement for power capacity (5 kW → 10 kW)
  - Longer backup power periods (2-4 hours → 24-72 hours)
  - Efficient hydrogen logistics improves business case

Thank You for Your Attention!

IFE Hynor (2018)