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Renewable Energy for BHP Billiton

Framework and Application to BHP Billiton's Global Assets

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Acronyms & Abbreviations

BMNC	BHP Billiton Base Metals, Northern Chile Assets
Bn	Billion
BoS	Balance of System
BTU	British Thermal Units, a measure of energy
CDM	The Clean Development Mechanism (CDM) is an arrangement for the reduction of GHG emissions established by the UNFCCC's Kyoto Protocol by which industrialized countries (identified as Annex I nations) can invest in emissions reductions projects in developing (Annex II) nations as a lower-cost alternative to reducing emissions in their own country.
CER	A Certified Emissions Reduction is a GHG emission reduction "credit" recognized in the mandatory emissions reduction mechanism setup by the United Nations Framework Convention on Climate Change (UNFCCC) called the Clean Development Mechanism (CDM).
CF	Capacity Factor
CO2 or CO_2	Carbon dioxide, the greenhouse gas (GHG) which makes up the majority of anthropogenic (human-generated) GHG emissions
CO2e	Carbon dioxide equivalent, the standard measure of GHG emissions, standardized to include GHGs that are not carbon dioxide (e.g. methane)
COE	Cost of Electricity
CPP	Captive Power Producer
CSG	Customer Service Group in BHP Billiton (Business Unit)
CSP	Concentrated Solar Thermal Power
DT	The Decision Team for energy and renewable energy
EBIT	Earnings Before Interest and Taxes (a measure of profit)
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortization (a measure of profit)
EHS	Environmental Health and Safety department of a company
ETS	European Union Emission Trading Scheme
EU	European Union
FCCC	United Nations Framework Convention on Climate Change (UN agency responsible for the Kyoto Protocol and other UN climate accords
FY	Fiscal Year, as differentiated from calendar year (CY)
GDP	Gross Domestic Product, a measure of all the goods and services provided over the course of a year
GHG	Greenhouse gas (gases such as carbon dioxide and methane - which are responsible for global warming)
Gt	Gigatonne (one billion metric tons)

HSEC	BHP Billiton's EHS department is called Health, Safety, Environment and Community
HTF	Heat Transfer Fluid
IGCC	Integrated Gasification Combined Cycle
IPCC	United Nations Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
ISCC	Integrated Solar Combined Cycle
kW	Kilowatt (unit of power; 1 kW = 1000 Watts)
kWH	Kilowatt-hour (unit of energy)
MM	Million
MW	Megawatt (unit of power; 1 MW = 1000 kW)
MWh	Megawatt-hour (unit of energy)
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory (United States)
O&M	Operation and Maintenance
PV	Photovoltaic
R&D	Research and Development
REWG	Renewable Energy Working Group, proposed cross-functional team for the evaluation of renewable energy technologies at BHP Billiton
SNRE	School of Natural Resources and Environment, at the University of Michigan
T&D	Transmission and Distribution
tCO2e	tonnes (metric) carbon dioxide equivalent
UN	United Nations
W	Watt
WBCSD	World Business Council for Sustainable Development, a global association of 200 companies and business leaders collaborating on issues related to sustainable development
WRI	World Resources Institute, an environmental think-tank

Chapter 1:
Executive Summary

Context and Project Description

Context and Need for Study

Two major factors have generated global interest in the development of renewable energy among corporations:

- The scientific, political, and societal consensus around the fact of global warming, its human causes, and its potential catastrophic impacts.
- The tightening supply, surging demand, and subsequent soaring prices of certain fossil fuels and concerns about energy security.

These factors have motivated escalating government action to reduce greenhouse gas emissions and diversify energy portfolios. Furthermore, mounting activism around these issues has led to an increase in corporate social responsibility and sustainability initiatives.

This context has spurred corporations to consider reducing their greenhouse gas emissions and intensity through energy efficiency initiatives, renewable energy projects, and greenhouse gas (GHG) emission reduction projects.

These external factors, combined with a variety of regional, and industry-specific factors have led global metals and mining company BHP Billiton to evaluate opportunities for the adoption of renewable energy. These factors include:

- BHP Billiton's significant energy demand
- The importance of energy to BHP Billiton's costs *and* revenues
- BHP Billiton's position as the industry leader
- The company's climate change policy and specific GHG emissions reduction targets
- BHP Billiton's desire to comply with legislative requirements for renewable energy
- BHP Billiton's need to manage its reputation and enhance its "license to operate"[1]

These factors, combined with the company's relative inexperience with renewables, and the need to consider the application of a broad range of emerging renewable energy technologies across a diverse set of global assets[2], have motivated our study.

1 "License to Operate" is a critical concept for BHP Billiton. The company highlights gaining and maintaining its "license to operate" locally, regionally, and globally as fundamental to its success. The concept encompasses the company's reputation as a corporate citizen, a partner to all stakeholders, and its commitment to sustainable development, health, safety, environment, and the communities where it operates, including the global community.

2 In the mining industry, "asset" refers to an operating unit such as a mine or a major operational facility (e.g. smelter).

Purpose

In fall 2006, Paul Doetsch and Steven Antalics of BHP Billiton engaged the School of Natural Resources and Environment Masters Project team to develop a general *framework* or *process* for:

1) Evaluating the potential for the adoption of renewable energy across a the range of operational assets, and
2) Identifying the most promising renewable energy technologies and project concepts for these assets.

This report articulates the resulting framework, which is essentially a seven-step process for evaluating the potential for renewable energy at a given asset, identifying specific appropriate technologies based on goals and available resources , and formulating project concepts based on the technologies which show the most promise for serving an asset's needs and management's goals. It serves as a "how to" for management seeking to identify potential renewable energy projects for an asset.

Scope

The emphasis of our study is on renewable solutions for generating *electricity* from wind, solar, and biomass. Our framework is, however, may be expanded to include a broader set of renewable energy resources and technologies, such as biofuels.

The emphasis on renewable electricity stemmed primarily from the fundamental differences between supporting electricity production versus fuel production, the complexity of biofuel production, and the number of intermediaries required for BHP Billiton to support a biofuel project. Our detailed examination of different renewable technologies confirmed that electricity generation is a more relevant and integral application of renewable energy technology for most industrial operations.[3] However, at the request of our client, the team assessed biofuel production in our site evaluation of the Corridor Sands asset. Biofuels were not explicitly included in our framework.

Finally, the framework focuses on the identification of renewable energy electricity generation at scales of greater than five MW capacity. We have chosen this focus on larger scale electricity generation because our aim has been to find technologies that can have potential to make a significant, measurable impact on the fossil fuel consumption and carbon emissions of an industrial facility. Our framework can, however, be used to evaluate smaller scale systems.

3 Electricity procurement is site-specific and integral to most industrial facilities. Biofuels are different: they are commodities that can be sourced from global markets. Direct procurement is the simplest way for BHP Billiton to incorporate biofuels. Procurement of biofuels, however, is different from the "adoption" of renewable energy as discussed here. Adoption, in this context, would require involvement in agriculture, which is a significant, non-core undertaking for BHP Billiton, and is primarily only relevant at assets like Corridor Sands where there is an significant need to develop livelihoods near the asset. We address this in more detail in our Corridor Sands site evaluation at the end of this report.

Process

Our framework emerged from the process of conducting two renewable energy assessments for BHP Billiton assets. The goal of these assessments was to identify the most promising renewable energy technologies for each asset. First, we conducted an assessment of the proposed Corridor Sands mine in southern Mozambique, with an emphasis on technological viability, low-cost economics, and identifying opportunities for livelihood development, as prioritized by Corridor Sands management. Next, we evaluated the Escondida copper mine and related assets in northern Chile, and considered—in addition to technology and economics—the pending regulatory requirements, the geopolitics of energy and renewable energy in the region, and implications for BHP Billiton's "license to operate."

From these analyses, we have developed preliminary recommendations of technologies and project concepts that demonstrate potential to serve the needs and goals of the assets, and for which we believe BHP Billiton should proceed to commission more detailed pre-feasibility assessments. We have also identified the principal drivers and goals at each asset which have led the assets to consider the adoption of renewable energy.

Asset Evaluations and Recommendations

Corridor Sands (proposed) titanium mine, southern Mozambique

Our review of the proposed Corridor Sands titanium mine in southern Mozambique identified two promising renewable energy projects that merit further examination by BHP Billiton: biomass gasification—which can serve Corridor Sands' electricity needs, and biofuel cultivation—which can fulfill BHP Billiton's goal to create sustainable livelihoods in the mine region.

The cultivation of eucalyptus and casuarina trees as a feedstock for biomass gasification to electricity demonstrates the most potential among renewable energy technologies to serve a significant portion of the direct electricity needs of the Corridor Sands operation. This option would also generate some livelihoods in the region.

The cultivation of energy crop *jatropha curcas* for the production of biodiesel, however, shows the greatest potential among renewable energy options for significant livelihood creation but is less appropriate for serving the electricity needs of the mine site. Livelihood creation is a critical need for the mine region, and as such served as a strong motivator for the adoption of renewable energy for Corridor Sands.

The different benefits of these recommendations—biofuel cultivation and biomass gasification—illustrate the importance of identifying clear drivers and goals for renewable energy adoption, and the significance of these goals in the selection of technologies. The biofuel recommendation stems from the high-priority goal at Corridor Sands to find opportunities for livelihood creation, which shifted consideration away from other renewable technologies such as wind or solar. However, the competing goal to find a dispatchable, low-cost source of renewable electricity would inform the adoption of biomass gasification, instead.

Escondida copper mine, northern Chile

Our review of the Escondida copper mine and related assets in northern Chile identified significant potential for electricity generation from the world-class solar resource in the region via concentrated solar thermal power (CSP) or solar photovoltaic (solar PV) technologies. We also suggested that the wind resource—while difficult to gauge with any certainty—merited further investigation due to anecdotally high wind speeds, available land, and the low cost of wind assessments (less than $2 million).

Our assessment also identified the pending legislative requirements (in the form of a renewable portfolio standard) and securing BHP Billiton's "license to operate" in the region, as the critical drivers for renewable energy for Escondida. Notably, we did not identify the significant and growing electricity demand at the site as a leading driver for the adoption of renewable energy—principally because none of the viable technologies in the region is suitable to meet the scale and profile of the demand at Escondida.

Framework for Evaluating Renewable Energy Options

We have identified the seven principal steps for evaluating the adoption of renewable energy across BHP Billiton's global assets:

1. Understand base case energy scenario, as well as the strategic and macro-environment
2. Identify drivers and develop renewable energy goals utilizing insight from the base case
3. Select and prioritize criteria for differentiating between renewable technologies
4. Assess renewable resources available near the project site
5. Identify viable technologies that utilize available resources
6. Match viable technologies to priority criteria
7. Develop renewable energy project concepts and conduct evaluations of these concepts

The first three steps of this process are particularly critical for the adoption of *renewable* energy. The company must consider whether the renewable technology will serve the energy needs of the asset directly (captive power), or whether the solution can contribute to an electrical grid from which the asset draws electricity. Renewable electricity generation from wind and solar, for example, in its current state of development, is more feasible with grid-integration, because of the non-dispatchability[4] of these technologies.

Thus, the option for grid-integration greatly expands the potential for the adoption of renewable energy. Essentially, grid-integration introduces a degree of separation between the technology's electricity generation attributes and the asset's electricity demand. As such, the possibility of grid integration is a critical enabler for renewable energy technologies, and has significant implications for which, if any, renewable technologies are viable for a specific context.

Given the primarily supplemental role of renewable energy generation in its current state of evolution, strategic considerations often serve as significant differentiators between the available technology options.

As part of Step 2, management must use the base case to develop a broad understanding of the drivers underlying the adoption of renewable energy and to define specific goals that renewable energy can help the company meet.

In Step 3, the goals articulated in Step 2 are translated into technology-specific criteria that can be used to distinguish between particular renewable energy technologies.

Step 4 involves the identification and approximation of the scale of the renewable resource that is available in the region. We have developed a *Resource Assessment Toolkit* to aid in evaluating resource potential, because this process varies considerably by resource and electricity conversion technology. Examples of resource assessment include the measurement of average solar radiation, wind location and speeds over time, and agricultural productivity in a region.

Step 5 involves the identification of viable, appropriate technologies for a given set of available resources at a site. For example, this step may inform the selection of a type of wind turbine for a certain class of wind or a preference for silicon solar photovoltaic, thin-film photovoltaic, or concentrated solar thermal (CSP) technology for a particular solar resource.

Step 6 requires the identification of a "short list" of appropriate technologies by matching viable technologies from Step 5 with the prioritized criteria and requirements from Step 3.

Finally, Step 7 involves the development of project concepts from the short-listed technologies, and the evaluation of those concepts across economic, strategic, social, and environmental criteria.

[4] Non-dispatchability refers to electricity generation from *intermittent* resources in the absence of viable electricity storage. Wind and solar are described as *intermittent* resources because the wind is not consistent and there is no sunshine at night. As a result, the electricity generating capacity from wind or solar technologies is considered *nondispatchable*.

Key Insights and Findings

Our research illuminated some important findings about the adoption of renewable energy for energy-intensive industries such as metals and mining.

Renewable Energy is a Value-Added Supplement to Conventional Energy Production

Role and Integration of Renewable Energy for Industrial Facilities

Currently, most renewable energy technologies cannot completely replace conventional generating capacity primarily because of their relatively limited capacity, non-dispatchability, and relatively higher cost.

In its current state of evolution, renewable energy offers the potential for strategic, and financial, reputational benefits for industrial facilities primarily as a *value-added supplement* to conventional sources of energy.

Of the technologies evaluated, biomass-to-electricity is the primary technology that can provide consistent baseload generation.

Two major options for the integration of renewable energy technologies exist: *direct supply to an asset through captive generation* and *grid-integration with third-party transmission and distribution*.

The option to *grid-integrate* renewable technologies reduces the concerns about variability in production, and thereby eliminates a significant obstacle to the adoption of these technologies.

Drivers of Renewable Energy for Industrial Facilities

Identifying drivers and developing clear goals related to renewable energy is critical because different goals inform the selection of different technologies. Goals might include hedging fossil fuel cost volatility, developing livelihoods, enhancing corporate "license to operate."

Given renewable energy's current primarily supplemental role, the drivers for its adoption may not be directly related to increasing capacity or serving core energy needs.

Key Benefits of Adopting Renewable Energy

Security

Energy security: Renewable "fuels" (including wind and sunshine) are often indigenous to the land and independent of typical fuel supply risks. Thus, renewable energy can benefit the company by diversifying its energy portfolio.

Energy price stability: Renewable "fuels" are often free and independent of volatile international fossil fuel prices, and can offer a "hedge" to fossil fuel dependency. Solar installations, in particular, have extremely stable (and relatively low) maintenance and operating costs.

Financial Benefits and Risk Mitigation

Renewable energy offers benefits in capital expenditure scale, timing, and risk profile through the flexibility that comes from the relatively small and modular nature of renewable technology investment and the avoidance of the significant "lumpy" and lengthy conventional generation upgrades (e.g. building a new coal power plant or LNG terminal, which are only worth building at a significant scale).

Renewable energy has *real option* value from the modular nature of the smaller investments, which can be timed more closely with increases in demand.

Renewable energy can reduce the risk of environmental and regulatory costs and burdens from the emissions and other externalities associated with conventional technologies.

Renewable energy lowers GHG emissions and emissions intensity, helping the company meet GHG emissions commitments.

Renewable energy presents an opportunity to generate revenue through GHG emissions reduction credits, which may be substantial as the market price for permits increases.

Strategic Benefits

Renewable energy can enhance "license to operate" by credibly signifying a commitment to sustainable development (critical in developing countries in which BHP Billiton operates) through the deployment of technologies that have superior environmental performance.

Renewable energy adoption can improve relations with government, NGOs, investors and other stakeholders, possibly reducing regulatory, approval, and oversight challenges and burdens (e.g. renewable energy can create domestic or community employment opportunities through energy-crop cultivation and management, improving community and government relations and enhancing corporate reputation).

Renewable energy can foster a culture of innovation and leadership in values and technology

Challenges to Implementing Renewable Energy for Industrial Facilities

Solar and wind technologies have higher variability of electricity generation and lower dispatchability relative to conventional generation and biomass-to-electricity.

Biomass-to-electricity feedstock cultivation can have adverse environmental and social impacts if not carefully managed.

In the absence of subsidies, renewable energy generation currently often costs more than conventional generation.

Price uncertainty in GHG emissions markets make the valuation of renewable energy investments challenging.

There is often limited experience and staff expertise around the procurement, engineering, and development of renewable energy projects.

If BHP Billiton desires to deploy renewable energy as captive power (to serve its assets directly), rather than developing grid-integrated renewable generation, a perception that renewable energy is unreliable or untested may need to be overcome.

Chapter 2:
Introduction and Background

Concerns about global warming, energy security, and the increasingly volatile price of fossil fuels have driven worldwide efforts to reduce greenhouse gas (GHG) emissions, diversify energy portfolios, and access low cost fuels. The impact of these drivers has been bolstered by the growing corporate social responsibility and sustainability movements. These forces have aligned to motivate action toward the adoption of renewable energy technologies among governments, industry, and civil society.

The metals and mining industry is particularly susceptible to these concerns, because it is directly responsible for an estimated seven to ten percent of the world's energy consumption[5] and approximately five percent of all global greenhouse gas emissions.[6] In response to these external forces, companies within the metals and mining industry have begun to take significant action to decrease their energy utilization, energy-intensity and GHG emissions. As part of this effort, these companies—including BHP Billiton—have begun to consider the adoption of low-carbon and carbon-neutral renewable energy technologies.

Definition of Renewable Energy

Renewable energy describes energy generated from unlimited or rapidly replenishing sources that "renew" on a timescale such that humans can utilize them indefinitely.[7] Examples include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action, and tidal action. Large-scale hydro is not considered here because it is well understood and has often already been exploited. Sources of renewable energy are considered inexhaustible but are generally flow-limited. That is they are limited in the amount of energy or power (capacity) that can be delivered per unit of time.[8] Renewable energy technologies are often defined in contrast to non-renewable fossil fuels as zero or low-GHG-emissions (e.g. wind and solar) or as GHG-neutral (e.g. biofuels and biomass). The scope of our study is restricted to the three most commonly used renewable resources (i.e., wind, solar and biomass) and the most widely deployed renewable resource-to-electricity conversion technologies.

Drivers for Renewable Energy

Energy Security and Increasing Energy Prices

Increasing demand for fossil fuels by the developing world, particularly from India and China, has generated a tightening global supply of energy commodities—particularly natural gas and petroleum—around the world. **Exhibit 2-1** and **Exhibit 2-2** illustrate the global trends in energy demand and oil prices, respectively.

5 Earthworks and Oxfam America, "Mining, Communities and the Environment," 2004, p. 12

6 Tim Herzog, Jonathan Pershing, and Kevin A Baumert, *Navigating the Numbers: Greenhouse Gas Data and International Climate Policy*, World Resources Institute, 2005, p. 70.

7 Australian Academy of Science, "Glossary," Accessed March, 2008, http://www.science.org.au/nova/005/005glo.htm

8 Energy Information Administration, "EIA Glossary," Accessed March, 2008. http://www.eia.doe.gov/glossary/glossary_r.htm,

Exhibit 2-1: Increasing Global Demand for Energy. Source: Int'l Energy Agency, World Energy Outlook 2007

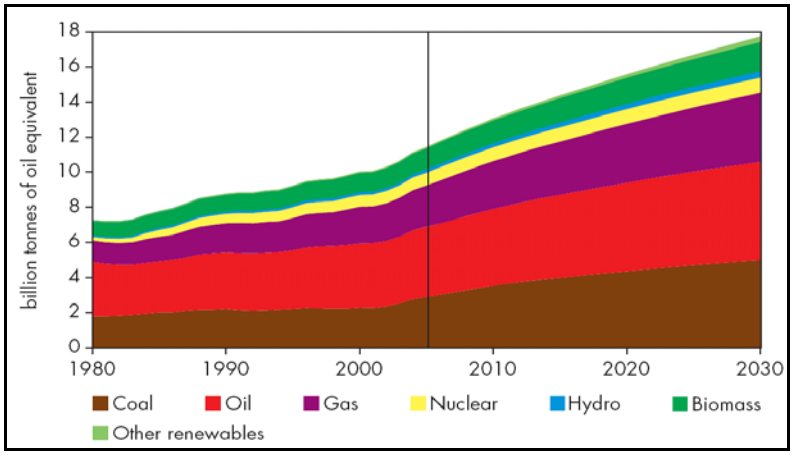


Exhibit 2-2: Historic and Projected World Oil Prices. Source: CountryWatch Energy Forecast, April 2007

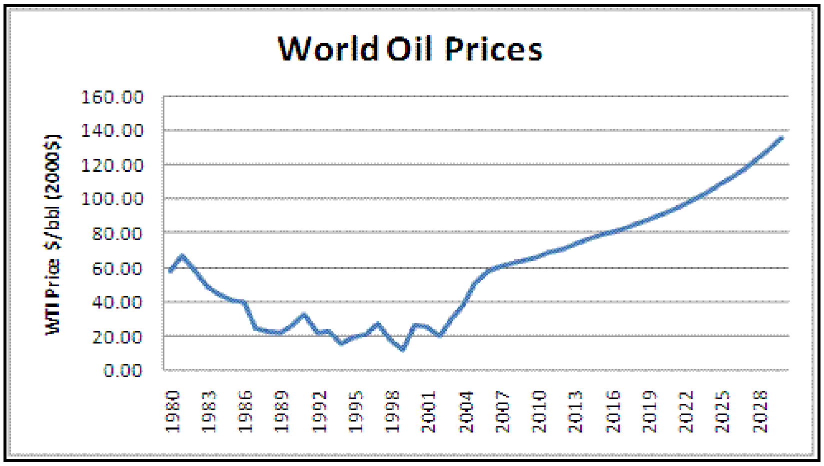
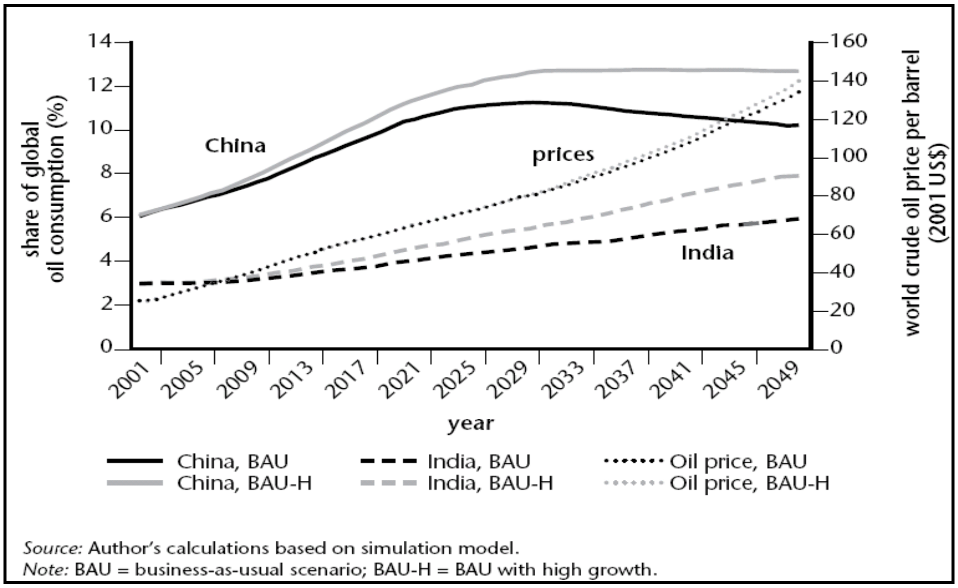


Exhibit 2-3 illustrates the how increasing demand from India and China is projected to correlate with the global price of oil in both a business as usual (BAU) and a high-growth business as usual (BAU-H) scenario.

Exhibit 2-3: Global oil price correlated with demand growth from India & China through 2020. Source: Winters and Yusuf, World Bank, 2007



The impact of this increased demand is exacerbated by the fact that new electricity generating capacity in many developed nations has shifted from coal to natural gas technology to reduce atmospheric emissions including GHGs. This trend is supported by the Energy Information Agency's long-term price projections presented in **Exhibit 2-4** (below), and the shift to electricity generated from oil and natural gas (as opposed to coal) is illustrated in **Exhibit 2-5** (below). This supply/demand scenario has led to increasing volatility and higher prices for natural gas generated electricity around the world. The resultant price inflation has inspired many countries and regions around the world to take significant measures to protect the security and stability of their energy supplies by diversifying their energy portfolios.

Exhibit 2-4: EIA annual energy (AEO) outlook for natural gas prices. Source: Energy Information Agency, 2004

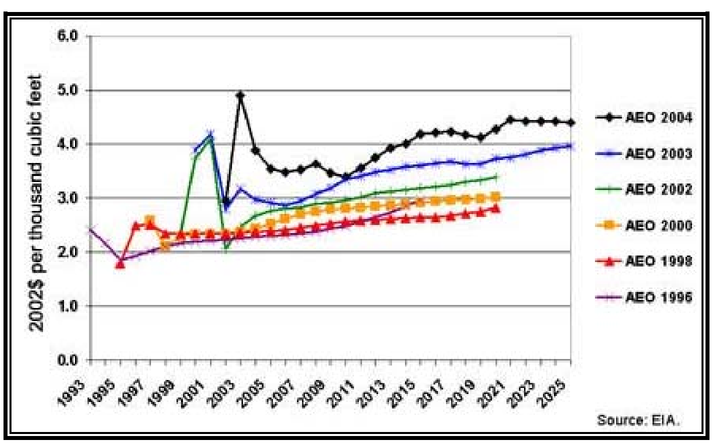
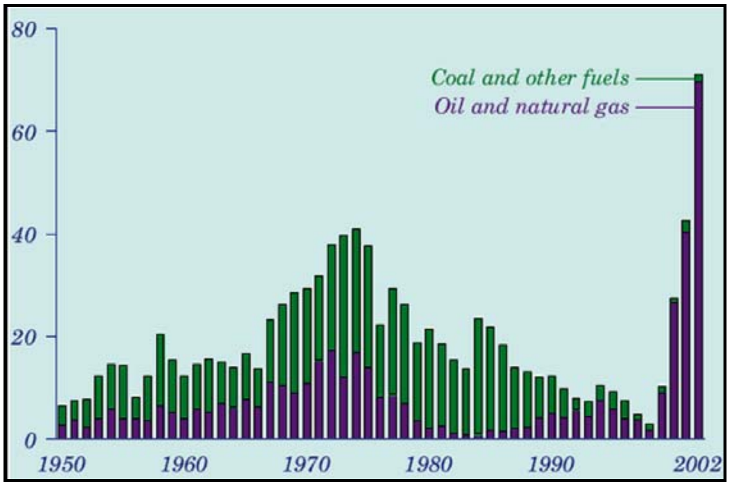


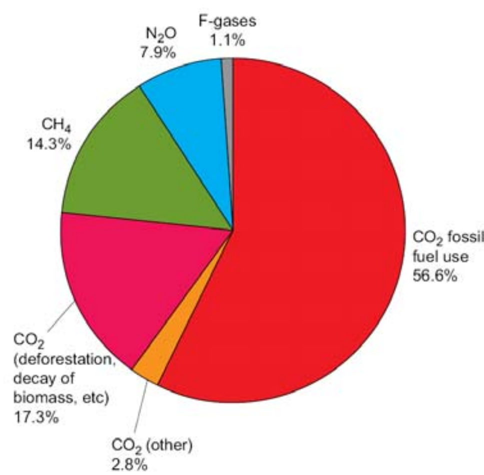
Exhibit 2-5: New electricity generation capacity in United States. Source: Energy Information Agency, 2004



Global Warming

Global warming refers to the increase in global temperatures as a result of the greenhouse effect. The principal cause of the greenhouse effect is the increasing presence of GHGs in the atmosphere, which may persist for more than a century. These gases, which are often naturally occurring, are increasing in the atmosphere as a result of human activity, primarily as a byproduct of energy use and land conversion. As illustrated in **Exhibit 2-6**, the most common GHG is carbon dioxide (CO_2)—which accounts for nearly 74% of total GHG emissions that result from human activity (anthropogenic). CO_2 from the combustion of fossil fuels makes up a full 56.6% of total global anthropogenic GHG emissions.[9]

Exhibit 2-6: Global anthropogenic greenhouse gas emissions in 2004. Source: IPCC 4th Assessment



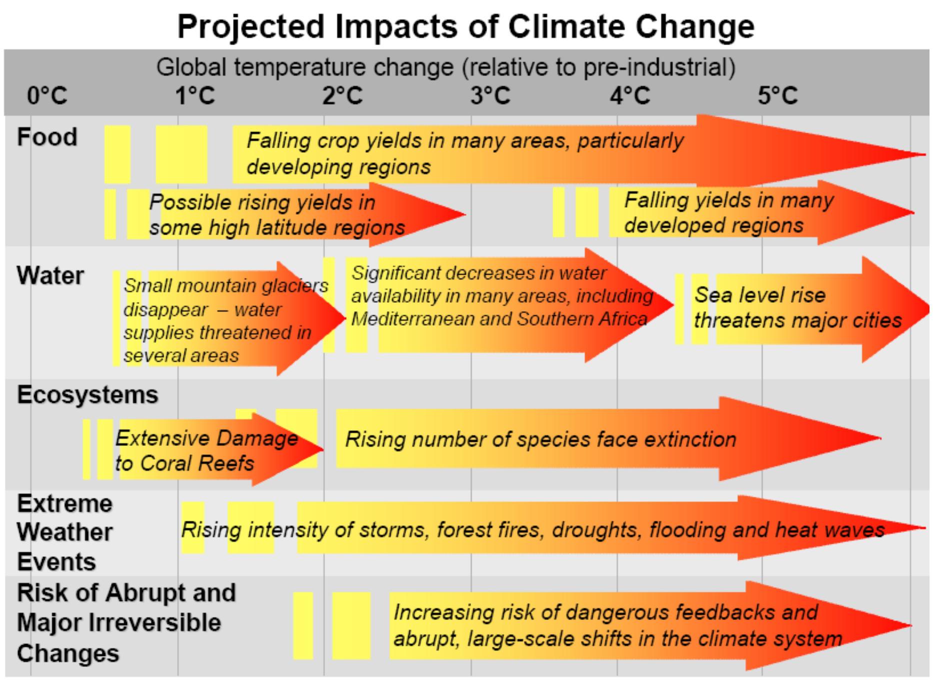
9 A *fossil fuel* is any carbon-containing fuel derived from the decomposed remains of prehistoric plants and animals, e.g. coal, petroleum, and natural gas.

Global warming has (and will continue to have) significant adverse affects on global systems and, as consequently, on human well-being as presented in **Exhibit 2-7**.

Sir Nicholas Stern, the former chief economist of the World Bank and head of the UK's Government Economic Service, predicts that the *economic* impacts of climate change, in the absence of mitigation and adaptation, "will be equivalent to losing at least 5% of global GDP each year, now and forever." He goes on to write that, "If a wider range of risks and impacts is taken into account, the estimates of damage could rise to 20% of GDP or more."[10]

Renewable energy plays a significant role in the movement to abate GHG emissions because it offers an opportunity to de-couple energy use from GHG emissions by provisioning energy from zero-carbon, low-carbon, or carbon-neutral renewable sources.

Exhibit 2-7: Impacts of Climate Change. Source: Stern, Stern Review on the Economics of Climate Change, 2006



Systems for Incentivizing GHG Emissions Abatement

As a result of the increasing awareness of climate change and its human causes as well as the increasing visibility of its impacts, governments, corporations, and civil society actors have begun to develop incentive systems to actively abate anthropogenic GHG emissions. The most important of these systems, the Kyoto Protocol (developed by the United Nations Framework Convention on Climate Change), is the primary global agreement to coordinate the reduction of GHG emissions.

10 Stern, N. H. The Economics of Climate Change: The Stern Review. Cambridge, UK: Cambridge University Press, 2007.

As part of Kyoto, various mechanisms have been developed to "price" or "tax" GHG emissions, in order to limit emissions and create incentives for emissions reduction. The largest existing implementation of such a market-based "cap and trade" system is the European Union Emission Trading Scheme (EU ETS) which caps EU emissions at a certain level and creates a market for GHG emissions permits (the right to emit GHGs), measured in tonnes (metric tons) of carbon dioxide equivalent (tCO_2e). This market offers an opportunity for companies who exceed a certain level of emissions to purchase permits for the right to emit more, but ensures that total EU emissions do not exceed a certain quantity.

The goal of these systems is to control total emissions in a way which can reduce the cost to the overall economy of emissions reduction by allowing flexibility in abatement through the buying and selling of permissions to emit. This system incentivizes the lowest cost means of abatement, and allows those companies with higher costs of abatement to purchase right to emit at a market-determined price, rather than requiring companies to directly pay their own relatively high cost of abatement[11]. Kyoto also allows for emission reduction "credits" to be generated in developing countries by reducing GHG emissions associated with projects such as displacement of fossil fuel based electricity by renewable electricity capacity. The credits, called *certified emission reductions* (CERs) are saleable within the EU ETS scheme. Since many of BHP Billiton's assets are in developing countries, the generation of CERs provides significant incentive for the company to consider renewable energy projects.

Relevance of GHG Emissions Abatement Systems to this Study

This GHG emissions "pricing" system has three effects that are relevant for our study of renewable energy. First, the system imposes a cost and risk burden on energy-intensive industries such as metals and mining—essentially charging the companies for their GHG emissions. Second, this charge serves to bring generally higher-cost renewable energy technologies closer to cost-competitiveness with conventional technology. Third, the pricing system rewards reductions in GHG emissions through revenue generation opportunities, which results in a shift toward cost-parity between renewable and fossil fuel-based electricity. Thus, adopting renewable energy presents an opportunity for metals and mining companies to reduce their emissions and possibly achieve financial benefits through lowering their total cost of abatement.

11 This "flexible mechanism" is effective because of the global impact of GHG emissions and the resulting global "fungibility" of emissions reductions. Because the greenhouse effect is a diffuse atmospheric phenomenon with global effect (and without significant specific local impacts), the reduction of GHG emissions on one part of the planet is considered equivalent (equally beneficial) to the reduction of emissions anywhere else on the planet. This explains the drive to find opportunities to reduce emissions at the lowest cost, regardless of location, to lower the overall cost of abatement to human society as a whole.

Trend towards Social Responsibility and Sustainability

In recent years, cultural shifts, increased government and media attention, and the decreasing barriers to information transfer, have created a societal expectations that corporations attempt to operate in more socially responsible and environmentally sustainable ways. This expectation has become so pervasive that most major corporations, private and public, have made some visible effort to address these expectations. At the very least, companies have developed communications about their commitments on their websites. Many companies in extractive and resources intensive industries, in particular, have embraced the principles of sustainable development in an effort to secure a "license to operate." This movement towards sustainability and sustainable development has been another motivating factor behind the adoption of renewable energy around the world. In attempt to transparently convey their sustainability initiatives to investors, many major public corporations, including BHP Billiton, have sought inclusion in sustainability performance indexes such the Dow Jones Sustainability Index.

The Metals and Mining Industry and Sustainable Development

BHP Billiton is primarily associated with the "metals and mining" industry, which is part of the basic materials sector of the global economy. Over the last twenty years, this industry has experienced the effects of several major trends which have made the companies in the industry more visible, more vulnerable to intervention, and encouraged the industry's embrace of the principles of sustainable development. To reiterate, these trends include increasing:

- Global demand for natural resources
- Industry consolidation
- Activism and environmentalism
- Regulation[12]
- Expropriation and nationalization
- Expectation of corporate social responsibility and sustainability

The booming global demand for—and tightening supply of—natural resources (driven by the economic growth of China and India) have spurred historically high prices for raw materials and resulted in windfall profits for the natural resources industry. Concurrently, within the last decade the natural resources industry has experienced extensive consolidation. Windfall profits and the increased visibility of the larger, consolidated entities have increased scrutiny and demands on these companies.

12 Laudicina, Paul A. 2005. World Out of Balance: Navigating Global Risks to Seize Competitive Advantage. New York: McGraw-Hill, 2005, Page 10.

In addition, companies in this industry and in other extractive industries such as oil and gas have faced significant reputational challenges in the past few decades due to environmental disasters, high profile accidents that have cost many lives, and political controversies. These companies have faced accusations of exploitation, contribution to violent conflict, and inappropriate engagement with corrupt governments. These events have occurred during the trend of increasing global activism[13] and the birth and expansion of the environmental movement.[14] Furthermore, most corporations are anticipating the increasing enactment of global legislation to address climate change, often *requiring* renewable energy. Many of these companies believe that adoption in advance of new rules may prepare them for new compliance requirements, help them maintain their leadership within their industries, and may gain them a seat at the table to influence this and other legislation.[15]

Yet, unlike other product-based industries which purchase raw materials from their suppliers (other firms), mining companies do not "purchase" their raw materials—they extract their inputs directly from the earth. As a result, their "suppliers" can be thought of as the countries, communities, and governments on whom they depend for their "license to operate," or permission (concessions) to extract resources. Thus, mining companies have become relatively vulnerable to interventions and interruptions based on the adverse impacts of their operations and the resulting reputational problems. These interventions often come from the government in the form of halting operations, refusing or slowing the permitting of new operations, and expropriation (including taxation and nationalization).

Companies in the industry have acknowledged the critical importance of deliberate action to secure and maintain their "license to operate" in the regions and nations where they have assets, as the resources they extract are often at least partially owned or controlled by the host government or community. Thus, natural resource companies have engaged in a variety of actions in this vein, increasing emphasis on positive government and community relations and working to improve the health, safety, environment, and community conditions in and around their operations. More recently, civil society and even investors have come to expect that companies act according to notions of corporate social responsibility and to operate sustainably. Elevated concerns about climate change have only bolstered these expectations.

These factors—combined with significant energy demand and GHG emissions profile of the industry—have motivated metals and mining companies to engage the issue of climate change through a variety of initiatives including energy efficiency improvements and switches to cleaner technologies. The companies have more recently begun to evaluate the adoption of renewable energy technologies to help reduce emissions and general environmental impact.

13 Laudicina, Paul A. 2005. World Out of Balance: Navigating Global Risks to Seize Competitive Advantage. New York: McGraw-Hill, 2005.

14 Hoffman, Andrew J., "Strategies for Sustainable Development," NRE 513: Strategies for Sustainable Development, Presentation, 2006.

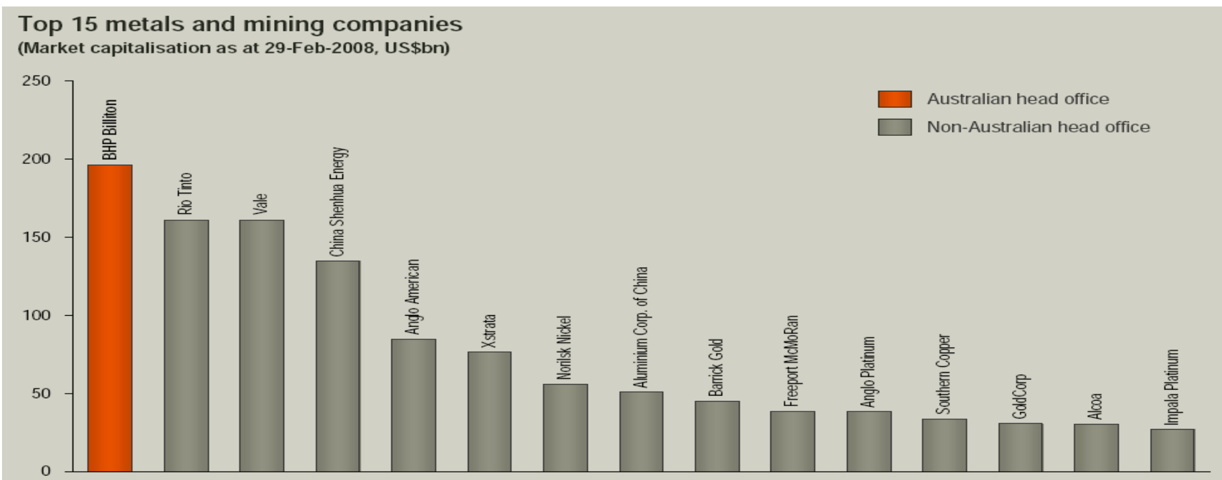
15 Hoffman, Andrew J, Carbon Strategies: How Leading Companies Are Reducing Their Climate Change Footprint. Ann Arbor: University of Michigan Press, 2007.

BHP Billiton

Company Overview

Over the period of 2001-2007, BHP Billiton became the world's largest diversified natural resources company (metals and mining). BHP Billiton is the product of the merger of Australian mining company BHP and UK miner Billiton in 2001 and the acquisition of WMC in 2005. BHP Billiton leads the metals and mining industry with a first quarter 2008 market capitalization of nearly US$200 billion[16], as illustrated in **Exhibit 2-8**.

Exhibit 2-8: Metals and mining companies, by market capitalization. Source: BHP Billiton, March 2008



The company has also experienced record profits in this period. The company's revenues in fiscal year 2007 were US$47.5 billion, with earnings before income and taxes (EBIT) of $20.1 billion and profits of $13.4 billion[17]. The company has had an astronomical five year average gross margin of nearly 60% and a significant five year earnings per share (EPS) growth rate of 61% on five-year average sales growth of 18%.[18] **Exhibit 2-9** shows a summary of income from 2003-2007.

16 Google Finance, "BHP Billiton Limited (Public, ASX:BHP)," http://finance.google.com/finance?q=asx%3Abhp&hl=en, accessed March 2008.

17 BHP Billiton, "BHP Billiton Company Profile," August 22, 2007, p. 1.

18 Reuters, "BHP Billiton (BHP) Ratios," http://stocks.us.reuters.com/stocks/ratios.asp?symbol=BHP, accessed March 2008.

Exhibit 2-9: Historical income statements, from FY2002. Source: BHP Billiton 2007

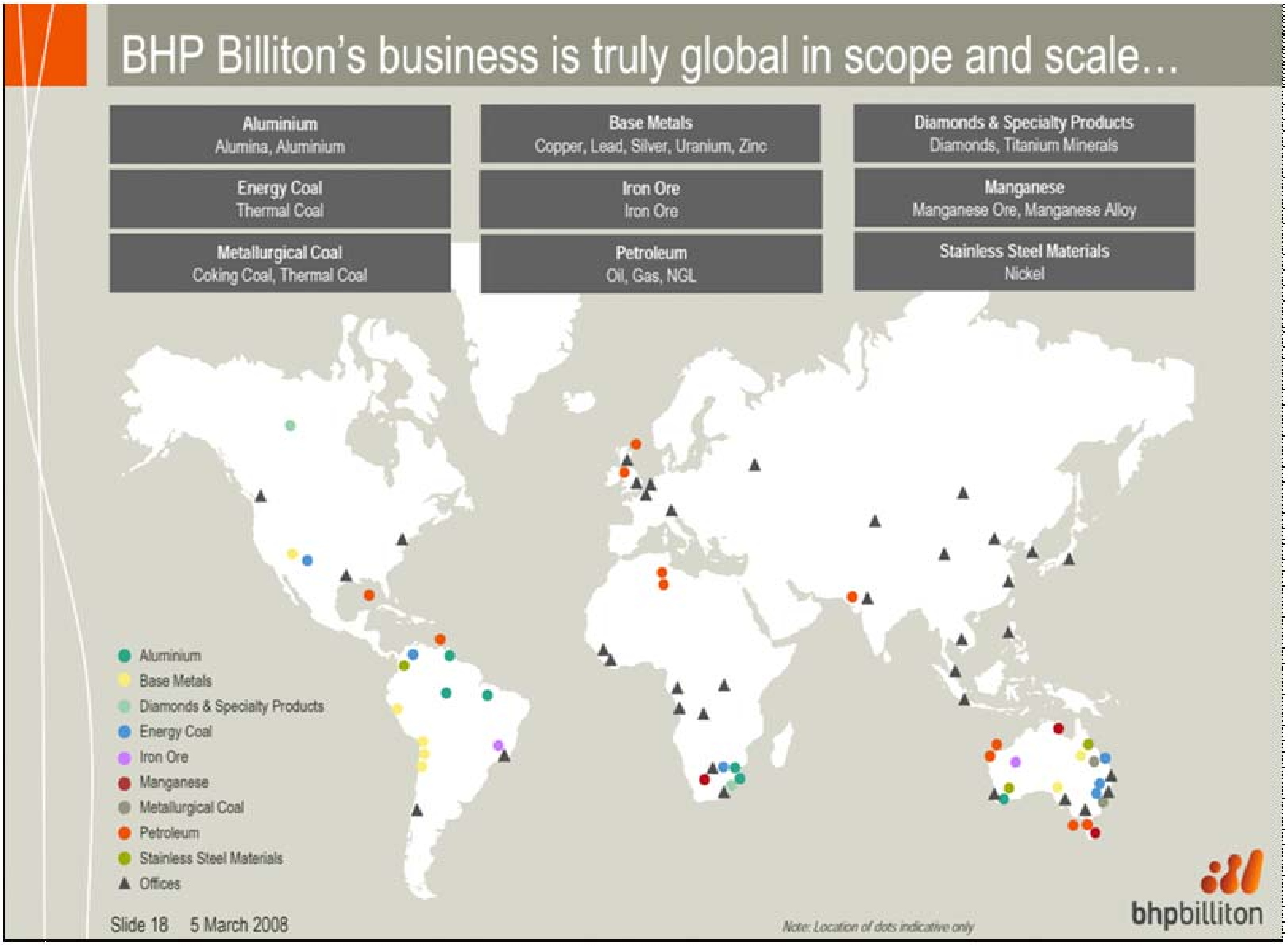
BHP Billiton Group

Five Year Summary

US$ million	2007[c]	2006[a]	2005[a]	2004[b]	2003[b]
Revenue together with share of jointly controlled entities' revenue (Turnover)	**47,473**	39,099	31,150	24,943	17,506
Underlying EBIT[c]	**20,067**	15,277	9,921	5,488	3,481
Attributable Profit - excluding exceptional items	**13,675**	10,154	6,426	3,510	1,920
Attributable Profit - including exceptional items	**13,416**	10,450	6,396	3,379	1,901
Net operating cash flow including dividends from jointly controlled entities and after net interest and taxation	**15,595**	10,476	8,374	5,100	3,631
Basic EPS - including exceptional items (US cents per share)	**229.5**	173.2	104.4	56.4	30.9
Basic EPS - excluding exceptional items (US cents per share)	**233.9**	168.2	104.9	54.3	30.6
Dividend per share[d]					
• BHP Billiton Plc (US cents)	**47.0**	36.0	28.0	26.0	14.5
• BHP Billiton Limited (US cents)	**47.0**	36.0	28.0	26.0	14.5
Underlying EBITDA Interest Coverage[c] (times)	**54.0**	44.3	51.7	21.1	13.3
Underlying gearing (per cent)	**25.0**	27.2	35.8	25.7	31.7

BHP Billiton manages over 100 locations in 25 countries and has over 38,000 employees. **Exhibit 2-10** illustrates the company's businesses and global footprint.

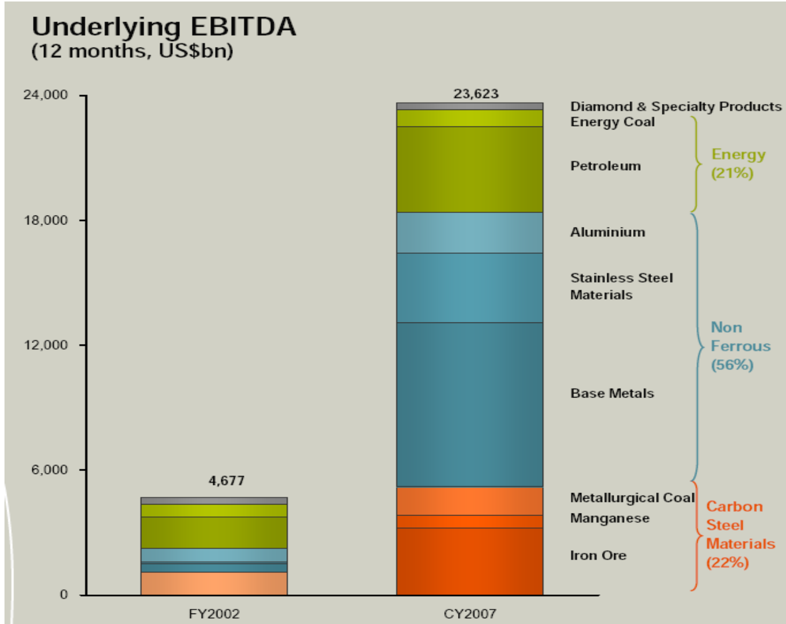
Exhibit 2-10: BHP Billiton's Businesses and Global Footprint Source: BHP Billiton, 2008



Organizational Structure

The company is divided by customer segment into nine business units called Customer Sector Groups (CSGs). As illustrated in **Exhibit 2-11**, the company generates the majority of its profits in the following CSGs: Base Metals (primarily copper), Petroleum, Iron Ore, Stainless Steel Materials, and Aluminum, respectively.

Exhibit 2-11: BHP Billiton profits (EBITDA) by Customer Sector Group. Source: BHP Billiton, March 2008



BHP Billiton's core operations are divided into vertical business units by customer. Outside of operations, there is a consolidated marketing group with two locations (Singapore and The Hague) and a corporate management team that cut across the businesses.

Marketing, in this industry, refers broadly to the commercialization of the materials extracted or produced, including sales, freight and transportation, and commodities trading. As a result of this structure and the diversity of geographies and large scale of business units, BHP Billiton's CSGs—and even the specific assets—operate with a considerable amount of autonomy.

This corporate structure—particularly the assets' autonomy—informs the flexibility required for our renewable energy framework, as far-flung assets will have significantly different requirements and considerable authority in their own energy procurement decisions.

Energy and BHP Billiton

The importance of energy to BHP Billiton influences the decision to consider, and whether to adopt renewable energy. Energy is an increasingly critical part of BHP Billiton's business, for the following reasons:

Energy's contribution to profitability – Société Générale's January 2007 analyst report predicts that BHP Billiton's energy related business (e.g., petroleum and coal) will contribute 35% to the company's earnings before interest and taxes (EBIT) by 2010.[19] This fact is significant as most of the

19 Société Générale Equity Research. BHP Billiton plc - Energy Theme May Soon Come Into Play, January 2007 30, 2007.

major energy companies—particularly the oil majors—have recently become proactive about investing in renewables and heavily promoting these investments.

Heavy energy usage – In fiscal year 2007, BHP Billiton used a total of 302.5 petajoules (quadrillion joules) of energy, which is equivalent to 84 terawatt-hours worth of electricity, or 49 million barrels of oil equivalent (BOE). Of this total, approximately 18.5 percent was used in the form of liquid fuels (8.8 million barrels of oil or 369 million gallons of fuel). The balance, equivalent to 68.4 terawatt-hours, was used primarily for electricity and heat generation in operations. BHP Billiton's total energy consumption in FY2007 was greater than the aggregate energy consumption of the entire nation of Mozambique in 2005, which has a population of 20 million people, and is home to one of BHP Billiton's most energy intensive facilities, the MOZAL aluminum smelter.[20] BHP Billiton Base Metal CSGs' operations in northern Chile alone demands more than 500 MW of generating capacity, with plans to expand to more than 800 MW by 2012.[21] In fact, the siting decision for some of the company's facilities—particularly the aluminum smelters such as MOZAL in Mozambique—are often driven by the availability and cost of electricity in a region.

Security of supply – Many of BHP Billiton's facilities are extremely electricity-intensive 24-hour operations which function 365 days a year. Often these facilities require hundreds of megawatts of baseload electricity generation capacity at all hours. For example, the Escondida mine and related operations currently has a load profile which constantly requires over 500 MW of capacity—enough to power a city of two to three million people in Chile.

These operations often include multiple stages of processing and transport at tremendous scale, and any interruption at one stage has significant implications for the subsequent processing or transport stages which can involve hundreds of people and millions of dollars worth of equipment. Thus, work stoppages are tremendously costly, and anything that compromises a stable supply of electricity can potentially cost the operation millions of dollars per day.

This combination of tremendous electricity demands and very high cost of interruption leads to a need for extremely robust and reliable electricity systems, and reinforces the importance of continuity of operations and a secure supply of fuel for the power generation facilities.

Significant greenhouse gas emissions – BHP Billiton reported emissions of 52 million tonnes of CO2e in FY2007, primarily from energy-consumption.[22] These emissions are more than 20 times the total 2005 emissions of Mozambique.[23] BHP Billiton did not, however, report the downstream emissions (from the after-sale "use-phase" of the company's products' lifecycle)—which would primarily include the emissions from the conversion of its iron ore product into steel and the

20 US Energy Information Administration, "Mozambique Energy Profile," Accessed March, 2008. http://tonto.eia.doe.gov/country/country_time_series.cfm?fips=MZ#prim
21 BHP Billiton Base Metals. "Power Situation in Northern Chile – Update," Santiago, October 2007.
22 BHP Billiton. "BHP Billiton Sustainability Report 2007." 2007.
23 US Energy Information Administration, "Mozambique Energy Profile," Accessed March, 2008. http://tonto.eia.doe.gov/country/country_time_series.cfm?fips=MZ#prim

combustion of its petroleum and energy coal production[24]. BHP Billiton reported total GHG emissions of more than 450 $MtCO_2e$ in 2005 – mostly CO_2 from fossil fuel combustion. If it were a nation, this emissions footprint would put BHP Billiton among the top 15 nations for total CO_2 emissions, and make BHP responsible (to a certain extent), for approximately 1.5 percent of *total global GHG emissions*. Today BHP Billiton's footprint is likely even more significant, given the mergers, acquisitions, and overall growth of the company.

The company's emissions are relevant to decisions regarding renewable energy projects, because these projects can serve to "offset" emissions and reduce the financial and reputational burden associated with these emissions. In fact, BHP Billiton (an Anglo-Australian company) is subject to emissions reduction requirements as part of the Kyoto-Protocol-based European ETS, since both the UK and Australia have ratified the agreement. The Kyoto Protocol (KP) allows for "flexible mechanisms"[25] for emissions reductions which allow nations for whom the cost of GHG emissions abatement maybe high to receive credit toward their own emissions reduction targets by "subsidizing" the development of low-emissions technologies or offset projects in the developing world (which would not otherwise have been developed without these subsidies).

Energy Procurement and Purchasing

Energy procurement for major industrial facilities is extremely important to the business and the arrangements can be very complex and dynamic. One asset may purchase power through a variety of independent power producers and may also self-generate a certain quantity of power. Other assets may own their generating facilities and sell electricity to external customers when they do not require their full capacity.

Similarly, in electricity and power procurement, the company can have generating facilities that serve the asset directly, or the company may purchase from a grid, or both. Often, if demand is significant, the company may have an arrangement for special transmission and distribution from a grid. The ownership arrangements for these generation facilities can also be quite complex, ranging from self-generation, where BHP Billiton owns and operates its own generating facilities, to power purchase agreements from independent power producers (IPP). **Exhibit 2-12** illustrates some of the power generation structures that have emerged to serve the needs of industrial customers, particularly in deregulated electricity markets.[26]

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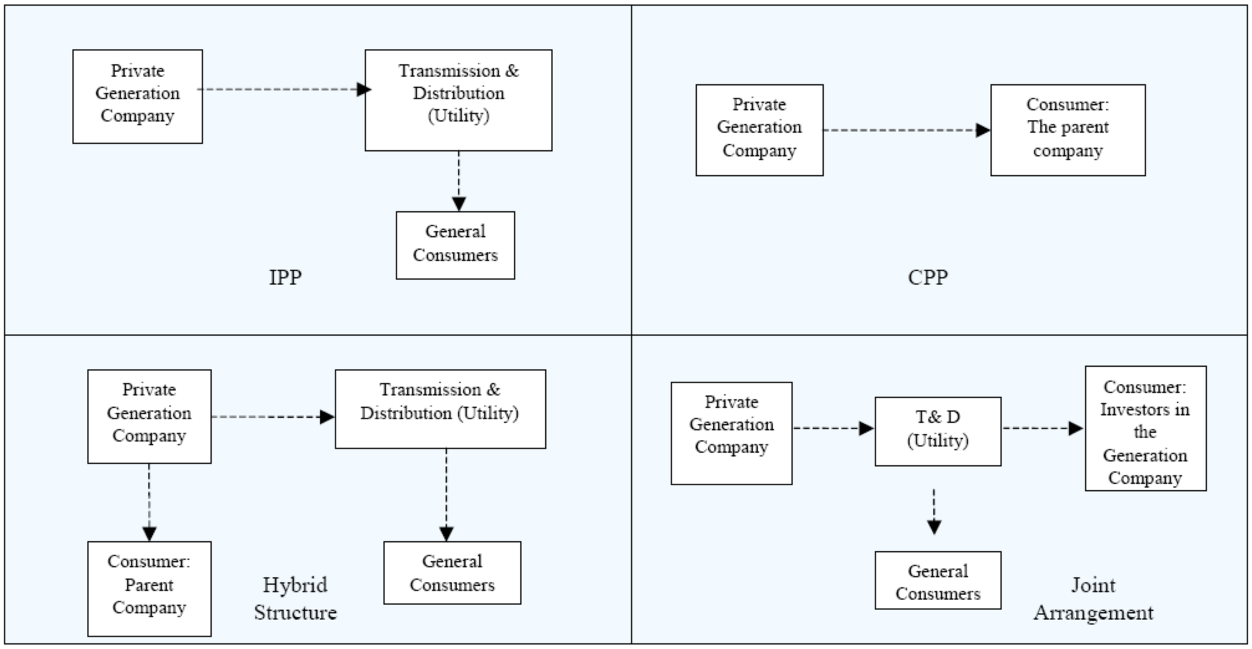
24 Reporting downstream emissions is still fairly unusual, as firms are not considered fully "responsible" for emissions that occur during the use phase of the products which they sell.

