DOE Hydrogen and Fuel Cells Program Record

Record: 20001 **Date: 4/16/20**

Title: Reversible Fuel Cell Targets

Originator: David Peterson

Peer Reviewed by: Max Wei (LBNL), Simon Thompson, Elizabeth Connelly, Neha Rustagi (DOE), Hossein Ghezel-Ayagh (FuelCell Energy), Chris Capuano (Nel), Josh Mermelstein (Innovative Fuel Cell Solutions)

Approved by: Dimitrios Papageorgopoulos and Sunita Satyapal **Date: 6/23/20**

Item

Performance, cost, and durability targets for unitized reversible fuel cells for electric energy storage applications, which were compiled with stakeholder input, are presented in Tables 1 and 2. These include targets for both low- and high-temperature technologies at both the cell/stack and system level with the same stack operating in both fuel cell and electrolyzer modes. Key **2030 system-level** reversible fuel cell targets established by DOE's Hydrogen and Fuel Cell Technologies Office based on extensive stakeholder engagement and industry input, include the following: \$1,800/kW (uninstalled capital cost, on a power basis), \$250/kWh (uninstalled capital cost, on an energy capacity basis), roundtrip efficiency of 60% (high temperature) and 40% (low temperature), 40,000 hour durability (with <10% degradation at end of life), and levelized cost of storage (LCOS) of \$0.20/kWh. Ultimate system targets as well as cell/stack targets and supporting Information are provided below.

Table 1a: Technical Targets for High-Temperature Unitized Reversible Fuel Cells (Cell/Stack level) for Electric Energy Storage Applications[1]

Cell/Stack

Characteristic	Units	2020 Status	2030 Targets	Ultimate Targets
Cell Performance/ Roundtrip Electric Efficiency[2] at 0.5 A/cm^2 FC; 1 A/cm^2 EL	%	~ 80[3]	85	90
Cell Durability/Degradation Rate[4, 5]	%/1000 hr	<1.5[6]	0.25	0.125

---

[1] All targets are to be met with the same cell and/or stack performing both fuel cell and electrolyzer functions (i.e., unitized operation). Also, all technical targets must be achieved simultaneously with the same cell/stack, although the 2020 Status values are not necessarily from the same device.

[2] Electric RTE measured as V_{FC}/V_{EL} at the current densities specified on the same single cell.

[3] B.Park, R. Scipioni, Q. Zhang, D. Cox, P. Voorhees, and S. Barnett, J. Mater. Chem. A 8 (2020) 11,687-11,694 (Conditions: 700 °C, 50vol% H_2-50vol% H_2O / air). Beginning-of-life (BOL) only; does not meet durability target. All targets must be met simultaneously. Note efficiencies of 90% also possible at 800 °C at specified current densities (BOL only).

[4] The 2030 target is based on end of life being limited to 10% loss in performance over lifetime (e.g., 40,000 hr for 2030). Performance loss, here, refers to loss in RTE at fixed current densities.

[5] With daily cycling between fuel cell and electrolyzer modes with a minimum of 30% time each in electrolysis mode and fuel cell mode. Standby and/or transient operation could be included in the daily cycling. Minimum current density of 0.25 A/cm^2 for fuel cell operation and 0.5 A/cm^2 for electrolysis operation. Given the wide range of possible duty cycles depending on the energy storage application targeted, flexibility is given for the daily cycling protocol to be used with only minimum requirements provided. The application targeted should dictate the duty cycle details which, in many instances, should be more aggressive than these minimum requirements.

[6] Single cell with daily cycles over 14,500 hr (Conditions: ≥0.25 A/cm^2 SOFC; ≥0.50 A/cm^2 SOEC); Versa Power Final Technical Report https://www.osti.gov/servlets/purl/1058912

Stack Capital Cost (Based on FC Power Output)[7]	$/kW	500	400	300

Table 1b: Technical Targets for High-Temperature Unitized Reversible Fuel Cell Systems for Electric Energy Storage Applications

System[8]		**2020 Status**	**2030 Targets**	**Ultimate Targets**
System Roundtrip Efficiency (includes thermal energy input)	%	37[9]	60	65
Lifetime/Durability[10, 11]	hr [Cycles]	10,000[9] [unknown]	40,000 [daily]	80,000 [daily]
Levelized Cost of Storage[12]	$/kWh	1.11[13]	0.20[14]	0.10[14]
System Capital Cost by Power[14]	$/kW	-	1,800	1,300
System Capital Cost by Energy[14]	$/kWh	-	250	150

