Smart Grid Technologies and the Development of a Decision Making Framework for Market Entry

by

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Bachelor of Science in Physics, Appalachian State University, 2001

Submitted to the MIT Sloan School of Management and the Department of Engineering Systems in Partial Fulfillment of the Requirements for the Degrees of

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ABSTRACT

This thesis explores business opportunities in the "smart grid" environment for the Power Electronics Global Product Group (PE GPG) of ABB, Ltd.

The goal of this thesis is three-fold:

1) Provide a detailed definition of the smart grid landscape.
2) Create a framework for decision makers in the face of uncertainty, providing a view of both current initiatives and growth opportunities.
3) Use this framework to identify areas where the PE GPG can have the greatest market success in terms of revenue and profit; and perform a high-level analysis of those key opportunities, including a preliminary market, technical, and financial assessment.

Working with key stakeholders across the unit and corporate level, the smart grid was defined, with a technologies map created, and key opportunities identified. With the opportunity set defined, a framework was developed to aid senior management in finding the best opportunities in the smart grid market. By subsequently applying this framework, two segments were identified as the most promising: **plug-in electric vehicle charging** and **battery energy storage**.

While straightforward to identify opportunities in this manner, this process really highlighted the need for a comprehensive framework for decision makers, as well as the importance of such tools in identifying promising new projects, allocating resources efficiently, and communicating the strategic vision throughout the organization on an ongoing basis.

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

AC – Alternating Current

AMI – Advanced meter infrastructure

AVC – Active Voltage Conditioners

BCG – Boston Consulting Group

DC – Direct Current

DPM – Directional Policy Matrix

EV – Electric Vehicle

FACTS – Flexible Alternating Current Transmission Systems

HAN – Home Area Network

HVDC – High Voltage Direct Current

IEC – International Electrotechnical Commission

IGBT – Insulated Gate Bipolar Transistor

IGCT – Insulated Gate Commutated Thyristor

ISI – Industry Specific Initiative

Li-ion – Lithium Ion

MV – Medium Voltage

NiMh – Nickel-Metal Hydride

NIST – National Institute of Standards and Technology

PE GPG – Power Electronics Global Product Group

PHEV – Plug-in Hybrid Electric Vehicle

PRU – Product Responsible Unit

TOU – Time of Use Pricing

V2G – Vehicle-to-Grid

STATCOM - Static Synchronous Compensator

1. INTRODUCTION

1.1 Project Motivation and Goal

With exposure to many industries in flux, ABB's Power Electronics Global Products Group (PE GPG), part of the Discrete Motion and Automation Division, is facing a time of transition. Over 80 percent of its revenues come from traditional industrial markets such as aluminum and steel manufacturing, conventional energy generation, and railway applications – all of which are broadly tied to consumer spending and to the overall economy (1). Facing the largest downturn in a generation, it has become quickly apparent that sales growth in these mature markets will not continue as predicted, or even recover to 2007 levels any time in the near future. However, with access to cutting-edge technology and the ability to leverage resources from the larger ABB enterprise, the PE GPG has many options for continued growth.

One potential key growth area lies within the realm of renewable energy, energy efficiency, and improved electric grids. The PE GPG has already made strong inroads into the wind power market, offering distributed generation integration with the semiconductor-based PCS 6000 power conversion system (2). However, even as renewable energy becomes a greater percentage of total generation, there are additional markets to explore.

The original motivation for this work was based on identifying new markets to enter, with a focus on the developing technologies of the smart grid. As the work progressed and a clear picture emerged of the PE GPG's position in the value chain, it became apparent that in addition to identifying the technologies themselves, it is also vital to clearly show how they integrate, strengthen, and build on the existing portfolio.

As a result, the project expanded into the area of decision making methodologies and portfolio strategy, drawing heavily on existing work in the field. A decision making strategy was developed, one that weighs the need for growth and expansion with the task of managing the existing commercial offerings.

1.2 Thesis Overview

The thesis proceeds as follows:

Chapter 2, ABB Background provides a brief explanation of the management and operating structure of ABB at the corporate and strategic business unit level. Additionally, it introduces the relevant technologies of the PE GPG.

Chapter 3, the Smart Grid achieves the primary goal of the project by providing an assessment of the current smart grid landscape, the key drivers, and the main challenges. This chapter also outlines ABB's smart grid strategy.

Chapter 4, Introducing a Scoring Model for Opportunity Selection and Portfolio Management examines the concept of portfolio management as well as its benefits and challenges. Additionally, a decision making framework is introduced which takes the key factors for strategic decision making and distills them into an easy-to-use matrix for evaluating projects and opportunities.

Chapter 5, Applying the Portfolio Scoring Model to the Smart Grid takes the framework created in the previous section and applies it to the actionable smart grid segments identified in Chapter 3. This entails an initial screen of all of the opportunities, as well as a more detailed assessment of the most promising ones.

Chapter 6, Integrating the Portfolio looks at the challenges associated with implementing the scoring model, including resource allocation, organizational alignment, and moving forward with the business case.

Chapter 7, Conclusions ties the results and discussions of the preceding chapters together and demonstrates how the frameworks and concepts developed in this thesis can be applied across different organizations and industries.

2. BACKGROUND

This chapter describes the general corporate structure of ABB, the key units involved in the study, and the culture and competitive landscape in which they operate. The objective of the chapter is to give the reader a better understanding of the general operating environment and the unique challenges faced by a widely dispersed multinational corporation.

2.1. ABB Corporate Background

ABB Asea Brown Boveri Ltd. was formed in the 1988 merger of two European industrial giants, ASEA AB of Västerås, Sweden and BBC Brown Boveri Ltd of Baden, Switzerland. Prior to the merger, ASEA was one of the top ten companies in the world in power technology, while BBC was a market leader in transmission systems, motor drives for powering rotating machinery, and generators. Identifying little potential for cannibalization and a chance for both entities to expand geographically, the two companies merged and proceeded to grow into new markets. Over 40 companies were acquired in the first year, followed by a strong push into newly opened central and eastern European markets following the collapse of the Iron Curtain. ABB continued its expansion through the 1990s, fueled mostly by acquisitions in key markets, such as U.S. company Combustion Engineering in 1990, and automation leader Elsag Bailey Process Automation in 1997 (3).

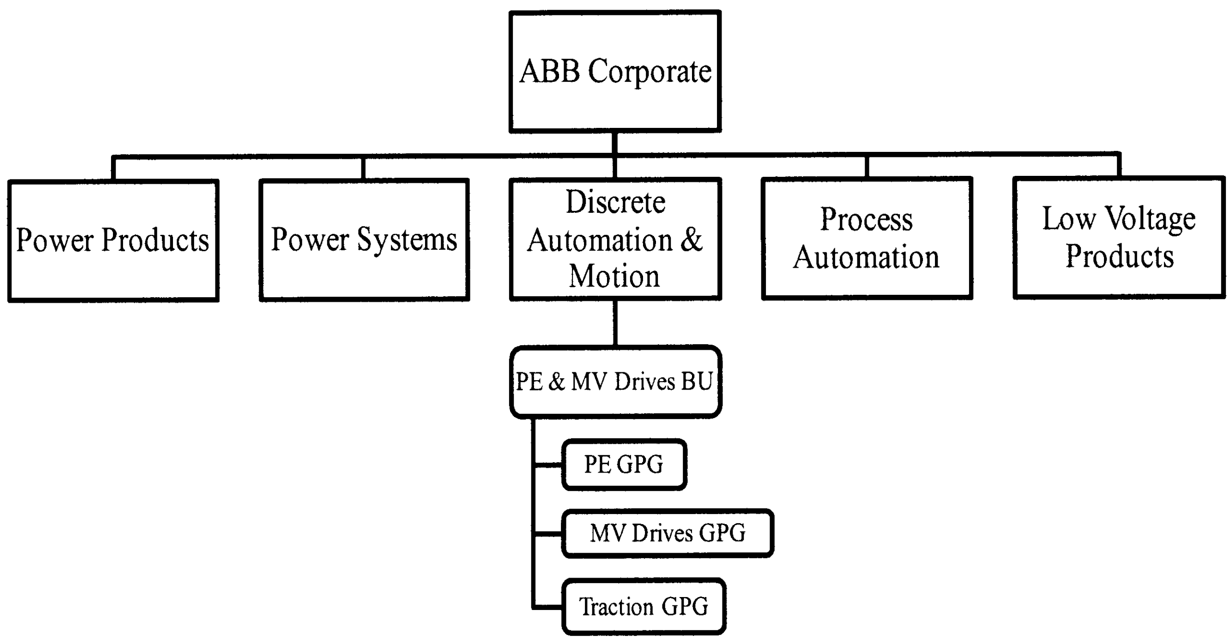
Realizing that they were losing competitive advantage in a number of markets, and desiring to focus on the alternative energy market, ABB began a period of divestiture and consolidation, beginning with the 1999 divestiture of its nuclear power and conventional power generation businesses. Forced to the brink of bankruptcy in the early 2000s through asbestos litigation related to Combustion Engineering, ABB underwent a series of drastic cost-cutting periods and corporate restructurings. The most significant of these, in 2002, forms the basis for the current corporate structure where the company is divided into five distinct divisions, each representing a broad technology range and to some extent possessing a unique culture. While this structure allows for a significant amount of autonomy and eases the burden on the executive team, the very independent divisional structure gives rise to "silos" where individual divisions and business lack communication with one another and a set of common goals.

Following recovery from its near-bankruptcy, ABB continued to divest non-core businesses, and focus on the industrial IT, power, and automation sectors. In 2008 ABB brought in a new CEO, Joseph Hogan, formerly the head of General Electric (GE) Healthcare, who outlined his "Mission and Vision 2011:" (4)

- **Improve performance**: ABB helps customers improve their operating performance, grid reliability and productivity whilst saving energy and lowering environmental impact.
- **Drive innovation**: Innovation and quality are key characteristics of our product, systems and service offering.
- **Attract talent**: ABB is committed to attracting and retaining dedicated and skilled people and offering employees an attractive, global work environment.
- **Act responsibly**: Sustainability, lowering environmental impact and business ethics are at the core of our market offering and our own operations.

2.1.1. Corporate Structure

ABB earned revenues of approximately $32 billion in 2009 over its five divisions as shown in Fig. 1.



Source: ABB, *Our Businesses,* ABB.com, http://www.abb.com/cawp/abbzh252/a92797a76354298bc1256aea00487bdb.aspx

Figure 1. ABB Corporate Structure

Power Products' major offerings include large distribution components such as transformers, switchgear, and circuit breakers. The Power Systems product range, which shares the same front-end sales organization as Power Products, includes substations and network management, among others. Discrete Automation and Motion offers drives, medium voltage power electronics, motors and generators, and robotics. Process Automation products include control systems and analytical systems, while Low Voltage Products manufactures smaller products such as circuit breakers, switches, and motor controls.

2.2. Power Electronics and Medium Voltage Drives

The Power Electronics and Medium Voltage (MV) Drives Business Unit is part of the Discrete Automation and Motion Division. It has approximately 1700 employees worldwide and is separated into three smaller Global Product Groups: Power Electronics, Medium Voltage Drives, and Traction Converters, as shown in Fig. 1. This is a somewhat unique arrangement, as given their size and breadth of offerings, these groups could be stand-alone business units. However, with their technological similarities and geographical co-location, they are organized as a single unit. Besides the common site for headquarters and some technological similarities, these groups have little in common, operating essentially independently for product development, manufacturing, sales, and marketing.

The PE GPG manufactures and distributed low- to medium-voltage (~ 480 to 6.6 kV) power electronic power conversion systems for a wide range of applications and industries – from traditional industrial markets such as aluminum production to emerging markets such as wind energy conversion. The specific offerings of the PE GPG are discussed in much greater detail in the next section.

The Medium Voltage Drives group manufactures medium voltage (~ 2.3 to 6.6 kV) alternating current (ac) drives which are used to control the speed and torque of induction and synchronous machines. These drives are used in numerous industries to increase the efficiency of rotating machinery such as fans and pumps. Compared to the products manufactured by the PE GPG, MV Drives are much more standardized across the product range, offer a more limited range of options, and are produced in much higher volumes.

The Traction Converter group manufactures on-board converters for propulsion and power supplies for the train and light rail industry. These products are mostly sold in Europe, where light rail travel has a significant market penetration. These systems are widely used to interface the 16.7 Hz rail electric network with the 50 Hz main power grid, providing power conversion at levels up to 1000 W (5). From a technology standpoint all three groups share solid-state power electronics as the base building block of their offerings, as detailed below.

2.3. Power Electronics Global Product Group

2.3.1. Organization

The PE GPG is composed of five different units called Product Responsible Units (PRU). These PRUs are varied in nature, representing a wide mix of applications and markets. The following lists the functions at a high-level; the detailed technologies are explained in the next section:

- **Power Quality Products (PQ)**: This PRU has grown directly out of a recent acquisition of a New Zealand firm, Vectek (6). The technology is a lower voltage power electronics platform, and adds capabilities in the PE GPG in terms of new markets, modular technology, and standardized manufacturing processes. The current markets for this unit are Active Voltage Conditioners (AVC) for precision manufacturing such as semiconductor fabrication, Low Voltage static synchronous compensators (STATCOM), at approximately 400 to 1000 V, for low-level reactive power compensation in industrial applications, and Marine Frequency Converters, a growing application of ship-to-shore power conversion which allows a universal connection to shore power to limit the necessity of merchant ships running their diesels while tied to the pier.

- **Converter Products (CP)**: Recently spun-off from another PRU, Converter Products was formed as a result of increasing demand for renewable energy conversion systems, initially targeting wind parks and large wind turbines (turbine ratings up to 5 MW). Its main product is a medium voltage converter, which can be tailored for specific applications such as fuel cells and other distributed generation.

- **High-Power Rectifiers (HPR)**: This unit sells converter products that turn a medium-voltage ac input into a low voltage, high-current direct current (dc) output for use in industrial applications. The key applications for this technology are aluminum smelting, chlorine electrolysis, and dc arc furnaces.

- **Excitation (EXS)**: This unit offers static excitation systems and voltage regulators for large synchronous machines for power generation. This is a similar technology to the high-power rectifiers as the input is ac and the output is dc for field excitation.

- **Advanced Power Electronics (APE)**: Based around a set of technologies rather than specific markets, the APE PRU is able to customize power electronics platforms for a wide range of industries and applications. They currently have projects in grid support for 17 kHz railway support systems, MV STATCOM for reactive power compensation to meet the power quality requirements of the electric grid, and ac excitation for pumped hydro storage applications, where a variable excitation field is applied to ac turbine-generators based on whether the turbine is generating or pumping. The biggest application for this is found in pumped storage technology where the efficiency is maximized at different speeds, depending on whether the turbine is generating or pumping.

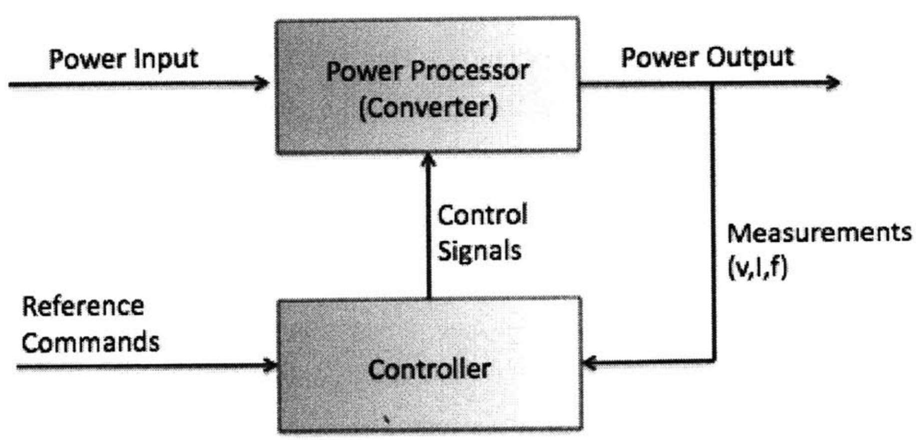
- **Service:** The group also operates a comprehensive global service organization, which provides complete life-cycle management support on ABB and non-ABB power electronics systems.

With the exception of the Power Quality PRU, which has maintained headquarters, engineering and manufacturing operations in New Zealand, all of PE GPG PRUs are headquartered in Turgi, Switzerland. The majority of manufacturing operations are performed there as well, with numerous Local Engineering Centers (LECs) around the world providing sales, engineering, and final assembly support.

2.3.2. Power Electronics Technology

<u>*Overview*</u>

Power electronics is the application of solid-state electronics for the control and conversion of electric power. Applications range in size from milliwatts (mW), used in small electronic devices such as mobile phones, to the approximately 1000 megawatt (MW) conversion systems for dc transmission lines (7). At the fundamental level the basic building block for any power electronics system is the *switching converter,* which in modern systems is a power semiconductor-based device such as a thyristor or transistor. These switching circuits enable the power electronic device to process raw input power and, under the influence of a control circuit, control the flow of output power as well as its form – ac or dc and the magnitudes of its currents and voltages. Fig. 2 shows a basic block diagram of a converter application.



Source: Oak Ridge National Laboratory, *Power Electronics for Distributed Generation,* 2005

Figure 2: Basic Power Electronics Block Diagram

The power processor performs the switching functions and contains the power electronic device or series of devices. Based on measurements and a series of settings through the reference commands, the controller sends a control signal to the power processor, adjusting its output characteristics. As seen in Fig. 1, processing the power requires additional hardware to manage the power flows in the system and provide protection and control. Among these are control systems, thermal management systems, protection devices, dc/ac disconnects, and an enclosure. The integrated system is referred to as a Power Conversion System (PCS). Table 1 shows the functions performed by PCSs, with their commonly used names. The specification applications of these in the PE GPG are discussed in the next section.