25 These "flexible mechanisms" are known as Joint Implementation when used between industrialized countries, and as the Clean Development Mechanism (CDM) when arranged between industrialized nations and less developed countries.

26 Biswas, Debashish, "Emerging Structure of Generation Entities and Role of Captive Power." PowerPoint presentation. Indian Institute of Management. April 7-8, 2003. Ahmedabad, Gujarat, India.

Exhibit 2-12: Power Generation Structures. Source: Biswas 2003



When considering options for adopting renewable energy, one fundamental consideration is whether a renewable electricity generation technology is expected to *directly serve the electricity needs of the asset* (captive power), or whether the technology can simply be *integrated into a transmission and distribution grid* for *general consumption* on that grid. The choice between these options would depend on the circumstances at the asset and the management team's goals and preferences. We discuss the implications of this in more detail in **Chapter 4**: **Framework for Evaluating Renewable Energy**.

It is important to note here that BHP Billiton's management generally prefers *not* to own or operate the power generation that serve its assets. BHP Billiton prefers to own and operate only the elements of its value chain which are part of its core business: mining, concentration, processing, smelting, etc. As part of these arrangements, BHP Billiton has the experience and leverage (as a large, wholesale purchaser of power) to create sophisticated "swap" contracts and purchase agreements which are highly relevant to the company's support of renewable energy. For example, BHP Billiton can use its leverage to create derivative contracts whereby it sponsors the development of natural gas generating facilities but never pays more than the standing price for coal-generated electricity. In the same vein the company can develop renewable energy projects where it receives "credit" for providing renewable energy without having any of the electrons from that renewable energy project actually directly supporting its operations.

Energy Challenges

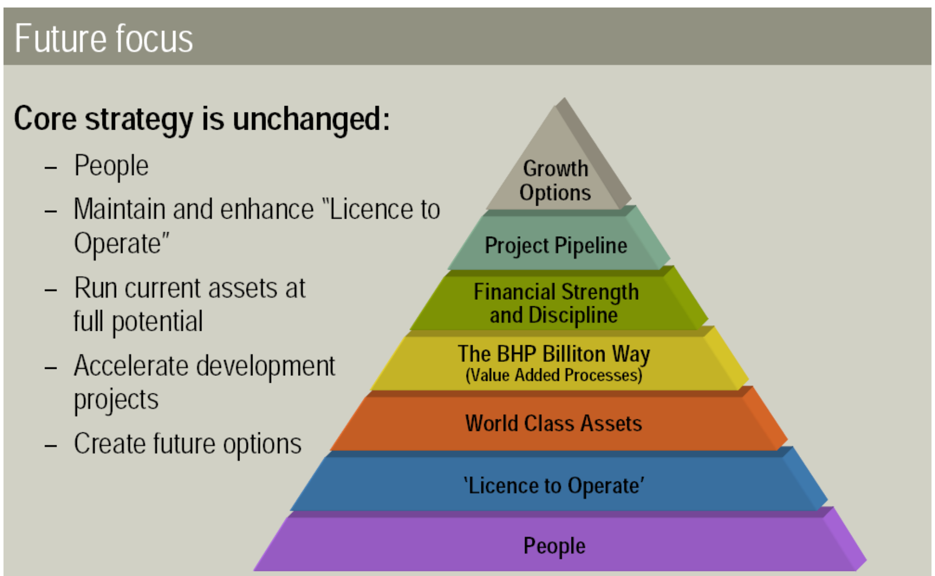
Not only does energy continue to increase in its importance to BHP Billiton, but obtaining sufficient, secure, and low-cost sources of energy is increasingly one the company's most significant challenges. BHP Billiton's operations are frequently remote, tremendous in scale, and highly energy-intensive with flat power demand profiles. The energy-intensity of operations often means that the cost of energy is often a highly significant percentage of the total cost of operations. The cost of downtime can be astronomical. One manager at Escondida explained that downtime in his facility alone cost the operation several thousand dollars per minute. Thus, operational continuity is a mission-critical concern for the company's assets, and energy sources must be sufficiently reliable and secure to support this criticality. Any factor that can jeopardize operational continuity receives significant attention from BHP Billiton's management—and, as such, securing a reliable energy supply is often paramount.

BHP Billiton's License to Operate and Commitment to Sustainable Development

BHP Billiton's motivation to secure its "license to operate" and its commitment to sustainable development are key drivers which motivate its interest in renewable energy. The company's current position as industry leader (and the requisite vulnerabilities of this position), record profitability, and its history of reputational crises—combined with the forces facing the industry—have inspired the company to proactively seek leadership on issues that promote the company's *license to operate*. Thus, *license to operate* is a critical concept for BHP Billiton, and as such has been built into the company's policy, strategy, and governance approach.

Exhibit 2-13 illustrates the company's view of its seven core strategic drivers, demonstrating the company's view of the foundational importance of gaining and maintaining this license to operate.[27]

Exhibit 2-13: BHP Billiton's Strategic Drivers. Source: BHP Billiton, 2007



BHP Billiton has defined its license to operate as a function of "healthy people, safe workplaces, environmental commitment, economic contribution, and sound governance." Thus, license to

27 BHP Billiton, "Sustainability Report 2006," 2006.

operate functions as a motivating factor for many of BHP Billiton's actions around health, safety, environment, and community issues.

These values are also coded into the company's charter, which specifically emphasizes identifies "Safety and Environment" as one of the company's six core values.[28] In an effort to operationalize these values, the company has organized to prioritize the management of these issues. As such, BHP Billiton has created a set of processes and policies that inform and support the company's operations around sustainable development, government relations, and health, safety, environment, and community.

This priority to secure its license to operate and the company's commitment to sustainability and social responsibility are part of what motivate BHP Billiton's interest in more environmentally friendly technology, including renewable energy.

BHP Billiton and Climate Change

BHP Billiton's commitments to sustainable development, the escalating concerns around climate change, and the company's acute exposure to environmental issues (including its GHG emissions profile) have motivated the identification of global warming as a specific area of emphasis. Concerns around climate change, in turn, further bolster the company's interest in renewable energy.

To address the potential GHG emissions liabilities, the company has articulated a Climate Change Policy with commitments to 1) gaining greater awareness of lifecycle energy and GHG intensity and emissions, 2) improving the management of these emissions through various mechanisms, 3) collaborating with stakeholders to promote emission reductions, and 4) influencing policymakers to adopt equitable, market-based climate legislation. As part of this policy, the company has committed US$300 million over the period of 2008-2012 to reducing emissions by supporting R&D, employee and community abatement projects, and by providing funding for internal emissions reduction projects which "might not otherwise be competitive within normal capital allocation processes."[29] The core components of the policy are shown in **Exhibit 2-14**.

28 BHP Billiton, "Charter," October 2007. http://www.bhpbilliton.com/bb/aboutUs/charter.jsp accessed March 2008.
29 BHP Billiton, "Climate Change Policy," October, 2007.

Exhibit 2-14: BHP Billiton Climate Change Policy, October 2007

BHP BILLITON
CLIMATE CHANGE POLICY

OVERVIEW

BHP Billiton believes that the risks of climate change associated with increasing greenhouse gas concentrations in the atmosphere need to be addressed through accelerated action. The actions should aim to stabilise concentrations at levels guided by the research of the United Nations Intergovernmental Panel on Climate Change. Behavioural change, innovation and technological progress are necessary to achieve stabilisation in a manner consistent with meeting natural resource and energy needs. Building on our earlier efforts, we will take action within our own businesses and work with governments, industry and other stakeholders to address this global challenge and find lasting solutions consistent with our goal of Zero Harm.

Our actions focus on four areas:

1. Understanding emissions from the full life cycle of our products.
2. Improving the management of energy and greenhouse gas emissions across our businesses.
3. Committing US$300 million over the next five years to support low emissions technology development, internal energy excellence projects and encourage emissions abatement by our employees and our local communities.
4. Using our technical capacity and our experience to assist governments and other stakeholders on the design of effective and equitable climate change policies including market-based mechanisms such as emissions trading.

Evaluating Renewable Energy Options

It is in the context of this array of societal, industry and firm-specific drivers for renewable energy that BHP Billiton has commissioned our study. Beyond this array of drivers, the dimension which created the need for our study is that our perspective must consider the application of renewable energy across a diverse set of assets, each of which has its own requirements, potential drivers, and renewable resources. As such, a key output of our study is the flexible framework for the application of renewable energy across these assets, which is featured in **Chapter 4**.

Our framework facilitates the selection of promising renewable technologies for an asset, considering the different goals which may motivate the adoption of renewable energy for that asset. Once renewable-energy related goals have been developed for an asset, the team has developed detailed "toolkit" guides for the management team to understand the process for assessing renewable energy resources, and for the selection of specific technologies appropriate to those resources. Finally, the framework offers guidance on matching renewable energy goals and criteria with technically viable technologies, and offers insight into the development of project concepts for more detailed evaluation.

We have also provided a sample conceptual-level application of our framework, based on our renewable energy evaluation of the Escondida copper mine in northern Chile. Finally, we have provided concluding thoughts and an appendix with more detailed assessments of the assets we visited -- which served as the basis for the formulation of our framework.

Methodology

The development of a broadly applicable framework is the result of an iterative process of applied research at BHP Billiton assets and an attempt at simplifying multi-criteria decision-making into a flexible, useful system. As such, we developed this framework for the evaluation of renewable energy in phases. We hope our work will continue to be refined and adopted into BHP Billiton's own decision processes.

In the winter and early the spring of 2007, our team conducted baseline research at the University of Michigan on renewable energy resources and technologies, working with Professor Gregory Keoleian and the Center for Sustainable Systems at the School of Natural Resources and Environment (SNRE). Our client at BHP Billiton identified the proposed Corridor Sands titanium dioxide mine in southern Mozambique as the first site for which we would evaluate renewable energy technologies. The lessons learned from this evaluation were to inform a first iteration of the framework. For this assessment, the team conducted research on baseline conditions in Mozambique as well as site-specific circumstances surrounding the proposed mine location, its energy demand and existing electricity supply systems.

In March-April 2007, BHP Billiton sponsored an initial seven-week study of renewable energy options for Corridor Sands by a team of MBA students from the Ross School of Business, also at the University of Michigan. Our team coordinated with this team to improve their understanding of renewable energy and of the client BHP Billiton.

The MBA team analyzed renewable energy options for the Corridor Sands site and developed a preliminary process for evaluating renewable energy technologies. The MBA team then eliminated various renewable technology options based on a variety of technical, strategic, negative impact-related "fatal flaws," and conducted an evaluation of technical viability and economic performance for the more promising technologies. The SNRE Masters Project team helped the MBA team develop a set of recommendations for Corridor Sands in late April, 2007.

Over summer of 2007, the Masters Project conducted a more detailed evaluation of the Corridor Sands site, culminating with a visit to the proposed mine site in Mozambique in August 2007. While in southern Africa, the team met with a variety of renewable energy specialists in South Africa and Maputo, Mozambique to discuss the viability of different technology configurations.

In fall of 2007, the Masters Project team concluded our initial evaluation of Corridor Sands, developing a preliminary project concept for the most viable option for electricity (biomass gasification), and evaluated this concept according to technical, economic, environmental, and social impact criteria. In the same study, we developed a project concept for biofuels cultivation from energy crop *jatropha curcas*. Our study can be found in **Appendix A: Corridor Sands Limitada Site Study**.

Then, based upon the thought process employed to develop this recommendation, the team developed a first draft of the general framework for evaluating renewable energy. The team then refined this framework during a site visit to the Escondida copper mine and related facilities in northern Chile in October 2007. During this visit, we engaged a variety of specialists and stakeholders in our evaluation, and received input from constituents from the energy, environmental, and engineering staff at BHP Billiton Base Metals headquarters in Santiago, Chile as well as in Antofagasta, Chile (the largest city near the mine site), and at the operational facilities.

Upon returning, the team developed a set of preliminary renewable energy recommendations for Escondida, which can be found in **Appendix B: Minera Escondida Limitada Site Study**. Finally, in the winter and spring of 2008, the team synthesized its learning from both site assessments into **Chapter 4**: **Framework for Evaluating Renewable Energy**. Based on the learning from Escondida, the improved framework recognizes the importance of a detailed evaluation of the "base case" at a particular asset, and emphasizes the deliberate articulation of renewable-energy related goals for certain asset. These goals informs a set of renewable-energy-specific criteria which should be used to evaluate different technologies for an asset.

The team also developed two detailed *toolkits* for the middle phases of the framework, which cover in more depth 1) the assessment of renewable energy resources and 2) the evaluation of renewable energy technologies. **Chapter 5: Resource Assessment Toolkit** informs the user how to conduct a renewable energy resource assessment—a fundamental process for understanding whether there exists a sufficient wind, solar, or biomass energy "resource" to support any renewable energy technology. **Chapter 6**: **Technology Assessment Toolkit** describes the process for identifying appropriate wind, solar, or biomass technologies to capitalize on the availability of the particular resource. This "technology" toolkit describes the principal features and benefits of the most current technologies which the management team should consider when evaluating the application of renewable energy.

Finally, the team demonstrated the application of the renewable energy framework, utilizing the Escondida asset as an example. This sample **Framework Application** is presented in **Chapter 7** of this report. Escondida serves as an interesting case given the significant electricity demand and the peculiar national, legislative, and geopolitical dynamics that influence the energy situation.

Chapter 3:
Technology Overview

Scope

This section provides an overview of the renewable energy technologies that are examined throughout this study. The purpose of this section is to provide general information about each of the technologies for someone unfamiliar with them. Later in the document, each of these technologies is examined in greater depth on measures of cost, performance, and environmental attributes.

Biomass-to-Electricity

Biomass is defined as "plant material, vegetation, or agricultural waste used as a fuel or energy source." Biomass may be converted into electricity via two basic methods – combustion and gasification. The most common method is to combust it in a steam boiler to drive a turbine. This may be done in a specifically designed biomass-fired boiler, or the biomass may be mixed up to 20% with coal in a process know as co-firing. Dedicated biomass boiler systems can range in size from 5 to 100 MW, while co-firing systems can achieve utility scale electricity production. Biomass may also be converted into synthesis gas in a process called gasification and then burned in a gas turbine or gas engine. Gasification is a more expensive and technically challenging process but results in higher conversion efficiency. Biomass gasification has most frequently been deployed in the 5 to 30 MW range. Biomass-to-electricity technologies are capable of producing baseload power at capacity factors similar to that of fossil fuel (80% of their "nameplate" capacity) provided that sufficient biomass fuel stock is available.

McNeil Biomass Generation Station
Burlington, VT.
Source: http://blog.futurelab.net

Concentrated Solar Power (CSP)

A concentrated solar thermal power facility uses mirrors to focus solar heat energy to produce steam or to heat a gas, which then drive turbines to generate electricity. The three main CSP technologies are parabolic trough (most common), central receiver, and dish/engine. Utility scale parabolic trough systems use a large number of trough-shaped reflectors to focus the sun's heat onto line receivers, filled with a heat-transfer fluid. The heat is used to produce steam, which in turn drives turbines to generate electricity. Central receiver systems configure sun-tracking mirrors around a central tower that focus the sun's heat onto a receiver and steam-turbine power generation unit on top of the tower. Dish/engine systems do not use steam for power-generation. Instead they focus the sun's heat onto Sterling engines, where heat-expansion of a gas, such as hydrogen, moves pistons to produce electricity.

Solar tower (top), parabolic trough (middle), dish-Stirling (bottom)
Sources: www.global-greenhouse-warming.com, Union of Concerned Scientists, and www.thefraserdomain.typepad.com

Solar Photovoltaics

A solar cell is composed of layers semiconductor material, which create an electric potential when light contacts the cell surface. This electric potential causes a flow of electrons, which generates direct current (DC) electricity. Invertors are used to convert DC to alternating current (AC) electricity since AC is the standard in most power grids. The two main types of solar cells are crystalline silicon and thin film. While single- and multi-crystalline silicon cells dominate the market today, thin-film installations are growing rapidly. Solar cells are arranged in groups to create modules, which can be mounted on rooftops or ground mounted. A group of solar modules makes up a solar array. Photovoltaics will usually generate 10-30% of their "nameplate" capacity based on the available solar resource, which is dependent on geographic location.

14 MW solar photovoltaic array at Nellis Air Force Base, AZ.
Source: www.nellis.af.mi

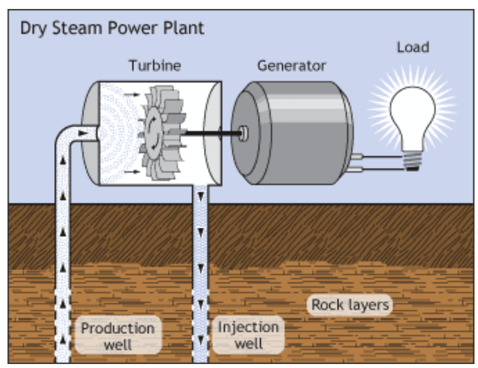
Wind

Wind towers harness the kinetic energy of wind through rotating blades, and turbines convert this energy into electricity. Wind turbines range in "nameplate" capacity between 500kW and 5MW. The most common sizes used today range between 1MW and 3MW. Turbines will generally produce only 30-35% of their "nameplate" capacity on average, depending on the wind resource, and the height and location of the tower. Depending on wind resource and land availability, wind power developments can deploy a single turbine or multiple turbines appropriately spaced apart.

1.5 MW wind turbines, Lamar, CO.
Source: NREL

Geothermal

Geothermal power plants utilize steam from underground water reservoirs that have been heated by geologic activity to drive a turbine that generates electricity. Some geothermal power plants extract the steam and release it while others re-inject it into the reservoir. Exploration for geothermal resource is similar to petroleum exploration in that it involves identifying promising areas and drilling test wells.



Schematic of a dry steam geothermal power plant.
Source: NREL

Chapter 4:
Framework for Evaluating Renewable Energy

Intent and Scope

The purpose of this Chapter is to articulate a general framework or process to aid managers at BHP Billiton and other natural resources companies in evaluating the adoption of renewable energy technologies.

1. Our goal is to develop a practical tool to helb+ BHP Billiton management:

2. Determine whether adopting renewable energy is appropriate for an asset[30]; and if so,

Identify which renewable energy technologies demonstrate potential to meet the needs of management.

The scope of this framework is the evaluation of renewable electricity (power generation) options – we do not discuss renewable sources of liquid fuel. In addition, the framework is designed primarily to inform the adoption of renewable projects with a capacity greater than 5 megawatts (MW).

Introduction to the Renewable Energy Framework

Intended Audience

In 2007, our team conducted brief site visits and renewable energy evaluations of the proposed Corridor Sands Limitada (CSL) mineral sands mine in southern Mozambique and Base Metals operations in northern Chile, which includes the Escondida copper mine, which is officially named Minera Escondida Limitada (MEL).

Based on input from management interviewed during these site evaluations, we determined that the primary intended audience for this framework should be the members of a decision team (DT) who are responsible for evaluating and selecting energy projects for a certain asset. The DT may include a combination of business unit executives and business unit energy managers, EHS managers, corporate energy specialists, and asset executives including project directors and senior engineers.

Place of Framework within BHP Billiton's Project Management Process

The entire scope of our master's thesis work – including this framework – exists in the *concept* or *identification* phase of BHP Billiton's internal project management process. As such this work represents the earliest conceptual analysis that occurs at the initiation of a project.

BHP Billiton's project management process (and the domain of our work), are illustrated in brief in **Exhibit 4-1**.

30 In the natural resources industry, an asset refers to an operating or production unit such as a mine or a smelter.

Exhibit 4-1: Project Management Framework. Source: BHP Billiton[31]

CONCEPT / PROJECT IDENTIFICATION	SELECTION & DEFINITION	EXECUTION	OPERATION
Define project opportunity, alignment with strategic objectives, potential business benefits and project deliverables.	Finalise the project scope, schedule, estimate, funding and prepare submission to authorising body.	Implement the project and deliver the defined business benefits and project outcomes.	Integrate the outcomes into "business as usual".

Unit of Analysis

Before walking through this framework process, the DT should determine what the appropriate unit of analysis should be: a single asset, multiple assets that share common dimensions, or perhaps an entire business unit. In many cases, assets should be considered standalone for evaluating renewable energy potential. In other cases, such as when multiple assets share a similar geography, product (e.g. copper or aluminum), set of stakeholders, regulations, and/or sources of electricity, it may be sensible to evaluate multiple assets as a single entity or to consider an entire business unit. Within BHP Billiton's corporate structure, each asset has a fair amount of autonomy and operates to a certain extent as a business unit, and therefore can have considerable input into and flexibility on energy decisions.

To illustrate the application of this framework, we will refer to our team's brief evaluation of BHP Billiton Base Metals business unit – specifically this business unit's operations in northern Chile (BMNC). The team visited northern Chile for one week in October, 2007. In **Chapter 6** we have demonstrated the application of this framework to BMNC.

In our evaluation, we have considered the three assets that are part of Base Metals in Northern Chile (Escondida, Cerro Colorado, and Spence) as our unit of analysis. All three are copper mines located within a hundred kilometers of one another in the Atacama Desert in northern Chile, and they each operate on one electrical grid. We chose to consider these operations as a unit (rather than isolating the Escondida mine) because a variety of factors including their physical proximity, common drivers, the same business and general processes, and a shared executive decision team. In this document, however, we will refer generically to the subject of analysis as the "asset," since the "asset" is typically the unit of analysis.

Framework Outline

We have designed this framework primarily as "how to" for managers, and have proposed seven principal steps for the evaluation of renewable energy.

31 BHP Billiton. "Small Project Management Framework" Revision 2007 v1.1. April 12, 2007.

Step 1 Understand the "base case" for an asset, which considers asset-specific energy supply, demand, and transmission infrastructure, as well as the corporate initiatives and macro-environment context that may inform decisions about renewable energy

Step 2 Identify the principal drivers for renewable energy in the "base case," and formulate a weighted set of goals for renewable energy at the asset

Step 3 Develop a set of criteria prioritized by the weighted goals that inform the selection of renewable energy solutions and aid in discriminating between technologies

Step 4 Assess the existing renewable energy resources (e.g. wind, solar radiation) available in the region and identify those that demonstrate potential for energy production

Step 5 Determine what technologies are available to convert the available renewable energy resources into usable form

Step 6 Match appropriate technology configurations to prioritized criteria

Step 7 Develop project concepts and evaluate these concepts according to technical, economic, social (community), safety, environmental, strategic and stakeholder concerns.

Exhibit 4-2 summarizes the steps of our framework and the principal questions the DT should ask at each stage.

Exhibit 4-2: Framework for Evaluating Renewable Energy for Natural Resources Company Assets

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7
Understand Base Case	**Identify Drivers and Develop Goals**	**Select and Prioritize Criteria**	**Assess Renewable Resources**	**Identify Viable Technologies Based on Resources**	**Match Technologies to Priority Criteria**	**Develop and Evaluate Project Concepts**
What are the current and planned sources of demand for energy, and at what cost? Does the asset receive electricity from a grid, directly from generators, or both? What is current and planned transmission and distribution infrastructure? What are the internal and external factors affecting energy supply and demand in the future? What is the magnitude and direction of the factors' impacts on the availability of energy and the optimal energy mix? What strategic and macro-environment factors are relevant to energy decision-making?	From the base case, what are key drivers for adoption of renewable energy projects? What goals can be set for renewable energy projects based upon these drivers? How important are each of these goals relative to one another? Should a renewable energy project be connected to a grid or serve the asset directly?	What are the key criteria that a renewable technology must possess in order to fulfill the goals in Step 2, and that will facilitate the discrimination between renewable energy configurations? How should the criteria be prioritized and weighted to reflect these goals?	What physical renewable energy resources are available? • Solar • Wind • Biomass • Energy crops What unique characteristics of the renewable energy resources available make them more/less attractive to utilize? Are there any significant flaws or negative impacts associated with the use of these resources?	Given the resources identified in Step 4, what technologies are best able to convert these into usable energy? • Solar PV • Solar Thermal • Wind turbines • Biomass gasification • Biomass combustion	What technologies identified in Step 5 best fulfill the priority criteria developed in Step 3? Which rank highest in overall ability to meet the criteria from Step 3? Are there any significant flaws or negative impacts associated with the use of these technologies?	What configurations of the technologies from Step 6 are appropriate for this asset? What are the specific potential characteristics of these configurations? • Levelized cost of electricity (LCOE) • Technical fit • Strategic fit • Social impacts • Environmental impacts • Safety concerns • Stakeholder effects

Evaluating the appropriateness of renewable energy technologies for a given asset generally involves a multi-criteria decision-making process. The process is often quite complex because it requires understanding, coordination, and prioritization across the realms of **technology**, **energy** and **finance**, and some understanding of the dynamics of **climate change** and how carbon offsets can be monetized or otherwise incorporated in project valuation.

In the process of our evaluations, we recognized that considering the adoption of renewable energy is often motivated by different drivers than those that inform many conventional energy decisions at an asset. Sourcing energy is a strategic decision for metals and mining assets given a) the tremendous demand at the assets, b) the long time-scale of the decision (5-40 years), c) the significant cost, and d) the critical need for a secure supply of power (because of the immense revenue impact of outages).

Sourcing renewable energy, on the other hand, is also a strategic decision, but is motivated by these and other strategic drivers. These additional drivers often come from the broader macro-environment context that inspires the decision to consider renewable energy. As such, it is critical to consider the corporate strategy that often underpins decisions to adopt renewable energy, and the need to align renewable energy goals with the operating conditions for the asset as well as the company's broader strategy.

Step 1: Understand the Base Case

Before the value of any potential renewable energy projects can be assessed, the DT should thoroughly understand a) the existing capabilities and limitations of renewable electricity, b) the existing energy "base case," c) the relevance of corporate initiatives, and d) the macro context – social, political, legal, economic, technological and environmental – in which the BHP Billiton and its assets operate. These dimensions should be considered in the context of how they inform the decision to adopt renewable energy.

To understand the base case, we recommend that the DT follow these broad steps:

1. Review existing documentation and plans for energy production, demand and transmission for the asset, prepared both by the asset itself and by the relevant staff of the Energy Excellence program
2. Assess the current and future level and intensity of demand for energy, power, and fuel at the asset, as well as the existing and planned energy infrastructure
3. Assess the existing and projected emissions profile of the asset, particularly the greenhouse gas footprint
4. Consider other major internal and external factors that will shape the asset's current energy usage, production, and infrastructure, including legislation, corporate initiatives and stakeholder concerns

General Context for Renewables: In evaluating whether to shift from fossil to renewable energy, BHP Billiton must first contextualize the uses of renewable energy in its power portfolio based upon the technical capabilities of renewable energy relative to existing sources of energy. For the short to middle-term scenarios (5-10 years), the ability of most renewable energy technologies to supply baseload power for energy-intensive, continuous-demand projects such as those in natural resource industries is severely limited (the major exception being biomass-to-electricity). This is due to their *relative* a) high cost, b) inefficiency of energy conversion, c) technological immaturity, d) scale, learning, and infrastructure disadvantages. As a result, we foresee renewable energy as serving a more strategic role in a) supplement existing conventional energy systems, b) meeting internal corporate GHG and energy diversification goals, c) aiding compliance with legislative mandates, and d) enhancing BHP Billiton's "license to operate." Therefore, a broad understanding of the project context, including macro-factors and corporate initiatives is critical to defining the underlying drivers and goals for renewable energy projects.

Energy Base Case: As with most business technology adoption decisions, BHP Billiton must compare the benefits and costs of a proposed shift in technologies to business as usual. Thus, a thorough understanding of the dimensions of existing energy systems and conventional options for expanding energy capacity is critical to evaluating the benefits and drawbacks of renewable energy technologies. The **energy base case** is an assessment of the current energy consumption, production, transmission and distribution situation at the assets as well as the predicted scenario (or options) going forward. Additionally, the base case will involve a consideration of energy procurement structures along the range of possibilities from self-generation (BHP Billiton owned and operated generation) and captive power producers (CPP) to independent power producers (IPP) and various hybrid and joint arrangements.

An evaluation of the energy-specific base case, current and planned, could include the following elements:

- Asset Power Supply
    a. Security of energy supply
    b. Emissions and greenhouse gas intensity
    c. Ability of existing power source(s) to integrate renewable generation
    d. Degree of grid-connectedness
    e. Proximity, configuration, and capability of existing transmission and distribution
    f. Supply growth projections
- Asset Power Demand
    a. Energy and capacity requirements
    b. Load profile and peak demand versus non-peak demand
    c. Predictability and variability of peak demand
    d. Demand growth projections
- Asset Power Economics
    a. Costs of down-time
    b. Cost (Levelized Cost of Electricity)

- Asset Electricity Generating Structures and Options
    a. Self-generation and captive generation vs. IPP, Hybrid, and Joint Arrangements

Corporate Initiatives: BHP Billiton HSEC has several strategic initiatives that may influence the decisions to undertake renewable energy projects or to influence power providers to adopt renewable energy technologies from which the company can source renewable energy credits through a "fossil-for-renewable" electricity grid swap. These initiatives include the GHG reduction targets of 6% emission intensity reduction by 2012, shadow-pricing for carbon emissions, and maintenance of sustainability index rankings. Furthermore, it is BHP Billiton policy to avoid paying penalties (or pass through of penalties from power providers) for non-compliance with legislative mandates.[32] For instance, if renewable energy mandates are in place, BHP Billiton policy would dictate that the power provider comply with the law by providing the appropriately sourced power.

Strategic and Macro-factors: The adoption of renewable energy technologies by companies such as BHP Billiton is often a strategic response to macro-factors rather than a straightforward technical solution to an energy shortage. Therefore, as part of the base case, the DT must define the **strategic environment** and **macro context** in which the corporation and its assets operate. The DT could consider the full range of macro-factors at play that may influence this decision by examining the following:

- Country and Regional Factors
    a. Legal factors or legislation that influences this decision
        i. Land access
        ii. GHG obligations
        iii. Renewable portfolio standards
    b. Social, cultural, or demographic considerations
    c. Economic impacts of energy decisions (e.g., jobs created/destroyed)
    d. Local, regional and national political forces
    e. Environmental factors
        i. Siting issues
        ii. Emissions
- Industry-Specific Factors
    a. Technological shifts in industry
    b. Identity of key stakeholders
    c. Other influencing factors on the industry
- Company-Specific Factors
    a. Company relationships with stakeholders (governments, community, and civil society)
    b. Company strategic initiatives
    c. Energy decision impact on customer perceptions
    d. Energy impact on external reputation and sustainability indices

32 Broughton, Linda. BHP Billiton Base Metals. Personal communication. Santiago, Chile. October 2007.

Some internal resources that may be useful for BHP Billiton staff include the price protocol for CO_2, which dictates the "shadow price" or charge for carbon emissions to be utilized in project valuation. In addition, the Energy Excellence group provides excellent resources for energy procurement, including a Greenhouse Gas Emissions Toolkit.

One prototype survey tool that the MS Project team has developed to aid the assessment of the energy-specific base case can be found at http://www.wolverinerenewables.com/Base-Case-Assessment.html (see screenshots in **Exhibit 4-11** and **Exhibit 4-12)**.

Step 2: Identify Drivers and Develop Goals for Renewable Energy

Once the base case has been fully considered, the DT should identify the principal drivers that motivate the adoption of renewable energy, and use this list of drivers to establish a set of goals related to energy which can be used to discriminate between different renewable energy technologies.

To identify the drivers and define goals, we recommend that the DT follow these broad steps:

1. Review base case information in light of renewable energy decisions
2. Identify the factors of the base case most relevant to the energy challenges, and distill the principal "drivers"
3. Formulate renewable energy-related goals that reflect the most important drivers
4. Distinguish between Threshold goals and Comparison goals
5. Weight the Comparison goals according to their relative importance, considering direct asset-level needs and quantifiable benefits as well as larger strategic and macro drivers.

Power–related Drivers for Renewable Energy: The issue of whether renewable energy solutions will directly serve the operational energy needs of the asset, should be addressed *first*, because it has broad implications for the subsequent renewable energy evaluation process. If power capacity is needed to directly serve asset operations, the DT should be keenly aware of the limitations of renewable energy technologies with respect to the ability provide significant baseload power. If baseload power is needed, several significant factors bias against the likelihood of a good match:

1. Most renewable energy production technologies are in their relative infancy, and offer nowhere near the scale or efficiency of production that fossil fuels provide
2. Metals and mining is generally an extremely energy intensive industry, and the assets often demand generation with
    a. extremely high capacities (greater than 100MW),
    b. stable load profiles,
    c. continuous production, and
    d. systems that can demand rapid shifts in power demand

3. Metals and mining operations can incur massive revenue losses if the continuity of operations is jeopardized by power outages.

The only renewable energy technologies assessed in this framework with the capability of providing baseload capacity is biomass gasification and/or combustion. Geothermal and large-scale hydropower are also capable of providing baseload power, but are beyond the scope of this framework. Solar and wind technologies provide intermittent power when the resource is available, and do not have sufficient storage capacity to independently provide continuous power. Biomass-to-electricity technologies provide high reliability (provided that the fuel source is stable) and offer continuous power generation with the capability of fuel switching (to fossil fuels) in the event of biomass shortages. Therefore, if baseload power for an asset is identified as a driver, all other technologies may be eliminated from consideration and the DT should narrow its focus to biomass conversion technologies.

If baseload power is not required, the field of renewable energy technologies under consideration remains broad, as all renewable energy technologies can provide grid-integrated solutions supporting a joint generation or independent power producer structure where operations will not depend on the renewable resource, then lower capacities and capacity factors may be viable.

Two Major Options for Renewable Energy Integration: Grid-Integration or Direct Supply to Asset

As part of Steps 1-3, management must consider the whether the renewable technology must serve the energy needs of the asset directly, or whether the solution can contribute to an electrical grid from which the asset draws electricity. This is a critical choice point, as it has significant implications for which, if any, renewable technologies are viable for a specific context.

Our study revealed that many of today's renewable electricity solutions, with the exception of biomass combustion, are ill-equipped (due to low capacity factors and intermittent production) to directly serve the highly demanding energy requirements of company assets.

Wind and solar, two of the most common renewable energy technologies, are variable sources of electricity, and as such serve best as one of several contributors to a flexible electricity grid. Thus wind and solar applications are less appropriate for directly serving the operational electricity needs of an asset, because assets often require a significant (>50 MW), nearly constant supply of highly dispatchable electricity generation.

The option of grid-integration adds significant flexibility to the demands of the solution, and makes the adoption of renewables much more viable. These grid-integrated renewable energy solutions are not unfamiliar territory for BHP Billiton, which has great experience with sophisticated energy procurement arrangements, including electricity price "swaps"[33] where the location and source of generation and consumption becomes nearly irrelevant.

Legislative Requirements for Renewable Energy

Finally, if renewable energy is required by a legislative or regulatory mandate, then some of the burden is lifted from developing a rigorous business case for the adoption of renewable energy, particularly since BHP Billiton's corporate policy requires regulatory compliance, and does not support the payment of fines for failure to comply. However, our study suggests that even in the presence the legislative requirements, there can be compelling financial and strategic reasons for BHP Billiton to consider adopting renewable capacity above and beyond that which is required by legislation, as we discuss in more detail in **Chapter 4**.

Other Drivers for Renewable Energy: Many scholars including Andrew Hoffman[34], Donald Reed, Marcel Jeucken, and Alois Flatz[35] have developed different schema for categorizing the universe of drivers that motivate environmental and sustainable business strategies which include the adoption of renewable energy. For our purposes, we can generalize on two broad categories of drivers that motivate action on renewable energy: 1) quantifiable, or measurable drivers upon which the DT can potentially present a "clear" business case, and 2) "strategic" or qualitative drivers which are harder to quantify, some of which may ultimately be more "material" than the quantifiable drivers.

Quantifiable, measurable drivers
Clear cost drivers
Improving operational performance and efficiency
Lowering cost of energy
GHG shadow prices
Clear revenue drivers
Developing new products and services
Earning new cash flows or lower project hurdle rates from greenhouse gas (GHG) credits
Employee attraction, retention, and productivity (revenue and cost)
Legislative and regulatory mandates and dictates of international treaties
Strategic, less quantifiable drivers
Promoting the right or "license" to operate (cost and risk reduction)

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33 Electricity swap contracts typically are established for a specified quantity of power that is referenced to the variable spot price at either the generator's or consumer's location. Basis swaps are also commonly used to lock in a fixed price at a location other than the delivery point of the futures contract. That is, the holder of an electricity basis swap has agreed to either pay or receive the difference between the specified contract price and the locational spot price at the time of the transaction. US Energy Information Administration, Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries," October 2002, accessed March 16 at http://www.eia.doe.gov/oiaf/servicerpt/derivative/chapter4.html.

34 Hoffman, A. J. (2000). Competitive environmental strategy : a guide to the changing business landscape. Washington, D.C.: Island, Page 29.

35 Dernbach, J. C. and I. Environmental Law (2002). Stumbling toward sustainability. Washington, DC, Environmental Law Institute. Pages 554-558.

Market positioning and maintaining competitiveness (revenue)
Learning and innovation (revenue and cost)
Demonstrating technology leadership
Reducing risk (ultimately cost-related)
Reputation management
Investor relations
Maintaining business continuity, security of fuel supply
Lowering the cost of / improving access to capital
"Pure" social / environmental / values-based drivers
Social responsibility and values / addressing equity concerns
Environmental values / responsibility
GHG reduction commitments

The intent of this list is to aid the DT in the identification and prioritization of business drivers which should inform the development of asset-specific goals related to renewable energy. From these drivers, the DT should formulate and prioritize a set of specific (if not necessarily measurable) energy-related goals which reflect the relative importance of drivers.

BHP Billiton has articulated its own related (but uncategorized) list of drivers, described as the Business Case for Sustainable Development. We have copied these drivers in **Exhibit 4-2**.

Goal Articulation: The process of goal articulation is intended to make explicit the objective of renewable energy solutions for an asset and tie them back to fundamental drivers identified in the base case. **Exhibit 4-3** exemplifies how asset-specific drivers might motivate the adoption of renewable energy goals.

Exhibit 4-3: Illustration of Drivers Informing Renewable Energy Goals

Driver → Informs	→ Goal
A desire to meet or exceed regulatory requirements	a goal to help power providers meet legislative requirements for renewable energy[36]
The intent to **reduce risk** of fuel cost volatility informs	a goal to reduce exposure to fossil fuel cost variability with renewable energy
The drive to **reduce operating costs** inspires	a goal to seek renewables with no fuel costs
Corporate greenhouse gas reduction targets and the potential for **incremental revenues** from carbon motivates	renewable energy adoption with incentives for GHG offsets
The desire to maintain **security of operations** and **reduce the risk** of work delay due to fuel supply interruptions drives	a goal to adopt renewables as part of business continuity through fuel (risk) diversification
Desire to **maintain license to operate** inspires	the goal to improve relationships with Stakeholders by incorporating renewable energy and demonstrating commitment to sustainable development
The desire for technology leadership may inform	the goal to innovate and discover new solutions to improve operational efficiency.
Need to maintain and improve community relations motivates	the development of livelihood development projects such as biofuel cultivation

Threshold and Comparison Goals: The team's experience working through the framework applications suggests that it is helpful to emphasize two types of goals that will aid in differentiating between different renewable energy projects. Goals which represent *threshold* or *maintenance* priorities, (such as a goal to preserve business continuity), can be used to eliminate technologies from consideration based on a "fatal flaw" inherent in a technology. Threshold goals would be set with respect to critical drivers of BHP Billiton business operations and strategy, such as revenue streams from an asset or safety/environmental impact. Technologies not meeting the base criteria would be eliminated immediately from further consideration.

Goals relating to less stringent drivers help generate distinctions between technologies that aid in comparison and selection, but do not warrant immediate elimination of technologies.

Exhibit 4-4 illustrates an example our team has drawn from BHP Billiton's Base Metals assets in northern Chile (BMNC).

36 This could also be cost driver, if there are significant fees associated with non-compliance.

Exhibit 4-4: Example of Step 2: Driver and Goal Analysis Output for BMNC

Base Case Information	Driver	Goal	Weight (%)
New regulatory requirement of 5% energy from renewable sources	Need to meet **legislative requirements** (BHPB policy discourages payment of penalties for non-compliance)	To supply 5% of energy requirements through renewable energy by 2010 (~25 MW) –	Threshold Goal*
Limited access, due to government and community concern, to mining concessions and water rights; increasing demands for both; history of abuse by mining companies	Need to gain and maintain **license to operate** and grow and foster positive relationships with communities and nations	To pursue projects that demonstrate BHPB's commitment to sustainable development to government, community and civil society (i.e. developing highly visible and favorable renewable energy projects) - Comparison Goal	40%
Corporate mandate to reduce GHG emissions	Need to meet internal **GHG reduction commitments**	To develop renewable energy capacity that will offset CO2e annually – Comparison Goal	30%
Industry trend emphasizes innovation in sustainability and technology	Desire to demonstrate **leadership in technology and sustainability**	To be the first-to-market in the industry with an innovative world-class renewable energy project – Comparison Goal	20%
Limited excess grid capacity, increasing demand	Need to provide a **secure and stable energy supply**	Develop additional capacity, possibly through renewable energy – Comparison Goal	10%
* Threshold goals require technologies that meet or exceed the threshold, and thus are not weighted. If these thresholds are met, the technologies will be evaluated according to Comparison goals.			

Step 3: Select and Prioritize Criteria

To meaningfully aid the selection of renewable energy technologies, the goals from Step 2 must inform a set of criteria for the identification of renewable energy projects that address the drivers and goals of the asset. The general categories of criteria must reflect both quantitative and qualitative standards across which the renewable energy technologies may be compared and by which preferences among technology options can be generated. Criteria may also be divided into Threshold and Comparison categories. Threshold criteria are those most closely linked to Threshold goals identified in Step 2. These criteria will serve to establish minimum standards for the project/technology. Comparison criteria are associated with Comparison goals from Step 2 and can be used to generate preferences among technologies that meet the Threshold criteria. **Exhibit 4-5** presents the key criteria identified for assessing and differentiating between renewable energy technologies.

Exhibit 4-5: Criteria for Selecting Renewable Energy Technologies

Criteria	Criteria Categories
Capacity factor Cost Optionality Reliability / Technology maturity Revenue opportunities Scalability	Technological Fit and Financial Criteria (Quantitative)
Greenhouse gas (GHG) offsets[37]	Financial and Strategic
Environmental impacts Internal acceptance Reputation Social impacts Technology leadership	Strategic Criteria (Qualitative)

The DT should select at least one criterion to reflect each goal identified in Step 2. The weight of each criterion will be informed by the weighting and frequency of each associated goal in Step 3. This weighting decision is ultimately up to the DT and will be determined according to circumstances at the asset under evaluation. As such, these criteria will be more or less relevant depending on how the DT weights each goal and ranks each criterion.

The Renewable Energy Toolkits in **Chapter 5** and **Chapter 6** will include detailed information about the characteristics of each technology across each of these criteria. We propose ranking the technologies according to these criteria on a simple three point scale (1, 4 and 9 for low, mid and high performance, respectively) which measures the relative degree to which the technology fulfills each criterion.

This technological fit and financial criteria list represents the team's determination of the most important general criteria both for identifying appropriate renewable energy technologies *and* for differentiating *between* these technologies. These criteria relate to specific drivers and goals from Step 2. The strategic are less measurable but in many cases more essential to the drivers and goals that inspire renewable energy projects.

Descriptions of Criteria

Capacity is based on the nameplate capacity of the technology and its capacity factor.[38] When combined, these two measures provide the average power output. This concept is highly relevant to

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37 Greenhouse gas emissions reduction is rapidly changing from a "strategic" qualitative criterion to a financial criterion as GHG markets emerge

renewable energy technologies. The relative capacity factor of wind and solar power – when compared to a coal-fired plant – is very low, given that wind and solar rarely produce electricity under optimal conditions. Because of this variability, wind and solar are not well suited to provide additional power generating capacity to an asset. They will always need a back-up option to ensure that power to the asset is not interrupted. Therefore, they are best suited to peak shaving and reducing the GHG emissions factor of the overall energy mix of an asset. Standalone biomass energy systems have a capacity factor in a similar range as coal-fired generation and are better suited to providing additional power generating capacity to an asset. However, biomass supply is much less secure than that of coal, and care must be taken to ensure that biomass supply is not disrupted.

Levelized Cost of Electricity (LCOE[39]) and stability of costs captures the capital *and* operating costs (including fuel) of electricity generation, distributing the capital cost over the projected lifetime generating hours of the plant. The output is a cost of electricity in $/kWh which is the best way to compare the cost of different power generation options. Thus, it is a key criterion for differentiating between energy solutions. However, this cost will not always trump the other criteria. For example, if maximal reliability is paramount, or the primary driver for a project is the positive social impacts from livelihood creation, then cost may not be a principal determinant. Certain renewable energy technologies also provide very low and stable operating costs, which may be an important differentiating criterion.

Environmental Impacts refer to the environmental impacts of a technology, both positive and negative, apart from the greenhouse gas offset. For example solar and wind energy may have a positive environmental impact because they produce no air pollutants during operation (in this case we are referring to non-GHG emissions), unlike the coal or diesel combustion which they can displace. Similarly, if rainforests are cleared for biomass energy crop cultivation—apart from the carbon debt (discussed below)—there can be significant habitat loss and biodiversity consequences. One argument against wind power is its potential impact on birds and bats, which are killed when they hit moving wind turbine blades. While many more birds die from collisions with cars and buildings, care must be used when siting wind turbines to avoid major migratory paths and areas inhabited by endangered birds and bats. Thus there are significant differentiators between renewable energy solutions along this criterion.

Greenhouse Gas Emissions (GHG) Offset potential describes the technology or the project's relative ability to displace greenhouse gas emissions. This bears mentioning independent of additional revenue opportunities, both because it is a significant benefit that renewable energy technologies provide, and because it can also be a sources of significant differentiation amongst the technologies. For example, biomass feedstock production can be greenhouse-gas neutral, but may

38 The ratio of average actual production of electricity to the available capacity to produce.

39 Levelized cost of electricity (LCOE) is the average cost of electricity over the operating life of the generation equipment. This cost figure captures the capital and operating expenditures in one number.

not actually offer GHG offsets. Furthermore, if a significant amount of GHGs are released clearing land to produce biomass feedstocks, then the project actually introduces a significant GHG debt rather than a GHG offset. If GHG offsets and climate change are primary motivators for renewable energy, this is a significant differentiating factor between biomass electricity generation and wind or solar electricity generation.

Internal Acceptance and Motivation refers to how readily the staff of the asset or the technology operator will accept, adopt, and support a given technology. Certain technologies may be much more acceptable to staff than others, and can be an important differentiating factor. Certain technologies may also have significantly greater potential to motivate staff and perhaps even improve recruitment and retention.

Optionality refers to two dimensions of certain renewable energy projects. One dimension of optionality is the *degree of asset specificity*. That is, how readily can BHP Billiton repurpose a renewable energy asset if it is no longer profitably deployed in its current location or configuration. For example, solar panels have low asset specificity, meaning it is relatively easy to move them from one site to another. A wind turbine has somewhat higher asset specificity because it is more costly to remove and transport one to another site. A biomass combustion facility configured to burn a very specific biomass feedstock would have the highest asset specificity of these three examples because it would be the most troublesome and costly to relocate.

The other dimension of optionality is *real-option flexibility*, which allows for the flexibility in investment decisions (e.g., to expand or contract an investment, or to switch fuels in response to market forces and resource availability). For example, wind developments often proceed in stages. After the first stage has proven successful, the option to proceed to the next stage is available, and this decision can be deferred as long as necessary in response to market forces. Fuel flexibility comes into play when a solar CSP facility is co-located with a natural gas combined cycle facility. When the sun is shining, the CSP facility produces electricity. As soon as the sun sets, the natural gas turbine is there to backup the solar energy. Biomass combustion and gasification system also have high fuel flexibility, as they are typically capable of utilizing fossil fuels in lieu of biomass.

Reliability / Technology Maturity conveys the degree of risk associated with a technology. This risk takes on two components. Reliability is the amount of downtime for unexpected repairs that can be expected for a given technology. Technological maturity is the level of experience that generators have had with a technology and helps to inform the estimate of reliability. A mature technology should have a well established measure of reliability. A technology in development likely has a much less certain estimate of reliability. This criterion will be significantly more important if the energy solution will be serving the asset's operations directly (in self-generate, Captive, or Hybrid structure), and the asset will be depending on the capacity for operations. More than likely, however, this will not be the case. A more likely scenario is that a renewable energy solution, if adopted, will be part of an IPP or Joint structure arrangement, where the renewable technology will feed electricity into a grid, arranged by the asset through a purchase agreement. In this scenario, the baseload energy and power will be provided by a conventional technology such as coal or natural gas. Clearly, the asset will not want to invest in experimental technology at significant scale for any purpose, but the criticality is greatly reduced when the application does not serve the asset directly. The DT must also consider availability of experienced maintenance personnel for even some of the more mature technologies in certain geographies (wind and solar thermal) – particularly emerging markets. Ultimately, reliability may not be a significant differentiator in the context of a grid feed-in application, so long as each technology under consideration meets a certain threshold of reliability.

Reputation. The different potential of technologies to enhance a company's reputation, or to promote and reinforce a mining company's license to operate, can make a tremendous difference in the selection of technologies. For example, in Chile the government granted water concessions for organizations who agreed to investigate the potential for geothermal energy. People took advantage of this incentive to lock-up water concession without any serious attempt to find appropriate geothermal sites. This deceit created significant negative impression of geothermal as a promising source of energy, enough so that BHP Billiton may avoid associating itself with geothermal exploration in Chile. Thus, reputational elements can be tremendous differentiator among different technologies.

The fundamental importance of reputation and "license to operate" as a motivator for companies in the natural resources industry warrants further emphasis and discussion. Reputation is important for most companies, but it is particularly critical – and historically a sore point – for mining companies. Unlike other companies which purchase raw materials from supplier companies, mining companies depend on the permission of governments and communities for their mining concessions and regulatory approval. Furthermore, what they do is extract non-renewable resources, often leaving scarred earth behind. BHP Billiton as the largest mining company in the world is much more likely to be a target of criticism, just as Coca-Cola and McDonalds, as industry leaders, are subject to the most scrutiny and condemnation.

For these reasons, any differential among technologies that may enhance or degrade BHP Billiton's reputation should be considered seriously, and may have a significant impact on the selection of technologies.

Scalability refers to the ability to size a specific technology at different capacities to meet the requirements of a project. Wind and solar are both fairly modular technologies. So provided there is enough land available, a wind project can be scaled in increments equal to the size of one turbine, and capacity can be added at any time. On the other hand, biomass combustion requires a certain minimum scale for it to be economical, but runs into the problem of feedstock supply, limiting the maximum scale.

Social Impacts refer to the positive or negative impacts of a technology, such as the livelihoods created and/or the livelihoods destroyed by the introduction of a technology. Constructing a large-scale wind development might stimulate the creation of jobs around providing ongoing service in addition to the temporary construction jobs, providing a positive social impact. However, wind turbines are often considered to have negative community impacts because their appearance which is described by some as a form of "visual pollution." Thus, wind power faces significant obstacles to siting as a result of this perceived negative social impact. In another example, the involuntary resettlements that result from the development of large scale hydropower projects represent significant negative social impacts from renewable energy projects. The development of the Three Gorges Dam of the Yangtzi River in China has required the involuntary resettlement of 1.25 million people thus far, with an expected 1.3 million by 2009.[40]

Technology Leadership and Innovation refers to the potential for a project choice to differentiate BHP Billiton as an innovative leader through the successful deployment of a new technology. This potential may inspire different prioritization of technologies. A related potential benefit – differentiation – refers to the potential for a technology to promote a brand impression of BHP Billiton both internally and externally through the deployment of an interesting technology.

Revenue Opportunities refers to the additional revenue opportunities that become possible with a certain technology. For example, most renewable energy technologies can generate revenues based the greenhouse gas offsets they produce **in addition to** revenue from the electricity they produce.

Exhibit 4-6 presents an example of a ranked criteria list for BMNC.

Exhibit 4-6: Example of Criteria Assignment Output

Goal	Type and Weight	Criteria
To cost-effectively supply up 5% of energy requirements through renewable energy (~25 MW)	Threshold*	Capacity* Cost
To pursue projects that demonstrate BHPB's commitment to sustainable development to government, community and civil society (i.e. developing highly visible and favorable renewable energy projects).	Comparison 40%	Stakeholder acceptance
To meet MEL's corporate GHG goals via renewable energy deployment if possible	Comparison 30%	GHG offsets Capacity
To be the first-to-market with innovative world-class renewable energy project	Comparison 20%	Innovation
Develop additional capacity through renewable energy	Comparison 10%	Capacity
* The threshold criteria most closely associated with the goal should serve as a minimum acceptable performance standard for technologies under consideration.		

40 Zhigang, Xing, "Three Gorges challenges to linger," China Daily, March 18, 2008. Accessed April 2008: http://www.china.org.cn/environment/opinions/2008-03/18/content_12920553.htm

The criteria should be assigned a weight according to their frequency of appearance and the importance of the goals with which they are associated. The actual weighting of the criteria requires user discretion and concurrence among DT members. In the case of MEL, capacity appears to be the most important criteria primarily because it is most closely associated with a Threshold goal, and secondarily, because it is associated with three of the five major goals that drive the adoption of renewable energy. Capacity is can serve as both a Threshold criteria and a Comparison criteria. The fact that it serves as a Threshold criteria does not imply that it will then be the highest ranking Comparison criteria, because as a Threshold criteria, capacity has already established a minimum standard for renewable energy technologies. In this case, cost might take precedence in the Comparison criteria as it is associated with the most critical goal.

Exhibit 4-7: Example of Criteria weighting output

Criteria	Weight
Capacity (~25 MW)	Threshold
Cost	40%
Capacity	30%
Stakeholder acceptance	20%
GHG offsets	15%
Innovation	5%

Ranking methodologies like this do not deliver perfect results, but serve as a systematic way to tackle a complex multi-criteria decision-making process. The ranking and weighting processes should ideally be conducted in an iterative, collaborative manner with various constituencies represented, including external stakeholders, as per the BHP Billiton project process. Iterations will serve to recalibrate rankings to generate the best solutions.

The team has developed a prototype "Drivers, Goals, and Criteria" survey intended to aid the DT in the identification of drivers, the development of renewable energy goals, and the prioritization of criteria. The survey questions have been copied into **Exhibit 4-13** and the survey itself is located at http://www.wolverinerenewables.com/Goals-Drivers.html.

Step 4: Assess Renewable Resources

One essential ingredient for energy production at any scale is the presence of adequate energetic resources. In Step 4, the DT will conduct an assessment to gauge the availability and quality of renewable resources in the vicinity of the asset. The resources identified in this Step must show sufficient energetic potential to generate electricity or provide fuel at a reasonable cost and at a minimum useful scale to supply at least some of the demand identified in Step 1 (Base Case). Step 4 can be conducted in parallel with Step 2.