---

[7] Costs based, in part, on modeled 100 kW SOFC stack cost at production volumes of 10, 100, and 1,000 MW per year using values given in stationary fuel cell cost studies by LBNL, Battelle, and Strategic Analysis, Inc.:
- R. Scataglini, A. Mayyas, M. Wei, S. Chan, T. Lipman, D. Gosselin, A. D'Alessio, H. Breunig, W. Colella, and B. James, A Total Cost of Ownership Model for Solid Oxide Fuel Cells in Combined Heat and Power and Power-Only Applications, 2015. https://www.energy.gov/sites/prod/files/2016/06/f32/fcto_lbnl_total_cost_ownership_sofc_systems.pdf
- Battelle Memorial Institute, Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications, 2016. https://www.energy.gov/sites/prod/files/2016/07/f33/fcto_battelle_mfg_cost_analysis_pp_chp_fc_systems.pdf
- Brian James and Dan DeSantis, Manufacturing Cost and Installed Price Analysis of Stationary Fuel Cell Systems, 2015. https://www.sainc.com/assets/site_18/files/publications/sa%202015%20manufacturing%20cost%20and%20installed%20price%20of%20stationary%20fuel%20cell%20systems_rev3.pdf

[8] Includes compression, H_2 processing, and storage.

[9] GrInHy Final Report, April 2019, RTE based on 78% (electrolyzer mode efficiency; does not include compression/H_2 processing) x 48% (fuel cell mode efficiency), https://www.green-industrial-hydrogen.com/news-detail/grinhy-project-ends-with-submission-of-final-report; K. Schwarze, O. Posdziech, J. Mermelstein, and S. Kroop, Fuel Cells 19, No. 4 (2019) 374.

[10] With daily cycling between fuel cell and electrolyzer operating modes following similar duty cycles to that given in the Cells/Stack table.

[11] Lifetime targets are consistent with FCTO MYRDD Plan stationary fuel cell durability targets: https://www.energy.gov/eere/fuelcells/doe-technical-targets-fuel-cell-systems-stationary-combined-heat-and-power (Table 2)

[12] System RTE, lifetime, and capital cost targets are consistent with achieving these LCOS values using assumptions for the other LCOS calculation input parameters based on industry/expert feedback. The $0.10/kWh ultimate target is considered aggressive; some energy storage applications will be able to accommodate a higher LCOS.

[13] Assumptions for calculation of 2020 LCOS Status are as follows: Duty cycle: 10 hr charge, 8 hr discharge and 350 cycles/year; electricity price: $0.04 /kWh; O&M: 3.5% of capital cost; installation costs: 33% of capital cost; capital cost: $3100/kW; 100% DOD (depth of discharge); 0% DEG (annual degradation rate of capacity); discount rate: 8%; and fuel cell power: 250 kW. The system roundtrip efficiency and lifetime used are those given as 2020 Status in the system target tables. A 10% degradation over the system lifetime is utilized and accounted for via oversizing the stack and increasing system costs accordingly so that at end of life the roundtrip efficiency specification is met.

[14] Based on DOE's Quadrennial Technology Review (QTR) Cost and Performance Targets for Electric Energy Storage Technologies (Table 3.4): https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter3.pdf.

Table 2a: Technical Targets for Low-Temperature Unitized Reversible Fuel Cells (Cell/Stack level) for Electric Energy Storage Applications[1]

Cell/Stack

Characteristic	Units	2020 Status	2030 Targets	Ultimate Targets
Cell Performance/Roundtrip Electric Efficiency at 0.5 A/cm^2 FC; 1 A/cm^2 EL[2]	%	52[3]	55	65
Cell Durability/Degradation Rate[4, 5]	%/1000 hr	-	0.25	0.125
Total Cell PGM Loading	mg/cm^2	1.3[3]	1.0	0.5
Stack Capital Cost (Based on FC Power Output)[6]	$/kW,	1,000	550	300

---

[1] All targets are to be met with the same cell and/or stack performing both fuel cell and electrolyzer functions (i.e., unitized operation). Also, all technical targets must be achieved simultaneously with the same cell/stack, although the 2020 Status values are not necessarily from the same device.

