MSc Program
Renewable Energy in Central and Eastern Europe

The Survival of the Power-Tech Dinosaurs

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
DI Lukas Weißensteiner

Mag. Stefan Starnberger, MIM

0151270

November 2011, Vienna

Affidavit

I, Stefan STARNBERGER, hereby declare

1. that I am the sole author of the present Master Thesis, "The Survival of the Power-Tech Dinosaurs – an analysis how Siemens, GE, Alstom and MHI are performing in the Renewable Energy Market", 137 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master Thesis as an examination paper in any form in Austria or abroad.

Vienna, _______________ ____________________________

Date Signature

Für

Elisabeth

&

unsere Kinder

Abstract

This paper is dedicated to examining the performance in the renewable electricity generation market of the four most important power technology companies - Siemens, GE, Alstom, and MHI. The key questions that will be answered are:

	Core questions
1	How did their portfolio and sales development correspond to the trend of increased renewable energy deployment?
2	In how far are they contributing to the current innovation demands for renewable energy sources?
3	How have they adapted their manufacturing and R&D footprints to the global demand shift towards emerging markets in the renewable energy market?
4	Have they been able to transfer their dominance from the fossil power market to the renewable energy sector?

The answers to these questions will be given with the help of the analysis framework provided by a Balanced Scorecard.

The traditional power technology companies have acknowledged the importance of renewable energy and have transformed their portfolio in the last years and have also managed to transform medium sized local companies into global renewable energy companies.

However, Siemens, GE, Alstom and MHI can be seen rather as followers than market changers as the companies have lost significant ground to new players.

For the future of our energy system but more importantly for the world's environmental system, mankind will require these companies to become drivers and not late followers or even burdens for the change towards a reduced or even carbon free economic development.

Table of content

List of Tables

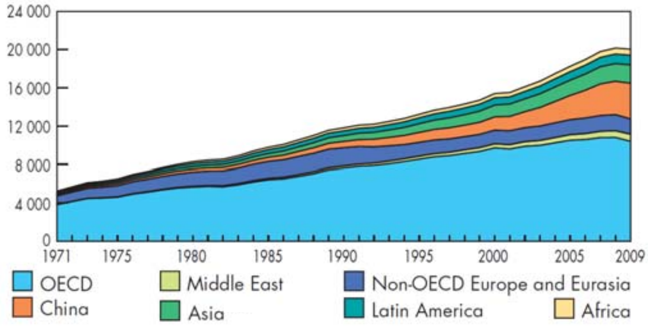
List of figures

1 Introduction

From the starting point of electricity production to today's time, a small number of companies has been dominating the electricity production industry. Not as producers but as suppliers of the increasingly important technology.

But in the last decades the electricity generation market has undergone significant changes. New powers have emerged with an unprecedented demand increase for energy (for instance China).

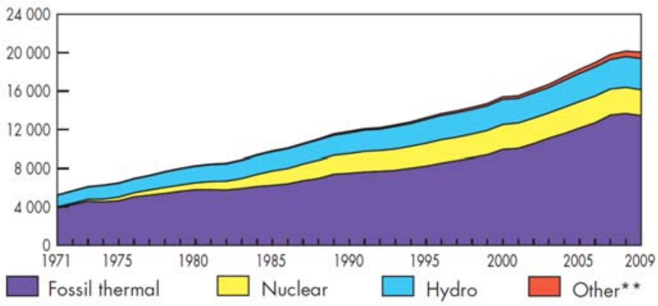
Figure 1 World electricity generation 1971 – 2009 by region (in TWh)



Source: IEA 2011a, p. 26

This demand increase has in the first line been covered by a boom in gas and coal based electricity production leading to the current status that 67% of the world's electricity is generated by coal, gas or oil.

Figure 2 World electricity generation 1971 – 2009 by fuel (in TWh)



Source: IEA 2011a, p. 24

In parallel to the boom in energy demand another topic has increased in importance with its highlight being the award of the 2007 Nobel Peace Prize[1] to former US Vice President Al Gore and to the IPCC[2]: *global warming*. With CO2 being the main driver, a new discussion has started on the sustainability of energy generation. This,

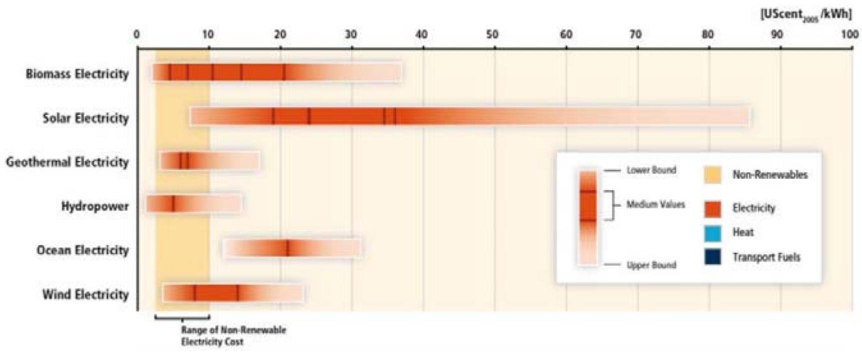
[1] http://www.nobelprize.org/nobel_prizes/peace/laureates/

[2] Intergovernmental Panel on Climate Change – for further information, please consult: http://www.ipcc.ch/

** Other includes geothermal, solar, wind, biofuels and waste, and heat in line with assuring supply security and balancing volatile resource prices, has increased the global focus on what are the two upper lines of figure 2 – Hydro and "Other" – renewable electricity production.

And in fact - looking to the added electricity production capacity between 2008 and 2009 the IPCC states that out of 300 GW in additional capacity, 140 GW (47%) came from additional renewable energy sources (IPCC 2011a, p. 6). There have been significant successes triggered by public and industry efforts to make renewable electricity generation competitive. In several technologies (e.g. wind and hydro) this is already the case.

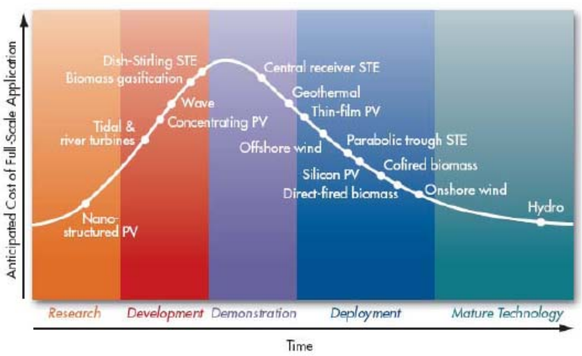
Figure 3 Levelized cost of energy of renewable technologies



Source: IPCC 2011, p. 10

However, electricity generation from renewable sources is currently not entirely at a mature stage compared to power generation from traditional fuels - both in times of technology and cost as well as with reference to the current transmission and distribution patterns.

Figure 4 Maturity stages of different renewable energy technologies



Source: Lako 2008, p. 9

Therefore, innovation for new technologies and industrialization for deployed technologies is paramount for the further decreasing of cost and the consequent increase in renewable power generation. This however needs both capital and know how in developing, manufacturing and deploying technologies for power generation – a challenge that seems suited to the giants of the power technology industry.

1.1 Core questions

Coming back to the initially mentioned power technology companies - they are faced with tremendously changing demand patterns. Additionally they have pioneered and coined the electricity generation from fossil and nuclear fuels during the last decades – so the core questions to be answered by this paper are:

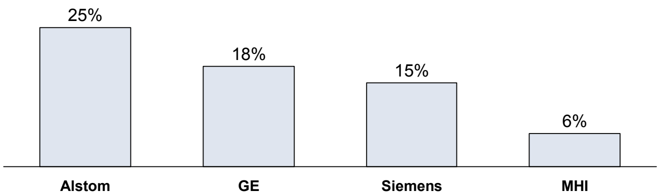
Table 1 Core Questions of this paper

	Core questions
1	How did their portfolio and sales development correspond to the trend of increased renewable energy deployment?
2	In how far are they contributing to the current innovation demands for renewable energy sources?
3	How have they adapted their manufacturing and R&D footprints to the global demand shift towards emerging markets in the renewable energy market?
4	Have they been able to transfer their dominance from the fossil power market to the renewable energy sector?

But, who are the large companies in focus? Four companies have been chosen to perform this investigation: Siemens, GE, Alstom and Mitsubishi Heavy Industries. The criteria applied to select these candidates have been:

Size (turnover) – together, these companies represent a 64% share of the global installed base in electricity production.

Figure 5 OEM[3] share of global installed base in steam, gas, hydro & nuclear (in %)



Source: Stahl 2010, p. 21

Completeness of the portfolio – the companies are active in all fossil power generation technologies and also compete in nuclear (with own turbines). **International coverage** – The companies chosen represent the market leaders of the traditional economic Triad, Europe (Alstom, Siemens), USA (GE) and Japan (MHI). Besides their home markets, all companies are globally active to provide technology and services to the power producing industry.

The author has chosen on purpose not to include new entrants from Asia (such as Shanghai Electric, BHEL, Harbin Power or Doosan).

[3] Original Equipment Manufacturer

1.2 Methodology

The guiding framework to answer the core questions of this paper will be provided by the Balanced Scorecard (BSC) concept, pioneered by Kaplan & Norton. This paper will therefore provide a "Renewable Balanced Scorecard" for each company in focus. Each core question will be answered by a corresponding BSC dimension.

Table 2 Core questions and corresponding BSC Dimensions

	Core questions	BSC Dimension
1	How did their portfolio and sales development correspond to the trend of increased renewable energy deployment?	FINANCIAL
2	In how far are they contributing to the current innovation demands for renewable energy sources?	LEARNING & GROWTH – INNOVATION
3	How have they adapted their manufacturing and R&D footprints to the global demand shift towards emerging markets in the renewable energy market?	INTERNAL BUSINESS PROCESSES
4	Have they been able to transfer their dominance from the fossil power market to the renewable energy sector?	CUSTOMER

Further information on the BSC will be given in chapter 4.

The companies in focus have been analyzed with the help of publicly available information such as company websites, press releases, product brochures, annual reports, investor presentations, ratings of financial institutions and media coverage. As the author is employed by one of the companies that are subject to research, this paper relies intentionally only on public information (i.e. secondary data).

In order to get a deeper understanding about the technologies of renewable electricity production this paper also covers a technical part in which overview information of recent literature has been collected. In order to derive the innovation fields a literature research has been performed. The sources of this material have been study material provided by the TU Vienna MSc Course in Renewable Energy in Central and Eastern Europe, conference presentations and reports of major research and governmental and non-governmental institutions such as the IEA[4], the European Commission, the IPCC, the US Department of Energy, REN21[5], the EPIA[6], and EWEA[7].

---

[4] IEA = International Agency

[5] REN21 = Renewable Energy Policy Network for the 21st Century

[6] EPIA = European Photovoltaic Industry Association

[7] EWEA = European Wind Energy Association

1.3 Structure of work

After the introduction this paper will give an overview on the different renewable electricity production technologies that are in the scope of this research, not only to explain the technological base but also to outline the innovation need for each specific technology.

Chapter 3 will then provide a deeper understanding of the researched companies and will outline the historical development and performance of their renewable energy portfolio.

The following chapter 4 will be dedicated to the "Renewable Balanced Scorecard". The methodological framework will be explained together with the selection and the definition of the KPIs[8] that will be used for the performance measurement of the companies. At the end of chapter 4 the KPIs will be calculated and evaluated along the provided criteria sets.

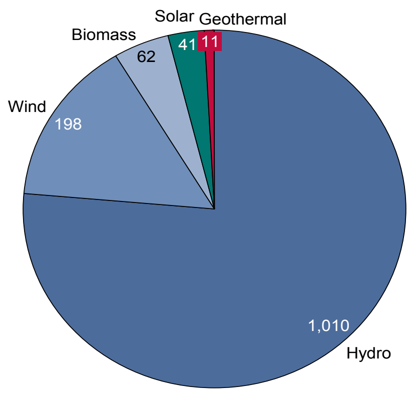
The conclusion will hence summarize the answers to the research questions and provide an outlook for necessary future research.

[8] Key Performance Indicators

2 Renewable Energy Sources

For the upcoming analyses the scope of research regarding the renewable energy sources has to be defined. For this paper, as stated before, the focus lies on electricity generation. The four most important energy sources that shall be described are – wind power, solar power (PV[9] & CSP[10]), hydro power, and biomass.

Figure 6 Global installed power capacity of renewable energy sources 2010 (in GW)



Source: REN21 2011, p. 73

Geothermal has not been chosen for further analysis due to the low capacity share and its restricted application area compared to most other renewable energy sources. Although similar argumentation could be used in the case of concentrated solar power, latter technology has been selected on purpose firstly due to the massive boom in recent years and secondly to draw a clear differentiation to solar power generated via photovoltaic.

In the following sections the paper will try to provide an overview on the different technologies answering these questions:

Section	Key questions
Technology	What is the technological base for energy production?
Innovation	What have been the latest technological developments? What are the key innovation challenges of this technology that have to be overcome in the next years?

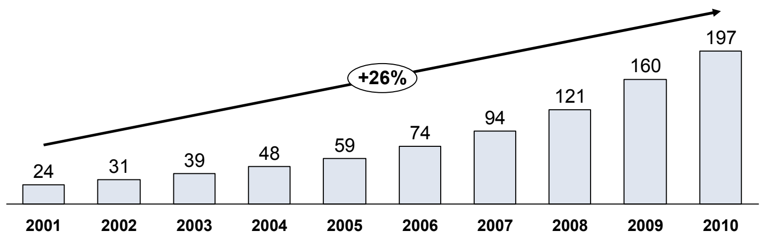
[9] PV = Photovoltaic

[10] CSP = Concentrating Solar Power

2.1 Wind energy

As has been stated before, the power markets have undergone significant changes during the last decades. It is thus consequent to start with one of the oldest forms of energy independence – wind energy. In the 14th century the feudal elite had the exclusive right to exploit and use water reserves and thus had a watermill monopoly with negative consequences on farmers and millers (Wizelius 2009, p. 10). The development of windmills (the wind could be used by anyone for free) was therefore used as a symbol of the liberation movement at that time (Wizelius 2009, p. 10).
This section will detail the technology of electricity generation by wind power. As the scope of this work is to give an overview, the reader is invited to consult further sources for more details on technological parameters and calculations[11].
With reference to the development of wind power it can be observed that the last 10 years showed an impressive growth story with annual growth rates of ~26%.

Figure 7 Global cumulative installed wind power capacity 2001 – 2010 (in GW)



Source: WWEA 2011a, p. 6

2.1.1 Wind energy technology

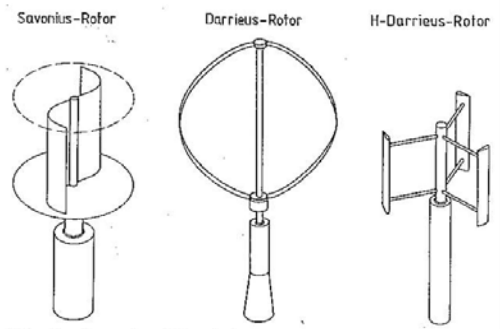
When talking about wind power the reader will have a clear picture in mind - a high tower dominated by three large blades. This is in fact the most widespread technology. But this paper will also outline the different technologies on the market before the focus will be on the differences between onshore and offshore wind power production. In general one can distinguish between wind power turbines with a vertical and a horizontal axis (Bockhorst 2002, p. 504).

[11] E.g. Wizelius Tore: "Developing Wind Power Projects", Earthscan, London, 2009.

2.1.1.1 Power turbines with a vertical axis

As for the turbines with a vertical axis, three types of rotors can be distinguished – the Savonius, Darrieus and the H-Rotor (Quaschning 2008, p. 230).

Figure 8 Vertical rotors



Source: E. Hau: Windkraftanlagen.Springer, 1996 – from www.iwr.de

Vertical rotors represent the oldest form of wind energy usage (Quaschning 2008, p. 229). Their principle is that wind can be used independently of the wind direction as the rotor turns on a perpendicular axis (Winkelmeier 2009, p. 1). The advantages of these systems are 1) simple build up & easy maintenance (generator, gear and control units can be deployed in the ground station), 2) independence from wind directions (suitable for regions with fast changing wind directions).

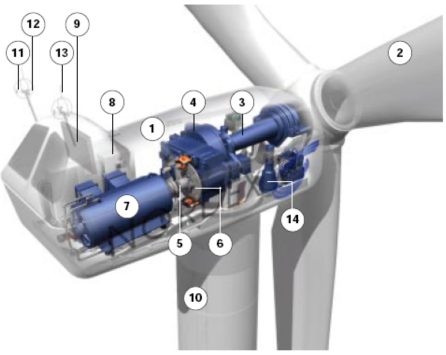
However, the disadvantages of higher material cost and low efficiency outweigh the advantages and have led to the success of horizontal rotors, leaving vertical rotors only niches and small applications (Quaschning, 2008, p. 231).

2.1.1.2 Power turbines with a horizontal axis

In contrast to vertical axis turbines the horizontal axis turbines are depending on the wind direction. Therefore key elements of this technology are the construction of blades as well as the automatic steering of the nacelle depending on the wind directions (Bockhorst 2002, p. 502). Regarding the blades, the well known picture is a tower with three blades; however, there are also installations with one or two blades (Wizelius 2009, pp. 80). The latter ones, however did not prove a widespread success due to efficiency and optical reasons.

The picture below outlines the main parts of a wind turbine (based on a Siemens Wind Turbine):

Figure 9 Key components of a wind turbine



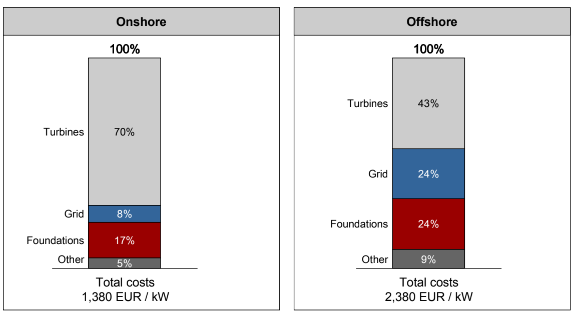
1. **The nacelle** contains the key components of the wind turbine and is accessed from the tower (10)
2. **The rotor blades**, each of which is some 20m long on a 600 kW turbine
3. **The low-speed shaft**, which rotates relatively slowly, from about 19 to 30 revolutions per minute
4. **The two speed gearbox**, which makes
5. **the high-speed shaft** rotate approx. 50 times faster than the low-speed shaft
6. **The disc brake**, which is used in case of failures in the aerodynamic brake and when the turbine is being serviced
7. **The electric generator** – either a so-called induction generator or an asynchronous generator with a typical maximum output of 600 kW.
8. **The electronic controller** for the monitoring of operations, the initiation of emergency stop, e.g. in case of overheating, and remote monitoring and reports to the operator.
9. **The cooling unit** for cooling of the generator and cooling of oil in the gearbox.
10. **The tower**, which is usually some 60m tall.
11. **The yaw mechanism**, which holds the mill up against the wind by means of electric engines (14).
12. **The anemometer and wind fane** which measures wind speed and direction for use in the automatic starting, stopping and turning of the turbine.
13. **Lightning conductor**
14. **The electric jaw engine**

Source: Based on Siemens Wind Power – www.siemens.com

2.1.2 On- vs. Offshore

In general wind power applications are distinguished between on- and offshore applications. Whereas the first application type has had a long tradition, the first offshore installation was built in 1990 and the first commercialization phase was around 2000 (Lako 2008, p. 38). Regarding offshore installations, the stronger winds and less impact on real estate value make offshore wind farming more interesting for investors despite the higher investment cost. Most offshore wind farms so far have been built in the shallow areas in close distance to the coast (Meilak, 2005). Only recently several projects have been commissioned in the North Sea such as Alpha Ventus. The most important difference between the two technologies is the cost structure. Here the difference seems clear – whereas turbines account for 70% of onshore installation cost this value is reduced to 43% in offshore installations. The highest difference can be seen in the grid connection cost, followed by the foundation cost. With reference to the total installation cost it can be observed that offshore wind parks have 73% higher cost than onshore applications.

Figure 10: Cost distribution of onshore and offshore installations



Source: BTM Consult 2008

2.1.3 Innovation

As could be seen in Figure 4, onshore wind power production is among the most mature technologies within the renewable energy sources. The design of wind power turbines has undergone significant changes from the beginning of power production with the "Original Danish concept" up to today's main design trends. The table below tries to summarize the main developments regarding design. Today one major recent design changes can be observed - the gearless concept. Besides the design trends another topic will be illustrated – the trend towards larger output sizes.

Table 3: Development of wind power turbine designs (no linear time development)

Time →

	Original Danish Concept						
Stall regulated	✓			✓			
Active stall			✓				
Fixed speed	✓	✓	✓				
Limited variable speed					✓		
Gearbox	✓	✓	✓	✓	✓	✓	
Pitch regulated		✓			✓	✓	✓
Variable speed				✓		✓	✓
Gearless							✓

Source: EWEA 2003, p 33

If we select several sources for upcoming innovation topics we can see a broad field of innovation topics – with a significant focus on further developing offshore technology.

Table 4: Selected innovation topics for wind power

Area	Topic
System	▪ Grid integration ▪ More intelligent control systems with additional sensors measuring system vibrations ▪ Condition monitoring for critical components
Rotor	▪ Advanced adaptable rotor concepts ▪ Aerofoil design targeted at control of loads ▪ Low solidity, downwind, flexible rotor designs ▪ Materials reducing weight and sound emissions
Drive	▪ Direct drive PMG technology incl. rare earth magnets and alternative electrical machine topologies
Offshore	▪ Higher tip speed designs ▪ Variable speed DC or AC HV generation for offshore ▪ Offshore meteorology – hardware for measurement and modeling issues ▪ Integration of support structure design for offshore turbines ▪ Improved access methods for offshore turbines ▪ SCADA for offshore – development for remote intervention ▪ Development of alternative and deep water foundation structure arrangements ▪ Floating turbines

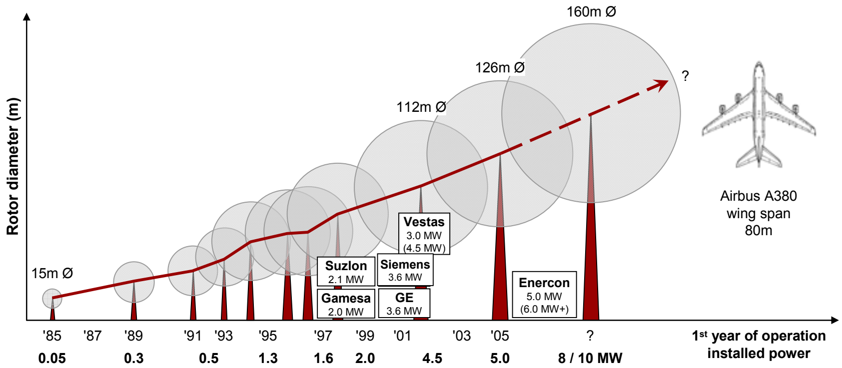
Sources: EWEA 2003, US Department of Energy 2004, European Commission 2005, TPWind 2008

This paper will touch in more detail: increased turbine sizes and the gearless drive concepts, being key issues for both, on- and offshore applications.

2.1.3.1 Turbine sizes

Turbine sizes have steadily increased since the beginning of large wind power installations (TPWind 2008, pp. 17). The trend towards increased turbines is largely leveraged by economic interest (large installations are more economic than smaller ones) as well as the increased use of offshore applications that provide the only "viable" possibility to increase wind power production in largely populated areas (European Commission 2005, pp. 9). Large onshore turbines are commonly used in upgrades of existing wind parks, where the additional impact plays a minor role.

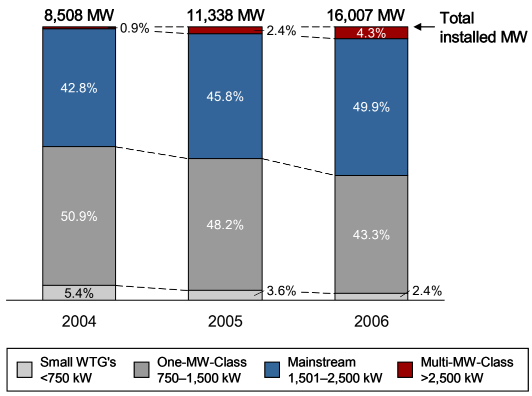
Figure 11: Overview of wind turbine sizes



Source: Beurskens 2010, p. 7

And in fact, BTM (2007) already observes an increasing (although still small) share of new installations is performed in the >2.5 MW sector.

Figure 12: New wind installations 2004-06 split to size classes



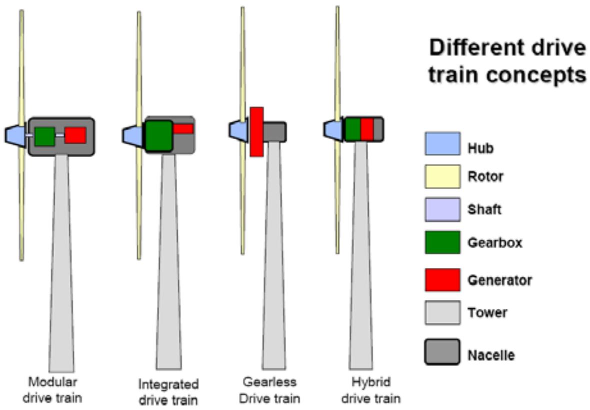
Source: BTM 2007

This development hence poses significant challenges to the wind turbine / rotor producers. The challenge lies in the following issue: The power a wind turbine can generate increases with the square of the rotors' diameter, however the relevant mass of the blades does not increase by the square but is increased to the third power of the rotor diameter (European Commission 2005, pp. 10). Therefore, manufacturers have to invest more resources into the research of their rotor designs and the material composites of their products in order to realize weight decreases, reduced cost, more reliability and to keep the noise production under control (European Commission 2005, pp. 10). According to EWEA (2011) even wind turbines with a 20 MW output are feasible. For the scope of this paper the activities of the companies in focus shall be challenged in how far they are currently developing wind turbines >5 MW.

2.1.3.2 Gearless drive train concepts

As we have seen before, the design of wind power turbines has undergone several changes. One of them was the change from a system with a gearbox towards a gearless drive train. The purpose of the gearbox is to increase the relatively low speed of the main shaft to the required speed of the generator (e.g. from 15-30 rpm to 1010-1515 rpm) (Wizelius 2009 p. 94). In order to perform this service, the gearbox itself needs lubrification and cooling which is mostly realized by an oil pump and an oil cooling system (Wizelius 2009 p. 94). A gearbox requires constant maintenance and it is one of the most important areas of failures and downtimes.

Figure 13 Overview drive train concepts



Source: Winkelmeier 2009, p. 10

Gearless drive concepts are lighter, need less maintenance (which is for instance a big challenge in offshore applications), and are therefore more reliable which yields to higher production and less maintenance cost[12].For the purpose of this paper the development steps of the four companies will be investigated later in this paper.

[12] http://www.technologyreview.com/energy/23517/ accessed on 12 May 2011

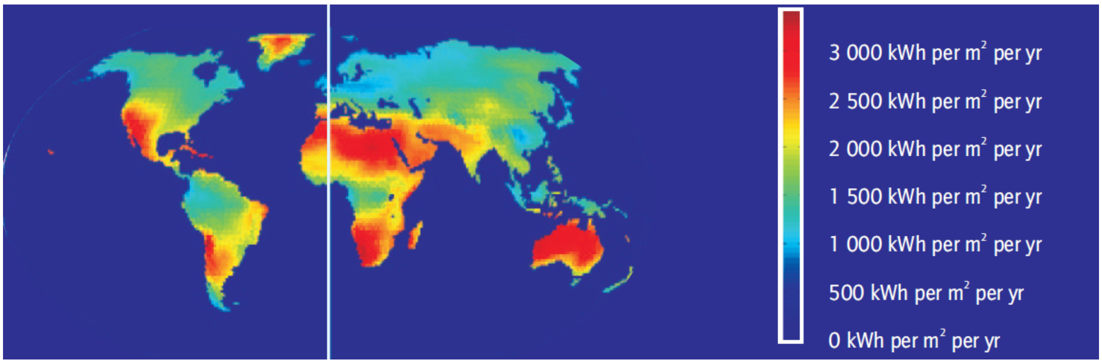
2.2 Solar Power – Concentrating Solar Power (CSP)

When it comes to solar thermal application we can distinguish between non-concentrating solar thermal applications and concentrating solar thermal applications (Quaschning 2008, p. 79). Regarding this thesis the focus lies on the latter as the non concentrating solar thermal applications are used for heat production only (Quaschning 2008, p. 79) which is not in focus of this paper.

2.2.1 CSP Technology

CSP plants produce power through the conversion of the solar energy into heat to generate mechanical power (in a turbine or engine) to produce electricity in a conventional generator (UN 2005, p. 24). After the generation of steam / heat the following part of the power plant is similar to plants generating electricity out of fossil fuels (Fawer 2006, p. 42). In contrast to photovoltaic, CSP can only use the direct radiation of the sunlight, consequently the application of these plants is rather limited to the world's 'sun belt', encompassing the South-West of the USA / Mexico, the South-West of South America, the Sahara region, Near Middle East, South African countries and Australia.

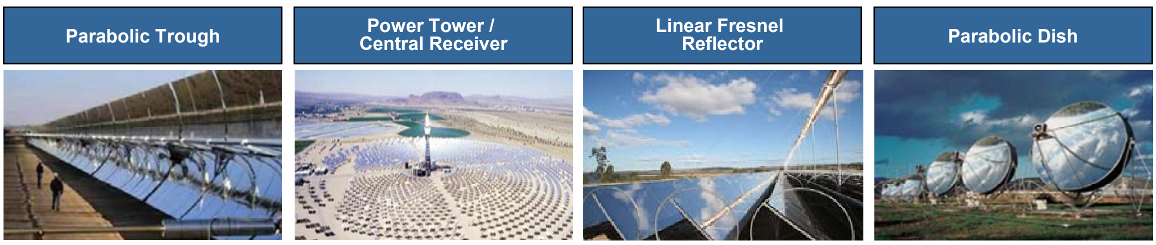
Figure 14 Suitable areas for CSP



Source: IEA 2010a, p. 10.

For the concentration of the sunlight four different technologies are being used:

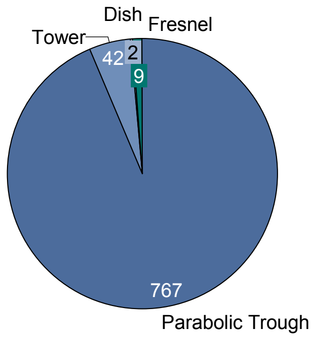
Figure 15 CSP technologies



Source: Pictures by Siemens; IEA 2010 pp. 11

Up to now, parabolic trough is the most frequently used technology.

Figure 16 CSP plants in operation 2010 (in MW)

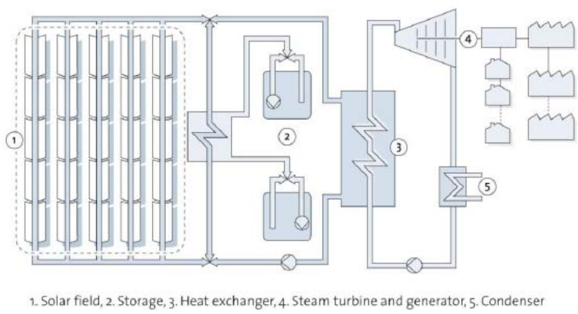


Source: Gesthuizen 2010, p. 94

2.2.1.1 Parabolic Trough

Referring to this technology, the sunlight is concentrated via parabolic mirrors on linear receiver tubes. In order to obtain the best position towards the sun, a 1-axis sun tracking is used The solar heat is collected via a high temperature fluid (e.g. synthetic oil) and used either in an indirect cycle steam turbine or even in direct steam generation (Konstantin 2007, pp. 251). For this technology the clear focus lies on further cost reduction via improved materials and increased efficiency as well as on high volume production (Quaschning 2008, pp. 124, SCHOTT 2009, pp. 3).

Figure 17 Parabolic Trough CSP plant layout

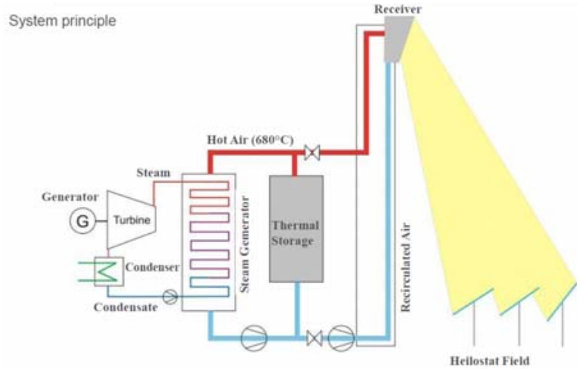


Source: Gladen 2010, p.6

2.2.1.2 Solar (Power) Tower / Central Receiver

The Solar Tower is still in demonstration concept (e.g. Solar Power Tower Jülich – Germany, Almeria – Spain, Barstow – USA, Rehovot - Israel) (Koll 2010, pp. 2, Quaschning 2008, p. 143, Weinrebe 2010, p. 15). A mirror field focuses the solar radiation on a central point receiver at the top of the solar tower. In order to reach the optimum position to the sun a 2-axis sun tracking is necessary. Air or molten salt is used to transport the heat to a gas or a steam turbine where electricity is produced via a generator (Quaschning 2008, pp. 142). The following picture depicts the layout of the solar power tower Jülich, where hot air is transferred to a steam generator which produces steam to drive a steam turbine.