Table 1: Power Conversion System Classifications

Conversion	Common Names
AC-to-DC	Rectifier
DC-to-AC	Inverter
DC-to-DC	Chopper, boost, buck, buck-boost
AC-to-AC	Cycloconverter, converter

Source: Oak Ridge National Laboratory, *Power Electronics for Distributed Generation,* 2005

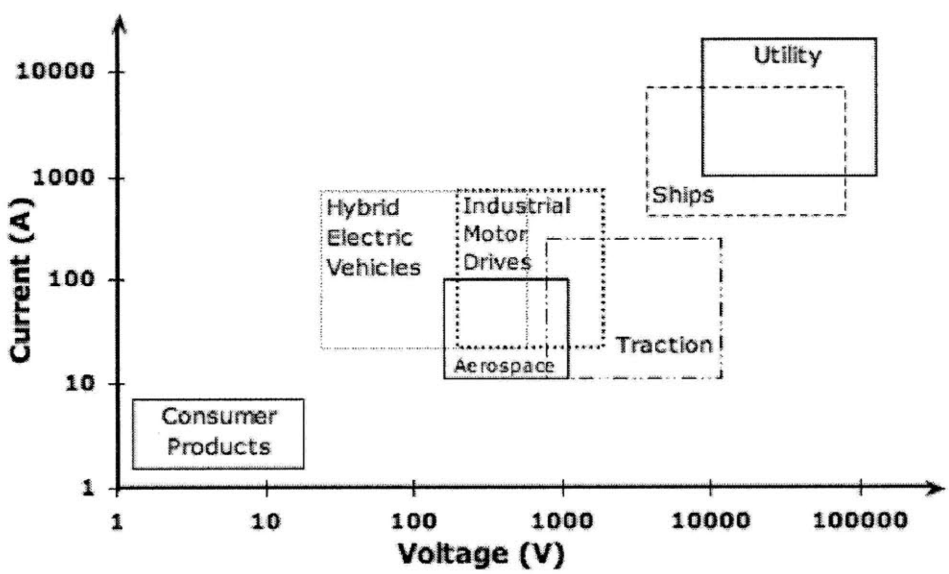
High efficiency is essential in any PCS. This is not just based on the desire to cut costs or save energy, but rather because low-efficiency converters with substantial output are very impractical. As the efficiency of the converter is the ratio of the power out to the power in, a converter with only 50 percent efficiency at rated load will be dissipating the other 50 percent of the input power as heat in the system. This kind of heat generation requires large cooling systems, causes the devices to operate at a high temperature, and reduces overall system reliability (7). The key to high power outputs is therefore to increase the efficiency of the conversion process. This also allows the converter elements to be placed with a higher density, reducing footprint and weight.

Applications

Worldwide, the greatest number of power electronics devices can be found as low-voltage rectifiers in consumer electronics such as laptop and cell-phone chargers, desktop computers, and televisions. In industrial applications, power electronics are most commonly used in variable speed drives for controlling the speed of induction motors in pumps and fans, such as in the offerings of the MV Drives unit.

Across all power levels, power electronics are becoming commonplace in the electricity industry where they are valued for their flexibility, small size, and high efficiency. It is estimated that 30 percent of all electric power generated utilizes power electronics somewhere between the point of generation and end use. This is expected to increase to as much as 80 percent by 2030, driven largely by the increased use of MV drives, utility applications such as high voltage direct current converter stations, and in the interface required between the electric grid and distributed energy sources such as fuel cells, wind turbines, solar cells, and energy storage devices (8). Additionally, power electronics are gaining increasing popularity providing grid support and controlling the amount of *reactive power* in a network, which does not transfer energy but can affect overall grid stability.

Fig. 3 details the approximate voltage and current ratings of power electronics devices for several different application areas. These include low-cost and low-power applications such as consumer electronics products, specific conversion applications such as the on-board converters in hybrid and fully-electric vehicles, and large substation applications with significant footprints and costing in the tens of millions of dollars, among others.



Source: Oak Ridge National Laboratory, *Power Electronics for Distributed Generation,* 2005

Figure 3: Voltage and current rating for different power electronics application areas

Power Electronics in the PE GPG

Table 2 summarizes the offerings across the PRU, including their primary applications and platform names.

Table 2: PE GPG Portfolio of Products

PRU	Application	Operation	Name
PQ	AVC, LV STATCOM	AC-to-AC	PCS100
CP	Wind power conversion	AC-to-AC	PCS6000
HPR	Aluminum and steel production	AC-to-DC	MCR200 series, Thyribloc / Rectibloc
EXS	Electricity Generation	AC-to-DC	Unitrol
APE	MV STATCOM, Rail network conversion	AC-to-AC, DC-to-AC	PCS6000

Source: ABB Power Electronics, *Power Electronics Portfolio*, http://www.abb.com/

While the PRUs serve a wide range of markets, they all share power electronics as the cornerstone of their products. Across the total portfolio, the PE GPG is able to reach a large swath of the power electronics market, represented in Fig. 3 as the range between motor drives and the lower areas of the utility applications. Based on the current product platforms, the PE GPG is not able to reach transmission-level applications, including high voltage direct current (HVDC) converters and Flexible Alternating Current Transmission Systems (FACTS), which are a set of technologies designed to enhance the capacity and flexibility of transmission systems. Additionally, product overlap at the lower power levels has resulted in an agreement that Low Voltage Products will be the only ABB supplier to target the solar energy market. Despite these limitations, there is still a wide range of new and existing markets for the PE GPG offerings, which will be discussed in more detail in Chapter 5.

Currently, the two most versatile platforms in the portfolio are the PCS100 and the PCS6000. The PCS6000 is the medium voltage "workhorse" of the PE GPG. It has proven adept in a wide range of applications, most recently as a wind turbine converter. For conversion applications, typical machine ratings are voltage of 3.3 to 4.5 kV and power up to 8 MW. Additionally, these machines can be connected in series or parallel for higher-power applications. The full specifications for the PCS6000 are shown in Appendix A.

The PCS100 is a low-voltage converter, with each stand-alone unit rated for 480 V and 125kW, however, like the PCS6000, multiple units can be connected in parallel for power ratings up to approximately 20 MW (9). Additionally, the PCS100 can be set up to perform multiples types of conversion, including ac to ac and dc to ac. Appendix B shows the specifications of the PCS100 when configured for energy storage applications.

2.3.1. Strategy

As mentioned in the Introduction, over 80 percent of the PE GPG's revenues have come from traditional industrial markets, which experienced a precipitous drop in spending over the last two years. While spending has rebounded to near 2008 levels, and the overall effect on the unit was mitigated by a strong order backlog, the drop definitely highlighted the dependence of the unit on these industrial markets. As a result, the PE GPG has been forced to reassess their overall strategy, increase their focus on operational excellence, and position itself to move into new markets.

The strategy of the power electronics global product group is to adapt and grow into new markets, while remaining competitive in the traditional markets. At a high level, the current core competencies of the unit are the ability to create custom engineered solutions at reasonable cost to meet their customer's needs, the application of medium voltage power electronics for power conversion, and superior aftermarket service. Building on this, one goal of the PE GPG is to improve competencies in leveraging product platforms for improving cost efficiency, decreasing manufacturing time, and increasing output. The purchase of Vectek, which brought onboard the PCS100 converter platform, a modular, scalable, lower cost technology, is one step in this direction. As a result, any new developments that can leverage the existing modular platforms, the PCS6000 and the PCS100, are favored heavily in the project selection process.

By moving into markets requiring potentially higher-volume and less customized applications, the strategy builds on an overall shift from a product focus to a market focus, where basic *product platforms* and *families* are adapted to serve multiple markets. Additionally, it represents an opportunity to become more strategically driven versus opportunistically driven, i.e. more responsive to the needs of the market and less driven by one-off custom projects, which do result in revenue but take valuable resources and often do not lead to additional business. Freeing those resources to fuel growth in new markets can potentially increase operating performance and create long-term, sustainable business opportunities.

3. THE SMART GRID

The first phase of this analysis is to define the smart grid landscape, the key technologies, players, and market drivers. This is accomplished through a combination of primary and secondary research, focusing on existing smart grid analysis and research tailored to the unique nature of the PE GPG. This chapter provides a high-level overview of the current smart grid landscape, drivers, challenges, and technologies, as well as a more detailed discussion of ABBs specific smart grid initiative.

3.1. Defining the Smart Grid

There has been much debate over the boundaries and definition of the smart grid. First introduced as a convenient phrase to describe specific intelligence advances in the electrical power network, it has now caught on to the extent that every organization has to give their own specific definition of the smart grid, such that the concept begins to lose meaning and become a catch-all for any type of advanced technology applied to the electric grid.

At its core, the smart grid can best be described as the intersection of the electrical infrastructure with the information infrastructure, and can be presented as the convergence of three layers of industries and capabilities, a shown in Table 3.

Table 3: Key Smart Grid Industries and Capabilities

Industry	Capability
Electric Power (Energy)	Transmission and Distribution
Telecommunications	Communications and Control
Information Technology (IT)	Applications and Services

Source: Greentech Media, *Smart Grid 2010,* 2009

As a result, the smart grid is not one technology, but a portfolio of technologies which combine to enhance the efficiency, reliability, and security of electric power transmission, generation, and consumption.

3.2. Drivers

There are numerous drivers for the smart grid, some more important than others, with the most significant ones outlined in Table 4, below.

Table 4: Primary Smart Grid Drivers

Growing Energy Demand
• Increasing global demand for energy, specifically expensive peak energy • Need for energy efficiency/conservation to counteract pace of demand growth, especially in emerging economies and China
Energy Independence and Security
• National security (fuel supplies and fuel diversification) • Rising and/or volatile fuel costs
Greenhouse Gas Reduction
• Increasing awareness of environmental issues, including global warming (electric generation is the largest source of greenhouse gas emissions in the world) • Social pressure to reduce carbon impact
Economic Impact
• Job creation and business opportunities in advanced technologies • High-cost of blackouts/brownouts (estimated $80 billion annual in the U.S.) (10) • Rising asset costs (cost of capital, raw materials, and labor) • Aging infrastructure
Policy and Regulation
• Renewable Portfolio Standards (RPS) in the U.S. (many states aiming for 20% renewable by 2020, or the like) • European Union Renewables Directive sets 2020 target date for 20% of energy from renewable sources (11) • China's State Grid announcement of specific plans for building a complete smart grid by 2020, increasing the installed capacity of renewable energy to 35% of the total (12)
Advanced Consumer Services
• "Smart home" networks • Vehicle-to-Grid (V2G) and electric vehicle charging
Quality of Service
• Delivering power that is free of sags, spikes, disturbances, and interruptions is important for many manufacturing intensive industries • Ability to anticipate and automatically respond to system disturbances
Cost reduction
• Advanced Metering Infrastructure (AMI) allows for automated meter reading, reducing labor costs • Time-of-use (TOU) pricing allows users to shift energy consumption to a lower cost period
Integration of Distributed Generation
• Advanced monitoring and control required to optimize generation assets and compensate for the intermittent nature of the electricity supply

Source: Greentech Media, *Smart Grid 2010*

These drivers are many and varied; further reinforcing the fact that smart grid upgrades will range in their scope and impact as different regions and countries try to meet different goals.

3.3. Smart Grid Implementation Challenges

As a system of multiple moving parts, varied stakeholders, and widely differing technologies the smart grid, in whole or part, will not come to fruition overnight. Below is a brief discussion of some of the key challenges facing widespread implementation of smart grid solutions.

Re-defining Utility Regulatory Policies

Regulation of transmission and distribution companies varies significantly throughout the world, but in the vast majority of cases, a utility or transmission company is remunerated from ratepayers or governments based on the amount of energy that they transmit. This immediately leads to a conflict with any policy that promotes energy efficiency or outright reduction of energy consumption. As a result, new regulatory models are required for there to be widespread support for energy efficient technologies.

One mechanism for this is via electricity decoupling, where a utility's rate of return is matched to a revenue target rather than bulk commodity sales, removing the incentive for utilities to increase sales as a means of increasing profit and revenue. This policy has been enacted in 17 U.S. states, with six more in the process of implementing decoupling mechanisms (13). In the E.U., decoupling policies have yet to take root, resulting in only voluntary and non-binding energy efficiency policies, most directed at increasing consumer and industrial efficiency rather than overall system efficiency. In the state-owned markets such as China, this is less of a problem as the government controls the prices throughout the value chain. Additionally, Chinese demand for energy is growing at such as rate that energy efficiency is encouraged by the government to reduce transmission and distribution congestion while new infrastructure is being built (14).

Lack of Clear Cost-Benefit Analysis

Building on the regulatory challenges above, another challenge facing the smart grid is the lack of a clear cost-benefit analysis applied across the whole set of technologies. As most utility investment projects, including smart grid projects such as smart meters, are approved based on a business case presented to a regulatory agency, the lack of a defined benefit from these technologies is a barrier to rapid implementation. A number of studies have quantified the benefits of the smart grid at a macroeconomic level, but inconclusive results and lack of a clear business case for specific technologies has slowed the adoption by utility customers (15). Additionally, a recent survey of U.S. utility professionals found that an equal amount expected the smart grid benefits to be measurable in one to three years (27 percent) as those who felt that benefits would take at least ten years to materialize (29 percent) (16). Finally, the smart grid will affect different stakeholders in different ways, and not everyone can expect to see the same level of economic benefit.

At a comprehensive level, one of the first indications of overall smart grid value will come as a result of the numerous pilot projects being put in place. To aid in quantifying these benefits, the Electric Power Research Institute (EPRI) conducted a study detailing a best-practices method that utilities and analysts can use for completing a cost-benefit analysis of smart grid pilots (15). Until then, most smart grid vendors will rely on data from individual technologies to prove benefits as the aggregate effects of the smart grid become clearer.

Interoperability Standards

The smart grid will lack the real intelligence it needs without a framework for interoperability standards for communications and data flow between devices. One of the largest perceived advantages of many smart grid technologies, at least from a marketing standpoint, is their ability to "plug and play," or operate seamlessly with only minor modifications, anywhere in the system. In addition to the sheer breadth of technologies requiring standards, the lack of a cohesive set of implementable standards makes this integration difficult. However, many of these standards needed do exist either in development or in use in other applications such as telecommunications, but the challenge lies in ensuring widespread and rapid adoption among the key stakeholders.

Fortunately, a number of regulatory institutions around the world have taken on this challenge. In late 2009 in the U.S. the National Institute of Standards and Technology (NIST) published their "Framework and Roadmap for Smart Grid Interoperability Standards," describing the conceptual framework of the smart grid, all of the major interactions points in the grid, and the priority action plans moving forward (17). In parallel, the international standards agency, the International Electrotechnical Commission (IEC), which has arguably more influence globally than NIST, has launched their own interoperability web portal which is intended to act as a repository of new and existing smart grid communication and interconnection standards (18). In addition to these two main standards bodies there are also many smaller commercial platforms taking hold for specific applications, such as ZigBee for home area networks (HAN) and WiMax for standard field local-area networks (LAN), such as those for AMI monitoring systems (19) , (20).

The Integration of Large Amounts of Renewable Energy

When discussing the challenges facing the integration of renewable energy, there are two aspects that need to be addressed: transmission and distribution. From a transmission standpoint, the challenge lies in moving electrons over large distances. This is being addressed through mechanisms such as high voltage direct current power lines and inventive regulatory schemes for transmitting energy across regulatory and state borders. As such, these solutions really fall under the category of "smart grid enablers" as they do not directly add any intelligence or functionality to the grid.

From a purely smart grid standpoint, a greater challenge lies in the distribution of intermittent renewable energy sources such as from solar panel and wind turbines. This can be further broken down into two main barriers that need to be overcome: (1) managing bi-directional power flows in a system traditionally designed for one-way flow and, (2) having the necessary functionality built into the system to manage the intermittent nature of these energy sources.

Consumer Adoption of Smart Grid Services

Finally, the last challenge is the behavioral change required to capture all of the value from smart grid solutions. As a number of the potential benefits from the smart grid – TOU pricing, demand response, and smart appliances using HANs – are based on customer interaction, ensuring that customers are engaged is key to capturing all of the value of the smart grid. Historically, customer interaction with electricity consumption has been very low. Overcoming this will require real engagement and outreach on the part of the utilities, especially in the early stages. Installation of smart meters alone for data collection does nothing to increase customer interaction, and it will be the next level of technologies – smart appliances, HAN, and services like electric vehicle charging – where active behavioral change will need to take place in order for customers to realize all of the benefits from these applications.

3.4. Applications and Enabling Technologies

Advanced Metering Infrastructure

Perhaps the most ubiquitous and visible smart grid technology, AMI is a complete overhaul of how end user data is compiled, analyzed, and displayed. Traditional electric meters measure only total consumption and have no way to determine when the power was consumed. Thus, by adding a time component to the measuring device, AMI provides utilities with new levels of control and management capabilities, allowing end-users to make informed decisions about their usage based on the current electricity price. In addition, AMI adds a host of other functions to the metering system, including remote meter reading, power outage sensors, and power quality monitors. There are two main components of an AMI system:

- The physical measurement device, or smart meter, which replaces the older electro-mechanical meters.
- The communications network required to transmit smart meter data.

These technologies will need to be applied in parallel to be most effective, and there has already been widespread installation in numerous markets. However, based on unfairness claims in advanced pricing schemes there has been significant push-back from consumers and regulators on some smart meter installations, including consumer-advocate lawsuits in California and Texas and a complete moratorium on smart meter installations in Australia (21) (22) (23). To manage this crisis, which many feel is related to marketing and consumer education rather than technology, a number of key industry players formed the Smart Grid Consumer Collaborative (SGCC) aimed at building consumer acceptance and awareness of the benefits of the smart grid (24). Despite these setbacks, AMI still offers significant benefits to the utilities through advanced monitoring systems and ease of installation. As a result, AMI and smart meters will most likely continue to be the first wave of smart grid installations.

Smart Homes and Home Area Networks

An offshoot of the AMI services, this is another advanced infrastructure technology where consumers have the ability to locally or remotely increase their interaction with home appliances and services. Additionally, this application will give many home appliances the ability to interact automatically with price signals from the utility – think along the lines of your dishwasher waiting three hours to run while waiting for a lower pricing signal. Users will also be able to control and monitor their homes via the internet or local applications, enabling the most efficient use of resources and having the potential to greatly reduce energy consumption. This idea is not new and has been seen in a number of advanced demonstrations; however the increase of AMI penetration and intelligence in the overall grid brings these networks much closer to being a reality.