[2] RTE measured as V_{FC}/V_{EL} at the current densities specified on the same MEA.

[3] https://www.hydrogen.energy.gov/pdfs/review19/fc183_danilovic_2019_o.pdf

[4] Based on end of life being 10% loss in performance over lifetime (e.g., 40,000 hr for 2030 target). Performance loss based on loss in RTE at fixed current densities.

[5] With daily cycling between fuel cell and electrolyzer modes with a minimum of 30% time each in electrolysis mode and fuel cell mode. Standby and/or transient operation could be included in the daily cycling. Minimum current density of 0.25 A/cm^2 for fuel cell operation and 0.5 A/cm^2 for electrolysis operation. Given the wide range of possible duty cycles depending on the energy storage application targeted, flexibility is given for the daily cycling protocol to be used with only minimum requirements provided. The application targeted should dictate the duty cycle details which, in many instances, should be more aggressive than these minimums.

[6] Costs based, in part, on modeled 100 kW PEM stack cost at 10, 100, and 1,000 MW per year using values given in stationary fuel cell cost studies by LBNL, Battelle, and Strategic Analysis Inc. with PGM loadings given in the Total Cell PGM Loading metric.:
- M. Wei, T. Lipman, A. Mayyas, J. Chien, S. Chan, D. Gosselin, H. Breunig, M. Stadler, T. McKone, P. Beattie, P. Chong, W. Colella, B. James. A Total Cost of Ownership Model for Low Temperature PEM Fuel Cells in Combined Heat and Power and Backup Power Applications, 2014. https://eta.lbl.gov/publications/total-cost-ownership-model-low
- Battelle Memorial Institute, Manufacturing Cost Analysis of 100 and 250 kW Fuel Cell Systems for Primary Power and Combined Heat and Power Applications, 2016. https://www.energy.gov/sites/prod/files/2016/07/f33/fcto_battelle_mfg_cost_analysis_pp_chp_fc_systems.pdf
- Brian James and Dan DeSantis, Manufacturing Cost and Installed Price Analysis of Stationary Fuel Cell Systems, 2015. https://www.sainc.com/assets/site_18/files/publications/sa%202015%20manufacturing%20cost%20and%20installed%20price%20of%20stationary%20fuel%20cell%20systems_rev3.pdf

Table 2b: Technical Targets for Low-Temperature Unitized Reversible Fuel Cell Systems for Electric Energy Storage Applications

System[7]		2020 Staus	2030 Targets	Ultimate Targets
System Roundtrip Efficiency	%	-	40	50
Lifetime/Durability[8,9]	hr [Cycles]	-	40,000 [daily]	80,000 [daily]
Levelized Cost of Storage[10]	$/kWh	1.60[11]	0.20[12]	0.10[12]
System Capital Cost by Power[12]	$/kW	-	1,800	1,300
System Capital Cost by Energy[12]	$/kWh	-	250	150

Supporting Information

Reversible fuel cells (RFC) are capable of operating in both power production (fuel cell) and energy storage (electrolysis) modes and are a promising way to store large amounts of energy at low cost. RFCs involve the production of hydrogen via electrolysis in which electrical energy is used to split water molecules into hydrogen and oxygen gases, with the hydrogen (and sometimes oxygen) then being stored. This water splitting process can be thought of as the RFC equivalent to charging a battery. In the fuel cell (discharge) mode, the stored hydrogen is then sent through the same electrochemical stack used for electrolysis to generate electricity and water, thereby, reversing the previous process. In this basic configuration, RFCs essentially act to store grid electricity as hydrogen for later conversion back to electricity. A discrete reversible fuel cell system uses separate electrolyzer and fuel cell stacks while the combination of these two processes into a single stack is commonly termed a unitized reversible fuel cell (URFC). Some advantages of carrying out fuel cell and electrolyzer operations in a single stack include significantly decreased cost, smaller footprint, and system simplification. For the purposes of this Record and the targets developed, references to reversible fuel cells are specific to the unitized, single stack arrangement.

The reversible fuel cell (RFC) characteristics, status, and targets in the tables were developed based on feedback by subject matter experts. DOE and Lawrence Berkeley National Laboratory (LBNL) initially

---

[7] Includes compression, H_2 processing, and storage.