Figure 18 Power Tower plant layout



Source: Koll 2010, p. 8

2.2.1.3 Linear Fresnel Collector

The Fresnel collector is working similar to the parabolic trough, although lower cost flat or slightly curved mirrors are used to reflect the sun to a downward-facing linear, fixed receiver (IEA 2010 a, p. 12). The heated fluid powers a steam turbine – although direct steam generation would also be feasible (IEA 2010a, p. 12). Although this technology has a lower efficiency than parabolic troughs its advantage lies in the lower capital cost (IEA 2010a, p. 12). 2 pilot projects (Spain and Australia) currently put the Linear Fresnel Collector in practice[13].

2.2.1.4 Parabolic Dish

Dish mirrors concentrate solar radiation and the generated heat drives a Stirling engine (Quaschning 2008, pp. 144) or a micro-turbine (IEA 2010a, p. 12) in the focal point. The parabolic dish technology is currently in test stage and is supported by several institutions. This technology is also suitable for smaller applications e.g. for self-sufficiency in remote areas (IEA 2010a, p. 12).

2.2.1.5 Summary

The following table shall summarize the specific advantages and disadvantages of the technologies compared with each other. It can be noted that further research is a prerequisite for all technologies, with the parabolic trough having the most advanced application stage.

[13] http://www.nrel.gov/csp/solarpaces accessed on 24 September 2011

Table 5 Overview on CSP technologies

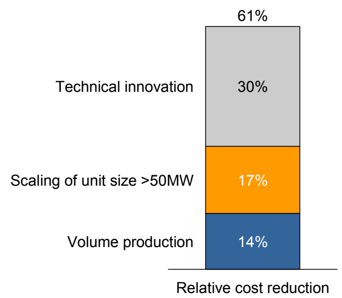
	Parabolic Trough	Power Tower / Central Receiver	Linear Fresnel Reflector	Parabolic Dish
Pro's:	▪ Highest level of technological and commercial maturity ▪ Combination with other plants feasible ▪ System reliability ▪ Lowest cost forecast (0.08 USD/kWh in 2015)	▪ Higher efficiency due to higher temperature ▪ Better integration in heat storage, better dispatchable	▪ Low-cost components (inexpensive receiver and collector design) ▪ Modular in small scale systems	▪ Potential of low capital cost ▪ Extremely modular ▪ Potential for twice the efficiency of trough
Con's:	▪ Relatively low efficiency level ▪ Low temperature limits effectiveness of on-site energy storage ▪ Water consumption in cooling towers (or air cooled condenser with 10% lower efficiency)	▪ Demonstration stage ▪ Higher equipment investment cost ▪ Heat source needed to keep salt in liquid state ▪ Finite scalability	▪ 2 demonstration projects (<2 MW) ▪ Lower efficiency due to lower temperature	▪ Intensive maintenance of stirling engine ▪ Limited attractiveness for large scale plants ▪ No feasible combination of efficiency and high durability yet

Sources: background interviews with Siemens Management Consulting, literature: Quaschning 2008, Koll 2010, Konstantin 2007

2.2.2 Innovation

Taking into consideration the small size of solar thermal applications so far it may not wonder that CSP technology is still to a very large extent based on the experiences made during the 70s and 80s (Sanchez 2009, p.8). Consequently, there is a vast area of required research to enable a cost reduction potential of 50-60% compared to today's level (Sanchez 2009, pp. 11). And in fact, the figure below outlines that the largest part of cost savings will be generated by technical innovation.

Figure 19 Relative cost reduction potential in CSP technology



Source: Sanchez 2009, p. 14

Sanchez (2009, pp. 23) outlines the main medium term development needs: storage developments, material developments to increase the durability of the applications and the integration of CSP with conventional power plants and the leverage of CSP in the energy chain. This is mostly in line with IEA's (2010a) evaluation of required R&D needs.

Table 6 IEA – proposed R&D actions for CSP

This roadmap recommends the following RD&D actions:	*Milestones*
1. Governments to ensure increased and sustained funding for public and private RD&D of CSP	2010 - 2040
2. Governments to develop ground and satellite measurement/modelling of solar resources	2010 - 2020
3. Research centres to develop air receivers for solar towers	2010 - 2020
4. Develop three-step thermal storage for all DSG solar plants	2010 - 2020
5. Seek new heat transfer fluids and storage media for line-focus solar plants	2012 - 2020
6. Develop solar-assisted hydrogen production	2010 - 2020
7. Develop solar tower with supercritical steam cycle	2015 - 2030
8. Develop solar tower with air receiver and Brayton cycle	2010 - 2020
9. Develop solar-only hydrogen production	2020 - 2030
10. Develop solar-assisted liquid fuel production	2020 - 2030

Source: IEA 2010a, p. 37

For the purpose of this paper two elements will be highlighted – heat transfer & storage research and the integration of CSP into fossil energy generation. Additionally the BSC dimension innovation will also have a deeper look on the activities of each company in the four types of CSP applications described.

2.2.2.1 Heat transfer and storage

The heat transfer is crucial as CSP always depends on the principle of transferring heat to electrical power. Three different technologies are currently either in operation, demonstration or development: Synthetic oil, molten salt, and direct steam. The table below shall give an overview including their advantages and disadvantages.

Table 7 Overview heat transfer technologies in CSP plants

	Synthetic oil	Molten salt	Direct steam generation (DSG)
Description	A synthetic oil is heated by the concentrated sun rays. The heated oil generates steam which powers a turbine.	Molten salt (nitrate) is heated and pumped into a storage tank. Via the heated salt steam is generated and used to power a turbine. Cooled salt is returned to a second storage tank to be sent back through the cycle.	Water is directly heated by the concentrated sun rays. The generated steam powers a turbine.
Advantages	▪ Proven technology	▪ Good storage behavior of salt, thus longer operating time and **lower electricity generation costs** ▪ Less environmental risk ▪ Good thermal stability of salt ▪ Long term experience ▪ Salt is less expensive than oil	▪ Higher efficiency due to higher operating temperatures, thus **lower electricity generation costs** ▪ No environmental risk ▪ Good thermal stability of steam ▪ Simpler plant configuration ▪ Lower O&M cost
Disadvantages	▪ Oil is expensive ▪ Thermal stability of oil only up to 390°C ▪ Additional components for oil cycle needed ▪ High power need for oil pump ▪ Environmental risk	▪ Salt is corrosive ▪ Salt freezes at 220 °C	▪ Heat storage currently under research
Status	In operation	In demonstration and operation	In demonstration

Source: Background interviews with Siemens Management Consulting; literature: Konstantin 2007, Quaschning 2008, Sanchez 2009, Seeler 2009, Tamme 2009, and Zarza 2009

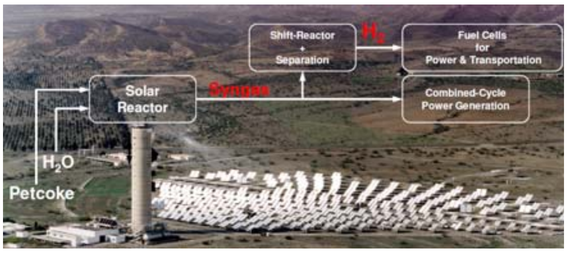
Referring to Direct steam generation (DSG) – the most important area of future research is the heat storage. Tamme (2009) suggests that different phase changing materials (PCM) – depending on the temperature range could be applied. However, there is no large scale application currently in place. For the purpose the molten salt activities of the selected companies will be compared.

2.2.2.2 Integrated solar-thermal-combined-cycle-plants (ISCC)

Concentrated solar power can also be integrated into conventional fossil fired power plants where the CSP part takes over the steam production during the day and can consequently reduce the fuel need (Konstantin 2007, pp. 256, Fawer 2006, p. 42). Especially during summer peak times the solar part can produce additional steam for the steam generator (HRSG) (Konstantin 2007, pp. 256). Abengoa Solar has built the first ISCC in Algeria (150 MWel – thereof 20MW solar thermal) (Vizcaino-Garcia 2010, p. 12). As combined cycle plants will play a significant role in the upcoming decades with regard to the energy mix, further research into the combination of renewables and fossil fuels seems obvious, in particular with regard to the currently unsolved issue of energy storage and the required stability of electricity generation.

Another interesting idea is to leverage CSP for the production of hydrogen (Sanchez 2009, p. 25). As depicted in the figure below, with the help of solar heat, H2O and petcoke are transferred into syngas where hydrogen is separated and the gas is used in a gas turbine.

Figure 20 Hydrogen production with CSP



Source: Sanchez 2009, p. 25

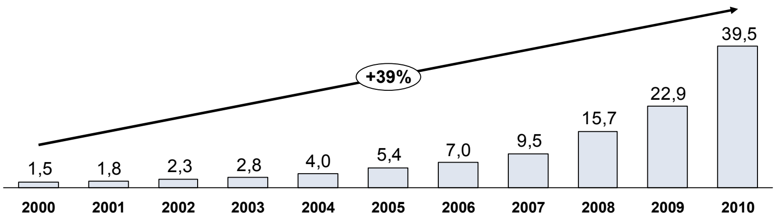
When comparing the world's largest potentials for CSP with the world's driest locations an interesting match occurs – CSP can also drive the desalination of water increasingly in the next years and decades (Kern 2010).

In the BSC dimension 'innovation' the activities of the researched companies in the different CSP technologies and their plans to build ISCCs will be examined.

2.3 Solar Power – Photovoltaic (PV)

In general, the energy of the sunlight on earth is not dependent on the location - as defined by the solar constant which is similar on the whole planet (1.34 kW/m²) (Bockhorst 2002). However, countries around the sun belt have more sun hours per year when they can profit from the solar energy (e.g. Germany 1000 h vs. 2500 h in Sahara region) (Bockhorst 2002). In contrast to solar thermal applications, photovoltaic applications can also leverage the diffuse sunlight and are not dependent on the direct radiation – hence usage of PV is also feasible outside the sunbelt (Quaschning 2008, pp. 55). PV installations have skyrocketed in the last 10 years with average annual growth rates of 39%.

Figure 21 Global cumulative installed PV power 2000 – 2010 (in GW)



Source: EPIA 2011 p. 8

Utility-size PV plants have been established in recent years triggered by attractive Feed in tariffs. Applications with a peak capacity of >90 MW are already connected to the grid. And this size is not the final stage as current plans in USA and China with plants >300 MW[14] and 2000 MW[15] respectively show.

Table 8 10 largest PV plants (in MW)

Name	Country	Peak capacity
Samia PV Power Plant	Canada	97
Montalto di Castro	Italy	84,2
Finsterwalde Solar Park	Germany	80,7
Ohotnikovo Solar Park	Ukraine	80
Lieberose PV Park	Germany	71,8
Rovigo PV Power Plant	Italy	70
Olmedilla PV Park	Spain	60
Strasskirchen Solar Park	Germany	54
Tutow Solar Park	Germany	52
Copper Mountain Solar	USA	48
Serenissima Solar Park	Italy	48

Source: http://en.wikipedia.org/wiki/List_of_photovoltaic_power_stations accessed on 04 October 2011

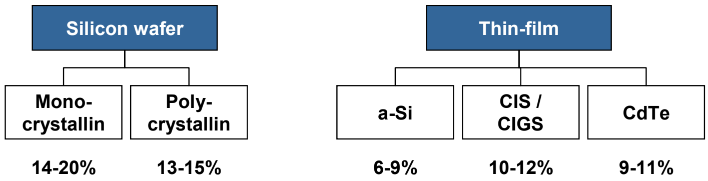
14 http://www.sustainablebusiness.com/index.cfm/go/news.display/id/19649 accessed on 04 October 2011

15 http://www.renewableenergyfocus.com/view/5333/first-solar-closer-to-2-gw-solar-power-plant-in-china/ accessed on 01 October 2011

2.3.1 PV Technology

The basic technology for PV is the so called "Photo-electric effect" discovered by the French scientist Becquerel in 1839 (Quaschning 2008, p. 149). In PV semiconductors are used – mostly silicon. Silicon is the second mostly represented element in the world (after oxygen) (Quaschning 2008, p. 154). In this paper we will focus on three technologies regarding PV modules – crystalline PV cells, thin film cells and the 3rd generation PV cells.

Figure 22 Commercial PV cell types and efficiency rates



Source: IEA 2010b, p. 8

2.3.1.1 Crystalline PV cells

In general it is possible to use different semiconductors to produce solar cells. However, due to its vast availability, silicon has been dominating (Quaschning 2008, p. 161). With regard to crystalline PV cells we can distinguish between mono- and poly-crystalline cells. They differ in their efficiency as well as in their effort for production. Production of mono-crystalline silicon is more expensive than poly-crystalline silicon bars (Quaschning 2008, pp. 161, Fechner 2009, pp. 2). Crystalline PV cells are the most important source of PV modules (80-90% of the supply) and seem to remain the dominating technology for the medium term (O'Rourke et al 2008, p. 33). However, the main challenge is to secure the supply with purified silicon for the PV wafer production (O'Rourke et al 2008, p. 34).

2.3.1.2 Thin film PV cells

The main advantages of thin film PV cells are the cheaper materials as well as their lower production cost (Quaschning 2008, p. 163). Thin layers of photosensitive materials are constructed on a low cost backing (e.g. glass, stainless steel or plastic) (Fechner 2009, p. 6). Four materials dominate the thin film market, amorphous silicon (a-Si), Cadmium telluride (CdTe), Copper indium diselenide ($CuInSe_2$/CIS) (Quaschning 2008, p. 163), and Copper indium gallium diselenide (CIGS) (O'Rourke et al 2008, p. 41). The main disadvantage of thin film PV cells is their lower efficiency and the lacking experience regarding their life expectancy (Fechner 2009, p. 7). Consequently, this results in a higher need of land and infrastructure when it comes to large scale applications (Koot 2008, p. 15). As a further downside the toxic characteristics of these materials has to be considered along with the relative scarcity of the materials compared to silicon (Quaschning 2008, p. 163). Thin film still represents a niche in the market, accounting for only ~15% of the global solar cell production capacity (EPIA 2011, p. 38). As of today no clear prediction can be made which material will in the end be the dominant thin film material (IEA 2010b, p. 25).

2.3.1.3 3rd generation PV cells

With regard to the 3rd generation of PV cells, we have to consider organic polymer cells as well as dye-sensitized materials (Shin 2009, p. 24). Dye-sensitized cells are the result of a hybrid approach where an organic cell retains an inorganic component (IEA 2010b, p. 25). Organic cells are today a niche technology – and they are expected to remain in this position if we focus on large scale electricity production. Their strength is clearly in off-grid mobile applications both for the developed and developing world (e.g. lighting, solar charging) (Limperis 2010, pp. 104).

2.3.2 Innovation

In this section the paper will deal with the necessary enhancement of existing technologies as well as with new applications.

2.3.2.1 Enhancement of thin film and 3rd generation

New developments in thin film like multi-crystalline thin-film on glass or microcrystalline technology require further research but seem to be promising (Fechner 2009, p. 6). According to the IEA (2010b) further improvements in thin film are subject to large scale deployment and further material research. For the purpose of this paper the innovation section of the BSC shall examine in how far the companies in focus are further driving the thin film research. With reference to the 3rd generation cells this paper will not concentrate on them as they are mostly subject to basic research.

2.3.2.2 Cost reductions

Mass production of solar panels (crystalline silicon, thin film and 3rd generation) as well as increased learning through project experiences are key to further drive costs down (Lako 2008, p. 31; IEA 2010b, pp. 24). In order to reduce the investment cost in the private sector the integration of PV modules into the building (e.g. as an integral part of the roof, walls or windows) has to be improved (Lako 2008, p. 31).

2.3.2.3 Integration of PV and solar heating

Another element of future application f.i. in the private area is using combined modules for electricity and heat generation (Lako 2008, p. 31).

2.3.2.4 High efficiency cells

Ultra high efficiency cells can e.g. use active layers which are dedicated to either match the solar spectrum or to modify the incoming solar spectrum (IEA 2010b, p. 26). However, these concepts are currently subject to basic research with still a long way to go before commercialization (IEA 2010b, p. 26). Therefore application is currently limited to space applications and PV concentrator systems (Fechner 2009, p. 7).

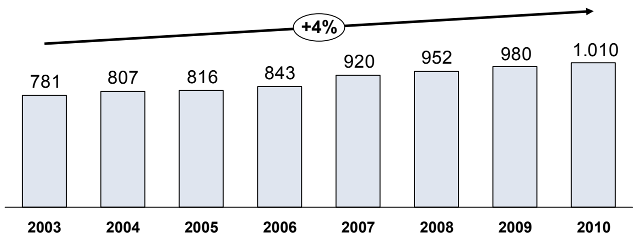
2.3.2.5 Concentrating PV

New cell application based on III-V semiconductors have reached lab efficiencies of >40% in production (Goldman Sachs Research 2008, p. 25, IEA 2010b, p. 42). In the case of concentrating PV, lenses focus sunlight onto highly efficient multiple-junction cells. Although the small cell size can lead to lower cost relative to conventional solar PV cells the downside of this technology is that a tracking is required to keep light focused on cells and that diffuse sunlight cannot be used (Fechner 2009, p. 7).

2.4 Hydropower

Hydropower is the most important installed renewable energy source - as has been shown before. Besides its current importance hydropower can look back on over a century of electricity production with some small applications being in operation for ~100 years (e.g. the small hydro power plant Gaming in Lower Austria that has been operating since 1926). This chapter will focus on the main application of hydropower – large and small hydropower. The future technologies, such as wave and tidal power will be touched in the innovation section of this chapter. As several definitions on small hydro power exist (e.g. manufacturers vary in their definition between 10, 15 and 30 MW) the definition of the European Small Hydro Association[16] shall prevail: As small hydro this paper understands hydro power plants with an installed capacity of maximum 10 MW. Hydropower is a mature market as can be seen by the low annual growth rate of 4%.

Figure 23 Global cumulative installed Hydropower 2003 – 2010 (in GW)



Source: REN21 annual reports 2005-2010

2.4.1 Hydropower technology

This section will give an overview on the hydro power station types as well as the used turbine types.

2.4.1.1 Hydro power station types

Three main types of power stations can be distinguished: (1) run-of-river power stations, (2) pondage power stations, and (3) (pump) storage power stations (Quaschning 2008, p. 272).

Run-of-river power stations

This type of power station uses the energy of a river flow for energy production. The usable water flow is used instantly. Therefore these power stations are constructed either directly on a river or at a river outlet channel (Konstantin 2007, p. 261).

[16] http://www.esha.be/index.php?id=44 visited on 10 October 2009

Figure 24 Hydro power station Freudenau (Austria)

Source: http://www.austria-lexikon.at accessed on 01 May 2011

Pondage power stations

In contrast to the above described run-of-river power stations, pondage power stations can balance the natural differences in the water flow availability (Quaschning 2008, p. 274). With the help of a weir, water is being impounded (ranges can vary from a few meters to several hundred meters) (Quaschning 2008, p. 274). This type can adapt the output flexibly through increasing or decreasing the water reservoir, depending on the electricity demand (Konstantin 2007, p. 262).

The most spectacular examples of this type are the Itaipu Binacional power station (Brazil and Paraguay) as well as the Three Gorges power project in China. The first has a nominal power of 14 GW and is being operated since 1991[17], the latter has a planned nominal power of 18.2 GW and shall begin its operation in 2011[18].

Figure 25 Itaipu Binacional power station

Source: www.itaipu.gov.br

Storage power stations

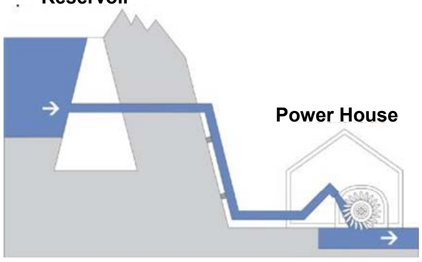
Storage power stations can either be used for electricity production or as a means to "store" electrical energy during low demand times and to make it available during peak times.

In the first case mountainous reservoirs or valleys with a natural water inlet are leveraged to use the high gross head between the water reservoir and a hydro turbine to generate electricity directly (Konstantin 2007, p. 262).

[17] http://www.itaipu.gov.br/en/press-office/itaipu-numbers visited on 20 October 2010

[18] http://en.wikipedia.org/wiki/Three_Gorges_Dam visited on 20 October 2010

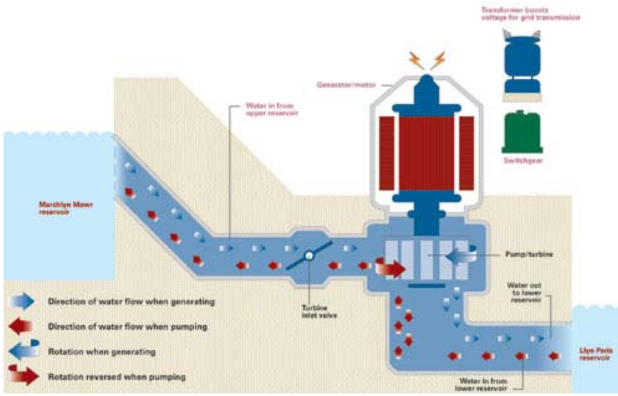
Figure 26 Schematic view on a storage power station



Source: www.vde.com

The latter system consists of a lower and an upper reservoir with a pump connection in between (Konstantin 2007, p. 263). In case of an oversupply of electrical energy electrical pumps will transport water from the lower to the upper reservoir (Quaschning 2008, p. 275). In case of electricity demand, water from the upper reservoir is again discharged to the lower reservoir passing by a turbine and thus producing electricity. Modern applications can reach efficiency rates of ~80% of the invested electrical energy (Quaschning 2008, p. 275). Pump storage stations can have very short start-up times (e.g. 98s). Hence they can also be used to balance the grid, for instance in case of natural variations in the electricity production (e.g. due to other renewable energy sources such as wind) (Quaschning 2008, p. 276).

Figure 27 Schematic view on a pump storage power station

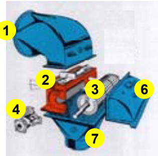
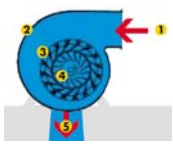
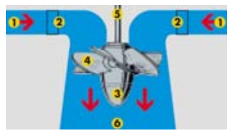
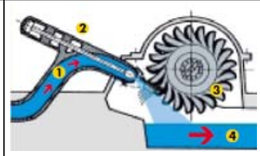


Source: www.fhc.co.uk/pumped_storage.htm

2.4.1.2 Hydro power turbine types

Four main types of turbines are dominating the hydro power production: (1) Ossberger turbine, (2) Francis turbine, (3) Kaplan turbine, (4) Pelton turbine (Konstantin 2007, p. 263). These turbines have a specific use case for each turbine type. The chart below outlines the different application areas and principles of the turbines.

Figure 28 Overview on hydro power turbine types

	Ossberger turbine	Francis turbine	Kaplan turbine	Pelton turbine
System				
Description	(1) Water intake (2) control device (3) runner (4) main bearing (6) air valve (7) water discharge	(1) Water intake (2) casing (3) flexible guide wheel (4) runner (5) Water discharge	(1) Water intake (2) adjustable control device (3) runner hub (4) adjustable blades (5) turbine shaft (6) water discharge	(1) water intake with injector (2) inlet (3) runner with blades (4) water discharge
Usage	▪ Small hydro plants	▪ Universal application	▪ Run-of-river plants	▪ Storage plants
Head	▪ 1-200 m	▪ 20 – 850 m	▪ 2 – 70 m	▪ 100 – 200 m
Capacity	▪ 1 kw – 2 MW	▪ 100 kW – 1000 MW	▪ 100 kW – 50 MW	▪ 100 kW – 400 MW

Source: Konstantin 2007, p. 263, Milles 2004, p. 2, www.ossberger.de

2.4.2 Innovation

As mentioned above, hydro power is a very mature technology. However, innovation still takes place, particularly outside the known areas (i.e. the usage of rivers and dams). The vision is to use the power of the world's largest water reserve – the oceans.

2.4.2.1 Technologies to leverage the oceans' potential

Wave Power – this technology is comparable to wind power plants – rotors use the wave flow to generate electricity (Quaschning 2008, pp. 287).

Tidal Power (Tidal Barrage) is comparable to pump stations – in this case however the tidal power is used (i.e. the flood). During flood times water gets into a reservoir whose discharge afterwards drives a turbine (Quaschning 2008, p. 284).

Ocean Thermal Energy conversion (OTEC) - This technology leverages the difference between warm surface water and cold deep water to drive a steam cycle to generate electricity. The warm water passes through a heat exchanger and vaporizes a working fluid with a low boiling point to drive a turbine[19].

Salinity Gradient - takes advantage of the osmotic pressure difference between sea and fresh water (Finley & Jones 2003, p. 2284). A series of different technologies is currently in development and testing (Finley & Jones 2003, p. 2286).

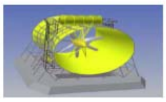
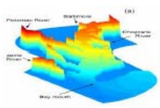
[19] http://www.lockheedmartin.com/products/OTEC/index.html accessed on 25 October 2010

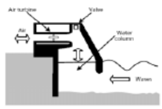
Figure 29 Potential of tidal and wave technologies

	Resource potential	Cost potential	Scalability / grid	Technology risk
Wave Power	10,000 to 15,000 TWh / year	120 USD / MWh	50 MW to 100 MW wave farms, costly transmission, grid constraints	High O&M; high weather exposure
Tidal Power	500 to 900 TWh / year	100 USD / MWh	20 MW to 50 MW CS farms, costly transmission, grid constraints	Technology unproven
OTEC	Unknown	Unknown	Limited geographically to regions with high ocean thermal gradients	Technology unproven and most applicable in developing parts of the world; offers the potential for low cost water desalination if current cot projections can be met
Salinity Gradient	200 TWh / year (Europe)	Unknown	Limited geographically to regions where there is a salinity differential	Cost reduction potential dependent on development of more efficient membrane technologies
Tidal Barrage	2 TW to 3 TW capacity	30 USD / MWh to 60 USD / MWh	Limited by a 5 meter tidal range requirement, but one project can scale to hundreds of MWs; approx. 40 potential sites globally	The proven technology was abandoned since the 240 MW installed in La Rance, France, but is now graining traction in South Korea, Russia, India and the UK

Source: Tisdale 2007, p. 11

Figure 30 Overview wave and tidal power technologies

	General Description	
Horizontal axis		A horizontal axis tidal turbine is similar to an onshore wind turbine. The turbine is capable of pivoting with the tide's direction shifts
Housed Horizontal Axis Turbine		Waves are lifted into a reservoir above sea level, which stores the water; energy is then extracted by using the difference in water level between the reservoir and the sea
OTEC		OTEC utilizes the temperature difference that exists between deep and shallow waters – within 20° of the equator in the tropics – to run a heat engine
Salinity Gradient		The difference in salinity between sea water and fresh water creates a pressure difference. Energy may be extracted by exploiting the pressure difference. The amount of energy extracted is proportional to this pressure difference

	General Description	
Point Absorber (Offshore)		Floating structure absorbing energy in all directions by virtue of its movements at or near the water's surface; these movements then pump a hydraulic system to generate power
Over-topping (Offshore Near-shore)		Waves are lifted into a reservoir above sea level, which stores the water. Energy is then extracted by using the difference in water level between the reservoir and the sea. The wave surge is captured by outstretched arms
Oscillating Water Column (Near-shore)		Partly submerged concrete or steel structure, open below the water surface, inside which air is trapped above the water surface. This air flows through a turbine, which in turn drives an electric generator
Attenuator (Offshore)		Long floating structure moored perpendicular to the waves. Energy is extracted restraining movements of the device at its bow and along its length

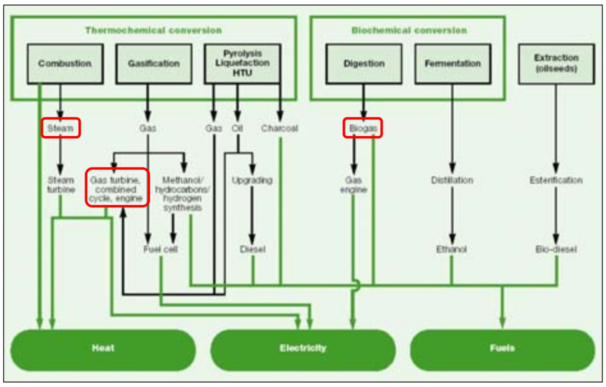
Source: Tisdale 2007, pp. 13

Summarizing it has to be mentioned that there is still a long way to go and that the mentioned technologies will start to play a significant role only in the upcoming decades. Therefore the innovation dimension of the renewables scorecard will examine in how far the companies in focus are active in these different fields.

2.5 Biomass

In contrast to the power producing technologies mentioned before (with the sole exception of CSP), the main usage of biomass is not only for the electricity generation. As indicated below, biomass is used to generate all three kinds of usable energy – heat, electricity and fuels. For the purpose of this paper we will only focus on the electricity production, particularly on three use cases, (1) the steam production out of biomass combustion, (2) gasification of biomass and the use in a gas turbine or engine and (3) the biogas production and usage in a gas engine / turbine.

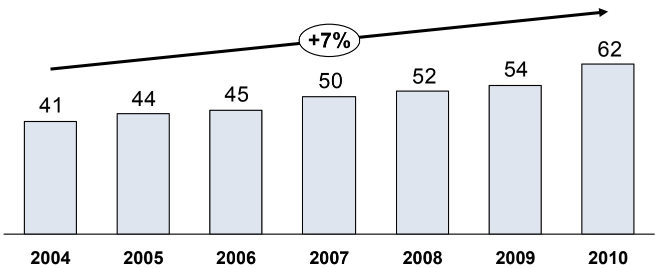
Figure 31 Conversion processes of biomass to heat / electricity / fuels



Source: Hofbauer 2009a, p. 57

Biomass electricity generation has an installed base of ~62 GW globally. The challenge in the biomass area is the fragmented market and the often small applications worldwide. Recently, however new dynamics came into the market with China announcing targets to build up 30 GW additional capacity in the upcoming years.

Figure 32 Global cumulative installed PV power 2000 – 2010 (in GW)



Source: IEA 2007, REN21 annual reports 2007-2010

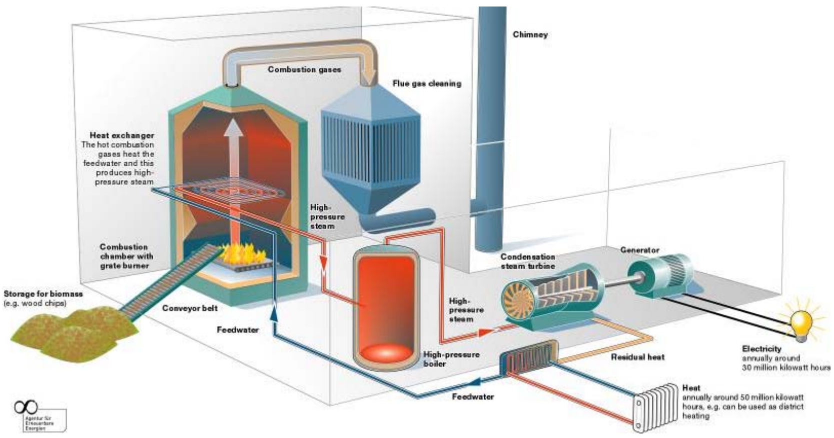
2.5.1 Biomass technology

The most frequent uses of biomass in electricity generation are co-firing in thermal power plants, combustion in CHP plants, gasification (anaerobic or IGCC) and the subsequent usage in turbines or engines.

2.5.1.1 Thermochemical conversion – combustion

The combustion of biomass is similar to a conventional steam power plant based on the Clausius-Rankine-Cycle (Konstantin 2007, p. 221) or an Organic-Rankine-Cycle (ETG 2006, p. 20). The most frequent usage of these principles is in Combined Heat & Power plants (CHP) (Lako 2008, p. 58). The figure below illustrates the functioning of such a plant.

Figure 33 Elements of a biomass CHP plant (5 MW plant)



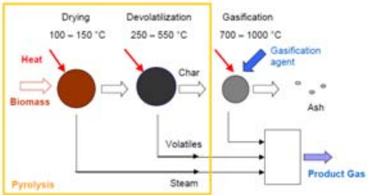
Source: http://www.unendlich-viel-energie.de/uploads/media/Biomass_CHP.jpg accessed on 01 September 2011

Most frequently Bubbling Fluidized Bed (BFB) boilers (max. capacity 120 MWel) and Circulating Fluidized Bed (CFB) boilers (max. capacity 240 MWel) (Lako 2008, p. 58) are used to drive a steam process. Both methods of combustion and the associated Clausius-Rankine-Cycle can be viewed as mature technologies (Lako 2008, p. 58).

2.5.1.2 Thermochemical conversion – gasification

The aim of biomass gasification is to produce a gaseous product that can further be used in several applications (Hofbauer 2009b, p. 38). During this process the biomass undergoes the stages described below.

Figure 34 Gasification processes of a single biomass particle



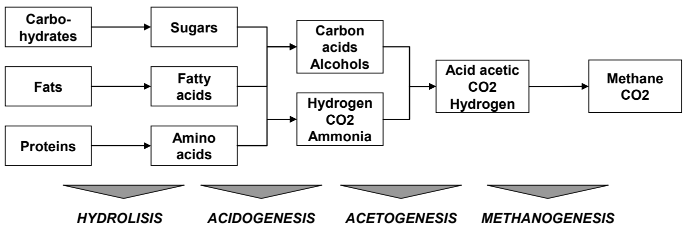
Source: Hofbauer 2009b, p. 38

"Gasification means the conversion of char (mainly solid carbon) with a gasification agent (air, oxygen or steam) into a product gas (producer gas)" (Hofbauer 2009b, p. 38). With regard to electricity production the further processing of this gas can have the following forms: (1) co-firing in fossil fired plants (2) integrated gasification combined cycle (IGCC) (3) direct usage of the gas in a gas engine (Hofbauer 2009b). The particular characteristics of IGCC will be explained in the "Innovation chapter".