Demand Response/Demand Side Management

Demand response is a set of technologies that give signals to users and provide incentives for them to reduce their consumption in times of peak demand. This can take many forms, from utility direct to consumer, or through third-party demand response aggregators who can act as "virtual power plants" by reducing load remotely at commercial and industrial clients. The DOE recently found the quantitative benefits of demand response hard to determine on a national level, as the benefits varies widely based on the quantification method, assumptions regarding customer participation and responsiveness, and market characteristics (25). However, on a regional level a number of studies have shown the potential benefits. A study commissioned by PJM Interconnection, Inc., which operates the world's largest wholesale energy market with over 165 GW of generating capacity across 13 U.S. states, found that demand response employed during times of peak demand could reduce energy prices by five to eight percent, for total yearly system savings of up to $200 million (26). This can significantly reduce required capital spending by removing the need for expensive and rarely used peaking power plants.

For demand response to succeed there needs to some method to reduce large amounts of consumption in times of peak demand, and as a result most successful demand response programs to date have focused on large commercial and industrial customers. Additionally, commercial demand response requires significant IT technology and investment, including large capital expenditures for system aggregators. However, at the consumer level, demand response builds on the advanced monitoring and communication capabilities of AMI. As a result, demand response growth is expected to continue with the proliferation of smart meters, although the same barriers for smart meters apply to demand response as well, especially around utilities taking automatic control of loads at a household level and incentivizing utilities for a reduction in consumption.

Grid Optimization/Distribution Automation

Another IT-based technology, grid optimization increases network intelligence and communication at every node, or network hub, in the electric power network, a vast series of interconnections analogous to the body's central nervous system. Even with AMI providing end user data, much of the transmission and distribution grid is not fully monitored – so much so that in some cases a utility first learns of an outage from an angry customer call (27). Providing grid optimization technology through the network will result in improvements in three key areas:

- System reliability
- Operational efficiency
- Asset utilization and protection

Installing grid optimization tools will be a concerted effort by utilities and vendors alike, requiring a full suite of hardware and software solutions. The challenge will lie in system integration at a large scale and working across the different standards of the systems.

Integration of Renewable Energy and Distributed Generation Sources

Another key benefit of the smart grid, the ability to integrate renewable energy is a necessary shift as countries seek to reduce their greenhouse gas emissions. More than the other applications, this requires a wide range of technologies, encompassing both IT and extensive hardware installations.

The terms "renewable energy" and "distributed generation" are often used interchangeably, but they are actually two distinct applications. Renewable energy comes from sources which are naturally replenished such as wind, sunlight, rain, tides, and geothermal heat while distributed generation refers to smaller-scale generation assets which can be renewable or fossil fuel based, such as a diesel generator or natural gas-fired turbine. Additionally, renewable energy can mean either a large centralized generation asset such as a solar thermal plant or commercial wind farm, or a smaller installation like a rooftop solar panel or stand-alone turbine, and is not necessarily a subset of distributed generation. While a full discussion of the advantages and scope of these technologies is too voluminous for inclusion in this document, it is widely expected that a shift to smaller scale generation and renewable energy sources will be a major factor in the future energy economy and one of the keys to moving toward a more sustainable society - the larger question remains when this shift will happen.

From a smart grid standpoint, there are two main challenges associated with this shift:

- The intermittent nature of the generation assets
- Two-way (or more) power flow integration across multiple access points

There are many techniques to deal with each of these challenges, but none of them are currently ideal. For instance, for intermittency it is theoretically possible to balance generation resources to meet demand, i.e. using solar during the day and wind power at night. However, the unpredictable nature of both if these resources makes this less than ideal. Also, energy storage is touted as a key enabler, but as a result of high costs, has yet to gain significant market penetration. As of now, this challenge remains unsolved.

Energy Storage

Commonly referred to as the "missing link" for renewable energy integration and a primary enabler of the smart grid, cost-effective energy storage remains one of the most sought-after breakthroughs in the market. While no truly economical storage technology currently exists, a smart grid will be vital to ensuring seamless integration and utilization of energy storage resources.

Energy storage has the capability to:

- Store and buffer intermittent renewable energy generation assets, capturing energy which would otherwise go unused when there is little demand

- Act as an emergency supply of energy in times of high-demand, specifically to protect against expensive brown- and black-outs.
- Increase the overall reliability and efficiency of the grid through peak shaving and frequency regulation.

A more detailed assessment of energy storage applications and technologies is contained in Chapter 5.

PHEV/EV Smart Charging and V2G

Another capability of a more intelligent grid, both on the consumer and utility side, is the ability to seamlessly incorporate advanced vehicle infrastructure technologies. Smart charging is simply the ability for the utility, network manager, or vehicle owner to control when and how plug-in electric vehicles, which include plug-in hybrid electric vehicles (PHEV) and pure electric vehicles (EV) are charged once connected to the grid. This capability will be key to managing demand when electric vehicles have a higher penetration as the grid, no matter how advanced, will not be able to handle demand if everyone puts his or her car on the charger as soon as they get home from work. In the nearer future, electric vehicle charging, especially fast-charging, will be an ancillary service provided away from home but still requiring advanced technologies and grid interaction. This concept will also be discussed in detail in Chapter 5.

Vehicle-to-Grid (V2G) is an even more advanced form of electric vehicle management where utilities will not only be able to control when and how electric vehicles are being charged, but in times of peak demand use the aggregate stored energy of the vehicle fleet as a grid support resource. This technology has the potential to have all of the benefits of energy storage without the high capital cost to the utility, but will come with all of the challenges of integration of electric vehicles, dealing with variable availability, and managing a wide range of battery types in the different vehicles. Additionally, as an energy storage solution, it has a high-capital cost in comparison to its overall capacity.

3.5. ABB's Role in the Smart Grid

As with most companies in the smart grid space, ABB has done their own study to determine the scope of their involvement, their offerings, and the value that they will add to the smart grid eco-system. As a fully integrated supplier of components and services ranging from light switches to electrical transformers to distribution and automation software they are a true "end-to-end" supplier in the energy industry.

However, as seen in the preceding section, while much of the smart grid is adding intelligence to the existing electrical infrastructure, fully integrated suppliers such as ABB, Siemens, and General Electric are still working to provide the right mix of products and services for the smart grid. With so much unknown about how the market will actually unfold, these giants have to come up with new strategies and technologies for the smart grid market. For instance, ABB worked for over a year to determine the macro-level impacts of the smart grid, their definition of the technologies, and the specific offerings available. Additionally, there has been much work done at the business unit and product group level to determine specific technology and market needs for the different smart grid segments.

3.5.1 ABB Smart Grid Vision

ABB presents its smart grid strategy based on four key drivers (28):

Capacity: expansion with emerging new requirements

Meeting the rise in global demand for electricity will mean adding a 1 GW power plant and all related infrastructure every week for the next 20 years[1]. This must be achieved in the most economic way with the most environmentally friendly technologies available. The reduction of carbon emissions is an overriding aim in all these efforts.

Reliability: grids designed to run at full capacity

As today's grids run over thousands of kilometers to transport the maximum possible energy, power flow must be carefully controlled along the length of the system. Automation infrastructure now available at the transmission level can be more widely used in distribution systems to provide seamless connections between power generators and individual consumers.

Efficiency: along the whole value chain

The efficient handling of electrical energy offers a huge savings potential. Today, almost 80 percent of primary energy is lost en route to the electricity consumer[2]. Achieving this full potential requires optimal power plant processes, efficient transmission and distribution systems and technologies to improve the efficiency of the energy use itself. Efficiency can be increased across the whole value chain, including power generation, transmission, industrial and commercial use.

Sustainability: renewable power integration

The final driver is the seamless integration of renewable generation onto the electric power grid. The International Energy Agency predicts that hydro power will remain the major source of renewable energy for the next two decades, followed by wind and solar. The challenges integrating these renewable energy

[1] ABB internal estimates
[2] ABB internal estimates

sources into the electrical system are different for each technology but the system of the future must accommodate them all.

3.5.2 Smart Grid Products and Strategy

The shaded areas in the Table 5 show the technologies either available or currently targeted for development in the ABB smart grid portfolio, as well as the relevant divisions.

Table 5: ABB Smart Grid Portfolio

Application	**ABB Division**				
	Power Products	***Power Systems***	***Discrete Automation & Motion***	***Process Automation***	***Low Voltage Products***
Distribution grid automation					
Vehicle Electrification					
Demand response – Commercial and Domestic					
Distributed generation integration					
Energy storage					
Electricity Transmission					
AMI					

Source: ABB.com, *Smart Grid Portal,* abb.com

Current Product Offering

Targeted Offering

As shown in Table 5, Power Products and Power Systems have the broadest reach across the smart grid, offering solutions for distribution automation, demand response, distributed generation integration, energy storage and electricity transmission. Through serving traditional power market customers, many of which will be key smart grid customers as well, they also have significantly more relevant channels to market than the other divisions. Process Automation is the most IT-intensive unit within ABB, and has tailored some of its process control technology to managing demand and increasing energy efficiency.

With the exception of demand response, which is based on controllers and drives, all of Discrete Automation & Motion's offerings are from the PE GPG. The current offerings for distributed generation include the PCS6000 wind turbine applications, and while the vehicle electrification and energy storage markets are targets at a corporate level, the specific technologies required to meet the needs of those markets have not been determined.

ABB is well positioned in the hardware space, especially around high power transmission and energy conversion, competing on quality and total cost of ownership with its main competitors in nearly every major market. At medium voltage levels and above (greater than approximately 1000 Volts), ABB's transmission and distribution products are some of the best in the industry and compete closely for market leadership. However, ABB does not currently possess a robust set of offerings in two key areas of the smart grid – AMI and distributed utility intelligence software. While not necessarily a handicap to selling into its traditional markets, this could potentially present a challenge in later stage, full grid installations or upgrades where customers are looking for one vendor to offer a comprehensive set of solutions.

At a corporate level, ABB's strategy in the short and medium term is to continue to apply existing hardware and software technologies for efficiency and network management, while in the long term either developing in-house or partnering with existing companies to provide substantially more IT-based grid management solutions. Through this ABB hopes to leverage its strengths in large, integrated high power hardware systems, while increasing the amount of IT infrastructure that it can contribute. At its core, the smart grid is the application of a strong IT network, providing intelligence and real-time feedback to operators and users alike, and the real value will come from end-to-end integration of this IT layer with the hardware layer. As the market becomes more clear and shifts into more integrated solutions, the advantage will be with those firms who can offer the most comprehensive end-to-end solutions.

4. INTRODUCING A SCORING MODEL FOR OPPORTUNITY SELECTION AND PORTFOLIO MANAGEMENT

This section introduces the concept of portfolio management for new project selection and the tools and frameworks required to enable clear decision making regarding which opportunities to pursue. Through a number of quantitative and qualitative factors, opportunities can be analyzed to a high degree of precision, enabling decision makers to make the best decisions with the information they have. The merits and development of the selected method are discussed below, as well as the steps to successful implementation.

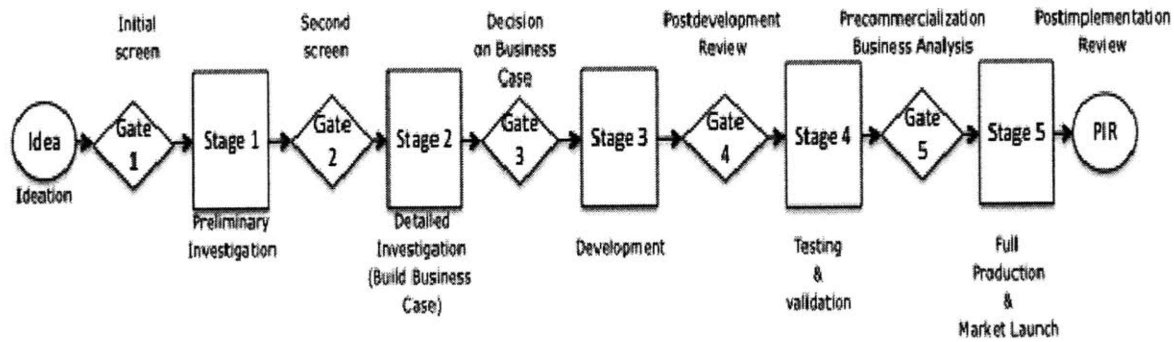
4.1. Portfolio Management

Portfolio management is a very broad term used to describe how organizations manage projects and resources across the spectrum of opportunities available over time. Portfolio management is important to ensure that a company can develop the right balance of projects and investments, communicate project priorities within the organization, and provide greater objectivity in project selection (29). As a management tool, portfolio management can be applied at many tiers of a company – from the corporate level down to the business unit – and as a result has been one of the most studied disciplines in modern business strategy.

Stemming from a combination of traditional strategic management with financial theory, early portfolio analysis was based around the idea of spreading risk across an organization. This concept was then applied to the operating units within a larger company and the units' behavior as a separate operating entity. One of the first efforts to quantify an organization in this form was the Boston Consulting Group (BCG) Growth Share Matrix, introduced in 1968, which classifies Strategic Business Units (SBUs) according to *market share* and *market growth,* contrasting the cash generation of a unit with the cash consumption (30). While a capable vehicle for discussion, it provides only a very simple, two-dimensional view. This simplicity, coupled with the attractiveness of the matrix approach, led practitioners to develop more continually more sophisticated and realistic frameworks. One of the most prominent remains the General Electric Directional Policy Matrix (DPM) (31). The DPM is more realistic than the BCG Matrix as it uses *market attractiveness* instead of market growth as the dimension of industry attractiveness and *competitive strength* instead of market share. These measures take into account a broader range of factors to determine the overall dynamics of the industry or market. Individual companies, academics, and management consultants have continued to build on these models, tailoring them to specific needs or macro-economic climates.

This thesis focuses on project selection as one of the keys to successful portfolio management. By applying a rigorous analysis to the projects in the development pipeline, an organization can greatly increase its chances of developing a winning portfolio. Additionally, the model developed in this section specifically looks at the earliest stages of project selection. It is at this point where all too often breakthrough projects are killed and less-impactful projects are allowed to go forward, as explained in the following sections.

Fig. 4 shows a generic, five-stage product development process.



Source: Cooper, R.G., *Winning at New Products, 2001*

Figure 4: Typical Product Development Process

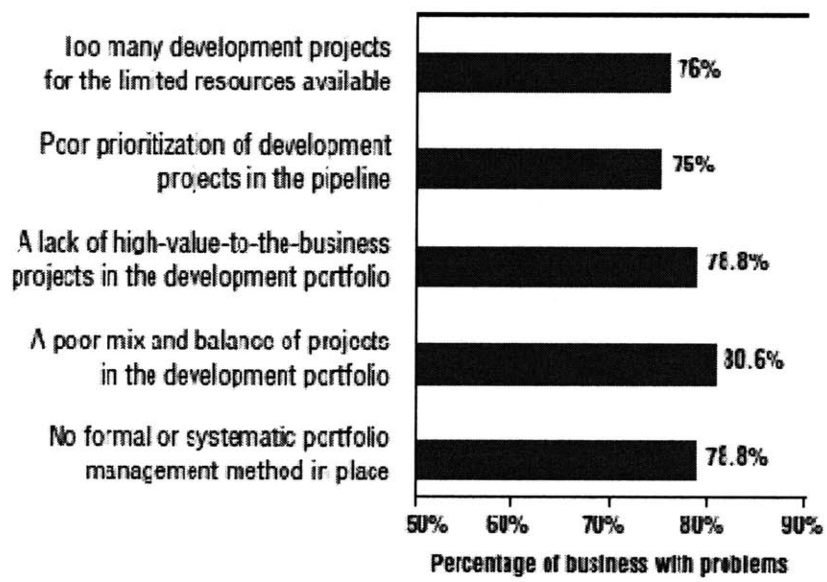
This type of model is used in many organizations, including ABB. Their five-step process looks very similar to the one pictured above, with a series of gates leading up to new product launch. At each gate a set of criteria is applied and formally reviewed, and the key decision makers determine which projects go forward.

This thesis is concerned with the very earliest stages of the process, specifically the steps leading from Ideation up to Gate 2. The key at these early stages is to apply a filter, or gate, in the development cycle where only the most promising opportunities can go forward for further evaluation. Additionally, as a project progresses through the product development process, additional models, especially financial or economic, can be applied to more effectively value an investment. The challenge lies in balancing the right amount of quantitative analysis with ease-of-use and applicability across the entire portfolio.

4.1.1. Why Portfolio Management?

Successful portfolio management is critical to business success for a number of reasons. First, a successful new product introduction lays the framework for continued or renewed business success. Second, when executed with rigor and consistency the portfolio becomes a clear representation of the unit strategy. Finally, a broad portfolio view allows for the most efficient allocation of resources. A successful portfolio management system can lead to the right balance of projects, a clear project strategy communication throughout the organization, and a more transparent and objective project selection process.

Thus, it is surprising that firms have historically struggled, and continue to struggle, with implementing a successful portfolio management process. Fig. 5 shows the results of a survey by the American Productivity and Quality Center that details the reality at many firms – projects are languishing in the pipeline too long, many projects are underperforming significantly, and, as a result of an over-reliance of financial evaluations, current stage-gate models favor minor product modifications over major innovation.



Source: Cooper, R.G., *Benchmarking NPD Best Practices,* 2004

Figure 5: New Product Development Survey Results

Introducing a clear portfolio management strategy, training the organization to use it, and applying it with rigor and objectivity can ameliorate or solve many of the above issues.

4.1.2. Goals of Portfolio Management

Portfolio management, especially portfolio management for new products, has three main goals (32):

Goal #1: Maximize the Value of the Portfolio

The main purpose of portfolio management is to maximize the financial value of new or existing projects in the organization, as related to a business objective. There are a number of frameworks to evaluate project value, including:

- *Net Present Value (NPV)*: Determine a project's net present value, and rank in descending order. Additionally, the NPV can be divided by a constraining resource, such as R&D costs remaining, to maximize the NPV of the portfolio across a given set of constraints. Projects should be executed in this order until no additional resources are available.