[8] With daily cycling between fuel cell and electrolyzer operating modes following similar duty cycles to that given in the Cells/Stack table.

[9] Lifetime targets are consistent with FCTO MYRDD Plan stationary fuel cell durability targets: https://www.energy.gov/eere/fuelcells/doe-technical-targets-fuel-cell-systems-stationary-combined-heat-and-power (Table 2)

[10] System RTE, lifetime, and capital cost targets are consistent with achieving these LCOS values using assumptions for the other LCOS calculation input parameters based on industry/expert feedback. The $0.10/kWh ultimate target is considered aggressive; some energy storage applications will be able to accommodate a higher LCOS.

[11] Assumptions for calculation of 2020 LCOS Status are as follows: Duty cycle: 10 hr charge, 8 hr discharge and 350 cycles/year; Electricity price, $0.04 /kWh; O&M, 3.5% of capital cost; Installation costs, 33% of capital cost; capital cost, $2800/kW; 100% DOD (depth of discharge); 0% DEG (annual degradation rate of capacity); discount rate, 8%; and fuel cell power, 250 kW. The system roundtrip efficiency and lifetime are assumed to be 25% and 10,000 hr. A 10% degradation over the system lifetime is utilized and accounted for via oversizing the stack and increasing system costs accordingly so that at end of life the roundtrip efficiency specification is met.

[12] Based on DOE's Quadrennial Technology Review (QTR) Cost and Performance Targets for Electric Energy Storage Technologies (Table 3.4): https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter3.pdf

formulated targets which were subsequently updated based on expert responses to a request for input. A total of ten responses were received, split roughly evenly between high-temperature (HT) and low-temperature (LT) expertise. Many of the same experts also participated in revising the updated targets further during an RFC project review meeting. The targets included in Tables 1 and 2 then were finalized based on these discussions.

All of the technical targets must be achieved simultaneously using the same cell/stack for operation in both fuel cell and electrolyzer modes. However, the 2020 status values included in the tables are not necessarily from the same device or system, though this will likely change in subsequent status updates as the technology advances.

The targets were developed for the purpose of guiding RFC R&D advancements in order to be competitive with incumbent and emerging energy storage technologies. There is a wide application space for which RFCs potentially could be used within energy storage, and each individual application or installation could have its own requirements based on location, grid profile, dynamic electricity pricing, and other specifics. It was therefore necessary to place some constraints to bound the technology application space to provide enough specificity to reasonably develop technical targets. Given the early stage in development of any such applications, it was decided to consider only a pure energy storage application for target development (e.g., opportunities to provide grid ancillary services and to generate and sell excess hydrogen were not considered in the target setting). In situations where opportunities such as these present themselves, some of the targets could be relaxed.

The Electric Energy Storage Targets from DOE's Quadrennial Technology Review (QTR) were considered in setting the system level targets. The 2015 QTR examined the status of the science and technology that are the foundation of the United States' energy system, together with the research, development, demonstration, and deployment opportunities to advance them. Included in it was a separate Technology Assessment specific to Electric Energy Storage with the targets included therein (Table 3.C.2) provided below in Table 3 as a reference (https://www.energy.gov/sites/prod/files/2015/09/f26/QTR2015-3C-Electric-Energy-Storage.pdf). This Technical Assessment explored a wide range of energy storage technologies (e.g., batteries, pumped hydro, fly wheels, compressed air energy storage, hydrogen energy storage, etc.) in numerous power system applications, which cover a wide range of storage capacities, power ratings, duty cycles (e.g., discharge duration and number of annual cycles), and other operating parameters. Past studies[13] indicate that hydrogen energy storage will be most competitive at larger storage capacities with longer duty cycles; hence, that is where most of the effort for this RFC taget setting process was focused.

---

[13] https://www.nrel.gov/docs/fy16osti/64764.pdf; Schmidt, et al., Joule 3, 81-100, 1/16/19.