2.5.1.3 Biochemical conversion – biogas

Biogas is generated via anaerobic digestion of solid biomass or other biological residues (Quaschning 2008, 301). The source can range from sewage sludge, manure, and food residues to specifically grown biomass (e.g. maize silage).
Via anaerobic digestion (bacterial digestion under the absence of oxygen) a flammable gas is produced that mainly consists of methane and carbon dioxide (Wellinger 2010, p. 4). The formation of biogas happens in a four stages process, described below:

Figure 35 Four stages of biogas production



Source: Wellinger 2010, p. 5

In the first phase, "complex molecules are broken down to constituent monomers" (Wellinger 2010, p. 5). These monomers (such as amino acids) are in the next phase transformed to "simple organic compounds" (e.g. lactic acids, glycerol, ethanol, methanol) by acidogenic bacteria (Wellinger 2010, p. 6). In the acetogenesis phase, acetate, CO2 and H2 is produced through carbohydrate fermentation and other metabolic processes (Wellinger 2010, p. 6). In the last stage, the methanogenesis, methanogenic anaerobic bacteria convert "the soluble matter into methane" (Wellinger 2010, p. 6).

The resulting biogas has now a methane content of 40% - 75% (Quaschning 2008, p. 301) and a CO2 content of 30% - 50% (Wellinger 2010, p. 65). Compared to natural gas with a methane content of >80% and a heating value of 47 MJ/kg (North Sea Gas), pure biogas only comes to a heating value of ~20 MJ/kg (Wellinger 2010, p. 65). Hence the challenge of biogas is to overcome the limited purity and heating value for its further utilization in the electricity production. This gas is often used in CHP[20] applications. For this purpose, Diesel engines, Petrol engines and microturbines can be used (Wellinger 2010, p. 73). The basis for this is however desulphurization (Wellinger 2010, p. 72). Further usage in fuel-cells is also possible with a focus on small scale (household application) (Wellinger 2010, p. 73).

2.5.2 Innovation

As with the preceding chapter, the innovation chapter will also be split into the three technologies in focus. For further analyses in the BSC the organic rankine cycle advancements and BIGCC will be selected.

2.5.2.1 Thermochemical conversion – combustion

With reference to combustion the following major areas of innovation are seen by the author – the further development of boilers and the reliability improvement of the Organic Rankine Cycle. An interesting improvement of biomass for further usage in co-firing applications seems torrefaction. This process is a thermal pre-treatment where biomass is heated under the absence of oxygen in a closed reactor to a temperature of 250-300°C for a period of 60 minutes (Lako 2008, p.70). The advantage of this principle is that the fuel properties of biomass (e.g. straw) can be improved before the energy generation process (Lako 2008, p. 70).

2.5.2.2 Thermochemical conversion – gasification

In this section two main elements shall be discussed – IGCC and pyrolisis.
IGCC – IGCC is a currently widely discussed term. IGCC stands for "**I**ntegrated **G**asification **C**ombined **C**ycle" (Lako 2008, p. 70). The principle of this technology is the same as with Combined Cycle Power Plants (CCPPs) where the hot flue gas of the gas turbines is used in a Heat Recovery Steam Generator

[20] Combined Heat and Power

(HRSG) to produce high pressure steam that can afterwards be used in a steam turbine (Konstantin 2007, p. 230). Similar to this principle, in IGCC plants, a producer gas is burned in the gas turbine and the waste heat from the gas turbine is then transferred to a boiler and afterwards to a steam turbine (Hofbauer 2009b, p. 77). There is one important element that shall be outlined here. When the public discussion comes to IGCC the author observes that there are two discussions mixed up. First, the discussion to use IGCC as a means to lower the CO2 output of coal firing and secondly, using IGCC with renewable energy. The first discussion is mainly focusing on the possibility of CO2 sequestration before the electricity production process (RWE 2005, p. 48). In this paper only the second discussion, or alternatively coined "BIGCC" – Biomass Integrated Gasification Combined Cycle (Gross 2003, p. 117) is referred to. Lako (2008, p. 69) argues that commercialization of this technology will be before 2015 with the main cost reduction potential being in the economy of scale and the further increasing of plant sizes from 50 to 75 MWel.

Pyrolisis – In the absence of air, biomass is rapidly heated to 450-600°C (Hofbauer 2009b, p. 53). Three primary products are the result of the biomass decomposition at elevated temperatures: gas, bio-oil and char (Hofbauer 2009b, p. 54). Pyrolisis is not a new invention but has been used for centuries in the production of charcoal through carbonization (IEA 2003, p. 104). In fast pyrolysis processes 80% of the yield is bio-oil whereas in slow pyrolysis processes more charcoal is being produced (IEA 2003, p. 104). After the pyrolysis, a further gasification process is often used that converts the remaining char into a carbon gas using steam and/or combustion (RDC 2004, p. 18). Bio-oil has significant advantages with regards to transport (and the consequent breaking of the dilemma between area of production and are of usage), further handling and energy content, compared to solid biomass (IEA 2003, p. 105; Gross 2003, p. 116). With reference to electricity production, the oil can further be used in a turbine (Lako 2008, p. 70), engine or in a boiler (Hofbauer 2009b, p. 66). Currently several test applications are in operation. Lako (2008, p. 66) argues that commercialization is possible by 2015 with the main research areas being in the pyrolysis process itself as well as in the upgrading of the oil and gas.

2.5.2.3 Biochemical conversion – biogas

Gas upgrading – as described above, bio gas does not have the same quality properties as natural gas. Hence for further usage in the conventional energy conversion chain, gas has to be upgraded (Milles 2003, p. 3). In particular H2S, water, CO2 and halogenated compounds need to be removed (Wellinger 2010, p. 65). Different technologies have emerged, e.g. water absorption, Polyethylene glycol absorption, Mono- and Di-ethanolamine, carbon molecular sieves, membrane separation and cryogenic removal (Wellinger 2010, pp. 67). However the cost of gas upgrading (Wellinger 2010, pp. 70) currently hinders commercialization. Therefore bringing costs down is seen as an important research area for the future.

3 Company overview

The following chapter of will elaborate on the energy business of Siemens, General Electric, Alstom and Mitsubishi Heavy Industries (MHI). In order to be able to answer the core questions and to give an insight into the structure of the renewable energy business for the companies in focus, the following elements shall be described of the companies:

1) Company size and importance of the energy business
2) Energy portfolio
3) Renewable energy portfolio and the specific development towards renewable energy

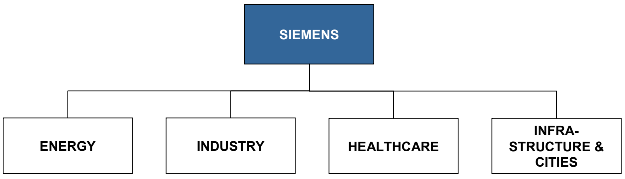
3.1 Siemens AG

Siemens AG is a German company with its roots in the German empire of 1847 when Werner von Siemens founded the "Telegraphen-Bauanstalt von Siemens & Halske" in Berlin (Feldenkirchen 2003). The real start of the energy business of Siemens dates back to 1866 when Werner von Siemens discovered the electrodynamic principle - the technological basis for the large scale production and distribution of electricity (Feldenkirchen 2003, p. 55). The real boost for its international business however came in the late 1960s when Siemens and AEG formed the joint venture (JV) "Kraftwerk Union AG" (KWU) (Feldenkirchen 2003, p. 383). This step was mainly due to increasing market pressure and the need for new investments to be able to compete not only in Germany but also on the international market (Feldenkirchen 2003, p. 383). In 1977 Siemens could then acquire the AEG share of KWU due to financial problems of AEG (Feldenkirchen 2003, p. 384). Since then Siemens has steadily grown its energy business with additional acquisitions (e.g. Westinghouse, VA Tech) and endogenous growth.

3.1.1 Company overview

Siemens is a 75 bn. EUR turnover company, employing ~400,000 employees (Siemens 2010a, pp. 18). Siemens is organized around four main sectors – industry, energy, healthcare & infrastructure & cities. This rather simple org-chart is the result of significant changes in the last decade where the Siemens business has been streamlined which has been accompanied by significant disinvestments in the telecommunications and IT business areas.

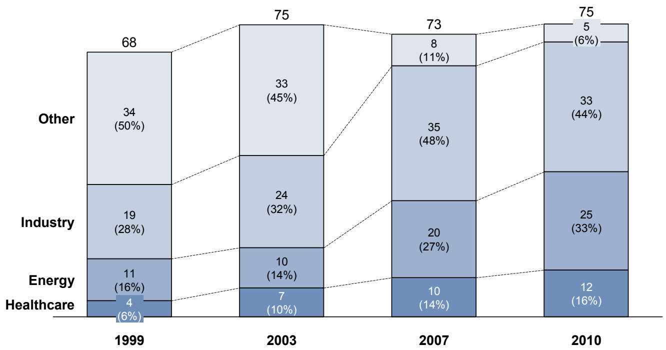
Figure 36 Org chart of Siemens



Source: ww.siemens.com

Reflecting this shift, the remaining sectors have had enormous growth rates, with a 25% growth rate of the energy business between 2007 and 2010. In total, the energy business ranks #2 with regard to turnover. Starting with October 2011, Siemens will have a fourth sector – Infrastructure & Cities which mainly will focus on the infrastructure demands of large cities (Siemens 2011b, p. 6).

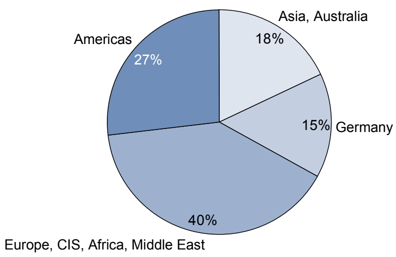
Figure 37 Siemens turnover development 1999 – 2010 (in bn. EUR)



Source: Siemens 2011a, p. 3

Referring to the regional distribution of its turnover, it can clearly be observed that the home base of Siemens is in Europe, with a clear edge of Germany. However, Siemens consistently claims to increase its turnover share mainly in growth countries with a clear focus on China and India.

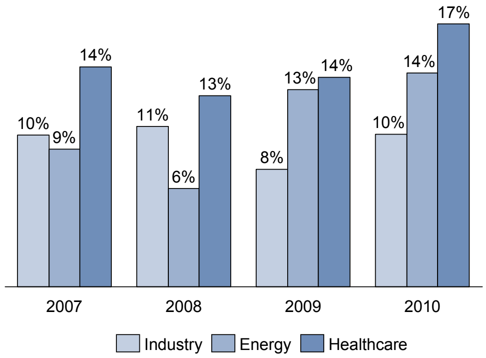
Figure 38 Siemens regional turnover distribution FY 2010 (in %)



Source: Siemens 2011c, p. 3

After having reviewed the turnover distribution, the next interesting part is the profitability of the energy business. The energy business has developed from a low performer in comparison with other businesses to a high performing unit with profit margins of 14% in 2010 (see below figure). Healthcare, though the business is the smallest within Siemens, is the clear #1 when it comes to profitability.

Figure 39 Siemens profitability of sectors 2007 – 2010 (in %)



Source: Siemens 2010a p. 13

3.1.2 Energy business

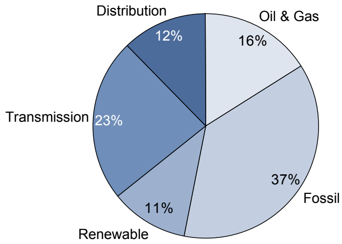
Siemens claims to be the "only integrated energy company". This claim shall be illustrated by the portfolio overview below. In fact it can be observed that Siemens could theoretically deliver portfolio elements for the whole energy conversion chain. The boxes below also represent the organizational split of the Siemens Energy Sector. In total ~88,000 employees work for the Siemens Energy Sector (Siemens 2011a, p. 17).

Figure 40 Siemens energy portfolio overview – "integrated energy company"

Source: Siemens Management Consulting

Besides the theoretical capability a further look needs to be given to the relative importance of the business units. Summarizing below figure it can be easily seen that fossil power generation (product and solution business of Siemens) is the key driver with 37% of the overall energy business. As the distribution and transmission business can be considered neutral with reference to the source of electricity, it is evident that fossil fuels are the major area of Siemens' business.

Figure 41 Siemens Energy – turnover distribution per business unit 2009 (in %)



Source: Adapted from Siemens 2010b, p. 7; turnover of the service business is divided to all other business units

In the power technology industry, Siemens holds a #2 position with an estimated market share of 18% (Bhatnagar & Gibson 2006, p. 7). Since the major restart of its power business in the 1970s with Kraftwerk Union, Siemens has not only had enormous endogenous growth but also performed several large scale acquisitions. The largest boost in the US business and the gas turbine business was the acquisition of US based Westinghouse in 1998 (Bhatnagar & Gibson 2006, p. 7). As a foothold in the 60 Hz market, Siemens could leverage the new market position to participate in the large gas turbine boom in the early 2000s in the USA (Hungenberg & Meffert 2005, p. 169). Westinghouse added 2 bn. USD turnover and 7,500 employees to Siemens' energy business[21]. This acquisition was followed by adding the power business of Austrian VA Tech to its portfolio in 2005. Via this step Siemens increased not only its presence in the Central European market (via VA Tech's solution business) but also added manufacturing and technology capacities in its transport and distribution business. Another 16,000 employees were added at that time with a turnover of EUR 3.9 bn. (industry and power business combined)[22]. To get a stronger foothold in the Russian area, Siemens also acquired 25% in Power Machines, which strengthened for instance the manufacturing capacities[23].

From a size perspective, two further acquisitions have been less important – the acquisition of Danish Bonus Energy and Israel SOLEL. These two acquisitions will be discussed in the next section.

However, there have not only been acquisitions the most prominent disinvestment in the recent time has been the split between AREVA and Siemens and Siemens's halt in its nuclear power business.

---

21 http://www.highbeam.com/doc/1G1-21127698.html accessed on 02 September 2011

22 http://www.siemens.com/investor/en/company_overview/portfolio_changes.htm accessed on 02 September 2011

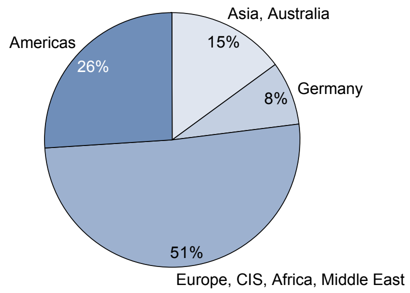
Table 9 Major acquisitions of Siemens Energy Sector

Company	Year	Reason	Main figures
Westinghouse (USA)	1998	Market foothold in U.S. (gas turbine business)	USD 2bn (turnover) 7,500 employees
Alstom (industrial turbines)	2003	Build up portfolio with industrial turbines	EUR 1.2 bn (price) EUR 1.25 bn (turnover) 6,500 employees
Bonus Energy (DK)	2004	New technology – wind turbines	EUR 300 mio (turnover) 750 employees
VA Tech (AUT)	2005	Foothold in CEE area T&D business expansion	EUR 3.9 bn (turnover) 16,000 employees
Wheelabrator Air Pollution Control Inc. (USA)	2005	Air pollution reduction products and solutions	USD 175 mio (turnover) 150 employees
Kuhnle, Kopp & Kausch (DE)	2006	Steam turbines, turbocompressors and fans for oil & gas / biomass business	EUR 270 mio. (turnover) 1,400 employees
Shanghai Electric Power Generation Equipment Co., Ltd.	2010 (start: 1996)	Footprint in the Chinese market – power equipment (mainly conventional power)	40% share by Siemens – no sales reported
SOLEL (ISR)	2010	New technology – Concentrated Solar Power	No sales reported 500 employees
NEM B.V. (NL)	2011	Strengthening of HRSG business (for CCPPs)	~300 mio (turnover) ~1000 employees

Source: http://www.siemens.com/investor/en/company_overview/portfolio_changes.htm accessed on 02. September 2011, press releases

As far as the regional business distribution is concerned, a similar picture as with the general Siemens turnover distribution can be seen – Europe is by far the most important geographical area, with the only difference that Germany does not account for such a high share.

Figure 42 Siemens Energy business regional turnover distribution FY 2010 (in %)



Source: Siemens 2011a, p. 17

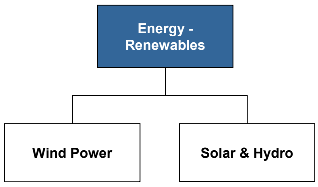
Summing up, we can see that Siemens is a large power technology player with a clear focus on Europe and fossil electricity production with a portfolio that covers the whole energy conversion chain from extraction (at least partly) to consumption. But is Siemens with its long tradition and its footprint in the fossil power generation a dinosaur hindering the passage into a cleaner future? When one asks Siemens - clearly no. From the company's side they will refer to its excellent rank in the Dow Jones Sustainability Index (no. 1 in diversified industries in 2011), its efficiency record CCPP plant in Irsching / Germany (60.75% fuel efficiency) and its progress in

IGCC applications. In the next section we will however have a deeper look in the "really green" side of the energy business – Siemens' renewable business.

3.1.3 Renewable energy business

In order to accommodate for its growing importance, Siemens has transformed its renewable energy business within the Energy Sector. Starting 01 October 2011 there will be two business units – Wind Power and Solar & Hydro (Siemens 2011e). The company explained this step by the concentration on different fields – whereas the wind business shall be driven by further internationalization and industrialization, the latter business division shall focus on technological development and growth (Siemens 2011e).

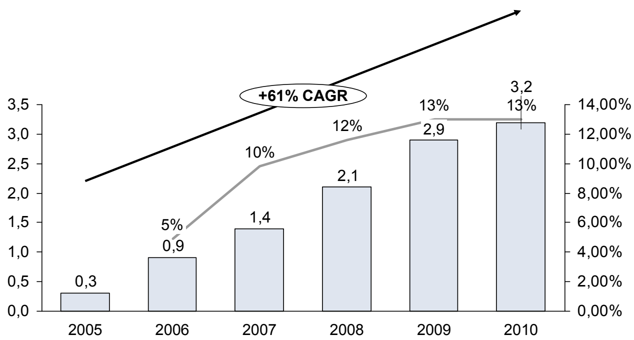
Figure 43 Siemens Renewable energy business – Org Chart



Source: adapted from Siemens 2011e

With reference to the business development, we can see a tremendous growth in Siemens' renewable business in the last 6 years, both in turnover and profitability. Since 2005 an average annual growth rate of 61% has been achieved which stems mainly from Siemens' wind business. This growth has not only been accomplished with regards to sales but has also led to an employee increase in this area from 800 in 2004 to 7,700 in 2011.

Figure 44 Siemens Renewable business - turnover and profitability development (in bn EUR)



Sources: Siemens 2008a, p. 4; Siemens 2010c, p. 6

Having seen the figures – the next step is to have a more detailed look into the business portfolio. To achieve this we will use the technologies described in chapter 2 of this paper as a guiding structure.

3.1.3.1 Wind energy

According to its own presentation, Siemens is the market leader in offshore business (Siemens 2010c, p. 7) but only market follower (#6) in onshore business (Siemens 2008a, p. 5). As the major part of Siemens' renewable business is reported to stem from wind power, the development rates of the whole Renewable Division of Siemens can serve as a proxy for this specific technology development.

Siemens had no prior investment in wind power business, the whole technological competency came from its 2004 acquisition of Bonus Energy (DK). The challenge of the merger was for instance to transform a medium sized company into a global world market leader. This is highly reflected in the different programs and achievements that Siemens presented to investors with reference to its wind power business – for instance the global expansion of manufacturing capacities (e.g. opening of new factories in US and China in 2010 as well as further planned sites in India, UK, Canada, Brazil and Russia (Siemens 2011e) and the expansion of its sales force through three regional sales centers in US, Asia and Europe (Siemens 2011e).

As far as the main markets are concerned it can be observed that (at least the communication) focus lies on its market leadership in offshore. This is also reflected that given all the backlog orders of the whole renewable business of Siemens, offshore wind power orders accounted for ~45% (Siemens 2010c, p. 10). With orders of 1,200 MW in GB (two projects >500 MW) or 300 MW in Germany, offshore projects can compete with onshore orders (largest onshore order was 350 MW in GB) (Siemens 2010c, p. 4).

With regard to innovations, three major areas can be seen, increasing output, gearless drive systems and facilitation of offshore applications. Currently a 3 MW turbine with a direct drive is in use with a 6 MW turbine currently being under development (Siemens 2010c, p. 11). The gearless drive system (pioneered by German ENERCON) has also been adapted by Siemens, claiming to decrease f.i. maintenance cost (which, especially in offshore applications, can be very high for a maintenance intensive component as the gearbox). A further innovative area in the offshore business is the technology of floating wind turbines – here Siemens installed the 1st large scale floating wind turbine in the North Sea (Norway) together with StatoilHydro[24]

[24] http://www.renewableenergyfocus.com/view/2128/floating-offshore-wind-turbine-installed-by-siemens-and-statoilhydro/ accessed on September 02 2011

As a clear goal in the future, Siemens sees to become #3 in the onshore business and to remain market leader in the offshore business (Siemens 2010c, p. 7). The importance of the offshore business is further strengthened by a 10% stake in British Marine Current Turbines (Siemens 2010c, p. 4) and a 49% stake in A2 SEA an offshore wind park installation company (Siemens 2011f, p. p.7) . The main target of the acquisition seems to strengthen Siemens' and A2 SEA's position in the installation of offshore wind parks, mainly to optimize vessels and to drive down installation cost for offshore applications[25].

3.1.3.2 Solar power – CSP

As with its wind business, Siemens' CSP business is mainly based on the 2010 acquisition of Israel based company SOLEL. Via this move Siemens could transform into the only company that is able to deliver turnkey solutions, having all key components (70% of the overall components) in hand from the receiver to the electricity generating power island[26]. In order to strengthen the receiver business in the area of molten salt receivers, Siemens has additionally acquired a 40% stake in its JV with Italian based Angelantoni Industries (Siemens 2010d). Siemens seems now to be in a "duopoly" with regards to its receiver business together with German company Schott (Stancich, 2011).

The next key component that Siemens has in hand is the steam turbine. The company has mainly built on its past experience with industrial turbines adapting them for solar power use with reference to the lower temperatures (370-550°C) and the required quick start up times (<20 minutes) (Williamson 2010).

With respect to the growth targets of its CSP activities, this business has a double digit growth rate target until 2015 (Siemens 2010d), in order to become the world's leading CSP vendor by 2015 (Williamson 2010). The most recent CSP project is the 50 MW project Termosolar Olivenza 1 (Siemens 2011h).

When it comes to innovation in the CSP field, two main priorities can be seen 1) leveraging the cost reduction potential of 40% (Siemens 2010c, p. 16) and 2) improving receiver molten salt technology.

In order to realize the reduction potential, Siemens builds on its large portfolio to optimize the overall CSP investment cost (Siemens 2010c, p. 16). With reference to the molten salt technology, Siemens currently operates a demonstration plant facility

[25] http://www.renewableenergyfocus.com/view/10608/siemens-becomes-partner-in-offshore-wind-park-installer-a2sea/ accessed on September 02 2011

[26] http://www.energy.siemens.com/mx/en/power-generation/renewables/solar-power/concentrated-solar-power.htm accessed on September 02 2011

in Priolo Gargallo (Sicily / Italy) and has recently agreed on a test facility with the University of Evora and other industrial partners in Portugal (Siemens 2011d).

3.1.3.3 Solar Power – PV

In PV Siemens is currently present in two fields – the inverter business as a product supplier and as an EPC[27] for large PV projects.

As an EPC, Siemens was responsible for large PV projects e.g. in Italy (San Donaci – 15 MW) or France (Les Mées – 30 MW) (Siemens 2010c, p. 4).

Siemens' history in PV business is a turbulent one – once being a PV producer itself, Siemens sold its PV production to Shell in 2001[28] which was afterwards sold to now German SolarWorld AG. Now, the company is again investing in the technological basis – acquiring a 16% stake in US based Semprius Inc., a company active in the production of High Concentrating Photovoltaic Modules. The aim of the investment is to give Siemens a leading position for the supply of the new modules and to provide Semprius with necessary funding to enable the upscaling of the production facilities (Siemens 2011g).

3.1.3.4 Hydro power

Voith Hydro is a Joint Venture between the two German companies Voith and Siemens. Voith actually holds the majority with 65%. In 2008/09 the JV had a turnover of € 1.1 bn with 4689 employees[29]. Voith Hydro covers both, small (e.g. via its subsidiary Kössler in Austria) and large hydro power. In 2005 Siemens was actually in the possession of another hydro power market player, Austrian VA Tech. Due to anti trust reasons, Siemens had to sell the hydro power business of VA Tech to Austrian based Andritz, who in turn became #2 in the hydro power business.

Besides the arrived technologies in hydro power, Voith Hydro is also active in ocean / tidal energy via its subsidiary Wavegen[30]. Additionally, Siemens directly invested in a 10% stake in the company Marine Current Turbines who installed the world's first offshore tidal turbine in 2003[31].

---

[27] EPC = Engineering Procurement Construction

[28] http://www.siemens.com/innovation/de/publikationen/zeitschriften_pictures_of_the_future/pof_fruehjahr_2007/technik_fuer_die_umwelt/strom_der_zukunft.htm visited on 04 September 2011

[29] http://www.voithhydro.com/vh_de_knzrnber_daten.htm visited on 12 December 2009

[30] http://www.wavegen.co.uk/what_we_offer_limpet.htm

[31] http://www.marineturbines.com/2/company/ accessed on 02 September 2011

3.1.3.5 Biomass

Siemens has a long tradition and large competency in biomass business. The company argues to have 6200 MW installed capacity in biomass power production (~10% of the global capacity). Siemens lacks one of the main components in the biomass business – the boiler. Except for this, Siemens holds the main competency in the power island that is being used by the industry. With reference to own EPC projects, Siemens can show the references of Moordijk (36.6 MW[32]), Simmering (24.5 MWel [33]), and Lockerbie/Sevens Croft (44 MW[34]).
The main part of the biomass business is formed by the company's industrial gas and steam turbine business (which is organized in its Oil & Gas Division). Siemens could form a broad portfolio e.g. via the acquisition of Alstom's industry turbine (Siemens 2008b, pp. 5) business and the acquisition of KK&K. Another acquisition – Sustec Holding brought Siemens a gasifier technology that is currently used in IGCC although also suited for biomass (Siemens 2007, pp. 4). The focus of Siemens is not on the solutions business but on the delivery of components. This is done on an international basis, with manufacturing in DE, UK, Sweden, and India.

3.1.4 Summary

It can be summarized that the renewable business of Siemens provides two insights – a remarkable growth (driven by the wind power business) and a growth that is mainly based on external competencies and innovations.

Table 10 Summary of Siemens' renewable portfolio

	Organization	Importance	Business Model	History
Wind Power	Own	⇧	Product / system supplier	Acquisition of Bonus Energy built foundation of business
Solar Power – CSP	Own	⬀	System supplier EPC (selectively)	Acqusition of SOLEL built foundation of business
Solar Power – PV	Own	⇔	Product supplier for inverters EPC for large scale applications	PV panel business was sold
Hydro Power	JV	⇔	System supplier EPC (selectively)	JV with Voith
Biomass	Own	⇔	System supplier (power train), gasifier and industrial sized gas / steam turbines	Own resources – recently no EPC business seen

Source: own representation & evaluation

In the future it will be interesting to follow Siemens' renewable business development in the light of the new organization for solar and hydro power.

[32] http://www.bmcmoerdijk.nl/index2.php?pid=24 accessed on 04 September 2011

[33] http://www.wienenergie.at/we/ep/programView.do/channelId/-26988/programId/17321/pageTypeId/11893 accessed on 04 September 2011

[34] http://www.eon-uk.com/generation/stevenscroft.aspx accessed on 04 September 2011

3.2 General Electric

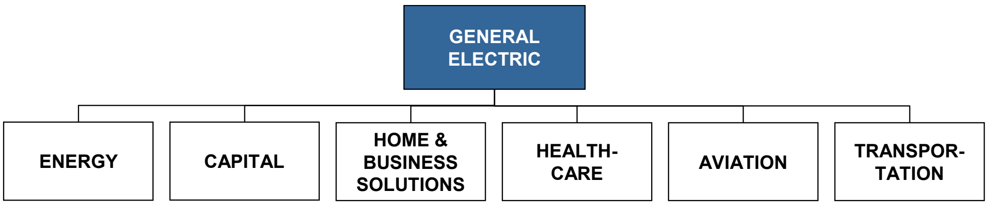
GE's history is comparable to the history of Siemens. As was the case with the latter, the company's root is a famous inventor – Thomas Alvar Edison. Similar to Siemens, Edison was also focusing on the two main elements of innovation of that time – energy and telecommunication.

Edison's most famous invention stands at the beginning of GE's history, the light bulb. Based on this invention the next step was to build electrification systems – including electricity generation – e.g. via America's first central power station in New York in 1882[35].

3.2.1 Company overview

GE is a US based 150 bn USD (~110 bn EUR) company with 287,000 employees (GE 2011a, pp. 1). Six main business fields are covered by GE – energy, banking (Capital), home & business solutions (including household appliances), healthcare, aviation and transportation. In contrast to the example of Siemens, GE has increased the number of business organizations, directly responsible to the CEO in the last years (comparing the last 3 annual reports from 2008 – 2010 of GE).

Figure 45 Org Chart GE

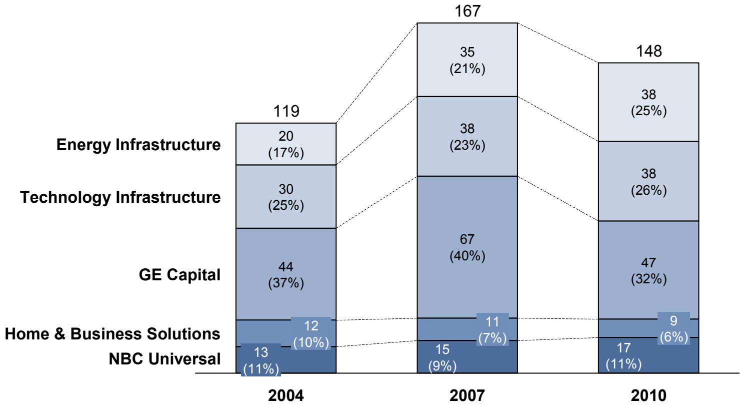


Source: http://www.ge.com/pdf/company/ge_organization_chart.pdf accessed on 04 August 2011

When it comes to the development of these different business fields it can be seen that GE's turnover development has undergone a massive change since 2004 with its Capital business being the most important in 2007. In the course of the global financial crisis this has however changed again in 2010. With regard to GE's energy business a steady increase since 2004 can be observed that put GE's energy business at the same importance rank as its technology infrastructure business, accounting for 25% of GE's sales. Since 2004 GE's energy business has nearly doubled.

[35] http://www.ge.com/innovation/timeline/index.html accessed on 01 August 2011

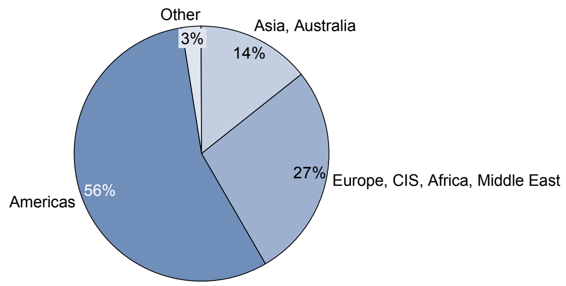
Figure 46 GE turnover development 2004 – 2010 (in bn. USD)



Sources: GE 2011a p. 39, GE 2009a p. 26

When it comes to GE's regional sales distribution, a similar picture as with Siemens can be seen - with the only difference that instead of Europe, the Americas are the major area of sales for GE.

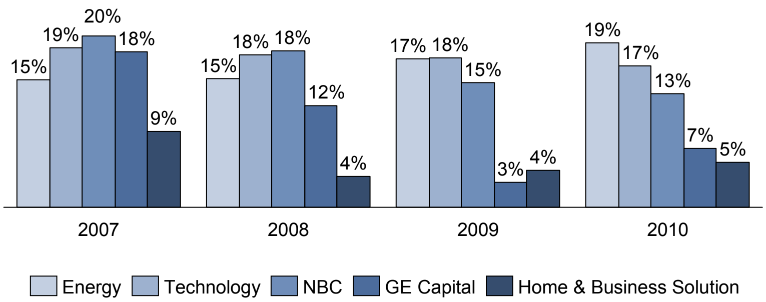
Figure 47 GE's regional turnover distribution FY 2010 (in %)



Source: GE 2011a, p. 44

The changes that GE has undergone with regard to its sales development can also be monitored in the development of the profit margins of GE's different business areas. From 2007 on, energy has become the #1 in profitability margins with the other businesses showing a clear deterioration, with the most significant being the negative development of GE's financial business, which again seems to be the result of the global financial crisis.