- *Expected Commercial Value (ECV)*: This method approximates *real-option theory*, as projects are evaluated on a stage-by-stage basis. At each stage values and probabilities are assigned until a final expected value can be calculated, as well as values at each intermediate stage. This value can then be indexed as with NPV to maximize overall value.

- *Scoring Model*: This combines elements of the above approach into a series of attributes for decision makers to rank. Adding up these weighted or un-weighted ranks gives an overall project attractiveness score, which can be set against some minimum value. This method is effective at combining both the quantitative and qualitative aspects of a project.

Goal #2: Seek Balance in the Portfolio

Here the goal is to strive for a portfolio that achieves a desired balance across a number of parameters. This can be expressed in terms of long term versus short term, high risk versus low risk, or across markets and technologies. One example of this is the McKinsey Portfolio of Initiatives model (33), which uses a bubble chart to show balance in terms of timing, risk, and market capitalization at stake.

Goal #3: Ensure That The Portfolio Is Strategically Aligned

This goal is designed to ensure that the overall strategy matches the strategic priorities of the organization. One method for this is to group projects by type and place into "strategic buckets (34)." One example of this is Honeywell, who separates their new projects into one of three categories: platform projects, new products, and minor projects. Then, each new project is ranked against the other projects in a bucket, resulting in multiple portfolios of projects, each managed separately.

The majority of the discussion below, and the development of the model, is driven by *Goal #1: Maximize the Value of the Portfolio*, which focuses on the project selection process as a key driver of portfolio value. The keys to achieving the remaining two goals are covered in more detail in the next chapter.

4.1.3. Pitfalls in Financial Models for Portfolio Management

Economic models are the most popular project selection tools, where a survey found that 77 percent of businesses use some sort of financial model with 40 percent citing it as the dominant early-stage project selection and portfolio development tool (34). Indeed, ABB uses a comprehensive NPV model as the cornerstone of its R&D selection tool. They are familiar to managers and are accepted for other types of investment analysis such as capital expenditure decisions. However, there are drawbacks to financial models, particularly in the early stages of project selection.

The most challenging project selection decisions occur in the early stages of the process where there is the greatest number of uncertainties. It is at this point where firms adhering to a strict financial model suffer the most, as they need ample financial data to evaluate the project. In addition to incremental revenues and sales in the future, the project planner must also estimate selling prices, production costs, development costs, and marketing expenses, among others. One study shows that firms were not off by only 10 or 20 percent on their estimates, but rather by orders of magnitude (35). Another potential pitfall in financial models is that based on the incremental nature of the financial evaluation, they tend to favor minor modifications and small, low-risk initiatives, effectively screening out high-risk potential breakthrough technologies very early in the process. One reason for this is the assumption inherent in a NPV model that there is a single and irreversible investment decision. For projects with a larger outlay, this fails to take into account that there are typically multiple stages at which to make investments. Another reason why breakthrough projects are penalized is that often the sales and payoff are harder to estimate, especially in the early stages.

4.1.4. Applying the Correct Model

With the above goals and challenges in mind, it is apparent that selecting the right framework for a specific organization or application is of utmost importance. The ideal balances of precision versus convenience and quantitative versus qualitative analysis are key questions that need to be considered when making this choice.

As this analysis most applies to *Goal #1: Maximize the Value of the Portfolio*, there are three basic models to choose from: *NPV*, *ECV*, and the scoring model. When looking at the challenge of evaluating opportunities at an initial level, such as the technologies of the smart grid, the project scoring model is the most appropriate (29). While some of the markets of the smart grid are mature, the majority are in their infancy, where there is very little in the way of solid financial data. To that end, the scoring model provides the best fit as it enables a view that can be applied at all levels of a product or market lifecycle and does not rely too heavily on financial models, but still provides an adequate level of quantitative analysis. A comprehensive scoring model also takes into account strategic factors as well, supporting the other goals of portfolio management.

4.2. Creating the Scoring Model

With the model structure determined at a high-level, the next step is to analyze the key drivers of the project and product development process and generate a set of criteria to capture these moving forward.

4.2.1. Defining the Criteria

Determining the right criteria for the model is a challenge, but there is a significant amount of practical research on the subject to draw from. Many organizations lack a rigorous model for new product introduction and the instinctive reaction becomes to create a very comprehensive analysis model, which all too often ends up being overly complex and burdensome. As a result, organizations develop many of the problems identified in Fig. 5, above. Using the appropriate number of criteria can help fix this problem.

The six criteria presented below are designed to capture many facets of the project, and are taken from extensive research on critical project success factors (29):

1. *Strategic Alignment:* Is the project aligned with the strategy and is it strategically important?

2. *Product and Competitive Advantage:* Does the project offer unique customer benefits? Does it meet customer needs better than the competitors?

3. *Market Attractiveness*: Is the target market an attractive one – size, growth, margins, level of competition?

4. *Leverage Core Competencies*: Does the project build on strengths, experiences, and competencies in marketing, technology, and operations?

5. *Technical Feasibility*: What is the likelihood of technical feasibility – uncertainty and complexity?

6. *Financial Reward*: Can this project make money? How sure are we? Is it worth the risk?

These factors are expanded and given a ranking between 1 and 10, as shown below in Table 6.

Table 6: Criteria Scorecard

	Rating Score				
Key Items	**0 (*None*)**	**4 (*Low*)**	**7 (*Medium*)**	**10 (*High*)**	**Rating**
1. Strategic Alignment and Importance • strategic fit and importance • fits our strategy • important to do • high impact on our business	Product not in alignment or important to our business strategy; low impact	Somewhat supports business strategy; not too important; modest impact	Supports business strategy; important; good impact	Product aligns well with our business strategy; product very important to strategy; high impact	
2. Product and Competitive Advantage • unique customer benefits • value for money	None; negative or neutral customer feedback; poor value	Limited; marginally superior; fairly neutral feedback; OK value	Some new benefits; somewhat superior, good value; positive feedback	Major new benefits; very positive customer feedback; great value	
3. Market Attractiveness • market size and growth • margins	Small or non-existent market; low growth & low margins; tough competition	Modest market; limited growth; fair margins; competitive	Significant market; good growth; good margins; modest competition	Large, growing, attractive market; good margins; weaker competition	
4. Leverages Core Competencies • technology • production • marketing and distribution/sales	No opportunities to leverage competencies; required skills/experiences/resources strengths are weak	Some opportunities to leverage competencies; our skills/experiences/resources strengths are modest	Considerable leverage possible; skills/experience needed are within organization	Excellent leverage of our strengths & competencies; excellent fit between needs, our skills, experience, resources	
5. Technical Feasibility • small technical gap • uses in-house technology • demonstrated technical feasibility	Low; big gap; new science; technology new to company; have not been able to demonstrate technical feasibility	Modest; fairly large gap; quite a few hurdles but do-able technology; fairly new to company; limited evidence to support technical feasibility	Good; small gap; some hurdles, but attainable; have some evidence of technical feasibility	Straight-forward; largely engineering-repackage; have technology in-house; have demonstrated technical feasibility	
6. Financial Reward vs. Risk • sizable, excellent opportunity • payback, NPV, & IRR OK • certainty of estimates • not too risky & difficult to do	Poor; limited opportunity; NPV negative; payback > 5yrs; difficult to make money; risky & tough to do	Modest opportunity; NPV positive; payback ~ 4yrs; fairly difficult to make money; fairly difficult and tough to do	Fairly good opportunity; NPV positive & good; payback ~ 2yrs; probably can make money; modest risk & difficulty	Excellent opportunity; NPV positive & high; payback < 1yr; not too risky & difficult to do	

Source: Cooper, R.G., *Portfolio Management for New Products,* 2004

4.3. Implementing the Scoring Model

With the scoring model generated, the next step in developing a project selection tool is determining how the model will be used to rank projects.

4.3.1 The Idea Screen

This step presents a method to perform the "Initial Screen" from Fig. 4 and is a high-level, initial application of the scoring model to the opportunities identified during idea generation. The goal of this step is to quickly filter out the unattractive ideas and move the others forward for a more detailed analysis. As project selection is a culling process, the approach is to subject projects initially to simple, easy-to-ask questions; in this manner, the list of projects is shortened to a smaller subset, which can then be evaluated more thoroughly.

Once the projects are rated on the scale of 1-10, they can be multiplied and summed to make a project attractiveness score. This value is adjusted to make a percentage out of 100, which can also be used to set a minimum score moving forward. For example, a firm could set a score of 60 out of 100 as the minimum value moving forward. Additionally, projects can be rank-ordered and executed until no further resources are available - this concept is explored in Chapter 6.

Another factor to consider is whether certain criteria are more important than others. The decision whether to use a weighting factor can be firm or project dependent. Many companies use equal weights on all factors, with the implication that the issue of what weights to use will take more time to resolve than actually ranking the project. However, some firms do use weighting factors, either fixed weights based on some specific key criteria, or variable weights which can change with the project type. These can be applied based on specific goals at the time or on the project type. Additionally, weights can be changed during a shift in strategy or technology. For example, if a unit seeks to change its existing strategy or is forming a new strategy, the *strategic alignment* ranking can be given less weight overall.

4.3.2 The Preliminary Assessment

With the most attractive projects initially identified, the next step is to move into a more detailed analysis. This step is similar to "Stage 1" from Fig. 4, where the goal is to create an assessment more defined and detailed than the preceding step, but short of a full business case. This is best defined as a *preliminary assessment*, where a quick market study is performed and the scoring model further refined. The task is to find out quickly, usually less than one month per project, and for minimal cost as much about market size, growth, segments, customers needs, and competition as possible (34). This can be further separated into three distinct research areas – market, technical, and business/financial.

In the market assessment, the goal is to determine the overall attractiveness of the market and the competitive landscape. The technical assessment identifies the specific technical needs of any potential product, the capabilities required, and the key technical risks. Finally, the business and financial assessment maps out the strategic and competitive rationale behind the project and, if available at this point, preliminary expected sales, costs, and required investments.

Following the more detailed analysis, the projects are ranked again, and the decision is made whether to move forward for a more detailed business case analysis. Additionally, while at this point in the evaluation there is often no clear limit on how many projects are eligible to move forward, product managers and decision makers should be thinking ahead about how the projects fit overall into the resources available (further discussed in Chapter 6).

5. APPLYING THE PORTFOLIO SCORING MODEL TO THE SMART GRID

This chapter takes the framework introduced in the preceding section and applies it to the key technologies of the smart grid. As defined above, the general steps are to define the overall segments or markets to be evaluated, complete an initial evaluation to determine areas for deeper analysis, perform a more detailed analysis on those areas, and move forward with a selection of opportunities. The number of projects and final selection is based on the model as well as a higher-level view of the resources available.

5.1. Defining the Smart Grid Segments

Following from the definitions provided and technologies detailed in Chapter 3, Fig. 6 represents a very high-level, or category, view of the segments of the smart grid.

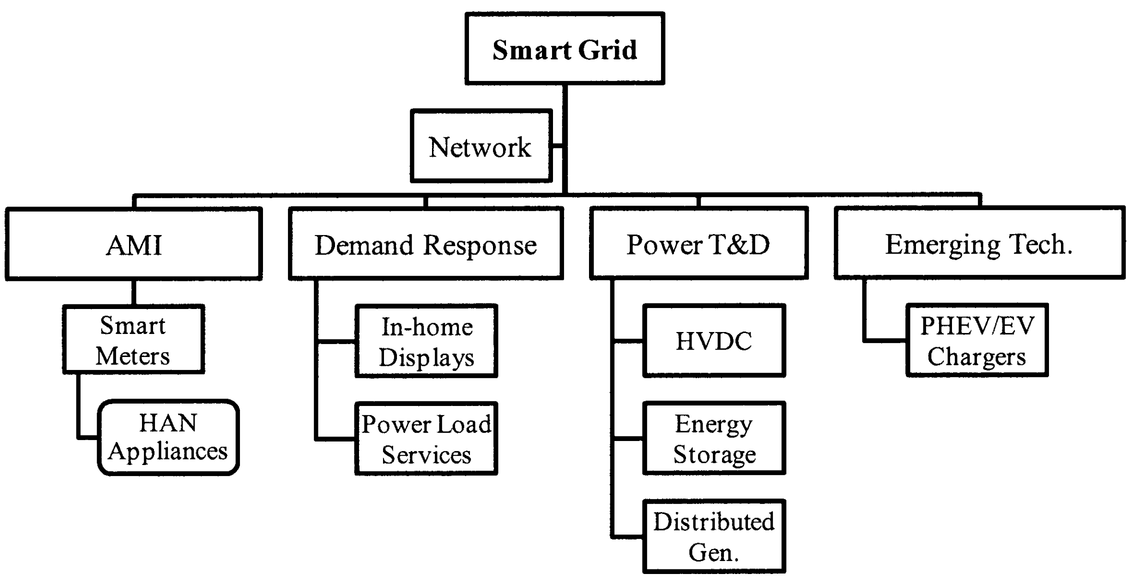


Figure 6: Smart Grid Market Segments

Each of the segments in Fig. 6 - AMI, Demand Response, Power T&D, and Emerging Technologies - represents a wide array of technologies, applications, and customer needs. The purpose of the idea screen is to study the segments in more detail and determine at a very early stage if a segment is promising enough for further analysis.

5.2. Applying the Scoring Model

The next step in the analysis is applying the scoring model developed in Chapter 4. This is completed in two steps. First, an initial screen is applied based on a high-level analysis of the smart grid segments. Second, the technologies that are deemed suitable for further exploration based on this initial application of the scoring model are analyzed in more detail. The second assessment looks more specifically at the actionable areas within the segment and the potential success of any proposed projects.

5.2.1. Applying an Initial Idea Screen

The following analysis represents the initial evaluation of the smart grid opportunity set for the PE GPG. The purpose of the analysis is to rank the projects according to the scale given in Table 6 from Chapter 4, assigning a score of 1 through 10 to each of the relevant criteria. By its very nature this is a subjective process, however the rigor of the initial analysis performed in this section, as well as the range of criteria, are designed to quantify the projects as much as possible.

All of the background information and insight was gained through secondary research on the relevant markets (analyst and consulting reports, technical publications, etc.), as well as primary research involving interviews and working sessions with key stakeholders within ABB. The criteria are all assigned relative to their fit within the PE GPG, with the assumption that the current strategy is as defined in Chapter 2 and that the technical capabilities are consistent with past product offerings.

AMI and HAN

Building on the introduction in Chapter 3, AMI represents a range of technologies aimed at measuring, collecting, and analyzing energy consumption data at the end-user level. However, AMI is more than just smart meters, building on a communications infrastructure to collect and manage the meter data. At the core of the application, though, is the smart meter. These are devices that replace the existing meters for residential and commercial customers, and are produced by dedicated meter vendors as well as integrated industrial firms such as GE and Siemens. As mentioned in Chapter 3, ABB currently has limited meter technology. To measure the electricity in a system, smart meters use either a small induction motor that turns from the incoming energy or solid state circuitry that uses digital signal processing to convert inputs into an electricity reading (36). Regardless of the method, the signal is then calibrated to show energy over a period of time, typically displayed in kilowatt-hours (kW-h). The technology in the meter is not advanced, and does not rely on power electronics for operations.

HAN, or "smart", appliances are more than just energy-efficient versions of common dishwasher, refrigerators, washing machines, and dryers. The U.S. Association of Home Appliance Manufacturers refers to modernization of the electricity usage system of the home appliance such that it monitors, projects, and adjusts to the needs of the owners (37). Additionally, HAN appliances can be integrated with smart meter systems for demand response. However, even with these advanced technologies, the core of the HAN appliance remains the appliance itself, thus traditional appliance manufacturers such as GE and Whirlpool are expected to dominate this new market.

1. *Strategic Alignment:* From a manufacturing standpoint, smart meters are produced in high-volumes, which some industry analysts predict will be a near-commodity soon. Additionally, the technology and market is very far from the core of the unit. This project has little or no alignment with the strategy of the PE GPG, falling more within the reach of units in the Low Voltage Products division. **Rating = 0**.

2. *Product and Competitive Advantage:* With no history in the market, or specific product defined, taking on AMI as a project would offer no additional customer benefits or meet customer needs any better than the competition. **Rating = 0**.

3. *Market Attractiveness*: From a growth and revenue standpoint, this is a very attractive market. Only looking at the U.S., the AMI market has the potential to reach almost $9 billion in sales by 2015, building on a compound annual growth rate (CAGR) of 52.4 percent - this includes the sale of smart meters as well as the fiber-optic and IP-based telecommunications networks (38). The margins of the industry are strong, but increasing competition and the potential for consolidation among some of the main players will drive margins down and make the overall market less attractive for new entrants. Additionally, the market for "smart" appliances is expected to grow very quickly for the foreseeable future as pricing, government subsidies, and energy efficiency drive consumer adoption of advanced technologies. The worldwide market is expected to grow from $3.06 billion in 2011 to over $15 billion in 2015, with smart washing machines and smart refrigerators accounting for over 35 percent of 2015 sales (39). **Rating = 8**.

4. *Leverage Core Competencies*: As detailed in Chapter 2, the current core competencies of the PE GPG are custom engineered solutions, the application of power electronics for power conversion, and superior aftermarket service. In the PE GPG, there is no history of experience in this type of product and smart meters will be mass-produced items, something this unit has never attempted. Additionally, while there are power electronics present in the appliances (like most modern electronics) the power levels are very low. The PE GPG has no power electronics that operate in this range, and based on how far the ratings of the power electronics in the appliances fall below the rating of even the PCS100, there is little expectation of leveraging existing strengths. **Rating = 0**.

