Powering Off-Grid Mobile Networks and Universal Connectivity: A New Business Case

In association with GenCell Energy

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Executive Summary

The accelerating drive for universal mobile access, for people and increasingly for connected vehicles and objects, means that expansion of the cellular network is outpacing that of the electricity grid.

Almost 1.2 million base stations will have unreliable grid power in 2020.

According to the GSMA, the number of off-grid base stations is expected to rise from 320,000 in 2014 to 390,000 in 2020, while base stations with unreliable power will rise from 700,000 to 791,000 in the same period.[1] This increase puts pressure on the business case for rural mobile, both for independent tower companies and mobile network operators (MNOs).

One of the most significant cost elements in deploying a remote base station is power, and so there is growing demand for a new power solution for off-grid and poor-grid base stations. Network deployers need to improve on the economics of off-grid and poor-grid sites while meeting environmental and quality of service targets.

Alternatives to the dominant solution, diesel, have often addressed some, but not all, of the operators' requirements. Solar and wind power are environmentally strong but costly to roll out, for instance. Even hydrogen fuel cells, the fastest growing solution, have the downside of high fuel and operating costs, because infrastructure needs to be built to distribute the hydrogen and the logistical costs are high in remote areas.

By 2022, over 40% of off-grid and poor-grid base stations, in most regions, will be powered by alternatives to diesel.

Operators are making heavy investments in solar, wind, fuel cell and battery technologies. By 2022, over 40% of off-grid and poor-grid base stations, in most regions, will be powered by alternatives to diesel. However, a survey of tower and network operators by Rethink Research found that most would invest more rapidly in a new solution if it addressed all their top five requirements:

- Fuel costs below those of diesel (targeting <$1 per 10 kWh)
- Operating cost reduction of at least 25%
- Unlimited and fully reliable power
- Environmental targets especially no emissions
- Safe disposal

[1] GSMA, 'Green Power for Mobile', 2014 https://www.gsma.com/.../wp-content/.../140617-GSMA-report-draft-vF-KR-v7.pdf

Patterns in Rural and Remote Mobile Network Deployment to Date

There are rising numbers of off-grid and poor-grid mobile base stations around the world, despite the extension of the electricity grid in most areas of the world. Access to electricity has risen, from 73% in 1994 to 85% in 2017 (World Bank), but that figure falls to 57% for rural inhabitants and businesses. A rising percentage of access to electricity is based on mini-grids or standalone solutions. The extension of the grid has, therefore, been offset by population growth, often in ultrarural areas.

Access to electricity has risen, from 73% in 1994 to 85% in 2017 (World Bank), but that figure falls to 57% for rural in-habitants and businesses.

In the case of base stations, the wider availability of grid electricity has been outpaced by the expansion of mobile networks into increasingly rural and remote locations. The drive for universal mobile coverage has often been stronger than for on-grid electrification as governments and industries look to harness the social and economic rewards of bridging the digital divide.

As demand for mobile data services rises, more base stations are required to support higher capacity as well as ubiquitous coverage. This is driven by several trends, as summarised in Table 1.

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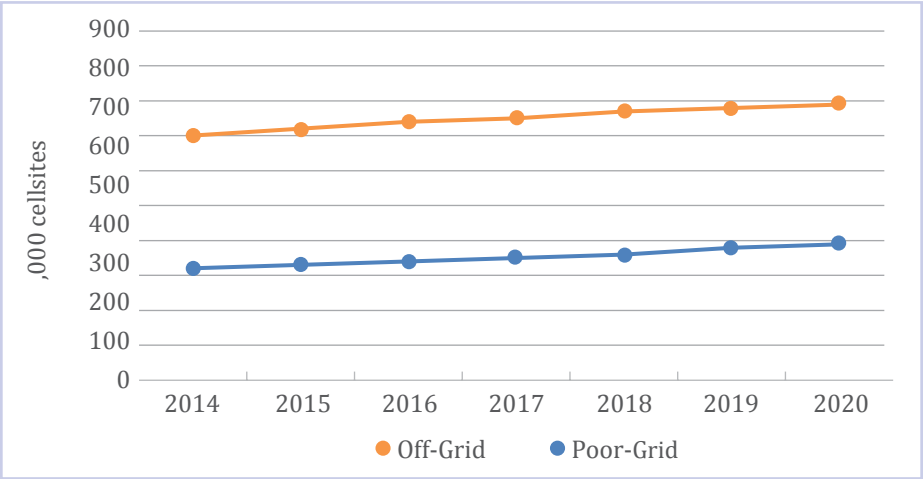
Table 1. Key drivers and trends for mobile in off-grid areas

Key driver	Trend
Government initiatives	Universal broadband programs. In rural areas, wireless is often preferred.
Private industry initiatives e.g. Facebook Inter-net.org	Extend connectivity to unserved communities to expand markets.
Rise of Internet of Things (IoT)	Some IoT services require ubiquitous coverage even in remote areas e.g. smart agriculture, connected mining.
Rising usage in ultra-rural areas	Cellular device is often the only way to access Internet and video

According to the GSMA, in 2014 there were 320,000 off-grid and 700,000 poor-grid base stations. These figures are expected to rise to 390,000 and 791,000 respectively by 2020, as seen in Figure 1.

Figure 1. Number of off-grid and poor-grid base stations 2014-2020[2]



In some regions, a significant percentage of base stations are in areas where they experience, on average, more than six hours a day of power outage.