Figure 48 GE's profitability of sectors 2007 – 2010 (in %)

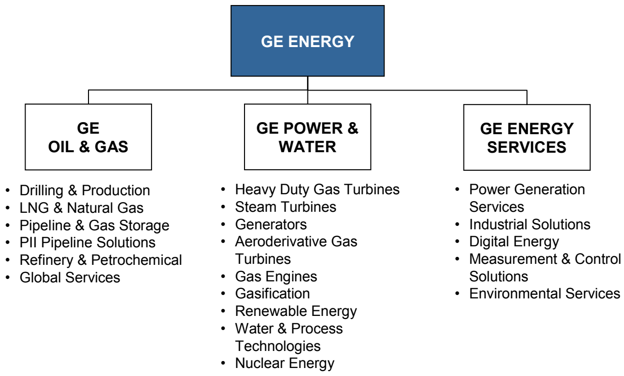


Source: GE 2011a, p. 39

3.2.2 Energy business

GE is the market leader in the power technology industry with ~19% market share (Bhatnagar & Gibson 2006, p. 6). The company's most important energy business pillars are its Oil & Gas business as well as its gas turbines. In contrast to its competitors GE has always been rather product and system than EPC driven (Bhatnagar & Gibson 2006, p. 6). The company is cooperating worldwide with a number of architect engineers or it acts as a junior partner in consortia to sell its products. With reference to the portfolio the company has split its energy business in 3 business units – Oil & Gas, Power & Water and Energy Services. In total, the energy business of GE employs >90.000 people worldwide (GE 2011b).

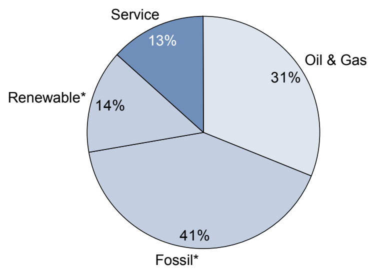
Figure 49 Portfolio GE Energy



Source: GE 2011b

For GE the most important business is its Power & Water business being responsible for 55% of 2010 turnover, followed by its Oil & Gas business. As GE does not disclose official information on the detailed split of its business, the business data have been collected by the author from different publicly available sources. If the Oil & Gas business is not considered, Renewable electricity generation actually holds a share of ~19% of GE's energy related sales.

Figure 50 GE Energy – turnover distribution per business unit 2010 (in %)



* Parts of GE's Power & Water

Source: Adapted and summarized from GE 2011a, GE 2011c, http://www.rechargenews.com/energy/wind/article205163.ece, http://www.sustainablebusiness.com/index.cfm/go/news.display/id/15130

Since 2004, GE Energy has almost doubled its turnover. This massive increase is not only the result of market shifts and booms but also the result of over 90 acquisitions since 2001 with a capital investment volume of 11bn USD (of which the majority was actually performed in 2011). This development turned GE from a gas turbine seller into a global reaching power technology provider in both fossil and renewables (GE 2011c, 12). For the purpose of this paper only the major acquisition with a focus on electricity generation are focused. Reviewing GE's acquisition and JV activities in the last years, three main findings can be drawn – GE has concentrated on big acquisitions recently to strengthen its Oil & Gas business, JVs and partnerships are frequently used, and companies with a clear product focus are being targeted. GE has strengthened its gas engine business via the acquisitions of Nuovo Pignone in 1997[36] and Austrian Jenbacher in 2002[37], and lately, Dresser.
With regard to renewable energy three major acquisitions shall be noted and discussed in greater detail in the following sections, the 2002 acquisitions of Enron's wind power business, the addition of Scanwind and PrimeStar Solar Inc. However, the major investment of GE have just been performed in 2011 – when GE particularly powered its oil & gas business as well as its components business for the power plant business: US based Dresser (GE 2011d) and European Converteam (GE 2011e) each with an investment of >3 bn USD. Referring to the JVs and partnerships the most notable is the JV with Hitachi in the nuclear field agreed in 2007 (GE 2007a) which seems to be a direct response to GE's loss of Westinghouse's nuclear business to competitor Toshiba in 2006 (Bhatnagar & Gibson 2006, p. 6). With Russian based OJSC NPO Saturn, GE started a JV in 2006 in which GE licensed its heavy duty gas turbines to the JV to get a stronger foothold in the Russian market (GE 2006a). Another more recent example is GE's teaming up with Korean Doosan to develop further large steam turbines and generators (GE 2010a). Below table shall give an overview about the main acquisition, their size and the strategic reasoning behind – it shall be noted that due to the fact that GE has done ~90 acquisitions only the most notable ones shall be considered.

[36] http://www.ge.com/company/leadership/bios_exec/claudi_santiago.html accessed on 01 August 2011

[37] http://www.news.at/articles/0247/30/45308/general-electric-jenbacher-ag accessed on 02 August 2011

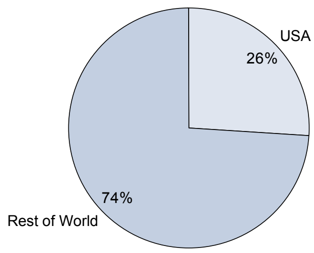
Table 11 Major acquisitions of GE Energy

Company	Year	Reason	Main figures
Alstom (heavy duty steam turbines business)	1999	Strengthen heavy duty steam turbines	700 mio. EUR sales 2,500 employees
Jenbacher (AUT)	2002	Technology acquisition small-medium sized gas engines	1.250 employees (2002) 250 mio EUR turnover (2002) ~220 mio EUR investment
ENRON (wind power business)	2002	New technology acquisition	600 mio. USD sales
ASTRO Power	2003	Entry into PV business	Not disclosed
JV GE-Hitachi Nuclear Energy	2006	Strengthen both pressurized water boiler and boiling water reactors market position	60% stake of GE in the company
Prime Star Solar	2007	Acquisition of Thin film technology	No significant sales 30 employees
Dresser	2011	Portfolio enlargement in gas engines and oil & gas business	3 bn USD investment 6,300 employees
Converteam	2011	Portfolio enlargement - power conversion and automation systems and power electronics, motors and generators (e.g. for wind turbines)	3.2 bn USD investment 5,500 employees

Source: GE Press Releases

GE developed within the last years from a US centered organization (63% of sales in 2002) into a power technology provider with a global reach (only 26% US sales in 2011). In spite of further research no detailed split of GE's business could be found.

Figure 51 GE Energy business regional turnover distribution FY 2011 (in %)



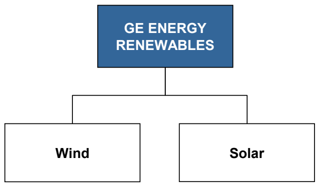
Source: GE 2011c, p. 67

After having reviewed all the precedently shown company data, what is GE's energy business all about? From the perspective of the author three things shall be outlined – GE's clear transformation from a US gas turbine seller, its "ecomagination" thrive as well as its fundamental build up of the oil & gas business. GE has clearly surpassed its past with both internationalizing its business as well as adding new portfolio elements and forming JVs to strengthen its international and technology presence. With ecomagination GE launched a campaign to "drive innovation & growth of profitable environmental solutions" (GE 2010b, p. 1). In total the company delivered a portfolio worth 25 bn. USD in annual sales, containing innovative areas such as IGCC, high efficient gas turbines for CCGT plants (with a reported efficiency >61%), the renewable business and energy saving products. Seeing all this, it can be summarized that GE is aggressively tackling the most significant challenges of the energy business with a broad portfolio that is however focused on certain core elements e.g. in renewable business which will be closer examined in the upcoming chapter.

3.2.3 Renewable energy business

GE's Renewable Energy business is organized in the GE Energy – Power & Water organization with a concentration on Wind power and Solar business. GE's gas engine business is organized together with GE's gas turbines.

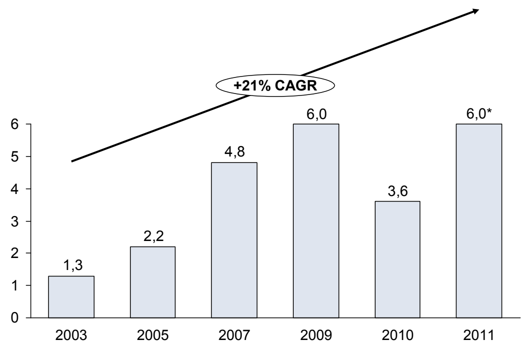
Figure 52 Org-Chart GE Renewable Energy



Source: www.ge.com

The renewables business of GE has experienced a tremendous growth since 2002 when GE acquired the wind business of ENRON with a sales volume of ~600 mio. USD. The company has meanwhile increased sales by a factor of 10 until 2009. In fact, wind power is the main source of revenues for GE's renewable business with the gas engine business and the solar business playing only a minor role.

Figure 53 GE Renewable business - turnover development (in bn USD)



*Estimate

Source: own research, GE 2011f, p. 9

3.2.3.1 Wind energy

Within less than a decade GE has formed the global #3 wind turbine manufacturer. The technological root goes back to GE's 2002 acquisition of ENRON's wind power business, the then wind power market leader in the US after Enron's bankruptcy (Bhatnagar & Gibson 2006, p. 6). Or as the current Renewables Vice President Abate put it: "When we entered the wind energy industry in 2002, it was a $200 million business for us. In total 3200 people are employed in GE's wind business worldwide (GE 2011f, p. 7). Today it has grown significantly, with revenues topping $6 billion."[38] And in fact, GE has transformed its wind business from a US player into a globally active company that provides wind turbines all over the world thus became global #2 behind Danish Vestas. As a precondition for growth, GE also had to move outside its home turf, the US. This move is reflected by the increased internationalization of its manufacturing plants to cater for regional demands – such as Chennai and Pune in India, Shenyang in China, Salzbergen – Germany, Verdal – Norway and Karlstad Sweden (GE 2011f, p.7). GE furthermore internationalized its supply chain and enhanced its market entry position, by entering a JV with Chinese Harbin Electric Machinery Co. Ltd. to manufacture near-shore and offshore wind turbines for the Chinese market (GE 2010c).

The clear market communication of GE lies on three areas, its reliability, increased turbine sizes as well as the future demands of offshore applications. With reference to reliability GE claims to have increased the availability of its fleet from 95% in 2006 to 98% in 2010 (GE 2010d, p. 8). GE's "industrial workhorse" and the foundation of its success was its 1.5 MW onshore wind tower. This has been topped by the 2.5 and 2.76 MW machines (GE 2011f, p. 10) with a 4.1 MW machines experiencing currently the first installations in offshore applications (GE 2011g).

The company's clear growth goals are outside of the US, namely in Canada, Eastern Europe (where the 2.5MW machine is targeted at), India & China and Latin America (GE 2010d, p. 10).

As far innovation is concerned, GE has acquired key technologies for its offshore business from Norwegian Scanwind, which was added to GE's portfolio of companies in 2009, helping the company to have a direct drive technology in house (GE 2009b). What GE presents as a vision sounds also breathtaking – GE is currently investigating a 15 MW turbine with "low-temp, super-conducting direct drive", "advanced power electronics" with the support of its recent acquisition

[38] http://www.rechargenews.com/energy/wind/article205163.ece accessed on 02 August 2011

Converteam and "stronger, lighter blades with nano reinforced composites" (GE 2011c, p. 36). As the clear quest in wind power business is how to engineer and build even larger turbines, two main elements need to be in focus, the height of the tower and the length of the blades. With reference to the first GE has made another step in driving installation costs down by acquiring the "Space frame tower system technology" from US based Wind Tower Systems Llc with its main usage in wind applications that require a hub height of >100m. The advantage of this technology is that towers are easier to transport and need less effort in erection (i.e. lesser usage of cranes) due to an integrated lifting concept (GE 2011h).

In addition to the supply of wind power technology two further aspects of GE's portfolio shall be highlighted – its direct investment in wind power projects as well as its activities as a Venture Capitalist (although not directly related to its renewable business). With reference to the first an investment volume of ~6 bn USD in renewable projects via direct project capital or lending is reported, with the majority being dedicated to wind power projects[39]. As far as the latter is concerned GE has invested in TPI Composites which is developing new materials for the demanding wind blades[40] (GE 2009c, p. 14).

Summing up we can see that GE drives further its international as well as its technological reach to defend its #3 market position in wind business with further focus on the international growth potential as well as the growth potential in offshore applications.

3.2.3.2 Solar power – CSP

GE has started its engagement in the CSP domain in 2007 with steam turbines building on the company's petrochemical industry steam turbine technology (GE 2011k). In 2011, GE has for the first time used a new concept of CSP trains where generators are located between two steam turbines to create a reheat configuration to increase the plants' cycle efficiency (GE 2011k). However, the boldest move GE announced was its offering of ISCC (Integrated Solar Combined Cycle) plants on the basis of its Flex Efficiency system. In these plants, the overall configuration of a combined cycle plant is added by a CSP plant that also transfers steam into the system to drive a steam turbine increasing the system's efficiency from ~60% to 70% (GE 2011l). Therefore, GE has entered into a global licensing agreement with US based eSolar to use its concentrating solar tower technology with the only

[39] http://2greenenergy.com/the-vector-keeping-up-with-ge/14068/ accessed on 04 September 2011; http://www.sustainablebusiness.com/index.cfm/go/news.display/id/15130 accessed on 04 September 2011

[40] For more information visit: http://www.tpicomposites.com/

exception of India and China (eSolar 2011). At the same time GE also became a minority stakeholder in the company for 40 mio. USD (eSolar 2011). In this case GE also buys key technology from outside with the exception that GE does not possess the technology itself but owns the license for it. The first application will be MetCap's IRCC (Integrated Renewable Combined Cycle) 530 MW plant in Karaman, Turkey where also 22MW wind power will be integrated (GE 2011m).

3.2.3.3 Solar Power – PV

GE's engagement in the solar industry began in 2004 with the acquisition of then bankrupt company AstroPower a manufacturer of solar cells, modules and panels (GE 2004a). In contrast to GE's success story in wind, the PV business however did not show a skyrocketing start resulting actually in a reduction of AstroPower's manufacturing plant in the US. A bolder step has been made in 2007 when the company acquired a minority stake in Prime Star Solar – a thin film expert founded only in 2006 (GE 2007b). In fact this engagement - with GE taking majority ownership in 2008 (GE 2008a) has resulted in the most efficient thin-film solar cell in 2011 – 13.1% efficiency (GE 2011c, p. 37). This solar cell is made out of cadmium telluride (CdTe) (GE 2010e). GE has also announced to open a new 600 MW production facility in the US with availability of the first products in 2013 with the target to reduce cost of the module by 50% in the upcoming years (Walsh 2011).
In addition to the solar panels, GE is also active in the inverter business with its Brillance product that actually builds on GE's experience in the wind power business (GE 2010e). Although GE is also in this field not active as an EPC it offers pre-bundled solutions in the form of 700 kw and 1 MW solar power blocks (GE 2010e). As was the case with other energy fields, GE also relies on partners in its PV business. Together with Japan based Showa Shell Sekiyu KK's Solar Frontier unit the company will make thin-film panels coated with a copper- indium-gallium-selenide compound (CIGS)[41].
GE also teamed up with German based Gehrlicher Solar AG to form a partnership that the project developer Gehrlicher will use GE products in its upcoming PV plant projects with a project in Aschheim, Germany being the first installation (GE 2011i).
GE is relatively late in the PV game with other competitors being by far more experienced and able to build on a much larger installed base and manufacturing capacity. The future years will show whether GE can build on its record efficiency modules to repeat a similar success story as has been its wind power business.

[41] http://www.bloomberg.com/news/2010-10-12/ge-expands-solar-business-as-immelt-seeks-to-mirror-wind-growth.html accessed on 04 September 2011

3.2.3.4 Hydro power

Hydro is actually the only example of disinvestment in the renewable energy business by GE. It took GE two times to come to a settlement - in 2006 GE announced to sell its hydro business (with 2000 employees) to Pescarmona Group of Companies a hydro player who wanted to complement its portfolio with GE's assets (GE 2006b). However, in July 2007 the two companies concluded not to finalize the agreement[42]. Finally, Austrian company Andritz took over GE's hydro business (Andritz 2008, pp. 8). This move seems for the author to be logical as GE has not been a major player in the hydro business field. Besides project investments GE is only active as a VC[43] with its stake in Pelamis Wave Power (GE 2009c, p. 14). The only remaining components solely dedicated to hydro power plants are hydro generators[44].

3.2.3.5 Biomass

Next renewable energy source – same start history – as with wind and solar power, also GE's biomass business is mainly built on a rather recent acquisition. In 2002 Austrian based Jenbacher was added to GE's portfolio. And again, GE has transformed the Austrian mid-sized company into a global player thus increasing sales to >600 mio. EUR and even increasing the staff in a high cost country from 1,250 to 1,400 employees[45]. GE Jenbacher provides gas engines in the range of 0.24 – 4.4 MW that can operate on the basis of various gases. Just recently the company added a 9.5 MW engine (J920-engine with a record efficiency of 48.7%)[46]. Although not all machines produced will be used for renewable energy, the portfolio itself has the power to facilitate renewable electricity generation. Major examples of Jenbacher's applications are the usage of GE engines in Chinese largest Ethanol production plant where its engines are part of a 36 MW biogas plant where waste

---

[42] http://www.reuters.com/article/2007/06/22/us-ge-pescarmona-hydro-idUSN2246016320070622 accessed on 04 September 2011

[43] VC = Venture Capitalist

[44] http://www.hydroworld.com/index/display/article-display/5877786894/articles/hrhrw/technologyandequipment/2011/07/ge-introduces_new.html accessed on 04 September 2011

[45] http://www.industriemagazin.net/home/artikel/Motorenbau/Jenbacher_Gasmotoren_Neuer_Energieversorgungsmotor_ab_2012/aid/4536?analytics_from=archiv; http://www.industriemagazin.net/top-250/details/pid/65/SchienenfahrzeugeSchienenbau/Plasser_Theurer_Export_von_Bahnbaumaschinen_GmbH?af=Rankings.Top250.Click.Unternehmen accessed on 04 September 2011

[46] http://www.wirtschaftsblatt.at/home/oesterreich/unternehmen/tirol/jenbacher-waechst-mit-neuem-chef-weiter-481763/index.do accessed on 04 September 2011

methane from the ethanol production process is further transferred in to energy (GE 2011j).

3.2.4 Summary

How can we put GE's renewable strategy in a nutshell? Basically, GE's renewable business is Wind and growingly Solar with some steady biomass.

Table 12 Summary of GE's renewable portfolio

	Organization	Importance	Business Model	History
Wind Power	Own	⇧	Product / system supplier	Acquisition of Enron Wind business built foundation of business
Solar Power – CSP	License	⬀	Product / licensor	Adapted steam turbine from Oil & Gas turbines Licensor for power tower technology – integration into ISCC
Solar Power – PV	Own	⇧	Product supplier for inverters and panels System solutions for large applications	Acquisition of Astro Power & Prime Star Solar
Hydro Power	No activity	0		Disinvestment in 2008
Biomass	Own	⬀	Product / system supplier	Acquisition of Jenbacher

Source: own representation & evaluation

What is remarkable about GE's renewable energy development is the clear growth path all investments and acquisitions have undergone (f.i. wind and biomass). The upcoming years will show whether GE will be able to pursue this in the areas of offshore, PV and in how far ISCC power plants will eventually be accepted in the markets.

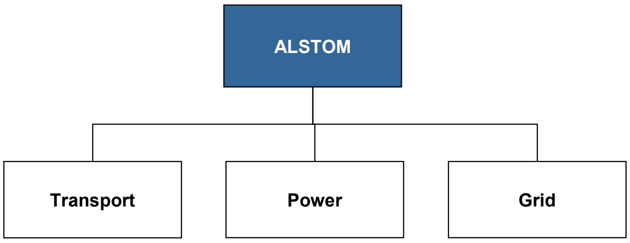
3.3 ALSTOM

In contrast to the two companies spotlighted before, Alstom's founding is not based on a genius inventor but the result of 1928 merger between Thomson Houston and Société Alsacienne de Constructions Méchaniques (SACM) which was afterwards named ALSTHOM. Alstom has since then had a rather turbulent development, however steadily with a clear focus on transportation and power equipment[47].

3.3.1 Company overview

The French based company reported turnover of EUR 20.9 bn employing 93,500 employees worldwide[48]. Alstom is organized along 3 business fields – Power, Transport & Grid. The latter is a recently added field – it was acquired from French Areva together with Schneider Electric in 2010 (Alstom 2010a).

Figure 54 Org Chart Alstom



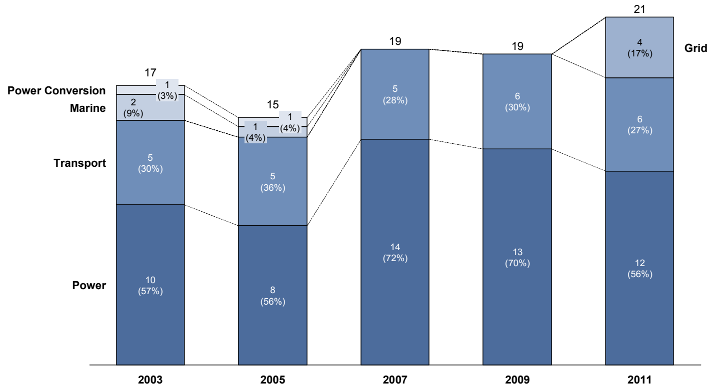
Source: http://www.alstom.com/ accessed on 01 August 2011

As far as the importance of the different business fields is concerned, below figure illustrates the turbulent development Alstom has undergone in the last 8 years. Due to financial problems, the French state acquired a 21% share in 2004. In 2006 two major disinvestments were done – power conversion and marine with a clear focus on the two traditional Alstom pillars – transport and power business. Although the new field "Grid" has actually increased revenues, it can still be observed that Alstom was clearly hit by the financial crisis and had to consider a 10% turnover loss from 2009 to 2011.

47 http://www.alstom.com/about/history/ accessed on 01 August 2011

48 http://www.alstom.com/aboutus/ accessed on 01 August 2011

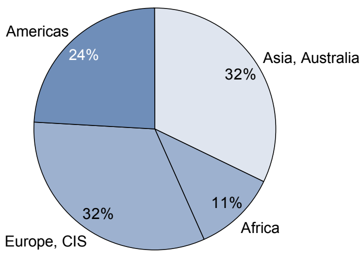
Figure 55 Alstom turnover development 2003 – 2011 (in bn. EUR)



Source: Alstom annual financial reports 2004-2011

As far as the sales distribution to regions is concerned, it can be observed that Alstom has the most equally distributed sales split so far with Asia and Europe having nearly equal importance followed by the Americas and Africa.

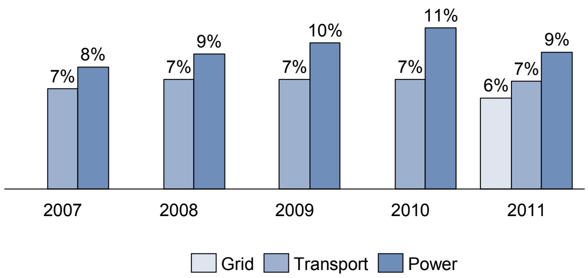
Figure 56 Alstom's regional turnover distribution FY 2011 (in %)



Source: own calculation and representation based on Alstom 2011a

Alstom has shown a stable margin performance since 2007. At this point it has to be noted that Alstom has made immense restructuring efforts in overcoming its losses from 2003 (-0.5% for transport and -8% for power) (Alstom 2005a, pp. 3). It is furthermore notable that the power sector has only been in a double digit profit zone in FY 2010, this is a rather low level compared to the two competitors highlighted before.

Alstom's profitability of sectors FY 2007 – 2011 (in %)

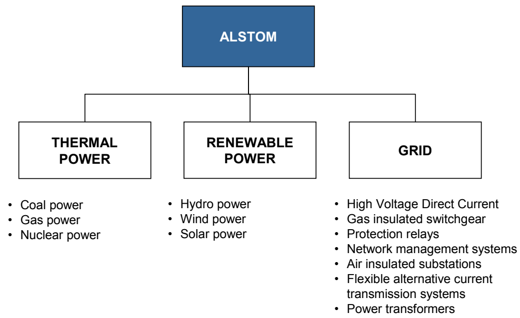


Source: Alstom annual financial reports 2007 - 2011

3.3.2 Energy business

Alstom is the global #4 in the power technology industry with an overall market share of ~11% (Bhatnagar & Gibson 2006, p. 9). Looking on the global installed base, Alstom with its market leadership in Coal and nuclear steam turbines, the company is the clear #1 with a 25% share (Uglow 2010, p. 25). The power business of Alstom has undergone significant changes in the last decades. The most significant early step of Alstom in the power business has been in 1969, when CGE (Compagnie Général d'Eléctricité) took the majority of the shares to form an even bigger company in 1989 when the company merged with UK based General Electric Company[49]. In 1999 the boldest move was made when ABB and Alstom merged their power business in the company "ABB Alstom Power", with Alstom selling its heavy duty gas turbine business to GE and its industrial gas turbine business to Siemens. Due to financial difficulties (for instance due to its gas turbine business) ABB sold its 50% share in the company to Alstom in 2000 (Alstom 2000a). Alstom is both a component as well as an EPC provider. Worldwide, Alstom employs 70,000 people in its power technology businesses. Organization-wise, the company is actually split into three areas, renewables, thermal and the grid business – three organizations that report directly to the Alstom head.

Figure 57 Org-chart and portfolio Alstom Energy business

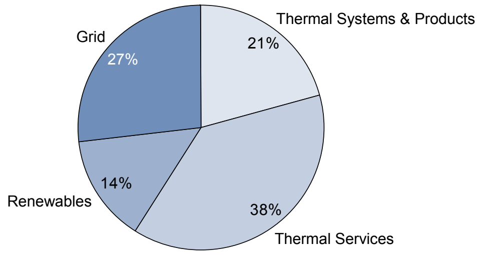


Source: Alstom 2011b, pp. 20

Alstom's clear strength is in the thermal power sector, notably in the coal business which accounts for ~60% of Alstom's power business. The grid business (with its significant importance in the upcoming needs to enhance grids also to allow more integration of renewable energy sources) accounts for 27% of sales. When it comes to renewables, wind, hydro and solar account for 14% of the company's sales in its power technology business. If we ignore grid business renewables have a share of 19% of Alstom's power business.

[49] http://www.alstom.com/about/history/ accessed on 01 August 2011

Figure 58 Alstom Power – turnover distribution per business unit 2011 (in %)



Source: own representation and calculation based on Alstom 2011a

Alstom shows a notable sales development – from 2005 – 2007 the company has increased its power sales by >60%, whereas sales from 2007 on have actually declined by 14%. The overall increase in power technology related sales was only compensated by the re-entry in the grid business. Therefore this paper will elaborate on the portfolio changes that the company has undergone.

This paper has already mentioned the acquisition of Areva's grid business. Besides this major step Alstom has mainly concentrated on extending its global reach via cooperations and Joint Ventures. The most notable JV has been performed with Chinese Shanghai Electric in 2011. With this JV, Alstom and Shanghai Electric have formed the global #1 boiler company for coal fired power plants with a turnover of EUR 2.5 bn and engineering and manufacturing locations in Germany, USA, India, France, the UK and China. The company will be a component supplier for Alstom's and Shanghai Electric's business (Alstom 2011c). Alstom has also set up manufacturing JVs for the Indian market with Bharat Forge Ltd. for steam power turbine island equipment (Alstom 2008a) and in Russia with Atomenergomash for the production of the entire conventional island for nuclear power plants (Alstom 2007a) and recently with RusHydro to manufacture hydro power plant equipment (Alstom 2011d). As carbon capture is a key asset for a coal power plant player, Alstom has acquired further competencies in this field in 2009 with the respective engineering group of Lummus Global (Alstom 2009a) – the company has several demonstration plants in operation. Besides the disinvestments in the gas turbine business before the merger with ABB, Alstom has also ended its activities in industrial sized boilers by selling the EUR 400 mio. business to then Austrian Energy & Environment AG (Alstom 2005b). In the renewables area Alstom has expanded its portfolio by exogenous growth – firstly by acquiring Spanish Ecotecnica in 2007 (Alstom 2007b), and secondly by a minority stake in US based expert for solar power towers Bright Source (Alstom 2011e).

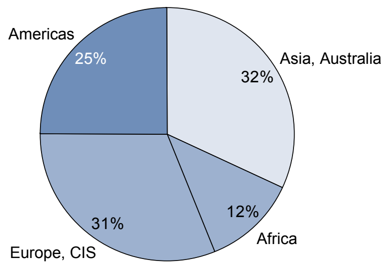
Figure 59 Major acquisitions of Alstom

Company	Year	Reason	Main figures
ABB Alstom Power	2000	Buy-out of ABB share	*Basis of current power business*
Ecotècnica	2007	Entry in wind power business	350 mio. EUR sales 765 employees
Alstom Atomenergomash LLC	2007	Strengthen market position in nuclear (notably Russia)	300 mio EUR investment 1 bn. EUR target sales 700 people
Bright Source Energy Inc.	2010	Entry in solar power business (solar tower technology)	Minority stake – 130 mio. EUR investment
Areva Grid	2011	Re-entry in grid business	3.5 bn EUR sales 20,000 employees
JV Alstom-Shanghai Electric Boilers Co.	2011	Market position in China Manufacturing synergies	2.5 bn EUR sales (50% owned by Alstom)

Source: Alstom Press Releases

With reference to the regional distribution of Alstom's power business sales, a similar picture as with the overall business sales can be seen.

Figure 60 Alstom power business regional turnover distribution FY 2011 (in %)



Source: Alstom 2011b

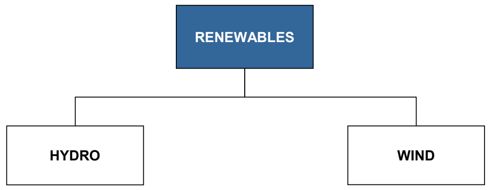
Alstom is the clear #1 in the old fossil world, namely the coal power plants. Consequently, the company has strengthened this business with JVs in China and India, the same applies similarly for its nuclear business. In contrast to GE and similar to Siemens Alstom goes to market with an EPC approach for fossil power plants. Consequently, Alstom further drives carbon capture and IGCC.

In the light of Alstom's troubles before 2005 to concentrate on its strength may seem a consequent step. Only in 2011 Alstom recognized again the importance of grid business and bought back its initial business from Areva. As far as renewables are concerned, Alstom can be seen as a late comer, except for hydro, with its acquisitions. Therefore the next step is to have a deeper look into this business area.

3.3.3 Renewable energy business

As we have seen before, Alstom's renewable business directly reports to the Alstom head. Within the renewables business two major businesses can be found – hydro and wind. So far, the third business – solar – is only based on a minority stake in a company.

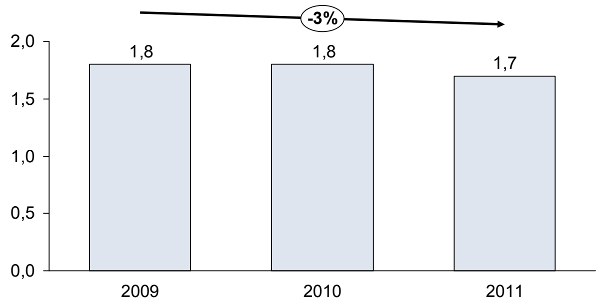
Figure 61 Org-Chart Alstom renewable energy business



Source: Alstom

With reference to the renewables sales, hydro is the dominating sales driver. Alstom renewables sales became a boost in 2007 when wind power was added to the portfolio. Alstom does not provide information on the specific profitability. Alstom has undergone a similar development in its renewables sales as competitor GE showing a recent decline that stems from the overall demand decrease due to the insecurities in the aftermath of the global financial crisis.

Figure 62 Alstom Renewable business - turnover development (in bn EUR)



Source: own representation based on annual financial presentations FY 2009-FY 2011

3.3.3.1 Wind energy

As mentioned before, Alstom is an absolute late entrant into the wind power business. The company entered the market place 3-5 years later than its major competitors GE and Siemens, putting Alstom in a technology and market growth backseat. In 2007 Alstom did not or could not do a bold move in the wind power business but acquired rather a market "dwarf" – Spanish based Ecotècnica with then sales of EUR 350 mio. and a tiny market share of 2% in the rather concentrated global wind power market (Alstom 2007b). Starting with a portfolio of 1.3 and 2 MW turbines, >3 MW turbines development were already in development in 2007 and have been sold for the first time on a large scale in 2010 (Alstom 2010b).

The latest move of Alstom was the consequent march into the offshore business. Alstom teamed up with French developer and utility EDF to participate in bids for several offshore plants that the French government plans in the next 10 years. By 2013 Alstom will provide 6 MW offshore turbines for offshore projects (Alstom 2011f). In the development of the 6 MW offshore turbine, Alstom is currently cooperating indirectly with GE. GE's 2011 acquisition Converteam has teamed up with Alstom to provide the company with a direct drive permanent magnet generator (Alstom 2011g) allowing Alstom to enter the gearless drive technology that all major competitors have already embraced. There is some irony in this story – Converteam has been formed on the basis of Alstom's 2005 disinvestment of its power conversion business (Alstom 2008b, p. 70), was acquired 2011 by GE and is now a key technology supplier for Alstom.

With regard to the internationality of Alstom's wind supply chain it has to be noted that Ecotècnica was solely producing in Spain. Alstom's competitors GE and Siemens have both internationalized their supply chain to become both cost competitive but also be able to localize their business. Alstom has done that partly – in 2009 with a wind turbine assembly facility in Brazil (Alstom 2009b) and in the USA (Alstom 2011b, p. 64).

However, innovation in the wind power business is not only driven by larger and more reliable turbines but also by the relevant infrastructure – Alstom Grid is currently developing floating offshore platform stations for wind parks, the company provides transformers, gas insulated switch gears and automation and control systems (Alstom 2010c).

Neither in on- nor in offshore nor in a regional market, has Alstom achieved to become a big player in wind power. What could be Alstom's strength is its capability to combine its competencies in wind power & its grid capabilities to become a strong innovation leader as only Siemens has these two competencies in house so far.

3.3.3.2 Solar power – CSP

Alstom is the 2nd largest shareholder in US based solar tower company Bright Source. The company is currently developing several CSP projects in the USA (Alstom 2010d). Besides the plan to leverage the specific capabilities of the two companies no further plans have been revealed so far by Alstom.