5. *Technical Feasibility*: The technology itself is not overly complex, but the technical resources required to bring a product to market are not currently held in the PE GPG. This includes the mass-

production mentioned above, as well as a significant amount of integration with communication infrastructure systems. **Rating = 2.**

6. *Financial Reward*: This is a large market, with low margins. Revenues for the major players will be significant, but for the PE GPG the costs required to enter this market, including new facilities and new technologies, would be prohibitively high. **Rating = 0.**

<u>*Demand Response*</u>

Chapter 3 provides an introduction to the technologies of the demand response market, which includes the IT networks to support pricing and demand signals, as well as the capitally-intensive control systems used by the aggregators to communicate across their networks and control consumption at customer sites. In order for demand response to function, there also needs to be an interface at the customer site where loads are controlled. For commercial applications, this interface is typically handled by an aggregator while smart meters provide the interface between residential customers and utilities (40). The individual loads and their controllers are enablers of demand reduction, but are not considered part of the demand response segment analyzed here.

1. *Strategic Alignment:* Demand response is mostly an IT-based solution and is already being pursued aggressively by other ABB divisions/units. Thus for ABB overall there is a strong strategic fit, just not in the PE GPG. **Rating = 0.**

2. *Product and Competitive Advantage:* With little in the way of electric network management software experience, and no clear channels to market with utility end-users, the PE GPG would not be able to offer any additional customer or technology value into this market. **Rating = 0.**

3. *Market Attractiveness*: The largest demand response market in the world is in the U.S., where 2009 revenues were $412 million, a 21 percent increase over 2008 (41). Revenues are expected to increase at near this rate as smart meters become more ubiquitous and more industrial customers sign up for voluntary demand response programs. **Rating = 7.**

4. *Leverage Core Competencies*: Based on the core competencies described for AMI, this project would build on no strengths in the PE GPG. Load control for motor drives will be a major part for demand response and energy efficiency, but those markets are covered by the MV Drives business unit. **Rating = 0.**

5. *Technical Feasibility*: This is a very complicated market, with many stakeholders, that relies on advanced communication networks, remote monitoring, and significant integration with customer systems. The PE GPG has no prior experience in this field. **Rating = 0.**

6. *Financial Reward*: To develop a full demand response solution requires a large development investment in software and services. The investment required and the lack of prior experience in this area makes this project a huge financial risk. **Rating = 0**.

<u>*HVDC Transmission*</u>

HVDC transmission uses high voltage direct current for the bulk transmission of electric power, versus the more common alternating current systems. Over long distances HVDC is more cost-effective than typical high-voltage ac transmission, with significantly lower line losses as well, and has seen increased use and promise in linking electrically or geographically separated electrical networks (42). HVDC encompasses a number of enabling technologies, including the actual cables themselves as well as inverter/rectifiers systems for the conversion of the dc transmitted power to ac power for the distribution systems.

1. *Strategic Alignment:* Both the cables and the conversion systems are key products of the Power Systems division, and while no formal agreement is in place that the PE GPG should not move into the HVDC market, this area is well-covered by other units within ABB. As a result, this market has no strategic alignment with the PE GPG. **Rating = 0**.

2. *Product and Competitive Advantage:* At the extreme high-end of their operating range, it is possible that the PCS6000 platform could be used for some of the new, lower voltage HVDC systems. However, this solution would be less cost-effective than other ABB (and competitor) offerings and could potentially stress the reliability of the systems by operating at such high powers. Overall, there is little competitive advantage to be offered by the PE GPG. **Rating = 2**.

3. *Market Attractiveness*: This is a very attractive market for the incumbents, with only a few major players competing worldwide in HVDC installations, including Siemens, GE, Areva, and ABB. The worldwide market is very cyclical with some very large contracts and then periods with little investment. However the market outlook is very positive, especially in China where the Chinese have committed to spending $44 billion by 2012 and analysts expect up to $90 billion spent by 2020 on new high-voltage lines (43). **Rating = 8**.

4. *Leverage Core Competencies*: Developing a product for HVDC conversion systems would build on the strengths of the unit in creating custom-engineered solutions, but the power ranges involved and increased manufacturing infrastructure required negate these competencies. **Rating = 2**.

5. *Technical Feasibility*: As mentioned for the product advantage, the PE GPG is physically capable of developing the technologies for HVDC systems, in fact, many of the components such as the IGCT and IGBT power semiconductors are identical. However, both the higher powers of the applications and the very specific control systems required make this a significant technical challenge. **Rating = 4**.

6. *Financial Reward*: The additional investment required to develop and manufacture high-power products makes this project a huge financial risk. **Rating = 0**.

Energy Storage

The generic term energy storage defines a broad array of technologies and applications. The specific application under consideration is energy storage applied in support of the electric grid. Generally speaking, there are six main storage technologies for the electric grid (44):

1. Pumped Hydroelectric: Pumped Hydro is one of the oldest and most widespread storage technologies and consists of a turbine, a waterway, an upper reservoir, and a lower reservoir. At times of low electricity demand, water is pumped uphill into the tank or reservoir. When energy is needed, it can then be released downhill to power the turbine and produce electricity.

2. Compressed Air Energy Storage (CAES): CAES is the use of relatively inexpensive electricity (i.e. at times of low demand) to pump air into tanks or, in larger applications, underground cavities. Later, at times of peak power this air can be extracted at high-pressures and used to displace the typical turbine compressor, which then powers a turbine to produce electricity.

3. Electrochemical Batteries: These consist of a large number electrochemical cells connected together to form a battery. There are various cell chemistries are used, with lead-acid, nickel-cadmium (NiCd), lithium-ion (Li-ion), sodium-sulfur (NaS), and nickel-metal hydride (Ni-MH), among the most common.

4. Flywheel Energy Storage: Flywheels store energy in a magnetically-levitated rotor which is spun up to approximately 60,000 rpm. The rotor is connected to a turbine which acts as a motor to input kinetic energy to the rotor, or as a generator, to extract the kinetic energy in the form of electricity.

5. Capacitors: Capacitors store energy in an electric field. These common electrical devices are found in the simplest of circuits. However newer, larger capacitors, called supercapacitors or ultacapacitors, are becoming increasingly common. These technologies are well-suited to energy storage applications as they can provide a significant amount of energy over a short period of time.

6. Superconducting Magnetic Energy Storage (SMES): SMES consists of a coil made of superconducting material which, using a cryogenic cooling system, is cooled into the superconducting temperature range (below the material's 'critical' temperature). Energy can then be stored in the magnetic field created by the flow of direct current in the coil. One key advantage to SMES systems is that as long as they are kept below the critical temperature, the energy in them can be stored indefinitely.

For the PE GPG, the key technologies it can provide to the energy storage market are power electronics converters to charge and discharge the storage device. Storage devices can be either ac or dc, but the key need is that the power electronics have to enable power to flow bi-directionally, that is into the device to charge or out of the device to use the stored energy.

1. *Strategic Alignment:* Entering the power conversion market for energy storage has the potential to have a high-impact on the business and, as power conversion will be vital in moving forward with energy storage, represents a real opportunity for the unit. **Rating = 9**.

2. *Product and Competitive Advantage:* There are a wide range of energy storage conversion applications, each with differing conversion needs. However, the PE GPG is able to reach a wide range of power and voltages through the PCS100 and PCS6000 platforms, which have proven competitive in other conversion applications. Additionally, based on the specifications of a number of recent battery energy storage pilots, the PCS100 products gained through the recent acquisition offer many things that the battery and utility industry is looking for – modularity, scalability, and low capital costs. At this point, there are no clear competitive advantages among the major suppliers such as GE and Siemens, and ABB should be able to produce a system of comparable quality. **Rating = 6**.

3. *Market Attractiveness*: The energy storage market has been much touted as one of the cornerstones of the smart grid. However, almost all of the current storage technologies remain too expensive for widespread adoption. Fortunately, this is widely expected to change as the battery manufacturers achieve economies of scale and utilities begin more storage pilot projects (45). As a result, the outlook for the overall storage market is positive where at a macro-economic level the smart grid energy storage market is expected to increase from $5 billion in 2010 to $15.4 billion by 2015. **Rating = 7**.

4. *Leverage Core Competencies*: For both the PCS6000 and PCS100 platforms, only minor changes are required to create an energy storage conversion system. The challenges for this market will be increasing the global manufacturing footprint of the LV unit, as well as opening up additional sales channels. **Rating = 6**.

5. *Technical Feasibility*: The market needs are in-line with the technical capabilities of the unit, as the PE GPG has deep experience in dc to ac inverters, which are necessary to connect energy storage systems to the grid. Additional work on the control system algorithms will be required, as well as testing and validation. As shown in Appendix B, significant thought has already gone into configuring the PCS100 for energy storage, further reducing the technology gap. **Rating = 8**.

6. *Financial Reward*: Looking at the small size of the technology gap and the significant market size, an initial high-level assessment of this market appears NPV positive. **Rating = 6**.

Distributed Generation

Similar to energy storage above, distributed generation represents a wide range of technologies and applications. Distributed generation typically refers to all power generation facilities with an output of up to 20 MW (8). At a high-level the key distributed generation technologies are solar cells, fuel cells, wind turbines, and microturbines. Microturbines are small combustion turbines that produce between 25 kW and 500 kW of power. All of these technologies can benefit from power electronics, where power electronics are used as a grid interface to convert the high-frequency ac or dc of the generation resource to the 50 or 60 Hz ac voltage of the electrical grid. Additionally, power electronics can also serve to improve the voltage regulation of the grid to the benefit of both the utility and the power producer. Power electronics applications in this area are in the earliest stages, but as costs come down in the construction and installation of PCS systems, the number of successful applications is expected to increase greatly (8).

1. *Strategic Alignment:* Furthering the position and increasing the offerings of the unit in this growing market is a strategic goal. Depending on the specific market entered, this has the potential to have a high impact on the business. **Rating = 9**.

2. *Product and Competitive Advantage:* The PE GPG already offers a number of solutions for distributed generation solutions. Foremost among these is the PCS6000 for wind turbine power conversion, as well as the PCS6000 tailored for MV STATCOMs which provide reactive power compensation to the grid. So far these solutions have been competitive, and received positive feedback from customers. Additionally, the ABB offerings have some technical advantages based on their smaller footprint and high overload ratings. **Rating = 7**.

3. *Market Attractiveness*: This is a large market, both financially and technologically, and based on the factors discussed in Chapter 3, will be one of the main drivers of the smart grid. The next section provides a more detailed segmentation in order to analyze all the attractiveness factors. **Rating = 7**.

4. *Leverage Core Competencies*: Many potential applications in this market will leverage existing core competencies, including the application of power electronics for medium voltage power conversion and the creation of custom engineered solutions (a strength of the PE GPG) able to meet the needs of a wide range of generation sources. **Rating = 8**.

5. *Technical Feasibility*: As mentioned above, the market needs are in-line with the technical capabilities of the unit. Additional work on the control system algorithms will be required, as well as testing and validation. **Rating = 8**.

6. *Financial Reward*: Continued development will be low-cost and low-risk, however based on the wide range of potential markets for the PE GPG solutions, there is a great deal of variability on the returns available as well as payback periods. **Rating = 6**.

PHEV/EV Chargers

PHEV/EV Charging is defined as the infrastructure required to support vehicle electrification. There are three main types of electric and hybrid electric vehicles expected to gain market penetration, two of which will require grid connected charging solutions:

- Hybrid Electric (HEV): A HEV runs on a combination of battery and fuel, where the battery is charged by an on-board internal combustion engine. An example of this kind of vehicle is the Toyota Prius. There is no extra charging infrastructure required for this application, as all of the battery charging is done internally.

- Plug-In Hybrid Electric Vehicles (PHEV): These vehicles have both batteries and internal engines, although the batteries have a higher capacity than those found in HEVs. The PHEV can be run on batteries alone, which are charged through the grid. Additionally, they have a small internal combustion engine onboard for back-up power and to increase range. The Chevrolet Volt is an example of a PHEV. It has an expected range of 40 miles on batteries alone and uses an on-board four-cylinder engine with 71 horsepower to extend the overall range to 300 miles (46).

- Electric Vehicles (EV): These vehicles run on battery power only, with no onboard charging. They are charged by connecting to the grid, with a typical charge taking six to eight hours. Ranges for electric vehicles vary based on the battery capacity and efficiency of the drivetrain. The Tesla Model S electric "supercar" has a predicted range of 300 miles on one charge, while the soon to be commercially available Nissan Leaf is expected to travel 100 miles per charge. Prices also range widely for these vehicles, with the Tesla priced at over $100,000 and the Leaf only $25,000 in the U.S. after a $7,500 government credit (47) (48).

To support the two types of electric vehicles requiring grid-connected charging, auto manufacturers, utilities, and industrial manufactures all need to ensure that there is adequate charging infrastructure in place to support widespread customer adoption. At a high level, the technology for vehicle charging is well-suited to power electronics applications, as the conversion of grid power to an appropriate charging voltage is one of the core functions of any charging device.

1. *Strategic Alignment:* While not explicitly stated as a strategic target, this market fits the strategy of leveraging existing technologies while reaching new customers and markets. Additionally, compared to the more traditional markets of the PR GPG, PHEV/EV chargers are on the cutting edge and could potentially boost brand recognition while sparking technology innovation. **Rating = 7**.

2. *Product and Competitive Advantage:* This market is in its infancy, but has a number of strong incumbents, especially in the U.S. However, the technology gap to a finished product is small and the current PCS100 systems could potentially compete on cost and quality. **Rating = 7.**

3. *Market Attractiveness*: Currently in its earliest stages, the PHEV infrastructure market is poised for growth as electric vehicles become more widespread. Initial reliable estimates put the ABB relevant market at only $50 million in 2010 but increasing at over 20 percent CAGR to $2 billion by 2020[3]. However, as discussed in the next section, there are a number of uncertainties in the market estimates at this point. Further segmentation is required to determine the specific market for the PE GPG. **Rating = 6.**

4. *Leverage Core Competencies*: This leverages ABB core competencies in power conversion and the modular nature of the LV STATCOM. Additionally, the skills and experience needed are found within the company. **Rating = 7.**

5. *Technical Feasibility*: The technology gap for organization is not expected to be large, building on the skills in power conversion. However, there are unknowns about how these technologies will be applied as well as a lack of unit-level knowledge and experience in charging system algorithms and charging system communications. **Rating = 6.**

6. *Financial Reward*: The business case is very uncertain, but the initial investment for a working prototype and potential pilot installations is very small and could have high strategic significance. **Rating = 5.**

The ratings obtained above are applied in the scoring model and tabulated in Table 7 to show the comparison amongst the technology options.

[3] ABB internal estimates

Table 7: Initial Smart Grid Opportunity Assessment

	Ratings (1 – 10)							
Application	Strategic Alignment	Product and Competitive Advantage	Market Attractiveness	Leverages Core Competencies	Technical Feasibility	Financial Reward vs. Risk	**Total Initial Score**	**Project Attractiveness Score (out of 100)**
AMI	0	0	8	0	2	0	10	**17**
Demand Response	0	0	7	0	0	0	7	**12**
HVDC Transmission	0	2	8	2	0	0	12	**20**
Energy Storage	9	6	7	6	8	6	**42**	**70**
Distributed Generation	9	7	7	8	8	6	**45**	**75**
PHEV/EV Chargers	7	7	6	7	6	5	**38**	**63**

As could be predicted from the discussion above, three of the seven technologies – energy storage, distributed generation, and PHEV chargers - have much higher scores than the rest. AMI, demand response, and HVDC transmission all score very low on strategic fit, potential competitive advantage, technical feasibility, and financial reward. However, all of these factors are subject to change. For example, the strategy of the PE GPG could change such that AMI becomes more aligned, or new technologies could be developed or acquired that make lower power HVDC applications more technically feasible. Therein lays the strength of the scoring model and idea screen. With this initial screen completed, if any of these factors do change, it is fairly straightforward to go back and reassess individual projects or opportunities. This does require a diligent project or product manager to continually be studying the market, something that can be challenging in resource constrained organizations. However, as the scoring model stands for the PE GPG, no further work will be done until a more compelling application set is identified.

Additionally, the three markets determined in the initial screen are not guaranteed to meet all of the strategic and financial goals of the PE GPG, but they do represent the most promising opportunities thus far in the smart grid and deserve to go forward for further assessment.

5.3. Preliminary Assessment

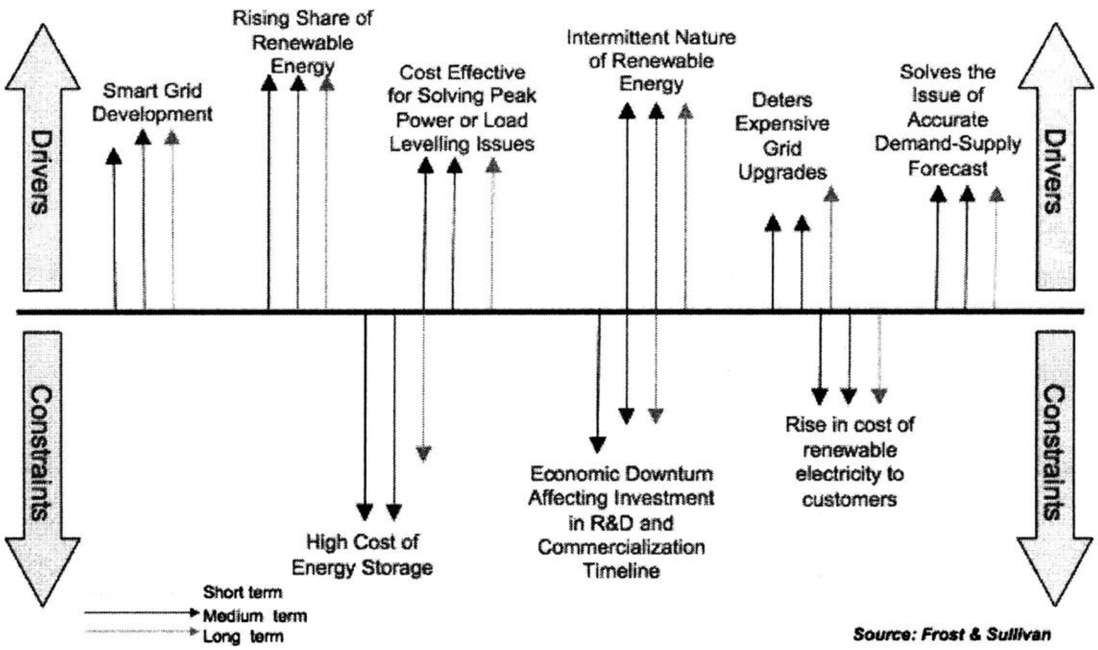
The next section moves beyond the initial screen and into a preliminary assessment of the identified segments. The goal of this analysis is to further define the actionable segments of the identified opportunities, assess their market impact, and determine the potential projects reachable by the PE GPG. At the end of the analysis, the scoring model is further refined to determine which, if any, opportunities move forward for further analysis.