In some regions, a significant percentage of base stations are in areas where they experience, on average, more than six hours a day of power outage (the GSMA definition of poor-grid). Those regions are summarised in Table 2.

Table 2. Leading regions with more than six hours per day of power outage.

	On-Grid Towers (x000s)	Poor-Grid Towers (x000s)	Off-Grid Towers (x000s)	% with 6+ hrs/day outage
Sub-Saharan Africa	72	190	99	80
South Asia	143	242	147	73
LATAM	156	74	32	41
MENA	79	32	18	39
SE Asia	575	203	85	33

As cellular services become mission critical for some enterprises, reliability is essential, boosting investment in backup solutions for continual availability in poor-grid areas.

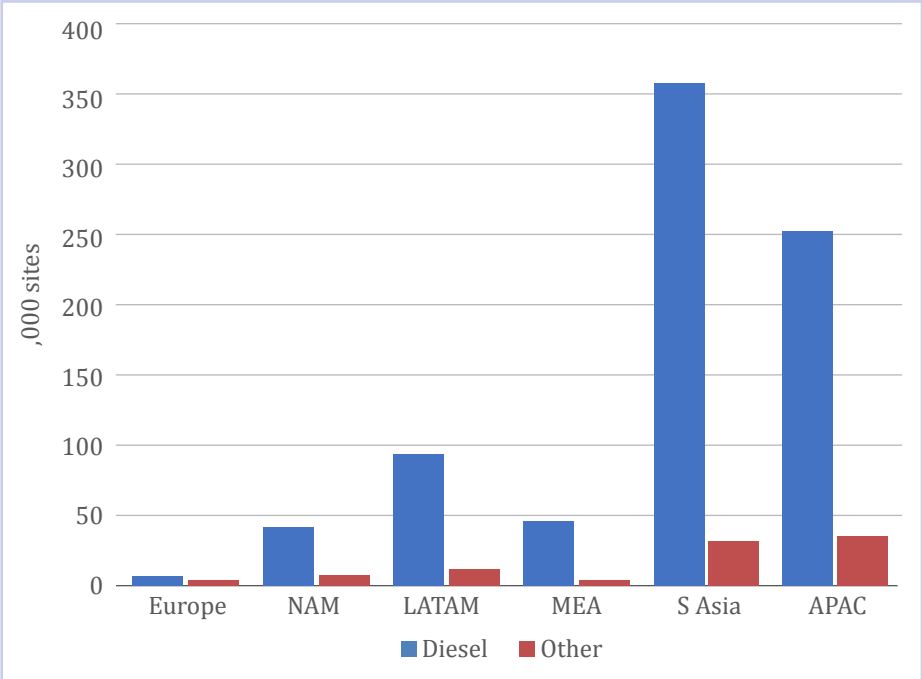
All these rising levels of usage also put pressure on the reliability of poor-grid services. As cellular services become mission critical for some enterprises, reliability is essential, boosting investment in backup solutions for continual availability in poor-grid areas.

[2] Source: GSMA and Rethink Research estimates

Mobile and Tower Operators Demand New Fuel Solutions

The trends outlined in the previous section are driving increasing demand for innovative off-grid power solutions for mobile base stations and their sites (towers, poles etc). The majority currently use diesel solutions, as Figure 2 illustrates.

Figure 2. % of off-grid and poor-grid sites powered by diesel and alternatives in 2014 by region



Despite the dominance of diesel, there is growing interest in alternatives. The search for these alternatives is being driven primarily by the tower operators' and mobile operators' need to reduce costs – diesel fuel can account for 50% of the operating cost of an off-grid base station, and in many areas fuel costs are rising.

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However, there are many other reasons why operators need new power options. Rethink Technology Research carried out a survey of 55 MNOs and towercos in the first quarter of 2018, in which they were asked about their plans for base station power solutions.

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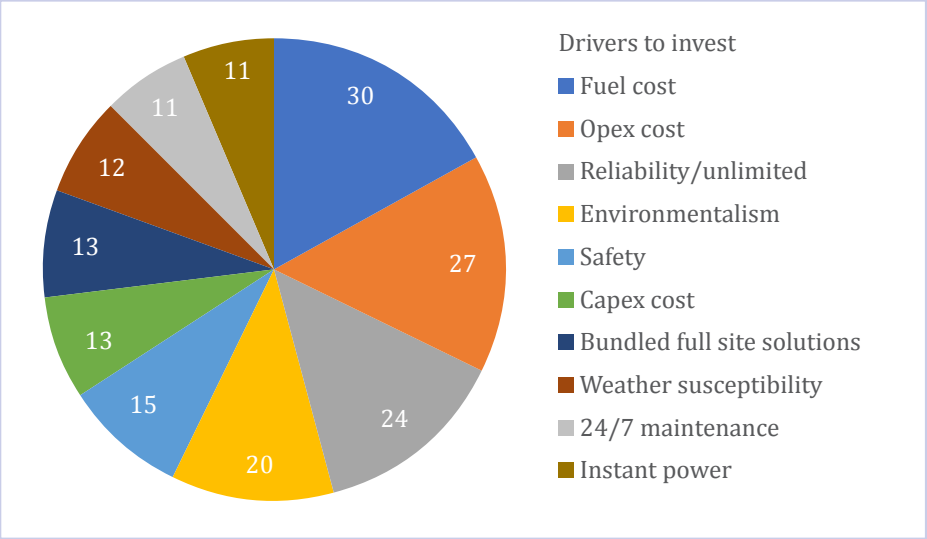
Figure 3. What are your top reasons to invest in a new power solution?