3.3.3.3 Solar Power – PV

No exposure of Alstom regarding PV has been reported so far.

3.3.3.4 Hydro power

Hydro is Alstom's renewable energy home turf. The company claims to be #1 in the hydro power installed base with a market share of ~25% in installed turbines & generators (Alstom 2009c, p. 45). Alstom offers turbines, generators, control systems and mechanical parts from product delivery up to turnkey plants.

The hydro business is again under 100% direct ownership of Alstom after a JV with French Bouygues group. The hydro business employs ~6,000 people globally. Small hydro is also a focus of Alstom with the smallest hydro turbine at a capacity of 5 MW (Alstom 2009d, p. 15).

In the hydro business Alstom has a clearly global footprint with manufacturing locations in Canada, Brazil, France, Switzerland, India, China (Alstom 2009c, p. 46), and recently in Russia via its local cooperation with RusHydro (Alstom 2011d). Besides the manufacturing, also R&D for Pelton turbines and technologies dedicated to the local market is performed in Alstom's Vadodara Global Research Center in India (Alstom 2008c).

Hydro power production can be seen as a mature technology – with regard to innovation, Alstom is currently driving efficiency of turbines as well as the further development of pumped storage plants to improve the plant's efficiency as a storage for overcapacities and thus providing a base for the further extension of renewables and their fluctuating power production (Alstom 2009c, p. 48). Besides the traditional hydro power technology, Alstom has recently set up a tidal research centre in Nantes (France) where a tidal turbine prototype shall be tested (Alstom 2011a, p. 21). Additionally the company has invested in a 40% stake in AWS Ocean Energy, a company engaged in wave power research[50] as well as a license agreement with Canadian Clean Current, active in tidal energy[51].

In contrast to the renewable energy sources discussed so far, hydro is the example where Alstom is a global player both with its sales as well as with its supply chain. With respect to innovative fields in hydro power – small hydro and ocean / tidal power it seems again, that the company is rather cautious in investments and radical innovations which is reflected in the limited investments and activities in these fields.

3.3.3.5 Biomass

Alstom is a coal player and having this in mind it becomes clear how Alstom sees biomass in the first place – as cogeneration possibility. Alstom has therefore established competencies in this field to burn biomass in coal fired plants. For small scale applications, Alstom has made significant disinvestments – to Siemens (as reported before) and to now bankrupt Austrian Energy & Environment, to whom the

[50] http://www.businessgreen.com/bg/news/2080560/alstom-sails-wave-power-cent-aws-stake accessed on 24 September 2011 – for more information, please consult: www.awsocean.com

[51] http://www.cleancurrent.com/ accessed on 24 September 2011

company sold its industrial boiler and plant business[52]. Alstom however offers steam turbines for biomass and industrial applications ranging from 10 to 100 MW[53].

3.3.4 Summary

Alstom's renewable energy exposure can be summarized as a big portion of hydro with a gentle wind topping and a soft touch of solar. In fact, Alstom has so far managed to be a relevant player in the hydro business without a clear competitive edge in any other renewable energy source.

Table 13 Summary of Alstom's renewable portfolio

	Organization	Importance	Business Model	History
Wind Power	Own	⇧	Product / system supplier / EPC	Acquisition of Ecotècnica Wind business built foundation of business
Solar Power – CSP	Minority investment	⬀	No evidence so far	2nd largest investor in power tower company Bright Source Energy
Solar Power – PV	No activities	0		
Hydro Power	Own	⇧	Product / system / EPC	Own activity
Biomass	Own	⬄	Product / system / EPC	Disinvestment of industrial boiler and industrial gas turbine business Steam turbines for applications 10-100 MW

Source: own representation & evaluation

For the next years it will be interesting to monitor Alstom's development in the wind power business, mainly whether the company will be able to position itself clearly (e.g. as a player in the offshore business) or whether it rests "stuck in the middle". For the hydro business it will be interesting to see whether Alstom shows any attempt to grow into small hydro and in solar the upcoming years will show in how far CSP has a clear growth future. If yes, Alstom's steam and EPC competency could position the company well to reap this market.

[52] http://www.a-tecindustries.at/loom_data/files/7/AEE_241005_deu.pdf accessed on 24 September 2011

[53] http://www.alstom.com/power/renewables/biomass/mt-steam-turbine/ accessed on 24 September 2011

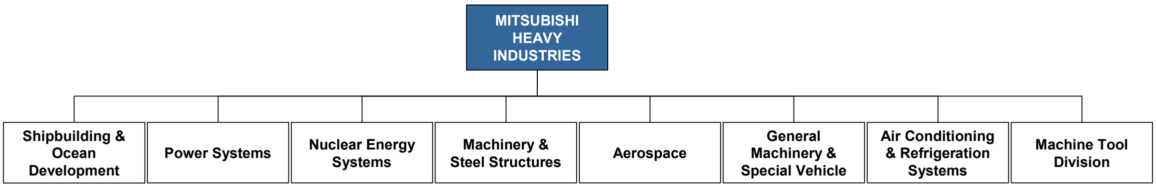
3.4 Mitsubishi Heavy Industries (MHI)

With the next company the last part of the Triad shall be highlighted – Japan. Mitsubishi Heavy Industries origins date back to 1884 when the company's predecessor the Mitsubishi Mail Steamship Co. started its operation in the ship building industry (Mitsubishi 2010a, p. 8).

3.4.1 Company overview

MHI is a USD 31.6 bn turnover company with 72,000 employees worldwide (Mitsubishi 2010b, pp. 12). Mitsubishi has a vastly diversified portfolio organized in eight operative business units, ranging from ship building, power business up to air conditioning.

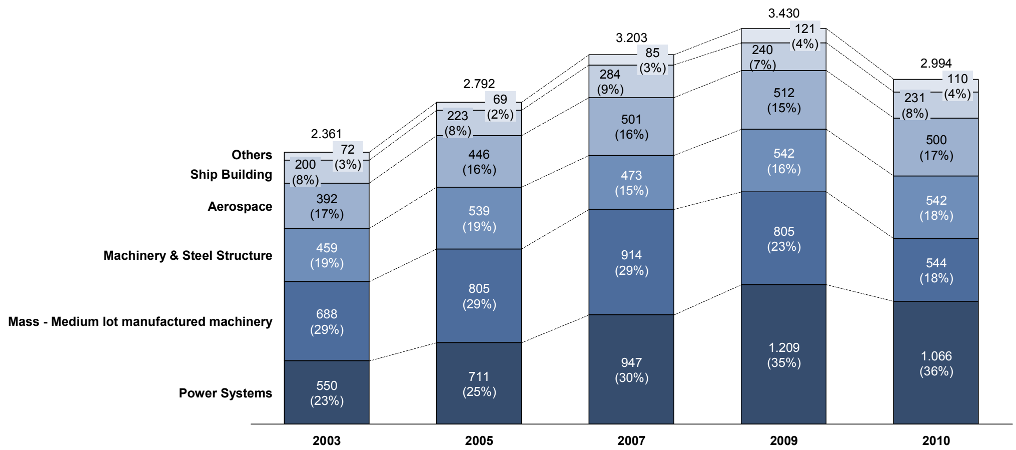
Figure 63 Org Chart Mitsubishi Heavy Industries



Source: Mitsubishi 2010a, p. 21

From a reporting stand point nuclear systems and power systems are summarized into power systems business both businesses showing a tremendous development since 2003. In fact, the power technology business of MHI has nearly doubled, becoming the most important business field and a clear driver of the company.

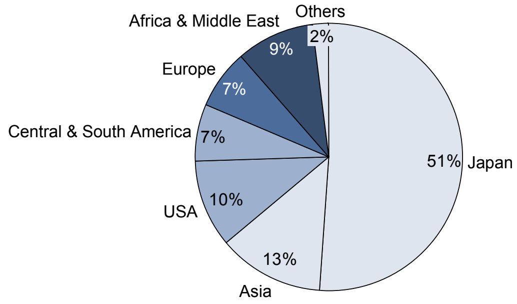
Figure 64 MHI turnover development 2003 – 2011 (in bn. YEN)



Source: Mitsubishi 2010a, p. 29; Mitsubishi 2010b, p. 50

The sales distribution reveals a clear picture. MHI's business is Japan centered. Although all other reported competitors have shown a more or less clear focus on their home market, MHI's share of domestic sales is outstanding with >50%, with its Asian and US business as #2 and #3.

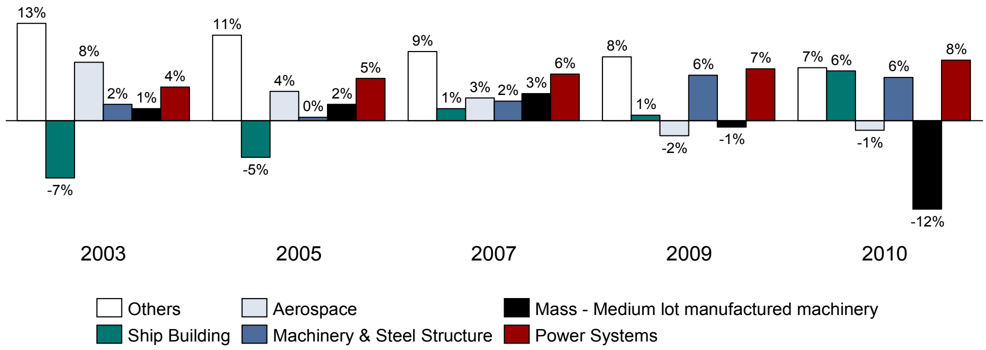
Figure 65 MHI's regional turnover distribution FY 2010 (in %)



Source: Mitsubishi 2010b, p. 51

The margin development of the company can be described as turbulent as its development of sales. The ship building part has achieved a positive comeback, in contrast to the aerospace industry and the mass– medium lot manufactured machinery business which have shown declines in their profitability. The power system business, however has increased its profitability margin significantly (from 4% to 8%). What has to be noted it that none of the business has recently topped the double digit frontier in the last 4 business years.

Figure 66 MHI's profitability of sectors FY 2003 – 2010 (in %)



Source: Mitsubishi 2010a, p. 29; Mitsubishi 2010b, p. 50

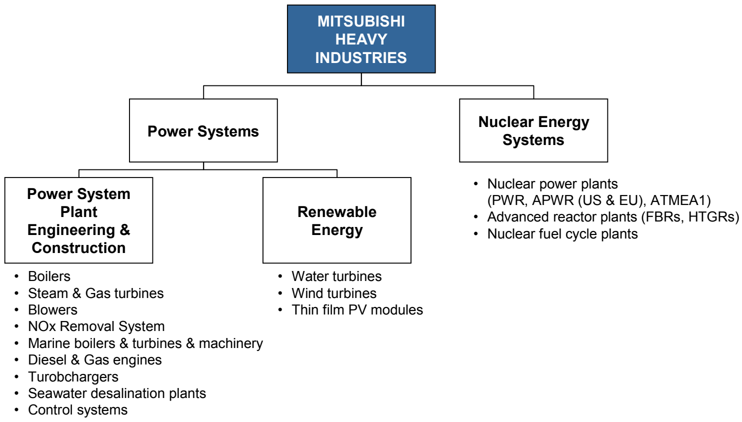
3.4.2 Energy business

In the power technology industry, MHI is the global #6 with an overall market share of ~7% (Bhatnagar & Gibson 2006, p. 11). When it comes to its global installed base (i.e. only focusing on the power production itself and not on distribution or transmission business) the company however is #4 behind GE, Alstom, and Siemens (Stahl 2010, p. 21). Mitsubishi's portfolio development should be seen in the light of its Japan centered business. Due to its insular environment, Japan could not rely on steady gas supply. Therefore, the country's electricity generation was mainly based on two energy sources – coal, nuclear and liquefied natural gas[54]. Hence, Mitsubishi's portfolio developed on the basis of these circumstances, taking

[54] http://www.fepc.or.jp/english/energy_electricity/energy_policy/index.html accessed on 24 September 2011

also early consideration of the country's early move toward renewable energy sources. Therefore, MHI's first large installations have been boilers for coal power plants (Mitsubishi 2010a, p. 51). With regard to renewables the first exports of large hydro turbines was already in the 70s and the first export of wind turbines could be recorded in 1988, long before most other large competitors have even thought about entering this market (Mitsubishi 2010a, p. 51). Additionally, Mitsubishi has built market leadership in the nice of small combined cycle plants and is the only company providing gas turbines that use blast furnace exhaust gases from the steel industry (Bhatnagar & Gibson 2006, p. 11). Mitsubishi's nuclear history dates back until 1957 when the country initialed its nuclear power program. It shall also be noted that MHI has a largely diversified power portfolio that also includes power turbines and engines for ships and batteries for storage purposes.

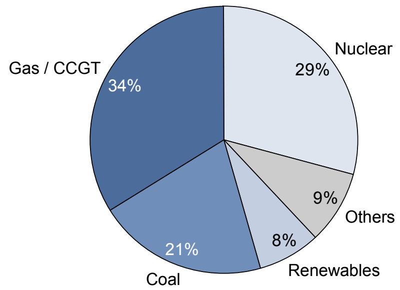
Figure 67 Org-chart and portfolio MHI's power system



Source: Mitsubishi 2010a, pp. 50

It can easily be depicted from the figure below that MHI clearly concentrates on its traditional business spheres, combined cycle, nuclear and coal (accounting for 84% of its power business) with renewables playing a minor role ~8% (a share that does not increase much even if the "others" share is ignored for the sake of comparability with MHI's competitors).

Figure 68 MHI Power business – turnover distribution per business unit 2010 (in %)



Source: calculation based on Mitsubishi 2010c, p. 4; Mitsubishi 2010b, p. 50, Mitsubishi 2011a, p. 11

In its business plans MHI has clustered its businesses into two categories – "Growth Business" and "Reform Business" with its power business being the most important field in the growth business (Mitsubishi 2010d, pp. 7). Two main growth topics have hence been identified – growing demands of emerging countries and the clear need of cleaner energy production (Mitsubishi 2010d, p. 9). Therefore Mitsubishi has set up various growth initiatives in the last years to overcome its Japan centered business model. One key element in broadening its market footprint was licensing – MHI licensed out its large sized gas turbines to Korean Doosan (for use in Korean and Middle East market) in 2007 and to Chinese Dongfang (for use in the Chinese market) as early as in 2002 (Mitsubishi 2007a). In the wind business, the company licensed its 1MW turbine to Chinese Wuzhong Instrument Co., Ltd (Mitsubishi 2007b), followed by its 2.5MW turbine in 2010 (Mitsubishi 2010e). MHI undertook a similar step in the Russian market in 2007 for gas and steam turbines with Renova where additionally a JV was set up to perform after sales service in the Russian market (Mitsubishi 2007c). To increase its footprint in India, MHI has entered into a manufacturing JV with Larson & Toubro to manufacture steam turbines and boilers for the local market (Mitsubishi 2011c, p. 9). With reference to the development of cleaner technologies, MHI does not rely solely on its own capabilities but has built alliances with other large power technology suppliers. The first example is the teaming up with GE to co-develop the next generation steam turbine for usage in combined cycle plants in the 50 Hz market (Mitsubishi 2009a). The second example is a Joint Venture in the hydro business between Hitachi, Mitsubishi Electric and Mitsubishi Heavy Industries in 2011 when the companies agreed on forming a new company – Hitachi Mitsubishi Hydro Corporation in which MHI took a 20% share and transferred all of its hydro power business (Mitsubishi 2011b). The move was undertaken under the light of fierce competition, growth possibilities outside Japan and a flat Japanese demand of new hydro power plants (Mitsubishi 2011b). In contrast to its competitors, MHI is not engaged in bold M&A activities. However, there are some selected examples. In wind business, MHI acquired UK based Artemis Intelligent Power to use the developed hydraulic power drive technology for MHI's entry in offshore technology (Mitsubishi 2010f). In the service area MHI additionally acquired Belgian Maintenance Partners NV to improve its service business in Europe, the Middle East and Africa (Mitsubishi 2009b).

Figure 69 Major acquisitions of MHI

Company	Year	Reason	Main figures
Renova Group, and Teploenergoservice-EK Corporation (TES)	2007	JV for service works in Russia	*No figures reported*
Maintenance Partners NV	2009	Service network in Europe, Africa and Near Middle East	*No figures reported*
Artemis Intelligent Power Ltd.	2010	Technology transfer for offshore turbines	25 employees
Hitachi Mitsubishi Hydro Corporation	2011	JV with Hitachi and Mitsubishi Electric to increase competitiveness in hydro power business	20% share of MHI 34.8 bn YEN combined sales
Auria Solar Co. Ltd. (Taiwan)	2011	Planned investment to increase competitiveness in PV panel production	Not disclosed so far
Larson & Toubro JVs: • L&T-MHI Boilers Private Limited • L&T-MHI Turbine Generators Private Limited	2011	JV for boiler and turbine manufacturing to increase footprint in Indian market	Annual manufacturing capacity: 10 boilers 4 GW of turbines and generators

Source: MHI Press Releases

As far as MHI's regional sales distribution is concerned it can only be hypothesized that its power business follows a similar pattern as its overall sales distribution (this is at least indicated by its nuclear business, where MHI's sales in Japan account for 82%) (Mitsubishi 2011a, p. 11).

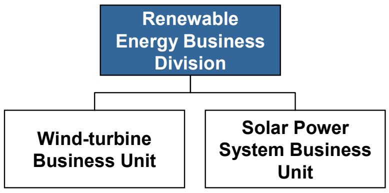
Summing up it can be observed that MHI's home base is clearly nuclear and combined cycle. This is further strengthened by the company by its activities in IGCC and, its R&D activities in nuclear (even in spite of the tragedy in Japan). With reference to its combined cycle business it is notable that it has actually set up an EPC hub in Europe –in Vienna (Mitsubishi 2011d). As all other major players also Mitsubishi is marketing a highly efficient gas turbine – its M501J series with planned efficiency of >60%, which shall start commercial operation in 2013 (Mitsubishi 2011c, p. 16). - a move that has been pioneered by Siemens recently In the IGCC business, MHI has actually a built reference with >10,500 operation hours in Japan and further plans to increase its IGCC business (Mitsubishi 2011c, p. 17).

The next section shall lead us now to have a closer look on MHI's renewable business portfolio.

3.4.3 Renewable energy business

Renewable energy is a distinct business unit in MHI's Power System's business, encompassing its wind turbine as well as its solar business. Gas engines and biomass integrated IGCC is not organized in the renewables business directly.

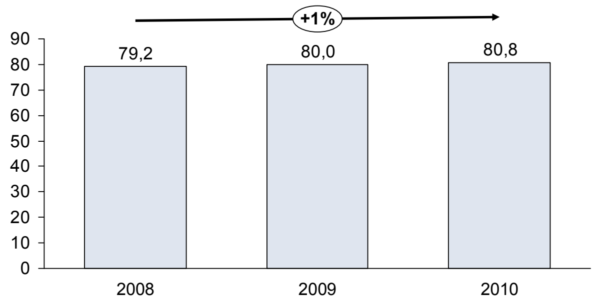
Figure 70 Org-Chart MHI renewable energy business



Source: Mitsubishi 2010a, p. 22

Renewable sales of MHI have not followed a steep development in the last years, at least they have reportedly not declined. The dominating driver of these sales is MHI's wind power business as its PV business is estimated to be below 10% of its renewables sales.

Figure 71 MHI's Renewable business - turnover development (in bn YEN)



Source: Mitsubishi 2010c, p. 4

3.4.3.1 Wind energy

MHI is the only company of the big four power technology suppliers who has developed its wind competency from within and did not acquire a medium sized wind power company in the early 2000s. The company can look back on >30 years experience in producing wind turbines. Taking this into consideration it is actually surprising that Mitsubishi has not been able to leverage its past. Mitsubishi holds a market share of just 2% on the global wind market (Lutton & Latrace 2011, p. 10).

Referring to MHI's portfolio – the company currently provides turbines with an output of 1MW, and 2.4 MW. MHI has started manufacturing in China by licensing in 2002. Except for this case, the company has been rather cautious in expanding its supply chain internationally. Although wind blades have been manufactured in Mexico since 2002 (Mitsubishi 2007d), MHI has started rather late - in 2011 - to build nacelles for its 2.4 MW machines in the US to leverage the local recovery of the wind turbine business (Mitsubishi 2010g).

Reviewing MHI's investor communication clearly brings out the company's focus on future offshore business. Recently MHI has entered into this field with two major steps. The first one was a Memorandum of Understanding with the British government to participate in the country's 'Offshore Wind Turbine Round 3' project to install 32 GW of offshore turbines in the United Kingdom (Mitsubishi 2011c, p. 13). Besides the prototyping and testing of a 5-7 MW turbine (Mitsubishi 2011c, p. 18), MHI's Ship Building division showed interest in the offshore installation, operation and maintenance vessel market[55]. The second step was the acquisition of Artemis in late 2010. MHI will leverage the gearless hydraulic drive concept developed by Artemis (Mitsubishi 2011c, p. 18).

Although it is not MHI's main business another aspect of the wind power business shall be noted in this paper. MHI has engaged in two 'Joint Implementation' projects to sell carbon emission certificates to Japan – one in Bulgaria and one in Spain, with MHI directly investing (via JVs) in a power project and providing the wind turbines (Mitsubishi 2010h).

Summing up it can be observed that MHI's wind business lacks speed in contrast to its competitors. The company has rather lately entered into the offshore market and – with the exception of the US where the company ranks #4 in the installed base (AWEA 2008, p. 10) - MHI could not leverage a significant top market position or market niche. It will be interesting to see in the upcoming years whether MHI will be able to become competitive in the offshore business or whether it stays stuck in the middle.

3.4.3.2 Solar power – CSP

MHI's experience in CSP actually dates longer back than any of its competitors – already in 1981 the company has had a solar tower test facility in Japan in operation (Mitsubishi 2010i, p. 6). However, meanwhile MHI has not leveraged this experience significantly further. In CSP Mitsubishi currently leverages its gas turbine know how for the 'dry-type solar thermal power generation' which is currently in an experimental stage with Australian CSIRO (Mitsubishi 2011e, p. 16). MHI claims to overcome the large water needs of the currently used steam turbine systems (water is needed to decrease the temperature of steam and condense it into water again) which it sees to be unsuitable for dry regions (Mitsubishi 2010i, pp. 7). The plant is

[55] http://www.renewableenergyfocus.com/view/7626/mitsubishi-enters-uk-offshore-wind-market/ accessed on 29 September 2011

currently in its experiment stage with the target of commercializing a 2.5 MW plant in 2013 and later a 10 MW plant[56]. It will be interesting to see whether MHI can really position itself with this technology.

3.4.3.3 Solar Power – PV

As with wind, MHI has established PV capacity on its own. The company started in 2002 to produce thin-film PV modules (Mitsubishi 2011f). It is important to highlight with reference to this specific technology that the present paper covers Mitsubishi Heavy Industries and not Mitsubishi Electric as the latter is in fact the larger player in the PV industry. In contrast to its 'cousin', MHI has not leveraged to achieve a significant position in the global market. Recently, the company announced to cooperate with Taiwanese company Auria Solar to establish a 65 MW micro-morph thin film PV module facility in Taiwan[57]. The main reason of the cooperation was to increase the cost competitiveness of MHI's PV panel production and to cooperate on an 11% efficiency panel. In the upcoming years we will see in how far this move can transfer MHI into a more significant player in the PV market.

3.4.3.4 Hydro power

MHI's JV with Mitsubishi Electric and Hitachi has already been reported. The move has to be additionally seen in the light of the insignificance of Mitsubishi's former position, being not even among the top 10 suppliers for hydro power plants worldwide.

3.4.3.5 Biomass

In its recent presentations MHI clearly highlights the importance of biomass. When it comes to the company's experience in this field a pilot project in biogas production in Japan is reported where gas engines of MHI are used to produce electricity (Mitsubishi 2011c, 26). With reference to IGCC, Mitsubishi has been awarded a 1 bn. EUR EPC contract for NUON's 1,200 MW IGCC plant in the Netherlands, where electricity will be produced from three sources, coal, petroleum, and biomass[58]. Mitsubishi has not so far announced concrete development plans for this technology. However, reviewing the investor presentations, IGCC will be a major topic for the Japanese company, although there are no clear statements on the

[56] http://www.mitsubishi.com/mpac/e/monitor/back/1012/news.html accessed on 29 September 2011

[57] http://www.auriasolar.com/html/press/Solarbuzz_Auria_Solar_and_Mitsubishi_Heavy_Industries_Plan_Co-operation_-_2011-03-31.pdf accessed on 28 September 2011

[58] http://www.power-technology.com/projects/nuonmagnum-igcc/ accessed on 24 September 2011

specific technology or business goals with reference to the biomass usage in these plants. Referring to the latter MHI offers gas engines that can be used to produce electricity out of biogas. No specific market data on this technology could be found by the author. As a coal player MHI has also developed a co-burning system that has been piloted in Japan in 2007 using sewage sludge[59]. Summing up it can be said that Mitsubishi offers a broad portfolio for biomass electricity generation but despite the highlighted importance in presentations no clear strategy could be seen so far.

3.4.4 Summary

MHI is a highly interesting study subject. In contrast to all other competitors, the group has so far developed major renewable technology from within i.e. without major acquisitions. Additionally MHI can build upon the longest tradition in renewable energy. However, reviewing its market position no single leadership topic can be found. At this point it has to be stressed that MHI is however a leader in geothermal power generation – which has not been highlighted here due to the scope of this paper.

Figure 72 Summary of MHI's renewable portfolio

	Organization	Importance	Business Model	History
Wind Power	Own	⇧	Product / system supplier	Own development since 1980
Solar Power – CSP	Own	⬀	Product / system / EPC	First installation in 1981 Currently one test facility in Australia
Solar Power – PV	Own	⇨	Product / system	Start in 2002, currently cooperation with Taiwanese company to bring costs down
Hydro Power	Minority share in JV	⇩		Brought in hydro business in JV with Mitsubishi Electric and Toshiba
Biomass	Own	⇨	Product / system / EPC	References in cogeneration and biomass integrated IGCC Recently developed gasification technology for chemical industry Gas engines – long standing business

Source: own representation & evaluation

From the author's perspective it will be highly interesting to further see whether MHI will eventually become a major player in any of the renewable energy fields or whether it stays a player in the nuclear and conventional power plant world.

[59] http://www.mhi.co.jp/en/products/detail/mitsubishi_biomass-coal_system.html accessed on 24 September 2011

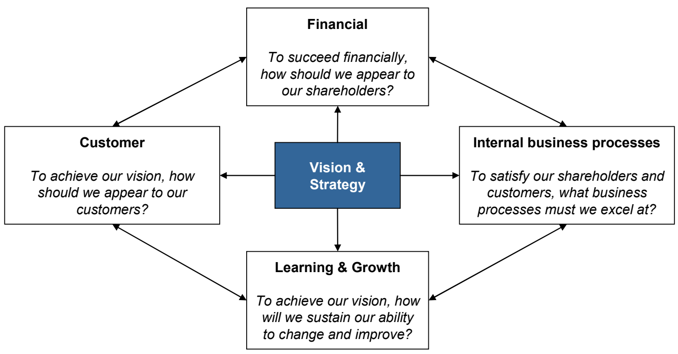
4 The Renewable BSC

So far this paper has analyzed the different renewable electricity generation technologies as well as the world's most important power technology providers. The consequent next step is to introduce the framework in which these companies will be analyzed and compared. Frequently, large corporations engage in benchmarking activities to analyze their competitive situation compared to their most important competitors. Therefore also this paper will rely on this method for the sake of comparability. As there is not only one dimension where the corporations in focus shall be compared an order giving framework shall be applied that is normally used as a company internal tool for strategic controlling activities. The following chapter is hence dedicated to give an introduction into the BSC principles and dimensions and to further analyze the companies on the basis of the presented framework.

4.1 Balanced Scorecard

The Balanced Scorecard was pioneered by Kaplan & Norton (1996) who proposed this framework to directly translate strategies into operative decision making and to provide the responsible managers with a multi-dimensional environment to give them early warning indicators in pursuing their strategies on a regular basis. Their concept of a balanced scorecard involved four dimensions, each with specific questions a company should pose when drafting and reviewing the BSC.

Figure 73 Balanced Scorecard dimensions



Source: Kaplan & Norton 1996, p. 76

The consequent next step is to adapt the BSC dimensions to the required business environment. Therefore, the following sections are dedicated to answer two main questions – what will be measured and compared and how will it be measured. In each of the following section the Key Performance Indicators for each dimension will be explained followed by a description how they are measured and visualized.

4.1.1 Financial

Renewable energy is seen in this paper (and as evidenced by the growth prospects laid down earlier) as growth areas. For growth companies Kaplan & Norton (1997, pp. 50) suggest different KPIs than for companies or products in a more mature stage (e.g. share of new products in sales). The financial dimension of the Renewable BSC will therefore be dedicated to answer the following questions:

1. Which importance does renewable energy have in the company's power technology sales?
2. Which rank does the company's renewable energy business have compared to the other competitors?
3. How financially successful is the power technology business for the company?

4.1.1.1 Importance of renewable in the company's power technology sales

The Key performance indicator shall reflect the importance of renewable sales in % of the overall power technology sales of the company. As could be observed in the depiction of the companies in focus, several companies (Siemens, Alstom) also account their grid business to the overall energy business. In the light of this paper, only the sales generated from power production and the related service business shall be considered. Therefore the KPI shall be calculated as follows:

Renewable Sales / Overall power technology sales
(excl. T&D business, incl. service)

Besides the benchmarking perspective that compares one company to the other, the main underlying question from this paper's view is: are the sales of power technology companies reflecting the current share of renewables in the newly installed capacity? Therefore for the focus of this paper the initially mentioned share of 47% share of renewable capacity additions shall be taken as the target. The current share of electricity generation from renewable sources shall be taken as the lower limit in the evaluation - 18%. In order to visualize the achievement of this target a traffic light systematic will be used with the following interpretations:

Table 14 Traffic light system for renewable energy share

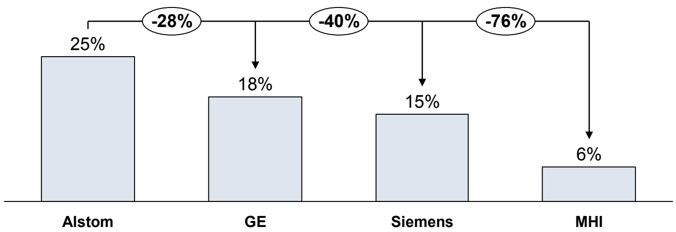
Renewable share ≥ 47%	Renewable share ≥ 18%	Renewable share <18%

Source: own representation

4.1.1.2 Rank in renewable energy sales

For this indicator the above defined sales volume is taken and compared to the other competitors. Again a traffic light shall signal the performance of each company. In order to allow for a more differentiated picture the ranking of the companies according to their global installed base shall be considered. The interesting point to study is in how far this picture is again reflected in the overall sales or whether a company can actually outperform its traditional position in the renewable field. The figure below states the overall share of the competitors in the global installed base, as well as the relative difference to the company with the biggest installed base – Alstom.

Figure 74 Market share of installed base



Source: own calculation based on Stahl 2010, p. 21

The key question is therefore whether this relation is also reflected in the direct comparison of the companies' renewable energy sales. Again a traffic light system will be used to depict the different positions:

Table 15 Traffic light system for rank in renewable energy sales

<-5% pts difference to installed base	<-20% pts difference to installed base	>-20% pts difference to installed base

Source: own representation

4.1.1.3 Profitability of power technology business

Unfortunately, not all companies are disclosing information on the profitability performance of their renewable energy business. Therefore only the profitability of their power technology sales shall be compared. Green will be used for above-average performance, yellow for below-average and red for an operative loss.

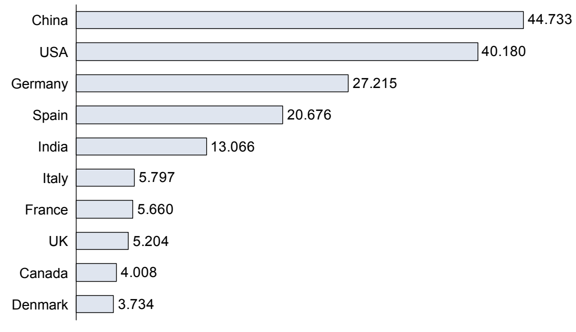
4.1.2 Internal business processes

For the internal business processes, according to Kaplan & Norton (1997, pp. 89), the management should identify those processes that are key to reach the goals of customers and owners of the company. With reference to the business processes the renewable BSC shall focus on two elements – the manufacturing footprint and R&D centers. Both are integral part of the value chain for renewables the first to allow for cost effective supplies to the target market and to cater for local content requirements, the latter to ensure that products are being developed according to local needs but also to leverage more favorable factor costs. In order to consider the multiple organization forms that the companies have in practice to enable local manufacturing and local design, both directly owned organizations, licensees and joint ventures are being considered. In order to qualify for a manufacturing or R&D footprint also a clear development plan shall be considered if production or start of research is planned to be in 2013 (dedicated plan also has to name the site and clarify the timeline).
The performance of each power technology supplier shall be measured compared to the most important markets for the specific renewable technology. This means that for each renewable energy source described in this paper, the most important markets are being highlighted. With reference to targets – again a traffic light systematic will be used. The ideal organizational set up will hence mirror the market situation. As the market differs for the specific renewable energy sources, the metrics will be defined for each technology separately. As such, the following sections will help to determine the target markets and the ranking criteria.

4.1.2.1 Wind power markets

According to the World Wind Energy Association (WWEA), the most important markets for wind power, according to their total capacity are: China, USA, the EU and India.