5.3.1. Energy Storage

Market Assessment

Energy storage has the potential to totally redefine the way energy is generated and used. It is one of the key enablers for integrating renewable energy onto the grid, and for the smart grid as a whole. The potential economic impact is staggering - a recent report from Sandia National Laboratories details seventeen discrete benefits to the grid from energy storage (44). While this report frames the benefits in terms of economic value to utilities, a follow-on analysis estimated that meeting these needs could lead to over $200 billion in revenue over the next ten years for makers of energy storage systems (49). This analysis is purely “technology-neutral”, meaning that it makes no judgment about the best storage technology to meet these needs. Additionally, it takes the data from the Sandia National Laboratories report and makes a number of assumptions based on the average market benefit, electricity price, and application discharge durations. This analysis shows the potential impact of energy storage on the grid, and while the economics may work out different the market opportunity is still sizable.

Despite these optimistic market predictions, the energy storage market faces a numerous challenges. Fig. 7 details some of the key drivers and challenges over the next ten years.



Source: Frost & Sullivan, *Renewable Energy Storage European Market Analysis,* 2009

Figure 7: Energy Storage Drivers and Challenges

As shown in Fig. 7, "constraints", the key barrier to widespread adoption is the high-cost of energy storage. Pumped hydro is typically the most economical technology overall, with installed costs of approximately $325/kWh, but very high overall costs as installations typically range into the tens of MW or more (50). Additionally, pumped hydro requires an area with elevation differences and adequate water resources, greatly reducing its geographic applicability. Batteries, on the other hand, are much more transportable and easier to picture in "plug and play" applications where storage is connected to the grid from an easy-to-install or pre-packaged battery systems. Total installed costs for battery systems, including the PCS, range from only $150/kWh for lead acid batteries up to $1300/kWh for Li-ion batteries. However, in the case of many of the advanced chemistries such as Li-ion, costs are expected to be halved in less than 10 years (51). Additionally, a number of analysts predict that the grid energy storage market will benefit from the significant investment battery companies are making in Li-ion batteries for electric vehicles. A recent report predicted that Li-ion batteries will become the fastest growing segment for utility-scale energy storage, growing to $1.1 billion overall by 2018 (52).

Also shown in Fig. 7, the main driver for energy storage is its potential to smooth the intermittent nature of renewable energy resources, in other words, to ensure that the supply remains constant even if the sun does not shine or the wind does not blow. Additionally, energy storage is gaining promise for electricity "peak shaving", where the stored energy is deployed only at the time of highest electrical demand. This can be used to displace even more expensive generation assets, and since energy prices are highest when demand is highest, this application makes the economics of energy storage much more favorable.

Despite some of these challenges, the energy storage market shows a great deal of promise. For batteries, capacitors, and SMES, power electronics will play a key role in connecting the storage device to the ac grid. There are really no threats or substitutes to power electronics in these applications, especially for battery energy storage systems (BESS), where flexibility and a small footprint are vital. Thus it is safe to assume that demand for power electronics applications will closely follow demand for energy storage.

Among the major suppliers of medium and high-voltage power electronics, such as ABB, GE, and Siemens, there is really no clear differentiation in the offerings for energy storage conversion. At the lower end of the voltage range (~ 400 V and below), there are numerous inverter manufacturers, such that applications in this range have reached near-commodity levels. This lower end is not a very attractive segment for a unit like the PE GPG who competes on quality and service. Fortunately, their offerings are in the higher range where customers typically base their purchasing decisions on more than cost.

Technical Assessment

From a technical standpoint, the energy storage technologies and applications above require a wide array of hardware and software to interface with the electric grid. The PE GPG's APE PRU has experience in two segments of the energy storage market – battery energy storage and pumped hydro. Both of these applications are for energy conversion, as no unit within ABB is currently manufacturing the actual storage technologies themselves.

In battery energy storage, both of the applications were custom solutions, one for an isolated portion of the electric grid in Fairbanks, AK and the other for a government funded storage project in the UK. The Alaska project, done in partnership with French battery manufacturer Saft using a NiCd battery chemistry, still ranks as the largest battery system in the world, with 13,760 individual battery cells connected in four strings able to provide up to 27 MW for fifteen minutes. The power electronics used are four paralleled IGCT units, rated at up to 15 MW each and connecting to the grid through transformers at 138 kV (53). The total installation cost was just over $30 million, with the PCS accounting for approximately 15% of the total[4]. This type of application is not expected to gain widespread penetration, but does provide good perspective on the technical capabilities of the unit.

For pumped hydro, the offerings come from the APE PRU and are based on the PCS 6000 series of converters (see Appendix A for technical ratings), which provide excitation for the motor/generators used to pump the water and subsequently generate electricity. This application is a good fit for the PCS 6000 and will continue to fit into the portfolio. For the purposes of this analysis, this is not a segment under consideration for new projects.

Ultracapacitors and SMES have similar conversion needs to batteries, namely they act as dc sources and must be converted to ac for grid connection. At this point, it is a safe assumption that any PE GPG developments for battery energy storage can be tailored to these applications in the final engineering phases. On the other hand, CAES acts much like a typical ac synchronous generator and most applications use transformers for grid connection, vice power electronics. Additionally, CAES is not expected to have a high-market penetration as costs of the other technologies continue to decrease. Flywheels use power electronics for the conversion of high-frequency ac to grid level ac, but continued high capital costs and technology questions have limited their overall appeal.

For the PE GPG, the best technical fit comes from the PCS 100 and PCS 6000 platforms. The PCS 100, which operates in the 100 kW to 20 MW range depending on the number of units utilized, appears to be an especially good technical fit for the requirements of the widest range of storage technologies, combining small size, high efficiency, and low cost. Additionally, from a technology gap standpoint the only real need is a comprehensive storage management system to control the bi-directional power flows.

Business and Financial Assessment

There are very compelling strategic reasons for entering the energy storage market. With the acquisition of the PCS 100 family of technologies, the PE GPG now has access to a low-cost, high performance, and highly modular power electronics platform. By dedicating a project and resources to energy storage, the PE GPG has the opportunity to position itself strongly in a rapidly growing market.

The costs for developing an energy storage system based on an existing technology platform are expected to be minimal, most likely less than $1 million as the development will mainly be on the control system

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[4] ABB internal estimates

rather than the actual hardware. Additionally, funds and resources will be required for marketing the new product. For expected sales, there are a number of variables to take into account for a market with such uncertainty. With the estimate detailed in the market assessment that storage maker revenues could reach $200 billion over 10 years, and assuming that PCS costs remain at approximately 10% of total system costs, that is a $20 billion relevant market. Even with a lower margin on the current PCS100 applications, a very low market penetration rate would provide adequate revenues to make this a good investment.

5.3.2. Distributed Generation

Defining the Segments

The rise in power electronics applications in distributed generation has not gone unnoticed by the PE GPG. Current offerings include full-scale converters for wind turbines and fuel cells, as well as converter systems to provide grid support in the form of reactive power compensation (54). Additionally, as mentioned in Chapter 2 there is a previously signed agreement that the Low Voltage Products division will be the sole ABB supplier of solar inverters. While this places an "unnatural" constraint on the technologies that can be explored, no development in the PE GPG will go forward in solar inverters as long as the agreement is in place. Ultimately, this leaves microturbines as the only undeveloped market for the PE GPG.

Microturbines, as they are referred to in distributed generation applications, are small combined heat and power (CHP) units roughly the size of a typical washing machine. They consist of a gas driven turbine generator, and a waste heat recovery system. Gas is used to drive the turbine generator and the waste heat is captured to provide central heating (55). Typically these installations range in size from 25 kW at the household level to 500 kW at the neighborhood or small commercial level.

Microturbine Market Assessment

A number of factors drive the microturbine market. By operating on natural gas, microturbines produce fewer emissions than baseload coal-fired power plants which are the norm in many areas. Additionally, they offer attractive payback periods, in the range of three to four years, for progressive consumers who want to provide heat and power for their homes, neighborhoods, or buildings. Finally, another driver is that they are an attractive replacement or alternative to boiler systems in many buildings.

The market for these systems is modest. The average price for per kW of a complete installation is approximately $3,000/kW, with costs expected to remain relatively stable over the next two to three years

(56). However, based on the high cost of production and a lack of market ready technology, the total yearly market revenues are only expected to reach $150 million worldwide by 2015, up from $65 million in 2008 (57). The power electronics component, which converts the ac voltage and frequency of the turbine output to grid ac voltage and frequency, typically accounts for 10 to 15 percent of the total system costs.

Technical Assessment

Microturbines are small systems that range in power from 25 kW to 500 kW. The total balance of plant is typically a generator, a heat recovery system, a control system, and a grid connection system. Most of the facilities that utilize microturbines are grid-connected, thus the high-frequency ac output of the turbine needs to be rectified and inverted to the grid level voltage and frequency. Power electronics are the product of choice to perform this operation.

From a PE GPG standpoint, the technology fit overall with this application is fair. These systems operate at low power and voltage, and with the basic building block of the PCS100 rated at 125 kW, only the highest power applications would be a good product fit. It is technically feasible to take the IGBT building blocks of the PCS 100 and apply them to an even lower power application, but the costs to develop would be high and there is no guarantee that the final product would offer any technical advantage over the widely available offerings in this power range.

Business and Financial Assessment

The strategic case for entering this market is weak. While this is an untapped segment of the distributed generation market, the overall market potential is modest. Additionally, the competitive landscape is fierce, with numerous turbine vendors competing for a small market with narrow margins. The quality of the PCS in these systems is not a real differentiator, and there are many suppliers in this power range. As mentioned in the technical assessment, the PCS100 could potentially serve the higher end of the microturbine market, but with these applications making up only a portion of the overall market, the development case is not compelling.

From a financial standpoint, any offering at this low power level would require expensive re-engineering of existing products. Additionally, expected sales are low, as the market is already fairly saturated with low voltage converters and there is no realistic expectation of significant short-term market penetration.

5.3.3. *PHEV/EV Charging*

Defining the PHEV/EV Charging Market

In the U.S., charging activities are defined in three levels (58):

- Level 1: This method uses a standard 120 VAC, 15 or 20 A household plug to provide up to 1.44 kW of power. This is the most common method of charging, and is an appropriate method for a PHEV with a 5 or 6 kWh battery, but as it can take more than eight hours to fully charge an EV at this power level, it is expected that most households with EVs will upgrade to dedicated Level 2 chargers, below.

- Level 2: This is described as the "primary" or "preferred" method of electric vehicle charging and is based on a 240 Vac, 15 to 40 A dedicated circuit providing up to approximately 6.6 kW of power. This application requires the installation of special equipment, which some vehicle manufacturers are bundling with the sale of the vehicle. For example, Nissan has partnered in the U.S. with the equipment provider Aerovironment to offer a $2,200, 220 Vac home charging station installed at the time of purchase (59). In Europe and many other parts of the world, the common grid rating is 220 Vac and 15 A, making this the de facto charging standard.

- Level 3: Level 3, or fast charging, is defined as anything above 240 Vac, or dc voltage up to 600 V. The California Air Resources Board lists a certification requirement for fast charging as a ten-minute charge that enables the vehicle to travel 100 miles; however, this can be done at many power levels. A dc charging system is used for fast charging as it bypasses the on-board converter of the electric vehicle and connect directly to the battery. Additionally, there are a wide range of charge types that can be applied to electric vehicles. Table 8 lists a few of the common terms and charging rates of dc fast charging for different types of vehicle applications.

Table 8: Electric Vehicle Fast Charging

Type of Charge	Charger Power Level, kW		
	Heavy Duty	SUV/Sedan	Small Sedan/Compact
Fast Charge, 10 minutes, 100% State of Charge (SOC)	500	250	125
Rapid Charge, 15 minutes, 60% SOC	250	125	60
Quick Charge, 30 minutes, 70% SOC	75	35	20
PHEV, 30 minutes, 100% SOC	40	20	10

Source: Botsford, C., *Fast Charging vs. Slow Charging: Pros and cons for the New Age of Electric Vehicles,* 2009

Meeting the technical requirements for the fast charge from Table 8 is currently the goal of most automotive and infrastructure manufacturers. Being able to quickly and conveniently charge an electric vehicle will greatly aid with adoption by reducing the "range anxiety", or fear of running out of battery, that many consumers have expressed (60). From a technology standpoint, with the proper control system, any technology that could achieve the fast charge could also achieve the other types of charges from Table 8, but possibly not in the most cost-effective manner as it would be operating well below its rated specifications.

Market Assessment

Electric vehicles have been available for over a century, pre-dating the adoption of the internal combustion engine. Unfortunately, they have been consistently plagued by poor battery technology and the widespread availability of cheap fossil fuels, prompting many failed attempts over the years at commercialization (61). In the last few years, however, it appears those trends are changing as governments and individuals try to reduce their environmental impact, and increased research in battery technology has brought down costs and improved energy density. A complete discussion of the drivers and challenges to vehicle electrification is too detailed for inclusion here, but many resources are widely available, including a number of comprehensive reports by the Electrification Coalition which detail a path to widespread electrification of the transportation sector (62).

Based on the significant unanswered technical questions and early stage of the market, adoption forecasts for electric vehicles vary by a factor of ten or more in many cases. For example, Switzerland and Germany alone both hope to have more than one million electric vehicles on the road by 2020, while in an optimistic scenario the U.S. could have 14 million electric vehicles by 2020 (63) (64). Additionally, the demand for electric vehicles in China is expected to be the highest in the world, with some estimates putting the number of electric vehicles as high as fifteen million by 2020 alone (65).

To arrive at a potential market for infrastructure providers such as ABB, we also need to look at the penetration and potential uses for the different types of chargers. As with the vehicles themselves, estimates vary greatly on the penetration rates for each of the technologies. A further refinement of the three use-cases from the overview results in the three most promising types of chargers (66):

- *Wall-mounted home chargers* at the 240 Vac level, targeting the six to eight hour charge. These are not "smart chargers" with built-in electronic control systems, but rather ac connections for the car's built-in charger.

- *Pole- or wall-mounted public chargers* up to 480 Vac for use in apartment buildings, restaurants, office buildings, etc. These will target slow charging for non-residential customers as well as offer "top-ups" in the one hour timeframe.

- *DC fast chargers* operate in the ranges shown in Table 8, providing quick charges for vehicles on-the-go or at short-term stops like restaurants.

There is actually a fourth, potentially disruptive, technology being touted by at least one company. The Palo Alto, California firm, Better Place, Inc., is trying to develop a charging infrastructure based on *battery-swapping stations* where vehicles drive through and have their batteries swapped in less than three minutes (67). While they are in the process of launching pilot projects in Japan, Denmark, Israel, and Australia over the next few years, serious doubts still remain about the viability of their business model (68). The charging of the batteries in the station does however require the use of power electronics, and despite the negative market outlook, are included in the market assessment below.

Market Size

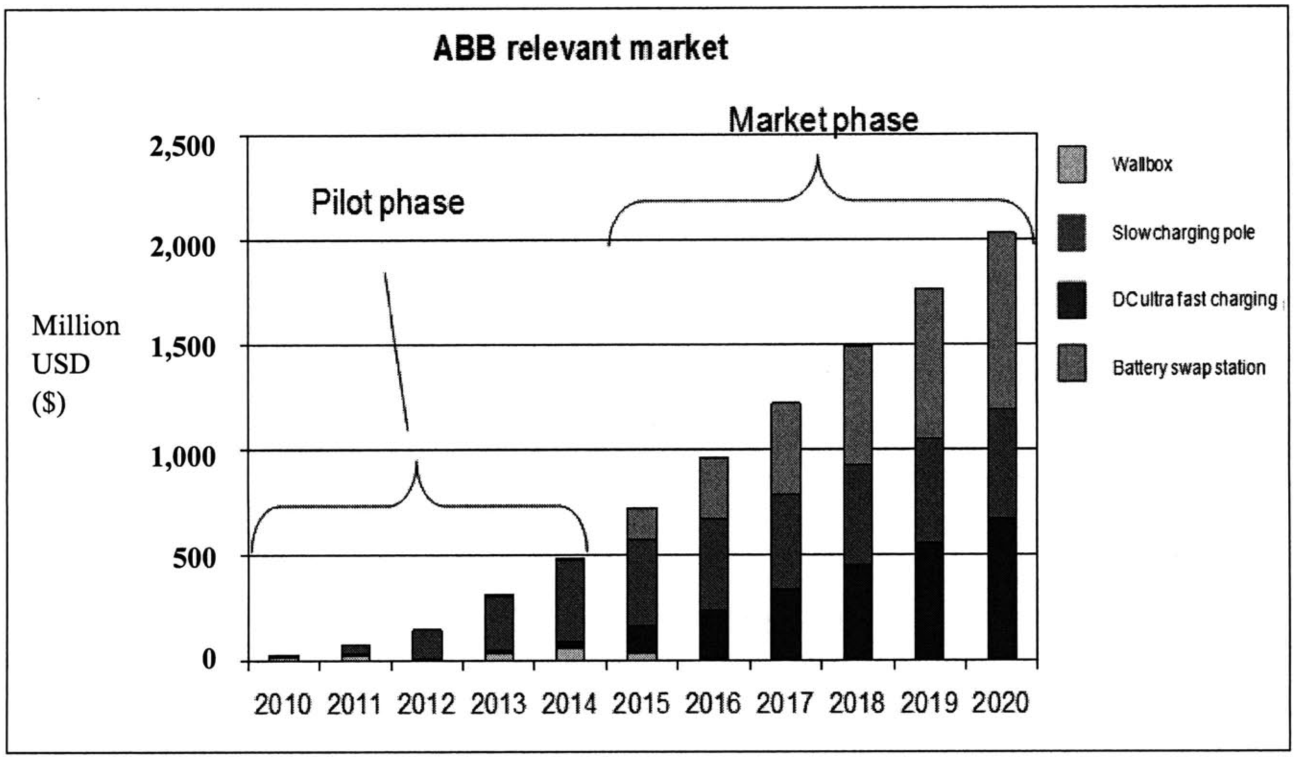
The next step in the analysis is to synthesize the various reports and estimates above, provide some level of sensitivity, and arrive at a rough Fig. for the ABB and PE GPG relevant market:

- With a total of 2.5 billion vehicles expected to be on the roads by 2020, assuming only a 2.5 percent penetration rate for both EVs and PHEVs results in 15 million EVs and 15 million PHEVs each.