This revealed that the most important drivers to invest in a new power technology are to reduce fuel costs, to reduce operating costs, to improve reliability, and to support environmental considerations (see Figure 3).

The most important drivers to invest in a new power technology are to reduce fuel costs and to re-duce operating costs.

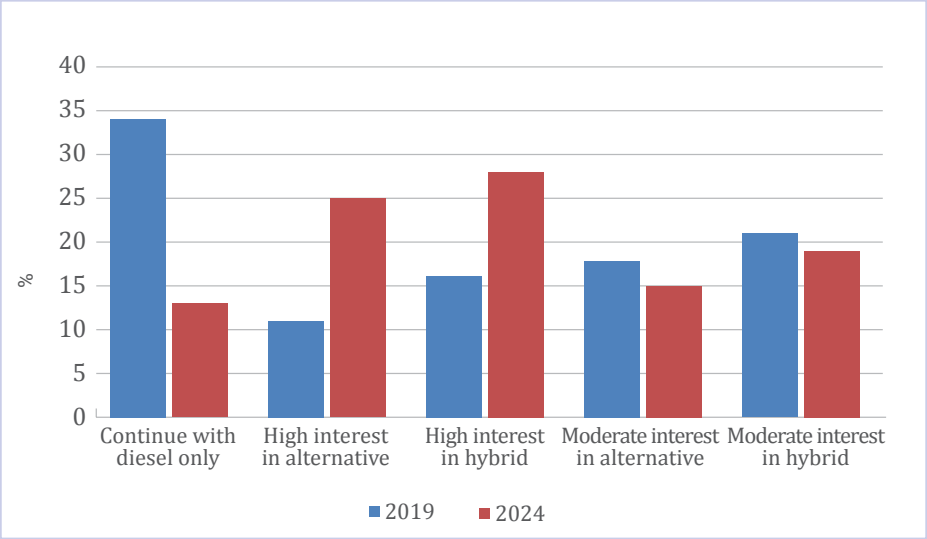
These challenging requirements are leading to rising levels of willingness to consider new approaches to base station power. In another Rethink survey, conducted in the fourth quarter of 2017 and questioning 120 operators, a significant appetite for alternatives to diesel was seen.

While over one-third of companies expect to stay with diesel as their exclusive or main source of primary power in 2019, only 13% expect to be in that position by 2024.

One-quarter of operators have a high interest in a replacement for diesel by that date, and 28% in a hybrid solution, while a further 15% and 19% respectively, say they are moderately interested.

(Note that many sites will use hybrid solutions, combining diesel with renewables, for example, or adding battery or fuel cells as a secondary source. By 2022, between 50% and 65% of sites will have battery backup to increase reliability and enable operators to use more non-optimal locations.) This is summarized in Figure 4.

Figure 4. Level of interest in alternatives to diesel



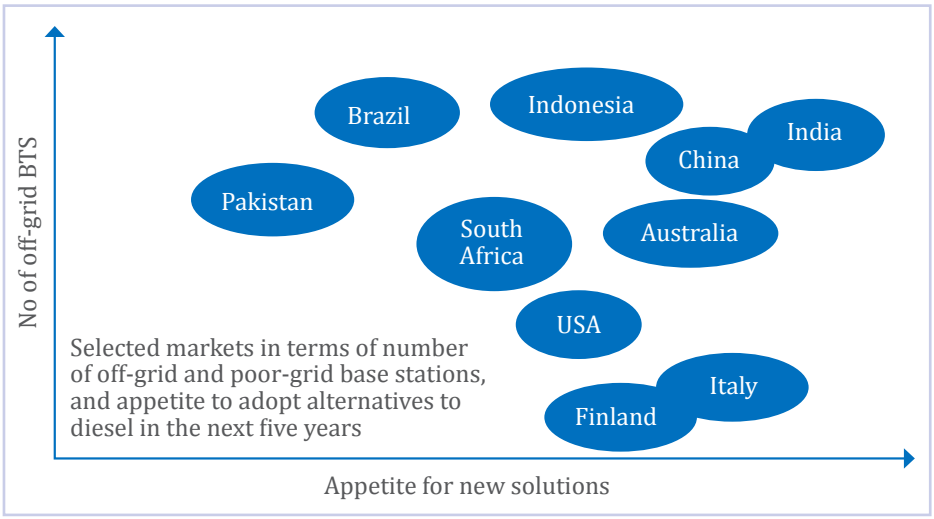
There are significant regional variations. Selected markets, which emerged from the research process as having particularly strong demand for new solutions, either because of their large (and growing) base of off-grid and poor-grid base stations, or their readiness to adopt new solutions.

For instance, markets like Italy are advanced in evaluating alternatives to diesel, but have relatively small off-grid bases; while markets like Brazil have very large off-grid bases, but have been slower to embrace new technologies.

India, whose government has set mandatory levels of deployment of renewables on base station sites, has both a very large off-grid base and a high level of appetite for change.

Selected markets have particularly strong demand for new solutions, either because of their large (and growing) base of off-grid and poor-grid base stations, or their readiness to adopt new solutions.