Figure 75 Installed wind power generation capacity 2010 (in MW)



Source: WWEA 2011a, p. 8

Consequently, the organizational setup of the companies in focus shall be measured against these 4 regions. The following traffic light systematic shall be applied to measure the performance of the companies:

Table 16 Traffic light system for market footprint in wind power business

Max. 1 market w/o footprint	Max. 2 markets w/o footprint	> 2 markets w/o footprint

Source: own representation

4.1.2.2 Solar power – PV markets

When it comes to photovoltaic, we have to draw a different picture on the basis of the technology. Meanwhile PV modules have been largely standardized and are easy to ship worldwide. Therefore, the manufacturing closeness to the consumption market is not seen as important as the possibility to take advantage from low factor costs. This has been seen in the rise of Chinese panel producers entering the market recently and the consequent decline of PV module prices globally. For the sake of comparison we will hence compare whether the company has a low cost manufacturing site for PV. As high cost the following markets shall be defined: EU15 + Switzerland, USA & Canada, and Japan. The traffic light systematic will hence look the following way:

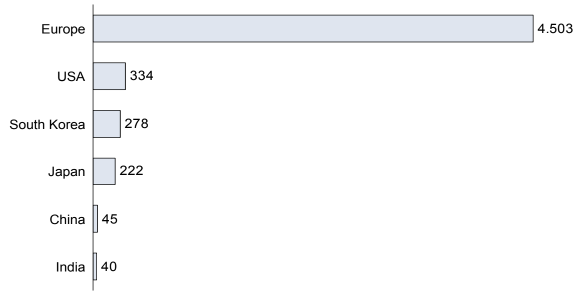
Table 17 Traffic light system for manufacturing footprint in PV

>50% of manufacturing capacity in low cost	<50% of manufacturing capacity in low cost	No manufacturing capacity in low cost

Source: own representation

With reference to the R&D locations, the comparison will have the same systematic as the wind power industry. The key markets for PV, according to the European Photovoltaic Industry Association (EPIA) are: the EU, USA and Japan. With reference to growth potentials, EPIA sees the largest growth potential in China, with India strong lagging behind and coming only in 2013 to the current level of today's demand in Japan (EPIA 2009, p 12).

Figure 76 New installed PV capacity in 2008 (in MW)



Source: EPIA 2009, pp. 13

The organizational setup of R&D will be measured against the 6 target countries, with the following traffic light systematic:

Table 18 Traffic light system for R&D footprint in PV business

Max. 2 market w/o footprint	Max. 3 markets w/o footprint	> 3 markets w/o footprint

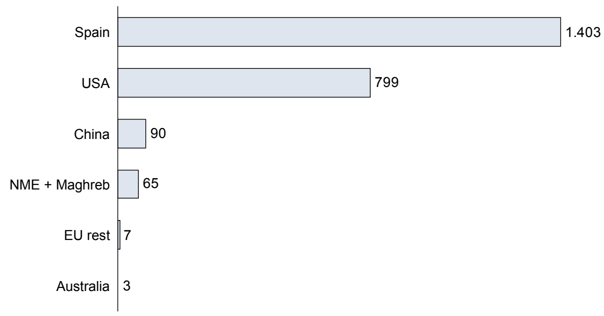
Source: own representation

Due to the special conditions of the Japanese market and the currently low demand in China and India the rating scale has been adjusted accordingly to allow for more markets to be missed in the traffic light systematic.

4.1.2.3 Solar power – CSP markets

CSP applications are restricted to the sunbelt. Therefore the organizational footprint has to be considered along this parameter as well as the current use of CSP worldwide. Consequently, the footprint will be challenged with the help of the current demand. For the manufacturing footprint the turbines will not be regarded as their coverage is rather big for most of the competitors, hence only the CSP specific products (e.g. collectors) are considered. As R&D locations in this field, also test facilities and local cooperation are to be considered. With reference to the current demand, the following picture can be seen:

Figure 77 CSP capacity in 2010 – in operation or currently being built (in MW)



Source: Gesthuizen 2010, pp. 94

Accordingly the countries relevant for the footprint will be: EU, USA, Near Middle East / Maghreb and China – India shall be added due to the massive growth plans in CSP of 20 GW by 2020 (Gesthuizen 2010, p. 100). For the comparison the same traffic light systematic as with PV R&D facilities will be adapted for the footprint for CSP.

Table 19 Traffic light system for manufacturing and R&D footprint in CSP business

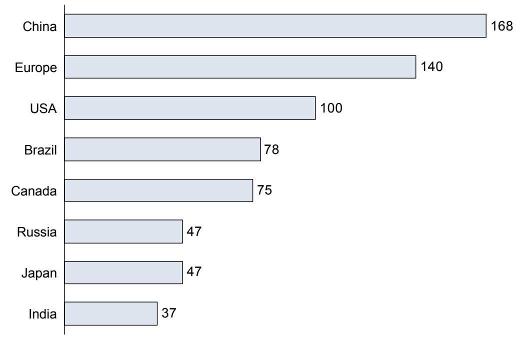
Max. 2 market w/o footprint	Max. 3 markets w/o footprint	> 3 markets w/o footprint

Source: own representation

4.1.2.4 Hydro power markets

For the hydro power market small hydro and large hydro are not differentiated. The most important markets for this type of electricity generation are: China, North America (USA & Canada), Europe, Brazil, Russia, India and Japan.

Figure 78 Installed hydro power capacity – 2008 (in GW)



Source: IEA 2011a, p. 19, European Commission 2010, p. 70

With reference to the manufacturing footprint the following traffic light systematic shall be applied:

Table 20 Traffic light system for manufacturing footprint in hydro power business

Max. 1 market w/o footprint	Max. 2 markets w/o footprint	> 2 markets w/o footprint

Source: own representation

As hydro power can be seen as a mature market with reference to the technology, the evaluation of R&D centers shall be loosened and applied as follows:

Table 21 Traffic light system for R&D footprint in hydro power business

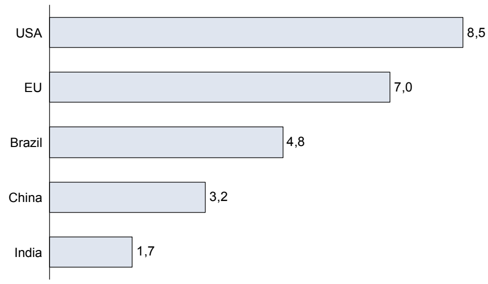
Max. 3 market w/o footprint	Max. 4 markets w/o footprint	> 4 markets w/o footprint

Source: own representation

4.1.2.5 Biomass markets

With reference to the biomass market, the 5 most important regions account for ~50% of biomass power capacity (REN21 2010, p. 18). In total it has to be stated that the electricity generation from biomass is difficult to pinpoint to single countries as the generation is highly fractured and often characterized by very small installations. The key markets for comparison are hence, the US, the EU, Brazil, China and India.

Figure 79 Installed biomass power capacity – 2009 (in GW)



Source: REN21 2010, p. 18

With reference to the manufacturing footprint the following traffic light systematic shall be applied:

Table 22 Traffic light system for footprint in biomass power business

Max. 1 market w/o footprint	Max. 2 markets w/o footprint	> 2 markets w/o footprint

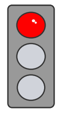
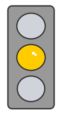
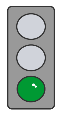
Source: own representation

4.1.3 Learning & Growth – innovation

For this BSC dimension a look has to be done on one of the initial targets of the paper – to highlight in how far established power technology suppliers can also have a positive impact on renewable energy. Hence, this dimension shall be seen under the focus topic of innovation, i.e. in how far the companies in focus are addressing the key innovation topics defined in chapter 2 of this paper. The focus on innovation is in line with Kaplan & Norton's (1997, pp. 121) view of this dimension – although they strongly argue that not only R&D but also employee potentials, motivation and empowerment and the required infrastructure should be part of this dimension. For the focus of this paper only the innovation focus will be stressed. Due to the difficulty to quantify innovation topics, a qualitative approach will be used again, reflecting whether the companies in focus are actually engaged in this specific innovation field. The basis of the evaluation will be the four stages of a technology's lifecycle that Grübler & Gritsevskyi (2002, pp. 282) built upon the works of Schumpeter: invention (first demonstration of feasibility), innovation (first regular production), niche markets (customer interaction and feedback) and diffusion (broad market acceptance and industrialization of production).

These four steps shall be transferred into a "digestible" traffic light system according to the following criteria set:

Table 23 Innovation evaluation criteria

	Achievements of the company	Evaluation
Not on innovation agenda	▪ No plans regarding this innovation field	
Test facility planned	▪ Topic on innovation agenda ▪ First concept developed	
Invention	▪ Feasibility clarified ▪ Product roadmap is detailed and communicated	
Innovation	▪ First product launch defined ▪ Test facility is running <1 year	
Niche markets	▪ Product is available ▪ Test facility running >1 year	
Diffusion	▪ Product is in commercialization stage ▪ Production scaled up ▪ Several orders in house and currently in execution	

Source: own representation

Although it might be interesting to take a deep look into each innovation topic and the performance of the market competitors, this detailed look, this paper will provide an overview. As the evaluation systematic will be the same for all technologies in focus, the innovation areas shall be summarized in the table below:

Table 24 Innovation areas for BSC evaluation

	Innovation areas
Wind	▪ Increasing turbine capacity (>5 MW) ▪ Gearless drive concept
Solar – CSP	▪ Molten salt ▪ Deployment of different technologies (Parabolic Trough, Solar Tower, Dish, Fresnel) ▪ Integrated solar-thermal-combined-cycle-plants (ISCC)
Solar – PV	▪ Thin film ▪ Combination of PV and residential heating ▪ High efficiency cells ▪ Concentrating PV
Hydro	▪ Wave power ▪ Tidal power ▪ Ocean Thermal Energy conversion ▪ Salinity Gradient
Biomass	▪ "BIGCC" – Biomass Integrated Gasification Combined Cycle ▪ Organic rankine cycle

Source: own representation

4.1.4 Customer

The final dimension brings the key question: how did the customers accept the companies' portfolios and have they been able to acquire a significant market share. The paper has started with the paradigm of choosing the world's most important power technology company as the candidates for evaluation. The evaluation of their performance has to acknowledge their status in the overall power technology market. Consequently, to be successful must mean that each company will have a similar market share rank in the respective renewable energy technology as it has in the overall market. Therefore the evaluation systematic shall be designed as follows:

Table 25 Traffic light system for market position

#1-3 in the market	#4-10 in the market	>#10 or no position at all

Source: own representation

4.2 Balanced Scorecard – results calculation

The following section shall be dedicated to the calculation of the BSC results and the interpretation of the results with the perspective on each single KPI. The overall picture of the BSC for each company shall be discussed in the next chapter.

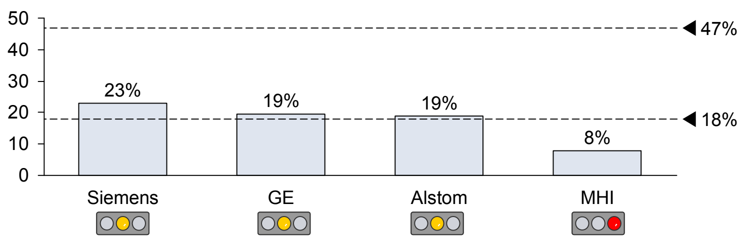
4.2.1 Financial

In this section the KPIs summarized in the financial dimension shall be calculated and interpreted.

4.2.1.1 Importance of renewable in the company's power technology sales

Based on the definition above it can be clearly seen that none of the four companies in focus has a renewable share in the area of the target range. MHI is the low light, with a share of only 8% of renewables in its current power technology sales.

Figure 80 KPI Importance of renewable in power technology sales

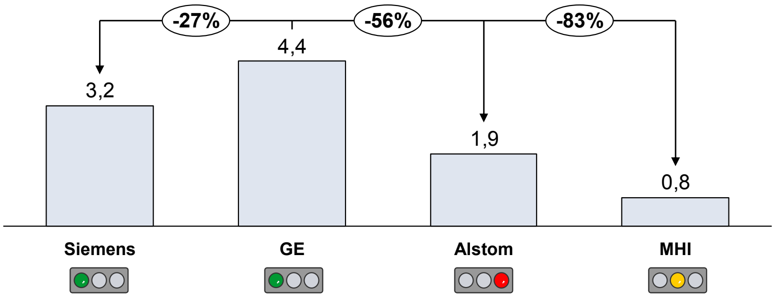


Source: own representation & calculation

4.2.1.2 Rank in renewable energy sales

The reference point for the comparison in renewable energy sales is not Alstom but GE as the company has the largest sales figure in the renewable power technology business. To allow for the comparison all sales have been recalculated in EUR based on the 2y average of the exchange rate, published by the ECB for USD[60] and for JPY[61]. This KPI shows clearly that GE and Siemens could turn around their positions, while MHI could again not reposition itself significantly whereas Alstom heavily lost ground in the renewable energy business, despite its good position in hydro business.

Figure 81 KPI rank in renewable energy sales (in bn. EUR and %)

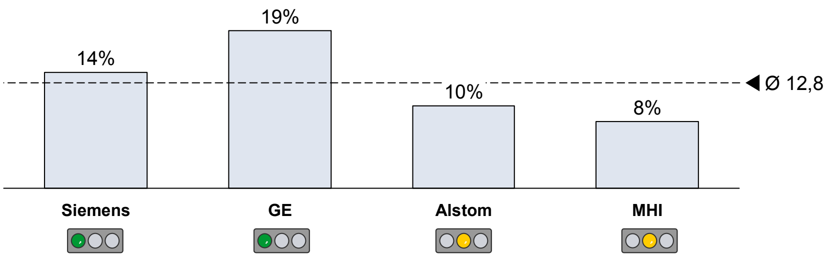


Source: own calculation and representation

4.2.1.3 Profitability of energy business

With reference to the profitability of the energy business, it can be observed that GE has the most profitable energy business, followed by Siemens. MHI is the low performer in the group of companies that are investigated in this paper. It has to be stated though that these figures do not represent the renewable energy profitability as they are not published officially except for Siemens.

Figure 82 KPI profitability of energy business (in %)



Source: own representation, based on company annual reports

[60] http://www.ecb.int/stats/exchange/eurofxref/html/eurofxref-graph-usd.en.html accessed on 29 October 2011
[61] http://www.ecb.int/stats/exchange/eurofxref/html/eurofxref-graph-jpy.en.html accessed on 29 October 2011

4.2.2 Internal business processes

After having reviewed the financial dimension, the internal business processes shall be highlighted with the clear focus on the manufacturing and R&D footprint of the companies.

4.2.2.1 Wind power market footprint

In wind power we again see the domination of Siemens and GE, who have actually set up or have revealed concrete plans to set up manufacturing locations in all of the key markets. Alstom has so far announced plans to locate manufacturing to India or China but has so far not revealed concrete plans to do so. Mitsubishi's manufacturing backbone is in Japan and the US, with some license agreements (as mentioned earlier) in China. In the light of the offshore activities Mitsubishi announced further activities in the UK but has so far not delivered concrete plans. This leads to the following evaluation picture:

Table 26 Wind power – manufacturing footprint

	China	USA	EU	India	Evaluation
Siemens	✓	✓	✓	✓	🟢⚪⚪
GE	✓	✓	✓	✓	🟢⚪⚪
Alstom		✓	✓		⚪🟡⚪
MHI	✓	✓			⚪🟡⚪

Source: own research, Koenemann 2010, pp. 158

With reference to the R&D locations, a similar picture can be seen again, with the only exception of an even worse situation for MHI which is mainly due to the fact that the Chinese footprint is due to a license agreement but lacks R&D resources for this market.

Table 27 Wind power – R&D footprint

	China	USA	EU	India	Evaluation
Siemens	✓	✓	✓	✓	🟢⚪⚪
GE	✓	✓	✓	✓	🟢⚪⚪
Alstom		✓	✓		⚪🟡⚪
MHI			✓		⚪⚪🔴

Source: own research

4.2.2.2 Solar power – CSP market footprint

For the CSP market footprint the KPI will not focus on the turbine as all companies in focus have globalized their production of turbines. Hence, the manufacturing map of the specific CSP equipment is as follows:

Table 28 Solar power – CSP manufacturing footprint

	China	USA	EU	India	NME & MAGHREB	Evaluation
Siemens			✓		✓	
GE		✓				
Alstom		✓				
MHI						

Source: own research

The picture shows clearly the early phase of this technology when manufacturers have started the commercialization and not have gone into massive internationalization of their supply chain which is also reflected by the concentration of the current market to Spain and the USA.

GE and Alstom's locations are based on the companies' investments in CSP as they do not possess own specific manufacturing resources in the required fields.

With reference to the R&D footprint it can be seen that Alstom and Siemens have the broadest set up in both R&D facilities as well as installed reference plants. Alstom's broad set up mainly stem from its engagement in Bright Source. Again, MHI is currently only present in Japan and Australia, both are not part of the focus market selection. In China and India plants are lacking and therefore the companies have also not invested in any R&D activities so far.

Table 29 Solar power – CSP R&D footprint

	China	USA	EU	India	NME & MAGHREB	Evaluation
Siemens		✓	✓		✓	
GE		✓	✓			
Alstom		✓	✓		✓	
MHI						

Source: own research

4.2.2.3 Solar power – PV market footprint

Only two companies are actually producing PV panels, GE and Alstom. Hence only the two companies can be compared in terms of manufacturing. Both companies are actually evaluated based on their plans – GE to open a 400 MW facility in the US and MHI to cooperate with a Taiwanese company. However, it can be seen that GE only has high cost production for PV cells and MHI has actually leveraged its location advantage to start cooperation in a low cost country. As far as Siemens is concerned – the company has concluded a framework contract with the world's largest PV producer – Suntech, in so far the company can be seen to leverage low cost panel production as Suntech's production mainly stems from China.

Table 30 Solar power – PV manufacturing footprint

	High Cost	Low Cost	Evaluation
Siemens	n/a	n/a	n/a
GE	100% (~400 MW)		
Alstom	n/a	n/a	n/a
MHI	43% 50 MW	57% 65 MW	

Source: own research

As far as R&D is concerned Siemens shall be in focus again as the company provides PV power plants on a turnkey basis. With respect to the R&D arena a clear concentration of the companies on their home market can be seen, suggesting that PV does either not require global R&D or another proof point of the weak market position of the companies in focus. The only exception is GE that has leveraged its various R&D centers for its future plans in PV.

Table 31 Solar power – PV R&D footprint

	China & Taiwan	USA	EU	India	Japan	Korea	Evaluation
Siemens			✓				
GE		✓	✓	✓			
Alstom	n/a	n/a	n/a	n/a	n/a	n/a	n/a
MHI	✓				✓		

Source: own research

4.2.2.4 Hydro power market footprint

The hydro power manufacturing footprint seems to reflect the maturity of this market. Production is not concentrated to some markets but is internationalized. This is reflected by the position of Siemens via its minority JV with Voith Hydro as well as Alstom's position. MHI has so far not reached a significant leverage.

Table 32 Hydro power manufacturing footprint

	China	USA / CAN	Brazil	EU	Russia	India	Japan	Evaluation
Siemens (Voith Hydro)	✓	✓	✓	✓	✓	✓	✓	🟢
GE	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Alstom	✓	✓	✓	✓	✓	✓		🟢
MHI (HM Hydro)							✓	🔴

Source: own research

The R&D footprint shows a more diverse picture, where Voith and Alstom pursue different approaches. Whereas Voith is strongly focused on the EU and the Americas, Alstom increased its R&D presence in the upcoming growth markets India and China in 2008 and 2010 respectively. MHI again is only focused on its core market Japan.

Table 33 Hydro power R&D footprint

	China	USA / CAN	Brazil	EU	Russia	India	Japan	Evaluation
Siemens (Voith Hydro)		✓	✓	✓				🟡
GE	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Alstom	✓			✓		✓		🟡
MHI (HM Hydro)							✓	🔴

Source: own research

4.2.2.5 Biomass power market footprint

In biomass a clear manufacturing concentration in the US and the EU can be seen. No company is actually addressing Brazil and China and India are also addressed in a limited way.

Table 34 Biomass power manufacturing footprint

	USA	EU	Brazil	China	India	Evaluation
Siemens	✓	✓			✓	🟡
GE	✓	✓		✓		🟡
Alstom		✓				🔴
MHI	✓					🔴

Source: own research

As far as the R&D facilities are concerned the global spread shrinks even more. Electricity generation from biomass can have various forms and is dependent on highly different input materials as well as infrastructural conditions, therefore it is worth noting that obviously the large technology suppliers have a rather limited focus on these differences, with Siemens being the only company that actively pursues R&D outside the established markets USA and EU.

Table 35 Biomass power R&D footprint

	USA	EU	Brazil	China	India	Evaluation
Siemens		✓			✓	🔴
GE	✓	✓				🔴
Alstom		✓				🔴
MHI						🔴

Source: own research

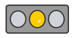
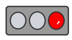
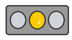
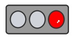
4.2.3 Learning & Growth – innovation

In the preceding section the R&D footprint has already been touched. Besides the geographical spread of research resources the next question is in how far the main innovation topics in electricity generation from renewables are tackled by the companies in focus.

4.2.3.1 Wind power innovation

The first topic to address will be the development of a >5 MW turbine specifically for offshore applications. Although all companies have communicated plans to be active in the development of a >5 MW offshore turbine only Siemens and Alstom have managed to build a prototype so far. MHI is currently developing the product, whereas GE has recently withdrawn from the offshore turbine market and has not yet specified its future strategy towards >5 MW turbines.

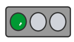
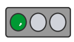
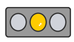
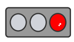
Table 36 Development of offshore turbine >5 MW

	Achievement	Evaluation
Siemens	▪ 6 MW gearless offshore wind turbine ▪ Prototype in operation since 06 2011 in Høvsøre (DK)	
GE	▪ Plans to develop 10-15 MW turbine announced ▪ Recent retreat from offshore activities (09 2011)	
Alstom	▪ 6 MW gearless offshore wind turbine ▪ Prototype currently being assembled	
MHI	▪ 5-7 MW gearless offshore wind turbine ▪ Market launch planned for 2015 – no prototype ready	

Source: own research

When it comes to the gearless drive concept it can be observed that this technology, pioneered by German Enercon has arrived to all companies in focus. Siemens and GE are the only companies who are already selling these types whereas Alstom and MHI have not delivered these concepts to concrete projects so far.

Table 37 Development of gearless wind turbines

	Achievement	Evaluation
Siemens	▪ Gearless 3 MW turbine with permanent magnet generator (+ 2.3 MW prototype installed) ▪ Commercial production since 2011	
GE	▪ Direct drive 4 MW turbine (offshore applications) ▪ 113 wind turbines in operation globally	
Alstom	▪ 6 MW gearless offshore wind turbine ▪ Prototype currently being assembled	
MHI	▪ 5-7 MW gearless offshore wind turbine ▪ Market launch planned for 2015 – no prototype ready	

Source: own research

4.2.3.2 Solar power – CSP innovation

Energy storage via molten salt is addressed by all companies except for MHI. The reason that GE's is currently rated "red" is that there are no concrete go to market plans and no communicated technological readiness by eSolar.

Table 38 Development of molten salt energy storage for CSP plants

	Achievement	Evaluation
Siemens	▪ Molten salt test facility in Sicily (since 2010) ▪ Further test facility in Portugal opened in 2011	
GE	▪ eSolar with funding to investigate molten salt storage ▪ GE and KLGA invested >100 mio USD in stake in molten salt CSP plant in Spain	
Alstom	▪ Bright Source developed molten salt storage concept ▪ Concept is integrated in design but not realized in a project	
MHI	▪ No activities on molten salt	

Source: own research

With reference to the further development of the different CSP technologies a clear clustering can be seen. Whereas Siemens currently is following the parabolic trough concept via its acquisitions all other competitors currently engage in the solar tower technology. It has to be noted that only component delivery such as steam turbines have not been considered as a commitment by the company to bring the technology itself further. What can further be seen is that all references stem from recent acquisitions except for MHI. MHI has been evaluated with a "yellow" mark due to the fact that the company's experience in solar tower technology stems from the 80s and the new test facility is currently being built up. When it comes to the concepts of Dish and Fresnel plants, it can be observed that none of the companies has so far has shown significant interest. This supports the assumption that the commercial break through is evaluated to come from parabolic trough or solar tower projects.

Table 39 Company engagement in CSP technologies

	Parabolic Trough	Tower	Dish	Fresnel
Siemens	▪ Several references via SOLEL	▪ Supply of steam turbines	▪ Supply of gear drives	▪ Supply of steam turbines
GE	▪ Supply of steam tubines	▪ eSolar Sierra Sun Tower Project	▪ -	▪ Supply of steam turbines
Alstom	▪ Supply of steam turbines	▪ Several references via Bright Source	▪ -	▪ Supply of steam turbines
MHI	▪ Supply of steam turbines	▪ In operation 1981-1983 ▪ Test facility in AUS	▪ -	▪ -

Source: own research

With the exception of GE no company has so far announced to build a complete ISCC neither alone nor with partners. This is astonishing as Siemens as well as Alstom would be – looking on their portfolio – capable of taking this step.

Table 40 Company engagement in ISCC

	Achievement	Evaluation
Siemens	▪ Supply of gas turbines and steam turbines for projects in Egypt & China ▪ Newly acquired NEM provided HRSG for Kuraymat project ▪ SOLEL with integrated portfolio for CSP generation ▪ No activities announced to build ISCC power plant	
GE	▪ Announced ISCC power plant in Turkey operating by 2015 ▪ eSolar with integrated portfolio for CSP generation ▪ Several references for component supply (e.g. Egypt)	
Alstom	▪ Supply of gas turbines and steam turbines for projects in Morocco ▪ Bright Source with integrated portfolio for CSP generation ▪ Own HRSG competency in house (however no reference) ▪ No activities announced to build ISCC power plant	
MHI	▪ Supply of steam turbines for project in Morocco ▪ No activities announced to build ISCC power plant	

Source: own research

4.2.3.3 Solar power – PV innovation

With reference to PV and the identified innovation fields it can be observed that the companies in focus only have a limited interest in the PV industry from a product perspective. GE and MHI are pursuing their thin film engagements, whereas Siemens (as EPC provider active in the PV market) has just entered the Concentrated PV market via a minority stake in Semprius. Alstom has not reported any activities in the PV module business so far. In total the picture is not surprising given the small market share the companies in focus have in the PV industry.

Table 41 Company engagement in PV innovation topics

	Thin Film	PV & solar heat	High eff. cells	Concentrating PV
Siemens	▪ -	▪ -	▪ -	▪ Investment in Semprius
GE	▪ Acqusition of Prime Star Solar ▪ New facility	▪ -	▪ -	▪ -
Alstom	▪ -	▪ -	▪ -	▪ -
MHI	▪ Capacity expansion	▪ -	▪ -	▪ -

Source: own research

4.2.3.4 Hydro power innovation

As has been stated before, hydro is seen as the most mature market of the renewable energy business. Hence the innovation focus will lie on the new technology fields in ocean and tidal power. As could be seen in the manufacturing footprint, Siemens (alone and via its JV with Voith Hydro) and Alstom are the most active companies in the investigated fields. Additionally, it has to be noted that only two technologies have attracted the companies' attention – wave and tidal power.

Table 42 Company engagement in ocean and tidal power innovation topics

	Wave Power	Tidal Power	Ocean Thermal	Salinity Gradient
Siemens	▪ Voith Hydro ▪ 10y test facility & first commercial plant in 2011	▪ 10% stake in Marine Current Turbines ▪ 1.2MW tidal energy convertor since 2008	▪ -	▪ -
GE	▪ Minority share in Pelamis ▪ Several test facilities	▪ -	▪ -	▪ -
Alstom	▪ AWS – product roadmap defined	▪ License from Clean Current ▪ Test facility since 2006	▪ -	▪ -
MHI	▪ -	▪ -	▪ -	▪ -

Source: own research

4.2.3.5 Biomass power innovation

With reference to the biomass innovation field BIGCC it can be observed that all major players are active in the IGCC business. When it however comes to the specific needs of BIGCC all companies claim to have the necessary turbines but only Siemens and MHI have developed (although not broadly operative in projects) own gasifier systems. In the case of ORC only Siemens and GE report activities, GE with own resources and Siemens via a minority investment in Maxxtec.

Figure 83 Company engagement in biomass power innovation topics

	BIGCC – Gasifier	BIGCC – Turbine	ORC
Siemens	▪ Gasifier marketed for coal ▪ Usage in biomass communicated and tested but not sold	▪ Several gas turbines in the market	▪ ORC technology and components via minority stake in Maxxtec ▪ Turbines available
GE	▪ Only support of research activities of external company	▪ Jenbacher gas engines ▪ GE small sized gas turbines	▪ ORC test facility for waste heat recovery
Alstom	▪ No product	▪ Several gas turbines in the market	▪ -
MHI	▪ Biomass gasifier currently in test facility ▪ Main focus: ethanol	▪ Several gas turbines in the market	▪ -

Source: own research

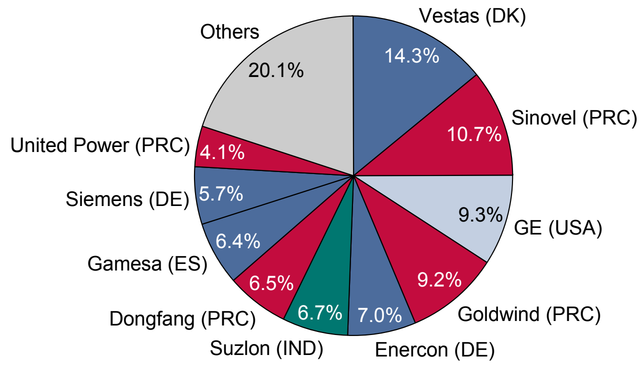
4.2.4 Customer

For this dimension the market shares of the companies in the different renewable energy resources shall be investigated.

4.2.4.1 Wind power market shares

Looking at the 2010 wind power market share distribution it provides a remarkable picture. Out of the top 10 suppliers four actually are coming from China (with a 31% overall market share) which led to the situation that long term #2 GE has fallen back to #3, closely followed by Chinese Goldwind.

Figure 84 Global wind power market share 2010 (in %)



Source: REN 21 2011, p. 39

Based on this overall picture, the evaluation for the four companies looks the following way:

Table 43 Market share evaluation – wind power

	Market Share	Rank	Evaluation
Siemens	5.7%	9	
GE	9.3%	3	
Alstom	~2%	>10	
MHI	~2%	>10	

Source: own representation, REN 21 2011, p. 39

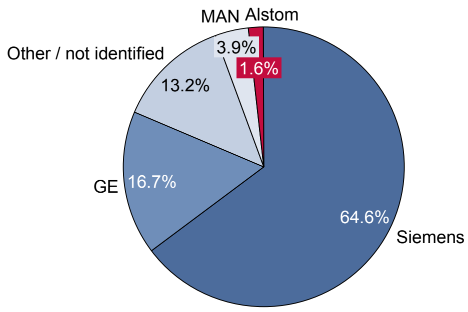
Only GE can hold its top ranking also in the wind power industry, whereas Siemens has even a hard time staying in the top 10. Alstom and MHI have only achieved meaningless market shares not allowing them to be even listed among the top 10 suppliers for wind turbines. What can be seen in this picture is that the large power technology suppliers of the past have obviously not anticipated the big boom of wind power and have therefore lost significant ground to new competitors, whose history was mainly built upon their wind competency (e.g. Vestas, Goldwind).

Given this picture it becomes obvious why Siemens and Alstom are mainly stressing their approach to offshore as this technology provides a larger entry barrier due to investment cost against other competitors. The following years will show whether the offshore market will really take off as predicted and whether Siemens, MHI and Alstom will be able to benefit also in times of market share and a consequent better position.

4.2.4.2 Solar power – CSP market shares

With reference to the CSP market (focus on turbine sales), the market dominance of the established power technology players comes back again. In particular Siemens has leveraged its industrial steam turbine to supply the majority of currently active projects. GE has recently increased its presence in the market, particularly in power tower projects. As only the newly built projects since 2005 have been considered, MHI is not part of the graph. MHI was heavily used in the CSP plants that were opened in the 1980s in the USA. However, there are no recent commercial CSP plants with an MHI turbine.

Figure 85 Global CSP market share 2010 (in %)



Source: own calculation and research based on NREL concentrated solar power projects database http://www.nrel.gov/csp/solarpaces/; only active installations are considered with operation start after 2005

The evaluation for the renewable BSC hence looks as follows:

Table 44 Market share evaluation – solar power – CSP

	Market Share	Rank	Evaluation
Siemens	65%	1	green
GE	17%	2	green
Alstom	2%	≥4	yellow
MHI	-	-	red

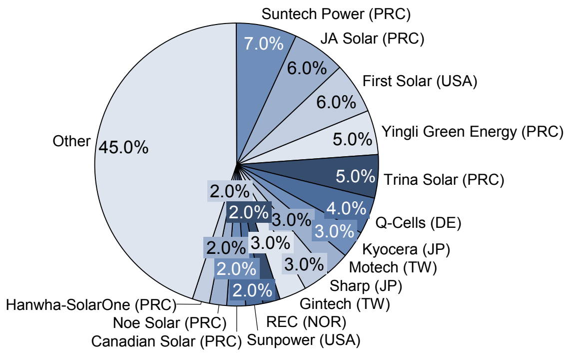
Source: own representation and research

As the current CSP market is at a rather low level, the future market share distribution is expected to be changing in the upcoming years, especially under the light of the recent acquisitions and investments performed by GE and Alstom. What is notable in this respect is that for turbine sales the companies actually could build on their existing portfolio and adapt it with limited modifications to the new technology. This, and the condition that building a turbine from scratch is a high barrier for new entrants, could have been the reasons for the current competitive landscape in CSP turbine business.