- Assumptions about the penetration of each of these technologies, including the number of chargers per vehicle and overall infrastructure investment, results in the following installed infrastructure by 2020:

    - 16 million wall-mounted chargers installed in private homes and apartments (roughly one charger for every two electric vehicles)
    - 8 million pole- or wall-mounted public chargers (50 percent of the total of wall-mounted chargers)
    - 40,000 dc fast chargers (0.5 percent of the public charger market)

Fig. 8 shows the application of the underlying price assumptions to result in the overall ABB relevant market.



Source: Internal ABB Estimates

Figure 8: ABB Relevant Charging Infrastructure Market

Technical Assessment

The three major applications listed above all have different technical needs. As dc fast charging operates in the ranges of the PCS100, it appears to be the best technical fit with the current product offerings. The wall- and pole-mounted chargers use little, if any, power electronics, acting just like any other ac electrical outlet. However, one of the key features of the dc fast charger is its ability to economically convert ac grid power into dc charging power for electric vehicle batteries, and power electronics will play a key role in this conversion. One potential opportunity is to leverage the existing technical fit to move into wall- and pole-mounted charges. This could potentially create opportunities for the PE GPG, but as these technologies exist elsewhere in ABB, specifically in Low Voltage Products, a better solution would be to partner with another unit to provide an end-to-end solution.

The PCS 100 platform is a good fit for this application. On the dc side it is rated from 400 to 690 V, which is in consistent with the charging ranges of most battery types, and the rated power of 125 kW provides flexibility for operating in parallel or series configurations. For example, assuming a 50 kWh battery pack, a ten minute quick charge from 10 percent to 80 percent will require approximately 210 kW of energy from the grid, which could be easily achieved with two PCS 100 units.

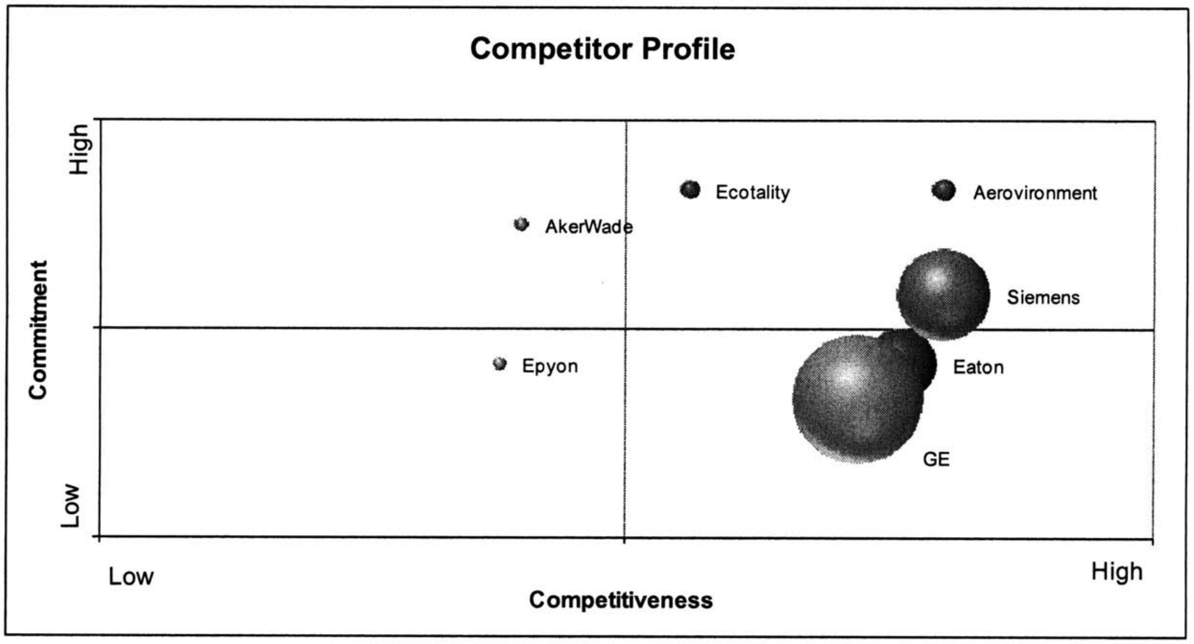
While the solution may be clear from a power electronics standpoint, two key technical issues remain. First, consider the charging scenario above. If the 210 kW is drawn at 480 V from the grid, the required current is roughly 440 Amperes. This current draw requires robust electrical safeguards. It also raises the question of the impact of these charging operations on the electric grid. If this type of application is operating at a roadside "gas station" with five or six outlets, the power required is over 1 MW - multiply this by the number of such stations required and the potential impact is high. However, initial studies indicate that the overall effect may not be detrimental to the grid, but will still require additional investment and systems from utilities and infrastructure providers (69). On a positive note, as the converter makes up just one part of the whole charging station, other units in ABB could be involved in the product offering for installation and grid support. This cross-selling could be a major point of differentiation against the competitors who only offer the charging converters.

The larger concern is that current battery chemistries may not be well suited to fast charge operations. Fast charging puts a great deal of strain on the battery and the support systems, potentially reducing system life and damaging the battery. Regardless, a number of companies are moving forward with fast charging, hopeful that battery technologies will keep pace (70).

Business and Financial Assessment

There a number of strategic reasons to consider entering the fast charging market. First, it represents an entirely new market for the PE GPG solutions. Second, it leverages the core competency in conversion systems held within the PE GPG. Finally, it has the potential to have a high impact on the business by opening up new sales channels and increasing the brand awareness of ABB's lower voltage power electronics offerings.

As a highly visible market where companies are trying hard to make a name for themselves, the fast charger market has a competitive landscape that is fairly transparent. Fig. 9 shows the key players and their commitment to the market (the size of the bubbles represents the company's overall market capitalization).



Source: ABB internal estimates

Figure 9: PHEV Competitor Profile

Commitment is a measure of how dedicated the company is to entering and succeeding in the market, and is ranked based on the scope and breadth of their offerings as well as press releases, pilot projects, and partnerships announced. Competitiveness is a subjective measure of the overall technical competence of the firm, as well as their experience in this kind of application, and their development resources. Overall, the most compelling competitors in this space are Aerovironment, Siemens, and ECOtality. ECOtality is moving from low level to high level charging and was recently awarded a $100 million grant to develop a charging network in partnership with Nissan (71). Siemens is working on in-vehicle charging systems (an area that ABB leadership has decided not to explore) and are partnering with RWE to develop charging infrastructure in Europe (72). Finally, Aerovironment is the market leader in charging solutions, with a proven fast charging solution and a deep product portfolio (73). Their offerings include fast charging systems for industrial and passenger vehicle applications, and they have entered into strategic partnerships with a number of advanced Li-ion battery manufacturers to test and promote fast charging solutions. As ABB has not committed to entering the market, they are not shown in the Fig. above. However, if they are able to develop a coherent and consistent strategy at the corporate level, as well as strategic partnerships with utilities and governments for development projects, they offer a level of competitiveness as high as Siemens or GE.

From a financial standpoint, the key development costs will be in designing a control system to support battery energy management, as well as overall product testing and validation. These are expected to be modest, but not trivial, costing approximately $5 million over the two year development timeframe. Additionally, expected sales are difficult to estimate but could be up to $200 million over the life of the investment[5]. Overall, short term returns appear to be low for this project, as initial installations will most likely be for pilot or test projects, and significant revenues are not expected in the next five years.

5.4. Determining the Winners

With the preliminary assessment complete for each of the three technologies, the final step is to apply the scoring model one more time to determine the winners, arriving at the final scores based on the discussion above and utilizing the overall criteria from Table 6.

Table 9: Final Smart Grid Opportunity Assessment

	Ratings (1 – 10)							
Application	Strategic Alignment	Product and Competitive Advantage	Market Attractiveness	Leverages Core Competencies	Technical Feasibility	Financial Reward vs. Risk	**Total Initial Score**	**Project Attractiveness Score (out of 100)**
Energy Storage	9	7	7	8	8	7	**46**	**77**
Distributed Generation	5	5	4	5	4	6	**29**	**48**
PHEV/EV Chargers	8	6	6	8	8	5	**41**	**69**

Based on the results calculated in Table 9, energy storage and PHEV/EV chargers are winners over distributed generation, specifically the microturbine market. They are both strategically aligned with the goals of the organization, technically feasible with the current resources and capabilities, and offer a potentially good financial return. As discussed after the initial screen, this does not mean that distributed generation is no longer an area for study or potential advancement, but based on the current technical capabilities, market assessment, and strategic fit, energy storage and EV chargers have the highest

[5] Internal estimates

potential and are recommended to move forward for a more detailed product and business case assessment.

This case presents a good example of how a project can be screened out after a preliminary assessment. In this analysis, distributed generation had the highest score after the idea screen. This was based on the large scope of the segment as well as the numerous drivers for adoption of energy storage technologies. However, with more data gathered and analyzed at a detailed level, the numerous constraints of the market became apparent, limiting the accessible markets to one small subset of distributed generation technologies. This situation, where a previously attractive project or segment is screened out of the portfolio, can arise at any point in the project selection process, and shows the value of the process, as well as the scoring model, in screening out projects with less potential impact to the business.

With the initial screen and preliminary assessment complete, the next step is to prepare the analysis for a gate meeting and present the results. Senior management has the ultimate say on what projects will go forward, and this assessment is the key input they will utilize when making their decisions. The next chapter details at a high-level the next steps moving forward as well as the challenges with managing new projects across the portfolio.

6. INTEGRATING THE PORTFOLIO

The previous sections focused on the initial stages of project selection as one of the main drivers of portfolio management. While an effective project selection process is key to successful portfolio management, it is only one part of the overall equation. This next section details how to integrate the project selection process with an existing portfolio management process, as well as the general challenges going forward

6.1. Resource Allocation

One of the key points brought to light in the earlier analysis is that regardless of the number of great ideas or breakthrough projects that are identified, none of these projects will go forward without adequate resources.

One of the easiest ways to determine the resources available for use is through a *resource capacity analysis*. The resource capacity analysis quantifies the projects' demand for resources versus the availability of the resources. This analysis can be completed by asking one of two questions (34):

- *Are there enough of the right resources to handle projects currently in the pipeline?* This is answered by looking at the current list of active projects and determining the resources required to complete them in time. Then compare this with the apparent availability of resources and any additional capacity is what can be applied to new products. Furthermore, this type of analysis typically aids in the identification of major gaps and bottlenecks.

- *Are there enough resources to achieve the new product goals?* At a high-level, determine what percentage of sales will be driven by new products and then estimate the resources required to meet these goals. Just like the previous example, most likely major gaps will be identified – forcing tough decisions about how to achieve the goals with the available resources.

- *Will the new initiatives be enough to take us to our new goals?* This is really a "reality check" to determine if the organization has the capabilities to meet all of its goals. If it is clear from the check that the goals cannot be met with current resources, each company or unit only has two viable options – (1) Add more resources for the key projects going forward, potentially drawing on corporate resources or, (2) Re-shape the goals so that they are achievable with the resources available. This is especially a challenge for strategic business units who are seemingly in a constant struggle for resources.

Table 10 is a generic example of the results of this analysis. It shows an example resource capacity analysis across a product portfolio. By grouping the resources by type – product management, marketing, and research – managers can make estimates of the resources required for each development project and quickly determine if those estimates meet or exceed the available resources. For many organizations, developing this type of chart may require a new way of looking at how projects are staffed and sent through the pipeline. This is especially true in engineering-based organizations where a lack of dedicated marketing resources results in haphazard assignment of market assessment and financial modeling.

Table 10: Example Resource Capacity versus Demand Analysis

Resource Demand Vs. Capacity Chart-Example

Project	Product Mgmt		Marketing		Research Group A		Research Group B	
	Person days	Cumulative	Person days	Cumulative	Person days	Cumulative	Person days	Cumulative
Alpha	3	3	2	2	10	10	5	5
Beta	4	7	2	4	10	20	5	10
Gamma	3	10	2	6	15	35	5	15
Delta	5	15	3	9	15	50	8	23
Epsilon	6	21	3	***12***	5	55	8	31
Foxtrot	6	***27***	2	***14***	5	60	5	36
Available Person days		20		10		60		40
% Utilization		***135.00%***		***140.00%***		100.00%		90.00%

Source: Cooper, R.G., *Winning at New Products, 2001*

This capacity analysis typically highlights some of the key problems in the portfolio:

- Too many projects in the pipeline, requiring the need for a prioritization and culling effort.
- Goals that do not match the capabilities of the organization, possibly based on unrealistic expectations of project impact and timing.
- Departments or groups that are major bottlenecks in the project development process.

While this analysis is just one tool in the portfolio management process, it is a good place to start as it provides a tactical view of where the unit is struggling and can aid in prioritizing problem resolution.

6.2. Aligning the Organization with the Portfolio Goals

Another key factor to consider when moving forward with an integrated strategy is ensuring that the organization is aligned with the new project and portfolio goals. Much like a lack of resources, the lack of an effective organization for portfolio management and execution will make it difficult to meet any new product goals.

Consider the example of the situation now faced by the PE GPG. Assume that the energy storage and EV chargers are indeed selected to move onto a more detailed business case development. This requires an investment of both time and money, tying up resources that could potentially be available for other projects. Additionally, looking at the five PRUs in the PE GPG, it is not immediately clear where battery energy storage and electric vehicle chargers best fit from a technology and market standpoint. In this case, there are two major options:

- Pull the appropriate resources from across the GPG to work on the development project, while keeping the project management function inside one of the existing PRUs.

- Form a new PRU around the promising development, or a PRU specifically dedicated to developing products for new markets.

The first approach is the easiest and quickest to implement, as it requires no real organization changes. However, depending on how development funds are allocated throughout the group this approach could unnecessarily "penalize" those units hosting the development, also potentially earning the ire of unit managers who see them as a resource drain or strategic distraction. In most of these cases, the immediate budget and resource needs will dominate, to the detriment of new projects. The second approach is more challenging to put into place initially, especially if drawing resources from other areas of the organization. However, in the long-term it provides an in-house development organization, or "skunk works", for potential breakthrough projects.

For the PE GPG, the Advanced Power Electronics PRU has the potential to be this development organization, pulling resources as required from other PRUs. This results in an approach that combines aspects of both options. As it already serves a broad number of markets, this unit can act as a pipeline for new projects, especially those leveraging the PCS 100 platform. For this effort to be successful, of primary importance will be gaining buy-in from the unit leadership, increasing the development resources available in the unit, and nurturing the project through its earliest stages. This approach has proven successful in the past, though, as the Converter Products unit was formerly part of APE, but was spun-off when the applications and technologies demonstrated adequate commercial promise and differentiation.

Additionally, building on the third goal of portfolio management, *ensure that the portfolio is strategically aligned,* is the concept of "strategic buckets" described in Chapter 4. These buckets can be established during the project selection process to group like projects together. Thus, when ranking projects at an initial level, they are ranked against or with other development projects. Additionally, current projects are ranked together to show which ones are adding the most value to the business at the present time. Table 11 provides an example of these buckets.

Table 11: Strategic Buckets for Grouping Projects

Experimental	Early Stage Development	Roll-out or Market Entry	Mature
• earliest stages of project selection • reviewed often during development to keep up with technology and market shifts	• moving from idea to concept generation and prototyping • reviews focus more on design effectiveness and concept development	• periodic monitoring to ensure market needs are still met • gain initial feedback from customers to incorporate in later designs or modifications	• monitor the market for disruption and emerging technologies • less frequent full reviews required

Using the buckets shown in Table 11, projects can be ranked depending on their place in the development cycle. Each stage in the process can have different review criteria, including timing of reviews, required deliverables for the review meetings, and different financial models. Finally, this "bucket" approach ties into section 6.3, as an organization can clearly define the resources for each bucket, and set portfolio goals based on the expected performance of each of the buckets. For example, if a view of the four buckets from Table 11 shows that the financial reward of the current projects in market entry is very low, then more resources can be dedicated to developing the early-stage projects to market entry. This concept is explored more fully in the next section, using tools to view the portfolio across the range of projects.

6.3. Integrating the Project Selection Process with the Portfolio Management Process

Another challenge moving forward is integrating the project selection process into the existing (or non-existing) portfolio management process. There are two different approaches for doing this, each suitable for a wide range of organizations (34):

Approach 1: The Gates Drive the Portfolio

This method follows the logic that if the gates or screens are effective, then a balanced and high-value portfolio will follow. This is *a real-time decision* process as at every gate, for every project, resources are re-allocated and priorities shifted. This type of approach is typically adopted at product-driven companies where the gate model is followed rigorously to develop new products. Thus in this approach the gates become a combination of an evaluation of the project under review as well as a prioritization of the project in relation to the rest of the projects.

This method is effective, but has some shortcomings. Specifically, while the project under discussion in evaluated thoroughly, the other projects in the portfolio are not formally assessed. This can lead to neglect of long-term projects as they languish in the development pipeline. To mitigate this, the approach can be augmented by portfolio reviews once or twice a year to assess all of the projects in the portfolio and determine if there is the right balance of projects, the right mix of project type, and if the projects are strategically aligned.