The major *cost* component of any renewable energy project's cost is the initial capital investment in the power plant and infrastructure. Operating costs are often low, as many renewable resource "fuels" are either free (wind or solar) or have low purchase prices (such as biomass residues). However, the presence, quality and availability of the renewable resource ultimately limits the power output of the plant and the *value* of the project. Therefore, understanding the economic value and technical viability of a project begins with determining the *resource availability*.

The DT will determine which renewable resources (or fuels) are sufficiently abundant in areas proximal to the desired site of an energy system. Since this framework is meant to enable a concept-level assessment of renewable energy projects; at this stage, a high-level estimation of the renewable energy resources in the area can be sufficient. Each resource should initially be assigned a rating of high, medium, or low availability. The team has developed a prototype Renewable Resources Assessment web survey tool to aid in this resources evaluation process as well. The survey questions have been included here in **Exhibit 4-14** and the live survey is located at http://www.wolverinerenewables.com/Resource-Asseessment.html. To conduct these assessments, the DT should be able to leverage the knowledge of the asset-based personnel, who may have a well-developed understanding of site-specific resources.

Chapter 5, the Resource Assessment Toolkit, presents a much more rigorous, technical resources assessment "toolkit" to guide the process for assessing the available renewable energy resources more systematically. The Chapter contains specific data sources and links necessary to develop regional and/or site-specific assessments for the following resources:

- Wind speed
- Solar radiation
- Biomass

Beyond strict resource availability, other factors that must be assessed include:

- Proximity of the source of demand to the renewable resource
- Availability and access to sufficient land for operation
- Environmental, social, economic, and community impacts of resource usage (mostly relevant to biomass)

At this stage, the DT could also conduct a preliminary "fatal flaw" cost/benefit analysis that encompasses social, environmental, and economic factors to assess the usefulness of further considering a project at this point. This preliminary analysis will be particularly important for the biomass resource assessment, which involves more complexity and may have a greater potential to adversely affect the local environment and community.

Exhibit 4-8: Example of resource assessment in Step 5 of framework. Source: Moazed (2008)

Resource	Resource Available	Rating	Viable Based on Assessment?
Wind Speed	Class 4-5	Med	Yes
Solar Radiation	7 W/m²	High	Yes
Biomass Residue Availability	0 tons/year	Low	No
Biomass Energy Crop Availability	0 tons/year	Low	No
Geothermal	Unknown	NA	No

Step 5: Identify Viable Technologies Based on Resources

Based on the existing resources identified in Step 4, the DT can select from an array of commercially available technologies. For the purposes of this project, we have focused primarily on the following technologies:

- Wind Turbines
- Solar Photovoltaic
- Solar Thermal
- Biomass Combustion
- Biomass Gasification

This Step is conceptually quite simple, but requires a fair understanding of the technologies required and the details of their deployment. Following the Resource Assessment Toolkit, the team has developed a Technology Assessment Toolkit which offers a technical overview of these available technologies and how to evaluate their appropriateness given a particular set of renewable resources and energy demand scenario.

Step 6: Match Viable Technologies to Renewable Energy Needs and Goals

The goal of Step 6 is to rank, either quantitatively or qualitatively, the technologies identified in Step 5 according to their performance with respect to the Comparison and Threshold criteria from Step 3. This ensures that the technologies are ranked according to their fit with the DT's renewable energy goals (Step 2).

The first Step in matching technological capability to the asset needs is to compare technology performance to Threshold criteria. Any technology not meeting the minimum performance standard set by the Threshold criteria should be eliminated from further consideration. Following the

Threshold screening, the remaining technologies should be evaluated based upon their performance with respect to Comparison criteria. This can be done either qualitatively or quantitatively. In **Exhibit 4-9**, the team first screened technologies against a 25 MW capacity Threshold criteria. Then, the team quantified technological performance across Comparison criteria using a 3 point ranking system (1, 4 and 9 for low, mid and high performance, respectively). The highest score for Solar Thermal indicates that this technology is most promising based upon asset-specific considerations.
The output of this Step is a ranked "short list" of potentially viable renewable energy technologies whose characteristics best fit the priorities established by the processes from Steps 2 (identifying drivers and establishing goals) and 3 (prioritizing criteria according to the ranked goals). One possible outcome of this Step is that no renewable energy technologies offer an acceptable or sufficient match according to the weighted criteria.

Exhibit 4-9 is an example of the output of Step 6 based on our analysis of the BMNC asset. **Chapter 7** illustrates a more detailed application of this framework to BMNC, discusses how each criteria apply to the selected technologies.

Exhibit 4-9: Example of quantitative comparison of renewable energy technologies across criteria. Source: Moazed (2008)

		Technology Performance		
Criteria	**Weight**	**Solar PV**	**Solar Thermal**	**Wind**
25 MW Capacity	Threshold *	Meets	Meets	Meets
Cost	40%	1	4	4
Capacity	30%	4	9	4
Stakeholder acceptance	20%	4	9	4
GHG offsets	15%	1	4	4
Innovation	5%	4	9	4
Total Score**		2.75	5.95	4.4

***** Technologies not meeting the threshold criteria should be eliminated from consideration
****** Total Score is the sum product of the criteria-specific weight and the technology performance for the criteria.

Step 7: Develop and Evaluate Project Concepts

Any technologies that pass the Threshold criteria and favorably meet the Comparison criteria in Step 6 show potential to be considered for adoption. At this stage the DT should develop project concepts for the most promising technology configurations that emerge from Step 6. These project concepts should then be evaluated to determine their technical and economic characteristics, and to understand more fully any relevant social (community), environmental, and safety considerations.

For each promising technology, a concept-level project plan should be developed. For example, the outcome of Step 6 was the identification of three technologies that passed the Threshold criteria for MEL: a concentrated solar thermal (CSP) installation, a solar PV array, and a wind farm. However, solar thermal and wind performed much better than solar PV with respect to Comparison criteria. So, for Step 7, the DT would generate project concepts for solar thermal and wind projects.

In general, this Step "fleshes out" technology configurations that are appropriate for the site. Once reasonable configurations have been conceived, they should be evaluated fairly rigorously according with a technical, economic, social, environmental, and safety review of the opportunity. Basic cost, performance, and impact characteristics should be estimated.

The direct value of any potential renewable energy projects will be the value of the energy, infrastructure, or feedstock that is offset by the renewable energy project. In addition, there may be credits generated for CO2 reduction that have a monetary value. **Exhibit 4-10** illustrates the components of the value of a renewable energy project.

Exhibit 4-10: Valuing Renewable Energy Projects

Incremental value of energy offset
- Cost of renewable energy CAPEX
- Cost of additional infrastructure needed to support renewable energy technology
- Operating & fuel costs
+ Value of GHG offsets generated
+ Value of strategic benefits, social benefits, or risk reduction
+ Potential tax benefits
+ Value of avoided fines
+ Additional subsidy or financing from grants or the climate change commitment
Value of the renewable energy project

For example, when developing a CSP, concept the team should determine what specific type of CSP technology is most appropriate, where the facility should be sited, whether it can be integrated with a fossil fuel generation facility to share a steam turbine, how and whether the plant should connected to a grid. The DT can reference Chapters 5 and 6 (the resource and technology toolkits) for more detailed information about the characteristics of and options for technologies. Based on these concepts, the DT should conduct a rough evaluation of the project's capital and operating costs to determine the LCOE. We have developed an LCOE calculator for renewable energy projects, which is displayed in **Exhibit 4-16**. The DT should also determine whether there are available contractors, partners or consultants to help scope, build and operate the project.

Once the project has been fairly well conceived, it should also be re-checked against the priority goals and criteria that were developed, the strategic alignment with the asset and the company, and the stakeholders' perception. At this stage, should the concept continue to pass these tests, the concept should re-enter BHP Billiton's project management process in the latter stages of the

"Identification Phase." This project development and evaluation should provide most of the information required for the "Tollgate 1" submission materials required to move the project from Identification to Selection and Definition. More detailed and rigorous evaluation of the project concept would likely require consultation with an external contractor and developer.

Supplemental Exhibits

Sample Assessment Tools

Exhibit 4-11: Online Survey for Step 1: Base Case Energy Assessment

Please fill this out to help understand the existing energy situation.

Name

[ ] First [ ] Last

Title

[ ]

Asset

[ ]

CSG

[Aluminium ▾]

Country

[ ]

Nearest City

[ ]

Geographic Coordinate- X Coordinate

[0]

Geographic Coordinate- Y Coordinate

[0]

How much diesel fuel do you expect to use this year (tonnes)?

[0]

How much diesel fuel do you expect to use to generate electricity this year (tonnes)?

[0]

How much diesel fuel do you expect to use this year (tonnes)?

[0]

How much diesel or Heavy Fuel Oil do you expect to use next year (tonnes)?

[0]

Total Electricity used last year (MWh)

[0]

Carbon Intensity of the electricity used last year?

[0]

Procedure is defined in the Greenhouse Gas Instruction Manual.

Please describe the sources of energy used and the percentages.

[ ]

Example: Coal - 35%; Natural Gas - 25%; Nuclear; 20%; Hydro - 20%

Average Power Need (MW)

0

Maximum Power Need (MW)

0

Is your asset connected to a grid?

Yes No

Power capacity of the grid on which your asset is located (MW)

Company name of your utility provider(s)

Average Cost of Electricity (in $US per kWh)

Distance to the nearest port from your asset (km)

Please summarize the major energy-demanding processes at your asset. Discuss the timing and intensity of the load patterns (peak versus non-peak).

Exhibit 4-12: Supplemental Survey for Step 1: Regulations and Incentives

This is designed to help understand the regulations and incentives behind renewable energy.

Name

First Last

CSG

Country

Province, State, or Region

Are there any national or regional regulations or incentives you are aware of that may require or reward renewable energy?

Yes

Has your country adopted the Kyoto Protocol?

Yes

Please describe any laws that may mandate your asset to purchase renewable energy.

Please describe any government programs that may add economic value to a renewable energy project

Are there any laws or policies being discussed by your government that could require you to use more energy produced from renewable sources?

Yes

What aspects of energy policy concern you most?

<u>Exhibit 4-13: Online Survey for Steps 2 & 3: Identifying Drivers, Developing Goals, and Ranking Criteria</u>

This stage is designed to help you identify your drivers and develop goals for renewable energy.

Name

First Last

CSG

Identifying Goals and Drivers

Please rank the following corporate drivers on a scale of 1-10? (10 is most important)

Being a Low-Cost Operation?

1

Secure Energy Supply?

1

License to Operate?

1

Internal GHG Reduction?

1

Meeting Legislative Requirements?

1

Demonstrating leadership in technology?

1

Improving Energy Efficiency?

1

Being an Industry Leader in Energy Efficiency and Technology?

1

Developing Criteria

What are the key criteria that a renewable technology must possess in order to fulfill corporate goals?
Please rank the following criteria on a scale of 1-10? (10 is most important)

Cost

1

Power Capacity (MW that can be delivered in response to peak demand)

1

Visibility

1

Scalability

1

Public Acceptance

1

Innovation

1

Proven technology

1

Exhibit 4-14: Online Survey for Step 4: Renewable Resource Assessment

This is the second Step in the process - to assess the renewable resource potential in a given area.

Name

First Last

Asset Name

CSG

Does your asset currently source any electricity from renewable energy?

Yes

If yes, which types of renewable energy does your asset source energy from?

Hydropow er Hydropower Geothermal Geothermal Solar Solar Wind Wind
Biomass Biomass

Which two technologies do you currently believe to have the best potential to further develop to provide power to your asset?

Hydropow er Hydropower Geothermal Geothermal Solar Solar Wind Wind
Biomass Biomass

Why did you choose these technologies

Do you have access to any available local meteorological data?

Yes

Please describe where this data is collected and who collects it.

Please include the contact information of at least two people who manage data related to solar, wind, and rain that your asset relies upon most.

Yes

Are there any wind power plants within 50 km of your asset?

Yes

Are there any solar power plants existing or being planned within 50 km of your asset?

Yes

Is agriculture common in any areas within 50 km of your asset?

Yes

Are there any facilities within 50 km that are converting agricultural waste into electricity

Yes

Are there any agricultural processing facilities within 50 km?

Yes

Which of the following geothermal resources exist within 50 km?

Active fault lin Active fault line Hot Springs Hot Springs Geysers Geysers

Exploration for Exploration for geothermal energy Geothermal pc Geothermal power plant

Please describe the type of agriculture taking place within 50 km and describe where this is being processed.

What will be the greatest problems in using renewable energy to power your asset and how might this be overcome?

Please add any other information or ideas that you think are relevant in identifying opportunities to use renewable energy cost-effectively at your asset.

Please upload any reports you are aware of that summarize the existing wind resources in your area.

Please upload any reports you know of that summarize the existing solar resources in your area.

Please upload a file containing measurements of the nearest wind tower to your asset.

Please upload any wind resource maps of your area that are available to you.

Please upload a map of the area surrounding your asset that include transmission and distribution lines as well as substations.

Exhibit 4-15: BHP Billiton's Business Case for Sustainable Development

Reduced Business Risk And Enhanced Business Opportunities - Understanding and managing risk provides greater certainty for shareholders, employees, customers, suppliers, and the communities in which we operate. By managing our business risk we can be better informed and more decisive and can pursue growth opportunities with increased confidence. The aim is to embed risk management in all critical business systems and processes so that risks can be identified and managed in a consistent and holistic manner.

Gaining And Maintaining Our License To Operate And Grow - Access to resources is crucial to the sustainability of our business. Fundamental to achieving access to resources is effectively addressing heightened political and societal expectations related to the environmental and social aspects of our business.

Improved Operational Performance And Efficiency - Many key operational performance indicators are inextricably linked to sustainability performance. For example, improving energy efficiencies reduce both costs and greenhouse gases; increasing plant life reduces maintenance cycles, which then reduces requirements for consumables and replacement items, reducing wastes immediately lowers operational costs. The application of innovation and business improvement processes not only improves operational efficiency and performance but also delivers sustainability gains.

Improved Attraction And Retention Of Our Workforce - Our workforce is an essential element of our business, and being able to attract and retain a quality workforce is fundamental to our success. Maintaining a healthy and safe workplace is a universal value of all employees. Effective employee development and training programs, attractive remuneration packages, addressing work/life balance, and providing a fair and non-discriminatory work environment all contribute to employee attraction and retention.

Maintained Security Of Operations - Asset security is a critical element that can be significantly impacted by the nature of relationships with host communities. Trusting and supportive relationships can lead to reduced security risks, whereas distrustful relationships can lead to heightened security risks. This is particularly critical for our operations in parts of the world with politically unstable environments.

Enhanced Reputation - The benefits of enhanced reputation are many but often difficult to quantify. Understanding what our stakeholders perceive as responsible behaviour, meeting these expectations and achieving recognition from financial institutions, investors and customers can deliver value. For example, enhanced reputation may foster an increased belief that the Company has the credibility and capabilities to deliver on its commitments. This can promote shareholders' faith in proposed investments, communities' faith in community development plans, governments' faith in successful delivery of projects, and business partners' faith that we are reliable and competent in all that we do.

Enhanced Ability To Strategically Plan For The Longer Term - By anticipating and understanding trends in society – new regulations, heightened societal expectations and improved scientific knowledge – and assessing these against our business models, our ability to proactively plan for the longer term is improved. This includes entering emerging markets, revising product mixes or changing operational technologies.[41]

[41] BHP Billiton, "BHP Billiton Sustainability Report 2007" 2007.

Calculating Costs for Renewable Energy Projects

Exhibit 4-16: Levelized Cost of Electricity (LCOE) Calculator

Estimating the Cost Of Electricity for a renewable energy project			
Technology:	Wind		
			Scenario
Installed capacity	10	MW	
Life of project	20	years	
Capacity Factor	30%		*Mid*
Installed capital cost	$1,610	per kW	*High*
O&M costs	$0.0092	per kWh	*Mid*
Discount rate	7%		
Capital Recovery Factor (CRF)	9%		
Levelized Cost of Electricity from RE project	**$0.0670**	**per kWh**	
Revenues/Credits			
Electricity offset			
Current cost of electricity	$0.10	$/kWh	
Feed-in tariff	$0.00	$/kWh	
- *Value of grid-offset electricity*	**$0.1000**	**$/kWh**	
Grid or baseline GHG Intensity			
% Coal	80%	(tCO2-e/MWh)	
% Oil	5%	(tCO2-e/MWh)	
% Diesel	5%	(tCO2-e/MWh)	
% Natural gas	10%	(tCO2-e/MWh)	
% Total	100%	(= 100%)	
Baseline GHG Intensity Factor	0.93	(tCO2-e/MWh)	
GHG offset			
Price of carbon	$10.00	$/tCO2-e	
Total GHG offset by RE project	24,333	tCO2-e	
- *Monetary value of GHG offset*	**$0.0093**	**$/kWh**	
Other credits			
Production Tax Credit	$0.00	$/kWh	
???	$0.00	$/kWh	
???	$0.00	$/kWh	
- *Other credits*	**$0.0000**	**$/kWh**	
Net Incremental Cost of Renewable-Sourced Electricity:	**-$0.0422**	**$/kWh**	
Lifetime impact			
Electricity delivered (annual)	**26,280**	**MWh/year**	
ectricity delivered over project lifetime	**526**	**GWh**	
lonetized value of GHG offset (annual)	**$243,327**	**$/year**	
Monetized value of GHG offset over project lifetime	**$2,577,805**		

Exhibit 4-17: Average Cost Data for Renewable Energy (Used for LCOE Calculator)

	Technology	Range	Capacity Factor (%)	O&M Cost (2005$/kWh)	Installed Capital Cost (2005$)
Solar Thermal - storage High	Solar Thermal - storage	High	55%	$0.02720	$5,240
Solar Thermal - storage Mid	Solar Thermal - storage	Mid	50%	$0.02270	$4,850
Solar Thermal - storage Low	Solar Thermal - storage	Low	45%	$0.01820	$4,450
Solar Thermal - no storage High	Solar Thermal - no storage	High	25%	$0.04510	$2,680
Solar Thermal - no storage Mid	Solar Thermal - no storage	Mid	20%	$0.03760	$2,480
Solar Thermal - no storage Low	Solar Thermal - no storage	Low	15%	$0.03010	$2,290
Solar PV High	Solar PV	High	25%	$0.00970	$7,810
Solar PV Mid	Solar PV	Mid	20%	$0.01210	$7,060
Solar PV Low	Solar PV	Low	15%	$0.01450	$6,310
Biomass Combustion High	Biomass Combustion	High	85%	$0.19020	$2,300
Biomass Combustion Mid	Biomass Combustion	Mid	80%	$0.06340	$2,450
Biomass Combustion Low	Biomass Combustion	Low	75%	$0.02113	$2,600
Biomass Gasification High	Biomass Gasification	High	85%	$0.26040	$5,075
Biomass Gasification Mid	Biomass Gasification	Mid	80%	$0.08680	$3,200
Biomass Gasification Low	Biomass Gasification	Low	75%	$0.02893	$1,450
Biomass Co-firing High	Biomass Co-firing	High	85%	$0.12680	$200
Biomass Co-firing Mid	Biomass Co-firing	Mid	80%	$0.06340	$125
Biomass Co-firing Low	Biomass Co-firing	Low	75%	$0.01585	$50
Wind High	Wind	High	40%	$0.01100	$1,610
Wind Mid	Wind	Mid	30%	$0.00920	$1,440
Wind Low	Wind	Low	20%	$0.00740	$1,270
CO2 High	Carbon	High	0	0	0
CO2 Mid	Carbon	Mid	10	10	10
CO2 Low	Carbon	Low	20	20	20

Chapter 5:
Resource Assessment Toolkit

Intent of the Toolkit

This toolkit provides an overview of solar, wind and biomass renewable energy resources which may be used for power generation. The toolkit is designed to guide BHP Billiton personnel to:

- Understand the important characteristics of renewable energy resources;
- Perform a basic evaluation of biomass resources for a given region or site to determine resource availability;
- Understand the additional steps necessary to perform a more detailed, site-specific resource assessment;
- Evaluate other inputs necessary to utilize specific renewable energy resources, such as land and water; and
- Identify and assess social and environmental benefits and/or costs associated with utilization of renewable energy resources.
- This toolkit provides the means to make an initial assessment of which renewable energy resources might be attractive for power generation. A site-specific characterization of available renewable energy resources should be conducted in consultation with an experienced renewable energy developer with experience in the solar, wind, and/or biomass industries, and is beyond the scope of this document.

Solar

Solar Radiation

Solar radiation is generally reported using terms such as "*insolation*" and "irradiance." The angle, intensity, and direct or diffuse nature of the incident rays from the sun are all crucial in determining the "quality" of the solar resource at a given site, and consequently to determine if solar power is feasible at all, and if yes, then which solar technologies will work best.

However, to determine the actual energy output and capacity factor of a solar power plant, the "*number of sunshine hours*" expected over time must be known. Therefore, data on daily, monthly, seasonal, and annual variation of insolation is crucial.

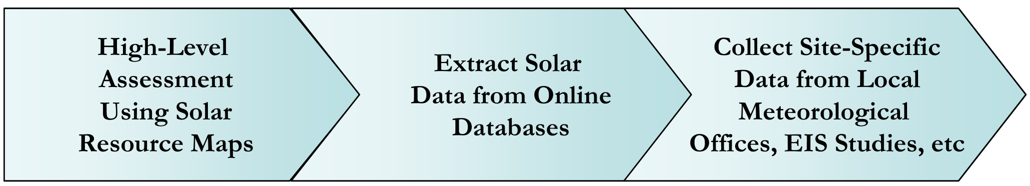
Solar radiation is measured as either "direct" or "diffuse." The sum of the two quantities is termed as "global" radiation. These terms are described in **Exhibit 5-1** below.

$$\text{Global radiation} = \text{Direct normal radiation} + \text{Diffuse radiation}$$

Exhibit 5-1: Solar radiation terminology

Insolation	Measure of solar radiation energy received on a given surface area in a given time. Expressed in either power units (irradiance) or energy units. W/m^2 $kWh/m^2/day$
Direct Insolation	Solar radiation that is transmitted directly through the atmosphere to the earth's surface without interacting with atmospheric components.
Diffuse Insolation	Solar radiation that is scattered or reflected by atmospheric components.

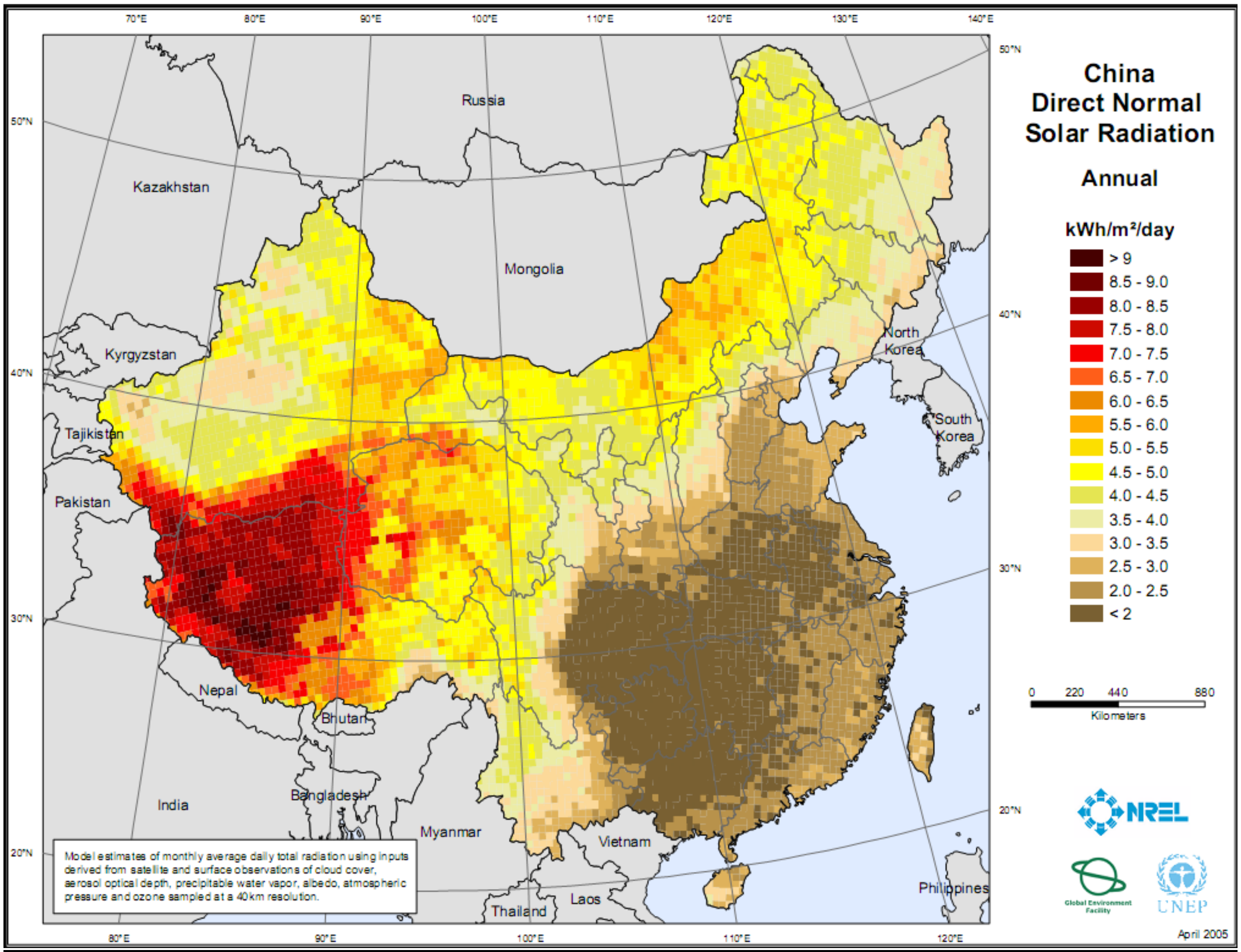
Method of Identifying Regions with High Solar Radiation



High-Level Assessment Using Solar Resource Maps

Solar resource maps (high-level solar radiation maps) are easily available through many online resources. Locating an asset on the *high-level* solar resource world map in **Exhibit 5-11** will provide an initial assessment of solar power potential in the area of that asset. If the asset is clearly in one of the regions marked as "good, very good, or excellent", then the solar resource is likely of high quality to utilize for power generation. Many agencies such as NREL, NASA, and UNEP also provide more granular maps and raw insolation data for free on the internet. One such solar radiation map is shown in **Exhibit 5-2** below.

Exhibit 5-2; Solar radiation map of China. Source: SWERA[42]



Solar Radiation Databases

The NASA solar database contains global solar radiation data based on geographical coordinates and an interactive world map. The database provides seasonal solar radiation trends over multiple years, providing a much more detailed look at resource potential. There are also other online databases for solar insolation data which may have better information for specific regions. See **Exhibit 5-12** for a list of these databases.

Site-Specific Solar Insolation Data from Local Sources

For some assets, there may be local sources of information on solar radiation. These sources may be in the form of raw data from meteorological offices and observatories, or data that has been

42 Solar and Wind Resource Assessment database, *UNEP*, http://swera.unep.net/index.php?id=solar_map

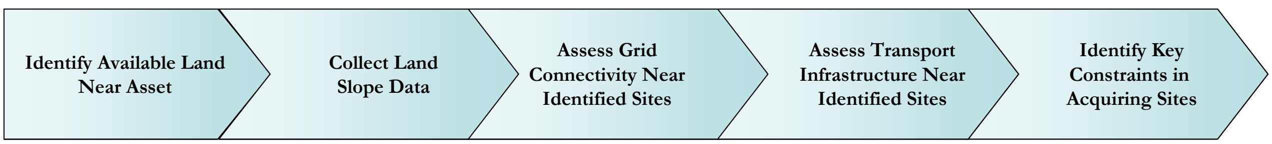
synthesized in an environmental assessment report or environmental impact statement prepared for the asset.

Land

With the exception of some rooftop and building-integrated solar applications, most solar technologies require open land spaces, especially for large-scale (megawatt range) installations. Land availability is expected to be crucial factor in determining feasible solar technologies for a given site, as much as the amount of available solar radiation. For large-scale projects, most solar technologies will require between 3 to 10 acres of "flat" land for every MW of installed capacity[43].

Method for Assessing Suitable Land for Solar Power

For small-scale projects unused rooftops and inclined walls on buildings at the asset may be used. However for larger projects, a green-field development is usually required. Land availability may be evaluated using the following steps:



1) Assess general land availability around the asset and identify potential 'candidate' sites in the region surrounding the asset for various potential solar project sizes (such as 10MW, 50MW, 100MW).
2) If available, collect land slope data for the identified sites.[44] In addition, sites should be selected that are not shaded by any obstructions, especially on south facing directions in the northern hemisphere, and north facing directions in the southern hemisphere, since these are the most desirable orientations for capturing solar energy.
3) Assess grid connectivity of the 'candidate' sites identified and distance from closest grid-connection points (such as substations).
4) Assess transportation infrastructure (such as roads, rail, and ports) which may be needed for installation and service of equipment in the identified areas.
5) Identify key constraints in securing these land resources for solar power projects.

Most solar-power farms may not allow multiple or mixed use of the land, such as farming or grazing. Hence, land areas that are known to be prime agricultural or grazing areas (or used for other activities that cannot be disrupted) should not be considered for solar power developments.

[43] http://www.nrel.gov/csp/troughnet/faqs.html#land

[44] Some solar technologies require land with slopes less than 1-3% (Per industry representatives at Concentrated Solar Power Summit, San Francisco, January 2008)

Water

Some solar power technologies require considerable amounts of water, while others do not. For example, a parabolic trough solar power system may need anywhere from 738 cubic meters to 18,000 cubic meters of cooling water every year for every megawatt of installed capacity.

Method for Assessing Water Resources

1. Identify sources of water near the asset or close to potential sites (water quality must be similar to that used at existing power-generation stations operating at or near the asset).
2. Identify potential future sources of water in the region (such as a planned desalination plant).
3. Estimate costs and risks with water supply and availability; assess key constraints, possible environmental impact, infrastructure weaknesses/needs, social perception, and political issues.

Wind

Wind Resource

Wind resource is usually measured by class, which takes into account average wind power density in Watts per meter squared (W/m^2) and speed.

Exhibit 5-3 below characterizes wind resources into 7 different classes. Most utility wind power developments require a Class 4 or higher wind resource to be economical. The table shows the effects of wind shear between 10 and 50 meters. Wind speed is generally higher farther from ground level.

Exhibit 5-3: Wind power class. Source: US Department of Energy, Energy Information Administration

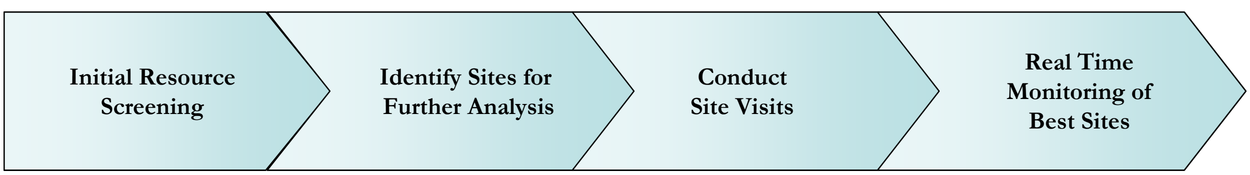
Wind Power Class	Height			
	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed m/s (mph)	Wind Power Density (W/m^2)	Speed m/s (mph)
1	<100	<4.4 (9.8)	<200	<5.6 (12.5)
2	100 - 150	4.4 (9.8)/5.1 (11.5)	200 - 300	5.6 (12.5)/6.4 (14.3)
3	150 - 200	5.1 (11.5)/5.6 (12.5)	300 - 400	6.4 (14.3)/7.0 (15.7)
4	200 - 250	5.6 (12.5)/6.0 (13.4)	400 - 500	7.0 (15.7)/7.5 (16.8)
5	250 - 300	6.0 (13.4)/6.4 (14.3)	500 - 600	7.5 (16.8)/8.0 (17.9)
6	300 - 400	6.4 (14.3)/7.0 (15.7)	600 - 800	8.0 (17.9)/8.8 (19.7)
7	>400	>7.0 (15.7)	>800	>8.8 (19.7)

Method for Assessing Wind Resources

In analyzing wind resources the key factors to consider are:

- Wind density, speed, direction, and variability;
- Distance to transmission infrastructure;
- Access to land where the above variables are favorable; and
- Potential aesthetic and environmental impacts of utilizing the resource.

There are four major steps required to assess wind resources. Each step provides an increasing level of detail about specific wind sites.

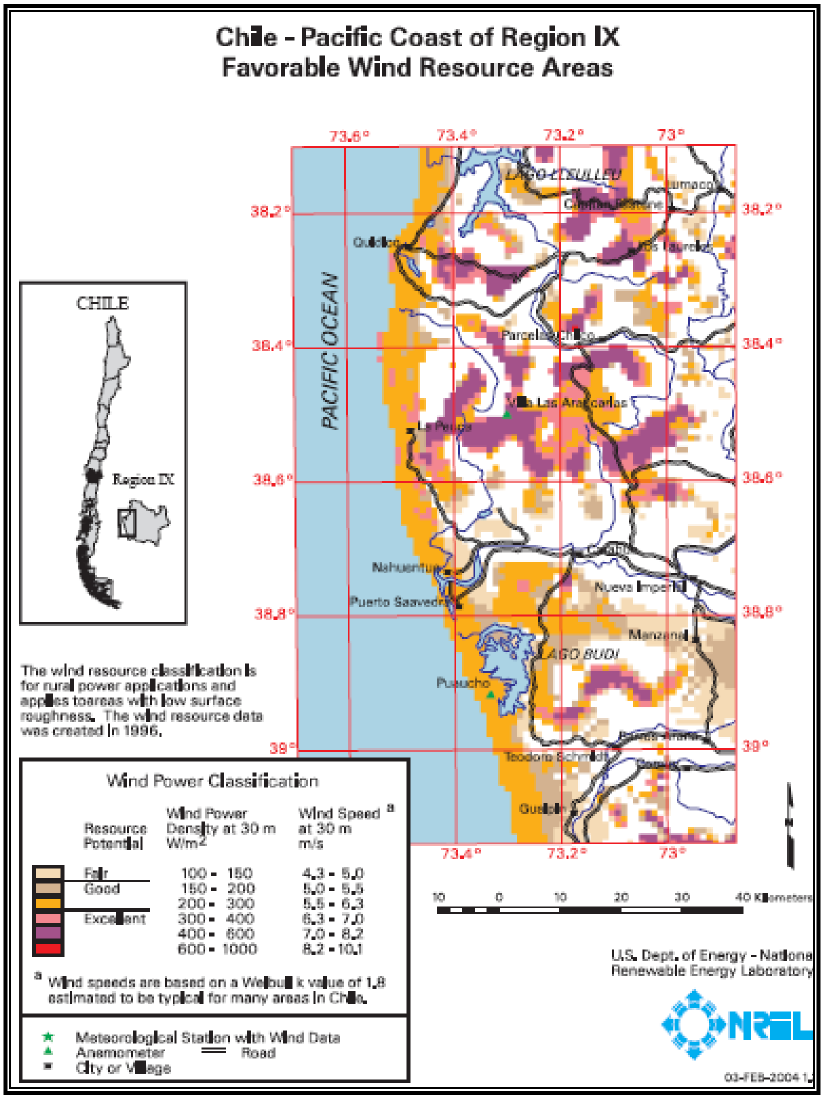


Initial Resource Screening

The easiest way to screen a potential wind resource is to use large scale wind maps. Several organizations produce free wind maps including the US National Renewable Energy Laboratory (NREL), the Solar and Wind Energy Assessment Program (SWERA), and the Asian Alternative Energy Program (ASTAE).

These maps provide a general indication of average wind potential over a large area. Wind resource maps are a good tool to utilize when making an initial screening. However, wind maps do not provide information on wind direction or variability. Wind maps are usually divided into specific wind classes which correspond to a range of wind speeds. Commercial wind developments usually look for Class 4 or higher wind sites. **Exhibit 5-4** below is a wind map of a region in southern Chile. Here, wind class has been replaced by a classification of fair, good, excellent. A Class 4 and above wind resource as shown in **Exhibit 5-3**, roughly aligns with the Excellent classification in the map.

Exhibit 5-4: Wind map of Region IX in Chile measures areas using wind speed and wind power density. Source: NREL



Identify Promising Sites for Further Assessment

The second step is to use wind computer models to provide a more accurate picture of a wind resource down to a much smaller scale. Wind models use information on topography, average weather patterns, seasonal variability, and historic wind speed data from available sources to identify promising areas for wind development. There are several companies that provide detailed modeling results for wind sites. 3Tier and Pacific Hydro have been used by BHP Billiton Base Metals Chile to evaluate wind resource potential. For purposes of the framework, modeling results are the recommended minimum level of detail before proceeding to the next step in the Framework for Evaluating Renewable Energy which is to evaluate technology options.

Conduct Site Visits

Once potential wind development sites are identified using modeling results, it may be appropriate to make site visits to the areas where wind resources look most promising. The purpose of the site visits is to evaluate and verify site conditions. The most important factors are available land area, land use, proximity to transmission, and accessibility of the location, potential aesthetic impacts, potential environmental impacts, and potential wind monitoring locations. Sites should then be ranked based on the wind resource and site specific factors. Ideally, site visits are done before moving onto the next phases of the Renewable Energy Framework.

Conduct Real-Time Monitoring of Best Sites

Before construction begins, top ranked wind sites are commonly monitored for at least a year using meteorological monitoring equipment that measures wind speed, wind direction, and temperature. Wind speed and direction should be recorded at multiple heights if possible to measure wind shear. This step should only be taken once wind energy has successfully moved through the selection framework and project economics look promising. NREL has produced a detailed Wind Resource Assessment Handbook which walks through the process of collecting wind data in detail.[45] Wind developers are likely to provide real-time monitoring services. These services cost approximately $US 100,000 per site according to Pacific Hydro.

Land Resource Assessment

Utilizing a wind resource also requires available land. This can be unutilized land or land that is being used in a way that is compatible with wind development, such as agriculture. There are generally two measures of land required for a wind development. The first measure includes the overall area of the entire project including the open spaces between the turbines. This measure is dependent on wind turbine size, spacing, and the configuration of the array of turbines and varies according to these factors. The range of land area per MW is on the order of 15 to 50 acres per MW of capacity.[46] Therefore a 50 MW wind farm using 1MW turbines could be spread over an area of 2500 acres. However, the vast majority of this land would still be available for other uses.

The second is the actual footprint of the site which comprises the turbines and their foundations, service roads, crane pads, electrical equipment, and any associated buildings. The range of land area per turbine according to the US National Renewable Energy Laboratory is 0.25 to 0.5 acres per

45 The Wind Resource Assessment Handbook is available at www.nrel.gov/wind/pdfs/22223.pdf

46 Horizon Wind Energy. http://www.horizonwind.com/about/govcom/

turbine. Therefore, a wind farm of 50 MW using 1 MW turbines would consume a maximum of 25 acres.

Biomass

Biomass Residues

Biomass is defined as plant material, vegetation, or agricultural waste used as a fuel or energy source. There are two primary sources of biomass feedstocks for electricity generation – biomass residues and dedicated energy crops (which can be further subdivided into herbaceous and woody crops). Biomass residues are typically procured from agricultural or industrial processes (e.g., cereal cultivation, wood mill or sugar cane processing). Dedicated energy crop plantations can be managed and supplied by the energy producer or a contracted supplier. For the purposes of this document, it is assumed that biomass will be procured from external providers and energy crop plantations and residue collection networks will not be managed directly by BHP Billiton.

Biomass residues are often available at low purchase prices since there are few alternative markets competing for this material and low (or negative) production costs. This benefit may be offset by the fact that residues are more variable than energy crops in terms of energy and moisture content, and chemical composition. Residues may also require more processing (sizing, drying and densification) prior to use as a fuel, and therefore, impose higher operating costs. Biomass residues are often collected in small volumes from multiple suppliers, making the logistics networks more complex and costly. **Exhibit 5-5** below shows different types of biomass residue.

Exhibit 5-5: Bailed straw (left), bundled forestry waste (center), and piled bagasse (right). Sources: www.magazine.ifrf.net, www.brazilintl.com

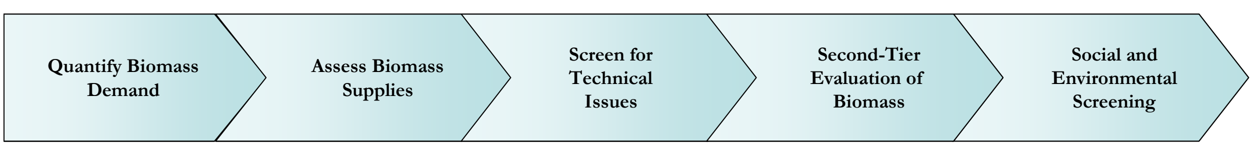
Biomass Energy Crops

Dedicated biomass crops show less variability in the above-mentioned characteristics, and may require less processing as the crops are selectively bred to have high energy content. However, the development of a dedicated biomass feedstock plantation exposes one's fuel source to the risks associated with agricultural crops (e.g., drought, pestilence, disease, etc.) as well as claims regarding food security threats, reduced biodiversity and displacement of small-scale farmers.

Exhibit 5-6 below shows cultivation and harvest of biomass energy crops. Because of the myriad complexities associated with biomass cultivation, it is recommended that BHP Billiton consult directly with local governments, agronomists, NGOs, before giving serious consideration to the notion of obtaining biomass from plantation-based sources.

Exhibit 5-6: Hybrid poplar (left) and willow (right) plantations. Source: Texas State Energy Conservation Office and Slough Heat & Power.

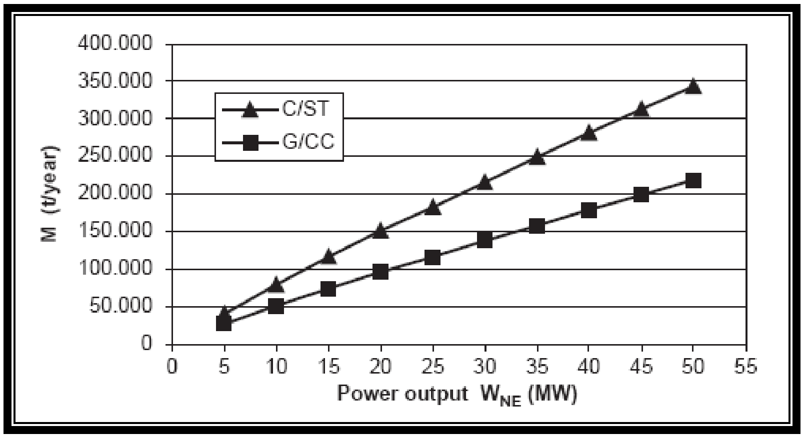
Method of Evaluating Biomass Feedstocks



<u>Quantify Annual Biomass Demand</u>

The first step in assessing biomass resource availability is to understand the power demand and amount of feedstock necessary to generate this power. This estimated renewable energy power demand should be evident after conducting the Base Case Analysis (Step 1 of the Renewable Energy Framework). Ultimately, the energy content (Higher Heat Value, MJ/kg) characteristics of the biomass and the energy conversion efficiency (Heat Rate, MJ/kWh) of the power plant will dictate the required biomass for a given power output. However, for this first pass at estimating biomass quantities, we recommend using the chart in **Exhibit 5-7** below. These estimates are based upon the following assumptions which are characteristic of common biomass combustion plants today.[47]

Exhibit 5-7: Estimated annual biomass consumption (Mt/yr) versus plant size for biomass combustion (C/ST) and gasification (G/CC). Source: Caputo et al (2005)



Assumptions
Power Plant Heat Rate:
10,000 MJ/KWh
Calorific Value (HHV)
14.6 MJ/kg
Average Moisture Content
30%
Operational Hours

__**Identify Biomass Residue Supply**__

After approximating the volume of biomass needed to supply the power needs, BHP Billiton should assess the availability of biomass from residue suppliers or from dedicated energy plantations. A general sense of the availability of biomass in a given region can be gleaned from maps of the regional or global net primary productivity (see **Exhibit 5-17**). However, asset personnel and local agronomists will typically have the best understanding of the nature and magnitude of agricultural and timber industry practices near the proposed or existing energy generating plant. These personnel should be consulted in order to identify large-volume biomass suppliers and to assess the potential for developing networks of small-volume suppliers of biomass residues.

Large quantities of high-energy value biomass crops or residues must be available within an economically viable distance of the power plant. The distance from which BHP Billiton procures biomass fuel will vary widely and is largely dependent upon the region-specific transportation infrastructure, cost of freight hauling, and the bulk density of the biomass (topics covered in subsequent steps of the Renewable Energy Framework). Citing the power plant near a biomass supply reduces uncertainty stemming from feedstock availability and also substantially reduces the cost of feedstock procurement. Potential valuable sources of biomass include:

- Industrial-scale agricultural;
  - Dedicated energy crops
  - Sugar cane waste (bagasse)

[47] Caputo, A.C. et al. Economics of biomass energy utilization in combustion and gasification plants: effects of logistics variables. Biomass & Bioenergy (28), 2005. pp 35-51

  - Rice husks
  - Coconut process wastes
  - Straw
- Residues from collective or cooperative farming communities
- Wood milling wastes;
- Wood pulp wastes;
- Forest thinning residues;

Combinations of these biomass sources may be able to supply adequate volumes of biomass fuel to a power plant. However, BHP Billiton or the contracting power provider must be able to ensure and coordinate a low-cost, stable, long-term supply of the biomass.

Screen Technical Issues with Biomass Feedstocks

The next step is to identify the most technically feasible, cost-effective biomass feedstock. Biomass economics are primarily driven by logistical complexity of the supply chain network and physical/chemical characteristics of the biomass. Biomass technical feasibility is a function of the security of the fuel supply and the physical/chemical characteristics of the biomass.

Supply chain logistics: Biomass residue supply chains are often complex and costly because they must supply large amounts of biomass residue by aggregating supplies from many disparate sources. As illustrated in **Exhibit 5-8** below, supply chain networks for biomass can account for up to 90% of the biomass feedstock costs.[48] Therefore, it is imperative to select feedstocks with the lowest complexity built into the supply chain.

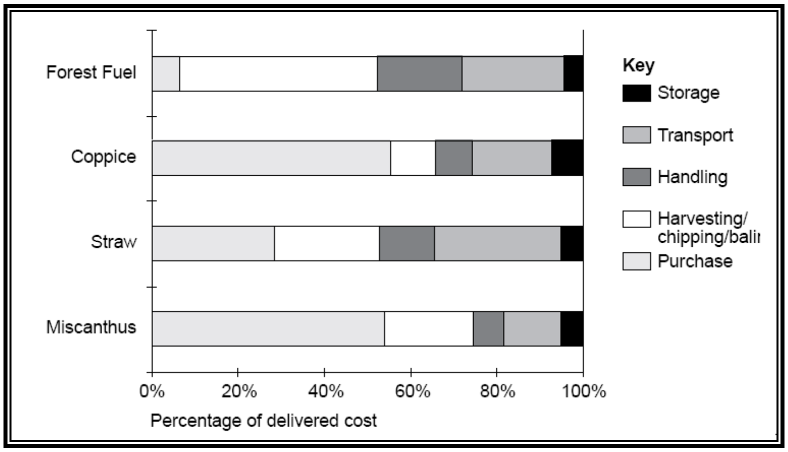
Steps that BHP Billiton can take to minimize supply chain impacts include:

- Densify the biomass prior to shipping;
- Always avoid transporting loose chips;
- Reduce the distance between power plant and supplier;
- Reduce the number of suppliers;
- Increase the volume per supplier;
- Aggregate feedstock from suppliers at centralized collection points;
- Use or rehabilitate existing transportation infrastructure; and

48 Allen. J., Brown. M. Logistics management and costs of biomass fuel supply. International Journal of Physical Distribution & Logistics Management, Vol. 28 No.6 (1998) pp463-477

- Avoid dedicated transportation routes by using empty freight returns to transport biomass (i.e., fill empty cargo vessels with biomass on return routes).[49]

Exhibit 5-8: Cost breakdown for delivered biomass. Source: Allen (1998)



Security of supply: BHP Billiton's operations require a stable and secure supply of power. Biomass generated electricity is capable of providing reliable power because it maintains a high capacity factor (~80%), similar to that of fossil fuel electricity generation plants. However, because biomass fuel supplies are susceptible to climatic and ecological factors (e.g., pestilence, drought) over which BHP Billiton or its power suppliers exercise little control, the fuel supply can be highly variable. Furthermore, biomass residue availability is susceptible to demand from competing markets (e.g., construction, charcoal, heat).

Steps that BHP Billiton can take to ensure security of supply include:

- Evaluating seasonality of biomass suppliers;
- Establishing multiple supply contracts for biomass;
- Selecting biomass with few competing uses;
- Storing biomass or alternate fuel types (e.g., coal) on-site; and
- Using co-fired biomass-to-electricity conversion devices (see Biomass Technology Toolkit)

Material properties: The ability to cost-effectively convert a particular biomass feedstock into electricity depends on its chemical and physical properties. These characteristics impact the cost effectiveness through both the actual conversion efficiency and processing and supply chain complexity. BHP Billiton personnel should assign each biomass source a value for the below characteristics using various online biomass databases (see **Exhibit 5-19** under Supplemental Exhibits). Next, personnel should evaluate the biomass sources in light of the impact of these

49 Hamelinck, Carlo N., Suurs, Roald A., Faaij, Andre P.C. International bioenergy transport costs and energy balance. Biomass & Energy 29 (2005) pp 114-134

characteristics on combustion efficiency and supply chain logistics, as explained in **Exhibit 5-18** under Supplemental Exhibits.

Conversion Efficiency Considerations

- Calorific value
- Fixed carbon to volatile ratio
- Moisture content (<40% desirable)
- Ash/residue
- Alkali metal content
- Homogeneity

Supply Chain Considerations

- Bulk density
- Moisture content

Exhibit 5-9: Physical and chemical properties of selected biomass materials (wt %).

Properties of selected biomass materials (wt%)

Material	Moisture content (%H_2O)	HHV[a] (MJ/kg)	FC content (%)	VM content (%)	Ash content (%)	Alkali metal content (as Na and K oxides) (%)
Fir	6.5	21	17.2	82.0	0.8	–
Danish pine	8.0	21.2	19.0	71.6	1.6	4.8
Willow	60	20.0	–	–	1.6	15.8
Poplar	45	18.5	–	–	2.1	16
Cereal straw	6	17.3	10.7	79.0	4.3	11.8
Miscanthus	11.5	18.5	15.9	66.8	2.8	–
Bagasse	45–50	19.4	–	–	3.5	4.4
Switchgrass	13–15	17.4	–	–	4.5	14
Bituminous coal	8–12	26–2	57	35	8	–

[a] Dry basis, unless stated otherwise.

Second Tier Evaluation of Energy Content

In Step 1, biomass demand was estimated using generic values. In this step, BHP Billiton personnel should attempt to refine the estimated biomass demand by using actual heat values and moisture content of biomass sources under consideration. A more refined estimate of the heat rate for the biomass-to-electricity plant should also be used if available. **Exhibit 5-19** provides references to several online databases from which the HHV and moisture content of the biomass resources can be derived. The steps for a Second Tier Evaluation are outlined below, and a sample calculation is provided in **Exhibit 5-10**.

- Estimate the annual energy required in terms of heat (MJ/year)
  - Approximate the power needs (MW).
  - Approximate annual operating hours (h).
  - Multiply power by annual operating hours to obtain annual energy (MWh/year).
  - Multiply annual energy by 1000 to obtain (kWh/year).

  - Estimate heat rate (MJ/kWh) for power plant.
  - Multiply heat rate by annual energy demand to obtain heat demand (MJ/year).

- Estimate the annual calorific content of the biomass (MJ/year)
  - Obtain the HHV (MJ/kg) of available biomass feedstock.
  - Estimate the moisture content (%) of the biomass.
  - Multiply HHV by (1 - moisture content) to obtain moisture-adjusted HHV (MJ/kg)
  - Estimate the mass (kg/year) of biomass available per year.
  - Multiply moisture-adjusted HHV by annual mass to obtain annual calorific content (MJ/year)

- Compare the calorific demand in Step 1 to the calorific supply in Step 2
  - If the supplied calorific content exceeds demand by an acceptable safety margin, proceed to next step.
  - If the demanded calorific content exceeds supply, consider adjusting the power needs; or discontinue the evaluation.

Exhibit 5-10: Sample Second Tier Evaluations. Source: Moazed (2008)

Line #	Variable		Value	Units	Source
1	Biomass Energy (HHV)		16	MJ/kg	Web Databases (Appendix X)
2	Biomass Moisture Content		40%	%	Literature
3	Power		10	MW	Base Case Analysis
4	Annual Hours of Operation		7,884	hours/y	Base Case Analysis
5	Annual Energy Generated		78,840	MWh/y	Line 3 * Line 4
6	Conversion Factor		1,000	kW/MW	Given
7	Annual Energy Generated		78,840,000	kWh/y	Line 5 * Line 6
	Plant Heat Rate				
8		Min	12	MJ/kWh	Literature or Plant Data
9		Max	21	MJ/kWh	Literature or Plant Data
	Annual Fuel Heat Demand				
10		Min	914,544,000	MJ/y	Line 7 * Line 8
11		Max	1,655,640,000	MJ/y	Line 7 * Line 9
	Annual Biomass Demand				
12		Min	95,265,000	kg/y	Line 9 / (Line 1* (1-Line 2))
13			95,265	t/y	Line 11 / 1,000
14		Max	172,462,500	kg/y	Line 10 / (Line 1 *(1- Line 2))
15			172,463	t/y	Line 13 / 1,000

<u>**Step 5 – Screening of biomass for social and environmental criteria**</u>

Biomass offers BHP Billiton the opportunity to address several strategic drivers: climate change, energy security and license to operate (through development in rural areas). If properly implemented it offers a truly sustainable solution. But, in planning and managing biomass-to-electricity projects, BHP Billiton must be highly attuned to the complex social, economic and environmental ramification of the project and the potentially irreversible results. This is particularly true in the case of biomass culled from plantations, but applies to use of biomass residues as well.

While evaluating the physical and chemical properties of biomass feedstock is relatively straightforward, the social, environmental and economic issues raised by biomass-to-electricity projects are complex and highly sensitive to local circumstances. As such, sweeping generalizations about the efficacy of particular approaches to biomass feedstock selection are not sufficient. In this Resource Assessment Toolkit, we inform decision-makers about the principal social, environmental, and economic trade-offs that biomass-to-electricity projects generate. Further detail of the impacts and mitigation strategies for these risks can be accessed in the United Nations' document titled *Sustainable Bioenergy: A Framework for Decision Makers (2008)*.

Food and Water Security

To the extent that increased demand for biomass feedstock diverts supplies of land from food crop production, regional food prices will increase. This is the most significant social and reputational threat from the increased demand for biomass resulting from a biomass-to-electricity project.

Access to food is largely determined by food prices, and food prices are subject to the availability of land, water, and other productive resources that can be diverted to fulfill the demand for biomass cultivation. The diversion of these resources from food production places supply restrictions on resources used in food production, resulting in increased in food prices. This is especially harmful to farmers who do not own their own land, and to the rural poor who are net food buyers, as they suffer disproportionately from price pressures on their already limited income.[50]

Depending upon the amount of irrigation required to grow dedicated biomass feedstocks, severe local water shortages may occur if supplies of fresh water are tight. Efficient use of water can limit the impacts of irrigating crops. However, it is generally preferable from a water resources perspective to select crops that can produce sufficient mass through rain-fed agriculture.

The effects of biomass demand on food security will be largely context-specific and dependent upon the general type (i.e., residue or dedicated crop) and resource intensity of a species cultivated. For instance, the use of land to grow resource-intensive, dedicated biomass crops is likely to displace food crops thereby increasing food prices, while the collection of biomass residues is less likely to result in food price increases. BHP Billiton can significantly mitigate this risk by sourcing biomass crops that thrive in arid, semi-arid, degraded, and marginal lands that are unsuitable for food production, such as casuarinas and eucalyptus.[51]

Biodiversity and Natural Resource Management

The uncontrolled harvesting of biomass residues and the cultivation of biomass feedstock crops both have the potential to exert devastating ecological consequences in the form of deforestation,

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50 United Nations, Energy. Sustainable Bioenergy: A Framework for Decision Makers (2008)
51 Ibid

biodiversity loss, eutrophication of water bodies, erosion and nutrient leaching. Most regions in which BHP Billiton operates will have regulations regarding the impacts on land, wildlife, water, and soil quality and these regulations should be consulted along with BHP Billiton's own HSEC standards. However, the government's capacity and/or willingness to enforce these regulations is often minimal. Because BHP Billiton or its power provider may source biomass from an external supplier, it is critical to ensure that the supplier is acting in compliance with environmental regulations and BHP Billiton's internal standards.