Figure 5. A limited selection of markets to show varying appetite for new solutions



The Influence of Government Policy

The influence of government incentives and the regulatory environment has a significant impact on the rate of investment in alternative power solutions.

The influence of government incentives and the regulatory environment has a significant impact on the rate of investment in alternative power solutions, of course. Common mechanisms include subsidies or grants for renewable energy installation, Feed-in Tariffs and renewable energy credits for businesses, together with mandates for mobile operators to power a set percentage of their sites with non-diesel solutions. Table 3 indicates the number of countries with active renewable energy programmes which include rural base stations.

Table 3. Countries with active renewable energy programmes covering rural BTS

Region	Number of countries with active renewable energy programmes covering rural base stations
Europe	9
Sub-Saharan Africa	13
South Asia	6
Asia Pacific	9
MENA	6
The Americas	11

The number of countries that have set policy targets for renewable electricity rose from 45 in 2005 to 73 in 2012 to 95 in 2016[3], and many have set rural electrification objectives – 35% by 2020 in Lesotho, for example, and 50% by 2025 in Benin. Some are setting specific targets for base stations, notably India, which has mandated renewable energy solutions for at least 50% of new base station sites.

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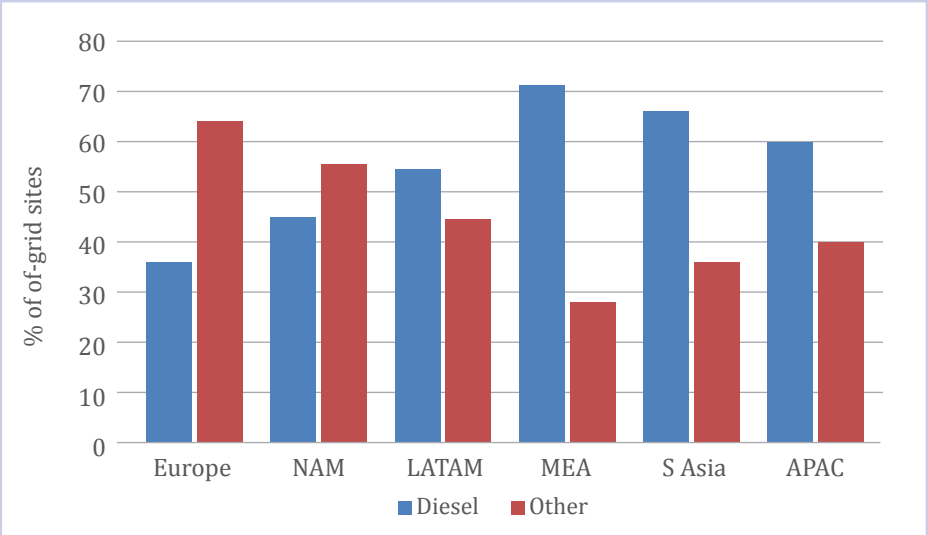
The Changing Base Station Power Landscape

This rising interest in diesel alternatives will lead to a very different base station power landscape by 2022, as seen in Figure 6, which summarizes Rethink's forecast of the increasing adoption of non-diesel power options between 2018 and 2022.

Figure 6. % of off –grid sites powered by diesel and alternatives in 2022



This rising interest in diesel alternatives will lead to a very different base station power landscape by 2022.

[3] Source: United Nations Sustainable Development Programme

In Europe and North America, there are few completely off-grid sites, but a rising number of sites which are considered 'poor-grid'.

The forecast indicates widening regional variations in the adoption of alternatives to diesel. In the absence of new solutions, South Asia will still be using diesel for two-thirds of its off-grid base stations by 2022, while in Africa (especially sub-Saharan Africa) the figure will be as high as 72%.

In Europe and North America, there are few completely off-grid sites, but a rising number of sites which are considered 'poor-grid' (i.e. they are unreliable for modern levels of mobile broadband usage and IoT coverage, even if they were acceptable for 2G and 3G usage). Europe will achieve the lowest reliance on diesel, and the highest adoption of solar and wind by 2022.

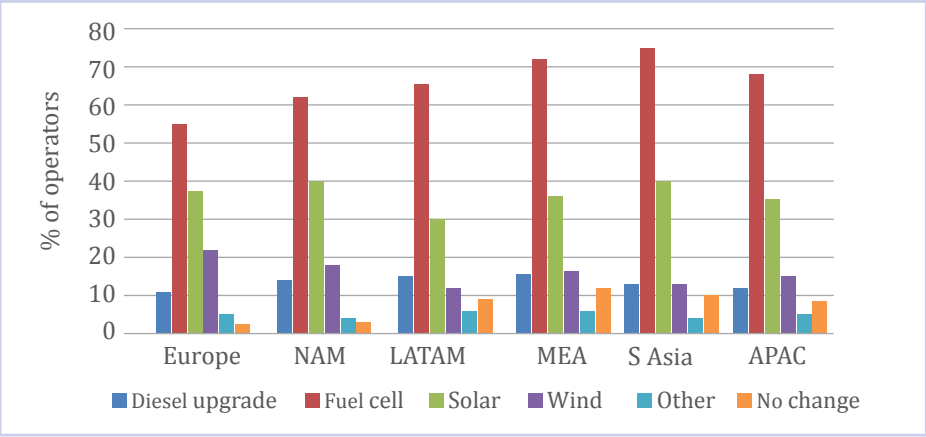
However, this forecast assumes no significant new power solution will emerge in that period. As this report will describe, we believe the shift to alternatives will be even more pronounced by 2022, if new technologies are commercialized in the coming 1-2 years, which lower barriers to the deployment of some non-diesel options, particularly fuel cells.