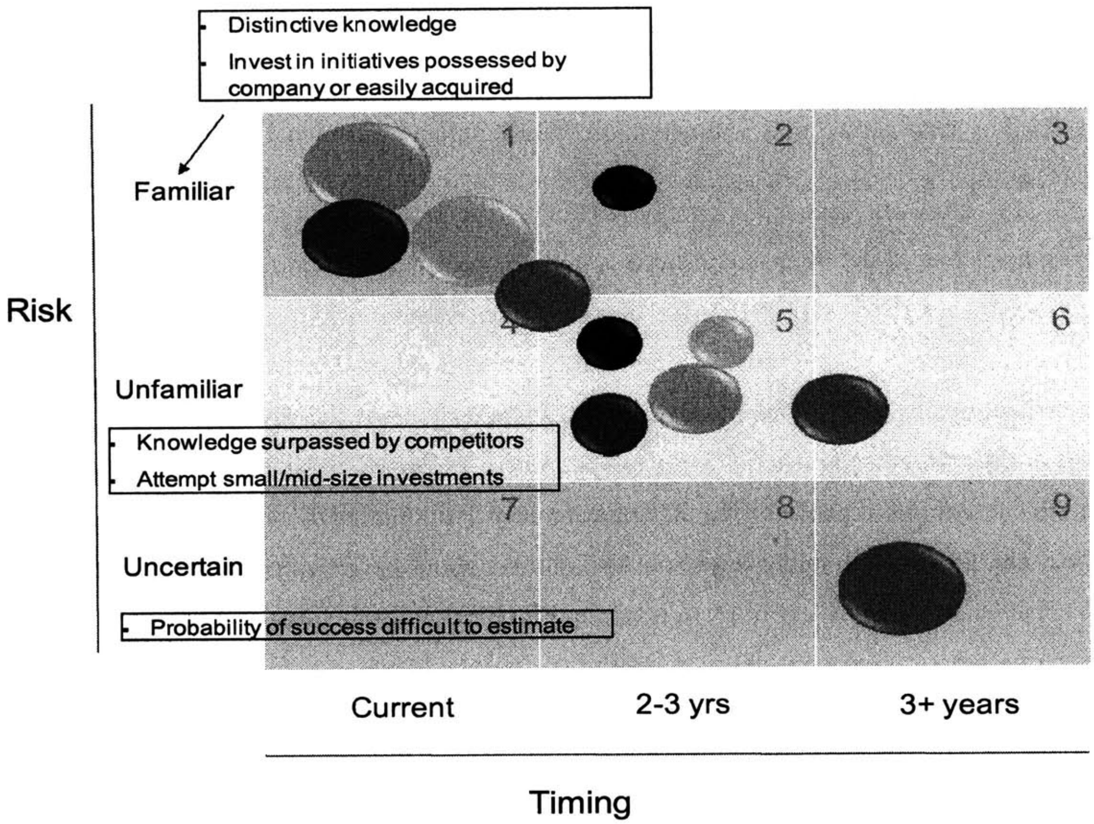
Approach 2: The Portfolio Drives the Project Pipeline

The second, more radical, approach is where all projects are considered together in comprehensive portfolio reviews, either as an entire portfolio or one of the strategic buckets discussed in Chapter 4. This means that when senior management meets to decide on a project, all projects are up for evaluation. This approach works best in fast-moving industries such as software, IT, and electronics firms, and may not translate as well to slower clockspeed industries (such as those targeted by the PE GPG). Additionally, it requires a high-level of commitment from senior management to continuously evaluate projects and take the opportunity multiple times a year for an in-depth look.

Despite these challenges, this method has the potential to positively shape the portfolio, as projects are continually-reassessed, with these assessments (up to four times a year) prioritizing the projects in relation to one another. One way to execute this is instead of ranking projects on an absolute scale as done in the scoring model above, force-rank the projects against one another to ensure that priorities are set in a clear and straightforward manner.

For the PE GPG, approach 1 seems the best fit overall. As the PE GPG operate in a slower moving industry, allowing the projects to be evaluated one at a time puts less pressure on the organization as a whole.

Additionally, while some portfolio tools are in place with senior management, pushing these tools into the hands of the PRU and product managers will result in more productive annual and bi-annual portfolio reviews. These also provide a clear view of where the projects fit into the portfolio overall, allowing a more clear allocation of resource. Bubble diagrams can be used to show many different aspects of the portfolio, including probability of success vs. value, market attractiveness vs. ease of implementation, etc. The McKinsey Portfolio of Initiatives is a very good example of this kind of bubble diagram, as it plots the project risk vs. project timing. Fig. 10 shows an example of this framework, where the bubbles represent individual projects and the bubble size is the potential revenues at stake.



Source: Bryan, L., *Just-in-time Strategy for a Turbulent World,* 2002

Figure 10: McKinsey Portfolio of Initiatives

Applying this kind of framework to the complete portfolio enables managers to have a clear view of where there are gaps in the portfolio and where development resources should be allocated. For example, if all of the projects end up in the top right corner, it should signal to managers that resources should be applied to developing long term investments. Additionally, if there are no products in the middle range of risk and timing, the unit could face difficulty meeting its goals in the two to three year timeframe.

Regardless of the approach chosen, it is vital that there is commitment from all levels to follow through with the analysis and evaluation. All potential projects need to be mapped out and vetted through the project selection model. Taking an objective look and remaining market focused will ensure strength in the portfolio at all stages of the product lifecycle.

6.4. Moving Forward with the Business Case

Finally, with all of the pieces in place, the next step is moving forward with the development of the business case. The goal of the business case is to develop a more robust assessment of the customer needs, as well as a more detailed look at the strategic fit within the company. For the PE GPG specifically there are a number of aspects of the business case that need to be analyzed in greater detail, although some or all of these could apply to any organization moving into new markets.

First, as the PE GPG grows its renewable energy portfolio beyond wind, and aims to have significant revenues in these areas one of the biggest questions is how to access the appropriate channels to market. As briefly mentioned when discussing PHEV/EV chargers, one potential solution to increasing channels to market is through partnerships and cross-selling with other ABB units. Unfortunately, these types of deals have been historically difficult to manage as the siloed nature of the divisions and businesses decreases the incentives for cross-divisional partnerships. There are hopes that this will change under the new CEO, but the cultural difference between the units are deep and long-lived, meaning that for the time being, no project can go forward solely based on assumptions about partnerships and leveraging other divisions' sales channels. This is a key limitation for the PE GPG, and something that it is working very hard to overcome by working more closely with corporate strategy teams as well as leveraging existing collaborations for new projects.

7. CONCLUSION

This chapter ties together the results and discussion of the preceding chapters, highlighting the key conclusions of the thesis. This chapter also offers some insight into how this specific research applies to other organizations that are entering new markets or facing shifts in their strategic direction.

Starting from a vague idea of a potential market to enter, this thesis defined the technologies of the smart grid and identified the most promising market opportunities for the PE GPG. During the process, the need for an objective and rigorous method to determine potentially impactful projects was identified. To satisfy this need, a scoring model was developed. This model can be applied at any time during a project's growth cycle, but has special relevance to the earliest stages, where there are the most uncertainties and unknowns about the market and technology needs. As shown in the later chapters, the model can also serve to increase the overall value of the portfolio of initiatives of the unit through strategic alignment and screening out projects of little impact which can act as a drain on valuable resources. To determine the inputs of the model, data was gathered from a wide range of sources, including analyst and market reports, and research about past projects and applications. Most valuable for refining the data were the many working sessions with key stakeholders and engineers undertaken to sort through the data and arrive at reasonable market and technology assessments. These sessions challenged previously held conceptions about different markets, brought new issues and ideas to light, and resulted in an overall stronger analysis for the scoring model.

In summary, the key conclusions of the thesis are:

- **The smart grid is a huge opportunity for traditional utility suppliers and new entrants alike.** With numerous new technologies and an unprecedented shift to lower carbon emissions, the utility industry is looking forward to a period of reinvention and massive change. For a company like ABB, this has huge potential, and for a unit such as the PE GPG, this represents a chance to reshape the strategy and enter new markets while the industry is in flux.

- **For the PE GPG, energy storage and electric vehicle fast charging are currently the most attractive segments of the smart grid.** Both of these applications are strong fit for the strategy and technical capabilities of the PE GPG. Based o n their potential, they deserve to be moved forward in the development process in order to determine the exact product specifications required, and to gain more understanding of how the market will unfold.

- **Portfolio management is a key enabler of a successful business**. While this seems like an obvious conclusion, companies continue to struggle with managing their portfolios. Putting some kind of framework in place, using it, and communicating the priorities is key to enacting the strategic vision.

- **Selecting the right projects is only the first step**. While all of the subsequent steps of the product development process are beyond the scope of this work, it is clear that the task does not stop at the business case. Developing the project and integrating it into the organization is one of the most important tasks for product managers and senior managers alike.

Every day organizations are faced with difficult decisions. Resource allocation, strategic direction, which markets to enter, which markets to exit – these are but a few of the challenges faced by managers at the business unit level. Additionally, they often do not have the tools available to evaluate these options in a clear and concise manner. This is especially true for product-driven or engineering-based firms; where many opportunities arrive as a result of *market push* rather than *customer pull.* A clear set of frameworks and models to aid in understanding the market, as well as the processes to support these models, are becoming a necessity.

One key tool for providing this vision is portfolio management. This thesis focuses specifically on the early stages of portfolio management, but the lessons here are universal. This early stage of portfolio management, project selection, is a pivotal time for every unit as decisions at this point can have significant impact on the future viability of the business. Failure to recognize trends or subtle shifts in the business landscape can either kill potentially breakthrough projects or allow mediocre projects to pass through and languish in "development hell", to borrow a phrase from the film industry.

This thesis creates and tests one potential framework – the scoring model. That is not to say that this is the "best" framework; in fact there may be no "best" framework. But what this offers is a chance for all the key stakeholders in a project to take an objective look at the key elements of a project and communicate clearly and concisely where that project fits into the overall portfolio of the unit. This is the key – any framework is better than no framework if only for the purpose of encouraging clarity and communication across the organization. In an organization such as ABB, communicating across business units is an enormous struggle, having a clear vision inside your organization is key to projecting that vision outside the organization.

In closing, the PE GPG is not alone in facing difficult decisions with a distinct lack of information. These challenges will always be present, but putting the right tools and organization in place will enable all levels of the organization to succeed. By providing an objective tool for project selection, the framework developed here can be integrated across all levels of portfolio management, and serve as an example of how to move forward with the best options.

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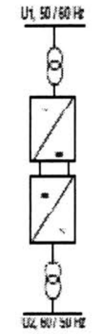
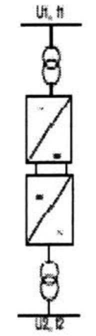
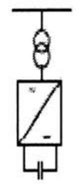
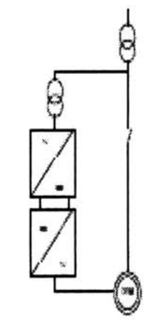
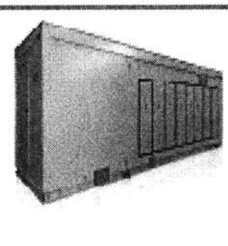
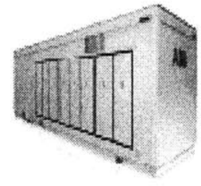
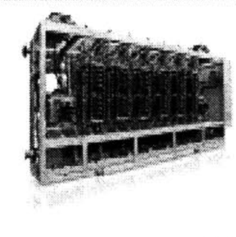
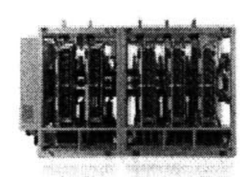
8. APPENDIX

A. Advanced Power Electronics Portfolio

System Family	PCS 6000	PCS 6000	PCS 6000	PCS 8000 / PCS 6000
Single line diagram				
Fields of Application	- Shore to ship power supply (Shore Connection)	- Grid interconnection for Rail Networks	- Wind farms: grid code compliance • Industry: voltage & power factor control, load balancing • Utility: reactive power compensation • Battery Energy Storage Systems	- AC Excitation for doubly fed induction machine (DFIM) • Cascade drive (VarSpeed)
Typical Photo				
Power Range	3 - 36 MVA, higher ratings on request	10 – 120 MVA, higher ratings on request	6 - 32 MVAr, higher ratings on request	5 - 50 MVA, higher ratings on request
Type of Converter	VSC: Voltage Source Converter			
Technology	MV IGCT			
Cooling Circuit	Closed water loop: water-air heat exchanger / water-water heat exchanger			
Voltage	Grid: user-defined (typical 33 kV .. 11 kV) Output: 6.6 kV .. 11 kV	Grid: user-defined (15 kV .. 132 kV) Higher voltages on request	Grid: user-defined (typical 10 kV .. 138 kV) Higher voltages on request	Grid: user-defined (6 kV .. 220 kV) Output: 3.3 kV or 6 kV (with redundancy)
In-/Output Frequency Range	Input: 50 / 60 Hz Output: 60 / 50 Hz	50 Hz (3ph) ↔ 16.7 Hz (1ph) 60 Hz (3ph) ↔ 25 Hz (1ph) Other frequencies on request	Grid frequency: 50 Hz or 60 Hz Other frequencies on request	Input: 50 Hz or 60 Hz Output: 0 Hz .. 68 Hz, higher on request
Examples	• Terminals for cruise ships, container vessels, LNG tankers, ferries and others	• Deutsche Bahn, Germany 15x 19 MVA • Swiss Railways, Switzerland 4x 21 MVA • E.ON, Germany 4x 103 MW	• INCO, Indonesia, 2x 32 MVAr • Braes of Doune, UK, 2x 12.5 MVAr • BCTC, Canada, 3x 12 MVAr	• Swiss Railways, 2x 80 MVA • Pump Energy Storage, 1x 200 MVA

Source: *Advanced Power Electronics – Portfolio,* ABB Power Electronics, 2009

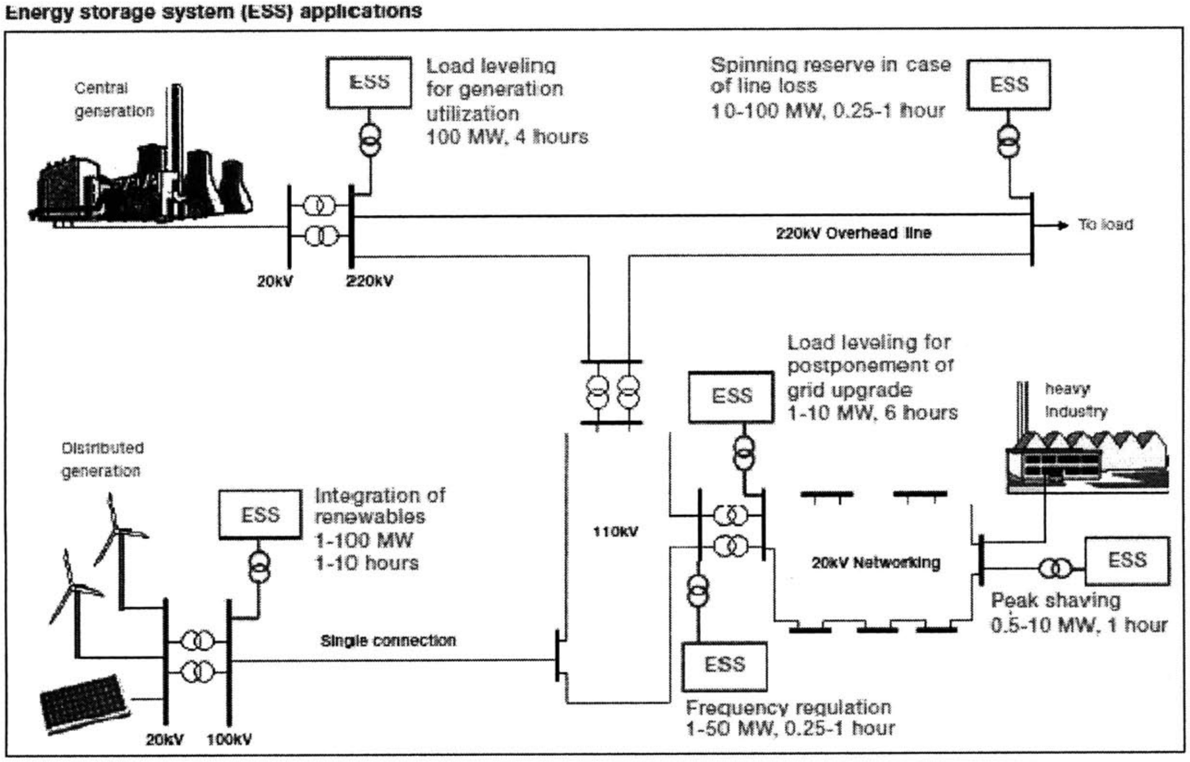
Figure 11: Advanced Power Electronics Portfolio

B. PCS 100 Battery Energy Storage System

Technical specifications

Connection	
Connection voltage	- 480V / 690V AC nominal (any LV or MV with standard transformer)
Connection frequency	- 50 or 60 Hz
Voltage variation	- ±10% (other by request)
AC current distortion	- < 3% at rated power
DC voltage	- 550 - 800V (480V AC)
	- 750 - 1050V (690V AC)
Performance	
Efficiency	- >95% at rated power
Standards	
Safety, EMC	- Designed to CE mark requirements
Quality	- ISO9000
Environmental	
Rack / enclosure rating	- IP20 / IP23
Container rating	- to IP54 (containerised option)
Ambient temperature	- 0-40°C, derating for temps to 50°C
Environmental cont /...	
Pollution degree rating	- 2
Cooling	- Forced air ventilation
Altitude above sea level	- < 1000m without derating
EMC emissions	- CISPR 11 level A
Humidity	- < 95% non-condensing
Standard colour	- RAL 7035 (IP20)
Interface	
User interface	- Graphic display touch panel
SCADA interface	- Ethernet, Modbus-TCP, dry contacts
	- Expanded interface options available
MTTR	- < 30 minute by module exchange
Norms / standard	- IEEE 519,
	- IEC62103 (EN 50178)

Energy storage system (ESS) applications



Source: *PCS 100 – Energy Storage Systems,* ABB Power Electronics, 2009

Figure 12: PCS 100 Specifications