The use of large-scale mono-cropping to cultivate biomass could lead to significant biodiversity loss, soil erosion, nutrient leaching and eutrophication of nearby water bodies. However, measures can be taken to ensure the sustainability of biomass feedstock cultivation, including: matching of crops with local conditions, intercropping, conservation tillage, and crop rotation. Benefits of establishing plantations on degraded land include the soil nutrient restoration (i.e., carbon and nitrogen), erosion prevention, and habitat provision.

Use of biomass residues significantly reduces the land requirements for biomass feedstock production. However, residues do serve important ecological functions such as erosion prevention and nutrient enhancement[52]. Therefore, removing 100% of forest or agricultural residues from an area can cause damage to the ecosystem and is undesirable. Also, the creation of markets for biomass residues may generate illicit, or at least undesirable, procurement of lumber from primary forests. These resources are non-renewable and the ecological consequences of harvesting from these forests are often irreversible. BHP Billiton can mitigate this risk by enforcing rigorous standards for its biomass supply chain partners.

Local Economic Impacts

The use of biomass residues for biomass-to-energy projects can upset existing biomass markets and leave those reliant upon these markets without economic alternatives. Biomass is often cultivated and/or harvested in poor, rural areas where the use of biomass for electricity generation may contend with present uses of biomass resources in applications like animal feed, fuel, bedding, fertilizer and construction material for which equivalently priced alternatives might not exist.[53] On the other hand, if BHP Billiton generates economies of scale in biomass residue logistics networks which are accessible to local users of biomass, it could result in significant savings of time spent harvesting and transporting wood fuel and other forms of biomass.

Cultivation of dedicated energy crops can create significant employment in rural, poor regions, but can also displace small-scale farmers. Because most biomass-based employment is likely to occur in the farming, transportation and processing sectors, most of the jobs created are in poor, rural

[52] Ibid
[53] Ibid

communities where under-employment is often rampant.[54] The construction and operation of biomass-to-electricity facilities may generate additional rural economic activity and higher incomes. However, large-scale mechanized farming of biomass may displace workers. Where job creation is a high-priority to BHP Billiton, it may be desirable to encourage biomass suppliers to focus on labor-intensive, manually harvested feedstocks.

Cultivation of dedicated energy crops can displace the poorest members of society, who typically do not have official title to their land.[55] While the biomass-based employment could yield new, stable income streams, they could also further marginalize the poor if they drive small farmers without title from their land and destroy their livelihoods.

By competing with local economies for access to limited biomass residue resources, BHP Billiton could cause significant disruption to the biomass value. Traditional biomass collection and processing is labor intensive and thus a significant source of formal and informal employment in developing countries. A case in point is charcoal collection, processing, and distribution which often provide income for the rural poor (although it contributes significantly to regional deforestation). Impacts on this sector should be considered carefully before moving forward on biomass-to-electricity projects.

Climate Change

The climate benefits from utilization of biomass for electricity generation are fairly well understood. Biomass can provide power (and heat) substituting for natural gas and coal. This yields significant greenhouse gas (GHG) emission reductions, even when life-cycle emissions from feedstock cultivation and procurement are accounted for, as coal is the most polluting fuel for electricity generation.[56] Where the biomass feedstock is in the form of a residue, the degradation and emission of methane is prevented, yielding even higher GHG emission reductions as methane has a global warming potential 21 times that of CO_2.

The economic benefits of using biomass-to-electricity projects to counter climate change are still under consideration. Studies indicate that the use of biomass-to-electricity is still a relatively expensive method of reducing GHG emissions, relative to other mitigation projects, with biomass co-firing in the range of $20-$30 per ton[57] and other projects (e.g., gasification and stand alone biomass combustion) at significantly higher costs.

There has been some question regarding the extent to which biomass-to-electricity projects truly offset emissions because the biomass cultivation, harvesting, and transportation logistics networks

54 Ibid
55 Ibid
56 Worldwatch Institute, Biofuels for Transport: Global Potential and Implications for Energy and Agriculture (London, UK: Earthscan, 2007)
57 Mckinsey & Company. Reducing U.S. Greenhouse Gas Emissions: How Much at What Cost?

are relatively energy intensive. Therefore, it is essential for BHP Billiton to consider GHG emissions throughout the full life-cycle of the biomass feedstocks. Full life-cycle GHG emissions of biomass vary widely based upon the following factors:

- Land use changes;
- Choice of feedstock;
- Agricultural practices;
- Supply chain network; and
- Efficiency of biomass-to-electricity conversion.

If for example native forest or grassland is cleared to plant annual biomass crops which are treated with chemical fertilizers and pesticide, harvested mechanically and transported a long distances to be converted into electricity, the biomass feedstock could have a greater impact on the climate that the coal or natural gas that it is displacing. On the other hand, perennial crops which utilize little fertilizer, and moderate amounts of energy in harvesting and transport are capable of offsetting major amounts of greenhouse gases. In general, crops that require high fossil energy inputs (e.g., conventional fertilizer) and have relatively low energy yields per hectare should be avoided. Also, clearing primary forests for biomass plantations results in large releases of previously sequestered carbon (in the form of wood) which negate benefits of the biomass feedstocks. As mentioned previously, the use of biomass residues as a feedstock for energy conversion often results in the highest GHG offset.

Supplemental Exhibits

Solar

Exhibit 5-11: World solar resource map (measured in kWh/m2/day). Source: www.oksolar.com

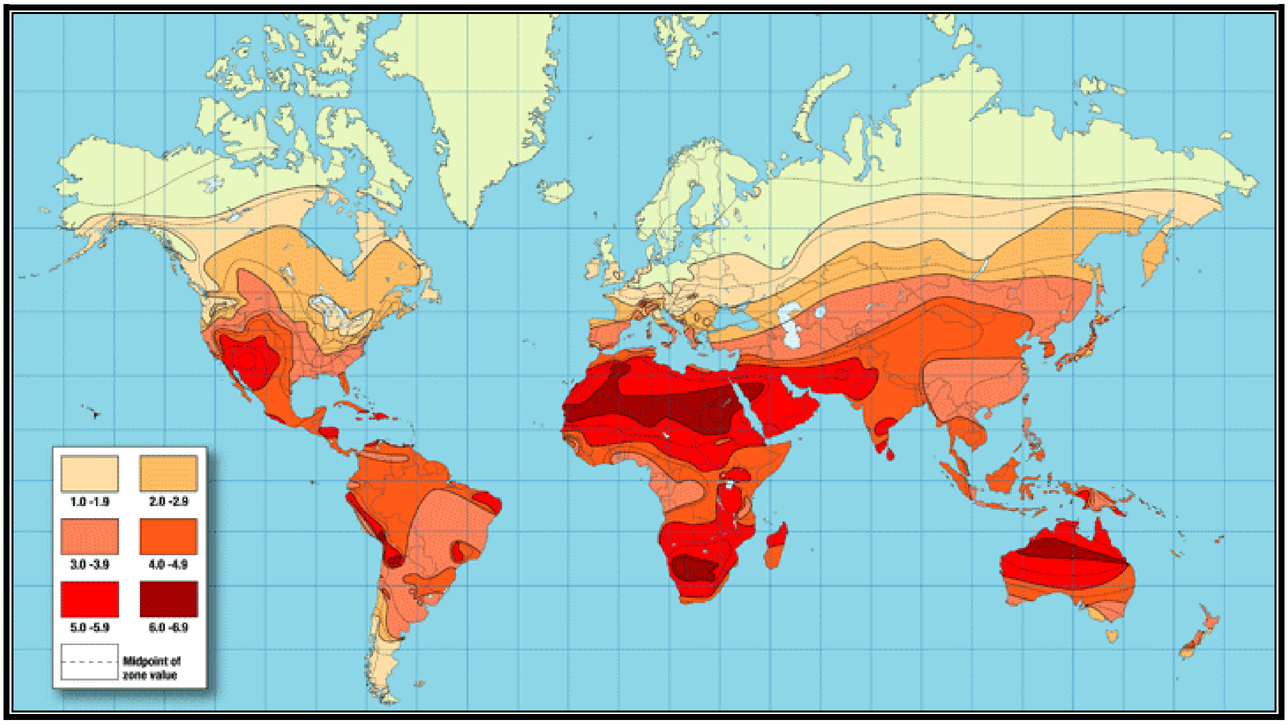


Exhibit 5-12: Web sources for solar resource data

Source	URL	Notes
NREL's World Radiation Data Center (WRDC)	http://wrdc-mgo.nrel.gov/	• Free • Raw global, diffuse, and normal radiation data available for various locations worldwide (each site is recognized by a code. E.g. Antofagasta, Chile = 854420)
UNEP's Solar & Wind Energy Resource Assessment (SWERA)	http://swera.unep.net/	• Free • Global and Direct Normal Radiation data and maps, downloadable • Several countries in Central and South America, Africa, and Asia.
NASA	http://eosweb.larc.nasa.gov/cgi-bin/sse/sizer.cgi?email=na	• Free, but login enforced. • Input = Coordinates of location of interest Output = "Global" solar radiation data

Exhibit 5-13: Solar resource map showing locations suited for solar thermal power plants.
Source: Solar Millenium AG, 2007.

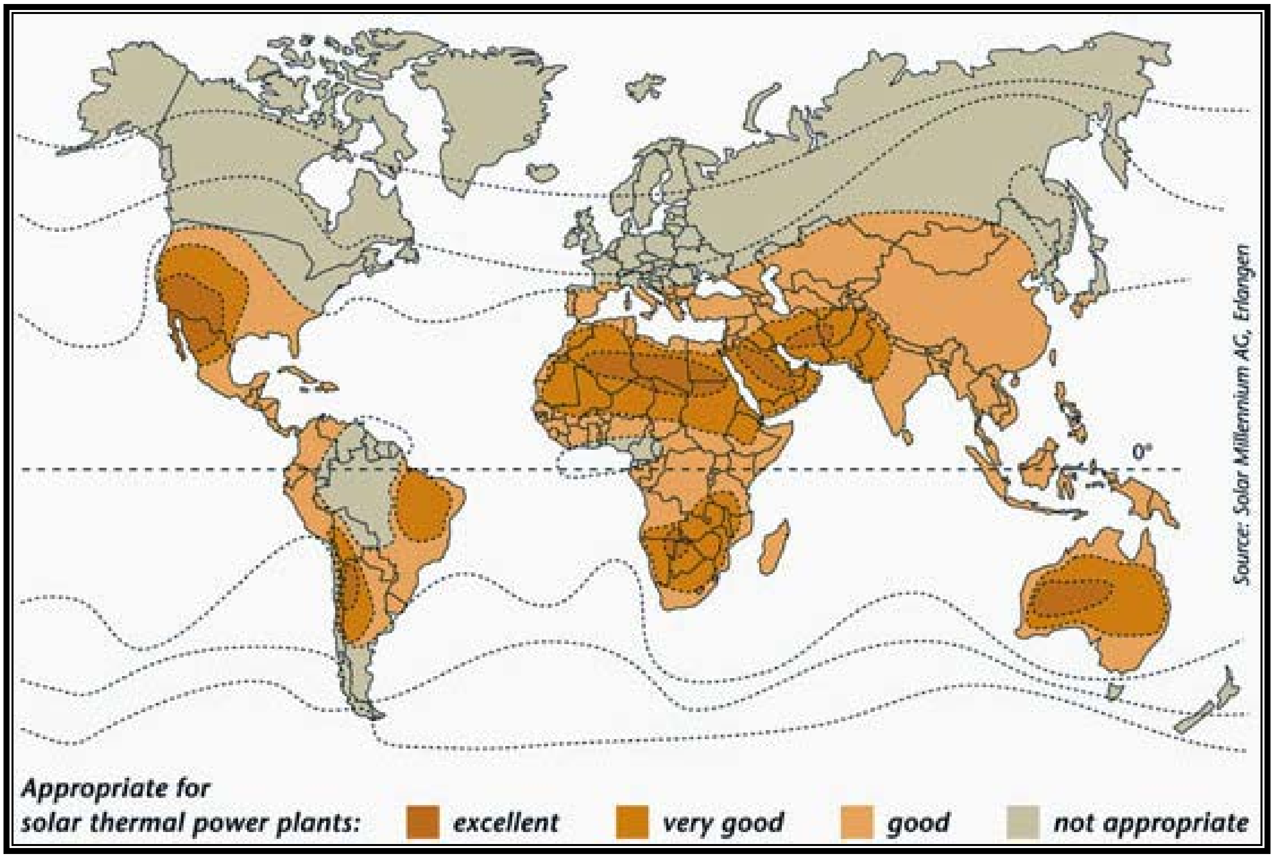


Exhibit 5-14: Estimated Net Water Consumption of Parabolic-Trough CSP Plants[58]

Type	gal/MWh	m^3/MWh
Wet-Cooling	1000	3.78
Dry-Cooling	80	0.3

58 NREL http://www.nrel.gov/csp/troughnet/faqs.html

Wind

Exhibit 5-15: Web-based resources for wind assessments

U.S. National Renewable Energy Laboratory Wind Resource Assessment Home Page

Website: http://www.nrel.gov/wind/resource_assessment.html

Description: This site provides numerous resources for conducting a wind assessment including international wind resource maps, GIS data and analysis tools, and a wind resource assessment handbook that walks through the steps necessary to conduct a very detailed wind assessment.

Database on Wind Characteristics

Website: http://www.winddata.com/

Description: This database is maintained by scientists at the Technical University of Denmark and the Riso National Laboratory. Access to the database is available for a fee. It contains four different categories of wind data: time series of wind characteristics, time series of wind turbine responses, wind resource data and wind farm data. These time series are primarily intended for wind [turbine] design purposes and the resource data can be used for sighting analysis. In the database you will find wind speed measurements, measured under different conditions and terrain types at 55 different locations inside Europe, Egypt, Japan, Mexico, Costa Rico and United States.

Exhibit 5-16: Wind mapping companies

3Tier

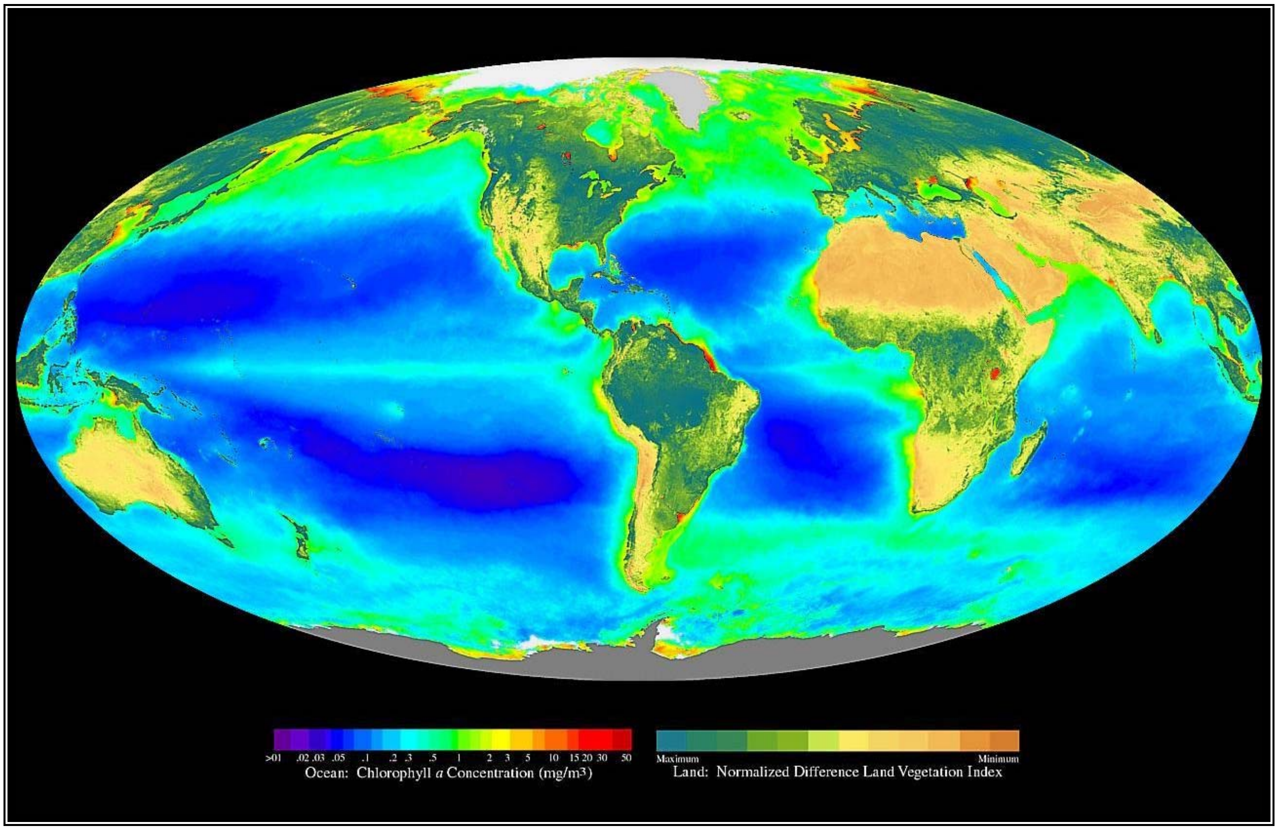
Website: http://www.3tiergroup.com/en/

Description: 3Tier provides a web based wind modeling tool that allows the user to evaluate a potential site quickly and at a low cost. The Firstlook Assessment tool is based on the latest scientific techniques, numerical weather prediction models, and observations from more than 2,000 meteorological towers. The Fullview Assessment tool provides an even more detailed view of a specific wind site including detailed wind maps, comprehensive energy analysis, and long term risk analysis for project financing.

AWS Truewind Website: http://www.awstruewind.com/ Description: AWS Truewind provides wind mapping, energy assessment, project engineering, performance evaluation and forecasting services. AWS Truewind claims that its MesoMap wind mapping system is the most widely tested and validated wind mapping system in existence today. MesoMap has been verified by comparing map predictions with independent observations for over 1000 stations around the world. The US National Renewable Energy Laboratory has been closely involved in the validation to ensure its objectivity.
Pacific Hydro Website: http://www.pacifichydro.com.au/ Description: Pacific Hydro is a hydro and wind project developer that operates in Australia, South America and Asia-Pacific. It is currently working with BHP Base Metals Chile to evaluate wind in northern Chile. It uses several software modeling tools to provide an initial screening, and then performs more detailed site assessment and meteorological monitoring.

Biomass

Exhibit 5-17: Global net primary productivity [59]



[59] Source: SeaWiFS Global Biosphere Sep 1997 - Aug 1998. This composite image gives an indication of the magnitude and distribution of global primary production, both oceanic (mg/m3 chlorophyll) and terrestrial (normalized difference land vegetation).

Exhibit 5-18: Biomass feedstock characteristics

Calorific Value

Although biomass is highly heterogeneous in many respects, its variation in dry-weight energy density (MJ/kg) is remarkably small. For instance, coal has roughly 30.2 MJ/kg, while dedicated energy hardwoods (e.g., eucalyptus) average 19.8 MJ/kg on a dry-weight basis, and agricultural residues average 18.6 MJ/kg. Biomass "green" or wet energy densities can vary significantly as moisture contents range from 30 – 60%, and thus the energy content of "green" or wet delivered biomass can range from 9 to 15 MJ/kg (40-70% of the dry energy content). [60]

Bulk or Energy Density

Dry-biomass (15% moisture content) generally has a heating value of between 16 and 20 MJ/kg – similar to that of lignite. Increased moisture content can lower the heating value slightly. However, the main characteristic value which influences the economic performance of biomass conversion is the volumetric heating value, or energy density (MJ/m^3). Reduced energy density of biomass also results in increased storage needs and expanded fuel processing (drying and sizing) and feeding systems. estimated that handling wood chips (energy density = ~ MJ/m^3) increases by a factor of ten the logistical efforts compared to that of handling coal, while the transportation of the equivalent energy content of a truckload of coal requires up to thirty loads of straw bales.

Fixed Carbon:Volatile Ratio

Volatile matter (VM) of a solid fuel is that portion driven-off as a gas by heating. The fixed carbon content (FC), is the mass remaining after the releases of volatiles, excluding ash and moisture content.[61] The significance of VM and FC content is that they provide a measure of the ease with which biomass feedstock can be ignited and subsequently gasified. A higher proportion of oxygen and hydrogen, compared with carbon, reduces the energy value of a fuel, due to the lower energy.

Moisture Content

Most biomass-based combustion systems burn biomass fuels with moisture contents in the range of 15% to 30%. While combustion is technically most efficient when moisture content is 0%, there are practical limitations to achieving this level of drying, and significant problems with heat distribution in the combustion chamber (due to quick combustion) under these circumstances. There are several common methods of lowering biomass moisture content, including heat-drying (this can make effective use of waste heat from the power plant) and open-air drying.

60 Klass, Donald L., Biomass for Renewable Energy, Fuels, and Chemicals, Academic Press, 1998.
61 McKendry, Peter. Energy production from biomass (part 1): overview of biomass. Bioresource Technology 83 (2002) pp 37-46

Ash Content

In general, biomass with low ash content and high ash melting temperature serve as the best fuels in combustion systems. For herbaceous biomass, ash melting typically ranges from 700 to 800 C, while woody biomass ash melting occurs at temperatures greater than 1200 C. Low ash melting temperatures cause slagging in grates and under stocker furnaces. Ash can also cause agglomeration of fluidized-bed combustion systems bed material.

Alkali Metal Content

Alkali metal content of biomass (i.e., NA, K, Mg, P and Ca) is important for conversion to electricity. Herbaceous fuels often have high chlorine content, which can cause corrosion in combustion systems. The reaction of alkali metals with silica present in the ash produces a stick, mobile liquid that can block airways in furnace and boiler plants.

Chlorine Content

Cl content is a function not just of the plant species, but also of the growing region soil characteristics and storage methods. Therefore, testing of the feedstock for Cl content (among other parameters) is highly recommended regardless of plant species. Biomass feedstocks with low Cl content should generally be selected over high Cl feedstocks to minimize corrosion. In general, biomass with low ash content and high ash melting temperature serve as the best fuels in combustion systems. For herbaceous biomass, ash melting typically ranges from 700 to 800 C, while woody biomass ash melting occurs at temperatures greater than 1200 C. Low ash melting temperatures cause slagging in grates and under stocker furnaces.

Exhibit 5-19: Biomass web-based databases

US DOE: Biomass Feedstock Composition and Property Database

Website: http://www1.eere.energy.gov/biomass/feedstock_databases.html

Descriptions: The database is a compilation of results from analytical tests conducted on biomass samples by Biomass Program scientists according to standard test methods. Nearly all are American Society for Testing and Materials (ASTM) methods. Information includes compositional analysis, structural chemical analysis, elemental analysis, proximate analysis, heating values, and lignin properties.

BIOBIB

Website: http://www.vt.tuwien.ac.at/biobib/oxford.html

Description: BIOBIB provides relevant data for thermal utilization of biofuels analyzed by standard analytical methods. BIOBIB includes data of the elemental composition, melting behavior of the ashes and more. BIOBIB contains information about different types of wood, straw and energy crops and waste-wood samples and biomass-waste-assortments of different biomass-treating industries (e.g.: wood processing industry, pulp and paper industry, food industry). Currently the database contains 647 different samples.

PHYLLIS

Website: http://www.ecn.nl/phyllis/

Description: Phyllis is designed and maintained by ECN Biomass with financial support from Novem, Shell Global Solutions and HoSt. Phyllis is a database, containing information on the composition of biomass and waste. Phyllis enables you to make analysis data of individual biomass or waste materials available and offers you the possibility to obtain the average composition of any combination of groups and/or subgroups. At present it contains about 2340 data records. You can get answers on questions like:

- What is the average chlorine content of wood?
- What is the ash content of willow?
- What is the average calorific value of chicken manure?

The Biomass Database

Website: http://www.det.csiro.au/science/energyresources/biomass.htm

Description: The Biomass Database project is funded by the Australian Greenhouse Office and the Joint Venture Agroforestry Program (JVAP). The intention is to disseminate information to an emerging Australian bioenergy industry. The database contains the results of analysis, including:

- Proximate and ultimate analysis
- Calorific value
- Ash elemental analysis
- Ash melting temperatures
- Sample fouling and corrosion propensity
- Gasification characteristics
- Assessment of liquid fuel production

Chapter 6:
Technology Assessment Toolkit

Intent of the Toolkit

This toolkit introduces the current state of solar, wind, and biomass technologies used for power generation. The toolkit is designed to guide BHP Billiton personnel to:

- Understand the potential of solar, wind, and biomass technologies;
- Identify promising technologies by comparing each technology's resource needs against data collected in the "Resource Assessment" stage in the Evaluation Framework;
- Compile data on cost, strengths, and weaknesses of above identified technologies. This data will feed into the next stage of the Evaluation Framework where technologies will be screened against BHP Billiton's strategic evaluation criteria.[62]

While this toolkit introduces several technologies that are currently available in the market, selection of specific technology and sizing of the systems must be conducted in consultation with an experienced renewable energy developer with significant experience in the solar, wind, or biomass industries, and is beyond the scope of this document.

Key Concepts

Capacity Factor

Capacity factor is the ratio of the actual energy generated in a given period relative to the maximum possible if the generator produced its rated output all of the time. Capacity factor is a key performance characteristic, as it expresses the productive output relative to the installed capacity and allows for capital costs to be expressed in levelized terms.[63]

$$\textit{Capacity Factor (CF)} = \frac{\textit{Actual Energy Output}}{\textit{Maximum possible (rated) Energy Output}}$$

Reasons for capacity factors being below 100% include: intermittent resource and/or fuel availability, and equipment downtimes (scheduled or unscheduled).

62 Strategic criteria are developed in Stage 3 of the Evaluation Framework.

63 The World Bank Energy Sector Management Assistance Program, "Technical and Economic Assessment of off-grid, mini-grid, and grid electrification technologies", *The World Bank*, December 2007. http://siteresources.worldbank.org/INTENERGY/Resources/MiniGridElectrificationTechnicalReport61207.pdf.

Rated Power versus Electrical Energy Output

Power generating devices are commonly classified by their rated power output in watts (or kilowatts, or megawatts), whereas their actual energy output given as follows: [64]

$$\text{Actual Electrical Energy Output (kWh)} = \text{Rated Power (kW)} \times \text{Time (hours)} \times \text{Capacity Factor}$$

For example, a power generating device with a maximum rated power output of 10kW, operating at 35% capacity for 10hrs, will produce 10kW x 10hrs x 0.35 = 35 kWh of electrical energy. Actual energy output is a more valuable measure than rated power when analyzing investments in renewable energy systems. [65]

Cost-of-Electricity

The cost of electricity (COE) is comprised of three components: capital and installation (C&I), operation and maintenance (O&M), and fuel (F) per the following equation:[66]

$$\text{COE (\$/kWh)} = \text{C\&I} + \text{O\&M} + \text{F}$$

For renewable energy technologies that require no fuel inputs, the "F" term is zero. The C&I term is given by the formula below, where Capex stands for capital expenditures, CF is the estimated capacity factor of the plant, CRF is the capital recovery factor.

$$C\&I\ (\$/kWh) = \frac{\text{Installed Capex per KW} \times CRF^{*}}{CF \times 8766\ \text{hours/year}}$$

$$^{*}CRF = \frac{\text{Discount Rate}}{1-(1+\text{Discount Rate})^{-PlantLife}}$$

Greenhouse Gas Offset

Greenhouse gas reduction potential is measured by the amount of carbon dioxide equivalents (CO_2e) displaced by a project.[67] In the case of renewable energy projects, carbon is displaced when

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64 American Wind Energy Association, "How Does A Wind Turbine's Energy Production Differ from Its Power Production?", http://www.awea.org/faq/basicen.html.

65 Ibid

66 California Energy Commission, *Distributed Energy Resource Guide*, http://www.energy.ca.gov/distgen/economics/decision.html; http://www.soi.wide.ad.jp/class/20070041/slides/08/18.html

67 Note that "upstream" emissions from the manufacture of renewable energy equipment (i.e. a wind turbine manufacturing facility) are not included for the purposes of measuring emissions from a renewable energy "project". Only emissions from the "use" phase are included.

carbon neutral sources of energy (e.g., wind, biomass and solar) are substituted for existing or planned fossil fuel based energy sources (e.g., coal, natural gas, heavy fuel oil). The amount of carbon offset is a function of the emissions factor (CO_2e/kWh) of the existing and planned source of electricity, as well as the size and emissions from the renewable source of electricity. The total mass of greenhouse gas (GHG) offset by a project can be roughly estimated as:

$$\text{Tonnes } CO_2e \text{ offset} = \mathbf{[}\text{Total kWh generated} \times \text{Emissions factor of grid (tonnes } CO_2e/\text{kWh)}\mathbf{]}$$
$$\mathbf{-\ [}\text{tonnes } CO_2e \text{ emitted from operations}\mathbf{]}$$ [68]

Certified Emissions Reduction Credits

Many owners of renewable energy projects seek to monetize the carbon emission reductions through the generation of saleable emission reduction credits. Many projects cited in developing nations or transitional economies are eligible to generate certified emission reduction (CER) credits under the UN Framework Convention on Climate Change's (UNFCCC) Clean Development Mechanism (CDM) protocol. Organizations in a Kyoto Annex I (developed) nations having difficulty meeting their emissions quotas can purchase CER credits from the project owner/developer to comply with their regulatory obligations to decrease GHG emissions. Price estimates for CERs are difficult to come by because CERs trade over-the–counter or through private contract, therefore, direct pricing information is unavailable. Research by Point Carbon[69] and World Bank[70] indicates that CERs have historically been purchased for 70 - 80% of the European Union Allowance (EUA) price. EUAs are the publicly traded emission allocations in the EU Emissions Trading Scheme and are currently traded at ~ €19 ($28.87) per tonne which implies that CERs are currently trading for ~ €15 (or $22.80) per tonne CO_2e. [71]

In order to generate CERs for the emissions offset by a project, the project must be located in an eligible non-Annex I (developing) nation. The project must use an approved "Methodology" under the CDM protocol, to rigorously document existing conditions and the estimated amount of carbon emissions that will be displaced by the introduction of renewable energy. The emissions reductions must be show to be "additional" to those emissions reductions which would have occurred anyway. A projects plan must then be documented and presented to the UNFCCC Executive Board for

68 Some renewable energy technologies, such as solar photovoltaics, emit no greenhouse gases during use, hence, this second term in the equation will be zero.

69 Point Carbon, "Carbon Market Analyst – Carbon 2007," March 2007.

70 World Bank, "State and Trends of the Carbon Market 2007," May 2007.

71 Point Carbon, Historic Carbon Prices, http://www.pointcarbon.com/category390.html?categoryID=390, accessed March 2008

registration under the CDM protocol. Finally, the projects must undergo extensive third-party verification monitoring.[72]

Solar Photovoltaics

There are two ways of converting the energy contained in sunlight into electricity. The first method uses ***photovoltaics*** to capture sunlight to convert it directly into electricity using semiconductor-based materials such as silicon. The second method harnesses ***solar thermal*** energy to produce electricity in power generation systems such as steam turbines. This section provides a discussion of the current state of technology in solar photovoltaics (PV).

Description of Technology

Photovoltaics convert sunlight directly into electricity. A PV cell is the basic unit of a solar photovoltaic installation (or "PV system"). The balance-of-system (BoS) components in a PV installation include the modules, inverters, batteries, charge controllers, and all associated mounting and control components as needed.[73,74] Solar PV systems can range from small rooftop modules generating a few watts of power, to multi-array, ground-mounted, utility-scale installations generating several megawatts of power (see **Exhibit 6-1**).

Exhibit 6-1: Ground-mounted solar PV modules at Nellis Air Force Base, USA (15 MW PV farm)[75]

[72] United Nations Framework Convention on Climate Change, http://cdm.unfccc.int/methodologies/index.html, accessed March 2008

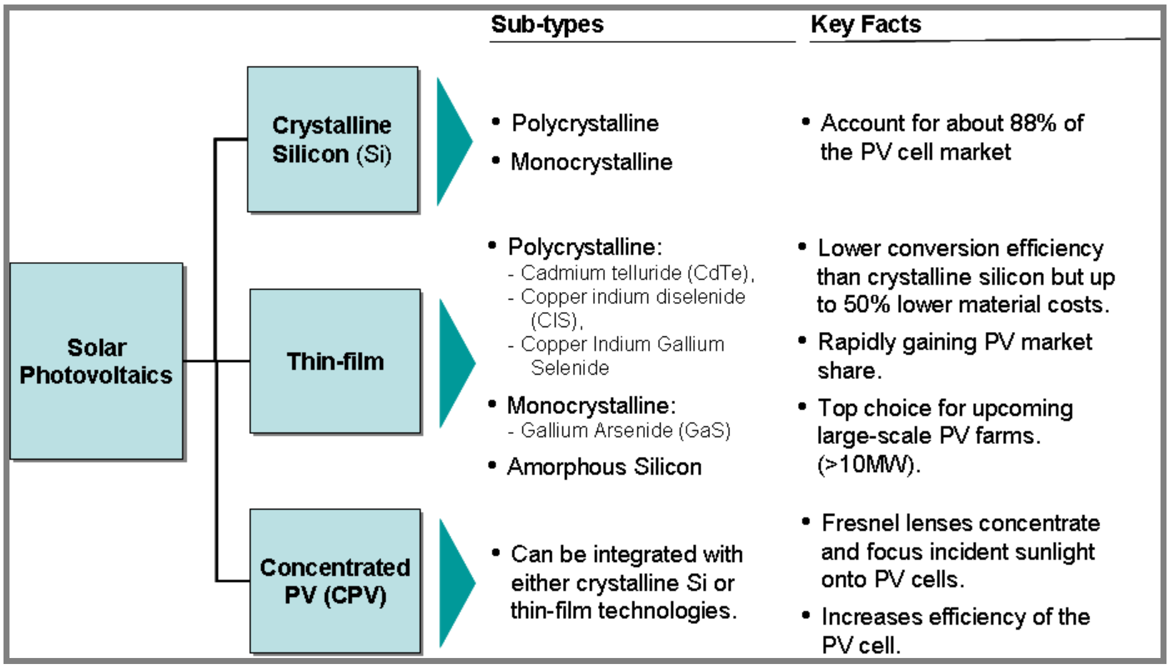
[73] Frost & Sullivan, "North American Solar Power Technology Markets", 26 December 2003, Retrieved: 2 February 2008

[74] Bower, Ward, "Inverters – critical photovoltaic balance-of-system components", Sandia National Laboratories, *Progress in Photovoltaics: Research and Applications*, Vol 8 Issue 1 Pg 113-126, 24 February 2000. http://www3.interscience.wiley.com/cgi-bin/abstract/70001634/ABSTRACT?CRETRY=1&SRETRY=0

[75] Photo source: Sunpower Corp company website, http://www.sunpowercorp.com/For-Power-Plants.aspx

A basic PV cell is made of a semiconductor material (most commonly, crystalline silicon), which captures solar radiation to generate a DC electric current. **Exhibit 6-2** describes the available PV technologies. While crystalline Si cells lead the market today (88% share), newer technologies, such as thin film PV, are expected to take 19% of the global PV market by 2012. [76]

Exhibit 6-2: Photovoltaic technologies[77]



Resource Needs

Solar photovoltaics can operate under various sunlight conditions, and even on cloudy days, which make them suitable for most northern climates. For example, several regions in southwest United States, one of the sunniest places on the planet, receives insolation levels greater than 300 W/m^2 (annual average)[78] while regions in more northern latitudes, such as in Germany, receive at best 135 W/m^2.[79] PV installations will operate under both conditions; however, reduced insolation levels will reduce the power output from the PV installation. The rated (maximum) power output of a solar

76 The Economic Times, "Moser Baer to invest $1.5bn in solar power", 10 Feb 2008, http://economictimes.indiatimes.com/News_by_Industry/Moser_Baer_to_invest_15_bn_in_solar_power/articleshow/2771966.cms.

77 Table created with data sourced from: (1) US DOE Energy Efficiency and Renewable Energy, http://www1.eere.energy.gov/solar/photovoltaics.html, Retrieved: 25 May 2007; (2) Frost & Sullivan reports, "North American Solar Power Technology Markets", 26 December 2003, Retrieved: 2 February 2008.

78 Arizona Solar Center, US solar radiation map, http://www.azsolarcenter.com/arizona/images/solmap.gif

79 Germany annual solar radiation map: http://www.solarserver.de/lexikon/images/strahlungskarte1981_2000.gif

module, kWp (or Wp), is measured at 1000 W/m^2 insolation.[80] At insolation levels lower than 1000 W/m^2, the PV system's power output will drop below the rated output.[81]

Exhibit 6-3 summarizes the resource needs for PV installations.

Exhibit 6-3: Resource needs for a typical PV installation

Solar Resource	>2 kWh/m^2/day (> 80 W/m^2), but ideal sites will receive at least 2 to 3 times more.[82]
Land	3-10 acres per MW of installed capacity.[83]

Costs

Solar photovoltaics continue to be more expensive than wind and solar thermal power, however, PV costs have steadily dropped over the years, and next-generation technologies, such as thin-film PVs, promise more cost-reduction leaps in the next several years.[84] Unless stated otherwise, capital and O&M costs described below are from a World Bank study published in December 2007. [85] These costs are summarized in **Exhibit 6-4** below.

Exhibit 6-4: Summary of cost ranges for a typical photovoltaic installation. Source: World Bank, 2007.

Technology	Scale / Capacity	Capital Costs (2005$)	O&M Costs (2005$)	Cost of Electricity (2005$)
Crystalline Silicon	>=5 MW capacity factor: 15% – 25%	$6.31 - $7.81 million/MW	0.97 - 1.45 ¢/kWh	33.7 – 52.6 ¢/kWh

80 Equivalent to "full sunlight".

81 The amount (fraction) of reduction is reported as the "capacity factor" of the PV installation in question.

82 Largest PV installations in the world are in areas receiving at least 100 W/m^2 or higher. Source: Greenpeace Energy, "Large-scale photovoltaic power plants range 1-50 MW", http://www.pvresources.com/en/top50pv.php. Retrieved: 1 February 2008.

83 Calculated using data sourced from: US DOE Energy Efficiency and Renewable Energy, "Solar PV FAQs", www.nrel.gov/docs/fy04osti/35097.pdf

84 The Economic Times, "Moser Baer to invest $1.5bn in solar power", 10 Feb 2008, http://economictimes.indiatimes.com/News_by_Industry/Moser_Baer_to_invest_15_bn_in_solar_power/articleshow/2771966.cms.

85 The World Bank Energy Sector Management Assistance Program, "Technical and Economic Assessment of off-grid, mini-grid, and grid electrification technologies", *The World Bank*, December 2007. http://siteresources.worldbank.org/INTENERGY/Resources/MiniGridElectrificationTechnicalReport61207.pdf.

Capital Cost

A 5MW PV project will require a capital investment between $6310 and $7810 per kW. [86] The PV cells themselves account for about 40% of the total, while the structural foundations and other pieces of equipment, system design and installation, and balance of system (BoS) account for the rest of the cost burden.[87] Refer to **Exhibit 6-31** to see where the capital cost burdens lie for a solar PV project.

Operating and Maintenance (O&M)

Photovoltaics require very little maintenance during their lifetime. Most PV technologies today can operate for over 20 years, but other system components, such as invertors, may need to be replaced sooner. Yet, O&M costs (fixed and variable) for PV systems are very low, at about 1 ¢/kWh on average.[88]

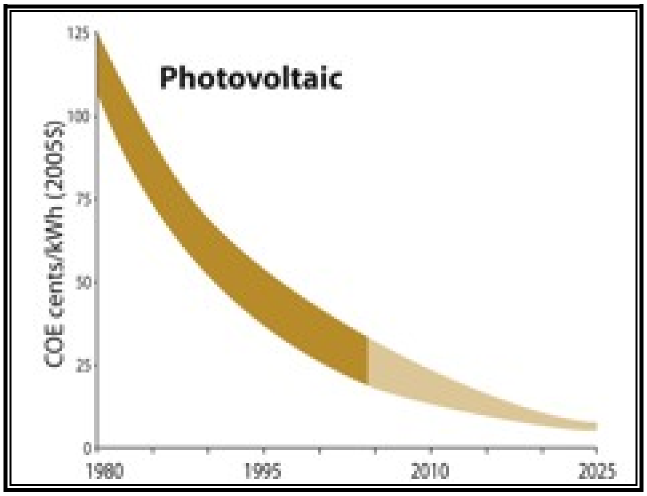
Cost of Electricity (COE)

The cost of electricity produced from solar PV modules has dropped rapidly since the 1980s[89] as R&D has focused on reducing material and manufacturing costs of PV cells, and increasing sunlight-to-electricity conversion efficiency of the modules. Thin-film & concentrated PV technologies are the results of such cost-reduction strategies, and promise significant reduction to the cost of electricity in coming years, with some projections citing a 40% reduction.[90] Large-scale PV farms (>5MW) are more viable today with lower-cost technologies like thin-film, although large projects – such as the 20-40MW projects that are under construction in Germany and Spain today - are still limited to countries that offer significant regulatory incentives to encourage solar power development.[91, 92]

Exhibit 6-5 below represents the cost of electricity produced from PVs since the 1980s and projected forward to 2025.

86 Ibid
87 Public Renewables Partnership, http://www.repartners.org/solar/pvcost.htm.
88 World Bank, 2007.
89 United States Department of Energy, National Renewable Energy Laboratories renewable energy cost curves, 2005.
90 Laumer, John, "Solar Photovoltaic Costs Projected to Plunge Over 40%", Treehugger.com, June 2, 2007. http://www.treehugger.com/files/2007/06/solar_photovolt_2.php.
91 Ibid
92 Greenpeace Energy, "Large-scale photovoltaic power plants range 1-50 MW", http://www.pvresources.com/en/top50pv.php. Retrieved: 1 February 2008.

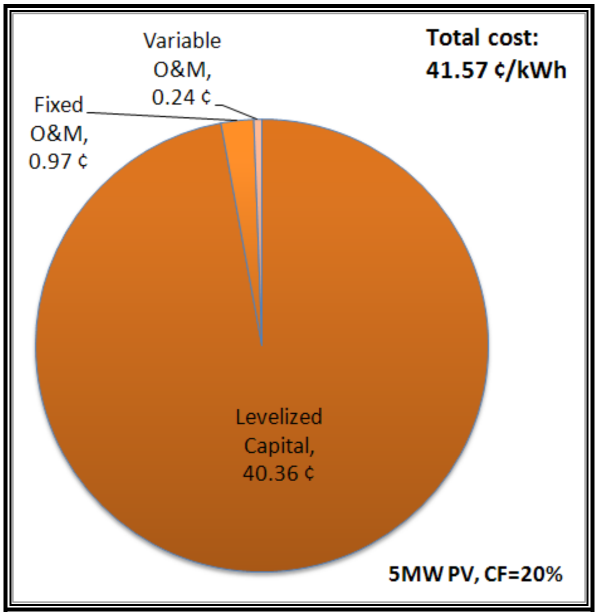
Exhibit 6-5: Cost curve for solar PVs (¢/kWh in 2005$). Source: NREL[93]



The cost of electricity generated from a PV installation will vary greatly based on the solar resource available at the specific geographical location under consideration. Therefore, the first step is to estimate a *capacity factor* for a concept PV farm sited at that location. This capacity factor estimates the actual power output of the installation, and correspondingly, the actual energy that can be fed into the grid. The World Bank study uses an average 20% capacity factor for its assessment of PV systems. However, actual capacity factors may be lower than 20% in cloudier places, such as Germany, or higher in sunnier regions, such as southwest United States. The cost of electricity will range accordingly based on the capacity factor. **Exhibit 6-6** below shows a typical cost-of-electricity breakdown for a typical, large-scale photovoltaic project running at 20% capacity factor.

93 United States Department of Energy, National Renewable Energy Laboratories renewable energy cost curves, 2005.

Exhibit 6-6: Cost of electricity (generating cost) summary for solar PV in ¢/kWh (2005$). Source: World Bank, 2007



Greenhouse Gas Offset

Energy and GHG emissions "footprint" of PV technologies

Most PV technologies require mined materials such as silicon, steel, and specialty heavy metals, and are also notably energy-intensive to manufacture. However from a life-cycle perspective, over their lifetime, PVs will generate enough greenhouse gas-free electricity to more than offset the energy created from mining and manufacturing (hence, PVs are considered as "net energy positive"). Meanwhile, life cycle GHG emissions footprint of silicon PVs is approximately 30 to 45 $kgCO_2e/MWh$.[94] This is very favorable compared with coal and biomass technologies, but loses out to wind, which has very low life cycle emissions. Thin-film PV technology requires less material input and less energy in the manufacturing process, and is considered to have the lowest "life cycle" energy and GHG footprint among existing PV technologies. [95]

CDM projects

There are currently two solar power projects registered under the UN FCCC's CDM program: a 1MW solar PV power plant in South Korea, and a 7.7 MW bundled project using small PV kits for lighting rural households in Morocco. The power plant and lighting projects are expected to offset

94 Fthenakis, Vasilis et al, "Emissions from Photovoltaic Life Cycles", *Environmental Science and Technology Journal*, January 4, 2008. http://dx.doi.org/10.1021/es071763q.

95 Ibid

600 and 39,000 tons CO_2e/year, respectively.[96] In general, the relative abundance of less expensive energy-generating carbon offset projects – such as biomass and wind energy - under the CDM program has prevented wide-spread adoption of solar projects.

Criteria Evaluation and Rating

First developed in the 1950s, PV technology has seen steady cost reductions from better technology and increased scales of production. The technology has also proven itself for many niche applications, such as satisfying remote power needs for telecommunications, pumping and lighting. PV systems have many attractive features, including modularity, zero fuel requirements, zero emissions, no noise, and no need for grid connection.[97] However, PV modules are still extremely expensive, and this capital intensity discourages the development and financing of large-scale PV projects. However, the high modularity of PV systems makes it possible to invest in smaller scale projects at first, and scale up over time. In fact, with the advent of lower-cost technologies, such as thin-film, and the success of photovoltaic projects worldwide, solar photovoltaic was termed as the "fastest growing energy technology in the world" with now nearly 7.7 GW of grid-connected photovoltaic installations worldwide.[98]

Exhibit 6-7 summarizes the strengths and weaknesses of PVs within each decision criteria used in the General Framework.

Rating Score:
1=High
2=Medium
3=Low

Exhibit 6-7: Solar PV strategic assessment summary

	Strengths	Weaknesses	Rating
Capacity Factor	• High capacity factor if only daytime operation needed: PVs operate in a wide range of solar radiation levels. • Battery storage can increase capacity factor.	• Without storage, energy can be delivered only during sunshine hours, which reduces capacity factor of the installation.	**3**
Cost	• Capital costs and cost-of-electricity are expected to fall with continued R&D (see cost curve). • O&M costs are miniscule for PVs as they need little to no maintenance during operations.	• Still a very expensive renewable energy option in most places without regulatory incentives. • Some non-solar components in the overall PV system may incur costly replacements – such as inverter boxes.	**3**

96 United Nations Environment Program, "Clean Development Mechanism Pipeline," http://cdmpipeline.org/, Accessed February 2008.

97 The World Bank Energy Sector Management Assistance Program, "Technical and Economic Assessment of off-grid, mini-grid, and grid electrification technologies", *The World Bank*, December 2007. http://siteresources.worldbank.org/INTENERGY/Resources/MiniGridElectrificationTechnicalReport61207.pdf

98 Martinot, Eric et. al., "Renewables 2007 Global Status Report", *Renewable Energy Policy Network for the 21st Century & Worldwatch Institute*. http://www.ren21.net/pdf/RE2007_Global_Status_Report.pdf.

	Strengths	Weaknesses	Rating
Environmental Impact	• Zero emissions during operating phase. • Net energy positive from a life-cycle perspective despite heavy material & energy use in manufacturing. • Thin-films have lowest life-cycle footprint among PVs.	• PVs are heavily dependent on mined products such as Silicon, steel, and specialty metals such as Gallium.	2
GHG offset	• Operation phase is free of GHG emissions.	• None	1
Internal Acceptance	• Generally high awareness of the technology makes PVs more easily accepted, as the technology is widely deployed, commercially proven, and available in many countries with a ever-growing number of providers.	• High capital costs, lack of cheap storage, and project scalability limits may attract skepticism towards PVs, especially for base-load power supply at assets.	2
Optionality	• Low asset specificity. PV cells can are relatively easy to dismantle, relocate, or resell into the market (high demand). • No fuel needed in operation phase.	• High capital cost lowers optionality value, but primarily for customized components only.	1
Reliability/ Technology maturity	• Crystalline Silicon technology is commercially proven and widely deployed. • Next-generation technologies like thin-film offer reliable performance at lower cost.	• Solar energy-to-electricity conversion efficiencies are still relatively low (<25%). • PV cells produce DC current while most grids require AC. DC-to-AC conversion losses reduce system efficiency.	2
Reputation	• PVs generally enjoy widespread support in public and media, and are well accepted as an appealing renewable energy option in most places worldwide. • A properly sited and designed PV project will be highly visible and boost the company's reputation.	• None.	1
Scalability	• Well suited for small-scale projects such as office buildings and off-grid, distributed power needs. • Very modular; easy to scale up. • Development of large-scale PV farms (up to 40MW) underway in Europe.	• Economies of scale are limited. • Large-scale projects are still prohibitively expensive without sufficient regulatory incentives.	1

	Strengths	Weaknesses	Rating
Social Impact	• Most PV projects, if sited properly, will have no negative impacts on society. • Some job creation possibilities in construction/ installation phase.	• Large-scale, ground-mounted PV projects require large tracts of land, which could impact communities living nearby.	2
Technology Leadership	• Opportunity to support development and commercialization of promising, next-generation PV technologies. • Natural fit with mining industry given high use of specialty metals and minerals in PV manufacturing.	• None.	1

Concentrated Solar Thermal Power

Description of Technology

Concentrated solar thermal power (CSP, for short) systems use special focusing collectors to concentrate solar radiation and use the resulting, concentrated thermal energy to generate electricity. CSP technologies are currently cheaper than photovoltaics, are designed for larger-scale operations, and also incorporate many features of conventional power station technology. Hence, CSP is more suitable than photovoltaics for large-scale power generation.

The most common CSP technologies currently available in the market are:

(a) Parabolic Trough;

(b) Central Receiver or Solar Tower; and

(c) Dish/Stirling Engine.

Of these, parabolic trough is the oldest, and most widely used commercial CSP technology today, while the other two are gaining increasing presence worldwide as they offer benefits over parabolic troughs, most notably much higher conversion efficiencies and lower cooling water demand. Still newer technologies, such as Linear Fresnel and Solar Chimney, are now emerging in the industry, and demonstration projects are expected to come online by 2012.[99]

99 CSP Today Summit 2008 (San Francisco), Various industry presentations, January 29-30, 2008.

Parabolic Trough

Parabolic Trough systems (right, photo source: Union of Concerned Scientists) collect sunlight, which is then concentrated into and absorbed by receiver tubes to generate low temperature steam. This steam is then used to drive a steam turbine. Trough systems use a heat-transfer fluid (HTF), such as synthetic oil or molten salt, in the receiver tubes. Troughs can focus solar radiation at 30 to 100 times its normal intensity (*concentration ratio*).[100]

Parabolic trough systems have been around since the 1980s (first plants built in the United States), and have undergone significant technology improvements since then. However, their solar-to-electric conversion efficiencies still remain low (exacerbated by parasitic losses that can be as high as 15%), and the plants require significant stretches of flat, open land spaces. Moreover, the plants consume significant amounts of cooling water (unless dry-cooling methods are employed).

See **Exhibit 6-32** and **Exhibit 6-33** for schematics of a typical parabolic trough plant.

Central Receiver (or Solar Tower)

In central receiver systems (right, photo source: NREL), multiple heliostats[101] track the sun and concentrate solar energy into a receiver on top of a tower. Here the heat is used to produce high-temperature steam, which drives turbines to generate electricity. Central receiver systems have a solar concentration ratio of as much as 1,500.[102]

Central receiver systems offer better energy conversion efficiencies than parabolic trough but have not been demonstrated at similar commercial scales, or at full operating loads.[103] Moreover, this technology requires more than twice the land area for every megawatt of capacity as compared to parabolic trough. However, this technology is an increasingly popular choice among developers where the

100 US DOE Energy Information Administration Energy Facts
101 Heliostats are special tracking mirrors. Source: Red Rock Energy, “How heliostats work”, http://www.redrok.com/concept.htm
102 US DOE Energy Information Administration Energy Facts
103 CSP Today Summit 2008.

higher efficiency and lower site preparation costs outweigh the costs of higher land use and perceived technology risk.[104]

Dish/Stirling Engine

In dish/Stirling engine systems (right), a parabolic reflective dish concentrates sunlight to heat a gas, such as hydrogen, in a power concentrator. This causes the gas to expand and push cylinders, and generators convert the mechanical energy into electricity. This eliminates the traditional steam turbines and massive cooling water demand that parabolic and tower technologies have. Dish/Stirling systems have a solar concentration ratio typically greater than 2000.[105] This helps dish/Stirling systems achieve higher energy conversion efficiencies (close to 30%)[106] than other CSP technologies.

The Dish and Stirling engine together form a single, stand-alone power-generation unit, ranging from 10-25kW in size, making it the most modular CSP technology available today.[107] The only downside of these systems is the lack of thermal storage potential and the relatively low adoption of the technology in commercial markets thus far. However, the next seven years are expected to see a surge in dish/Stirling installations, mostly in the US.[108]

New Technologies – Linear Fresnel

Linear Fresnel is a relatively new technology and is essentially a modified version of the parabolic trough design but with lower capital costs. This cost reduction is achieved by a combination of structural design changes and reduced material use. However, these design changes also reduce the overall energy conversion efficiency of the system and costs need to reduce enough to offset the efficiency loss. The technology, while promising, is still immature and not been demonstrated on scale. Moreover, it retains similar land and water demands like the parabolic trough systems.

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104 Ibid

105 US DOE Energy Information Administration Energy Facts

106 Sandia National Laboraories, “Sandia, Stirling to build solar dish engine power plant”, http://www.sandia.gov/news/resources/releases/2004/renew-energy-batt/Stirling.html, 9 November 2004

107 Ibid

108 Schmidt, Julie, “Stirling Energy takes on the solar power challenge”, *USA Today*, 20 January 2008. http://www.usatoday.com/money/industries/energy/environment/2008-01-20-solar-power_N.htm. Retrieved: 29 January 2008.

Exhibit 6-8 below summarizes the key differentiating characteristics of the CSP technologies discussed in the sections above, and compares their relative performance in each category.[109] Green = Good; Yellow = Fair; Red = Poor.

Exhibit 6-8: CSP technology comparison

	Parabolic Trough	Central Receiver	Dish/ Stirling	Linear Fresnel
Demonstrated capability	↑	⇔	⇔	↓
Efficiency	↓	↑	↑	↓
Technology Adoption	↑	↑	↓	⇔
Modularity	↓	⇔	↑	↓
Land use efficiency	↓	↓	↑	↓
Water use efficiency	↓	⇔	↑	↓
Storage potential	↑	↑	↓	⇔

Integrated Solar Combined Cycle (ISCC)

The biggest advantage of solar thermal power systems over solar photovoltaics is that CSP can be integrated into a regular combined cycle plant that is burning common fossil fuels such as natural gas or coal. This fossil fuel hybrid setup is termed as Integrated Solar Combined Cycle (or ISCC) and uses the heat from the solar array to supplement the heat from the gas turbine exhaust of the combined cycle plant. For an ISCC plant with installed capacity of 100-300 MW in a site with good solar resource, the solar input could account for about 20-25% of the total capacity.[110]

109 Relative performance "ratings" presented in this table are educated judgments of the authors, based on the various research materials used to inform this report.

110 Solarpaces, "Solar Parabolic Trough", http://www.solarpaces.org/CSP_Technology/docs/solar_trough.pdf, (publication date unavailable).

ISCC Strengths

Base-load generation: While the solar units operate during sunshine hours, the fossil-fuel counterparts can share a greater burden during non-sunshine hours to even out generation throughout the day.