Table 3: QTR Electric Energy Storage Targets

Range of baselines	System capital cost by energy: \$805–\$10,020/kWh
	Levelized cost: \$0.01-\$0.64/kWh/cycle
	System efficiency: 75%–92%
	Cycle life: 4,500–225,000 over life of plant
	System capital cost by power: \$300–\$4,600/kW
Near-term targets	System capital cost by energy: less than \$250/kWh
	Levelized cost: less than \$0.20/kWh/cycle
	System efficiency: more than 75%
	Cycle life: more than 4,000 cycles
	System capital cost by power: less than \$1,750/kW (rounded to \$1,800/kW)
Long-term targets	System capital cost by energy: less than \$150/kWh
	Levelized cost: less than \$0.10/kWh/cycle
	System efficiency: more than 80%
	Cycle life: more than 5,000 cycles
	System capital cost by power: less than \$1,250/kW (rounded to \$1,300/kW)

Below are additional details for some of the RFC targets, beyond what is already footnoted in Tables 1 and 2. Status and target numbers were vetted with RFC experts as described at the beginning of this section. The below content is grouped by characteristic and is relevant for both low- and high-temperature RFCs, unless only one is specified.

Cell Performance/RTE

RTE changes significantly with current density; as a result, an effort was made to find an alternate performance metric in order to avoid specifying a single operating point (i.e., current density) on the fuel cell and electolysis polarization curves. Area specific resistance was considered for HTRFCs; however, this would require the slope of the polarization curve to be the same in both fuel cell and electrolyzer operation, and this is not always the case. In the end no other single metric could be identified that can effectively measure both fuel cell and electrolyzer performance. Thus, appropriate current densities, based on feedback from subject matter experts, were selected to specify the target for RTE. The general consensus was that in real world applications RFCs are likely to be operated at higher current density in electrolysis mode than in fuel cell mode; hence, the asymmetric current densities of 0.5 A/cm^2 fuel cell and 1 A/cm^2 electrolyzer were selected for the RTE calculation. Note that a published reference and peer review of this Record indicated a real world example of operating at 0.3 A/cm^2 in fuel cell mode and 0.38 A/cm^2 in electrolysis mode, with the latter limited only due to limitations of the power electronics.[14] In

---

[14] J. Mermelstein and O. Posdziech, Fuel Cells 17, No. 4 (2017) 562.

practice, system level trade offs, designs and the specific application (e.g., duty cycle) will have an impact on the current densities used. The values selected here are expected to be representative system operating points, with the purpose of selecting them being to guide needed RFC R&D advancements.

The roundtrip efficiency of high-temperature RFCs is inherently higher than low-temperature RFCs; however, that does not preclude the latter from being a competitive solution. For example, LTRFCs could be better suited for energy storage applications in which there is substantial idle time (i.e., RFC not operating as a fuel cell or a electrolyzer) when potential thermal management drawbacks of HTRFCs are taken into consideration.

Cell Durability/Degradation Rate

Stack durability will need to be similar to cell durability, but given the early stage of technology development, only cell durability is specified in the targets at this time. Realizing the duty cycle specifications could vary substantially depending on the application targeted, an attempt was made to balance being overly prescriptive in defining the cycling attributes with ensuring there are some minimum requirements for tracking progress against the targets. There was general agreement from the RFC experts that daily cycling is a good starting point and is relevant for the electric energy storage applications for which hydrogen energy storage is likely to be suited. There was no general agreement on current density requirements though some experts pointed out that the current densities could be different in FC and electrolysis modes (likely higher in electrolysis mode as discussed above).

System RTE

These are values that the RFC experts think the technology can achieve with sufficient R&D, though the ultimate target is a stretch for both LT and HT. Levelized cost of storage (LCOS) is the most critical figure of merit and it is possible that a high RTE could be traded off with other system operating aspects to reduce LCOS, resulting in a more competitive system.

Hydrogen compression and hydrogen processing need to be included in the system RTE determination. For example, a system may be required to remove residual moisture from the product hydrogen gas from the electrolyzer in order to meet hydrogen purity requirements. A peer review of this Record indicated that efficiency penalties (e.g., compressor and balance-of-plant) can vary widely (e.g. 5% to over 10%) and there are design trade-offs which can significantly effect these efficiency losses.