The Main Alternatives to Diesel, Compared

The shift to alternatives will be even more pronounced by 2022, if new technologies are commercialized.

The main alternatives for primary power are hydrogen fuel cells and solar, with some use of wind power. For backup, fuel cells and batteries are the dominant alternatives. In the survey of 55 tower and network operators (Figure 7), Rethink drove down into the most popular alternatives for investment over the next six years.

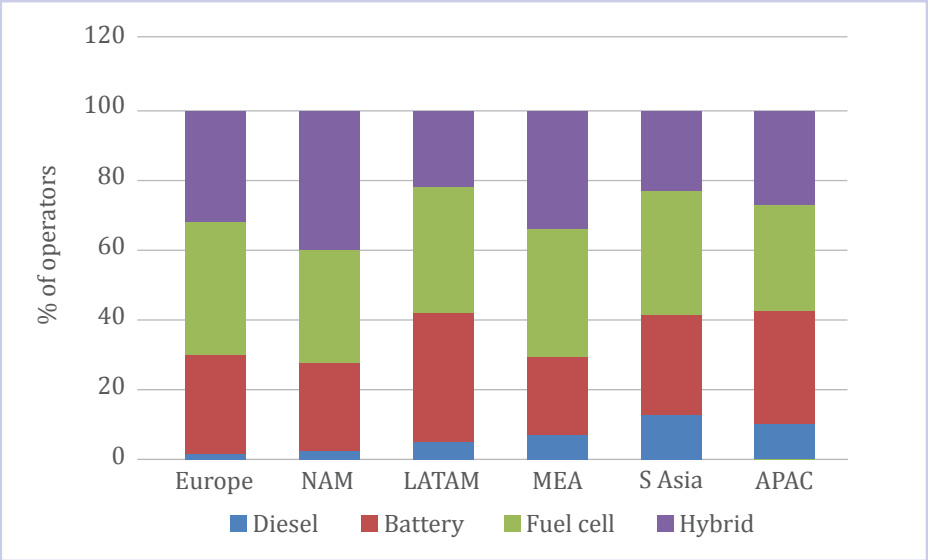
Figure 7. Solutions in which operators expect to invest by 2023



The solution for primary power, in which the highest percentage of respondents expect to invest for the first time before 2024, emerged as fuel cells, ranging from 55% of operators in Europe to 76% in South Asia. This was followed by solar. (The European and North American figures are relatively low because a significant number of companies have already made some deployments of fuel cells.)

The solution in which the highest number expect to invest for the first time before 2024 is fuel cells, making them the main alternative to diesel.

Figure 8. Backup solutions in which operators expect to invest by 2023



For backup power, there was an even sharper move away from deploying diesel generators at new sites, with operators favouring battery, fuel cells and hybrids.

These trends mean hydrogen fuel cells will be the most widely adopted alternative to diesel, though the level of uptake will vary considerably according to region too. In terms of the percentage of base stations for which they provide primary power, fuel cells will range between 32% and 11% of the installed base (far higher in newly deployed sites). Despite the proliferation of new power solutions, the survey shows that there is no single approach which addresses all the operators' business case requirements. Respondents were asked to name the top three disadvantages which they saw to each major power option. Seven factors emerged as the most likely to appear in these ratings. In the case of diesel, the main reasons operators were seeking alternatives were total cost of ownership (TCO) including capex, opex and fuel; as well as environmental factors (Figure 9).

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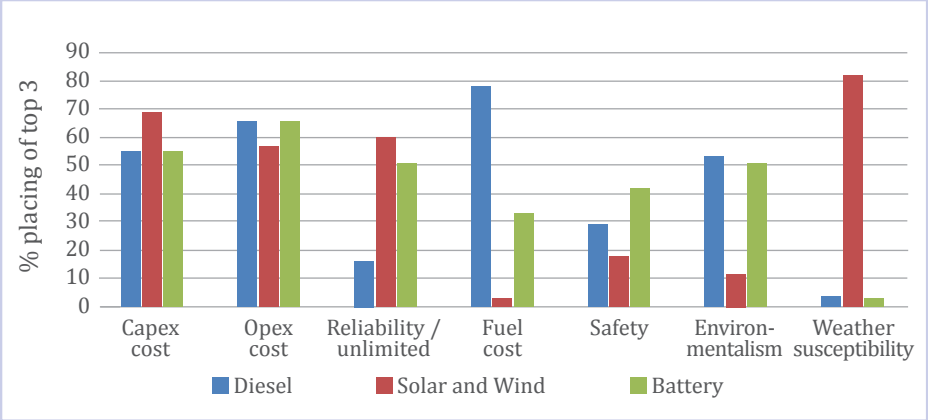
Figure 9. Most significant downsides of fuel options for off-grid



For battery, the main issues emerged as cost, reliability and environmentalism (disposal issues). For solar and wind, the main challenges were seen as upfront cost, reliability and weather susceptibility.

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Perceived Benefits of Hydrogen Fuel Cells

Operators have become increasingly interested in fuel cells as the primary fuel source, to replace diesel.