Cost savings: The solar increment to an existing combined-cycle plant is much cheaper than a standalone CSP plant (nearly 40% less) because of the shared power-gen unit.

More scalability: By sharing a power-gen unit, CSP can be added in small

ISCC Weaknesses

Fossil-fuel dependence: This system is still heavily dependent on fossil fuels, which are subject to the usual availability, market price, and GHG-legislation risks.

Siting: Sufficient and appropriate land resource to site the solar arrays & components may be impossible to find near existing combined-cycle plants.

Harder to accurately measure GHG emissions reductions since solar and fossil fuel sections operate simultaneously and continually.

Thermal Storage[111]

Parabolic trough systems already employ a heat-transfer fluid (HTF) to transmit the collected solar thermal energy to the steam generation units. CSP plants can be outfitted with additional capacity and the extra thermal energy can be stored in insulated thermal storage units. This can make power generation possible during cloudy periods or at night. With storage, capacity factors can be raised from 25% to 50%, or even higher.[112] Actual capacity factors will vary depending on (a) number of sunshine hours available at the site, and (b) amount of storage built into the plant design.

The two main *benefits* of storage are:

1. Flexibility to even out power generation through the day, which makes it possible to provide intermediate or even base-load power supply.

2. Increased capacity factors and dispatchability increase the value of CSP power and consequently lowers the cost of electricity.

[111] Unless stated otherwise, all the information in this section sources from: Solarpaces, "Solar Parabolic Trough", http://www.solarpaces.org/CSP_Technology/docs/solar_trough.pdf, (publication date unavailable).

[112] Parabolic Trough Thermal Energy Storage, *TroughNet*, National Renewable Energy Laboratory, http://www.nrel.gov/csp/troughnet/thermal_energy_storage.html.

However, current thermal storage designs have downsides:

1. Increased upfront capital costs (insulated tanks, pumps): These can add as much as 30% to overall system costs.[113]

2. Increased O&M costs: While HTFs like molten salt cost merely $0.50/lb, pumping and temperature control needs can increase operating costs.[114]

3. The commercial reliability and viability of thermal storage technologies has not been sufficiently demonstrated yet. However, some new large-scale projects in Spain and in the United States have been designed with thermal storage, and these will help the industry prove or disprove the commercial viability of storage.

Heat-storage media

Synthetic oils are the most commonly used heat-transfer medium today.

Molten salt is a promising heat-storage medium – it holds heat for a while, and its use has been demonstrated with both parabolic troughs and central receiver systems. However, this design has at least two known downsides[115] and R&D is still underway to resolve these: (a) the storage tanks are expensive (i.e. higher upfront capital investment required); and (b) molten salt can solidify within the heat-transfer tubes of parabolic-trough systems if high enough temperatures are not maintained within the system (leading to higher operating costs, loss of efficiency and reduced capacity factor).

Solid media – Ceramics, rock, etc. These options are still mostly under R&D.[116]

Resource Needs

CSP requires *Direct Normal Insolation (DNI)* [117] and, unlike photovoltaics, cannot operate on a cloudy day. As a result, this is a critical factor in determining the location of the facility and ultimately the cost of power generated by the facility. Factors in determining the most suitable site for a solar CSP installation include DNI greater than 5 kWh/m^2/day (208 W/m^2) [118], and an approximate *land slope* of less than 1-3%.[119]

Additionally, the most commonly used CSP technologies, namely parabolic trough and solar tower, use large volumes of *water* in the cooling towers of their steam-driven power generation units. While

113 CSP Today Summit 2008.
114 Acciona Energies, presentation by CEO of Acciona North America, December 2007
115 CSP Today Summit 2008.
116 Solarpaces.org
117 See “Resource Assessment Toolkit”.
118 NREL; CSP Today Summit 2008.
119 Ibid

dry cooling towers use significantly less water than wet-cooling towers, the overall efficiency of the system drops. Moreover, even a small amount of water usage may be significant for some BHP Billiton assets where CSP may be promising but water is extremely scarce (such as Western Australia or Northern Chile).

Exhibit 6-9 summarizes the key resource needs for parabolic trough plant.

Exhibit 6-9: Resource needs for a typical CSP plant (parabolic-trough)

Solar resource	DNI >= 5 kWh/m²/day (208 W/m²) [120]
Land	5-8 acres per MW of installed capacity[121] Slope < 1-3%
Water	Wet-cooling: 800 -1000 gal/MWh (3.8 m³/MWh) [122] Dry-cooled: 80 gal/MWh (0.3 m³/MWh)[123]

Costs

CSP projects are highly capital intensive, with equipment contributing the biggest cost burden, and installation, site preparation, and operational costs having considerably lower contributions. Since parabolic trough technology has progressed the most toward commercial application among the available CSP technologies, all cost figures reported below are applicable primarily to this technology only. However, other CSP technologies incur costs within similar orders of magnitude, and the figures listed here are reasonable "first-pass" estimates for CSP technologies in general. These costs are summarized in **Exhibit 6-10** below, following by a discussion of each of the cost categories.

Exhibit 6-10: Summary of cost ranges for a typical parabolic trough plant. Source: World Bank, 2007.

Technology	Scale / Capacity	Capital Costs (2005$)	O&M Costs (2005$)	Cost of Electricity (2005$)
CSP parabolic trough Without storage (CF=20%)	>30 MW capacity factor: 15% – 25%	$2.3 - $2.7 million/MW	3.01 – 4.51 ¢/kWh	14.9 – 21.0 ¢/kWh
CSP parabolic trough With storage (CF=50%)	>30 MW capacity factor: 45% – 55%	$4.45 – $5.24 million/MW	1.82 – 2.62 ¢/kWh	11.7 – 14.3 ¢/kWh

120 Dr. Michael Geyer, "Overview of CSP: Cost and Performance for Central Station Systems", 28 June 2005, *Solarpages.org*
121 CSP Today Summit 2008.
122 NREL, "Parabolic trough power plant system technology", http://www.nrel.gov/csp/troughnet/power_plant_systems.html, Retrieved: 10 December 2007
123 CSP Today Summit 2008.

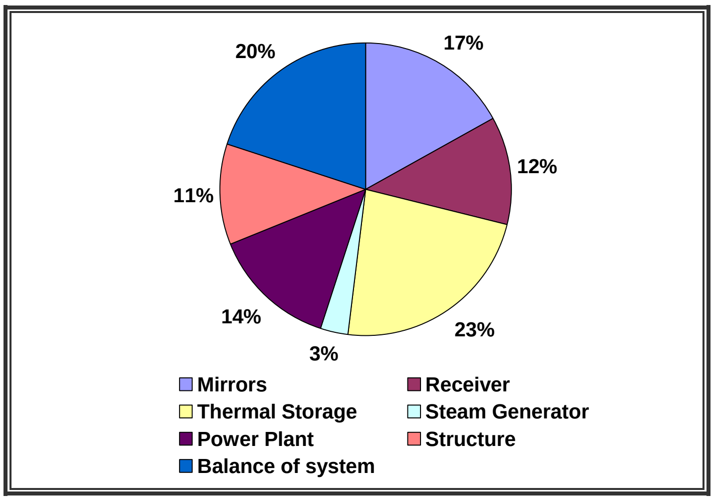
Capital Cost

Capital costs include the cost of equipment and installation costs. A World Bank study estimated that a 30MW parabolic trough plant with no thermal storage will require an upfront capital investment between $2300/kW and $2700/kW. Refer to **Exhibit 6-41** to see where the capital cost burdens lie for a typical parabolic trough project. **Exhibit 6-11** below shows a breakdown of just the equipment costs for a typical parabolic trough system. This chart indicates three areas where the incremental capital cost of CSP can be adjusted: thermal storage, steam generation, and power plant:

Adding thermal storage capacity can increase upfront capital costs by as much as 30% (contributed mainly by the thermally insulated storage tanks and additional pumping equipment).[124]

In an ISCC configuration - and especially if a CSP system is added on to an existing combined cycle plant at an asset - the incremental solar-only components will cost at least 20% less than a stand-alone configuration that has its own steam and power units. Some costs categorized under BoS will also be shared in an ISCC configuration; hence, the actual cost saving potential for a solar-only increment is higher than 20%.

Exhibit 6-11: Equipment costs breakdown for a CSP plant. Source: NREL[125]



Operating and Maintenance (O&M) Costs

This cost category includes labor, monitoring equipment, cleaning, and other miscellaneous costs associated with day-to-day operations, and occasional repair maintenance for a CSP plant operation. O&M costs should also include the cost of cooling water required by the plant, and this cost could vary from one asset to another. However, on average, at existing plants in the United States, O&M

124 CSP Summit 2008 presentations (specifically, Solel company presentations).

125 Price, Hank, "Due-Diligence Study of Parabolic Trough and Power Tower Technologies", National Renewable Energy Laboratory, November 13, 2003. www.nrel.gov/analysis/seminar/docs/2003/hank_price_presentation.ppt.

cost range from $50 to $65 per installed MW.[126, 127] CSP plants also incur several parasitic losses (pumping of HTF, steam generators et cetera), and these losses contribute to the relatively low capacity factors of CSP plants.

The World Bank study reports O&M costs in levelized terms ($/kWh generated) but assumes that O&M costs do not differ between CSP plants that have thermal storage, and those that do not. However, until thermal storage technology reaches commercial maturity, plants with storage can be expected to incur higher O&M costs.[128] However, these extra costs may still be outweighed by the benefit of increased power generation that thermal storage provides.

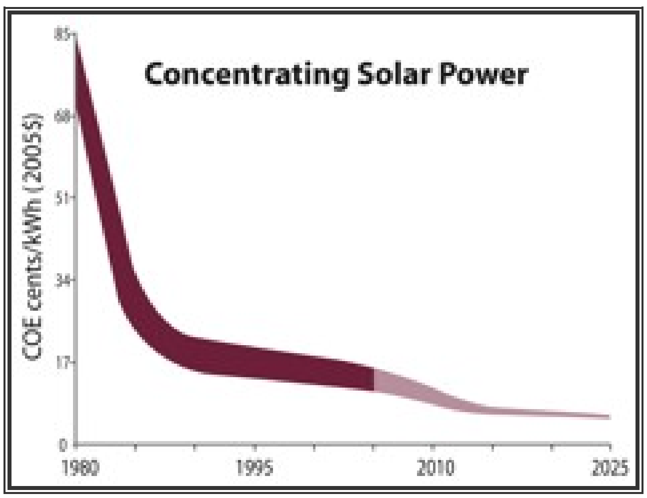
Fuel Costs

Stand-alone CSP plants operate on solar resource alone, which is freely available. The fossil-hybrid, ISCC configuration does require a fuel input (such as, natural gas, coal), however, CSP technology by itself requires no fuel inputs, and therefore this is not added to the cost of electricity.

Cost of Electricity (Generating costs)

The cost of electricity produced from solar thermal technologies has dropped since the 1980s[129] as R&D has focused on reducing equipment costs, and increasing sunlight-to-electricity conversion efficiency of the systems. **Exhibit 6-12** shows the past and projected cost curve for CSP.

Exhibit 6-12: Cost curve for CSP (¢/kWh in 2005$). Source: NREL[130]



126 Acciona Energies, presentation by CEO of Acciona North America, December 2007
127 CSP Summit 2008 presentations.
128 Solel company presentation, CSP Summit 2008.
129 NREL renewable energy cost curves, 2005, www.nrel.gov/analysis/docs/cost_curves_2005.ppt.
130 Ibid

The World Bank estimates that the cost of electricity from CSP ranges from 12 to 18 ¢/kWh in 2005$, using a discount rate of 10%. However, at some large CSP installations in the United States, which do not incorporate much thermal storage and are often supplemented with some natural gas, the current cost quotes are closer to 22 ¢/kWh without regulatory incentives.[131]

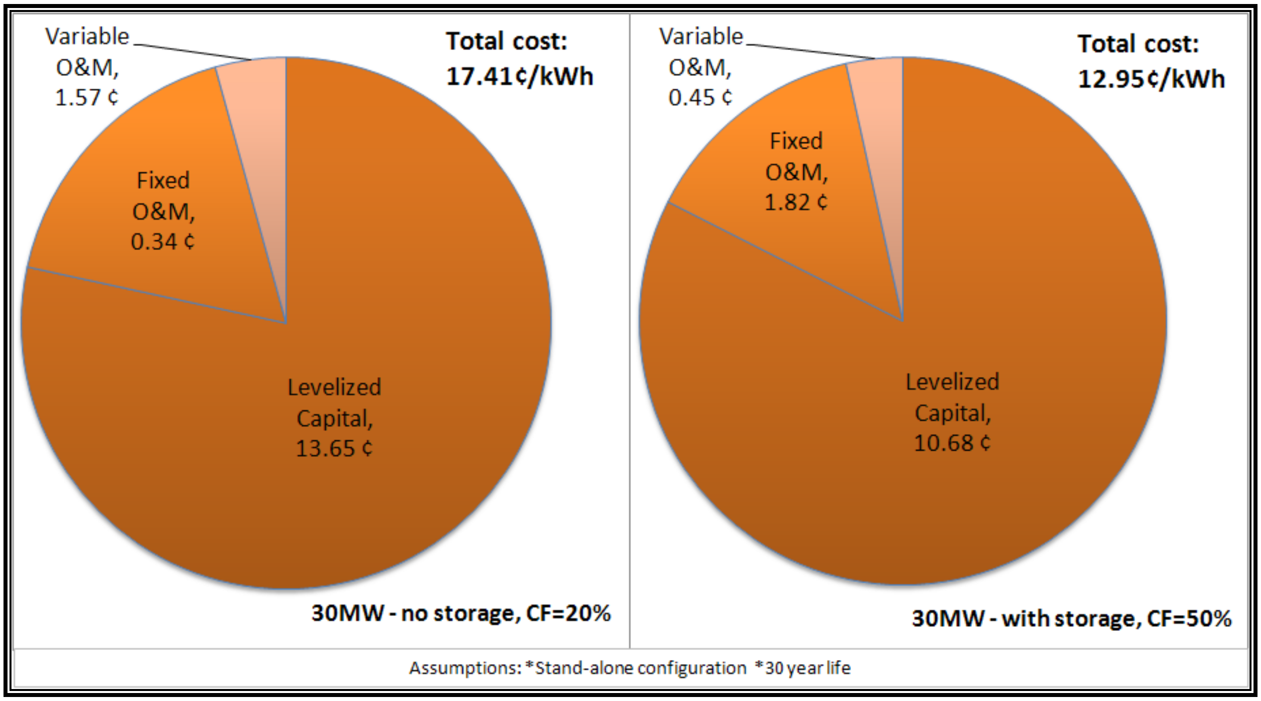
The electricity generation cost is driven primarily by upfront equipment and setup costs (CSP plants are highly capital-intensive). However, the *levelized capital cost* ($ per kWh generated) varies with the capacity factor of the plant, which in turn is driven by the amount of thermal storage capacity built into the design, assuming thermal storage becomes technically reliable and commercialized in upcoming years. While thermal storage requires additional upfront capital investment, increased storage can lead to increased power generation over the plant's life, and this will help reduce the levelized capital cost ($/kWh) incurred by the project. Advancements in the technology and the use of low-cost thermal storage are expected bring CSP power cost to 4¢–5¢ per kWh in the next few decades.[132]

A generating cost breakdown for a typical parabolic trough CSP system, with and without storage, is presented in **Exhibit 6-13**. On average, a 30MW plant with storage - where the capacity factor is high - will produce lower cost electricity than a plant without storage (because the capacity factor is lower in the latter configuration).

131 In the United States, with the Investment Tax Credit, Acciona reports a cost-of-electricity at its Nevada plant as 15 ¢/kWh. Otherwise, the cost is 22 ¢/kWh. Source: Peter Duprey, CEO of Acciona Energies North America, presentation at the University of Michigan Ann Arbor, December 2007.

132 Sandia National Laboratories, "CSP Technologies Overview", http://www.energylan.sandia.gov/sunlab/overview.htm. Retrieved: January 29, 2008.

Exhibit 6-13: Cost of electricity (generating cost) summary for CSP in ¢/kWh (2005$). Source: World Bank, 2007



Potential for Economies of Scale:

Studies have shown that doubling the size of a CSP operation reduces the capital cost by approximately 12-14%.[133] Going from a 10MW to 80MW can result in over 40% cost reduction.[134]

The increased manufacturing volume of collectors for larger plants drives down the cost per square meter.

A power plant that is twice the size will not cost twice as much to build (construction costs such as site setup, labor, et cetera).

O&M costs for larger power plants will typically be less on a per kilowatt basis. For example, it takes about the same number of operators to operate a 10 MW plant as it does a 400 MW plant. Note, however, that solar field maintenance costs scale more linearly with solar field size.

133 Solarpaces, "Solar Parabolic Trough", http://www.solarpaces.org/CSP_Technology/docs/solar_trough.pdf
134 Ibid

Greenhouse Gas Offset

Energy and GHG emissions "footprint" of CSP technologies

CSP technologies require heavy material inputs, especially for the solar collectors (reflective mirrors and tubes carrying the HTF). These materials are energy-intensive to mine and process, and the CSP components are also energy-intensive to manufacture. However from a life-cycle perspective, over their lifetime, CSP plants generate enough greenhouse gas-free electricity to more than offset the energy and GHG footprint created from manufacturing, installation, and maintenance ("net energy positive"). While reliable numbers are currently unavailable for an entire CSP plant, life-cycle assessments of solar collectors alone show that the energy consumed in manufacturing, installation and maintenance, is recovered in less than two years of plant operation (and CSP plants can operate for over 25 years).[135]

CDM projects

To date, there are no CDM projects currently using concentrated solar thermal power technologies, although organizations like the World Bank are exploring opportunities to expand the adoption of such technologies in many developing countries that get excellent solar resources. At least one large CSP project is currently undergoing feasibility studies to understand CDM potential – a 100 MW central receiver solar farm near Upington (Northern Cape area) in South Africa.[136, 137]

Criteria Evaluation and Rating

Parabolic trough systems have been in operating in the United States since the 1980s, and several technological advances have been made since to both bring down capital and operating costs, and to increase the solar-to-electricity conversion efficiency of the systems. CSP has recently re-emerged in the global scene after a long quiet period, with many Spanish and American utilities and technology providers reinvesting in CSP technology for several, upcoming large-scale projects. While parabolic trough and central receiver systems are well suited and primarily designed for large-scale, grid-connected plants, the stand-alone dish/Stirling engine units are more suited for small, off-grid applications.

135 Ardente Fulvio et. al "Life cycle assessment of a solar thermal collector: sensitivity analysis, energy and environmental balances", March 9, 2004. *ScienceDirect*, Retrieved: February 25, 2008.

136 Davie, Kevin, "Sun and mirrors", Mail & Guardian online, http://www.mg.co.za/articlePage.aspx?articleid=316977&area=/insight/insight__economy__business/

137 Eskom, South Africa's monopoly utility, is spearheading this project since their existing coal-powered power plants are unable to keep up with burgeoning demand. Factors such as the long time it takes to build and bring coal plants to maximum operating capacity, the fear of possible GHG-emissions restrictions, and the potential for earning CDM emissions credits, are driving Eskom's interest in cleaner, renewable technologies that also show potential for competitively priced electricity in the long term.

Exhibit 6-14 presents a summary of strengths and weaknesses of CSP technologies, in general, for each of the evaluation criteria defined in the General Framework.

Rating Score:
1=High
2=Medium
3=Low

Exhibit 6-14: CSP strategic assessment summary

	Strengths	Weaknesses	Rating
Capacity Factor	• Newer CSP technologies such as dish/Stirling and direct-steam configurations, offer greater capacity factors than traditional parabolic trough designs. • Potential for daylong, base-load energy production with thermal storage (CF can increase to 40% or more).	• Most storage options are not commercially proven yet. • Without storage, capacity factors are low as plants generate power only during sunshine hours (CF: ~20-25% at best). • Considerable parasitic losses contribute to the low capacity factors.	2
Cost	• ISCC option is more affordable than stand-alone, and solar array component costs are dropping. • Advancements in the technology and the use of low-cost thermal storage are expected make CSP power more competitive with conventional power sources.	• Highly capital-intensive. • Cheaper solar components trade some efficiency for cost reduction. • Some thermal storage could add costly maintenance burdens.	3
Environmental Impact	• GHG emissions-free technology. • Sites best suited for CSP (high or low-altitude desert regions) generally have little flora/fauna that can be impacted.	• Potential biodiversity impact due to large land-use. • High water demand of some of the technologies may be detrimental to the health of local water sources.	2
GHG offset	• Operation phase is GHG-free if operation is solar-only.	• ISCC configuration has GHG emissions.	1
Internal Acceptance	• The ability of CSP systems to use a renewable, GHG-free resource to provide large-scale base-load power (unlike PVs and wind) can be a strong draw for decision-makers within the company.	• Relatively low worldwide adoption of the technology compared to other renewable energy technologies such as wind and PVs, may raise skepticism over true reliability of the technology for secure power supply.	2
Optionality	• ISCC option offers more fuel flexibility. • Solar resource is free, reliable, and predictable, thus reducing the need for too much fuel optionality. • Some components can be easily relocated or returned to market.	• Asset specificity is relatively high.	2
Reliability/ Technology maturity	• Parabolic trough is mature and reliable, and Central receiver is gaining greater commercial	• Some reliability issues still exist with newer CSP technologies, especially at commercial scale.	2

	Strengths	Weaknesses	Rating
	adoption. • All technologies successfully demonstrated. Successful project demonstrations in Spain.	• Storage options yet to be demonstrated for reliability at scale.	
Reputation	• CSP projects thus far have been viewed very favorably by media and environmental groups as GHG-free, renewable energy source.	• Land and water usage may be viewed unfavorably by public and environmental groups.	2
Scalability	• Good for utility-scale, grid-connected applications (30-100MW). • Solar components of CSP technologies are very modular and easily scalable. Commercially proven. • ISCC option offers more scalability potential.	• Scale limited by availability of land and designed capacity of power-generation units.	1
Social Impact	• Potential to supplement power needs of local communities around assets.	• Land usage could be viewed unfavorably unless remote, unused sites as used. • High water demand of trough and central receiver technologies could compete with agriculture and drinking water sources.	2
Technology Leadership	• Several mining facilities are located in areas receiving top-class solar radiation, and the potential of CSP technologies can be best exploited and demonstrated at such locations.	• None	1

Wind Power

Description of Technology

Utility scale wind turbines for land based applications come in a variety of sizes ranging from about 700 kW to 2.5MW. Offshore turbines currently under development are pushing into the 5MW and above range. Wind developers size turbines to match the overall generating capacity required, the space available, the quality of the wind resource, and the cost of each turbine model. There is a trend toward larger turbines which can reduce the installation cost because fewer turbines need to be installed and maintained over the lifetime of the project for a given level of capacity.

Wind turbines come with various features to boost performance and reduce maintenance costs such as direct drive shafts that do not require gear boxes and automatic stall blade designs that slow a turbine down if the wind gets too high. However, the most important aspect to consider when picking a turbine manufacturer is its ability to provide service and spare parts to the equipment locally with a quick response time.

Intermittency is a key characteristic of wind power. At good wind sites, the wind blows all the time, but the strength of the wind varies such that a wind turbine is rarely producing at its peak capacity. Either the wind is too weak and the turbine is turning slowly or the wind is too strong and the turbine stalls to prevent damage. This intermittency is best described in terms of wind's capacity factor. That is, on average, the percentage of the available capacity that is being utilized to generate electricity. In order to be economically viable, most utility scale wind developments must reach a capacity factor of about 30%. That means that a 50MW wind development will produce on average 15MW of electricity. In order to produce 50MW on average, a wind development would need to have a capacity of 167MW. The variability of the amount of electricity generated is one of the key challenges and can present problems when integrating wind power into a grid system. This is usually not a problem for small scale wind developments, and becomes more pronounced at larger scales.

Resource Needs

Utility scale wind developments generally need a Class 4 or higher wind resource.[138] The ideal wind resource is a steady moderate wind speed with little seasonal or diurnal variation. For an overview of the steps necessary to conduct a wind resource assessment, see the wind section of the Resource Assessment Toolkit.

Wind development also requires available land. This can be unutilized land or land that is being used in a way that is compatible with wind development, such as agriculture. There are generally two measures of land required for a wind development. The first measure includes the overall area of the entire project including the open spaces between the turbines. This measure is dependent on wind turbine size, spacing, and the configuration of the array of turbines and varies according to these factors. The range of land area per MW is on the order of 15 to 50 acres per MW of capacity. Therefore a 50 MW wind farm using 1MW turbines would be spread over an area of 2500 acres. However, the vast majority of this land would still be available for other uses.

The second is the actual footprint of the site which comprises the turbines and their foundations, service roads, crane pads, electrical equipment, and any associated buildings. The range of land area per turbine according to the US National Renewable Energy Laboratory is 0.25 to 0.5 acres per turbine. Therefore, a wind farm of 50 MW using 1MW turbines would use a maximum of 25 acres.

138 Vaughan Charles, "The Economics of Wind Energy", Clipper Windpower, Inc. presentation. www.eere.energy.gov/windandhydro/windpoweringamerica/pdfs/workshops/2006_summit/vaughan.pdf

Exhibit 6-15: Resource needs of a wind power project

Wind Resource	Class 4 or greater *At 50 meters height, characterized by* - *Wind power density = 400 – 500 W/m³* - *Speed = 7.0 - 7.5 meters/second*
Land	15 – 50 acres per MW overall area 0.25 – 0.5 acres per turbine actual land consumed

Costs

Costs for wind development include equipment, installation, operation, and maintenance costs, of which the largest is for equipment. These costs are summarized in **Exhibit 6-16.**

Exhibit 6-16: Summary of cost ranges for a typical wind power project. Source: World Bank, 2007.

Technology	Scale / Capacity	Capital Costs (2005$)	O&M Costs[139] (2005$)	Cost of Electricity (2005$)
Wind	>=10 MW	$1.27 – 1.61 million/MW	0.74 – 1.10 ¢/kWh	5.8 – 8.0 ¢/kWh
Wind	>= 100 MW	$1.09 – 1.39 million/MW	0.60 - 0.90 ¢/kWh	5.0 – 6.8 ¢/kWh

Capital Costs

Capital costs include the cost of equipment and installation costs, with the former accounting for most of the cost burden. As wind turbine sizes have increased over time, the upfront capital cost of wind power, including installation, has fallen. This trend is likely to slow as onshore turbines become constrained by the lack of installation equipment that can handle the heavier, higher capacity turbines. Refer to **Exhibit 6-38** to see where the capital cost burdens lie for a wind project.

Per the World Bank study, cost of installed capacity currently ranges between approximately $1 million and $1.6 million per MW (in 2005$). Economies of scale are seen in both individual turbines and a whole wind farm. Therefore, opting for larger wind turbines or increasing the number of units in a wind farm helps reduce the capital intensity of the project. However, sizing of both the turbines and the overall farm are dependent on other very crucial factors, such as wind resource and land availability.

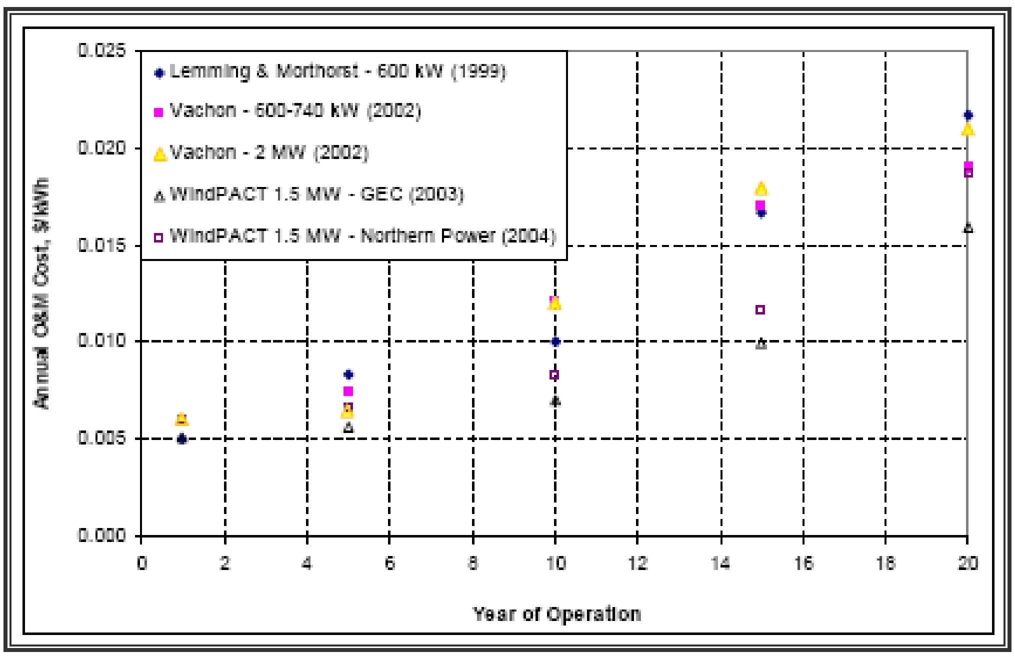
139 Note that these figures do not account for the practical fact that O&M costs for wind turbines rise over time as the equipment ages. Hence, the cost of electricity will increase accordingly. However, this rise is generally offset by equipment depreciation and the historical rise in grid electricity prices. O&M costs can almost double after 20 years. (Source: Sandia National Laboratories).

However, some industry sources are now reporting figures not less than $2 million per MW, somewhat irrespective of size of the farm, citing rising input material costs (especially steel), and other supply chain bottlenecks which are contributing to wind turbine supply shortages in a market that is facing meteoric rise in demand.[140]

Operating and Maintenance Costs

Modern wind turbines have very high availability factors, meaning they do not require lengthy stops for scheduled or unscheduled maintenance. New wind turbines need very little attention but as they age, they require more maintenance. **Exhibit 6-17** shows the average cost for a range of wind turbines over 20 years of operation, compiled by Sandia National Laboratories. The World Bank study assumes an average lifetime O&M cost, but when a formal feasibility study is conducted for a potential wind power project, a year-by-year calculation should be performed to analyze how generating costs might rise over time.

Exhibit 6-17: Estimated O&M cost ($/kWh) over lifetime of wind turbines.
(Source: Sandia National Laboratories)



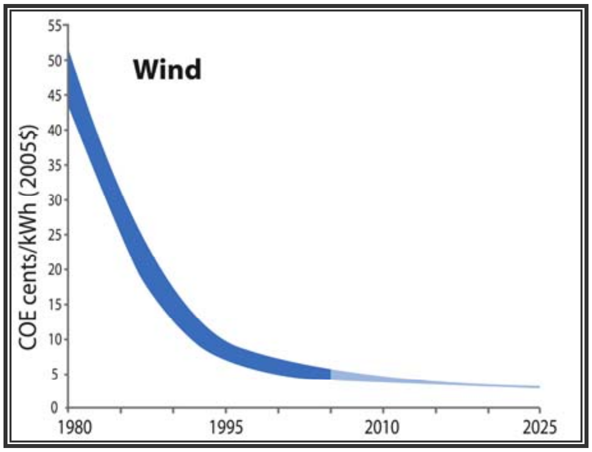
Cost of Electricity (Generating Costs)

Wind power is one of the cost-competitive renewable energy technologies available today. Costs have dropped significantly over time with technology improvements, increase in production volumes, and a more competitive marketplace. **Exhibit 6-18** below shows how wind power costs

140 Peter Duprey, CEO Acciona Energies North America (November 2007), and Mark Tholke, EnXco (January 2008).

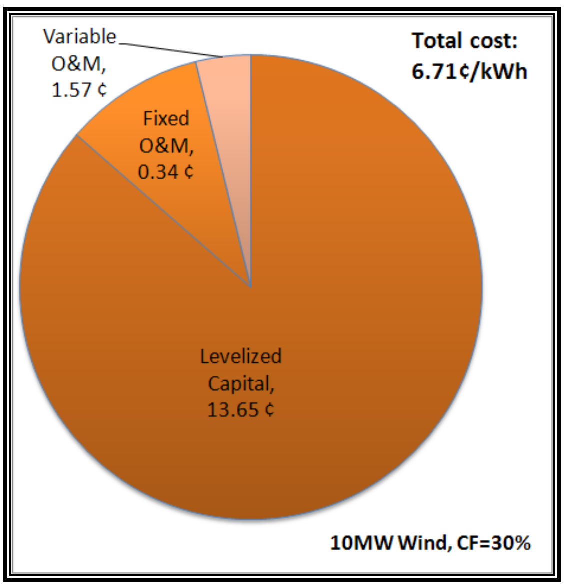
have changed from the 1980s and projected costs until 2025. The lower edge of the band represents Class 6 wind resources while the upper edge represents Class 4 resources.

Exhibit 6-18: Cost curve for wind power (¢/kWh in 2005$). Source: NREL.



Economies of scale play a big role in the cost of electricity produced by wind farms. A 100 MW project can generate electricity for less than 6¢/kWh, while the cost of electricity from a tiny, 100 kW project is closer to 20¢/kWh. Therefore wind power has gained wider use in large, utility-scale projects, with the biggest ones located in United States and Europe. **Exhibit 6-19** presents a typical generating cost breakdown for a 10 MW wind farm, with average 30% capacity factor.

Exhibit 6-19: Cost of electricity (generating cost) summary for wind power in ¢/kWh (2005$). Source: World Bank, 2007.



Greenhouse Gas Offset

Energy and GHG emissions "footprint" of wind power

While wind turbines and towers require heavy material inputs, such as steel and copper, once installed and operational, modern wind turbines rapidly recover all the energy spent in manufacturing, installing, maintaining, and finally scrapping them. Under "good" (class 4 and above) wind conditions it takes between two and three months for a turbine to recover all of the energy involved in the upstream stages. Since wind turbines can operate for 20 years or more, wind power is one of the most "net energy positive" renewable energy options available today. In fact, over its lifetime, wind turbines can generate nearly 30 times more than the energy input into manufacturing, installation, etc.[141] Moreover, the operational phase is entirely GHG emissions free, and maintenance requirements are very low. Consequently, from a life-cycle perspective, wind power's GHG emissions footprint is also very low, at approximately 9.7 kg CO_2e/MW (compare this to 978 kg CO_2e/MW for coal power).[142]

CDM projects

There are currently 133 wind energy projects registered under the UN FCCC's CDM program. These projects range in size from 467 MW to 1.2 MW and are primarily located in China and India.[143]

The median is 30 MW in size and is expected to yield wind project is expected to yield 52,000 tCO_2e and the equivalent number of certified emission reduction (CERs) credits per year, with an average issuance of 82% of the projected value. However, the actual number of CERs generated per project is also highly dependent upon the gird energy composition of the country in which the wind project is located. For instance, in China, where 64% of electricity is supplied by coal-based power, a wind project would offset significantly more emissions than if it were cited in India where coal comprises only 38% of electricity generation.[144]

EUAs are the publicly traded emission allocations in the EU Emissions Trading Scheme and are currently traded at ~ €19 (or $28.87). CERs trade over the counter rather than through public markets and are typically priced at 75% of the EUA price. This implies that the median annual CER-derived cash flow for wind projects of $923,262 ($28.87 × 52,000 CERs/year × 82% delivery rate × 75% discount to current EUA price).

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141 Heller, Martin C., Keoleian, Gregory A., Mann, Margaret K., Volk, Timothy A. *Life cycle energy and environmental benefits of generating electricity from willow biomass*. Renewable Energy 29 (2004) pp. 1023-1042.

142 Heller, Martin C., Keoleian, Gregory A., Mann, Margaret K., Volk, Timothy A. *Life cycle energy and environmental benefits of generating electricity from willow biomass*. Renewable Energy 29 (2004) pp. 1023-1042.

143 United Nations Environment Program, "Clean Development Mechanism Pipeline," http://cdmpipeline.org/, Accessed February 2008.

144 Ibid

All large-scale wind energy projects (>15 MW) have cited approved methodology ACM 0002 under the CDM. Projects attempting to obtain CERs under ACM 0002, must meet certain project-specific eligibility requirements, as well as the general requirements for CDM projects. Small-scale wind energy projects (<15MW) must meet the less rigorous baseline calculations and emissions monitoring specified under approved Methodology ASM I.D.[145]

Criteria Evaluation and Rating

Rating Score:
1=High
2=Medium
3=Low

Exhibit 6-20: Wind power strategic assessment summary

	Strengths	Weaknesses	Rating
Capacity Factor	• Properly sited wind turbines will generate electricity the majority of the time, but not always at full capacity, for an average capacity factor of around 30%.	• Difficult to predict output especially at sites where wind speed is variable.	2
Cost	• Cost of electricity is coming into range of fossil fuel based electricity generation.	• In some areas, wind depends on heavy subsidies that may be eliminated over time. • O&M costs may rise over time as equipment ages and some part replacements could be capital-intensive.	1
Environmental Impacts	• Compatible with mixed land uses such as agriculture.	• Impact on wildlife, in particular birds and bats could be a potential problem.	
GHG offset	• Operation phase is GHG-free.	• None	1
Internal Acceptance	• Maturity of technology and high reliability should translate into high internal acceptance.	• May encounter some skepticism because of intermittent nature of wind energy generation	1
Optionality	• Turbines can be relocated if necessary.	• Cost of relocation may outweigh benefits.	2
Reliability/ Technology Maturity	• Wind turbines are considered a mature, reliable technology for onshore applications.	• Larger offshore turbines still face some technical challenges of operating in more extreme environments.	1
Reputation	• Wind farm installations are rapidly expanding in many countries worldwide because of its appeal as a clean renewable energy option. With proper siting, wind projects are highly visible and favorably received.	• Bad siting of a wind farm can be detrimental to the company's reputation (for e.g. if unforeseen and undesirable environmental or social impacts emerge after installation).	1
Scalability	• Highly scalable and good for utility-scale, grid-connected	• Geography can limit ability to scale.	2

145 Ibid

	Strengths	Weaknesses	Rating
	applications (30-100MW).	• Requires turbines to be spread out over large land area.	
Social Impacts	• Small amount of job creation in wind turbine installation and maintenance.	• Visual impacts are a potential problem, especially around tourist areas that capitalize on pristine views.	
Technology Leadership	• Low speed turbines and vertical axis turbines in development.	• Small room for innovation leaps for majority of wind technology.	**3**

Biomass Combustion and Gasification

This section is designed to guide BHP Billiton personnel in screening thermal biomass-to-electricity technology categories (i.e. biomass combustion, co-firing, biomass gasification). While there is some discussion of specific system configurations (such as, fluidized bed gasification), the selection and sizing of these systems must be conducted in consultation with an experienced energy consultant and is beyond the scope of this document.

Description of Technology

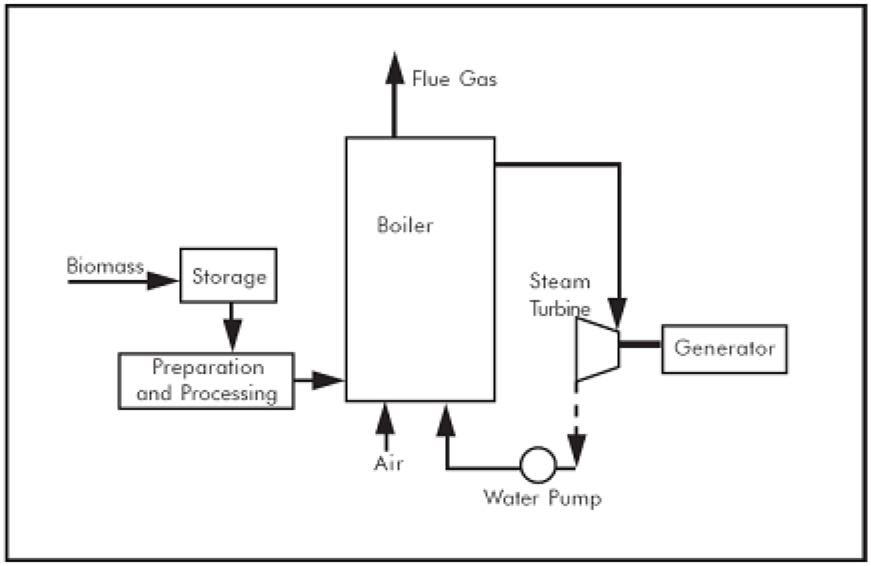
Biomass can be used as a primary energy source or secondary energy source to power gas turbines. As a primary energy source, biomass is used for direct combustion as a bulk fuel that heats fluid contained in a boiler and generates high-pressure steam. The steam is used to drive a steam turbine attached to a traditional generator. In direct combustion systems, biomass can be used as a stand-alone fuel, or it can be "co-fired" with fossil fuels. As a secondary energy source, biomass is first converted into a fuel, which is then combusted used to drive a gas turbine and generator. Secondary energy systems may also be co-fired with fossil fuels.

All assessments below presume a reasonable proximity to a secure and continuous source of reasonable quality biomass feedstock supply and an effective biomass supply chain. Without these systems in place, biomass-to-energy systems should not be considered. This topic is addressed in further detail in the biomass section of the Resource Assessment Toolkit.

Direct Combustion

Although there are many technologies by which biomass may be converted to electricity, the two most prevalent are fluidized bed and grate-fired boilers (see **Exhibit 6-40** for a more detailed list of combustion technologies). Fluidized-bed boilers are more technically complex, larger and more efficient, while grate-fired boilers are more tolerant of heterogeneous fuel sizes. A gasification process schematic is presented in **Exhibit 6-21** below, whereas a process flow diagram from an actual plant in operation is provided in **Exhibit 6-44**.

Exhibit 6-21: Biomass combustion process schematic. Source: World Bank, 2007.



Both grate-fired and fluidized bed boilers employ traditional Rankine cycle steam technology to generate electricity. These systems are comprised of the following subsystems: (1) a biomass combustion section, (2) a boiler that generates steam utilizing the hot gases generated by the combustion process, and (3) an energy recovery section (or power island) in which steam expands in a turbine generating electrical energy via a generator.

Biomass may be combusted in stand-alone biomass-to-electricity combustion plants, which range in scale from 2 to 100 MW and have capacity factors on the order of 80%, similar to that of fossil fuel plants. However, biomass is also commonly combusted in conjunction with fossil fuels (or co-fired) such as coal. Co-firing configurations are addressed in the following section.

Grate (Stoker) Boilers: In general, grate boilers burn biomass on a grate (stationary, vibrating or moving) in the lower chamber of the boiler to release volatile gases which then combust in an upper chamber and heat a boiler. Stoker boilers are the simplest design and have been in operation the longest. This conversion technology is most common in the medium power range plants from 1 to 30 MW thermal inputs. It is most suitable for homogenous fuels like woodchip and bark.

Fluidized Bed Combustion Systems: Fluidized-bed combustors are the most advanced of direct combustion technologies. In these systems, the biomass is ground to a small granular form and mixed/burned in a hot bed of inert material (e.g., quartz). Air is injected into the bed to create a suspended state called "fluidization" in the quartz medium. The air also serves to distribute fuel through the fluidized bed. This increases the heat transfer, allowing for combustion below the temperature that which normally creates NO_X emissions and improves the overall efficiency of the power plant. An external gas burner is needed to pre-heat the bed media during plant start-up. Fluid bed boilers have been in operation for more than 20 years and range in scale from 15 to 715 MW (thermal) input, with bubbling fluid bed boilers restricted to the lower range and circulating fluid bed boilers distributed throughout the entire range.[146] There are over 110 fluid bed boilers in operation in the US.[147]

Power Islands: Following combustion of the biomass in either type of boiler, the generated steam is used to turn a steam turbine which generates electricity via a generator. The turbine and generator are often referred to as a "power island." The power islands used in biomass are similar to those deployed at most fossil fuel plants.

Co-fired Combustion

Co-fired biomass systems offer BHP Billiton an excellent entry option into biomass/renewable power generation for use at its assets or for power swap agreements. These systems involve substituting biomass for a portion of fossil fuel (often coal) in an existing power plant furnace. Because much of the existing power plant equipment (e.g., boiler and power island) can be used without major modifications, co-firing is far less expensive than building a new biomass power plant. Co-firing involves the modification of existing coal combustion power plants to replace 1 to 15% (up to 40%) of the fuel mixture (on a heat value basis)[148] with biomass. Co-firing at pulverized coal plants is limited to 2% biomass capacity, while cyclone boilers can accommodate higher biomass rates. The unit sizes of co-fired coal plants range from 32 MW to 700 MW.[149] There are two main co-fired configurations for biomass and coal fueled plants (see **Exhibit 6-42** for a more detailed list of combustion technologies):

Option 1. Blend coal and biomass, and feed the blended fuel through a single feed system

Option 2. Construct separate fuel feed systems for each system and feed into a shared boiler

Option 3. Construct separate feed and boilers, feeding steam from each boiler to a shared turbine.

In general, the cost-based decision-making should be based upon whether the biomass fuels displacing higher-cost coal and the carbon offsets generated, can more than offset the cost of plant modification. Other strategic decision-making should be based upon the technologies comparison to the criteria developed in Step 3 of the Framework (biomass technologies are discussed with respect to these criteria later in this section).

146 Bridgwater AV, Toft AJ, and Brammer JG. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable & Sustainable Energy Reviews 6 (2002) pg 188.

147 Ibid

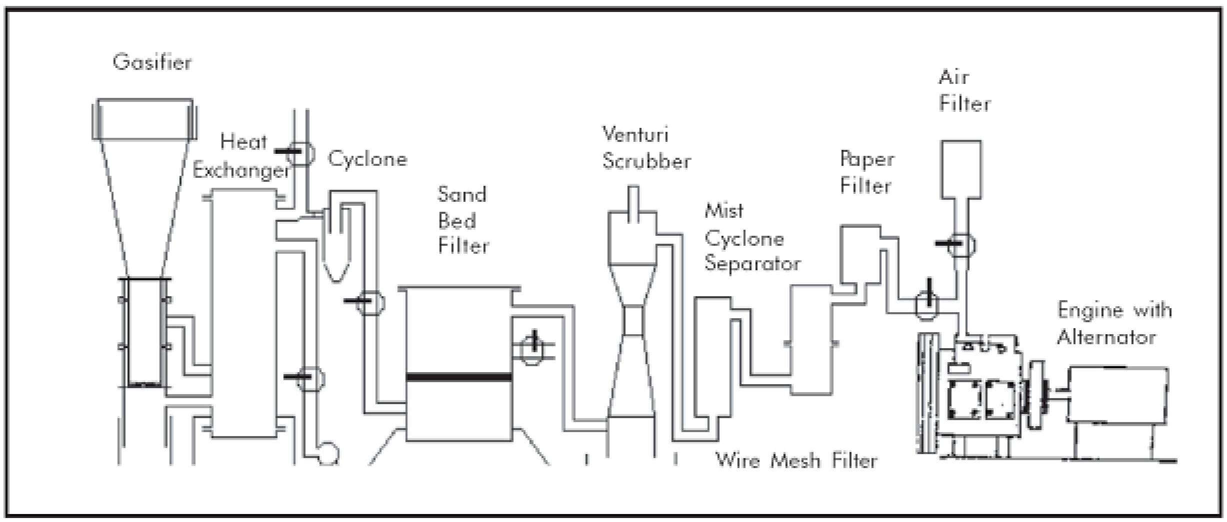
148 Faaij, Andre P. C. Bio-energy in Europe: changing technology choices. Energy Policy 34 (2006), pp 322-342

149 Hughes, E., "Biomass co-firing: economics, policy and opportunities", *Biomass & Bioenergy*, 19 (2000), pp 457-465

Gasification

Gasification is a thermo-chemical process by which biomass or other carbon-based feedstock are converted into a mixture of gases by partial oxidation at very high temperatures. The gas mixture is called synthesis gas or syngas and is composed primarily of H_2 and CO with lesser portions of CO_2, CH_4, N_2 and other trace elements. During gasification, biomass is converted from a solid form into a combustible, mid-to-low calorific level (1,000-1,200 kcal/m^3) syngas. The syngas is filtered and then combusted to drive a gas turbine (and steam turbine in the case of combined-cycle gasification) to generate electricity. Biomass gasification systems have been deployed in the range of 5 to 30 MW, and plants of up to 300 MW are under consideration.[150] Gasification systems have capacity factors on the order of 80%, similar to that of fossil fuel plants. However, their overall reliability is not as great, because this is a relatively nascent technology. A gasification process schematic is presented in **Exhibit 6-22** below, whereas a process flow diagram from an actual plant in operation is provided in **Exhibit 6-45**.

Exhibit 6-22: Biomass gasification process schematic. Source: World Bank, 2007.



Fluidized Bed Gasification: There are many types of gasification units, however only fluidized bed gasification configurations are currently considered for applications over 1 MW. In these systems, air is blown through a bed of solid particles at a sufficient velocity to keep the particles in suspension. The bed is heated using an external source and the biomass feedstock is introduced at the bottom of a reactor vessel after the temperature is appropriately high. The biomass is mixed with the bed material, facilitating combustion.

150 Caputo, C. Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. Biomass & Bioenergy 28 (2005)

Integrated Combined Cycle Gasification: Fluidized bed systems may be either open cycle or combined cycle. In IGCC systems the waste heat is captured and used to generate steam to drive a steam turbine in conjunction with the primary gas-fired turbine. These systems can provide efficiencies of 50-60%[151], thereby significantly reducing the required biomass needed for a given power output when compared to direct combustion technologies. Combined cycle gasification plants approach maximum efficiency in the 25 – 30 MW range, with the largest incremental gains made in the 5 – 15 MW range.[152] Increased efficiency results in a lower demand for biomass fuels, and therefore decreases the effects of the highly variable and costly logistics systems for biomass fuel procurement and processing systems. Additional detail on the technology capability and sample process flow diagram are provided in the Biomass section under Supplemental Exhibits, respectively. Capital cost information can also be found under Supplemental Exhibits.

Gasification plants offer potential benefits in many respects, yet they have not been widely adopted for many reasons. Currently, research into improved gasification technologies at large scales has stalled, and therefore, capital costs remain high and operating problems continue to plague the technology. However, if research resumes and capital costs are reduced, the combination of high electrical efficiencies and relatively low unit capital costs can make biomass gasification an attractive option.

Co-fired Gasification

The syngas generated by the gasification unit may also be co-fired with other fossil fuels such as coal, natural gas, or fuel oil (in dual fuel generator sets). If syngas is fired in a natural gas combined cycle system, it has the potential to reach efficiencies as high as 60%. As with the co-fired combustion technology, co-fired gasification reduces the overall costs, because the fossil fuel power island (turbine and generator) can be used to convert the syngas into electricity. Therefore, only the incremental cost associated with the gasification unit and modification of the existing fossil fuel system to accommodate the syngas must be incurred. There are three configuration options of a co-fired gasification system:

- Option 1. Gasify coal and biomass, and feed the syngas to a shared turbine
- Option 2. Gasify biomass separately, blend the syngas with natural gas in a gas turbine
- Option 3. Gasify wood separately, feed it to a dual-fuel generator to co-fire with diesel or fuel oil

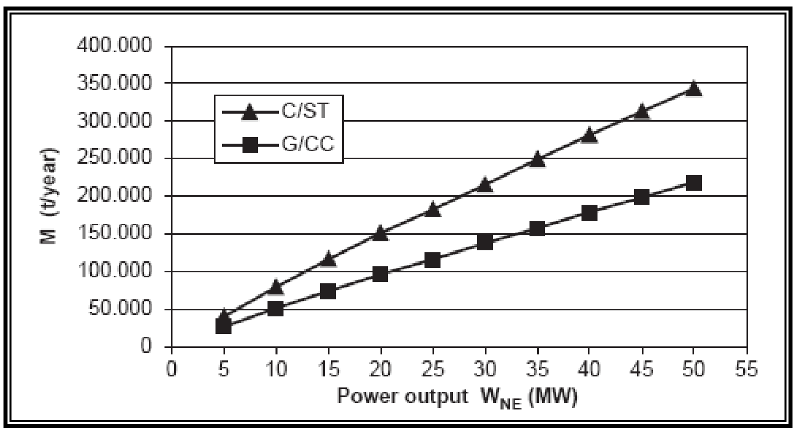
151 Ibid
152 Ibid

Resource Needs

The resource needs for the actual citing, construction and operation of a biomass plant are minimal and do not differ substantially between the technologies (gasification and combustion) or from fossil fired plants. The resource demands consist only of the land necessary for the building and fuel storage, a sufficient source of cooling water, infrastructure for fuel delivery and reasonable power grid access points. The primary resource need for biomass plants is associated with the feedstock, and these demands can be quite high. Annual feedstock demand can range from 50,000 tons to 350,000 tons for plants to produce 5 to 50 MW, respectively, as illustrated in **Exhibit 6-23** below, but can be much higher depending upon the energy content and the bulk density of the fuel source.[153] See the Biomass Resource Assessment Toolkit for further discussion on the environmental, social and economic impacts of biomass fuel sources.

Exhibit 6-23: Biomass demand (tons/year) for various size biomass combustion (C/ST) and gasification (G/CC) plants.

Source: Caputo (2005)



Costs

Exhibit 6-24 below provides a summary of costs and biomass-to-power conversion efficiencies (η) for a range of project scales. Note that the cost figures discussed in this section have been sourced from two different studies: costs for "stand-alone" configuration are from World Bank (2007), whereas costs for "co-fired" configuration are from Hughes (2005).

153 Caputo (2005)

Exhibit 6-24 Summary of cost ranges for biomass combustion and gasification technologies. Sources: World Bank (2007) and Hughes (2005).

Technology configuration	Scale / Capacity	Capital Costs (2005$)	O&M Costs[154] (2005$)	Cost of Electricity (2005$)
Combustion				
Stand-alone (η: 20-40%)	1 – 100 MW	$1.50 – $1.91 million/MW	0.99 – 1.03 ¢/kWh	5.4 – 6.5 ¢/kWh
Co-fired (η: 30-40%)	5 – 20 MW	$0.05 - $0.2 million/MW	Not available	< 3 ¢/kWh
Gasification				
Stand-alone (η: 40-50%)	1 – 30 MW	$1.76 – $2.30 million/MW	1.14 – 1.72 ¢/kWh	6.4 – 7.6 ¢/kWh
Co-fired (η >50%)	Insufficient data	< $1.45 million/MW	Not available	< 10 ¢/kWh

Capital Costs

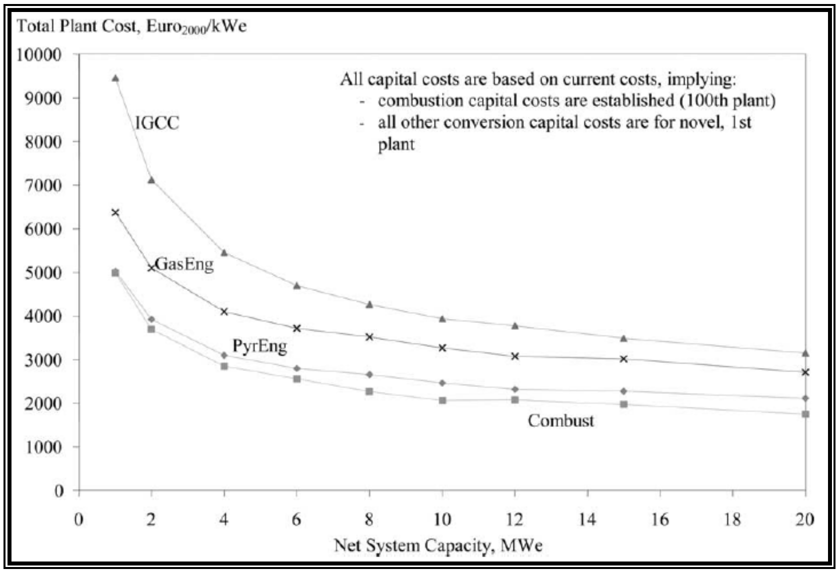
Capital costs include the cost of equipment and installation costs. A study commissioned by The World Bank indicates that the normalized ($/kW) capital cost for a biomass gasification plant is higher than that for a stand-alone biomass combustion plant ($2030/kW versus $1700/kW, on average, in 2005$). This is primarily due to the relative difference in maturity of the technologies and limited supply of (and demand for) gasifier components. As gasification technology matures, the capital costs should decline to be more aligned with that of the mature combustion technologies. Capital costs for co-fired biomass at existing plants are assumed to be nominal, as it consists of the installation of an additional fuel feed and blending system, which is insignificant compared with construction of a full biomass-to-electricity plant. Refer to **Exhibit 6-34** to see where capital cost burdens lie for biomass combustion and gasification plants.