4.2.4.3 Solar power – PV market shares

The PV module market is highly fragmented with the top 10 global suppliers accounting for less than 50% of the overall market. None of the companies in focus plays any role in a top position.

Figure 86 Global PV panel market share 2010 (in %)



REN 21 2011, p. 41

Also Siemens, although not active in the module production but in the EPC business cannot count on a significant market share given the newly installed capacity of 18 GW in 2010 and a total project volume of <100 MW.

Table 45 Market share evaluation – solar power – PV

	Market Share	Rank	Evaluation
Siemens	None	-	
GE	<1%	-	
Alstom	None	-	
MHI	<1%	-	

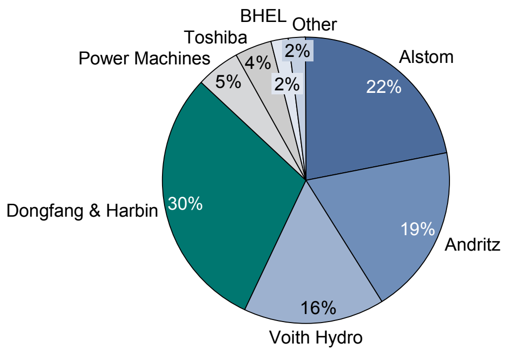
Source: own representation, REN 21 2011, p. 41

It is again outstanding that the PV module market has not at all been influenced or pioneered by the leading power technology suppliers although their other businesses have shown that they are able to engage in large scale production activities. Furthermore the rise of Chinese module producers is remarkable, with 4 of the global top 5 producers coming from China.

4.2.4.4 Hydro power market shares

In the hydro power market European companies are still dominating. However, recently Dongfang and Harbin are reported to have a market share of ~30% posing a significant competition statement to the established players.

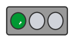
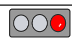
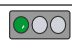
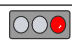
Figure 87 Global hydro power market shares (in %)



Source: estimation based on Alstom 2009c, p. 30; Andritz 2009, p. 6

With reference to the companies in focus of this paper it has to be stated that Alstom is the only company who has a strong market foothold on its own. GE has sold its business to Austrian Andritz and therefore has no market position at all. Siemens is only present via Voith Hydro and Mitsubishi's hydro business is not even considered in any market share overview.

Table 46 Market share evaluation – hydro power

	Market Share	Rank	Evaluation
Siemens	16% (via Voith Hydro)	3	
GE	-	-	
Alstom	22%	1	
MHI	<2%	-	

Source: own representation and research

4.2.4.5 Biomass power market shares

As the biomass market is so highly fragmented no reliable source or data could be delivered to support the market share analysis of biomass power market with a focus to electricity generation. Therefore this KPI is left out entirely.

5 Conclusion

The final chapter of this paper shall be divided into three sections – firstly the individual results of each company's Renewable BSC shall be interpreted, secondly the core questions shall be answered comparatively for the group of companies and thirdly these views shall be summarized and an outlook on future need of research shall be given

5.1 Renewable BSC conclusion – individual perspective

The results of the Renewable BSC shall be interpreted along the four dimensions. In the end the whole Renewable BSC will be presented showing the strengths and weaknesses of each company in focus with reference to its renewable energy strategy.

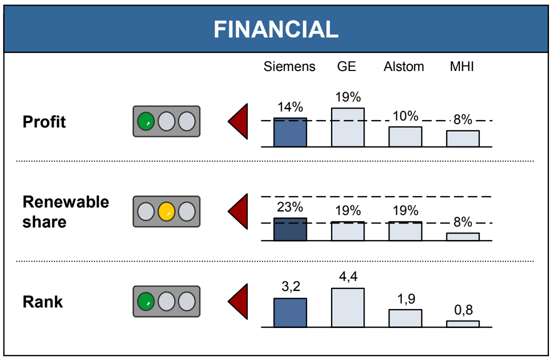
5.1.1 Renewable BSC – Siemens

Having both reviewed Siemens' way towards renewables as well as the company's performance on the BSC dimensions compared to its competitors the following section shall be dedicated to summarize its BSC specifically.

5.1.1.1 Siemens Renewable BSC – Financial dimension

Siemens is performing well in profit and rank. With reference to the according research questions: it can be seen that the Siemens has adapted its strategy toward the needs of renewables which can be seen by the renewables share that is higher than the current share of renewable electricity generation – however Siemens' sales do not reflect at all the current demand changes in the newly installed base. Siemens did not have to face a corresponding decline in profit but could maintain and even improve its profitability and is still more profitable than the average of the companies in focus. With reference to its relative market position compared to its competitors Siemens' renewable business puts the company in a better position in than its traditional business.

Figure 88 Siemens Renewable BSC – Financial dimension

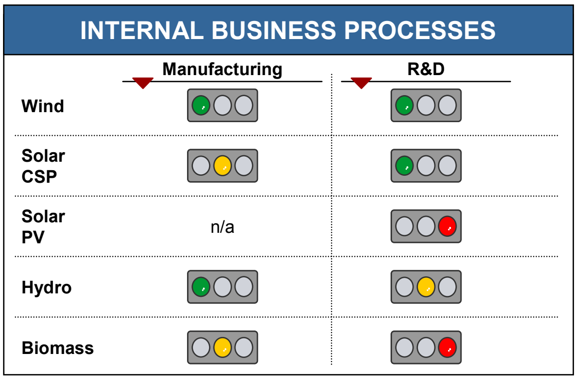


Source: own representation

5.1.1.2 Siemens Renewable BSC – internal business processes dimension

Siemens' track record in internationalizing its business is mixed. The company has achieved to significantly internationalize its wind business both in manufacturing as well as in R&D. A similar picture can be drawn in Solar CSP with the exception that due to the current market size no significant manufacturing is so far seen by any competitor. As Siemens does not produce PV modules itself only R&D activities can be seen – however they are centralized in Europe. In Hydro Siemens' JV with Voith proves to be a global player except for additional potential in internationalizing its R&D. With reference to biomass more globalization could be seen both in manufacturing as well as in R&D.

Figure 89 Siemens Renewable BSC – internal business processes dimension



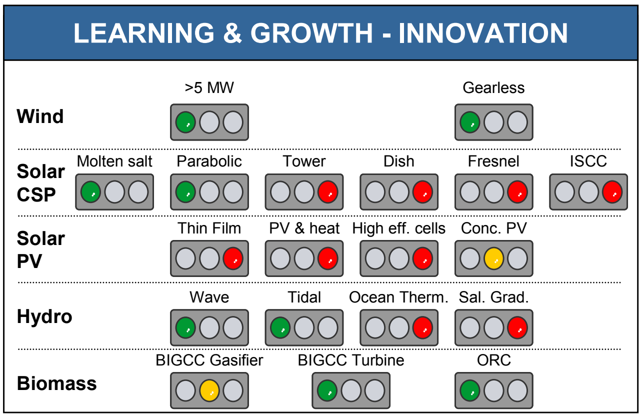
Source: own representation

So has Siemens arranged for the demand shift that has happened with respect to its global coverage? Definitely in the case of wind – for the other technologies Siemens has improvement potential in order to avoid losing ground against emerging competitors, as has been the case in its PV business.

5.1.1.3 Siemens Renewable BSC – learning & growth – innovation dimension

The Siemens renewable case has shown that one assumption of this paper is supported: that large companies are able to foster innovation and cost decrease with respect to internationalization and industrialization of businesses. This holds true for wind as well as CSP. But the Siemens case also highlights another topic – the basic technologies and basic innovations have not been derived from internal but through acquisitions from small to medium-sized (e.g. Bonus Energy, SOLEL,) or other large corporations (e.g. industrial steam turbine business of Alstom). With reference to the support of new innovative fields an overall positive picture can be drawn with gaps being in CSP technologies except for parabolic troughs, the PV area and ocean thermal and salinity gradient technologies.

Figure 90 Siemens Renewable BSC – learning & growth – innovation dimension



Source: own representation

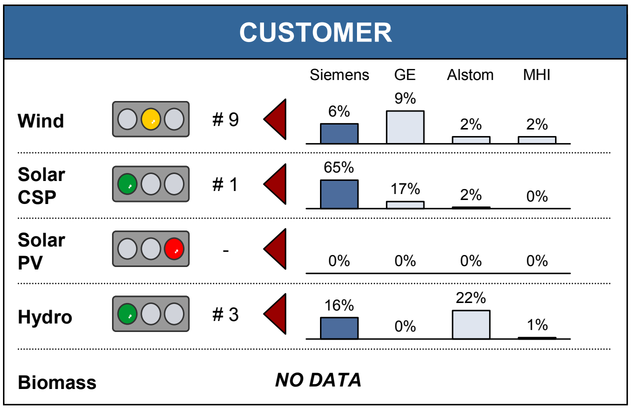
Summing up it can be said that Siemens supports the innovation in renewable areas, although it has to be stated again that this support mostly builds on technologies that Siemens has not developed originally.

5.1.1.4 Siemens Renewable BSC – customer dimension

The final dimension clearly shows the fierce competition in renewables that traditional power technology suppliers face. Siemens could only keep a top 3 ranking in two industries – solar CSP and hydro. This is in so far remarkable as the latter is due to the company's JV with Voith. Although Siemens claims to be the #1 in offshore applications, the company is only (compared to its usual strength in fossil fired applications) a medium sized player.

With respect to the research question for this dimension it can be summarized that Siemens could only transfer its dominance to the CSP market and hydro (one tiny market and the second only via a JV). Time will show in how far Siemens will actually keep its dominance in offshore power or if the company will also lose ground to the currently dominating companies.

Figure 91 Siemens Renewable BSC – customer dimension

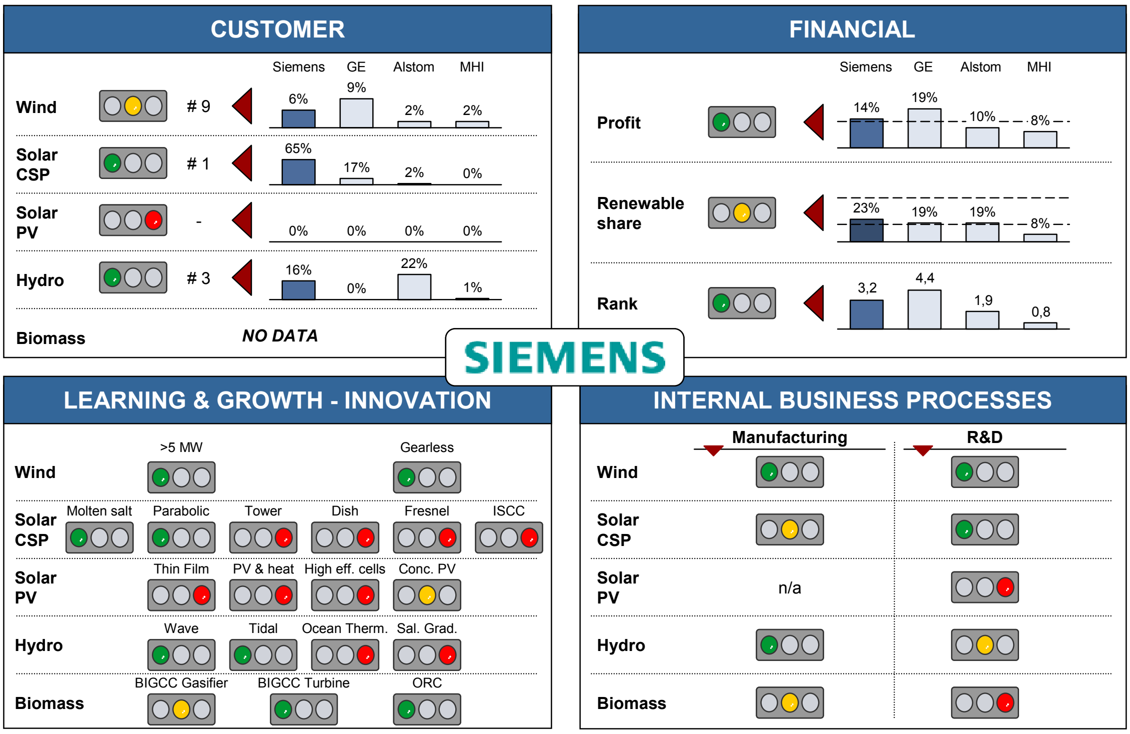


Source: own representation

5.1.1.5 Siemens Renewable BSC – summary

Summing up it has to be stated that Siemens has achieved several successes in niches – offshore and solar CSP, where the company is also driving innovation forward. In total, Siemens could not leverage its traditional strength and dominance to the renewables scene. The upcoming years will show in how far the company can regain dominance and strength via its broad portfolio offering that also includes e.g. transmission & distribution.

Figure 92 Siemens Renewable BSC



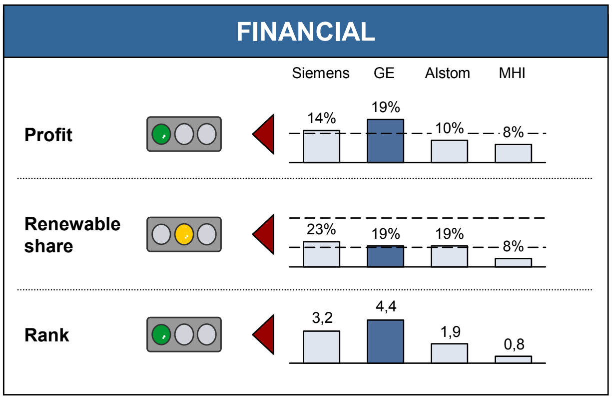
Source: own representation

5.1.2 Renewable BSC – GE

5.1.2.1 GE Renewable BSC – Financial dimension

GE is the best performer both in profit as well as in absolute size. GE has partly adapted its strategy towards renewables. With only 19% renewable share in its power technology sales, the company's sales do not at all correspond to the current demand shift and share of 47%. Compared to its rivals, GE is outperforming them significantly in rank, which is mainly due to the company's strength in its wind power business.

Figure 93 GE Renewable BSC – Financial dimension

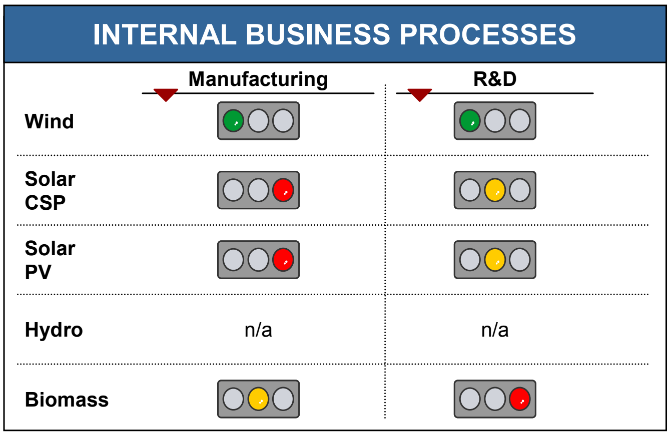


Source: own representation

5.1.2.2 GE Renewable BSC – internal business processes dimension

With the exception of its wind power business, GE has not achieved a significant internationalization of its renewable energy business.

Figure 94 GE Renewable BSC – internal busines processes dimension

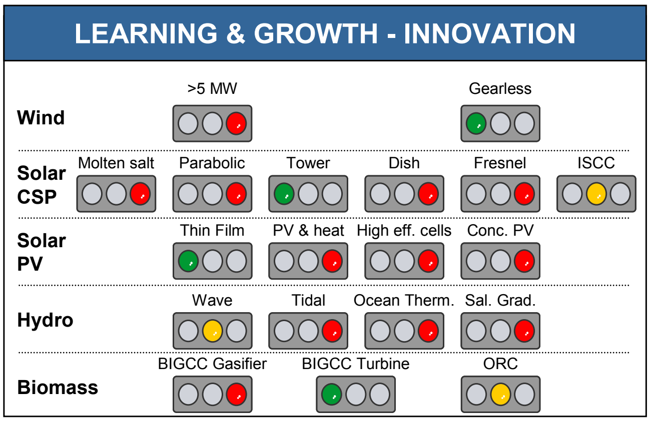


Source: own representation

5.1.2.3 GE Renewable BSC – learning & growth – innovation dimension

The GE renewable case is in one respect similar to Siemens' case – wind power, where the company has transformed a small player in to a global player. And again all technologies where GE is currently driving innovation forward have their origin outside of GE. Overall, GE seems to be rather selective in its innovation approach, with a focus on only some topics. If GE transfers its performance in wind power to the new fields of CSP and PV an interesting technology race can be expected.

Figure 95 GE Renewable BSC – learning & growth – innovation dimension

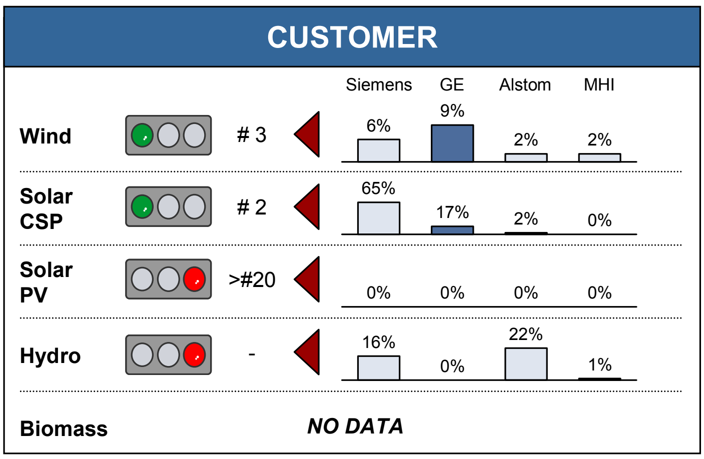


Source: own representation

5.1.2.4 GE Renewable BSC – customer dimension

The final dimension reveals a similar picture as could be seen in the case of Siemens. GE could leverage two top three positions, however no single market leadership. With regard to PV business the planned capacity addition and the company's further research will show in how far GE will be able to play a significant role in PV in the future – at least in the US: What is obvious is the company's retreat from hydro business.

Figure 96 GE Renewable BSC – customer dimension

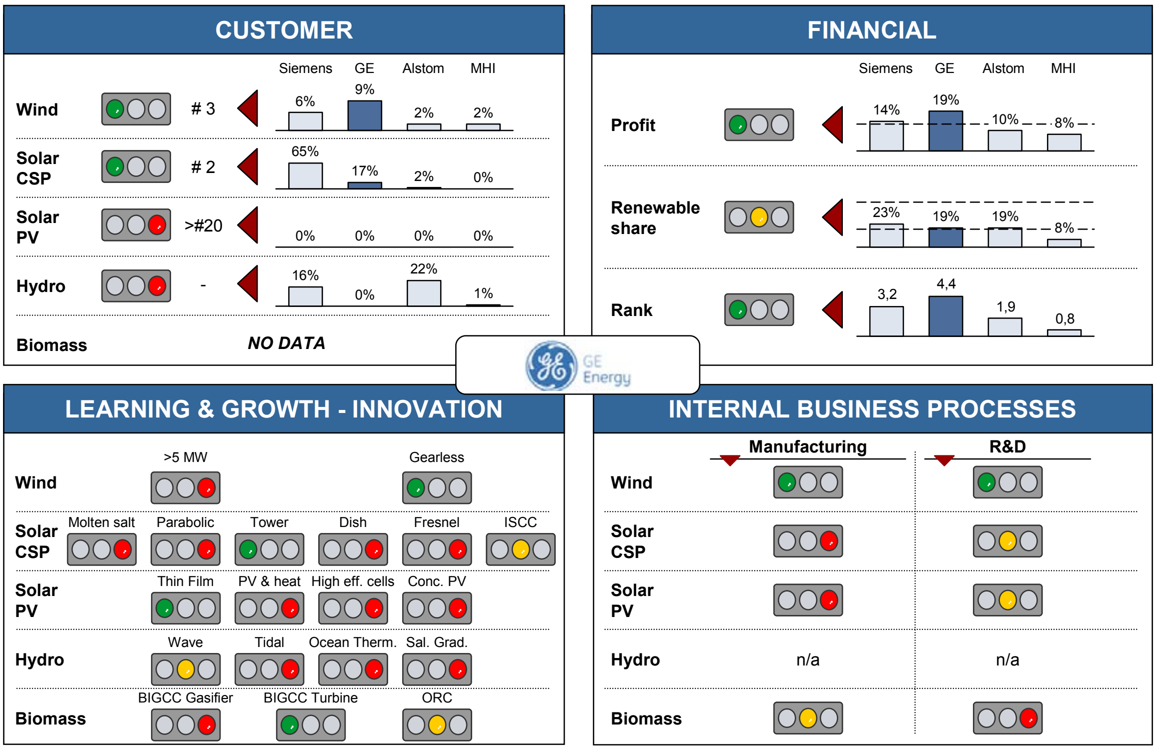


Source: own representation

5.1.2.5 GE Renewable BSC – summary

GE's approach to renewables is selective but in case the company has chosen its field, powerful. This is reflected by the company's success story in wind and its recent growth in CSP. But as was the case in Siemens' renewable case, GE could not leverage its traditional strengths in the overall renewable energy area, with a clear defeat in hydro business. As GE retreated also from offshore developments recently an interesting technology race in CSP with Siemens can be expected.

Figure 97 GE Renewable BSC



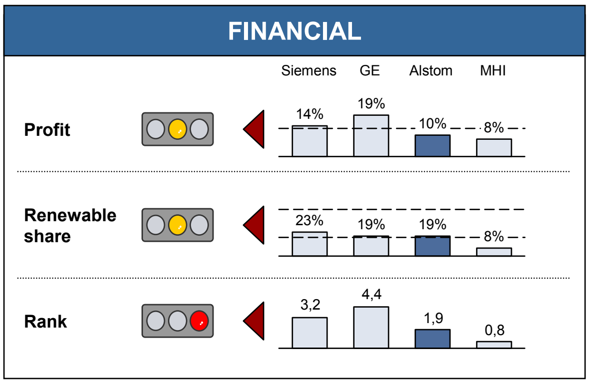
Source: own representation

5.1.3 Renewable BSC – Alstom

5.1.3.1 Alstom Renewable BSC – Financial dimension

Compared to its competitors Alstom shows a mediocre performance, with the share of renewables being at the same rate as GE's being at the lower level of performance. With reference to market dominance, Alstom has significantly lost terrain compared to its major rivals.

Figure 98 Alstom Renewable BSC – Financial dimension

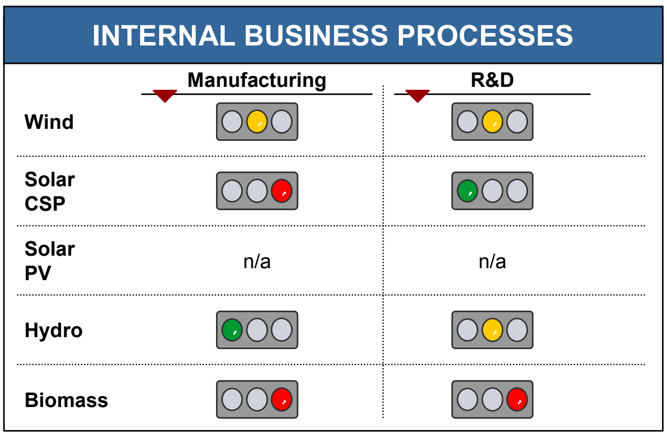


Source: own representation

5.1.3.2 Alstom Renewable BSC – internal business processes dimension

Except for hydro, Alstom has entered the renewable energy market very late, both in wind as well as in CSP, or in the case of PV not at all. This is reflected in the company's footprint where Alstom has a strong internationalization of its hydro business and has started to internationalize its wind footprint.

Figure 99 Alstom Renewable BSC – internal busines processes dimension

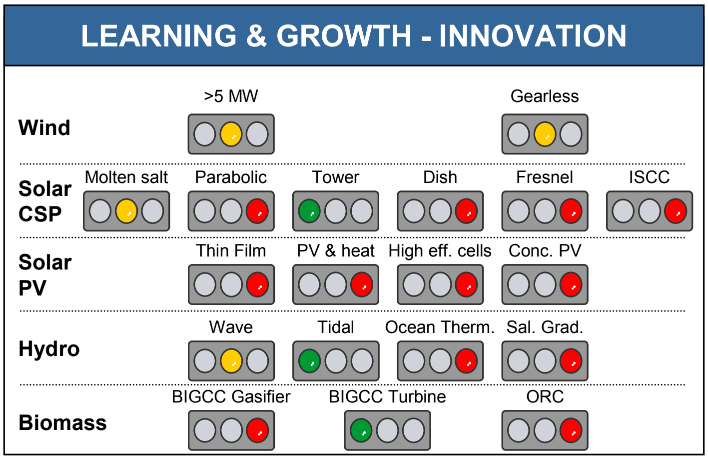


Source: own representation

5.1.3.3 Alstom Renewable BSC – learning & growth – innovation dimension

Alstom's innovation landscape is showing significant gaps due to its absence from the PV market. In total Alstom cannot be perceived as an innovation leader, however the company shows significant interest in hydro innovation topics as well as CSP and wind. Alstom again repeats the pattern of Siemens and GE to acquire basis technology from external companies (wind, CSP, hydro innovations). The upcoming years will show in how far Alstom will be able to play a role in offshore wind and CSP.

Figure 100 Alstom Renewable BSC – learning & growth – innovation dimension

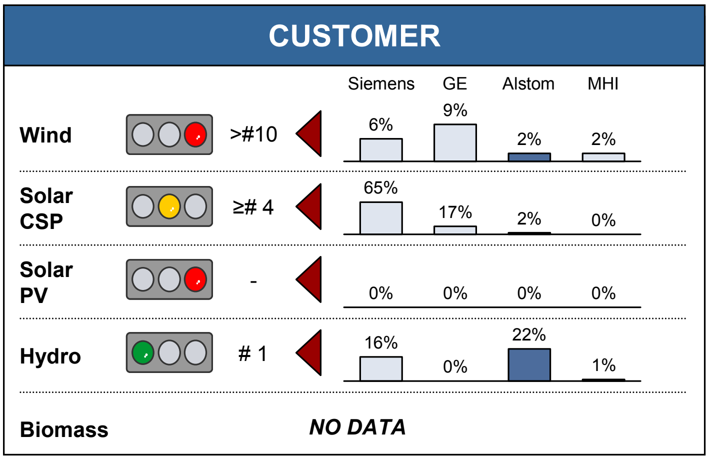


Source: own representation

5.1.3.4 Alstom Renewable BSC – customer dimension

Alstom is the clear market leader in hydro – in all other areas the company has lost ground to its rivals or new competitors.

Figure 101 Alstom Renewable BSC – customer dimension

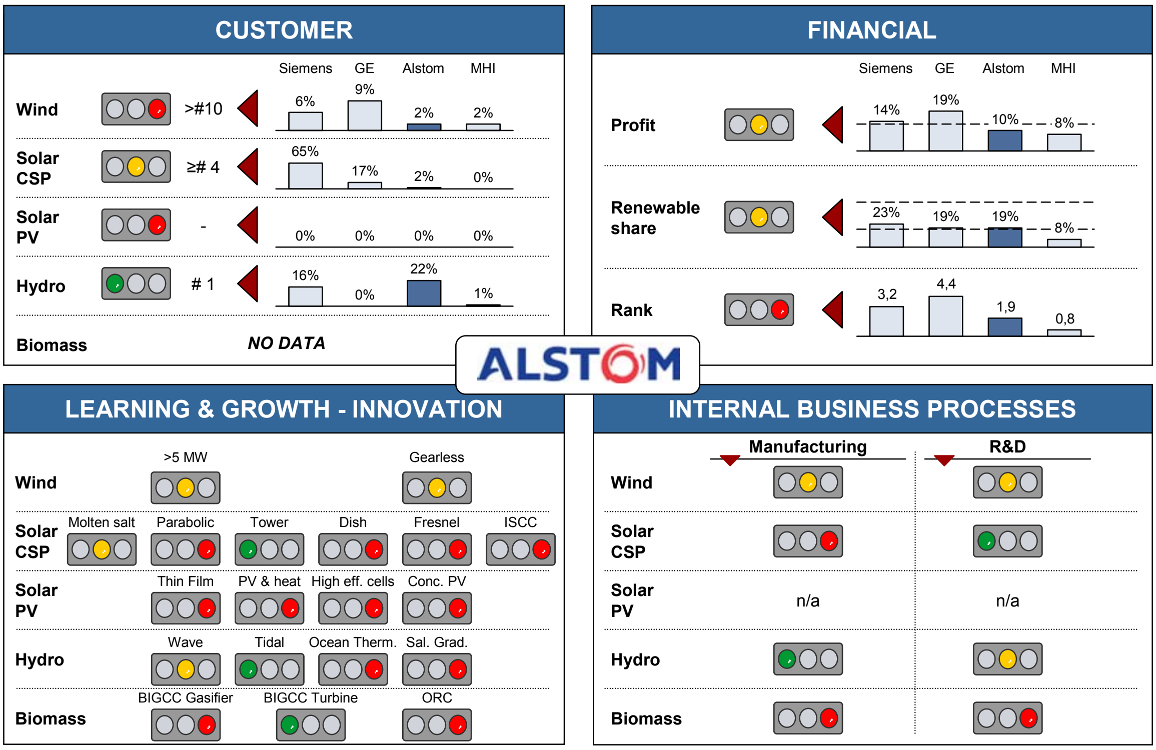


Source: own representation

5.1.3.5 Alstom Renewable BSC – summary

Alstom's mediocre overall situation might have its roots in the financial difficulties and the consequent restructuring needs the company had to face before 2005. Obviously Alstom lost valuable time to restructure its business which resulted in its late entry in the wind race. With CSP the race is currently open – and there the company's investment in Bright Source might pay off and provide another top 3 ranking or market leadership to Alstom in the field of renewables.

Figure 102 Alstom Renewable BSC



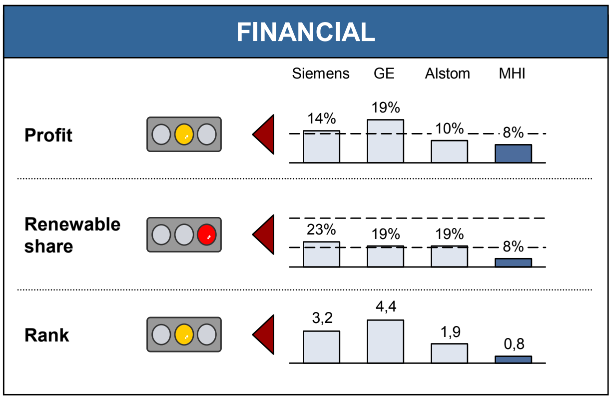
Source: own representation

5.1.4 Renewable BSC – MHI

5.1.4.1 MHI Renewable BSC – Financial dimension

MHI is the lowlight of the four companies in focus when it comes to renewables – in profit, the overall share of renewables (results from the company's large focus on nuclear) and its rank among the three companies. The company has lost significant terrain to its competitors.

Figure 103 MHI Renewable BSC – Financial dimension

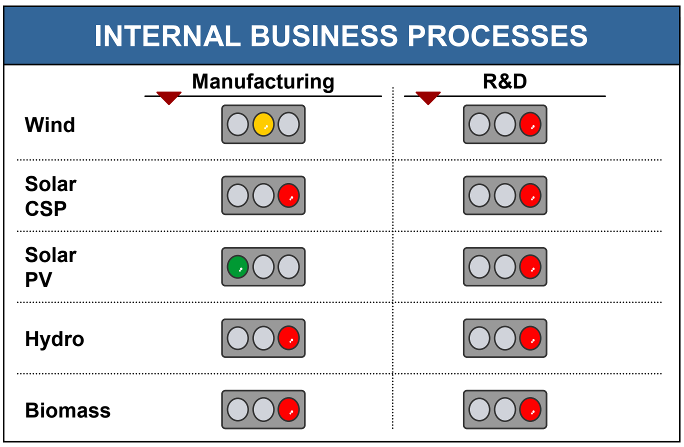


Source: own representation

5.1.4.2 MHI Renewable BSC – internal business processes dimension

With reference to its footprint the Japan focused business of MHI is revealed once again – with the exception of wind and its recent cost driven move in PV to Taiwan. When it comes to R&D the company currently does not open significantly to spur its technology with new global insights.

Figure 104 MHI Renewable BSC – internal busines processes dimension

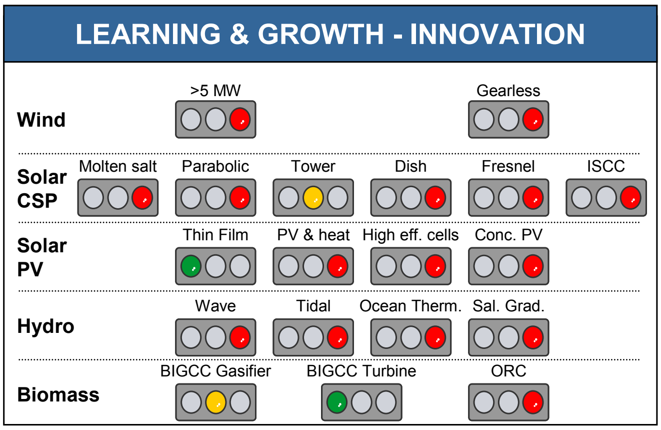


Source: own representation

5.1.4.3 MHI Renewable BSC – learning & growth – innovation dimension

MHI's technology case is the contrast to the competitors described so far. MHI has (with the recent exception in wind business for gearless drive concepts) developed all technologies in house. This has not happened as a follower, but already in the 1980s when the company first built wind turbines and had a solar tower in operation. However, MHI could not at all leverage these advantages technologically – MHI is either not active (e.g. hydro) or a late follower (e.g. wind, CSP) of technologies.