The operators were also asked about the pros and cons of fuel cells. Fuel cells are energy conversion devices producing DC electrical current and commonly run on hydrogen. They operate electrochemically, like batteries, but have an external source of fuel.

Fuel cells were, in the early years, mainly used in telecoms for backup, but as the technology has evolved, operators have become increasingly interested in them as the primary fuel source, to replace diesel. These were perceived to address many of the key requirements for investment, which is why they are seeing the highest growth in adoption.

The key advantages of fuel cells over other alternatives are summarized in Table 4.

Table 4. Key advantages of fuel cells over other solutions

Compared to diesel generator	Compared to battery	Compared to solar and wind
Emission-free at point of use, reduced lifecycle emissions	Longer runtime because fuel and energy separated	Lower capex cost
Silent	Larger temperature range	Highly reliable
Highly efficient	Highly reliable	Can be deployed in any climate/terrain
Few moving parts to reduce maintenance cost	Reduced environmental concerns (disposal)	Low susceptibility to weather conditions
More predictable fuel costs		
Limited risk of fuel theft or hazardous spillage		
Highly reliable		

Perceived Disadvantages of Hydrogen Fuel Cells

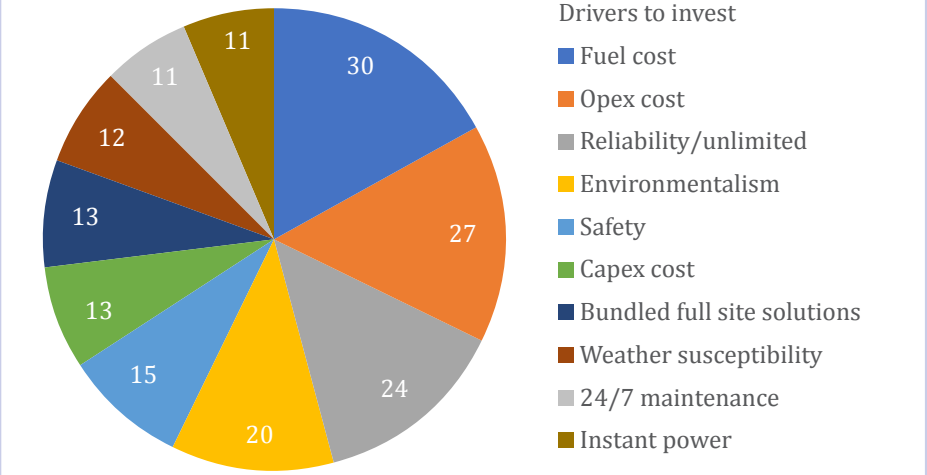
Despite these advantages, fuel cells have not displaced diesel solutions at the rate that was widely predicted a few years ago. This is because, while they address many of the drawbacks of the other solutions, they also have some significant downsides.

The operator survey explored the main downsides that the respondents cited for hydrogen fuel cells. Overwhelmingly, the most important barriers were seen to relate to operating and fuel costs, because of the cost of transporting and distributing hydrogen to the sites. To do this, significant investment is required in the transport infrastructure. 91% placed operating costs in their top three, and 51% fuel costs, in both cases mainly because of distribution.

The most important barriers were seen to relate to operating and fuel costs, because of the cost of transporting and distributing hydrogen to the sites.

Figure 10 highlights the percentage of MNOs and tower operators which placed each factor in their top three issues with hydrogen fuel cells (multiple responses allowed).

Figure 10. Most significant perceived downsides of hydrogen fuel cells



There is currently no perfect solution which ticks all the boxes for base station power in off-grid and poor-grid environments.

This finding, and the preceding chapters, show that there is currently no perfect solution which ticks all the boxes for base station power in off-grid and poor-grid environments.

The lack of an option with no significant downside runs the risk of delaying operator investment in new solutions, or in upgrading their current sites. That, in turn, could have a negative impact on MNOs' ability to expand their off-grid coverage, to reduce their total cost of ownership, and to meet environmental targets.

A New Fuel Cell Solution Could Accelerate Poor-Grid Investment

The majority of operators are at the stage of evaluating solutions rather than making concrete, wide-scale plans. Respondents were clear that their timelines to deploy new solutions were generally subject to change, at least for plans beyond the end of 2019. Some changes in the market could accelerate, or delay, their plans by up to 18 months.

If the disadvantages of the various solutions, as outlined above, were addressed at a faster rate than operators currently expect, it could bring forward their deployment timelines.

Summary: an alternative fuel cell technology could accelerate operator investment

- The most important factors which would accelerate operators' investment in a new technology are reduced fuel costs and operating costs.
- These are the only two areas where hydrogen fuel cells do not meet operator objectives.
- A solution with all the benefits of hydrogen fuel cells, and at least 25% lower costs, would accelerate investment.
- That would have a significant impact on the operator business model for off-grid communications, and contribute to government programmes for universal connectivity and Internet services.