The results from an alternate study demonstrate the impacts of the economies of scale on normalized (€/kW) construction costs for biomass gasification and combustion plants, as well as biomass pyrolysis plants, which are beyond the scope of this study. As can be seen in **Exhibit 6-25** below, normalized capital costs drop precipitously over the 1 to 10 MW range and tend to stabilize for capacity beyond that range.[155]

154 Note that these figures do not account for the practical fact that O&M costs for wind turbines rise over time as the equipment ages. Hence, the cost of electricity will increase accordingly. However, this rise is generally offset by equipment depreciation and the historical rise in grid electricity prices. O&M costs can almost double after 20 years. (Source: Sandia National Laboratories).

155 Bridgwater AV, Toft AJ, and Brammer JG. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable & Sustainable Energy Reviews 6 (2002) pg 233.

Exhibit 6-25: Comparison of capital costs of four biomass conversion technologies. Source: Bridgewater et al, 2002[156]



Key

IGCC: Integrated gasification combined cycle.

GasEng: Gasification followed by combustion in a dual fuel diesel engine.

PyrEng: Fast pyrolysis followed by combustion in a dual fuel diesel engine.

Combust: Combustion followed by steam turbine generation.

Operating and Maintenance (O&M) costs

Operating and maintenance (O&M) costs includes fuel procurement, labor, ash disposal, biomass treatment (drying and sizing), monitoring, cleaning, and other miscellaneous costs associated with day-to-day operations and occasional repair maintenance for biomass plant operation. O&M costs should also include the cost of water, and this cost will vary from one asset to another. **Exhibit 6-26** illustrates the total operating costs (€/year) for combustion and combined-cycle gasification system. Economies of scale are generally not realized in biomass system O&M costs as the fuel procurement costs and logistics networks complexity tend to vary directly with facility size, although modest gains can be realized by making large purchases of biomass from single suppliers.

Models of biomass supply chains indicate that anywhere from 30-90% of the fuel costs are attributable to logistics and handling, while 10-50% of costs are attributable to fuel purchase price.[157] As a result, conversion technologies with greater efficiencies are likely to yield lower operating costs and demand less storage capacity due to the reduced fuel to energy ratio. Therefore, biomass gasification is thought to have lower operating costs than combustion, as its fuel consumption is expected to be 10-15% less (although the figures from World Bank below contradict this). But, because biomass combustion technology is a more mature technology, it has lower variable costs relative to the biomass gasification technologies. See **Exhibit 6-43** for additional detail on cost breakdowns of biomass logistics.

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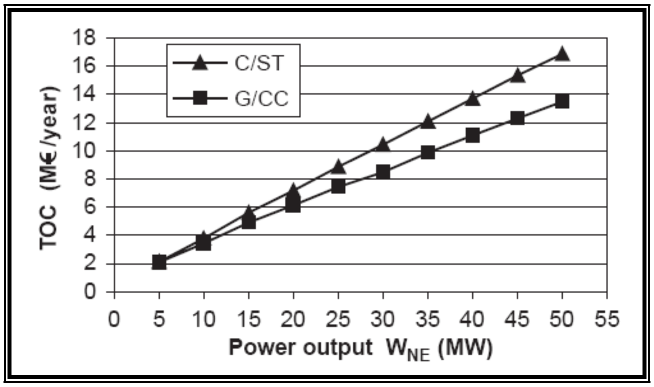
156 Bridgwater AV, Toft AJ, and Brammer JG. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. Renewable & Sustainable Energy Reviews 6 (2002) pg 233.

157 Allen. J., Brown. M. Logistics management and costs of biomass fuel supply. International Journal of Physical Distribution & Logistics Management, Vol. 28 No.6 (1998) pp463-477

A World Bank study projects standard O&M costs for a 50 MW biomass combustion facility are 0.45 US ¢/kWh (for fixed O&M), 0.41 ¢/kWh (variable O&M) and 2.5 ¢/kWh (fuel), assuming fuel costs of $16.6/ton (or $0.99/GJ), for a total of 3.36 ¢/kWh[158]. This implies that fuel costs can comprise over 70% of the O&M costs.

Exhibit 6-26: Total operating costs (TOC, €/year) for various size biomass combustion (C/ST) and gasification (G/CC) plants. Source: Caputo (2005)



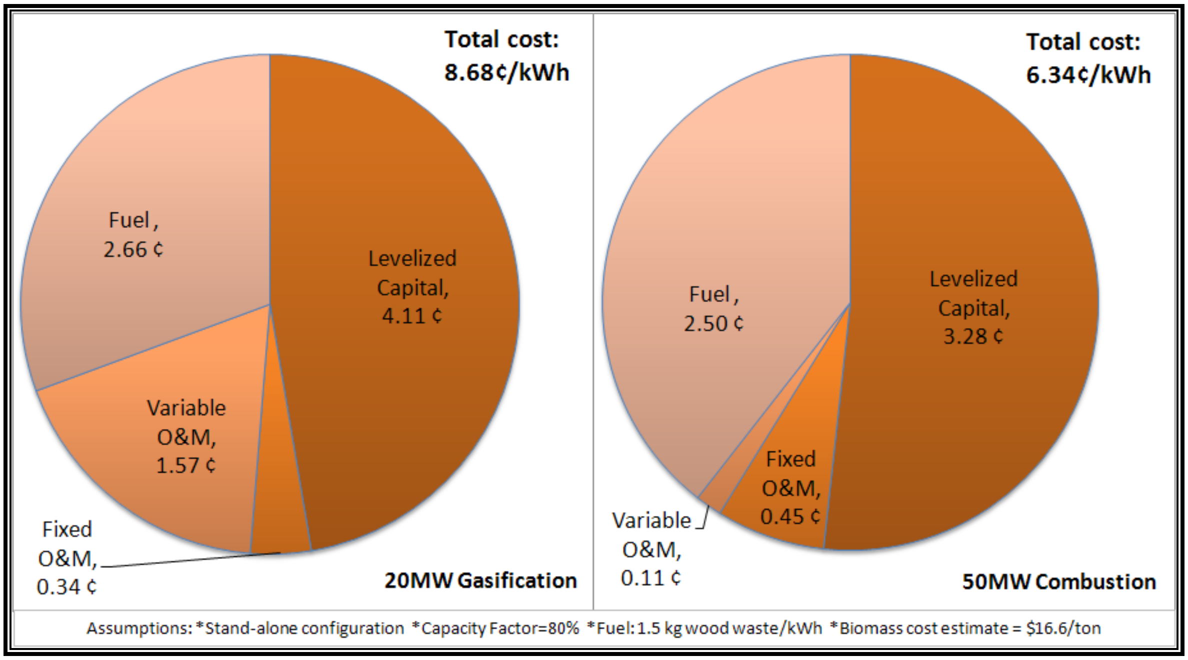
Cost of Electricity (Generating cost)

Producing electricity using any of the biomass conversion technologies considered above is more expensive than fossil fuel sources, as a result of the higher complexity logistics systems involved in biomass fuel supply chains and the purchase price for biomass feedstock. Biomass residues or wastes can generally be purchased for a relatively low cost, however, in areas with competing demand for biomass, prices may increase to $40 - $60/ton. Since fuel costs make up a large proportion of total cost of electricity, this is a critical factor in assessing the economic viability of a biomass-to-electricity plant. **Exhibit 6-27** summarizes the cost components that drive the generating cost (or cost of electricity) produced for gasification and combustion technologies. Capital costs and fuel costs are the largest cost components for biomass-to-electricity systems. World Bank estimates biomass-to-electricity power to be cost-competitive with fossil fuel plants in the 8.68 to 6.34 ¢/kWh range for gasification and combustion, respectively. Co-fired biomass power could be provided at even lower costs, given the nominal capital costs. The high variability of fuel availability and price must be kept in mind when evaluating the cost biomass-derived electricity systems.

158 World Bank (2007)

Exhibit 6-27: Cost of electricity (generating cost) summary for biomass gasification and combustion in ¢/kWh (2005$).

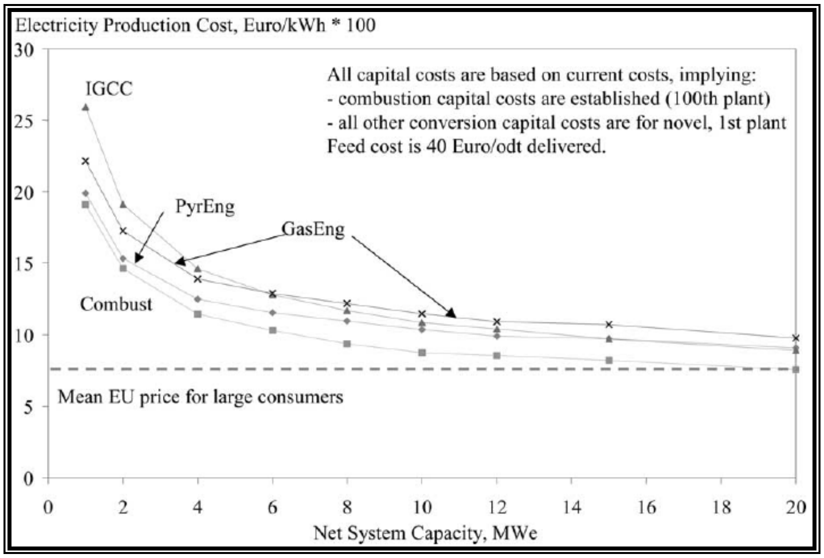
Source: World Bank, 2007



The World Bank study referenced above takes into account a range of capital, fuel, and O&M costs associated with a single plant size for each technology. However, economies of scale may be realized for each type of plant. **Exhibit 6-28** illustrates the expected impact of plant size on the levelized cost of electricity (€/kWh) for biomass gasification and combustion systems, as well as biomass pyrolysis systems, which are beyond the scope of this study. The levelized cost of electricity falls steeply for all technologies over the 2 to 15 MW range. However, the cost decline is most dramatic for systems with high capital costs and higher fuel-to-energy conversion efficiencies (e.g., combined cycle gasification)[159]. In general, as the size of the biomass-to-electricity system increases, both the cost of electricity and the difference in cost between gasification and combustion systems decrease.

159 Bridgewater et al (2002).

Exhibit 6-28: Comparison of electricity production costs of four biomass conversion systems. Source: Bridgewater et al (2002)



Key

IGCC: Integrated gasification combined cycle.

GasEng: Gasification followed by combustion in a dual fuel diesel engine.

PyrEng: Fast pyrolysis followed by combustion in a dual fuel diesel engine.

Combust: Combustion followed by steam turbine generation.

Greenhouse Gas Offset

Energy and GHG emissions "footprint" of biomass energy

Significant reductions in greenhouse gas emissions typically result from substitution of biomass fuels for fossil fuel even when life cycle emissions are accounted. Biomass is generally considered to be a "carbon neutral" fuel source because an equivalent amount of CO_2 is absorbed during the growing biomass fuel feedstock as is released during combustion or gasification. However, "upsteam" life cycle emissions for biomass should also be considered when estimating total impacts on greenhouse gas emissions by biomass. Contributions of greenhouse gas (primarily CO_2 and N2O) emissions from cultivation, fertilization, harvest, transport and processing of dedicated energy crops, such as short-rotation-coppice willow plantations, generate CO_2 emissions. But, when compared to the "upstream" emissions from coal mining and transport, the biomass-related emissions are net negative, thus biomass energy still results in significant GHG reductions even when accounting for its life-cycle emissions.

Studies indicate that the net emissions generated by combined-cycle natural gas power plants and coal power plants are approximately 499.1[160] and 978[161] kg CO_2e/MWh, respectively. For the coal plant, 95% of the CO_2e emissions are attributable to combustion, with 42.8 and 7.6 kg CO_2e/MWh

160 Spath, Pamela L., Mann, Margaret K. Life Cycle *Assessment of a Natural Gas Combined-Cycle Power Generation System*, National Renewable Energy Laboratory (2000).

161 Heller, Martin C., Keoleian, Gregory A., Mann, Margaret K., Volk, Timothy A. *Life cycle energy and environmental benefits of generating electricity from willow biomass*. Renewable Energy 29 (2004) pp. 1023-1042.

released from mining and transportation, respectively. In the combined-cycle natural gas scenario, production and distribution accounts for 25% of life cycle emissions, while combustion accounts for 75%. Co-firing biomass at 10% in a coal plant can reduce overall life cycle emissions from 978 to 883 kg CO_2e/MWh. Standalone biomass power plants can achieve life-cycle emissions of CO_2e on the order of 39.89 to 52.4 kg CO_2e/MWh for gasification and combustion, respectively. Not only does biomass essentially eliminates GHG emissions compared to coal, but it also performs comparably to solar photovoltaic. It does, however, have higher GHG emissions than wind power (which has life cycle emissions of 9.7 kg CO_2e/MWh).[162]

CDM Projects

There are a total of 508 total biomass-to-electricity projects in all phases of development (including pre-registration) within the CDM framework. However, only 198 of these have been registered under the CDM protocol.[163] The largest CDM biomass-to-energy project is an 80 MW bagasse-to-electricity plant in Brazil, while the smallest is a 0.3 MW biomass residue plant in India. The vast majority of biomass-related CDM projects are in India, Brazil and Malaysia, but there are also several large-scale projects in China. A median size CDM biomass project is about 10 MW and is expected to generate a median of 51,000 CERs per year, with 89% success rate for reaching the estimated carbon reduction target.[164] This implies that the median annual CER cash flow for biomass projects of $982,806 ($28.87 × 75% discount to current EUA price × 51,000 CERs/year × 89% delivery rate).

The number of CERs generated per project is highly dependent upon the gird energy composition of the country in which the biomass project is located. For instance, in Brazil, where 84% of electricity is supplied by renewable (i.e., hydro) power, a biomass project would only offset emissions from the 16% of non-renewable energy.

All large-scale biomass-to-energy projects (>15 MW) have cited approved methodology ACM 0006 under the CDM. Projects attempting to obtain CERs under ACM 0006, must meet certain project-specific eligibility requirements, as well as the general requirements for CDM projects. The projects must utilize crop residues as the main source of fuel (co-firing with fossil-fuels is permitted). In most cases, these projects have used bagasse, rice husks, corn stover, or some other industrial-scale crop residue as a feedstock. Projects must not result in the increased growth of crops for the purpose of energy consumption. In other words, the crop demand must be external to the project demand for the crop residue. Small-scale biomass-to-energy projects (<15MW) must meet the less rigorous

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162 Heller, Martin C., Keoleian, Gregory A., Mann, Margaret K., Volk, Timothy A. *Life cycle energy and environmental benefits of generating electricity from willow biomass*. Renewable Energy 29 (2004) pp. 1023-1042.

163 United Nations Environment Program, "Clean Development Mechanism Pipeline," http://cdmpipeline.org/, Accessed February 2008.

164 Ibid

baseline calculations and emissions monitoring specified under approved Methodology ASM III.D.[165]

Criteria Evaluation and Rating

The subsequent discussion, along with **Exhibit 6-29** and **Exhibit 6-30**, provides a qualitative assessment of the performance of the two general biomass conversion technologies (combustion and gasification) with respect to the strategic criteria identified in Step 3 of the Framework for Evaluating Renewable Electricity Technologies. The tables also consider co-firing for each conversion technology. The tables are meant to help differentiate the biomass technologies from one another and compare to wind and solar technologies. The user must consider the technology as a system which includes the feedstock production and logistics chain (which will be similar between the two conversion technologies, but will distinguish the technologies from wind and solar). As such, in assessing criteria such as cost, availability and public perception, we have attempted to account for the biomass feedstock impacts. However, the wide degree of variability in feedstock procurement logistics, quality and security calls for high levels of user discretion.

Biomass Combustion (stand-alone)

Biomass combustion plants offer the relative benefits of fuel flexibility, reduced emissions, moderate capital costs, and high capacity factors. However, in stand-alone configurations biomass-to-electricity combustion systems may encounter some disadvantages. First, they have modest efficiencies (20%- 40%). Due to their moderate sizes they are unable to achieve the economies of scale that are present in large coal combustion plants. Also, the relatively low heating value and moisture content of biomass fuels takes a toll on efficiency. Second, power generation is entirely reliant on the availability of biomass fuels, which are often supplied on a seasonal or unpredictable basis. Therefore, a stockpile of biomass and/or alternative reserve fuels (e.g., coal) must be kept on-hand to ensure a supply of fuel for continuous power generation.

Biomass Combustion (co-fired)

Co-firing biomass within existing fossil power plants offers the advantages of high reliability, flexibility of fuels sources, relatively high efficiencies (25 – 40%), low capital costs, assured offset of coal emissions, and technological maturity when compared to other biomass generation technology categories.[166] Co-fired incurs the lowest investment cost of any renewable energy source because the boiler and the power island (turbine and generator) have already been purchased by for coal combustion, and thus, the transition to biomass burning requires only modification of the existing plant through a biomass-coal blending system ($50-$100/kW biomass) or the addition of a biomass

165 Ibid

166 Hughes, E., "Biomass co-firing: economics, policy and opportunities", *Biomass & Bioenergy*, 19 (2000), pp 457-465.

fuel feeding system ($175-$200/kW biomass).[167] Furthermore, co-fired combustion systems have the highest capacity factor of any renewable energy technology.[168] Finally, these systems offer high availability and optionality, with the ability to incorporate multiple biomass fuels (provided they fall within system specification) and to increase the proportion of fossil fuels in the event of biomass shortages. It should be noted that there is a modest reduction in overall power plant efficiency when biomass is introduced as a fuel, due to its lower heat value and higher moister content when compared to those of coal.[169]

Biomass Gasification (stand-alone)

Gasification adds complexity above and beyond that of direct combustion systems, as the biomass must be converted to a gas form prior to combustion. This results in lower capacity factors and higher rates of maintenance and down-time for many systems. Second, gasification units deployed to date have been relatively capital intensive, small-scale, and have had moderate success rates due to the complexity of the gasification technology. Gasifiers are highly sensitive to feedstock size, moisture content and chemical content. Therefore, the feedstock must be relatively uniform prior to conversion to syngas.

Biomass Gasification (co-fired)

Biomass co-gasification leads to the similar benefits as co-fired (e.g., lower capital investment, higher efficiencies, etc.). However, it also suffers from the same drawbacks as biomass gasification (e.g., added technological complexity, relatively high cost for gasifier).

Exhibit 6-29: Biomass combustion strategic assessment summary

Rating Score:
1=High
2=Medium
3=Low

	Strengths	Weaknesses	Rating
Capacity Factor	• CF = 80%, on par with fossil fuels.	• Subject to constraints on feedstock availability. • Co-firing does not increase system capacity.	**1**
Cost	• Moderate capital costs for stand-alone. • Nominal capital costs for co-fired systems. • Operating costs low if feedstock is a waste stream/residues.	• Extensive logistics network to deliver and process adequate biomass fuels increases cost. • Variable (fuel costs) subject to fluctuations due to shortages and alternate biomass market demands.	**2 stand-alone 1 co-fired**

167 Ibid
168 Hughes, 2000.
169 Ibid

	Strengths	Weaknesses	Rating
Environmental Impact	• Reduces CO_2, NOx and SOx emissions.	• May reduce biodiversity in feedstock harvest areas. • Still emits CO_2 from combustion process. • Still reliant on fossil fuels if co-firing.	**2 or 3**
GHG offset	• High capacity factor of reneables leads to more offsets. • Co-firing with coal displaces highly polluting coal fuel.	• Possible GHG emissions associated with biomass harvest, transport and processing.	**1**
Internal Acceptance	• High potential for demo project given the ability to integrate into existing fossil plants (co-fired). • High capacity and reliability may increase attractiveness to asset managers.	• Stand-alone systems are dependent upon secure fuel supply. • May experience resistance to reliance on variable fuel supply (biomass) for critical operations.	**2 stand alone 1 co-fired**
Optionality	• Co-firing provides for significant flexibility which can mitigate feedstock risks. • Accepts a wide variety of biomass feedstocks, adding flexibility.	• Stand-alone systems have little fuel flexibility. • Co-firing blends of fuels can increase operational complexity.	**1 co-fired 3 stand-alone**
Reliability/ Technology Maturity	• Widely deployed and compatible with mature fossil fuel (i.e., coal) technologies. • Reliable.	• None.	**1**
Reputation	• Potential conversion of waste to energy. • Some appeal as a renewable energy source. • Job creation.	• Large downside risk if fuel is sourced unsustainably.	**2 or 3**
Scalability	• Highly scalable (from 2 to 100 MW).	• Co-firing biomass does not add capacity but replaces existing fuel supply. • Stand-alone systems are limited to under 100MWe.	**2**
Social Impact	• Labor-intensive nature of biomass fuel source creates agricultural and processing jobs.	• May displace existing land use. • May displace existing economies. • Feedstock production may compete with and increase cost of food and water.	**2**

	Strengths	Weaknesses	Rating
Technology Leadership	• Widely deployed at scale • Some incremental technology improvements (e.g., higher efficiency combustion technologies).	• Low potential for major technological innovation due to maturity of technology.	3

Exhibit 6-30: Biomass gasification strategic assessment summary

	Strengths	Weaknesses	Rating
Capacity Factor	▪ CF = 80% on par with fossil fuels.	▪ Subject to constraints of feedstock availability. ▪ Subject to technological complexity.	**1 or 2**
Cost	▪ Low variable costs from increased efficiencies.	▪ Very high capital costs. ▪ Low potential to use heterogeneous biomass wastes.	**3**
Environmental Impact	▪ Reduces CO2, NOx and SOx emissions.	▪ May reduce biodiversity in feedstock harvest areas ▪ Still emits CO2 from combustion process. ▪ Still reliant on fossil fuels if co-firing.	**3**
GHG offset	▪ Higher capacity factor and efficiency leads to more offsets.	▪ Potentially significant GHG emissions associated with biomass harvest, transport and processing.	**1**
Internal Acceptance	▪ Scalability and co-firing makes gasification suitable for demonstration projects.	▪ Technology risk due to immaturity.	**2**
Optionality	▪ Can co-fire fossil inputs with some modification.	▪ Increased complexity with immature technology and co-firing.	**1**
Reliability/ Technology Maturity	▪ Nascent commercial maturity for small scale (<30 MW). ▪ High availability on demand.	▪ Not commercially demonstrated for large scale (>30 MW). ▪ Increased potential for technical difficulties due to added process steps.	**3**
Reputation	▪ Potential conversion of waste to energy. ▪ Some appeal as a renewable energy source. ▪ Job creation.	▪ Large downside risk if fuel is sourced unsustainably.	**2 or 3**
Scalability	▪ Modular, so capacity can be added incrementally.	▪ Not sufficiently proven at high capacities.	**2**
Social Impact	Labor-intensive nature of biomass fuel source creates agricultural and processing jobs.	▪ May displace existing land use. ▪ May displace existing economies. ▪ Feedstock production may compete with and increase cost of food and water.	**2**

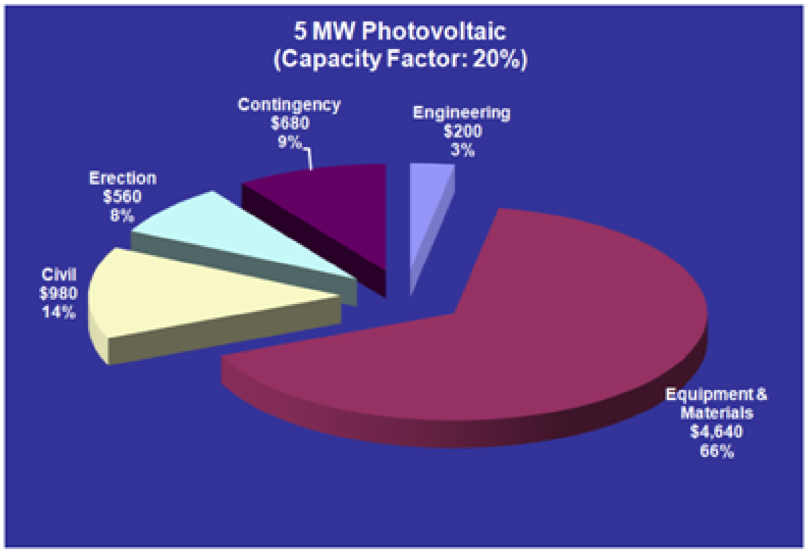
	Strengths	Weaknesses	Rating
Innovation	▪ Emerging conversion technology.	▪ Research has slowed, so few advances being made, particularly in Integrated Combined Cycle.	**1**

Supplemental Exhibits

Solar Photovoltaics

Exhibit 6-31: Capital costs breakdown for a typical photovoltaic (PV) installation (2005 $/kW).

Data source: World Bank, 2007.



Concentrated Solar Thermal Power

Exhibit 6-32: Components of a CSP plant. Source: Bandyopadhyay (2007)

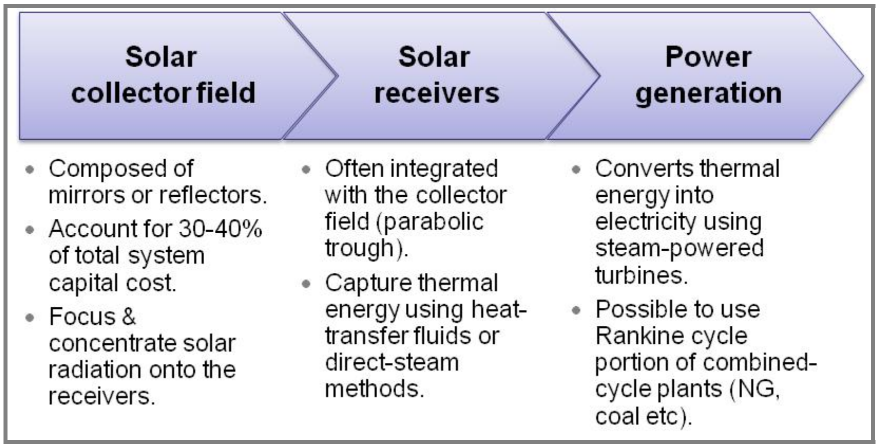


Exhibit 6-33: Schematic for a parabolic-trough CSP plant (with storage). Source: Solarpaces.org

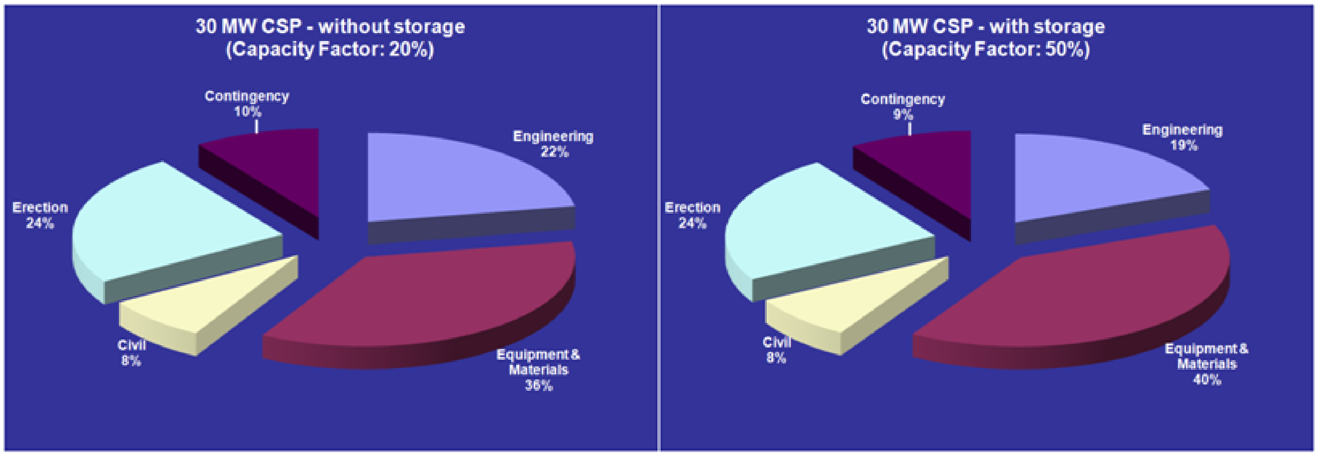


Exhibit 6-34: Capital costs breakdown for a typical CSP project (2005 $/kW). Data source: World Bank, 2007

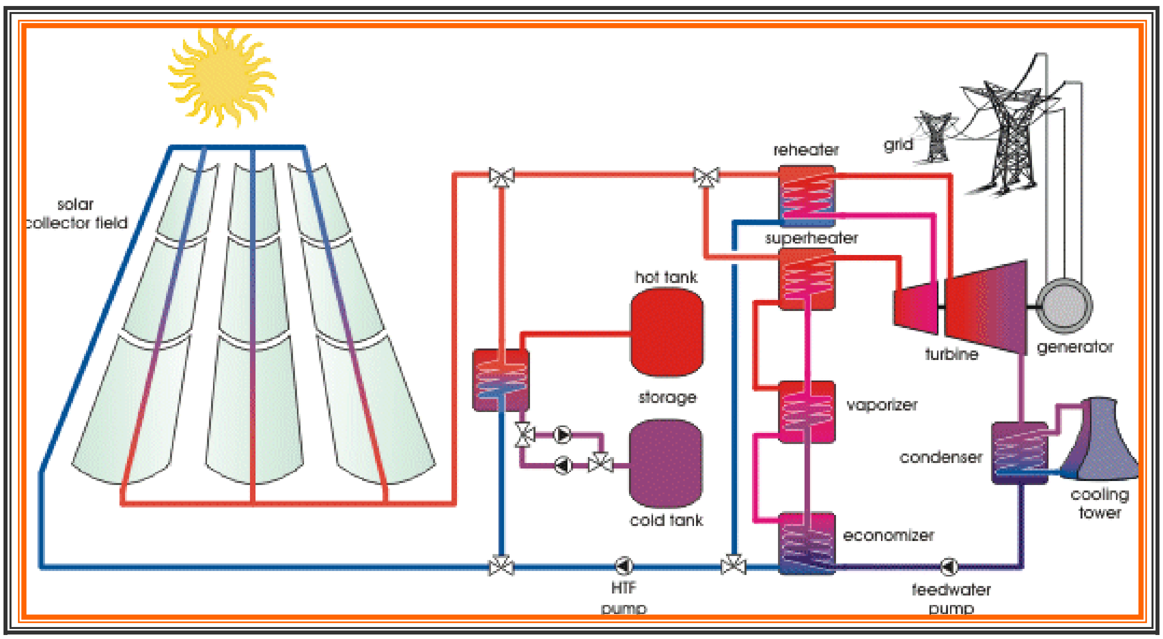
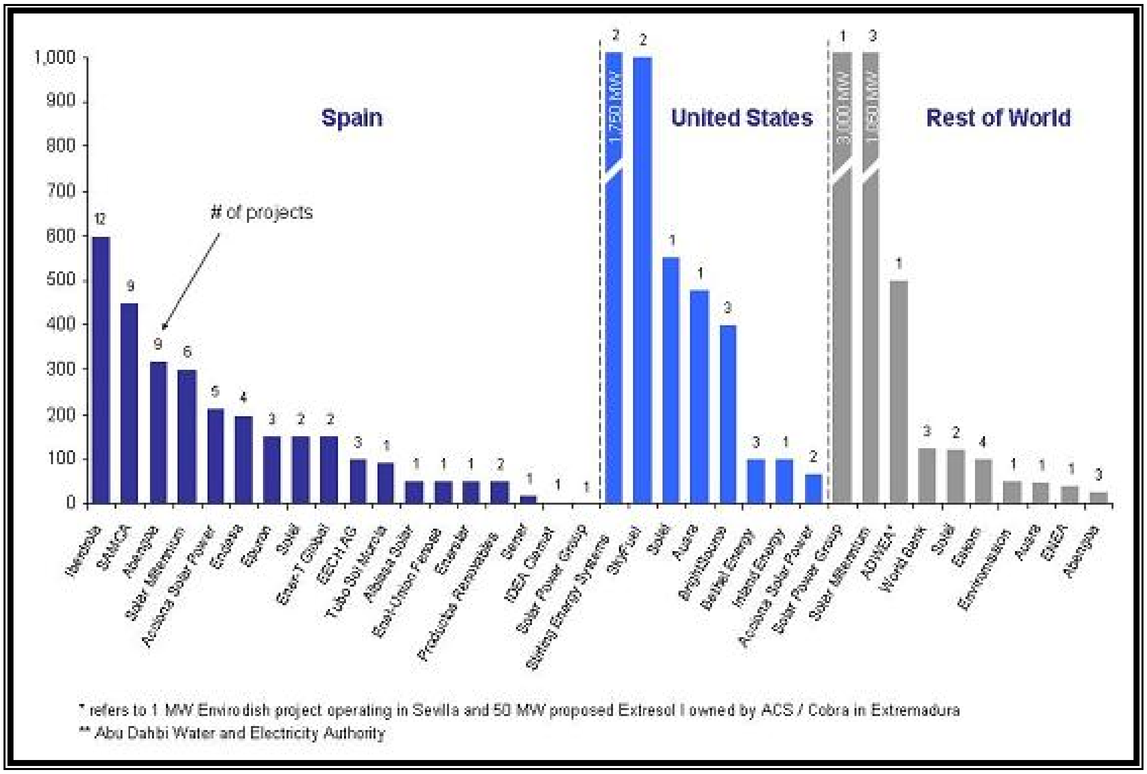


Exhibit 6-35: Global CSP project pipeline by developer (2007)[170]



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170 Renewable Energy Access, "CSP as scalable energy alternative", December 13, 2007. http://www.renewableenergyweekly.com/rea/news/story;jsessionid=BAD4215B9BF527682301E58FC269B98F?id=50835. Original photo credit: Emerging Energy Research.

Exhibit 6-36: CSP technology maturity curve[171]

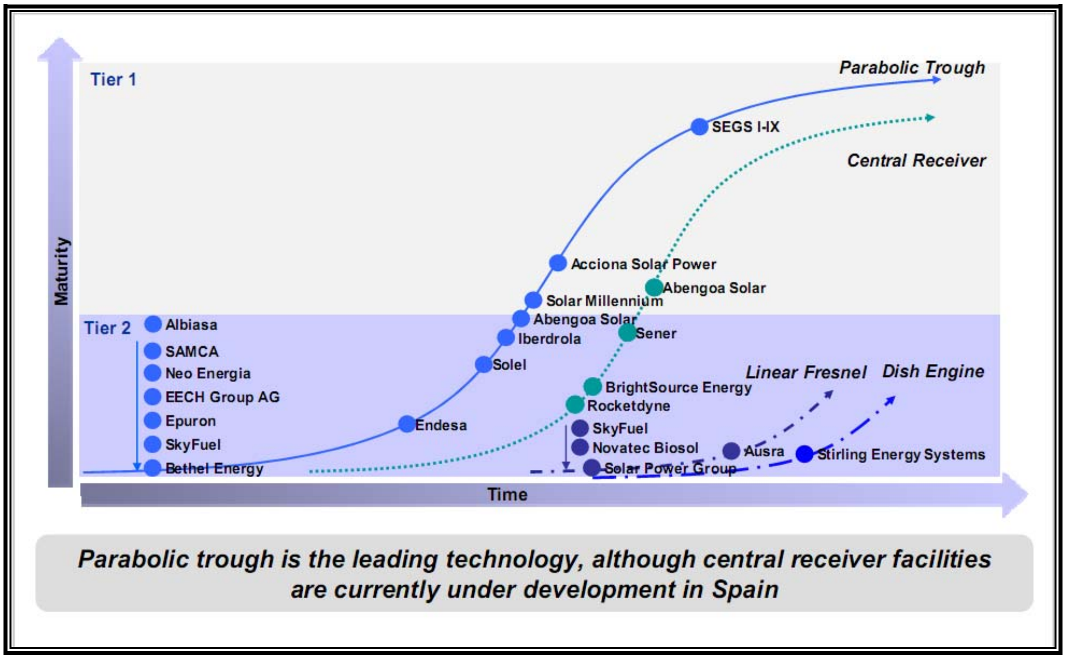
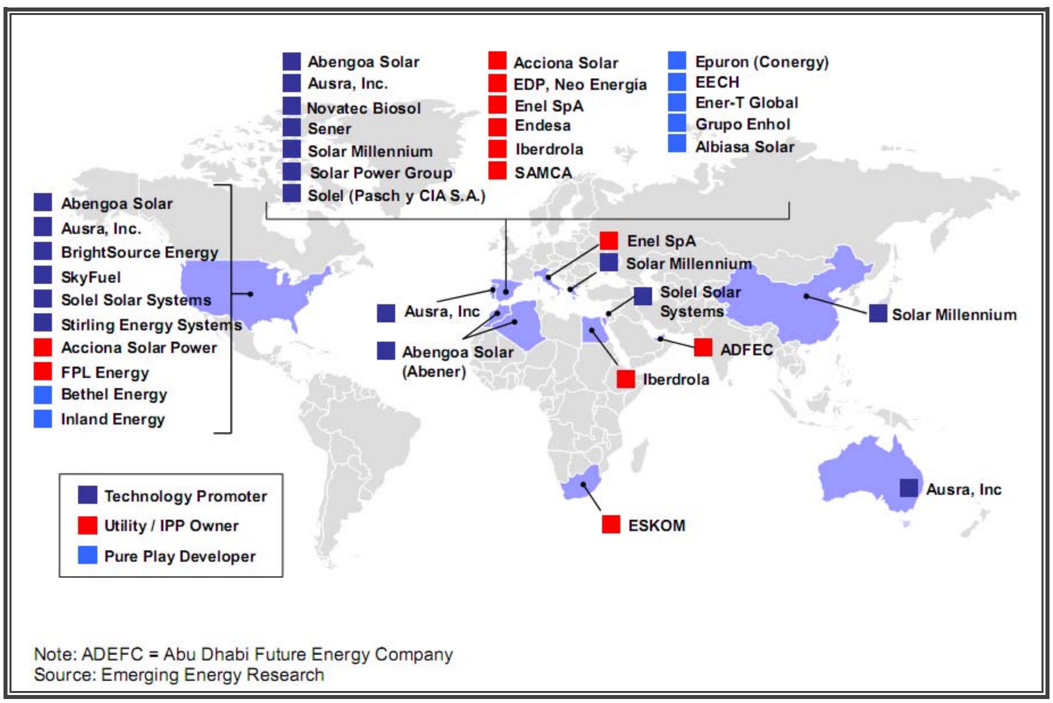


Exhibit 6-37: Leading CSP developers' global focus[172]



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171 Emerging Energy Research, "Global Concentrated Solar Power Markets and Strategies, 2007-2020" *(Promotion Brochure),* November 2007. http://www.emerging-energy.com/user/GlobalConcentratingSolarPowerMarketsandStrategies200720201451383184_pub/SolarCSPPromo.pdf.

172 Emerging Energy Research, 2007.

Wind Power

Exhibit 6-38: Capital costs breakdown for a typical wind project (2005 $/kW). Data source: World Bank, 2007

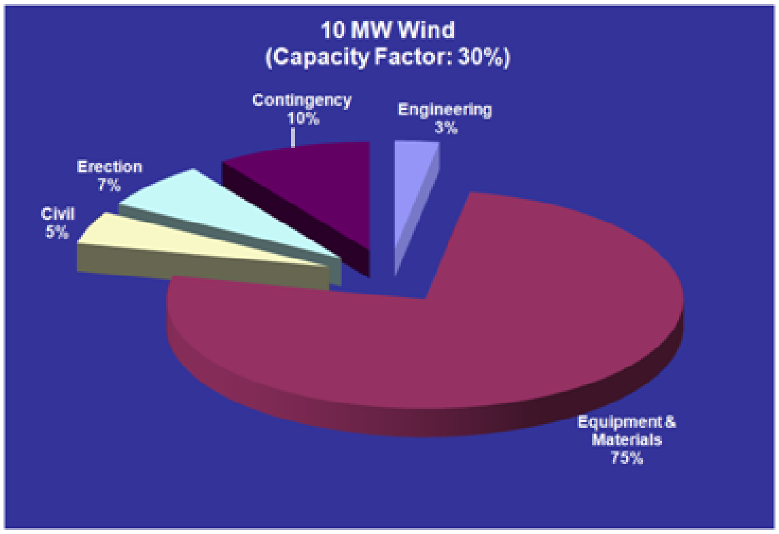
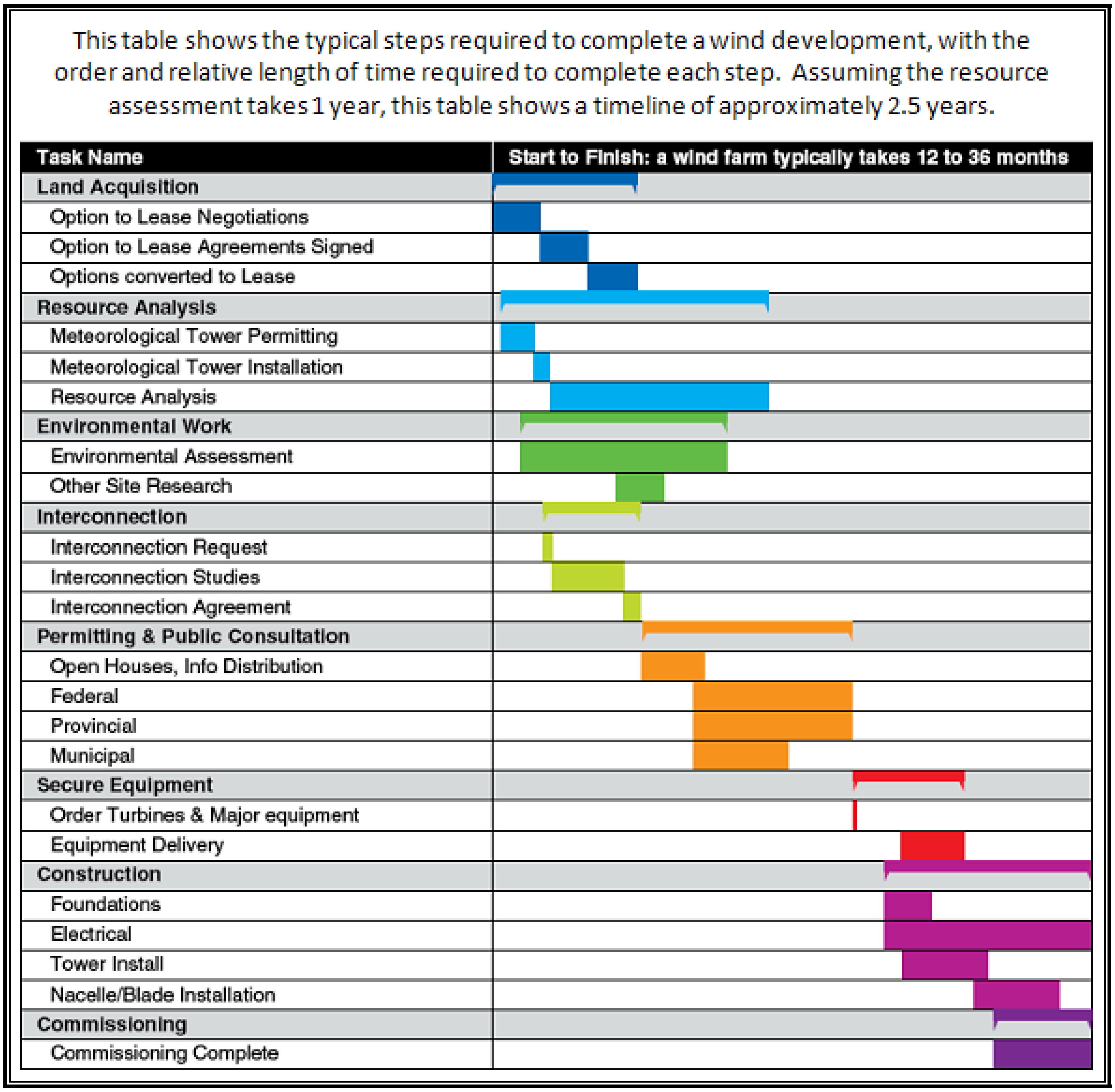


Exhibit 6-39: Typical wind project development timeline. Source: Canadian Wind Energy Association.



Biomass

Exhibit 6-40: Biomass combustion technologies

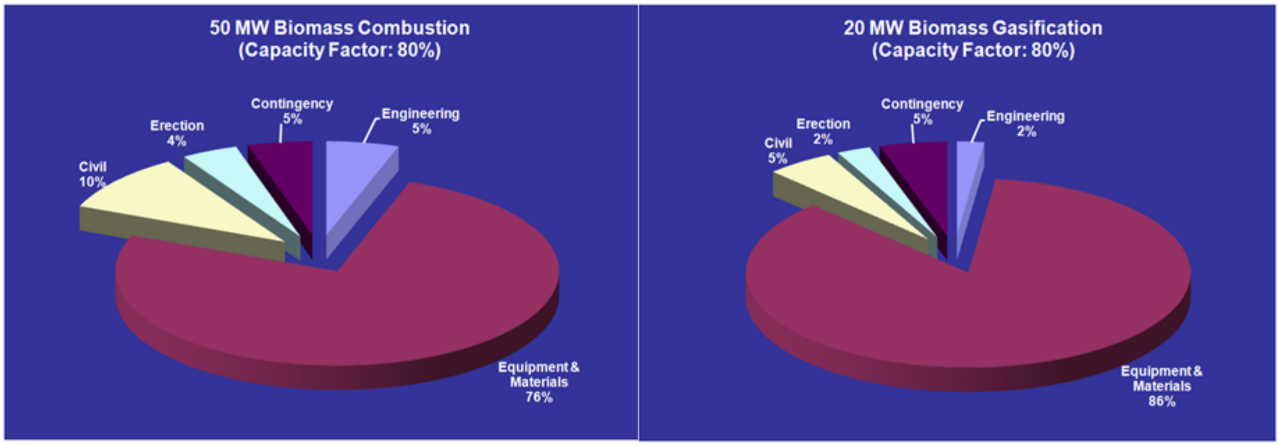


Exhibit 6-41: Capital costs breakdown for typical biomass gasification and combustion projects. (2005 $/kW). Data source: World Bank, 2007.

Biomass Conversion Technology	Commonly used fuel types[a]	Particle Size Requirements	Moisture Content Requirements (wet basis)[b]	Average capacity range / link to examples
Stoker grate boilers	Sawdust, non-stringy bark, shavings, end cuts, chips, chip rejects, hog fuel	0.25 – 2 in (6 -50 mm)	10-50% (keep within 10% of design rate)	20 to 300 Mwe many in 20 to 50 MWe range
Fluidized-bed combustor (FB- bubbling or CFB- circulating)	Low alkali content fuels, mostly wood residues or peat no flour or stringy materials	< 2 in (<50 mm)	< 60%	Many at 20 to 25 MWe, up to 300 Example 1 Example 2
Co-firing: pulverized coal boiler	Sawdust, non-stringy bark, shavings, flour, sander dust	<0.25 in (<6 mm)	< 25%	Up to 1500 MWe[e] Example
Co-firing: cyclones	Sawdust, non-stringy bark, shavings, flour, sander dust	<0.5 in (<12 mm)	10 – 50%	40 to 1150 MWe[e] Example
Co-firing: stokers, fluidized bed	Sawdust, non-stringy bark, shavings, flour, hog fuel	< 3 in (<72 mm)	10 – 50%	MWe[e] Example

Source:
Compiled by Lynn Wright, Oak Ridge, TN.

[a] Primary source for fuel types is: Badger, Phillip C. 2002. Processing Cost Analysis for Biomass Feedstocks. ORNL/TM-2002/199. Available at http://bioenergy.ornl.gov/main.aspx (search by title or author)
[b] Most primary biomass, as harvested, has a moisture content (MC) of 50 to 60% (by wet weight) while secondary or tertiary sources of biomass may be delivered at between 10 and 30%. A lower MC always improves efficiency and some technologies require low MC biomass to operate properly while others can handle a range of MC.
[c] Wood residues may include forest logging residues and storm damaged trees (hog fuel), primary mill residues (e.g., chipped bark and chip rejects), secondary mill residues (e.g., dry sawdust), urban wood residues such as construction and demolition debris, pallets and packaging materials, tree trimmings, urban land clearing debris, and other wood residue components of municipal solid waste (as wood chips).

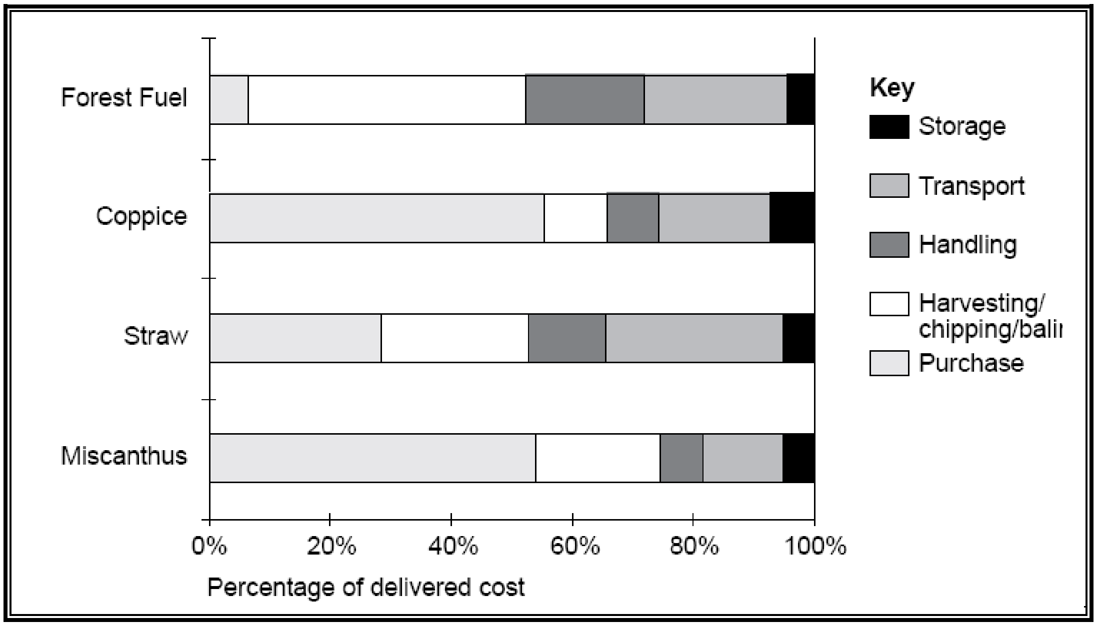
[d] Agricultural residues may include straws and dried grasses, nut hulls, orchard trimmings, fruit pits, etc. Slagging may be more of a problem in some types of combustion units with high alkali straws and grasses, unless the boilers have been specially designed to handle these type fuels.
[e] The biomass component of a co-firing facility will usually be less than the equivalent of 50MWe.

Exhibit 6-42: Biomass gasification technologies

Biomass Conversion Technology	Commonly used fuel types[a]	Particle Size Requirements	Moisture Content Requirements (wet basis)[b]	Average capacity range / link to examples
Downdraft, moving bed atmospheric gasifier	Wood chips, pellets, wood scrapes, nut shells	< 2 in (<50 mm)	<15%	~ 25-100 kWe Example
Circulating fluidized bed (CFB), dual vessel, gasifier	Most wood and chipped agricultural residues but no flour or stringy materials	0.25 – 2 in (6 -50 mm)	15-50%	~ 5 to 10 Mwe Example

[a] Primary source for fuel types is: Badger, Phillip C. 2002. Processing Cost Analysis for Biomass Feedstocks. ORNL/TM-2002/199. Available at http://bioenergy.ornl.gov/main.aspx (search by title or author)
[b] Most primary biomass, as harvested, has a moisture content (MC) of 50 to 60% (by wet weight) while secondary or tertiary sources of biomass may be delivered at between 10 and 30%. A lower MC always improves efficiency and some technologies require low MC biomass to operate properly while others can handle a range of MC.

Exhibit 6-43: Proportional breakdown of biomass fuel supply systems. Source: Allen (1998)



<u>Sample Process Flow Diagrams for Biomass Gasification and Combustion Conversion Technologies</u>

Exhibit 6-44: Example of Biomass Vibratory Grate Combustion System, Williams Lake Power Plant, British Columbia

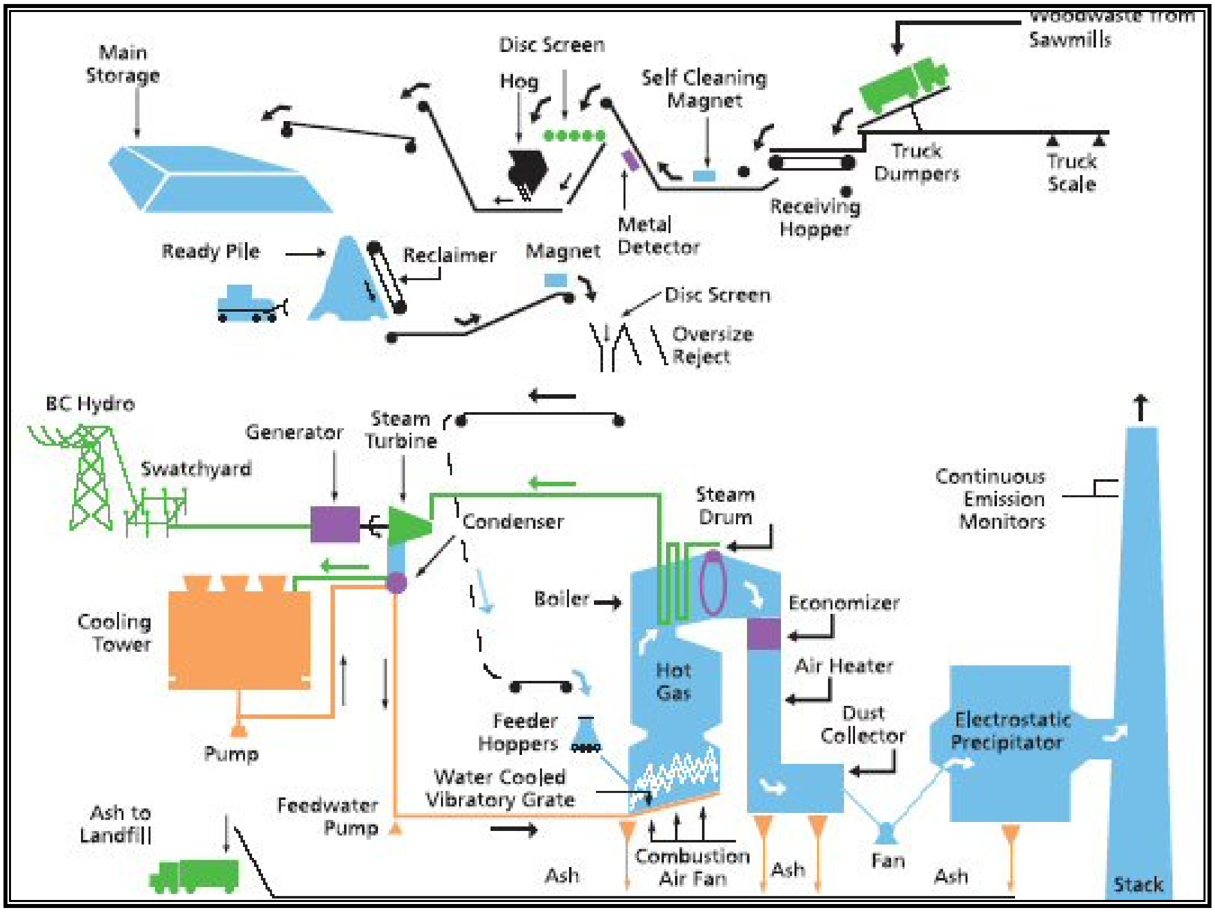


Exhibit 6-45: Example of Co-Fired Integrated Combined Cycle Gasification. Source: Tampa Electric Company.