Particularly for HTRFCs, there are thermodynamic considerations that need to be taken into account. As an example, in fuel cell mode the maximum cell thermodynamic efficiency is ~78% @ 800 °C, however this is based on reversible open circuit voltage (OCV) and not a practical operating voltage. Assuming a reasonable operating cell voltage of 0.8 V/cell in FC mode, the thermodynamic maximum LHV efficiency is ~64%. In electrolysis mode, operating at thermoneutral voltage, the cell efficiency is by definition 100%, resulting in a round trip efficiency of ~64%. Pressurized operation and a lower operating temperature will both increase this RTE. The ultimate system RTE target for HTRFCs was set based on these thermodynamic considerations and on input from technical experts that agreed that either 65% or 70% would be appropriate as an ultimate stretch goal, but should not compromise cost or durability or lead to an increased LCOS as a result.

Levelized Cost of Storage

LCOS is considered to be the figure of merit for comparison to other electric energy storage technologies. The targets are taken directly from DOE's Quadriennal Technology Review (QTR) for which significant effort was undertaken to develop cost and performance targets for electric energy storage technologies. The RFC experts agreed that the LCOS targets from the QTR seemed appropriate and were not aware of a better source for LCOS targets. The $0.10/kWh ultimate target is likely aggressive, as some energy storage applications can accommodate a higher LCOS. In order to not limit potential opportunities by focusing on just one specific storage application, an aggressive, referenceable target was selected for the LCOS. As the needs of the broad energy storage space becomes better studied and established, along with RFC's role in it, LCOS targets can be updated accordingly.

The System RTE, Lifetime, and Capital Cost targets are consistent with achieving these LCOS target values with reasonable assumptions for the other LCOS calculation input parameters. Example inputs used for an LTRFC LCOS calculation[15], which surpasses the ultimate LCOS target, are provided in Table 4. This calculation is based on a daily cycle to be inline with expectations that hydrogen energy storage is better suited for longer duration cycles. A 250 kW fuel cell system is assumed, as this is acceptably close to the power output used in LBNL's cost analysis and is reasonably sized for a hydrogen energy storage system. System Capital Cost by Power and System Capital Cost by Energy are interrelated, depending on the other assumptions used in the LCOS calculation and on the application targeted. Consequently, it is possible to meet the LCOS target while meeting only one of these system capital cost targets.

Table 4: Example LCOS Calculation for LTRFC Ultimate Targets

LCOS ASSUMPTIONS		
O&M	3.5	% of capital cost
Installation Costs + "Soft Costs"	33	% of capital cost
Electricity Price	0.02	$/kWh
Depth of Discharge	100	%
Degradation Rate (Accounted for separately by oversizing stack by 10%)	0	%
Discount Rate	7	%
System size (FC/EL)	250/854	kW
Current Density (FC mode)	0.50	A/cm^2
Current Density (EL mode)	1.00	A/cm^2
Charge Hours	10	h/day
Discharge Hours	13	h/day
Number of Cycles	350	cycles/year
FC-Efficiency	63	%
EL-Efficiency	74	%
Roundtrip Efficiency	46	%
PGM Loading	0.5	mg/cm^2
System Capital Cost by Power	1300	$/kW

---

[15] LCOS calculation based on the approach used by Schmidt, et al., Joule 3, 81-100, 1/16/19 and https://www.apricum-group.com/how-to-determine-meaningful-comparable-costs-of-energy-storage/

System Capital Cost by Energy	110	$/kWh
Lifetime	10	years
LEVELIZED COST OF STORAGE		
LCOS	0.094	$/kWh

System Capital Cost by Power and by Energy
After careful consideration and analysis, the QTR targets were chosen for the overarching system level RFC metrics. Capital costs were rounded to significant figures comparable to other significant figures (i.e., $1,750/kW was rounded to $1,800/kW as the 2020 target). LBNL carried out cost analysis using the existing stationary fuel cell cost studies given in Footnote 7 for HTRFCs and Footnote 6 for LTRFCs as a starting point. They modified these stationary fuel cell cost numbers by removing the fuel processing equipment and adding other BOP components, including hydrogen storage vessels, as needed. Targets were developed based on manufacturing volumes of 100, 1,000 and 10,000 units per year for the current, 2030, and ultimate targets. The resulting numbers were in a similar range to the QTR cost targets. Ultimately, the QTR numbers were used as they provide a peer-reviewed and more easily referenced source.

No cost status is provided for 2020 due to a lack of available information. There are no commercial reversible fuel cell systems available and any one-off demos are of limited relevance to large-scale energy storage and cost estimates for them cannot be easily extrapolated for commercially relevant systems.