Figure 105 MHI Renewable BSC – learning & growth – innovation dimension

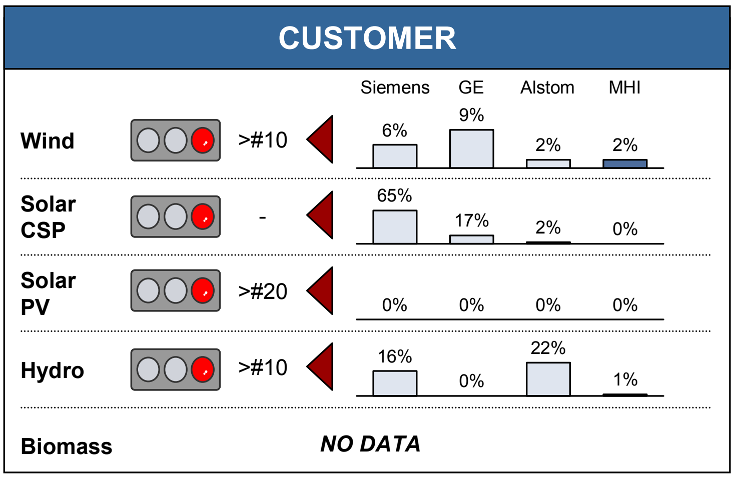


Source: own representation

5.1.4.4 MHI Renewable BSC – customer dimension

In renewable energy MHI did not only lose ground to established and new competitors – the company was actually defeated without any top rank in the renewable energy technologies in scope.

Figure 106 MHI Renewable BSC – customer dimension

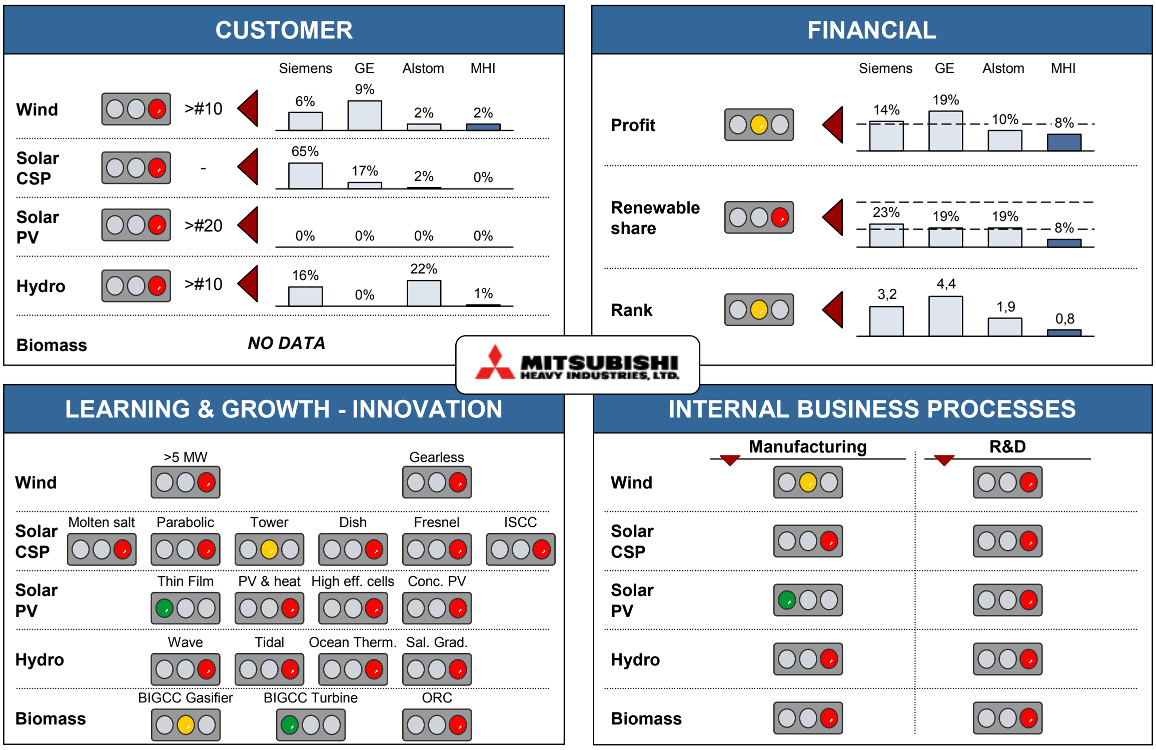


Source: own representation

5.1.4.5 MHI Renewable BSC – summary

MHI's BSC shows clearly its defeat in the renewable power technology industry. MHI's business has not at all transformed fundamentally to the demands of renewable energy. From this basis it is hard to give a positive outlook in any of the technologies in focus, as the company is even late or not aggressive in any market. Furthermore the past has shown that MHI has not performed bold moves with strategic M&A activities.

Figure 107 MHI Renewable BSC



Source: own representation

5.2 Renewable BSC conclusion – summary

Coming back to the core questions – the following section shall summarize the findings and help to answer the paper's core questions on the performance of established power technology suppliers.

	Core question
1	**How did their portfolio and sales development correspond to the trend of increased renewable energy deployment?**

No company could achieve sales in renewables that matched the rate of the new installed base – i.e. looking to the renewables scene, the companies have significantly lost ground. With the exception of MHI all established power technology suppliers only have a share that matches the current share of renewable electricity generation.

Although the companies communicate to have understood the market needs for renewable electricity production the performance figures clearly state the contrary. This is partly reflected by the development of their specific portfolio which in most cases was based rather on acquisitions than on own developments.

	Core question
2	**In how far are they contributing to the current innovation demands for renewable energy sources?**

Overall the companies in focus are corresponding to the majority of identified innovation topics (although to a highly different degree) – again either directly or via JVs, licenses and M&A activities. The major gap areas can be seen in PV as none of the companies has a major foothold in the market. The companies, however can be seen as drivers for the further development in the wind and CSP business.

	Core question
3	**How have they adapted their manufacturing and R&D footprints to the global demand shift towards emerging markets in the renewable energy market?**

In wind and hydro power the companies have mostly built up strongly internationalized organizations both in manufacturing as well as in R&D. In hydro this has happened over several decades, whereas in wind the common way was to buy a mid-sized company and then to rapidly internationalize its sales as well as its operation. In this respect, Alstom, GE and Siemens can be seen as a kind of incubators for the companies they have acquired in this field. The CSP market is still too young to predict the outcome of the current activities, however it can be assumed that the internationalization will be according to a similar pattern once the demand for this technology increases.

The importance of emerging markets – for instance China and India has been acknowledged and the companies have built manufacturing as well as R&D hubs in these markets although there is significant room for improvement, to benefit from the human capital of these emerging countries.

	Core question
4	**Have they been able to transfer their dominance from the fossil power market to the renewable energy sector?**

To the last question a clear NO can be answered. Only Alstom could keep its #1 position in hydro – except for this no company in focus was in the position to call itself market leader except for market subsegments. With the single exception of GE they totally lost ground to new suppliers in the wind arena. In PV the companies have no considerable market share at all. In CSP the companies are now early reacting to avoid the same story as in wind or in PV. Obviously, not only the world but also the renewable power technology market has entered the age of multipolarity.

From the author's perspective the performance of the established companies shows a great deficiency in their ability to change and to adapt to market environment changes. They have in most cases been the follower and not the driver of change and had to compensate their lack of awareness and low reaction speed with huge M&A investments and significant losses of market shares to new entrants.

Obviously the companies have considered their lessons and now react more proactively in the fields of offshore wind and CSP. For the future of our energy system but more importantly for the world's environmental system, mankind will require these companies to become drivers and not late followers or even burdens for the change towards a reduced or even carbon free economic development.

The Power-Tech Dinosaurs have partly adapted their way of life and survived – however their footprint has shrunk significantly in the new world.

5.3 Outlook for further research

For further research three areas are suggested:

Innovations

This paper was only aimed at giving an overview on the innovation topics for renewable electricity generation. Hence further follow up research on the development and viability of these fields shall be suggested.

New entrants from emerging markets

As has been stated before, new entrants in the power technology industry have not been considered in this paper. For future research it is suggested to investigate their performance both in the traditional fuel based and the renewable electricity generation technology market.

Biomass & Geothermal

Biomass markets are highly fragmented and only limited information is available on the biomass electricity power technology market – hence further efforts are needed to increase the transparency in this field. With reference to geothermal – this paper has not touched on this market – further comparative analyses of this market shall be suggested.

Alstom 2000a, "ALSTOM completes the acquisition of ABB's 50% share in ABB ALSTOM Power", Press Release, 11th May 2000, France, 2000.

Alstom 2005a, "FULL YEAR RESULTS 2004/05", Press Release, 31st May 2005, France, 2005.

Alstom 2005b, "ALSTOM signs agreements with Austrian Energy & Environment AG for the sale of its industrial boilers activity", Press Release, 24th October 2005, France, 2005.

Alstom 2007a, "Alstom and Atomenergomash finalize strategic partnership in nuclear power plant market", Press Release, 29th June 2007, France, 2007.

Alstom 2007b, "Alstom completes the acquisition of Spanish wind turbine company Ecotècnia thus extending its wide portfolio of technologies", Press Release, 05th November 2007, France, 2007.

Alstom 2008a, "Alstom and Bharat Forge intend to set up a joint venture in India for power plant equipment manufacturing", Press Release, 10th November 2008, France, 2008.

Alstom 2008b, "Annual Report 2007/2008", 23rd May 2008, France, 2008.

Alstom 2008c, "Alstom Hydro strengthens R&D capabilities in India with launch of its new Global Technology Centre", 11th November 2008, France, 2008.

Alstom 2009a, "Alstom reinforces its capabilities in CO2 capture with the acquisition of former Lummus Global engineering unit", Press Release, 5th November 2009, France, 2009.

Alstom 2009b, "Alstom enters the Brazilian wind power market via installation of a wind turbine assembly factory in Bahia", Press Release, 21st December 2009, France, 2009.

Alstom 2009c, "Power Generation: CO2free?", Presentation for Analyst Days in Scandinavia, 12th March 2009.

Alstom 2009d, "Annual Report 2008/2009", France, 2009.

Alstom 2010a, "Alstom creates a third Sector, Alstom Grid, with the acquisition of the transmission business of Areva", Press Release, 08th June 2010, France, 2010.

Alstom 2010b, "Alstom wins order worth over €200 million with Iberdrola to add 217 MW extension to Whitelee wind farm", Press Release, 07th September 2010, France, 2010.

Alstom 2010c, "Alstom Grid wins innovative offshore platform substation contract in Germany", Press Release, 20th September 2010, France, 2010.

Alstom 2010d, "Alstom enters solar market by investing in BrightSource Energy", Press Release, 20th May 2010, France, 2010.

Alstom 2011a, "Annual results Fiscal Year 2010/2011", Investor Presentation, 4th May 2011, France, 2011.

Alstom 2011b, "Shareholders' Meeting", Investor Presentation, 28th June 2011, France, 2011.

Alstom 2011c, "Alstom and Shanghai Electric intend to join forces to create the world leader in boilers for coal-fired power", 20th April 2011, France, 2011.

Alstom 2011d, "Alstom signs series of agreements in the Russian energy sector", Press Release, 21st June 2011, France, 2011.

Alstom 2011e, "An additional $75m investment in BrightSource Energy to strengthen its position in solar power as part of its renewable offering", Press Release, 31st March 2011, France, 2011.

Alstom 2011f, "Offshore Wind Energy: EDF Energies Nouvelles and Alstom team up to respond to the call for tenders planned in France", Press Release, 19th January 2011, France, 2011.

Alstom 2011g, "Innovating for reliability to bring down the Cost of Energy of offshore wind", Press Release, 15th March 2011, France, 2011.

Andritz 2008, "Acquisition of GE Hydro", in: Hydro News, October 2008, Vienna, Austria, 2008.

Andritz 2009, "Andritz – Company presentation 2009", February 2009, Vienna, Austria, 2009.

AWEA, "American Wind Energy Association Annual Wind Industry Report YEAR ENDING 2008", American Wind Energy Association, USA, 2008.

Beurskens Jos, "Offshore-Windenergie, der Motor der modernen Windenergieforschung", 20 Jahre DEWI, Wilhelmshaven, Germany, 2010

Bhatnagar Tarun & Gibson Colin, "Austerlitz to Borodino - The Global Power Technology Industry, 2006-2011", HSBC Global Research, October 2006, United Kingdom, 2006.

Bockhorst Michael, "ABC Energie Eine Einführung mit Lexikon: Energieerzeugung und Energienutzung, Probleme und Lösungsansätze", Bonn, 2002.

BTM Consult 2007, "International Wind Energy Development – World Market Update 2006", BTM Consult ApS, Rinkobing, Denmark, 2007.

BTM Consult 2008, "International Wind Energy Development – World Market Update 2007", BTM Consult ApS, Rinkobing, Denmark, 2008.

eSolar, "GE to Invest up to $40 Million in eSolar", Press Release, 8th August 2011, Burbank, USA, 2011.

ETG, "Dezentrale Energieversorgung 2020 – Eine Studie der ETG", Energietechnische Gesellschaft im VDE, December 2006, Germany, 2006.

European Commission 2005, "European Wind Energy at the dawn of the 21st century", Office for Official Publications of the European Commission, Luxembourg, 2005.

European Commission 2010, "Europe's energy position markets and supply", Publications Office of the European Union, Luxembourg, 2010.

EPIA 2009, "Global market outlook for photovoltaics until 2013", European Photovoltaic Industry Association, March 2009, Bonn, Germany, 2009.

EPIA 2011, "Global market outlook for photovoltaics until 2015", European Photovoltaic Industry Association, 2011, Bonn, Germany, 2011.

EWEA 2003, "Wind Energy – The Facts, Vol. 1 – Technology", European Wind Energy Association, Brussels, Belgium, 2003.

EWEA 2011, "UpWind – Design limits and solutions for very large wind turbines", European Wind Energy Association, Brussels, Belgium, 2011.

Fawer Mathias, "Nachhaltigkeitsstudie – Solarenergie 2006 Licht- und Schattenseiten einer Industrie", Sarasin & Cie AG, Basel, Switzerland, 2006.

Fechner Hubert, "Introduction on photovoltaics, physical basics, semiconductors – Module 3", Study material for MSc Course "Renewable Energy in Central and Eastern Europe", 2009.

Feldenkirchen Wilfried, "Siemens – von der Werkstatt zum Weltunternehmen", Piper Verlag GmbH, München, Germany, 2003.

Finley A.T. & Jones W., "Recent Developments in Salinity Gradient Power", in: Marine Technology Society OCEANS 2003 – Scientific papers, 2003.

GE 2004a, "GE Energy Completes Acquisition of AstroPower", Press Release, 31st March 2004, Atlanta, USA, 2004.

GE 2006a, "GE And NPO Saturn in Negotiations to Create Heavy Duty Gas Turbine Joint Venture in Russia", Press Release, 17th October 2006, Fairfield, USA, 2006.

GE 2006b, "GE Enters into Agreement to Sell Hydro Business to Pescarmona Group of Companies (PGC), Press Release, 20th December 2006, Atlanta, USA, 2006.

GE 2007a, "GE, Hitachi Forge Global Alliance in Nuclear Industry", Press Release, 4th June 2007, Fairfield, USA, 2007.

GE 2007b, "GE To Make Strategic Investment in Emerging Solar Technology Company", Press Release, 19th September 2007, Fairfield, USA, 2007.

GE 2008a, "GE Becomes Majority Shareholder in Emerging Solar Technology Company", Press Release, 6th November 2008, Fairfield, USA, 2008.

GE 2009a, "We are GE – GE 2008 Annual Report", 6th February 2009, Fairfield, USA, 2009.

GE 2009b "GE Energy Expands in Growing Offshore Wind Sector with Key Technology Buy", Press Release, 14th September 2009, Fairfield, USA, 2009.

GE 2009c "Ecomagination" Presentatoin at Cleantech Leaders Conference, 11th March 2009, New York City, USA, 2009.

GE 2010a, "GE Energy and Doosan Heavy Industries & Construction Sign Agreement to Develop Advanced Large Steam Turbines and Generators", Press Release, 19th July 2010, Fairfield, USA, 2010.

GE 2010b, "Ecomagination", presentation at Jefferies Global Clean Technology Investor Conference, 16th March 2010, USA, 2010.

GE 2010c, "GE and Harbin Electric Form Joint Venture to Capture Growth Opportunities in the World's Largest Wind Turbine Sales Territory", Press Release, 27th September 2010, Fairfield, USA, 2010.

GE 2010d, "GE Power & Water – Renewable Energy", GE company presentation, Fairfield, USA, 2010.

GE 2010e, "GE Sees Bright Future for Thin Film Solar Technology", Press Release, 18th March 2010, Fairfield, USA, 2010.

GE 2011a, "Growth Starts Here – GE 2010 Annual Report", 12th February 2011, Fairfield, USA, 2011.

GE 2011b, "GE Energy Fact Sheet", Fairfield, USA, 2011.

GE 2011c, "GE Energy – Energy Investment Meeting", Investor presentation, 20th September 2011, Fairfield, USA, 2011.

GE 2011d, "GE Completes $3 Billion Acquisition of Dresser, Inc.", Press Release, 1st February 2011, Fairfield, USA, 2011.

GE 2011e, "GE Energy Completes $3.2 Billion Deal to Acquire Converteam", Press Release, 9th February 2011, Fairfield, USA, 2011.

GE 2011f, "GE Energy – From Scanwind to GE – becoming a global player anchored in Mid-Norway", Presentation of GE Wind Energy Nordic Region, January 2011, Trondheim, Norway, 2011.

GE 2011g, "GE Introduces 4.1-113 Offshore Turbine", Press Release, 27th March 2011, Fairfield, USA, 2011.

GE 2011h, "GE Completes Acquisition of Next-Generation Wind Turbine Tower Technology", Press Release, 11th February 2011, Fairfield, USA, 2011.

GE 2011i, "GE and Gehrlicher Solar Team up to Build Solar Parks Worldwide", Press Release, 14th June 2011, Fairfield, USA, 2011.

GE 2011j, "GE's Biogas Engines to Power China's Largest Ethanol Production Plant", Press Release, 14th April 2011, Jenbach, Austria, 2011.

GE 2011k, "GE Oil & Gas Heralds New Decade of Innovation with Renewable Energy Solutions for the Concentrated Solar Power Industry", Press Release, 01st February 2011, Fairfield, USA, 2011.

GE 2011l, "GE Energy Invests in eSolar, a Key Step to Combining Natural Gas and Renewable Energy for Cleaner, More Reliable Power", Press Release, 06th June 2011, Houston, USA, 2011.

GE 2011m, "MetCap Energy Selects GE's New FlexEfficiency Technology for World's First Integrated Renewables Combined Cycle Power Plant", Press Release, 07th June 2011, Fairfield, USA, 2011.

Gesthuizen Jan, "The CSP boom has begun", in: Sun & Wind Energy, ed. 6/2010 pp. 94-100, Bielefeld, Germany, 2010.

Gladen Henner, "CSP Project Development in Spain, US and Egypt –Lessons Learned", Presentation at Intersolar Europe, Munich, Germany, 10th June 2010.

Gross Robert, "Progress in renewable energy", in: Environment International 29 (2003), pp. 105-122, 2003.

Grübler Arnulf & Gritsevskyi Andrii, "A Model of Endogenous Technological Change through Uncertain Returns on Innovation", in: Grübler Arnulf & Nakicenovic Nebojsa & Nordhaus William D., "Technological change and the environment", Resources for the Future, Washington DC, USA, 2002.

Hofbauer Hermann 2009a, "Fundamentals of Thermal Biomass Utilization – Module 2", Study material for MSc Course "Renewable Energy in Central and Eastern Europe", Vienna, Austria, 2009.

Hofbauer Hermann 2009b, "Plant Engineering for Thermal Biomass Utilization – Module 2", Study material for MSc Course "Renewable Energy in Central and Eastern Europe", Vienna, Austria, 2009.

Hungenberg Harald & Meffert Jürgen (editors), "Handbuch Strategisches Management", Gabler Verlag, Wiesbaden, Germany, 2005.

Goldman Sachs Research, "Considerations on the Renewable Energy Sector", Presentation, June 2008, Munich, Germany, 2008.

IEA 2003, "Renewables for Power Generation – Status & Prospects", International Energy Agency, Paris, France, 2003.

IEA 2007, "Biomass for Power Generation and CHP", IEA Energy Technology Essentials, International Energy Agency, Paris, France, 2007.

IEA 2010a, "Technology Roadmap Concentrating Solar Power", International Energy Agency, Paris, France, 2010.

IEA 2010b, "Technology Roadmap Solar Photovoltaic Energy", International Energy Agency, Paris, France 2010.

IEA 2011a, "Key World Energy Statistics 2011", International Energy Agency, Paris, France, 2011.

IPCC, 2011: "Summary for Policymakers", in: IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation [O. Edenhofer, R. Pichs ‐ Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011.

Kaplan Robert & Norton David 1996a, "Using the balanced scorecard as a strategic management system", Harvard Business Review, Vol.74/Jan-Feb 1996, pp.75-85, USA, 1996.

Kaplan Robert & Norton David 1997, "Balanced Scorecard – Strategien erfolgreich umsetzen", Schäffer-Poeschel Verlag, Stuttgart, Germany, 1997.

Kern Jürgen, "Combined Solar Power and Desalination Plants", Presentation at Intersolar Europe, 10th June 2010, Munich, Germany, 2010.

Koenemann Detlef, "Production in all the important markets", in: Sun & Wind Energy, ed. 6/2010, pp. 158-162, Bielefeld, Germany, 2010

Koll G., "Solar Power Tower Jülich", Presentation at Intersolar Europe, 10th June 2010, Munich, Germany, 2010.

Koot Edwin, "The global PV market: fasten your seatbelts - Analyses of market demand to 2010", Solar Plaza, July 2008.

Konstantin Panos, "Praxisbuch Energiewirtschaft – Energieumwandlung, -transport und –beschaffung im liberalisierten Markt", VDI Springer Verlag, Berlin, Germany, 2007.

Lako P., "Mapping Climate Mitigation Technologies and Associated Goods Within the Renewable Energy Supply Sector", International Centre for Trade and Sustainable Development (ICTSD), The Netherlands, 2008.

Limperis Anja, "Best fit for OPV is the off-grid market", Sun & Wind Energy 06/2010, pp. 104-106, Bielefeld, Germany, 2010.

Lutton Josh & LaTrace Adrian, "Blown Away: The Approaching Consolidation of the Wind Turbine Industry", Woodlawn Associates Management Consulting Report, January 2011, USA, 2011.

Meilak Joe, "Deep Offshore Wind Farms - Challenges and Opportunities", Windtech International, Nr. 8, 2005.

Milles Uwe 2003, "Biogas", BINE Informationsdienst, basis Energie 16, Fachinformationszentrum Karlsruhe, December 2003, Bonn, Germany, 2003.

Milles Uwe 2004, "Wasserkraft", BINE Informationsdienst, basis Energie 18, Fachinformationszentrum Karlsruhe, November 2004, Bonn, Germany, 2004.

Mitsubishi 2007a, "MHI License Production and Sales of Large-size Gas Turbines To Doosan of Korea", Press Release, 29th May 2007, Tokyo, Japan, 2007.

Mitsubishi 2007b, "MHI to License 1 MW Wind Turbine Technology to China, Entering into Chinese Market for Wind Power Generation Systems", Press Release, 28th May 2007, Tokyo, Japan, 2007.

Mitsubishi 2007c, "MHI to Collaborate with Renova Group and ZAO Ural Turbine Works Of Russia in Gas and Steam Turbine Businesses", Press Release, 27th September 2007, Tokyo, Japan, 2007.

Mitsubishi 2007d, "MHI to Triple Wind Turbine Production Capacity to 1,200MW/Year", Press Release, 10th April 2007, Tokyo, Japan, 2007.

Mitsubishi 2009a, "Mitsubishi Heavy Industries and GE Energy Sign Final Agreements To Co-Develop World's Most Advanced New Steam Turbine For Combined-Cycle Power Plants", Press Release, 23rd June 2009, Tokyo, Japan, 2009.

Mitsubishi 2009b, "Mitsubishi Heavy Industries Group Acquires Maintenance Partners NV of Belgium", Press Release, 06th April 2009, Tokyo, Japan, 2009.

Mitsubishi 2010a, "MHI Guide Book 2010", October 2010, Tokyo, Japan, 2010.

Mitsubishi 2010b, "Annual Report 2010", March 2010, Tokyo, Japan, 2010.

Mitsubishi 2010c, "Power Systems Business Operation", Investor Presentation, 3rd June 2010, Tokyo, Japan, 2010.

Mitsubishi 2010d, "2010 Medium-Term Business Plan (2010-2014)", Investor Presentation, 28th April 2010, Tokyo, Japan, 2010.

Mitsubishi 2010e, "MHI to Provide 2.5 MW Wind Turbine Technology to Chinese Company - Licensing Expansion Targets China's Rapidly Growing Market", Press Release, 15th November 2010, Tokyo, Japan, 2010.

Mitsubishi 2010f, "MHI Acquires Artemis Intelligent Power, a UK Venture Company, To Secure Unique Hydraulic Power Drive Technology", Press Release, 3rd December 2010, Tokyo, Japan, 2010.

Mitsubishi 2010g, "MHI to Build Wind Turbine Manufacturing Plant in Arkansas, USA", Press Release, 07th April 2010, Tokyo, Japan, 2010.

Mitsubishi 2010h, "Carbon Credit from MHI Wind Power Business in Bulgaria Transferred to Japan", Pres Release, 12th July 2010, Tokyo, Japan, 2010.

Mitsubishi 2010i, "Concentrated Solar Hot Air Turbine Power Generation System", Presentation at the 2nd Japan-Arab Economic Forum, December 2010, Tunis, Tunisia, 2010.

Mitsubishi 2011a, "Nuclear Energy Systems Business Operation", Investor Presentation, 1st June 2011, Tokyo, Japan, 2011.

Mitsubishi 2011b, "Hitachi, Mitsubishi Electric and Mitsubishi Heavy Industries Sign Absorption-type Company Split Agreements on Transfer of Hydroelectric Power Generation System Operations to HM Hydro", Press Release, 4th August 2011, Tokyo, Japan, 2011.

Mitsubishi 2011c, "Power Systems Business Operation", Investor Presentation, 1st June 2011, Tokyo, Japan, 2011.

Mitsubishi 2011d, "MHI to Establish Power System Engineering Subsidiary in Austria To Enhance Order-taking, Project Execution and Procurement Capabilities", Press Release, 15th June 2011, Tokyo, Japan, 2011.

Mitsubishi 2011e, "Strategies for the Energy & Environment Business", Investor Presentation, 1st June 2011, Tokyo, Japan, 2011.

Mitsubishi 2011f, "MHI to Begin Discussions on Details of Photovoltaic Module Business Tie-up With Auria Solar of Taiwan", Press Release, 30th March 2011, Tokyo, Japan, 2011.

O'Rourke et al, "Solar PV industry outlook and economics", Deutsche Bank, 27th May 2008.

Quaschning Volker, "Regenerative Energiesysteme: Technologie – Berechnung – Simulation", Hanser Verlag, München, Germany, 2008.

REN 21 2010, "Renewables 2010 – Global Status Report", Renewable Energy Policy Network for the 21st Century, September 2010, Germany, 2010.

REN 21 2011, "Renewables 2011 – Global Status Report, "Renewable Energy Policy Network for the 21st Century, August 2011, Germany, 2011.

RWE, "Weltenergiereport 2005 – Bestimmungsgrößen der Energiepreise", Essen, Germany, 2005.

RDC – Resource Dynamics Corporation, "Combined Heat and Power Market Potential for Opportunity Fuels", U.S. Department of Energy, USA, 2004.

Sanchez Marcelino, "The need for R&D +innovation in CSP: Projections of impact in cost reductions", presentation at the CSP Today 2009, Seville, Spain, 2009.

SCHOTT Solar S.L., "Advances in Parabolic Trough Receiver Technology", presentation at the CSP Today 2009, Seville, Spain, 2009.

Seeler Fabian, "Chemistry makes CSP more successful", presentation at the CSP Today 2009, Seville, Spain 2009.

Shin, ChungKwan, "Solar PV industry - Clouds to part", Samsung Securities – Equity Research Industry Report, 16th April 2009, Korea, 2009.

Siemens 2006a, "Wind Energy: Key Markets and Global Industry Outlook", Munich, Germany, 2006.

Siemens 2006b, "Trends in Use of Solar Thermal Energy as Primary Energy Source", Munich, Germany, 2006.

Siemens 2007, "Siemens IGCC and Gasification Technology – Today's Solution and Developments", presentation at 2nd International Freiberg Conference on IGCC & XtL Technologies, 08th May 2007, Freiberg, Germany, 2007.

Siemens 2008a, "Siemens Energy – Renewable Energy Division", presentation at Capital Market Days Energy, 01st July, 2008, Munich, Germany, 2008.

Siemens 2008b, "Siemens Industrial Gas Turbines Fuel flexibility and alternative fuels for gas turbines", presentation at NRC-CNRC & IAGT Fall Forum 2008, 20th October 2008, Ottawa, Canada, 2008.

Siemens 2010a, "Siemens' growth gains momentum", presentation at Q4 FY 2010 and Annual Analyst Conference, 2010, Munich, Germany, 2010.

Siemens 2010b, "Siemens Energy a source of added value", presentation at Capital Market Day Energy, 29th June 2010, Nuremberg, Germany, 2010.

Siemens 2010c, "Siemens Energy: Renewable Energy Division", presentation at Capital Market Day Energy, 29th June 2010, Nuremberg Germany, 2010.

Siemens 2010d, "Siemens to increase stake in Archimede Solar Energy to 45 percent", Siemens press release, 17th May 2010, Erlangen, Germany, 2010

Siemens 2011a, "Value creation through capital efficient growth", presentation at Commerzbank German Investment Seminar, 10th January 2011, Munich, Germany, 2011.

Siemens 2011b, "Outstanding broad-based growth", presentation at JP Morgan Conference, 9th June 2011, New York, USA, 2011.

Siemens 2011c, "The company – Siemens 2011", company presentation of Siemens, Status July 2011, Munich, Germany, 2011.

Siemens 2011d, "Siemens to build molten salt solar thermal test facility in Portugal", Siemens press release, 01st February 2011, Erlangen, Germany, 2011.

Siemens 2011e, "Siemens to strengthen its renewables business – Company to set up two divisions for wind power, and solar and hydro", Siemens press release, 4th August 2011, Erlangen, Germany, 2011.

Siemens 2011f, "Strong growth and underlying profit in third quarter", Q3 FY 11 Analyst call, 28th July 2011, Munich, Germany, 2011.

Siemens 2011g, "Siemens acquires stake in U.S.-based photovoltaics company Semprius - Next-generation technology high concentrating photovoltaics promises maximum efficiency", Siemens press release, 17th June 2011, Erlangen, Germany, 2011.

Siemens 2011h, "Siemens to supply solar field for 50 MW CSP plant Termosolar Olivenza 1 in Spain", Siemens press release, 4th July 2011, Erlangen, Germany 2011.

Siemens 2011i, "Siemens and Suntech enter framework agreement for PV panels", Siemens press release, 27th January, 2011, Erlangen, Germany, 2011.

Stancich Rikki, "Is Siemens' solar spending spree paying off?", CSP today, March 26, 2010 (http://social.csptoday.com/qa/siemens-solar-spending-spree-paying accessed on September 02 2011).

Stahl Fredric, "Alstom: No free lunch – risk reward balanced", UBS Investment Research, 01st July 2010, Switzerland, 2010.

Tamme Rainer: "Improving thermal storage for DSG plants - The promise of phase change materials (PCM)", presentation at the CSP Today 2009, Seville, Spain 2009.

Tisdale Reese, "Ocean Energy Moves to Next Phase - Market Brief", Emerging Energy Research, 19th September 2007, Great Britain, 2007.

TPWind, "Strategic Research Agenda / Market Deployment Strategy – From 2008 To 2030", Brussels, Belgium, 2008.

Uglow Ben, "Alstom Attractive Valuation – but Concerns on Power Capex", Morgan Stanley Research Europe, 12th July 2010, Great Britain, 2010.

U.S. Department of Energy, "Wind Energy – Multi Year Program Plan 2005 – 2010", November 2004, Washington D.C., USA, 2004.

Vizcaino-Garcia Mariano, "Concentrating Solar Power Plants", Presentation at Intersolar Europe, 10th June 2010, Munich, Germany, 2010.

Walsh Bryan, "Betting on Big Solar", in: Time Magazine, 04th July 2011, USA, 2011.

Weinrebe Gerhard, "Advanced Parabolic Trough Collectors for CSP Applications", Presentation at Intersolar Europe, 10th June 2010, Munich, Germany, 2010.

Wellinger Arthur, "Module 1 Biogas", Study material for MSc Course "Renewable Energy in Central and Eastern Europe", Vienna, Austria, 2010.

Williamson Kari, "The power of the concentrated sun", Renewable Energy Focus, August 19, 2010 (http://www.renewableenergyfocus.com/view/11674/the-power-of-the-concentrated-sun/ accessed on September 02 2011).

Winkelmeier Hans, "Module 4 Wind Power", Study material for MSc Course "Renewable Energy in Central and Eastern Europe", Vienna, Austria, 2009.

Wizelius Tore: "Developing Wind Power Projects", Earthscan, London, 2009.

WWEA, "World Wind Energy Report 2009", Bonn, Germany, 2010.

Zarza Eduardo, "DIRECT STEAM GENERATION with Parabolic Trough Collectors - Benefits, disadvantages, state-of-the-art and plans for commercial deployment", presentation at the CSP Today 2009, Seville, Spain 2009.