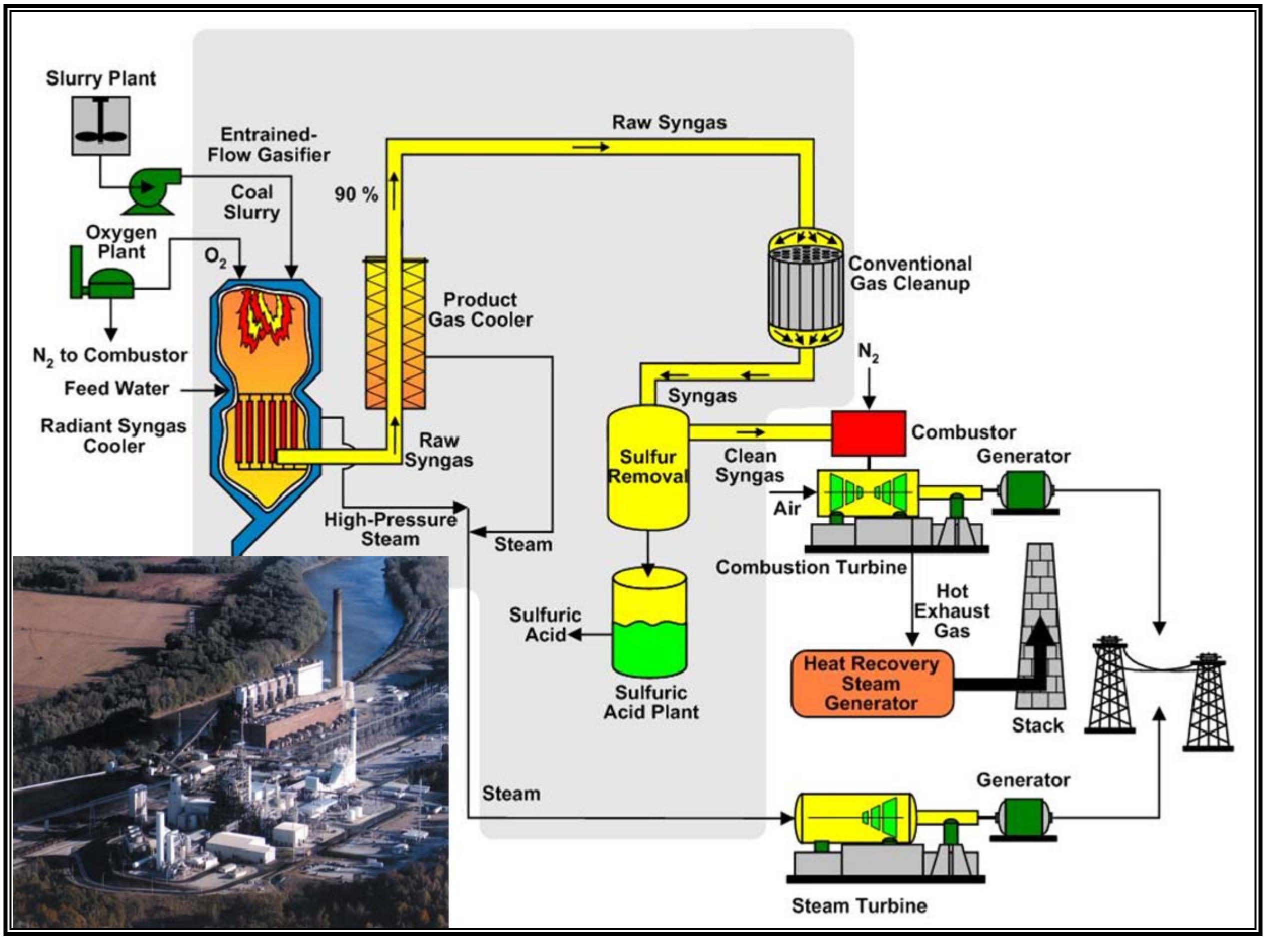


Exhibit 6-46: Major biomass product and service providers

Company	Services	Types of Installation	Size of Installiations	Contact
Kvaerner	Design, engineering, fabrication	Combined heat and power (fluidised bed combustion)	6-20 MWe	Kavaerner Power
Foster Wheeler	Engineering and manufacturing	Circulating fluidised bed and grate boilers for biomass combustion Gasification and co-fired gasification units	110-150 MWe 13-20 MWe	Foster Wheeler CFB
Standardkessel Baumgarte	Planning, design, construction of turnkey power plants	Grate fired boiler-based technology	20-60 MWe	Standardkessel
Babcock & Wilcox Company	Design, manufacture, install and service	Grate combustion, fluidized bed		Babcock & Wilcox
Bono Energia	Design, production of turnkey power plants	Combined heat and power (grate fired technology)	2-12 MWe	Bono Energia
Wartsila	Design, production of turnkey power plants	Modularised combined heat and biopower systems	1 - 7 MWe	Wartsila Biopower
Alstom Power	Design, production of turnkey power plants	Fluidised bubbling bed or grate-fired combustion, turbines, turnkey plants	2 - 200 MWe	Alstom Power

Source: Moazed (2008) and Frost & Sullivan, Biomass Power plant Markets, Market Engineering Research, 22 July 2002

Chapter 7: Framework Application to Minera Escondida Limitada

Scope

The purpose of this section is to failiarize the reader with the Framework for Evaluating Renewable Energy Options (Framework) through its application to a case study of BHP Billiton's copper mine, Minera Escondida Limitada (MEL). The team visited the MEL site situated 200 km inland from the port city of Antafogasta, Chile in October 2007. The first section conveys the understanding of the asset-specific circumstances that was gleaned from our interviews with Base Metals Division executives, MEL energy managers, local academicians, and energy experts familiar with the energy infrastructure in Chile. The subsequent sections offer a direct application of the Framework (Steps 1 to 6) to the MEL site, in order to determine how the framework can be used to obtain a concept level understanding for which renewable energy technology will best meet the asset's needs. A detailed economic analysis of the recommended renewable energy technology (concentrated solar thermal power) is provided is the MEL case study (see **Appendix B**).

Minera Escondida Limitada (MEL) Site Background

Introduction

In October 2007, executives in BHP Billiton's Base Metals division faced several key challenges over the upcoming years in securing supplies of energy for the world's most productive copper mine, MEL. Overall, times were good for Base Metals as they reaped record-setting profits due to record-high prices for copper. However, the higher prices were accompanied by higher expectations from local and regional stakeholders. In 2006, the Chilean government had imposed a new royalty on the mining industry and declined to award MEL valuable water rights needed to expand copper production.[173] Meanwhile, Argentina had completely cut off its natural gas supply to northern Chile, which formerly fueled the majority of MEL's power. The shortage of natural gas caused a switch to more expensive fuels and sharply increased the average cost of electricity while severely constraining growth. In response to the restricted supply from Argentina, Chile's legislature was considering the enactment of a renewable energy portfolio standard to diversify Chile's power portfolio, making the country less vulnerable to such fuel supply constraints. This law would require power providers, including those supplying MEL's power, to generate 5% of their energy using renewable fuel sources by 2010.

173 The Mining News, "News on Mining Impacts," http://www.theminingnews.org/news.cfm?newsID=529, accessed November 2007.

History of Escondida

Escondida's massive copper ore deposit was discovered on March 14, 1981, when a joint exploration venture between Minera Utah de Chile Inc. and Getty Mining (Chile) Inc. financed a mining exploration program in northern Chile in a 50-50 joint venture. Rights to the ore deposit were subsequently transferred to the current owners and a project was developed into what is now known as Minera Escondida Limitada (MEL). Some of the largest natural resources companies currently own Escondida: BHP Billiton (57.5 percent ownership and the operator of the mine); Rio Tinto PLC (30 per cent); Jeco Corporation, a Japanese holding lead by Mitsubishi Corporation (10 percent); and International Finance Corporation (IFC), a World Bank subsidiary (2.5 percent).[174]

Copper Markets

The fundamentals of the copper market shifted in the early 2000s, leading to a sustained spike in prices. This was driven to a large part by growing demand for raw materials in China that was for the construction of factories, cars, appliances and electrical power infrastructure. The surge in demand and prices had not been anticipated by the copper industry, and prices were expected to remain high into the foreseeable future. After reaching a 14-year low of $0.604 cents per pound in 2001, the price for copper increased almost 7 times to $4.07 per pound by May 29, 2006.[175] This price increase led to windfall profits for Escondida.

Exhibit 7-1: Escondida annual income and price of copper. Source (Escondida Annual Report, 2006)

Year	2002	2003	2004	2005	2006
Income (US$ millions)	933	1.595	3.150	4.360	8.375
Fine Copper Tons Sold	741.289	970.098	1.145.913	1.225.069	1.266.386
Average Copper Price (¢/LB)	70.65	80.73	130.11	167.08	305.2

Chile: Indirect Expropriation of Copper Profits

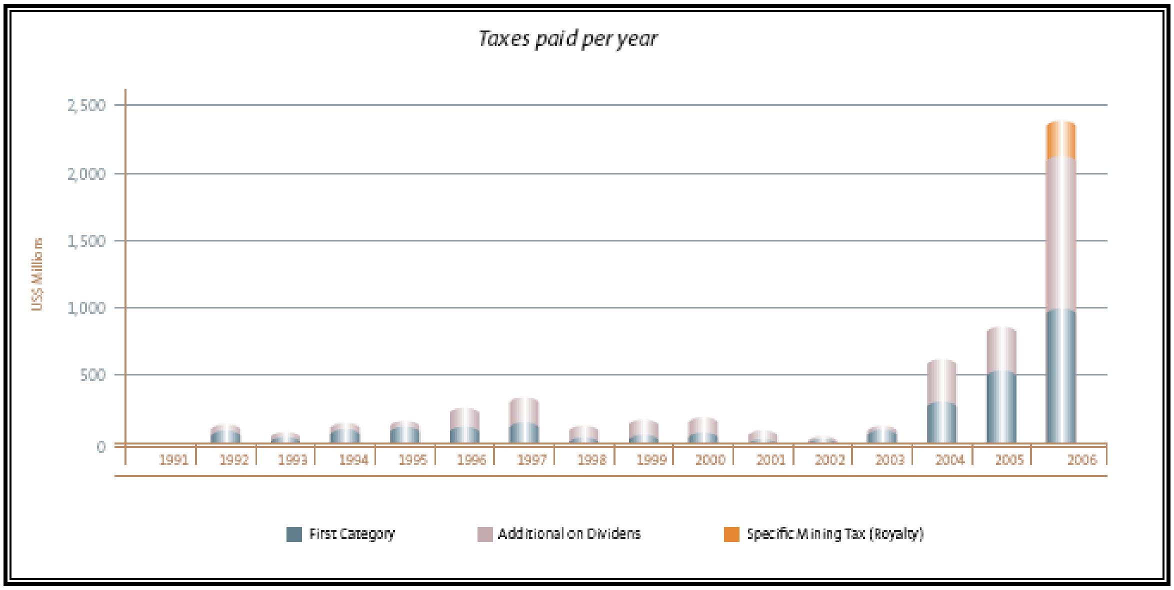
Chile has the world's largest proven reserves of copper. Thus, the Chilean government receives a significant portion of its revenue from copper royalties. In 2006, Chile passed the Specific Mining Tax (Royalty), which required the mining industry to pay additional taxes of 0% to 5% on top of the corporate income taxes, with mines selling more than 50,000 metric tons of fine copper paying the

174 BHP Billiton, website

175 Codelco Copper Case. Harvard Business Review.

entire fixed rate of 5%. In 2006, MEL paid Chile's Public Treasury a total $2,411 million in taxes and royalties, including $266 million for the newly enacted Specific Mining Tax.[176]

Exhibit 7-2: Escondida annual tax payment to Chilean government. Source: (Escondida Annual Report, 2006)



Mining and Refining Copper at MEL

MEL produces copper concentrate from mined ore by means of the sulphide ore flotation process, oxide ore leaching, and low-grade sulphide bio-leaching processes. In June, 2006, Escondida harvested the first batch of copper cathodes produced from a new bio-leaching process that enabled Escondida to process low-grade sulphide ore. Construction of this new plant added 180,000 tons of copper cathodes per year and included the construction of a sea water desalination plant in Coloso. This desalination plant was the largest in South America.[177] After processing, water was pumped from sea-level up to 3200 m elevation a distance of 170 km from the coast. MEL generates approximately 360 million tonnes of mineral annually.[178]

MEL's physical infrastructure consists of the following:

- two open pit mines (Escondida, and Escondida Norte)
- processing mills
- two concentrator plants (Laguna Seca, and Los Colorados)

176 Escondida Annual Report

177 Minera Escondida Limitada, Sustainability Report, 2006.

178 Minera Escondida Limitada, "We are the largest dingle mine copper producer in the world," http://www.escondida.cl/mel/en/index.asp, accessed November 2007.

- an electro-winning plant
- two 170-km pipelines that transport copper concentrate
- a copper concentrate dewatering and filter plant, and
- a sea water desalination plant in Coloso and 170 km of pumping infrastructure.

Power at MEL

Power Demand and Portfolio

The base-load power demand at MEL is a relatively stable 410 MW with peak loads reaching 430 MW . The power demand is split between the main mining/processing facility at Escondida and the water purification and copper concentrate dewatering facility located at the port of Coloso. At Escondida, the vast majority of power is consumed by the milling (~800,000 MWh/year) and electro-winning (~400,000 MWh/year) processes. At Coloso, the majority of power was consumed in water desalination and pumping (~350,000 MWh/year), copper concentrate dewatering (~39,000 MWh/year) , and water purification (~39,000 MWh/year).[179]

In October, 2007, MEL had six contracts with three power generators to supply over 500 MW. Prior to 2004, 48% of MEL's power was derived from natural gas, and 49% from coal and pet coke. In response to Argentinean natural gas export restrictions, MEL's current power portfolio has shifted to 68% coal and pet coke, 27% diesel, and 1.5% natural gas. Going forward, the power portfolio from 2007 onward is expected to stabilize at 78% coal and pet coke, 17.4% natural gas, 1% diesel, and 1% fuel oil. The transition from natural gas to diesel power led to a 23% (or 675,000 tons CO_2e/year) increase in carbon emissions at MEL (see table below).[180]

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179 Mauricio Ortiz, "Power Situation at Minera Escondida Limitada," PowerPoint presentation to Master's Project Team, October 2007. BHP Billiton, Base Metals Headquarters, Santiago, Chile.

180 Ibid

Exhibit 7-3: Escondida emissions factors before and after natural gas restrictions. Source: Moazed (2008)

Energy Carrier	Emission Factor (ton/MWh)	New MEL Mix	Old MEL Mix
Coal	1.04	48.30%	29.20%
Pet Coke	1.32	19.75%	20.60%
Diesel	0.71	27.30%	0.70%
Diesel & Fuel Oil	0.76	0.30%	0.30%
Fuel Oil	0.79	2.50%	0.15%
Natural Gas	0.45	1.50%	48.60%
MEL Emission Factor (ton/MWh)		0.99	0.80

Chilean Electricity Industry and Regulatory Framework

The Chilean electricity industry is heavily privatized, with the government present only in a regulation, monitoring, and planning capacity. The market is partially regulated. Consumers who use <2,000 kW are part of the regulated market, while those with an electricity demand >2,000 kW, or with other non-standard requirements, are free to negotiate their own power contracts. The latter customers account for about 55% of total electricity sales.[181]

Energy Shortages

The Chilean electricity grid is divided into four autonomous grids. MEL's power is derived solely from the northern grid or Sistema Interconectado del Norte Grande (SING), which has an installed capacity of 3,634 MW at the end of 2004. Unregulated customers account for over 90% of electricity sales in the SING, due to the presence of many large mining customers, including MEL.[182] As such, residential and small-scale commercial demand accounts for only 10% of electricity demand. Total demand on the SING grid was approximately 1,890 MW, of which MEL was responsible for 28%. In 2004, natural gas imported from Argentina accounted for approximately 58% of the installed capacity, while coal accounted for 33% and other non-renewable sources comprised the remaining 9%. Until recently, imported natural gas from Argentina accounted for over 80% of Chile's natural gas supply, with only 20% generated internally, but supplied to grid systems other than the SING.

181 Energy Information Administration, "Country Analysis Brief, Chile," September 2006.
182 O'Ryan and Febre Ingenieros Consultores, "Global and Local Environmental and Energy Security benefits of the Development of the Renewable Energy Sector in Chile," April 2006.

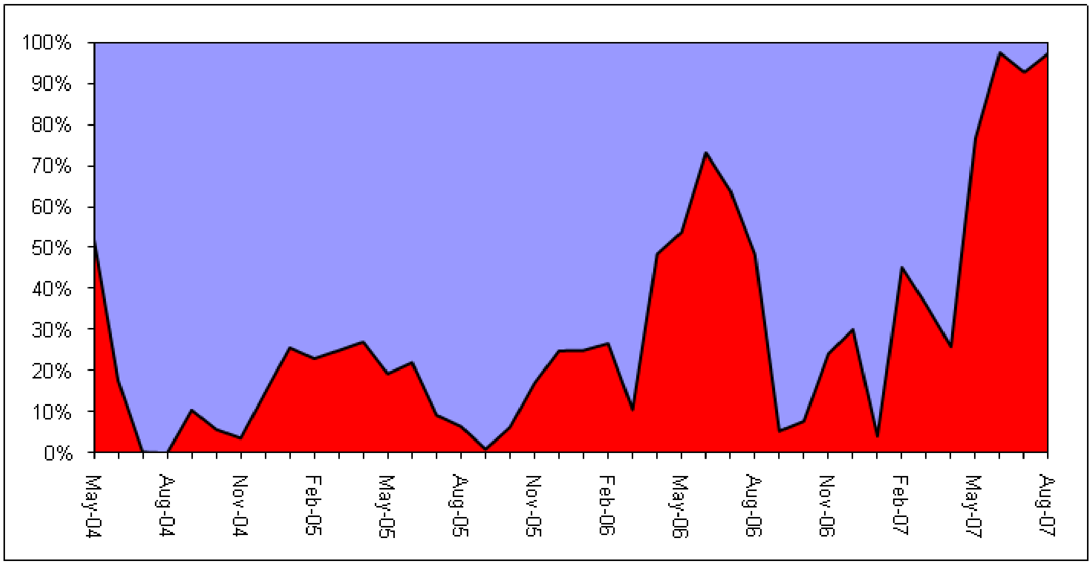
The SING was initially burdened by massive overcapacity—peak electricity demand reached just 39% of capacity in 2002—a result of the simultaneous construction in 1998-99 of two rival gas pipelines from Argentina and their associated combined-cycle electricity-generating plants, when there was a market for only one such project. However, beginning in 2004, Argentina began restricting natural gas supply, and the installed capacity shrank to only 2,160 MW. As a result the SING maintains a very low operating reserve margin of generating capacity, and the opportunities to implement new projects with significant power demand are limited.[183]

Exhibit 7-4: SING grid and regional map. Source: EIA (2006)

Since 2004, Argentinean natural gas exports to Chile have fluctuated between 20-50 percent below contracted volumes, with natural gas flows ceasing completely on some occasions. The import cuts have caused shutdowns at power plants and forced power generators to switch to more costly fuels, such as diesel. Along with the cuts in volumes, Argentina has also increased natural gas prices: in July 2006, Argentina increased its natural gas export tax to 45 percent, from 20 percent[184].

183 Energy Information Administration (2006)
184 Ibid

Exhibit 7-5: Percentage of Argentina's natural gas supply contracts restricted from export to Chile. Source: EIA (2006)



MEL Response to Energy Shortage

In light of impending power shortages and high electricity prices, BHP Billiton is pursuing alternative sources of power generation to ensure security of supply. An expensive, but necessary, proposed interim solution (2007 – 2010) is to replace the gas generation with diesel at current power generators, while exploring alternative mid- to long-term solutions. As a result of the switch between the predominant power sources, the current levelized cost of electricity on the SING rose dramatically to $170/MWh[185].

The proposed mid-term solution involved the construction of a liquefied natural gas (LNG) regasification terminal to supply existing natural gas combined cycle generating facilities. Competing mining companies, Suez and Codelco, formed a joint venture named GNL Mejillones to develop such an LNG regasification terminal at the port of Mejillones (near Antofagasta). The regasification facility would supply natural gas sufficient to generate 1,100 MW of electricity.[186] GNL Mejillones also signed contracts with MEL for the sale of up to 150 MW beginning in 2009.[187]

185 Ortiz (2007)
186 Energy Information Administration (2006)
187 Ibid

To address the power shortages in the long-term, BHP Billiton is arranging to secure power purchase agreements for up to 340 MW of power from a new coal plant that would be constructed that would be connected to the SING.[188]

Pending Legislation: Renewable Portfolio Standards

Historically, Chile's regulatory framework had been neutral with respect to the technologies and energy sources used to generate electricity and these sources all had to compete on similar terms. However, in January 2006, Short Laws I & II proposed extending benefits to renewable energy production. The Short Law I established preferential conditions for renewable projects of less than 20MW by exempting small plants from trunk transmission tolls, dispatching 100% of generation to the grid, and guaranteeing a price equivalent to the node price determined by the regulated price for utilities[189]. The Short Law II established additional benefits, stipulating that 5% of the energy tendered by distributors must be supplied using renewable energy sources with a proposed penalty of approximately $27/MWh for non-compliance. This would put the long-term levelized cost of electricity for MEL at approximately $0.082 per kWh ($ 0.055 / kWh + $0.027 kWh penalty).[190]

Expansion: Water and Energy Challenges

Providing sufficient water to ensure cost-effective operations at MEL is one of the major impediments to expansion of the mine. Water is a scarce resource for MEL which is located in the Atacama Desert – the driest location on earth. As a result, water is pumped to the sites from up to 170 km away and up steep inclines (e.g., from sea level to 3200 meters elevation).[191] This results in tremendous power demand and a massive water delivery infrastructure.

MEL is investigating several alternative water supply expansion projects, including:

> **Hamburo Sur New Wells Project** seeks to obtain an additional 150 liters per second from the Hamburo Sur area by installing an additional 30 pumping wells.[192]
>
> **Pampa Colorado Water Supply Project** was proposed to acquire water from the Pampa Colorada area. The project consisted of extracting water from a subterranean aquifer high in the Andes and included provisions for environmental monitoring. Permits for this project were being reviewed in fall of 2007 and were subject to an Environmental Impact Study approval. The government ultimately rejected the permit application.[193]

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188 Ibid
189 Government of Chile, National Commission on Energy, "Chile's Energy Security Policy," November 1, 2006.
190 Pacific Hydro, October 2007
191 Bernardo Tapia, Minera Escodida Limitada, Personal communication. Antofogasta, Chile. October 2007.
192 Minera Escondida Limitada, "Sustainability Report," 2006.
193 Minera Escondida Limitada, "Sustainability Report," 2006.

Desalination Plant at Coloso Port provides a reliable but expensive source of water for Escondida. One of the major costs of running this project was the cost of the energy required to desalinate and pump the water. An upgrade to this facility is being considered as an alternative as the Pampa Colorado project was not approved. This upgrade would require a constant supply of 250 MW of power after completion, roughly the entire power supply that is provided by a mid-small scale natural gas power generation facility.[194] [195] It is estimated that the desalinization plant upgrade at the Coloso Port would be nearly $2 billion over the project lifetime.

Without securing an additional source of water, MEL would not be able to expand their production in response to high copper prices and would sacrifice a significant opportunity to generate additional revenues.[196]

BHP Billiton Corporate Climate Change Policy

BHP Billiton's Corporate Climate Change Policy establishes emissions reduction goals that are to be met by asset operations, including MEL. The policy's target is to reduce energy and greenhouse gas emissions intensity by 13 and 6 percent, respectively, over the period 2006-2012. Escondida is required to create management plans for greenhouse gases and energy that will be incorporated into the business operation plan. Carbon prices are incorporated into capital decisions of $100 million or more and BHP Billiton has a carbon-trading desk that is capable of certifying and selling any carbon credits that assets generate under the Kyoto Protocol standards. Furthermore, $300 million has been committed from 2007-2012 for projects that would support low emissions technology deployment, internal energy excellence projects, and encourage emissions abatement.[197] This could potentially be used to help energy projects help clear a financial hurdle rate that they would otherwise not be able to clear.

Planning for the Future

Base Metals is not planning on owning or operating any energy generation facilities themselves but they do exert significant influence on the future energy mix of the northern grid by paying for feasibility studies and signing long-term contracts to purchase electricity from power providers. With the price of copper where there is pressure to secure a reliable source of power quickly, and importing natural gas from Argentina or Bolivia is not an option. Deciding upon the configuration and contract structure for new power generation in the SING while considering potential

194 Ibid
195 Bernardo Tapia (2007)
196 Ibid
197 BHP Billiton, Sustainable Development, "Climate Change," http://www.bhpbilliton.com/bb/sustainableDevelopment/environmentalCommitment/climateChange.jsp, accessed January 2008.

requirements to procure renewable energy and internal GHG goals presents a serious challenge for Base Metals. Furthermore, renewable energy typically does not provide the type of baseload power that MEL requires for effective operations.

Framework Application

Below is a step-by-step application of the Framework for Renewable Energy Assessment to the MEL asset. This example application is designed to aid BHP Billiton corporate and asset managers evaluate renewable energy options in a structured manner, accounting for both corporate and asset-specific drivers and goals. The framework largely rests upon a foundational "base case" that has been outlined in the previous section, therefore, some information is repeated below in the context of the Framework development.

Step 1: Understand the Base Case

In developing the base case, the objective is to generate a well-rounded understanding of the technical and regulatory issues influencing power supply/demand at the asset, as well as the strategic factors underlying any decision to pursue renewable energy projects.

Key questions to be answered in the exploration of the base case include the following:

What are the current and planned sources of supply/demand for energy and at what cost?

> **Supply:** MEL currently has 6 contracts with external power providers to supply up to 500 MW of power. The majority of this 500 MW was previously supplied via natural gas combined cycle plants, however, following Argentina's curtailing of natural gas supplies, power providers have transitioned to more expensive diesel fuels for use in the combined cycle plants. This has increased the cost of electricity to $0.082/kWh. Diesel is serving as a short-term solution while plans are underway to construct a LNG terminal and regasification facility in Mejillones that will supply natural gas to the combined-cycle plants. MEL will procure up to 120 MW of power to MEL from the Mejillones supplied plants. Furthermore, MEL is supporting the construction of a new coal plant in the region and plans to purchase up to 340 MW of power from the plant. Future costs are expected to be lower than $0.17/kWh.
>
> **Demand:** MEL currently has a relatively flat and predictable power demand profile of 410 – 430 MW. There are planned expansions in the ore processing capacity which require additional water supply and pumping infrastructure. This is projected to result in additional power demands of up to 250 MW. Total demand on the SING is 1,890 MW while total capacity is 2,160 MW, leaving little room for expansion without building additional power infrastructure.

What is the current transmission and distribution infrastructure?

The SING is completely isolated from the central and southern grid in Chile. Small renewable energy projects (under 20 MWh) have first-rights to grid access and are not charged for T&D costs.

What are the internal and external factors affecting energy supply and demand?

Legislative Requirements: Short Laws I and II will likely require the adoption of renewable power projects to supply up to 5% of energy on the SING by 2010. This energy will not necessarily be directed to or paid for by BHP Billiton operations at MEL, however, BHP Billiton would incur a pass through of penalty costs should the power provider fail to comply with the law. Given that BHP Billiton currently uses ~430 MW (with plans to expand), the power provider must supply up to ~25 MW of renewable electricity to the grid for MEL's portion of the power consumption alone. This large proportion of the grid demand (~28%) gives BHP Billiton leverage to influence the energy infrastructure investments by independent power providers. In all, ~100 MW of renewable electricity will be required on the SING. BHP Billiton and MEL have significant clout in determining the source of this energy through negotiation of power purchase agreements with suppliers.

Stakeholder Engagement: MEL's access to mineral and water rights, necessary to continue cost-effective operations, is indirectly influenced by its relationship with local communities and regional and federal governments. Given the potential for power shortages on the SING, which could impact local communities, and the federal government's desire to broaden the power portfolio into renewable energy, BHP Billiton may be well-positioned to build stronger relationships with these stakeholders by influencing its power provider to build additional capacity on the SING using renewable energy technologies. By responsibly engaging stakeholders BHP Billiton seeks to become the company of choice for countries/communities to work within the natural resource extraction industry.

Corporate Climate Change Policy: Contrary to climate change policy of reducing GHG intensity by 20%, the change in power fuel portfolio at MEL has led to an increase of 23% in GHG intensity (from 0.8 to 0.99 kg/ton). Procuring renewable energy for use at the site could help MEL make progress toward fulfilling corporate GHG reduction goals.

Corporate Technology Leadership Initiative: BHP Billiton strives to maintain a competitive advantage over other natural resource extraction companies by employing the most advanced, and environmentally responsible technologies.

Step 2: Identify Drivers and Develop Goals

In this step, it is critical to elicit and understanding of which particulars of the base case influence the case for renewable energy (drivers) and what goals for renewable energy might be adopted based upon these drivers. These goals should then be weighted according to the relative importance of the goal. There are no strict rules for weighting the goals. This process calls for user discretion and should be agreed upon by the DT members, as it ultimately informs the prioritization of renewable energy technologies.

Based on conversations with various corporate and asset-level stakeholders at MEL, we identified the following as the principle drivers of renewable energy adoption in Chile, in priority order, and approximated a weighting scheme:

Exhibit 7-6: Example of drivers and goal weighting in Step 2 of the framework. Source: Moazed (2008)

Base Case Information	**Driver**	**Goal**	**Type and Weight (%)**
Pending regulatory requirement of 5% energy from renewable sources	Need to cost-effectively meet legislative requirements (BHPB policy discourages payment of penalties for non-compliance)	To supply up 5% of energy requirements through renewable energy (~25 MW)	Threshold*
Limited access to mining concessions and water rights, increasing demands for both; history of abuse by mining companies	Need to gain and maintain license to operate and grow and foster positive relationships with communities and nations	To pursue projects that demonstrate BHPB's commitment to sustainable development to government, community and civil society (i.e. developing highly visible and favorable renewable energy projects)	Comparison 40%
BHPB corporate mandate to reduce GHG emissions	Need to meet internal GHG reduction requirements	To meet CO2e reduction goals via renewable energy	Comparison 30%
Industry trend emphasizes innovation in sustainability and technology	Desire to demonstrate leadership in technology and sustainability	To be the first-to-market in the industry with an innovative world-class renewable energy project	Comparison 20%
Limited excess grid capacity, increasing demand	Need to provide secure and stable energy supply	Develop additional capacity, partially through renewable energy	Comparison 10%
*- Threshold goals require technologies to meet or exceed the threshold. If these thresholds are met, the technologies will be evaluated according to Comparison goals.			

The ability of a renewable energy technology to meet the goal of supplying the energy necessary to comply with the pending legislative requirements (~25MW) is seen as a Threshold goal. Technologies unable to meet this goal should not be considered for adoption, unless BHP Billiton is willing to meet this goal using a portfolio of renewable energy technologies. The Comparison goals are then weighted according to their relative importance of the associated drivers.

Step 3: Develop and Prioritize Project Criteria

In this step, the user attempts to develop a list of technology-specific criteria for evaluating renewable energy projects based upon the desire to meet the goals identified in Step 2. Threshold criteria should be identified and The Framework contains a comprehensive list of criteria that are capable of distinguishing the performance of renewable energy project types (i.e., wind, solar, biomass) with respect to most goals. The user should select criteria from this list that relate to the goals from Step 2.

In the case of MEL, the team developed the following relationship between goals and criteria.

Exhibit 7-7: Example of criteria development in Step 3 of framework. Source: Moazed (2008)

Goal	Type and Weight	Criteria
To cost-effectively supply up 5% of energy requirements through renewable energy (~25 MW)	Threshold*	Capacity* Cost
To pursue projects that demonstrate BHPB's commitment to sustainable development to government, community and civil society (i.e. developing highly visible and favorable renewable energy projects).	Comparison 40%	Stakeholder acceptance
To meet MEL's corporate GHG goals via renewable energy deployment if possible	Comparison 30%	GHG offsets Capacity
To be the first-to-market with innovative world-class renewable energy project	Comparison 20%	Innovation
Develop additional capacity through renewable energy	Comparison 10%	Capacity
*-The Threshold criteria most closely associated with the goal should serve as a minimum acceptable performance standard for technologies under consideration.		

The criteria should be assigned a weight according to their frequency of appearance and the importance of the goals with which they are associated. Again, the actual weighting of the criteria requires user discretion and concurrence among DT members. In the case of MEL, capacity appears to be the most important criteria primarily because it is most closely associated with a Threshold goal, and secondarily, because it is associated with three of the five major goals that drive the adoption of renewable energy. Capacity is can serve as both a Threshold criteria and a Comparison criteria. The fact that it serves as a Threshold criteria does not imply that it will then be the highest ranking Comparison criteria, because as a Threshold criteria, capacity has already established a minimum standard for renewable energy technologies. In this case, cost might take precedence in the Comparison criteria as it is associated with the most critical goal.

Exhibit 7-8: Example of criteria weighting in Step 3 of framework. Source: Moazed (2008)

Criteria	Weight
Capacity (~25 MW)	Threshold
Cost	40%
Capacity	30%
Stakeholder acceptance	20%
GHG offsets	15%
Innovation	5%

Step 4: Assess Renewable Resources

The following summarizes the investigation of renewable resources made by following the Resource Assessment Toolkits and based on information available during our site visit to MEL.

Solar: MEL is located in the Atacama Desert which is the driest place on the planet and has one of the best solar resources in the world. According to country-level data collected by the United Nations Environment Program, north-central Chile receives some of the most consistent and highest intensity solar radiation in the world. The dry, high-altitude Atacama Desert receives excellent year-round radiation that frequently measures more than 9 $kWh/m^2/day$. This is nearly 30% stronger than the best radiation received at existing CSP plants operating in the United States and Spain. Solar resources are considered among the best in the world, and MEL should undertake further exploration of conversion technologies using solar energy.

Wind: There is anecdotal evidence of relatively strong and reliable wind resources in the mid-elevation plateau between the Port of Coloso and the high plains of the Atacama Desert. However, wind resources have yet to be assessed in sufficient detail in this region. As such, MEL has entered into an MOU with Pacific Hydro to investigate wind energy potential during our study. Based upon a high-level assessment of regional and global scale wind maps, the team estimated that wind is in the Class 4. However, the team recommends further investigation of wind resources through purchase of site-specific wind maps from 3Tier and follow-up wind monitoring. In general, wind resources should be further explored. Site specific wind data can be assessed after collecting a year's worth of data using wind-monitoring towers.

Exhibit 7-9: Example of resource assessment in Step 5 of framework. Source: Moazed (2008)

Resource	Resource Available	Rating	Viable Based on Assessment?	Technologies to be Retained or Removed
Wind Speed	Class 4-5	Med	Yes	Wind Turbines
Solar Radiation	7 W/m²	High	Yes	Solar PV Solar Thermal
Biomass Residue Availability	0 tons/year	Low	No	Biomass Combustion Biomass Gasification
Biomass Energy Crop Availability	0 tons/year	Low	No	Biomass Combustion Biomass Gasification
Geothermal	Unknown	Low	No	Geothermal

Biomass: The lack of precipitation in the Atacama Desert severely restricts the primary productivity of the surrounding land. During the site visit, no nearby sources of biomass were identified. In fact, there is no visible vegetation whatsoever within a reasonable distance from the site. As such, biomass was not considered to be a viable resource for energy conversion due to the long distance and complex supply chain logistics to provide biomass waste or energy crops. Therefore, biomass resources are considered poor or unavailable.

Geothermal: In the absence of clearly identified resources, significant geothermal resources are prohibitively expensive and risky to discover and exploit. Professor Marcos Crutchik Norambuena of the University of Antofagasta informed the MS Team that a single exploratory perforation would cost approximately $2 Million (Norambuena 2007). Due to the expense of exploration geothermal resources are considered relatively unattractive.

Step 5: Identify Viable Renewable Energy Technologies

Based upon the resource assessment in Step 4, the renewable energy conversion technologies that are most capable of performing effectively in the vicinity of MEL, include:

- Concentrated Solar Thermal
- Solar PV
- Wind Turbines

Step 6: Match Viable Technologies to Criteria

This step brings together the weighted criteria from Step 3 and the viable technologies from Step 5, in order to obtain a relative ranking of renewable technologies according to the prioritized criteria. General guidelines for the relative performance of each technology with respect to the major criteria from Step 3 can be found in the Technology Assessment Toolkit. The output of Step 6 is a ranked list of viable renewable energy technologies whose characteristics best fit the priorities established by the processes from Steps 2 (identifying drivers and establishing goals) and 3 (prioritizing criteria according to the ranked goals). This list can be developed quantitatively or qualitatively, as demonstrated below.

All technologies under consideration have the ability to meet the threshold criteria of 25 MW of capacity. However, solar power offers the greatest promise for the MEL site based on its ability to fulfill the list of Comparison criteria. Solar resources can be converted to electricity using two main technology configurations: **photovoltaics (PV)** and **concentrated solar power (CSP)**. Both of these technologies are highly scalable, relatively proven, and have extremely stable and low operating costs. Furthermore, relative to wind energy, solar technologies offer highly predictable electricity generation and likely a higher capacity factor due to the availability of the resource (lack of cloud cover in the Atacama Desert). Overall, both technologies warrant favorable ratings, with the one open question regarding the availability of water required for the CSP operation. However, the levelized cost of electricity for PV configurations could be fairly high compared to the planned coal plant, due to the high capital costs for PV technologies.

Concentrated Solar Thermal Power: Concentrated solar thermal power (CSP) is currently the most promising large-scale renewable energy option for MEL because it best meets the criteria of capacity, cost, stakeholder acceptance, and innovation.

> **Capacity:** The deployment capacity of CSP and the quality of the solar resources in the Atacama Desert make the technology capable of meeting the Threshold criteria of providing 25 MW of power needed to comply with impending renewable portfolio standards. However, CSP operates at a 30-40% capacity factor, so the nameplate capacity of the plant would have to be significantly larger than 25 MW (~60-85 MW). CSP is an attractive option for intermediate load power during daytime hours, as the resource availability in the Atacama Desert is extremely high. CSP power is unavailable during evening hours and therefore, cannot provide standalone baseload power for continuous operations, such as those at the MEL mine sites.
>
> CSP also has the significant benefit of being able to incorporate thermal storage which both increases power output of the plant (through higher capacity factor) and provides the flexibility to generate power on demand (dispatchability).
>
> **Cost:** The levelized cost of electricity for solar thermal is estimated to be in the $0.09 - $0.17/kWh range. However, the CSP plant may be able to tie into existing steam generation turbines in the area, thereby reducing capital and levelized costs significantly. These cost estimates include industry-averages for water delivery infrastructure. Since water is generally unavailable in the Atacama Desert, we anticipate higher than average costs associated with water supply.

Stakeholder acceptance: The regional and national governments are likely to be receptive to the concept of developing their world class solar resources to produce one of the most effective CSP plants in the world. This would also generate much needed capacity expansions in the SING, making daytime power outages in residential areas less likely. Finally, the Atacama Desert is largely uninhabited and supports very little flora and fauna, so barriers to construction of CSP plants, which require large tracts of land, are likely to be low. The only concern that remains is the quantity of water required to operate the facility and whether access to water rights carries with it significant social, environmental, or political implications.

GHG offsets: CSP's offset potential is based upon its capacity. Any energy that it produces will likely offset coal emissions from plants or fuel displacement.

Innovation: CSP is also in alignment of BHP Billiton's strategy to pursue projects that are large, efficient, and could be considered distinctive as the first major CSP project in Latin America.

Solar PV: Solar PV may be an attractive option for small, remote projects, such as pumping water from wellfields to the ore processing sites. However, the capacity and cost limit its attractiveness for large-scale projects.

Capacity: Solar PV can be scaled to meet the project Threshold criteria (25 MW), however, the deployed nameplate capacity would have to be in the 120 MW range based upon the relatively low capacity factor for the technology.

Cost: The levelized cost of electricity for solar thermal is estimated to be in the $0.19 to $0.30/kWh range.

Stakeholder acceptance: The regional and national government are likely to be receptive to the concept of developing their world class solar resources to produce one of largest and most effective PV plants. However, PV is only capable of supporting relatively modest capacity expansions of intermediate load capacity in the SING, and is incapable of providing standalone baseload capacity for continuous operations. Finally, the Atacama Desert (the likely location of any PV plant) is largely uninhabited and supports very little flora and fauna, so barriers to construction of CSP plants, which require large tracts of land, are likely to be low.

GHG offsets: PV's offset potential is based upon its capacity. Any energy that it produces will likely offset coal emissions from plants or fuel displacement. Since the capacity of PV is relatively low, the GHG offsets are expected to be equivalently low.

Innovation: A major PV project is aligned with BHP Billiton's strategy to pursue projects that are considered best-in-class due to the absence of any existing large-scale solar projects in northern Chile and the world-class solar resource present in the area.

Wind: Wind energy is scalable, could provide a low levelized cost of electricity, is likely to be favorably perceived, and is technically mature and reliable. Furthermore the presence of Pacific Hydro – a major global wind developer – in Santiago makes wind more attractive. However the economics cannot be validated without the 1 year study, and land use rights must be obtained for sites with the best resources, creating risk of failure. Also, the optimal site may be too distant from transmission and distribution, destroying the low-cost economics. Lastly, wind's potential may be complicated by the lower predictability and relative intermittency of electricity production.

Wind energy may still be quite attractive if the study finds significant resources available on usable land near transmission and distribution. While the risks are great, the cost of studying the potential for wind energy is relatively low (less than $2 Million total), and will eliminate most of the uncertainties associated with the technology. While wind is somewhat promising, the class of wind resources is unknown, and the reliability of wind power in general makes it unattractive as a base or intermediate load source of power. This is mostly a concern if the wind farm is directly powering operations at the asset.

Capacity: Given that wind has a capacity factor in the 30% range and is relatively intermittent under the best of circumstances, the nameplate capacity of a wind farm would have to be at least 75 MW to meet the Threshold criteria. Wind power may be an attractive option for *supplementing* base/intermediate load generation, using techniques currently employed by leading utility companies worldwide who have successfully integrated wind energy in their energy supply portfolios. However, the relatively flat power demand curves for MEL makes wind power less desirable for site operations and more appropriate for grid feed-in and "renewable-for-fossil" power swap arrangements that do not directly support asset operations.

Cost: Wind is generally a cost-competitive ($0.06 - $0.09/kWh) renewable energy source if adequate resources are available to push capacity factors toward 30%. The quality of wind resources at MEL are anticipated to be moderate and highly intermittent at best, so the capacity factor is likely to be significantly lower than 30%, and as a result, more wind turbines would need to be deployed to achieve the 25 MW capacity. This would increase the cost of electricity significantly.

Stakeholder acceptance: Regional and national government are likely to be moderately receptive to the concept of developing wind farms in the Atacama Desert. This would generate modest capacity expansions in the SING, making nighttime power outages in residential areas less likely. Finally, the Atacama Desert (likely location of any wind farm) is largely uninhabited and supports very little flora and fauna, so barriers to construction of wind farm, which require large tracts of land, are likely to be low.

GHG offsets: Wind's offset potential is based upon its capacity. Any energy that it produces will likely offset coal emissions from plants or fuel displacement.

Innovation: Wind farms have been widely deployed and the wind resources in the Atacama Desert are not known to be world-class.

Exhibit 7-10: Example of quantitative comparison of renewable energy technologies across criteria. Source: Moazed (2008)

		Technology Performance		
Criteria	**Weight**	**Solar PV**	**Solar Thermal**	**Wind**
25 MW Capacity	Threshold*	Meets	Meets	Meets
Cost	40%	1	4	4
Capacity	30%	4	9	4
Stakeholder acceptance	20%	4	9	4
GHG offsets	15%	1	4	4
Innovation	5%	4	9	4
Total Score**		2.75	5.95	4.4

* Technologies that do not meet the threshold criteria should be eliminated from consideration.

** Total Score is the sum product of the criteria-specific weight and the technology performance for the criteria.

Step 7: Conduct Detailed Economic, Social and Environmental Screening of Project

A more thorough assessment of the most promising renewable energy technologies (CSP and Wind) is presented in the MEL Site Evaluation for Renewable Energy.

Supplemental Exhibits

Exhibit 7-11: Size of Chilean Copper Mines and Their Share of World Production. Source: Brook Hunt (2006)

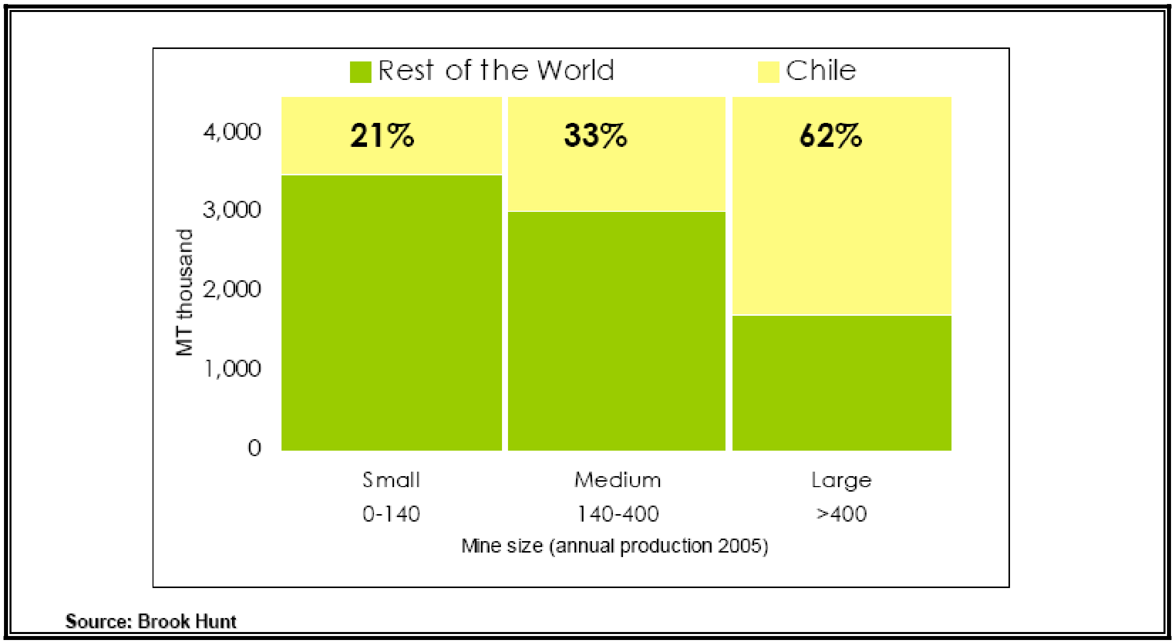

Exhibit 7-12: Major Events in the history of Escondida. Source: Escondida Annual Report (2006)

Year	Phase	Capacity (tonnes/year)
1981	Discovery of the orebody	-
1990	Start-up of the concentrator plant, Los Colorados	35,000
1993	Start-up of Phase I expansion	45,600
1994	Start-up of Phase II expansion	80,000
1996	Start-up of Phase III expansion	105,000
1998	Phase 3.5; Well fields of Monuraqui	120,000
2001	Expansion of the oxide plant	150,000
2006	Sulfide Leach Project	180,000

Exhibit 7-13: Copper prices, (1998 - 2007). Source: London Metal Exchange (2008)

Exhibit 7-14: Chile's historical natural gas production and consumption prior to cut-off from Argentinean imports. Source: IEA (2006)

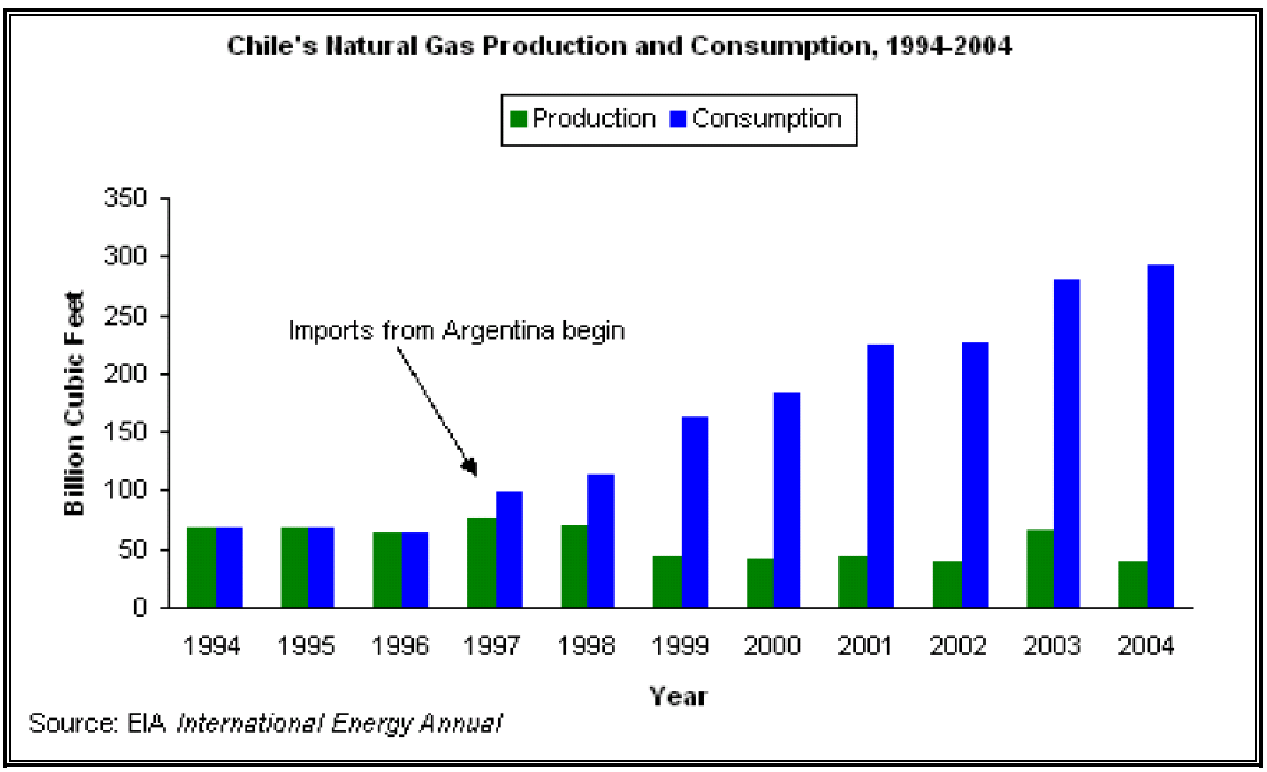

Exhibit 7-15: Major operating costs for MEL. Source: Escondida Annual Report (2006)

	MUS$ 2005	MUS$ 2006	%
Costs for Tangible Assets and Services According to Fourth Financial Statement method			
Energy	138,300	157,200	20.38%
Spare parts	93,800	109,200	14.16%
Fuel and Lubricants	65,300	84,000	10.89%
Mill balls	47,800	46,100	5.98%
Reagents	51,900	60,200	7.81%
Explosives	26,700	26,800	3.48%
Consultancies	10,000	8,100	1.05%
Subtotal	433,800	491,600	100.00%
Other items	101,546	285,449	
Subtotal	535,346	777,049	

Exhibit 7-16: Water use at MEL. Source: Escondida Annual Report (2006)

	Unit	2003	2004	2005	2006
Monturaqui and Punta Negra	(m3/year)	45,501,221	51,785,294	53,087,276	50,307,075
Mine Drain and Hamburgo	(m3/year)	10,005,810	12,893,760	15,156,568	16,899,952
Fresh Water Total	(m3/year)	55,507,031	64,679,055	68,243,844	67,207,027
Water bought from Zaldivar	(m3/year)	–	–	–	647,777
Water proceeding from desalination plant	(m3/year)	–	–	–	1,195,139
Water Recovered Total	(m3/year)	22,454,940	23,189,526	22,570,730	19,929,905
Total Water Consumption	(m3/year)	77,961,970	87,868,581	90,814,574	88,979,848
Treated sulphide ore tons	(ton/year)	70,348,620	82,379,181	86,053,826	84,158,048
Water consumed by sulphide ore	m3/year	1.11	1.07	1.06	1.06
Water consumed by Hydrometallurgy	m3/year	1,615,685	1,843,408	2,629,233	3,994,832

Exhibit 7-17: Water resources employed by Minera Escondida. Source: Ortiz (2007)

Exhibit 7-18: Escondida open pit copper mine. Source: BHP Billiton (2008)

Chapter 8: Conclusions

Insights on the Adoption of Renewable Energy

Several insights emerged during our thirteen-month exploration of renewable energy and its application for BHP Billiton. Many of these insights reflect the limitations of renewable energy technologies in their current state of development and may be fairly obvious. However, in our experience, one can lose sight of these limitations amid the rush to adopt "clean-tech."

Renewable energy is not a clear choice for captive power generation to serve BHP Billiton's industrial facilities – yet.

Today, the limited capacity and non-dispatchability of many renewable technologies (particularly solar and wind applications), and the frequent (relatively) high cost of generation make these technologies difficult to utilize for *captive power generation* at high-demand industrial facilities with continuous operations. Grid-integrated renewable energy projects can alleviate many of the challenges with renewable energy technologies, such as the non-dispatchability of wind and solar, which stems from the intermittent nature of the resource and the dearth of feasible energy storage options. Current grid-integrated applications of wind and solar can decrease the emissions factor of electricity generation but may require some backup capacity to address intermittent generation. As renewable energy technologies evolve and are able to include energy storage, provide increased capacity, and offer a lower levelized cost of electricity, these technologies will become more attractive. If the price of greenhouse gas emissions permits increases, fossil fuel demand continues to constrain supply, and governments continue to support renewables, then the rate of evolution of renewable technologies should continue to accelerate.

Today, adopting renewable energy is motivated more by strategy than by energy needs.

The purpose of our study was to aid BHP Billiton in the evaluating renewable energy technologies and their appropriateness for the company's industrial assets. When we began our work, we presumed that one of the major drivers for the adoption of renewable energy technologies would be the increasing demand for energy and the need for additional generating capacity. Therefore, we thought that the crux of the decision about adopting renewable energy would be related to the cost of energy provided, the technical performance, and the fit with existing or planned infrastructure. Given the limitations and costs of current renewable energy, the decision to adopt renewables will likely be driven more by regulatory requirements, the desire to enhance BHP Billiton's "license to operate," the need to reduce the GHG emissions, and other strategic benefits described in the Executive Summary.

In retrospect, we recognize that renewable energy in its current state may not completely replace conventional technologies to serve the energy requirements of large industrial facilities. However, renewables can serve as a beneficial *strategic* supplement to existing generation technologies, and will only increase in importance as the price of fossil fuels and the cost of emitting greenhouse gases increases. Today, renewable energy projects can serve as a hedge or diversification tool that reduces risk and volatility for an asset; as preparation for the future of energy supply and emissions reduction schema; as a vehicle for demonstrating distinctiveness, leadership, and innovation; and finally as an enhancement of a company's license to operate.

Success depends on organizational commitment to adopting renewable energy

Given the unique challenges and strategic dimensions of deploying renewable energy technologies at large industrial facilities, successful adoption of these technologies requires clear communication of a project's value, its acceptance by internal and external stakeholders, and the long-term (beyond a single project) vision and commitment of an internal "champion." In our experience at BHP Billiton, renewable energy projects may be motivated by corporate-level goals and strategies. However, these projects run the risk of being perceived as a distraction by the assets. At worst, the projects may be perceived as having potential to jeopardize the continuity of operations. Therefore—to promote broad commitment—corporate-level decision makers should allow for significant asset-level ownership, input, and flexibility in designing and deploying projects.

Suggested Next Steps for BHP Billiton

Considering these insights, we propose the following next steps for BHP Billiton to develop organizational capacity around the development of renewable energy projects which will facilitate the broader adoption of renewable energy technologies.

Create a working group on renewable energy and climate change

BHP Billiton should develop a cross-functional team of employees with an interest in renewable energy and climate change to develop competencies around the application of renewable energy technology and an understanding of the relevant driving factors, such as climate change legislation and GHG emissions markets. This "Renewable Energy Working Group" should consist of employees from the HSEC department, the Energy Excellence group, and interested parties from the Customer Service Groups (CSGs) and operational assets. This team may at some point require either new hires with expertise in renewable energy, or access to third-party advisory on the subject. The team should meet regularly and be informed by senior management, strategic planning, the climate change practice leader (Ed Mongan), marketing, finance and accounting, and CSG and asset-level management, as well as external experts and stakeholders.

Survey assets for renewable energy opportunities

The Renewable Energy Working Group (REWG) should do a broad survey of assets to gauge interest, and identify potential significant opportunities and/or highly relevant drivers for renewable energies. This survey will serve not only as a baseline of information regarding the assets, but also as a mechanism for the identification of renewable energy as a priority and an initial cultivation of interest and knowledge among members of the REWG and at the assets and CSGs.