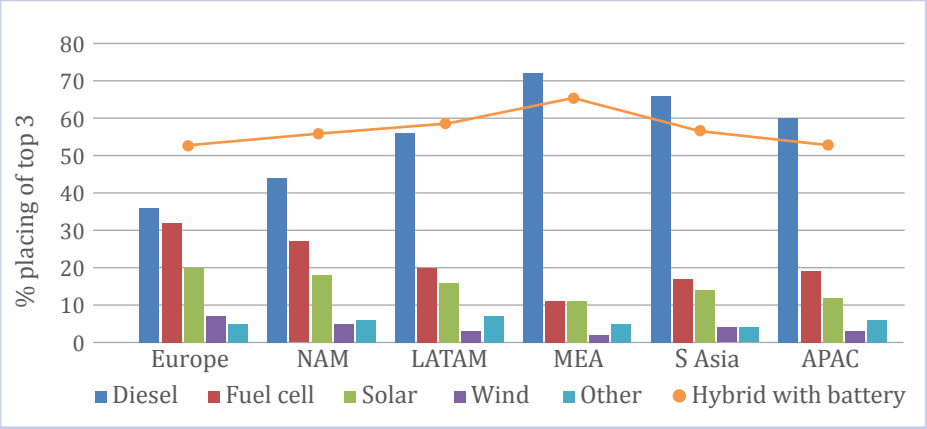
Rethink modelled the impact of a solution that addressed all the towercos' and MNOs' top four concerns. Based on the surveys, and our inhouse model, we compared the pattern of adoption based on currently available solutions, assuming no significant new entrants before 2022; and the pattern should a new solution be available from 2018 onwards, which addressed the issues of fuel and operating cost convincingly.

An alternative fuel cell technology would have a significant impact on the operator business model for off-grid communications, and contribute to government programmes for universal connectivity and Internet services.

The most important factors which would accelerate operators' investment in a new technology are reduced fuel costs and operating costs.

Figure 11 indicates our forecast for the decline of diesel solutions by 2022, if no radically different solution becomes commercial. In this scenario, the percentage of sites whose primary power source is diesel will fall from between 80% and 94%, depending on region, in 2014; to between 36% and 72% in 2022.

Figure 11. % of off-grid sites powered by diesel and alternatives in 2022



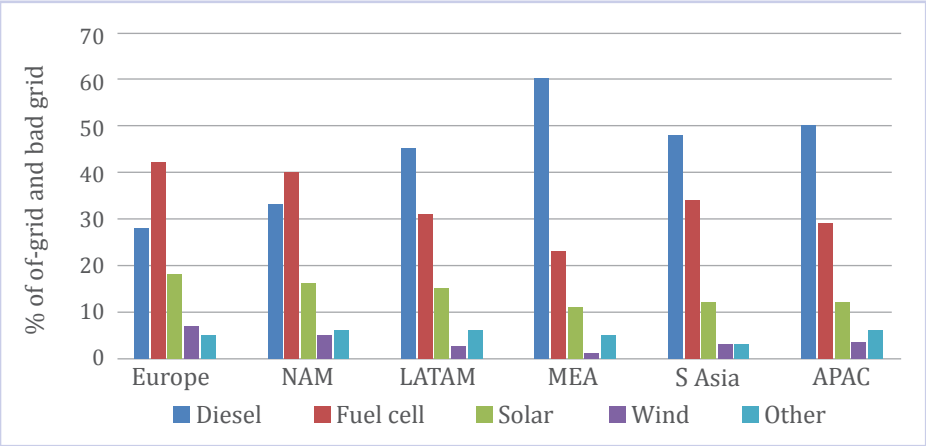
We have assumed that the most likely such solution will be a fuel cell with significantly lower fuel transport costs.

If a solution which addressed the opex and fuel cost concerns did emerge, Rethink calculates the pattern of off-grid and poor-grid base stations would be very different by 2022, as shown in Figure 12 (on the next page). We have assumed that the most likely such solution will be a fuel cell with significantly lower fuel transport costs.

This would result in a far higher adoption of fuel cells across the installed base of off-grid and poor-grid base stations. In developed economies, addressing barriers to adoption would increase usage of fuel cells by 30% (Europe) to 48% (NAM).

But the biggest shift would be seen in economies where the transportation costs and logistics have the greatest economic impact. So a new solution would lead to fuel cell adoption across the installed base more than doubling in Africa and South Asia, and rising by 53% in APAC and 55% in LATAM. The increased uptake of fuel cells would be mainly at the expense of diesel, reducing the barriers for operators to transition from legacy to fuel cell technologies, though it would also have some impact on solar and wind adoption.

Figure 12. Power landscape in 2022 if barriers to fuel cells are addressed



In other words, addressing the issue of fuel transportation would considerably enhance the attractiveness of fuel cell technologies for powering off-grid and poor-grid base stations, and would drive many towercos and MNOs to accelerate their plans to invest in this approach.

The Ammonia Fuel Cell Solution

Among the emerging alternatives for base station power, the most promising and near term is, in Rethink's opinion, the ammonia fuel cell.

Instead of building hydrogen infrastructure, hydrogen can be created from ammonia, which has existing widespread infrastructure. It is the second most-used chemical in the world and is widely distributed by pipelines and vehicles.

Ammonia can be converted to hydrogen to fuel the cells, creating an emissions-free power source that scores highly on reliability and TCO, and has lower fuel costs than diesel.

Ammonia can be converted to hydrogen to fuel the cells, creating an emissions-free power source that scores highly on reliability and TCO, and has lower fuel costs than diesel.

Ammonia could save $357 million per 1,000 base stations over 12-15 years with high reliability, safety and environmentalism.

This has all the advantages of the hydrogen fuel cell, but greatly reduces the cost of fuel and of transportation.

Its advantages lie in the following key characteristics:

- Reduced fuel and operating cost - according to GenCell, which is pioneering ammonia fuel cell technology for telecoms and other sectors, the solution can save up to $357 million per 1,000 base stations over 12-15 years, compared to diesel.[4] One 12-ton tank of ammonia can fuel a base station 24 hours a day, for a year.
- High levels of safety compared to flammable diesel.
- High levels of environmentalism compared to diesel or battery (which has disposal issues).
- High reliability and availability.

The advantages over other solutions are summarised in Table 5.

Table 5. Ammonia fuel cells versus other power solutions

Requirement	Diesel	Solar and wind	Traditional fuel cell	Ammonia fuel cell
Low fuel cost	•	•		•
Low opex cost		•		•
Reliability/unlimited	•		•	•
Environmentalism		•	•	•
Safety	•	•	•	•
Low capex cost	•		•	•
Bundled full site solution	•		•	•
No weather susceptibility			•	•
Frequent maintenance	•			
Instant power	• with battery		•	

5. http://www.fch.europa.eu/page/fp7-projects-application-area utm_source=website &utm_medium=link&utm_campaign=201706_WP1

An ammonia fuel cell solution has been a subject of academic research for some years. For instance, the European Union co-funded a project to research such a solution for off-grid base stations in 2009-2012 as part of its FP7 programme. However, it has not been commercially available in the telecoms market.

Indeed, while many survey respondents were aware of it as an academic study, only 3% were aware it was already a commercial option for mobile base station power. Overall, awareness of ammonia as a fuel was low with regards to base stations.

However, when the characteristics of the solution were outlined, 76% said they would be 'very interested' or 'interested' in such an offering for off-grid and poor-grid base stations.

More detail about the cost savings compared to diesel are provided in Table 6 (overleaf). This shows that, in a survey of 27 countries around the world, ammonia fuel cells work out cheaper than diesel by, on average, $250 million per 1,000 base stations.

Four regions will save about $300-$350 million compared to diesel.

76% said they would be 'very interested' or 'interested' in such an offering for off-grid and poor-grid base stations.

Table 6. Cost savings from 24x7x365 operation at 1,000 towers over 10 years

Region	Country	Ammonia price/ton (US$)	Diesel price/liter (US$)	Savings (US$ million)
Europe	Italy	286	1.75	357
Europe	France	281	1.71	348
Europe	UK	291	1.71	345
Europe	Netherland	273	1.54	303
Europe	Germany	267	1.46	283
Asia	South Korea	257	1.27	234
Africa	South Africa	271	1.16	200
Asia	Japan	306	1.1	174
Asia	China	228	1.01	170
Asia	Australia	303	1.06	164
Asia	India	333	1.02	146
Asia	Taiwan	269	0.81	105
NA	USA - New England	237	0.78	105
NA	USA - Mid Atlantic	243	0.78	103
NA	USA - South	253	0.78	101
NA	USA - West Coast	261	0.78	99
NA	USA - Southwest	264	0.78	98

As noted above, while respondents were aware of ammonia as a fuel in general terms, there was very low awareness of its applicability to base station power solutions. However, the ecosystem will develop as commercial offerings emerge, and a critical enabler of that will be a choice of strong providers of ammonia. The leading suppliers are listed in Table 7.

Table 7. Leading suppliers of ammonia

Company	Region	URL
Linde	Europe	www.linde.com
Air Liquide	Europe	www.airliquide.com
Blended Products	UK	www.blendedproducts.co.uk
Praxair	USA	www.praxair.com
Ube Industries	Japan	www.ube-ind.co.jp/ube/en

Conclusion

Successful commercial application of ammonia-enabled hydrogen fuel cells would significantly accelerate the expansion of the mobile communications network to more off-grid and remote locations.

To summarise, successful commercial application of ammonia-enabled hydrogen fuel cells would significantly accelerate the expansion of the mobile communications network to more off-grid and remote locations, by reducing the cost and risk of doing this, and meeting the key requirements of towercos and operators.

This expansion would, in turn, drive social and economic benefits by making broadband connectivity available to currently unserved people, as well as supporting remote enterprises such as mines. In addition, the ammonia solution would lower the barriers to investment in modernizing power solutions on existing sites, leading to greatly reduced emissions and cost of ownership in the current off-grid and poor-grid networks, as well as improved reliability to support improved quality of service, and even critical services.

Ammonia-enabled fuel cells would bring operators a big step closer to providing universal broadband coverage at an affordable cost.

Combined, these results would help to transform the business case for extending mobile connectivity to remote users and locations. This will bring operators a big step closer to providing universal broadband coverage, at affordable cost.

About Rethink Technology Research

Rethink Technology Research is a specialized research and consulting firm with 12 years' experience in surveying wireless, broad-band, over-the-top and quad play operators. This has resulted in a broad research base of over 140 service providers (MNOs, telcos, cable and satellite operators, over-the-top providers) worldwide. These organizations are surveyed on a regular basis about their network infrastructure and business plans, and have a relationship of trust with Rethink.

Rethink also has deep relationships with the telecoms ecosystem (tier one device OEMs, vendors, technology developers, integrators, regulators etc), and is perceived as a thought leader in many areas of the telecoms and media sectors. Key areas of expertise and research experience include HetNet migration, small cells and carrier WiFi; transformation strategies for the RAN and the BSS/OSS; convergence of IT and network skills and platforms; device and chipset roadmaps; spectrum strategy.

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