Select high potential assets for applying the framework

The REWG will then select a number of assets that demonstrate potential from a resources, needs, or interest perspective as pilots for the testing and refining of our framework. Look for assets where some renewable energy generation is required by law, and where there are experienced renewable energy project development partners. Devote specific resources to investigate grid-connected assets for which captive power generation is not required, and where the grid may be able to integrate with intermittent power sources.

Drive promising small-scale opportunities to execution as demonstration projects

Any promising small-scale[198] opportunities (perhaps less than 5MW, or less than some threshold of capital expenditure) that are identified should be moved through the project management process to build expertise in the application of renewable energy technologies. The team should execute the most promising of these projects with the assistance of one or more third-party specialists. If necessary, the team should seek financial support for the project from the $300 million committed as per the Climate Change Policy, which is intended to support projects that would not otherwise "be competitive within [the] normal capital allocation process."[199]

Evaluate and communicate

Once small-scale demonstration projects have been executed, the REWG should carefully monitor their performance, develop communications and educational programs about the projects across assets and CSGs, and evaluate the identification, execution, and operation of the projects, developing key performance indicators for comparison between projects.

Proceed to renewable energy project of more significant scale

To culminate the pilot phase of renewable energy learning, the REWG should utilize the framework to identify and screen several of the most promising opportunities for integrating renewable energy

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198 The threshold that defines "small-scale" should be determined internally and measured by the most relevant.

at a scale which is appropriate to the organization and the asset's overall capacity requirements. Finally, the team should aim to move one concept project through execution as a demonstration project for the organization, and to serve as a platform on which further renewable energy developments can be considered.

Future Drivers for Renewable Energy

As our team considered the broader future of renewable energy and its adoption by major natural resources companies, we found that the fundamental drivers for the adoption of renewable energy in the mid- to long-term are driven by two major factors related to the "cost" of renewable energy: global movement toward more climate-change-related regulation (market price of GHG emission permits) and the continued rise of conventional energy prices due to high demand and tight supply.

Hoffman's interviews of climate change strategists from leading multinational companies confirm these two trends, and identify a third area of consensus: the emerging concern about climate change and an interest in related technologies among the investment community. He concludes that these three major drivers will ensure that the landscape of emissions reduction will become less voluntary, as evidenced by his interviewees' consensus that regulation on GHG emissions in the US is a foregone conclusion (spurring worldwide push for GHG regulation and higher permit prices), energy costs will continue to increase, and that interest within the investment community in climate risks and opportunities will continue to grow.[200]

Increasing Regulatory Action Will Boost the "Price" of GHG Emissions for BHP Billiton

Over the next decade and beyond, the regulation of carbon emissions across the globe is likely to be more common and more stringent.[201] In addition, cap and trade systems for GHG emissions are likely to become more widespread. And, as economic growth continues, emissions "caps" are ratcheted downwards, and the opportunities for low-cost abatement are exploited, the tax or "price" for) GHG emissions should increase. Consequently, this increase will drive demand for low-emissions energy generation including renewable energy technologies. Enlarging the GHG emissions market through increased regulation will also stimulate demand for offset projects in developing countries that do not have their own GHG emissions regulations. As acceptance of offset projects grows, these projects will become more common, particularly since they can often be implemented at lower cost than reducing emissions in the developed world. These trends should spur the renewable energy industry to increase research and development and achieve greater

200 Hoffman, Andrew J, Carbon Strategies: How Leading Companies Are Reducing Their Climate Change Footprint. Ann Arbor: University of Michigan Press, 2007.
201 Ibid

economies of scale in production. This will likely decrease the cost of renewable energy generation for all potential adopters in the mid- to long-run as the market adjusts, which will further accelerate the adoption of renewable energy.

Energy Prices Will Continue to Rise

The trend of increasing energy prices will likely be another significant driver for the adoption of renewable energy, as higher energy prices help remove the cost barriers associated with renewable technologies. These rising prices are likely to continue until growth in China, India, and the less developed countries slows significantly. In the long run, increased capacity and additional exploration for oil and natural gas are unlikely to be sufficient to meet increasing global demand.

Interest and Concern from the Investment Community

As investors come to see the risks related to climate change as *material*, it is therefore part of their fiduciary responsibility to consider these risks in investment decisions. Thus, as emissions disclosures and efforts at abatement become *business as usual* and no longer discretionary, an increase in renewable energy adoption should follow. In addition, as investors continue to see bright investment opportunities in renewable energy technologies, technology improvements and lower costs should also follow.[202]

As these drivers become progressively more important, we anticipate a promising future for the adoption of renewable energy across the global economy—and expect these technologies to be increasingly attractive to industrial companies. Ultimately, we hope and anticipate that industrial companies like BHP Billiton that stay sufficiently ahead of the curve—with renewable energy and carbon abatement—will reap benefits in the marketplace.

[202] Ibid

Appendix A:
Corridor Sands Limitada (CSL) Site Study

Corridor Sands Limitada

Renewable Energy Technology Assessment

Preliminary Findings

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Executive Summary

This document is an overview of the University of Michigan Master's Project Team's evaluation of promising renewable energy technologies and configurations for incorporation at BHP Billiton's titanium mine, Corridor Sands Limitada (CSL), in Mozambique. This evaluation is based on desk research as well as a comprehensive site visit to Mozambique and South Africa in August of 2007. The Master's Project's scope is primarily focused on renewable sources of *electricity* from wind, solar, and biomass; however, for this particular site assessment we were specifically requested to evaluate the potential to make biodiesel from energy crops as well.

The CSL mine is in the initial planning and evaluation stages; therefore, it is not yet an operating asset. Currently the mine site is undergoing pilot scale testing and a team is coordinating the relocation of people currently living on the titanium deposit. When operational, the mine is estimated to require 15 – 20 MW of power on a continuous basis. According CSL energy contractors Philip Morkel and SNC Lavalin, the "base case" electricity source for the proposed mine would likely be a natural gas turbine, a natural gas engine(s), or a heavy fuel oil (HFO) generator set(s). For purposes of the study, the MS project team focused its assessment of technologies on those capable of providing base load power of 5 to 18 MW to the asset.

The team also assessed the viability of creating a jatropha plantation in the area to generate economic livelihoods for farmers displaced by the mine site development and to provide BHP Billiton with an economic source of biodiesel fuel.

The team's preliminary analysis of the technical compatibility with planned infrastructure, economic viability, potential community development benefits, and strategic fit of each technology has led us to the following recommendations regarding renewable energy opportunities for CSL:

- Pursue staged investment in the cultivation of jatropha and processing of jatropha oil into biodiesel for use at CSL and for sale in appropriate markets.
- Pursue staged investment in generation of approximately 5 MW of electricity through biomass gasification, using locally grown and sustainable feedstock such as *eucalyptus* and *casuarina* trees.

Table 1: Summary of Recommended Opportunities

	Natural Gas Base Case	**HFO Genset Base Case**
Jatropha	Jatropha can be converted to biodiesel for use in CSL equipment and sold in fuel commodity markets. No jatropha oil will be used for electricity generation.	Jatropha oil can be processed directly in Wartsila gensets for electricity. Jatropha could also be processed into biodiesel and sold on commodity markets if the economics were superior (likely).
Biomass Gasification[203]	Trees could be harvested and gasified 7-9 years after planting with the resulting syngas fed through a natural gas combustion unit to produce electricity at ~4.5¢/kwh. This would displace a portion of the natural gas generated electricity.	Trees could be harvested after 7-9 years and gasified with the resulting syngas fed through dual-fuel gensets to produce electricity at ~4.5¢/kwh. This would displace a portion of the HFO generated electricity.

Technologies considered in the evaluation but failing to meet one or more of the screening criteria included: concentrated solar thermal and wind turbines. Both of these options could not provide continuous base load generation because of the intermittent nature of the resources that they utilize. Energy storage options for these technologies are not currently available commercially. Furthermore, they were the most costly options evaluated.

Based on these findings, we recommend that CSL move into test cultivation of jatropha, eucalyptus, and casuarina under advisement of qualified agricultural experts to determine appropriate conditions for each plant species. Following adequate and successful testing, we recommend BHP Billiton move forward to commercial scale with the jatropha and biomass options with a 100 hectare test plot of jatropha and a 300 hectare plot of either eucalyptus or casuarinas, determined by the results of the original test plantings. Large-scale eucalyptus and/or casuarinas plantation needed for full-scale (5 MW) power generation could be managed directly or through contract with an experienced commercial scale energy crop cultivator.

Introduction

BHP Billiton engaged the SNRE/Erb Institute Master's Project team (MS project team) to identify and evaluate promising renewable energy technologies for use at the proposed Corridor Sands Limitada (CSL) mineral sands mine near Chibuto, Mozambique, and develop a flexible framework for the evaluation and selection of renewable energy technologies across BHP Billiton's global assets. This document represents our preliminary conclusions for CSL, which will help to inform the development of the flexible framework for evaluating renewable energy options at BHP Billiton assets globally.

Our team began work in late 2006 conducting baseline research on renewable energy technologies under the guidance of Dr. Gregory Keoleian at the University of Michigan. The team collaborated with a Ross School of Business Multidisciplinary Action Project (MAP) team that conducted an initial analysis of the CSL site in the spring of 2007. The MS project team traveled to Mozambique and South Africa in August 2007 to meet with CSL personnel and energy experts and contractors.

[203] Preliminary approximation of levelized cost of electricity (LCOE) which includes initial capital expenditures.

Based upon our findings from all three phases of the research, the MS project team conducted an assessment of renewable energy options for CSL.

Background

Corridor Sands is a proposed heavy minerals mine located near Chibuto in the Gaza province of southern Mozambique. It is currently in the initial planning and evaluation stages; therefore, it is not yet an operating asset. Corridor Sands will involve the opencast mining, processing and smelting of iron and titanium bearing sand. The mine is estimated to contain about 73 million tons of ilmenite,[204] which may be refined into various titanium products. Currently the mine site is undergoing pilot scale testing and a team is coordinating the relocation of people currently living on the titanium deposit.

Infrastructure is one of the key components of the mining operation. Transport of the refined ore is one concern. Two major possibilities have been considered, including construction of a loading pier near the mine, or transporting the ore or refined product via train to the capital Maputo, where large port infrastructure already exists. Another aspect under consideration is how the asset will be powered. When operational, the mine is estimated to require 15 – 18 MW of power on a fairly continuous basis. One possibility considered was extending transmission lines from South Africa to the asset. Another possibility included using natural gas or heavy fuel oil to generate electricity on-site. According CSL energy contractors Philip Morkel and SNC Levelin, the "base case" electricity source for the proposed mine will likely be a natural gas turbine, a natural gas engine(s), or a Heavy Fuel Oil generator set(s). For purposes of the study, the MS project team geared its assessment of technologies toward those capable of providing base load power of 5 to 18 MW to the asset.

Another very important and sensitive aspect of Corridor Sands is the need to relocate a large number of people who are currently living on the land occupied by the mineral sands deposit. BHP Billiton is working in concert with the Mozambican government on a comprehensive relocation program that involves assuring that relocated people can reestablish sustainable livelihoods once they move. To that end, BHP Billiton has indicated interest in investigating potential links between the development of renewable energy sources for CSL, and the creation of sustainable livelihoods for those people displaced by the mine and other members of the surrounding community.

Evaluation Methodology and Results

The MS project team built upon the analysis conducted by the MAP team that visited Mozambique in the spring of 2007. One of the major components of that analysis was a screening process for various renewable energy technologies. This screening process was referred to as the fatal flaw analysis, because it first looked at threshold criteria that each technology must meet in order to be considered further. If a specific technology, or feedstock – in the case of biomass and biofuels – did not meet one of the threshold criteria, it was eliminated from further review. **Figure 1** below is a visual representation of the fatal flaw analysis applied to the technologies that we evaluated in Mozambique.

[204] BHP Billiton Bankable Feasibility Study, Corridor Sands. 2002. Cited in Mining Weekly Online July 7, 2006.

The MS project team's site evaluation required that we conduct a new assessment of some renewable energy technologies and their applicability to the CSL site, because the team investigated several technologies which were not addressed by the MAP team, including:

- Biomass combustion
- Biomass gasification
- Concentrated solar thermal
- Jatropha-based biodiesel

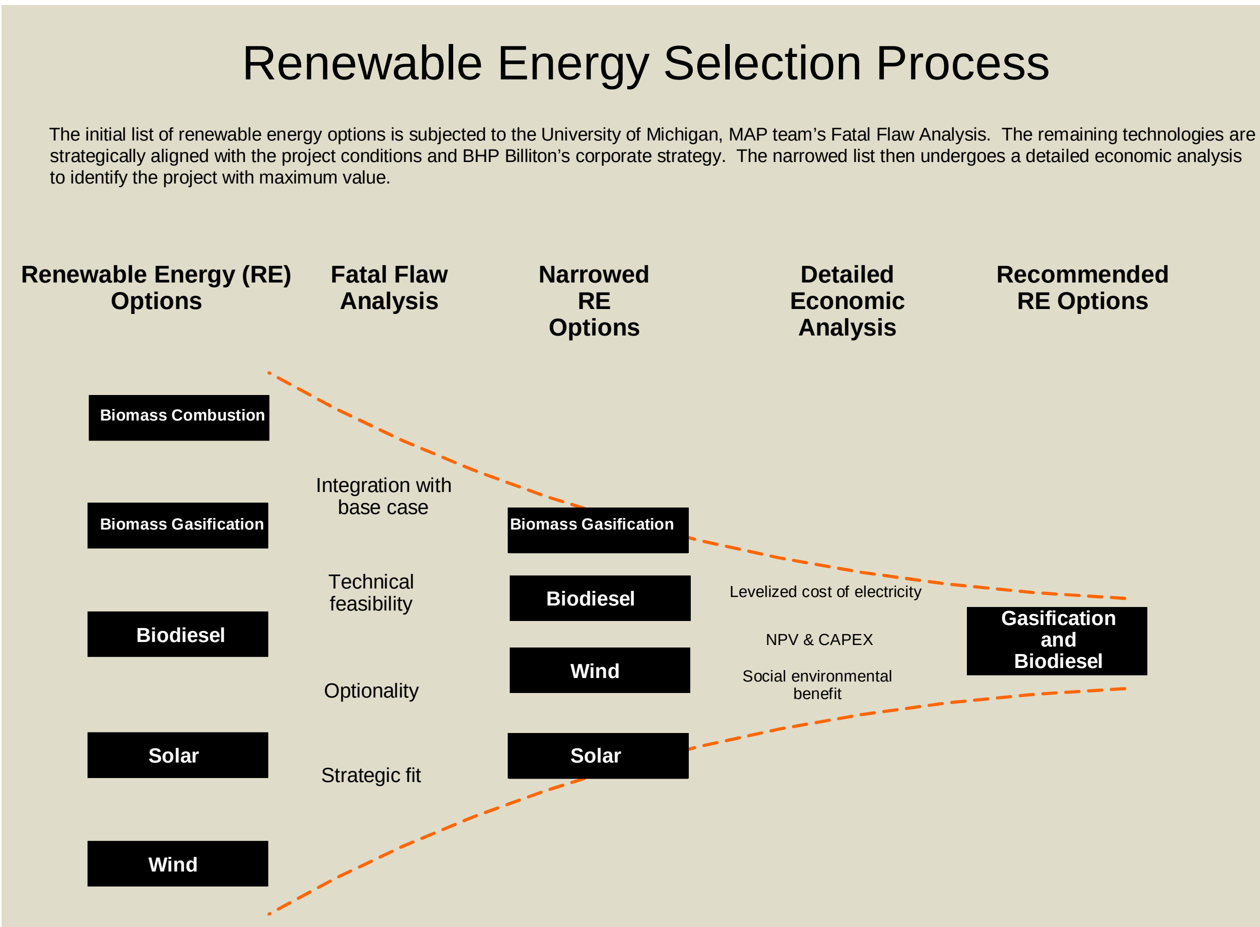

Figure 1: Renewable Energy Selection Process

Renewable energy technologies were evaluated based on their characteristics and according to the following criteria:

- Economic feasibility (NPV, levelized cost per kWh)
- Technical feasibility (technical risk)

- Socioeconomic benefit to local/regional community (jobs created, local revenue generated)
- Fit with the two proposed base cases (natural gas and heavy fuel oil),
- Financial risk (low capital requirements, degree of asset specificity)
- Optionality (options to scale up or discontinue the project, learning opportunities)

This analysis is effective because it limits the amount of very detailed cost research necessary, by only screening out the less promising technologies prior to the economic analysis. **Table 2** summarizes the results of our financial assessment of each technology that made it past the initial screening process.

Table 2: Detailed Summary of Recommendations

Technology	MW Capacity (delivered)	Total CAPEX (millions)	Levelized Cost of Elecricity (cents per kWh)	NPV (millions)	Land Use (Hectares)	Notes
Renewable Technologies						
Biomass Gasification (Co-Fired)	5	$5.4	4.2	$0.8	2,600	• Requires Natural Gas Base Case • CAPEX is $2.4 MM in year 0 + $3.0 MM in year 7
Jatropha	7.5	$14	HFO Base Case COE + 3.9	-$30 (@ $350/tonne of HFO)	10,000	• Requires HFO base case • Biodiesel is a higher value use
Concentrated Solar Thermal (with Storage)	15	$141	9-13	($27)	66	• Calculated using Natural Gas Base Case • Intermittent power, incapable of supplying base load generation without constant sunlight. • Possible grid integrated solution.
Wind	10-12	$51-63	10-14	($70)	13 footprint 700 total space	• Calculated using Natural Gas Base Case • Intermittent power, incapable of supplying base load generating power without constant wind. • Possible grid integrated solution.
Base Cases						
Natural Gas	23		7.1 (6.5+.6 carbon charge)			
Heavy Fuel Oil (HFO)	23		8.4 (7.5+.9 carbon charge)			

Discussion of Technology Options

Biomass Gasification to Electricity and Biofuels Production

Electricity generation using biomass gasification possesses many advantages over the competing renewable technologies: it is capable of providing cost-competitive, stable base load power, it provides fuel flexibility in the case biomass feedstock shortages, it provides agricultural jobs within the local community, has high optionality, and can integrate with either base case scenario. Biomass gasification is capable of delivering more than 5 MW of power provided that sufficient feedstock is available; however, BHP Billiton must balance the benefits of increased renewable capacity with the risk of reliance on biomass fuels as its supply is less controllable than fossil fuel commodities. The levelized cost of electricity (LCOE) for biomass gasification is expected to the on the order of $0.042/kWh for a co-fired natural gas system. Jatropha-based biodiesel also provides many of the same advantages as biomass gasification, in addition to its low asset-specificity.

Concentrated Solar Thermal

Currently, concentrated solar thermal presents the next best opportunity, with a preliminary estimated LCOE of 9-13 ¢/kWh. The solar option is challenged by the $140 MM capital investment required, and a resulting negative NPV of $27 MM. This investment provides no optionality and limited exit options from this opportunity because of the extremely high asset specificity. Solar achieves better economies of scale at the 30MW range, but this is beyond the power requirement at the Corridor Sands facility. Furthermore, in its current state of evolution, solar delivers power on an intermittent basis, depending upon the immediate solar radiation, and therefore, it is less than an ideal source of base load power for the CSL asset. Also, the solar option offers very little community benefit. The benefits of solar - low operating costs and low risk of failure - are not enough to compensate for the downsides.

Wind Turbines

The MS project team determined that wind energy is among the least viable options to supply power to CSL for a variety of reasons. At a LCOE of 10-14 ¢/kWh and a negative NPV of $70 MM, wind is among the most expensive scenarios evaluated. Additionally, the most ideal sites to develop wind power are near the coast, over 50 km away. Transmission lines directly from the generation sites to CSL would be prohibitively expensive. A power swap is more likely to be economically feasible but CSL has indicated that neither connecting to the grid nor negotiating a swap agreement are currently attractive options. Lastly, wind does not provide any community development benefits and wind power is intermittent, therefore it is not suitable to provide baseload electricity to CSL.

Next Steps for Biomass Gasification and Biofuels

Based on these findings, we recommend that CSL move into test cultivation of jatropha, eucalyptus, and casuarina at a multi-hectare scale under advisement of qualified agricultural experts to determine appropriate conditions for each plant species with the purpose of determining the preferred growing conditions for each species, considering:

- Sub-species

- Soil type(s)
- Fertilization
- Intercropping
- Irrigation

Following successful test, the scale-up to larger dimensions will provide a commercial test of the value chain, including the downstream processing technologies. This combined recommendation has the following effects:

- Minimizes initial capital expenditures on renewable energy options
- Maximizes the optionality and ability to adjust based on future changes in price of HFO, diesel, natural gas, and gasification technologies
- Maximizes the site energy security by retaining multiple energy options
- Provides the greatest potential social benefit to relocated individuals by creating thousands of additional agriculturally-based jobs
- The remainder of this document presents a more detailed review of the two proposed opportunities, based on the cultivation of jatropha, eucalyptus and casuarinas.

Jatropha Biodiesel

The MS team recommends a step-wise implementation plan for jatropha to mitigate execution risks because the plant has yet to be cultivated at commercial scale in Mozambique.

Planting Jatropha

The MS project team's analysis indicates that jatropha may be grown cost-effectively in Mozambique. Oil can be extracted from jatropha seeds and then processed into biodiesel. Jatropha plants take 3-5 years to reach maturity and will then produce seeds consistently for about 30 years. Jatropha plants require little water and will primarily be planted on marginal lands that are not suitable for food crops.

The primary initial investment in planting and growing jatropha is in labor costs, with an additional investment required for simple tools and equipment for clearing land. Once plants reach maturity a modest capital investment will be needed to purchase an oil extraction unit. At that time an option is created to either:

1. Capitalize a biodiesel refinery to further process jatropha oil into biodiesel
2. Use unrefined jatropha oil directly in HFO gensets (HFO base case only) to generate electricity

3. Sell the unrefined jatropha oil to biodiesel commodity markets or refiners for processing

We anticipate that converting jatropha oil into biodiesel will be the highest value option for BHP Billiton. Producing biodiesel from jatropha oil is a relatively simple reaction called transesterification. Turn-key, modular processing units are available for purchase globally. A 10,000 hectare plantation would create about 2,500 jobs related to cultivating the plant, managing the plantation and processing/distributing the oil. Once this scale has been achieved and workers are trained to grow jatropha, CSL could also distribute seeds and offer to purchase jatropha oil-seeds directly from farmers for the equivalent of around $0.50 per liter of oil. This would be profitable for CSL and provide additional income to small-scale farmer entrepreneurs.
Assuming that a 10,000 hectare plantation can produce on average 2,000 liters per hectare the economics for biodiesel are attractive.[205]

Table 3: Jatropha NPV and IRR at 2,000 liters per hectare oil yield

Average 30-Year Selling Price of biodiesel ($/Liter)	NPV	IRR
$0.77	$0.8 MM	6.25%
$1.13	$43.5 MM	18.4%
$1.45	$82.0 MM	27.3%

Even if the 10,000 hectare plantation only produces an average of 1,000 liters per hectare the project would probably create a positive NPV.

Table 4: Jatropha NPV and IRR at 1,000 liters per hectare oil yield

Average 30-Year Selling Price of biodiesel ($/Liter)	NPV	IRR
$0.77	$-20.5 MM	0%
$1.13	$5.8 MM	9.4%
$1.45	$28.9 MM	18.9%

In September, 2007 the retail price of diesel in Mozambique was $1.16 per liter. The markup for transport and retail pricing is typically about 20% of what is available for purchase so current prices that BHP Billiton could receive for biodiesel production would probably be about $0.93 per liter if operations were active today.

205 Mosmart Investments suggested a range of 2,000-3,000 Liters per hectare from jatropha at maturity. They stipulated that this may be lower in early stages of growth as cultivation methods are being refined, or in very dry areas. Other sources such as Technoserve and Mbio indicated that a range of 1000 Liters per hectare could be expected although they had not grown it themselves. It would be wise to do some testing to optimize growth rates and oil yields of jatropha near the project site before committing to making any major investments as well as measuring the production yield on Mosmart's plantation in Inhuambane.

Using Jatropha Oil in HFO Gensets

We do not anticipate that using jatropha oil in HFO gensets would be the highest value use of jatropha oil. However, this option does add some flexibility because:

- Jatropha oil could be used in HFO gensets prior to an additional investment in a biodiesel refining facility
- No additional capital expenditure beyond growing jatropha and expelling the oil is required for electricity generation if CSL installs HFO gensets to supply their baseload electricity
- CO_2 credits from displacing HFO could yield significant revenue
- Additional gensets could be added when production at CSL is ramped up in Phase 2

Table 5 below compares project costs with various scenarios for HFO, assuming that a 10,000 hectare plantation can produce on average 2,000 liters per hectare.

Table 5: Project economics given HFO price scenarios

Average 30-Year FOB Purchase Price of HFO ($/tonne)	NPV	Levelized Cost of Electricity (Cents per kWh)
250	$-40.0MM	Base + 2.3
350	$-29.5 MM	Base + 1.7
700	$2.6 MM	Base - 0.15
1000	$30.3 MM	Base – 1.7

In September, 2007 Intermediate Fuel Oil (IFO) in Richards Bay, South Africa sold for $415 per tonne. IFO is generally more expensive than HFO so this gives some upper bound on HFO prices in southern Africa. Diesel prices and HFO prices are usually positively correlated, therefore the highest long-term value of jatropha oil will probably be to produce biodiesel since at current prices, the NPV for producing biodiesel is higher then that for generating electricity. However, these prices should be evaluated with an official price protocol for HFO generated by BHP Billiton.

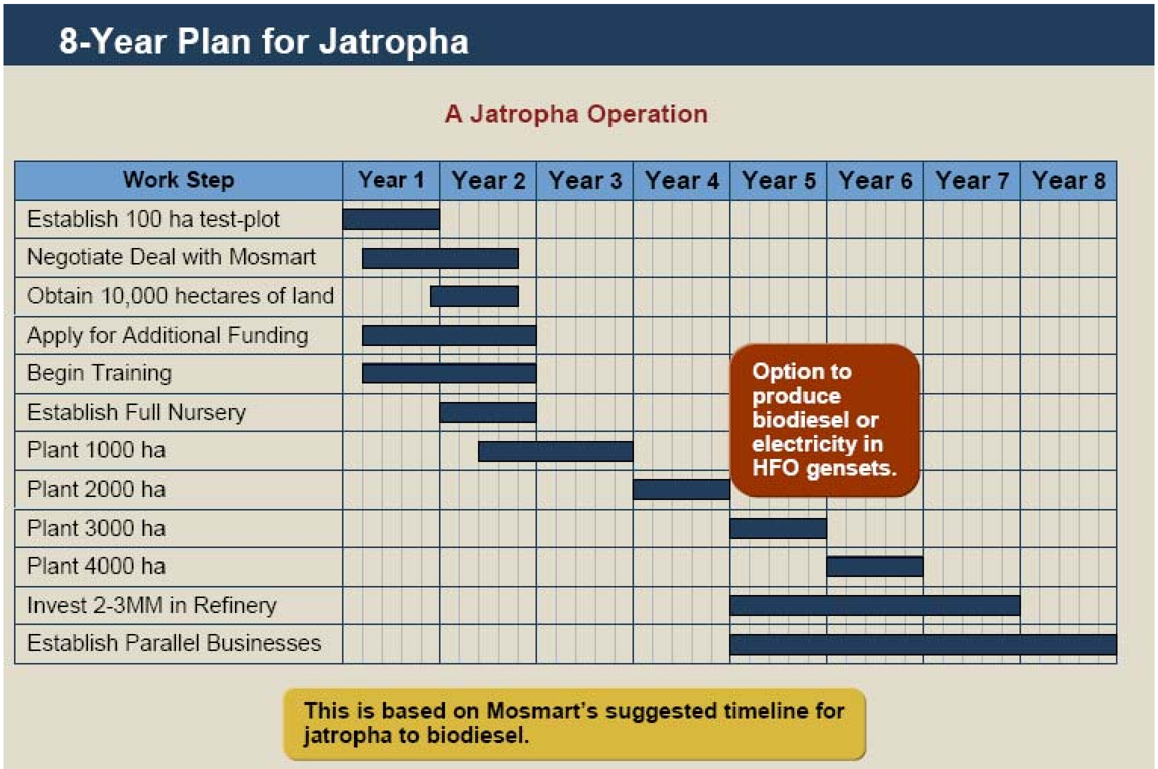

Figure 2: Project Plan for Jatropha

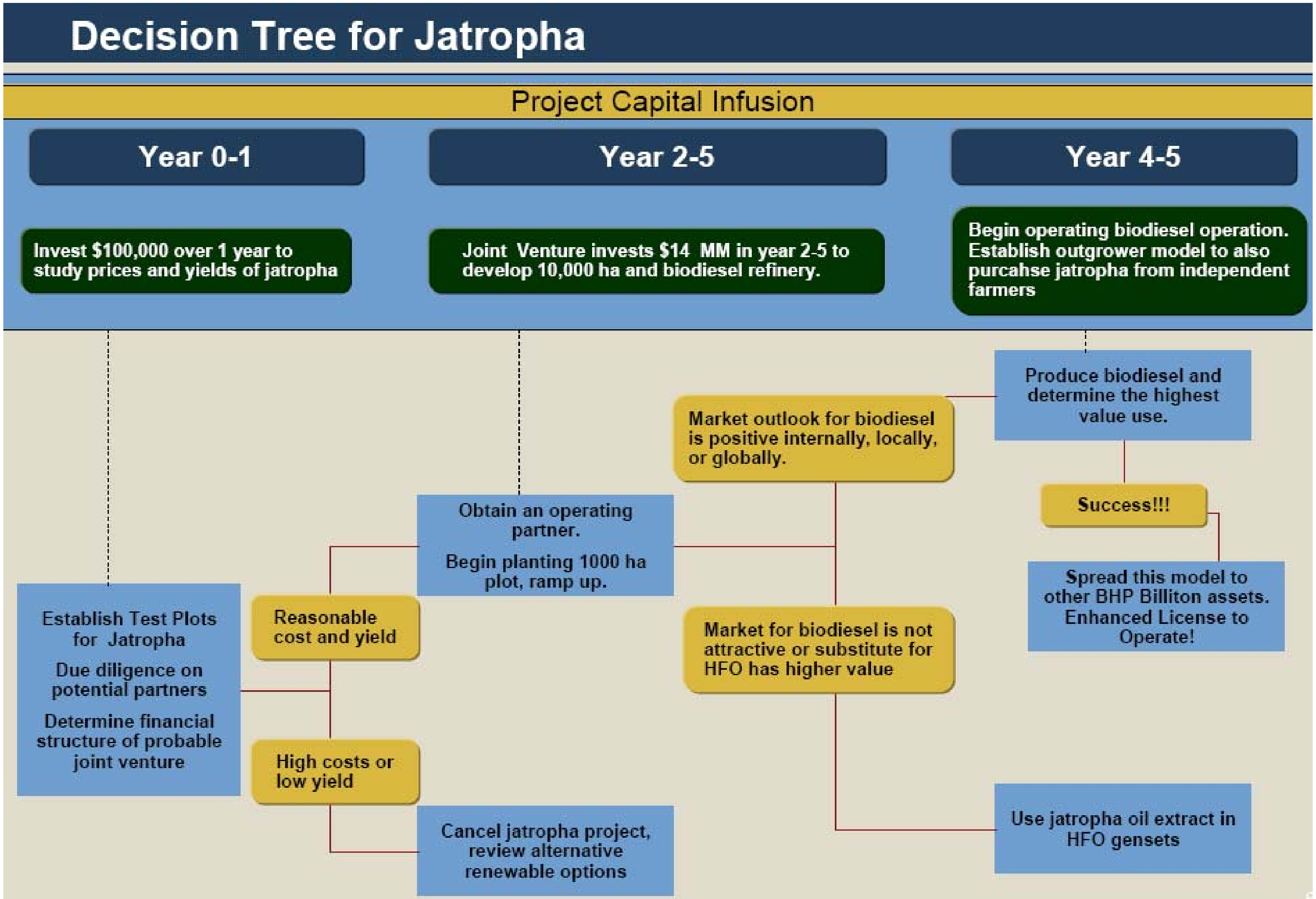

Figure 3: Decision Tree for Jatropha

Table 6: Summary of key risks for jatropha conversion to biodiesel

Risk	Risk Likelihood	Risk Magnitude	Mitigation	Residual Risk
Execution Risk • Crop failure • Drought/Fire • Management • Social Acceptance • Cost Over-run	Moderate to High	Moderate	• Partner with people who have expert knowledge of Jatropha and Biodiesel • Low Initial Investment • Invest in Learning	Low-Moderate
Market Risk • Price of HFO • Price of Diesel • Price of Natural Gas • Tax	Low in the Long Term Moderate in Short Term	High	• Retain option to produce biodiesel or electricity • Retain option to kill project early • Retain option to seek internal, local, and export markets for jatropha oil • Appreciate social value that comes from job creation	Low-Moderate
Country Risk • Expropriation of property or high future taxation	Moderate	High	• This project will help to mitigate some country risk for all BHP Billiton projects in Mozambique by providing jobs and social benefits	Low-Moderate
Currency Risk • Costs raise due to changes in currency	Low	Moderate	• None	Low

Biomass Gasification to Electricity

Biomass gasification, in conjunction with development of a local biomass feedstock source (e.g., *eucalyptus* or *casuarina* plantation), is one of two preferred renewable options to supply baseload power to the asset. Biomass gasification was evaluated with respect to its ability to provide power on a stand-alone basis and as a hybrid, or co-fire, option with these baseload technologies. Standalone biomass gasification was eliminated from consideration due to the low security of feedstock supply and high risk associated with exposure to unmanageable risk elements (e.g., pestilence, disease, climatic stress that could impact the availability of biomass fuel). However, biomass gasification can be integrated with natural gas combustion and HFO baseline power options in hybrid systems which would reduce the associated risk of complete reliance on biomass, ensure a more secure supply of power, and increase project optionality. In natural gas co-fired systems, the levelized cost per kWh of electricity provided by gasification is approximately $0.043/kWh based on current cost estimates and the project has an NPV of $0.7 MM over 30-years. The capital cost of biomass gasification units are projected to fall as the technology and market have not yet matured. Since the capital investment in the gasification unit would not be required until year 7 of the project, given that biomass yields would not be harvestable until this point, the capital cost of a gasification unit may be much lower by that time.

<u>Biomass Plantation</u>

The CSL biomass gasification would require a feedstock in the form of a consistent supply of wood supplied through a short-rotation woody crop (SRWC) plantation system or through the provision of a consistent source of biomass residues. During the team's site visit, all major sources of biomass residues (e.g., sugar processing, rice plantations, woodmills) were investigated and found to produce insufficient quantities of biomass for consistent supply of feedstock to a gasification system. Thus, biomass residues were eliminated from further consideration as gasification feedstocks. BHP Billiton currently has the option to access up to 3,000 hectares of available, marginal land in Block C[206] to create a bio-energy plantation. Additional land is likely available north of this area, and the government has indicated its willingness to provide access to additional land if required.[207]

206 Area of available, marginal land provided via Imran Shirani
207 Conversation with Derek Higgo, CSL .

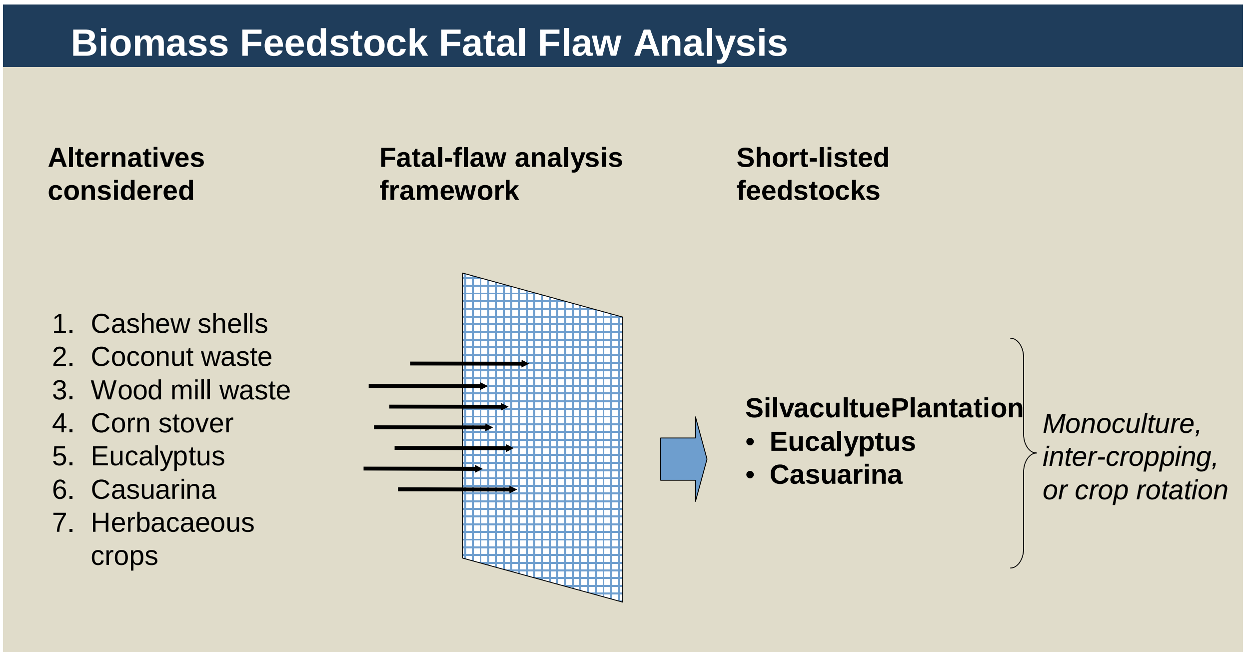

Figure 4: Biomass Feedstock Assessment

Plantation Type, Size and Structure

There is evidence that Eucalyptus and Casuarina can be grown cost-effectively in Mozambique. Conservative estimates of time-to-maturity for these trees is 7 years, and they can produce multiple harvests without replanting due to their ability to coppice (re-sprout from trunks after harvest). Replanting may be required after the second or third harvest (years 14 or 21). The plants require little water and can tolerate coarse, acidic soils such as those found on the marginal lands available throughout Block C. Thus, the plantations would not compete with prime agricultural land.

In order to supply 5 MW of power, BHP Billiton would need access to a plantation capable of supplying approximately 120 green tonnes[208] of biomass per day. This would require planting a total of 2,600 hectares (with a 10% margin-of-safety), which would be harvested annually in 330 hectare sections on a 7-year rotational harvest cycle. The operation would employ up to 200 low-skill workers. The plantation could be owned and operated directly by BHP Billiton, by a joint venture, or through third-party contract. In modeling the costs for this project, the MS team assumed that BHP Billiton would directly own and manage the plantation and provide fuel at the internal transfer price of production to the biomass gasifier.

Once BHP Billiton or its partner has successfully demonstrated the centrally-operated plantation and developed a local silvaculture skill-set through local employment at the plantation, BHP Billiton could also provide saplings to local small- to medium-scale entrepreneurs. BHP Billiton could also consider developing an outgrower model for individual families, and offer to buy the wood from them at a set price if they choose to grow crops for cash. Because SRWC harvests are infrequent (7-year cycle), BHP Billiton would have to develop a substantially different payout model (relative to jatropha harvesting) for entrepreneurs and outgrowers for their biomass harvests. The potential payment structure would provide an incentive for growers to maintain their crops over the 5-7 year time frame, while protecting against a "take the money and run" scenario. Essentially, BHP Billiton could issue a limited credit stream to growers, large enough to incentivize the growing and maintenance of the crop, but small enough to prevent the premature

[208] "Green tonnage" is the mass prior to drying

harvesting and sale to alternative markets (fuel wood, paper/pulp, and construction materials). This stream of income for farmers would then be supplemented by a significant payout upon delivery of the wood at harvest. However, this "outgrower" model would have to be considered very carefully to ensure that programs would not compromise family food production (via shade, water consumption, etc) and that expectations are carefully set and sufficient training offered.

Plantation Timeline

The overall timeline of the project is captured in Figure 2. A 2-year pilot scale test is required to determine the suitability of the region for full-scale biomass production. The testing will improve BHP Billiton's understanding of the interaction between selected test crops, climatic and soil conditions, silvaculture methods and biomass accumulation rates. The effects of intercropping with food or other energy crops could also be investigated. The pilot test would ultimately allow BHP Billiton to more precisely design, cite and scale the plantation. A successful pilot scale test would prompt BHP to expand the plantation to a full-scale model. If unsuccessful in the pilot phase, the project could be terminated, and only the nominal economic loss associated with the land clearing and planting of the test plot.

There is significant ramp-up time to harvest for biomass, with optimal harvest efficiencies often reached in the 5 – 7 year range. As such, the MS team anticipates the first harvest of SRWC would be 7 years from time zero. Just prior to first harvest, BHP Billiton should value the alternative markets for the biomass (construction, paper pulp, and permanent carbon credits) relative to its value as a fuel feedstock.

In year 7, if biomass gasification is determined to be the highest-value use of the SRWC, BHP Billiton should begin continuously harvesting from 330 hectare lots each year to provide a steady supply of feedstock to the gasification plant. We have conservatively assumed that the plantations would require sequential replanting of plots after the second harvest (starting at year 21 full-scale), however, operation depends upon the ability of the harvested trunks to continue coppicing.

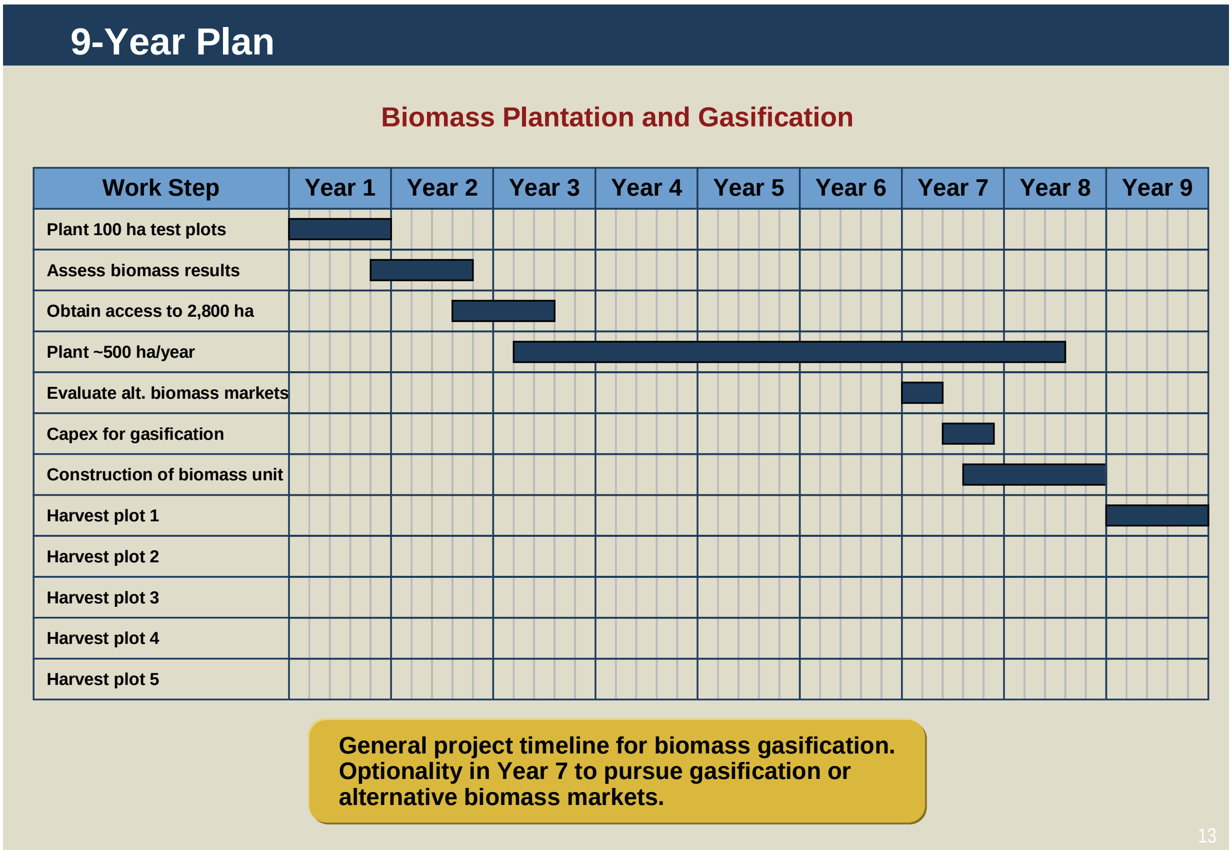

Figure 5: Biomass Project Plan

Plantation Economics

The cost associated with the two-year pilot test clearing and planting of a 100 ha lot with saplings is assumed to be nominal relative to those incurred in full-scale production. The major costs categories in planting and growing the full-scale plantation are labor, machinery and fertilizer for clearing and planting. The team estimates that planting up to 2,600 ha of trees over the initial 7 years of the project will cost approximately \$1.8 – \$2.0 MM (present value). Annual harvesting, biomass transport and maintenance costs are projected to be \$0.5 MM (present value). Annual replanting costs are projected to be in the \$0.6 MM (present value) range.
Once the trees reach maturity, a capital infusion of approximately \$100,000 will be needed to purchase hauling vehicles and harvesting tools, and to establish roadways.

Plantation Optionality

A decision tree capturing the key decision points and optionality is presented in Figure 3. Multiple alternative markets would likely exist for lumber produced at the biomass plantation. For instance, if the price of natural gas decreases substantially between year 0 and year 7, thereby lowering the relative value of biomass as a substitute fuel, the biomass could be harvested and exported to biomass energy markets in Europe or to the construction industry. If the full-scale plantation is implemented, the following options are created at year 7:

- Further process the trees for gasification and eventual conversion into electricity;
- Harvest and sell the trees to alternative markets (e.g., lumber, construction materials, energy, or paper pulp) and pursue other energy options; or

- Keep the trees in place and garner CER credits for the carbon sequestered as a result of the project and pursue other energy options.

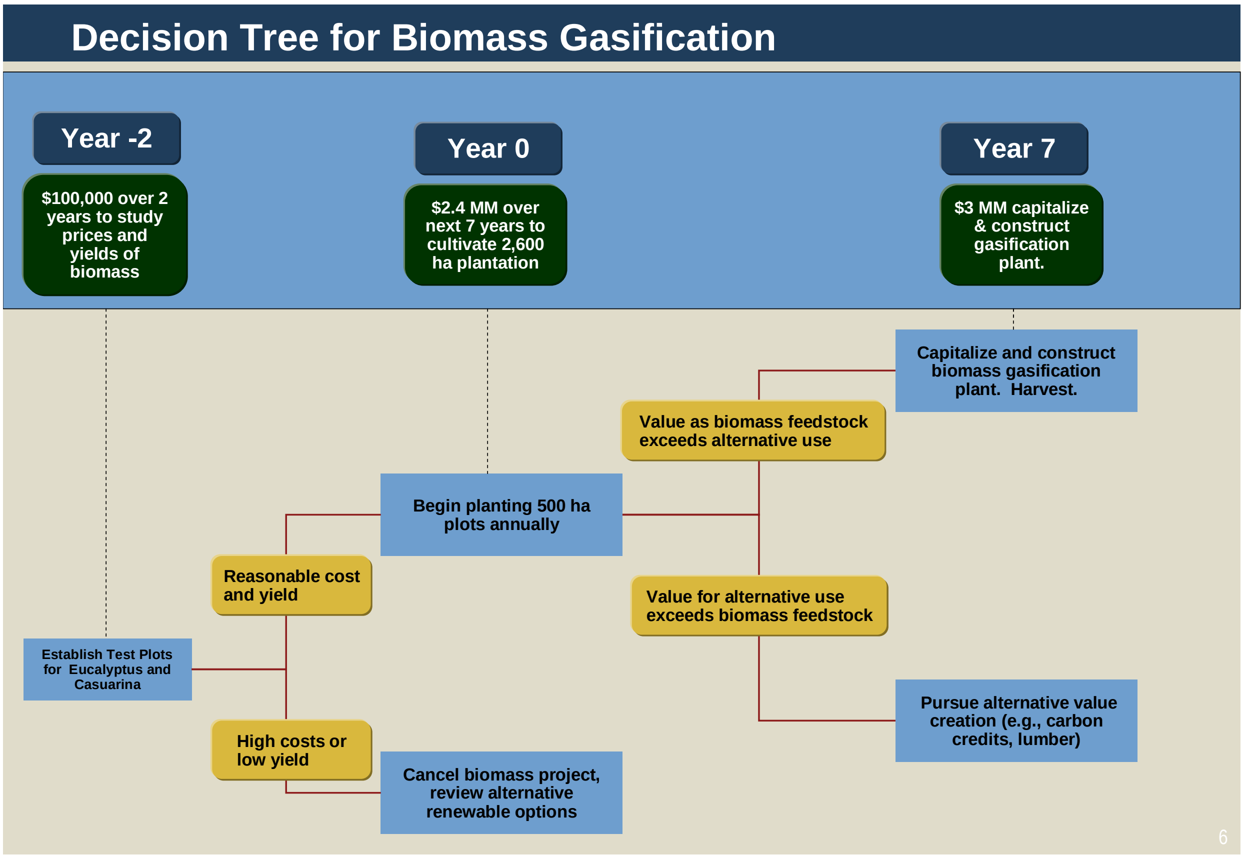

Figure 6: Biomass Gasification Decision Tree

Biomass Processing and Conversion Technologies

The team envisions providing up to 5 MW of power via biomass gasification with the remaining 10-13 MW provided by natural gas engines or HFO gensets in order to minimize risks associated with full reliance on biomass crop yields. A 5 MW gasification plant is estimated to cost $2.4 MM (without the power island, which would be shared with natural gas or HFO system).[209] The syngas produced in a biomass gasification system can be co-combusted with natural gas to fire a shared gas engine or gas turbine or with HFO in a dual-fuel generator set. While economies of scale and improved efficiency can be achieved with gasification systems as the power output increases, the maximum improvements in capital cost per MW are realized as the gasification power output exceeds the 5 MW range. However, further reductions in capital costs per MW and improvements in efficiency are believed to be offset by the increased risk associated with feedstock production variability. Therefore, we have capped the size of gasification unit in our analysis at 5 MW.

[209] World Bank, Technical and Economic Assessment: Off-Grid, Mini-Grid and Grid Electrification Technologies (2006)

Biomass Feedstock Logistics

BHP Billiton or its contractor would utilize standard methods such as manual-harvesting, truck transport, air-drying and mechanical size reduction to harvest, deliver and process the biomass. Manually-harvested trees would be air-dried in the field to achieve moisture contents optimal for gasification (20-30%). The logs would then be loaded onto and transported by log-hauling trucks to the gasification facility. At the gasification facility logs would be processed to optimal size in a mechanical log shredder. Waste-heat from the combustion unit could be used if further drying of the shredded wood is required to maximize the gasifier efficiency. Harvesting, processing and delivery costs are captured in the project economic analysis and are encompassed in an internal charge on a "dollars per ton of biomass delivered" basis.

Biomass Co-firing Conversion Technologies

Co-firing facilities build on existing (or proposed) fossil fuel plants, therefore, they are less capital intensive than 100% biomass facilities, as only the incremental cost of modifying the facility to incorporate biomass feedstocks is attributable to the biomass project. These projects require small infusions of capital relative to the construction of a 100% biomass-reliant conversion facility. Biomass co-firing facilities can utilize either *gasification* or *direct combustion*-based technologies. However, the proposed energy technologies for the baseload power at the site (natural gas and HFO combustion) align best with biomass *gasification* technologies. Therefore, *direct combustion* was eliminated from consideration because it does not offer an integrated option with these technologies and would require a separate power island (steam turbine and generator) as opposed to the gas engine or gas turbine utilized in natural gas scenario or the generator sets in the HFO scenario.

Co-fired Gas Engine

At the time of our visit it was communicated that the lowest cost base case electricity for CSL is to provide power with natural gas utilizing internal combustion gas engines.[210] In this scenario, CSL's power would be supplied by six 3MWe GE Jenbacher gas-fired engines. The team envisions tuning several of these engines to fire a lower-BTU fuel comprised of syngas (from biomass gasification) and natural gas, to provide up to 5 MW of power.

Co-firing syngas and natural gas in gas engines would displace some of the natural gas demand, and would increase the heat content of the syngas, allowing it to be combusted with high efficiency in a gas engine. Conversely, the heat content of the blended syngas/natural gas fuel would be lower than that of natural gas alone. When the gasifier needs to be taken offline for maintenance, natural gas from the pipeline can keep the gensets running, providing uninterrupted power even during gasifier maintenance.

Co-fired Gas Turbine

CSL has also analyzed natural gas turbine configuration. Syngas generated from biomass gasification could be co-fired with natural gas in either an open-cycle or a combined-cycle gas turbine plant. Gas turbine systems are more costly than the gas engine configuration due a drop off in efficiency of gas turbines as ambient temperatures rise relative to the efficiency of gas

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[210] Conversation with CSL energy contractor SNC Levelin and sub-contractor Philip Morkel.

engines. The decrease in system efficiency leads to greater natural gas consumption and a larger pipeline capacity. However, combined-cycle gas turbine plants, while more capital intensive, produce significant improvements in the plant efficiency (30-40%). Increased plant efficiency would reduce the project fuel demand and pipeline size. More efficient syngas conversion would also decrease the land and labor required to procure biomass feedstock. The incremental costs associated with conversion of the open-cycle natural gas system into a combined cycle unit would primarily result from the purchase of a waste heat recovery system and a steam turbine. CSL has indicated that it is not interested in pursuing a combined cycle system, however, an independent power producer may determine that the increased efficiency is worth the additional investment.

Co-fired Diesel/HFO Generator Sets

Should BHP Billiton elect to use HFO-fired generator sets to provide the bulk of the base-load power, syngas from the biomass gasification unit would be used to augment the HFO pilot fuel combustion in one or more dual-fuel gensets. In this case, syngas would displace HFO in the genset, but there would always be an option of reverting back to HFO should the need arise to take the gasifier down for maintenance, or should the biomass feedstock crop fail. The primary benefit of moving from natural gas to HFO is the cost savings associated with not having to build a gas pipeline from Chokwe. However, additional cost of transporting and storing HFO the site will be incurred.

The energy conversion rates for HFO have yet to be provided to the team. Absent these values the team was unable to calculate a levelized cost of electicity for co-fired HFO and syngas plant with any level of certainty. However, we estimate the incremental NPV of replacing 340,000 MMBtu/year of HFO would result in a highly positive NPV (approximately $12 MM). In order to calculate the levelized cost of electricity, the team requires heat-to-power conversion rate of the HFO gensets, and capital costs associated with the plant.

Biomass Gasification Risks

Table 7: Risks of biomass gasification to electricity

Risk Matrix – Biomass Gasification

Description of Risk	Severity	Likelihood	Mitigation Strategies	Residual Risk
Execution risk is establishing feedstock plantation	High	Moderate	• Pilot Project • Optionality/co-firing • Partnerships in plantation	Low
External risk to feedstock • Pestilence • Disease • Fire • Climatic stress	High	Moderate	• Pilot Project • Optionality/co-firing • Pest, fire mgmt	Moderate
Technology risk for biomass gasification	Moderate	Low	• Project timeline allows further technology development	Low
Market factors influencing base case price of electricity natural/HFO	Moderate	Moderate	• Optionality to sell to other biomass market segments	Low

Biomass Gasification Next Steps

- Refine capital costs based on more in-depth engineering cost analyses using specific information from gasification manufacturers and definitive base case scenario

- Under advisement of a qualified agronomist, design and develop a pilot plantation to test growing methods for eucalyptus and casuarina species under a representative set of soil, moisture, and nutrient conditions to determine the most promising species for commercial cultivation in Mozambique, and the preferred cultivation methods.

- Pending positive outcome from pilot plantation, secure 2,800 ha for biomass plantation

Algae Biomass – Potential Future Technology

Algae is a potentially disruptive technology that should be further investigated as a source of biomass to produce biodiesel. Algae is not currently a commercially viable source of oil but several companies have recently begun to invest in developing this technology in response to high oil prices and increasing concern for global warming mitigation. Algae has high potential of the potential bio-feedstocks to produce bio-fuels at a large enough scale to significantly reduce dependency on fossil fuels. Additional benefits of algae-derived oil would include:

- Non-competition with food crops

- Serves as a CO_2 sink, absorbing emissions from large sources

- Being researched by Ritva Muhlbauer (Global Technology BHP Billiton, Johannesburg), requests being made for more funding

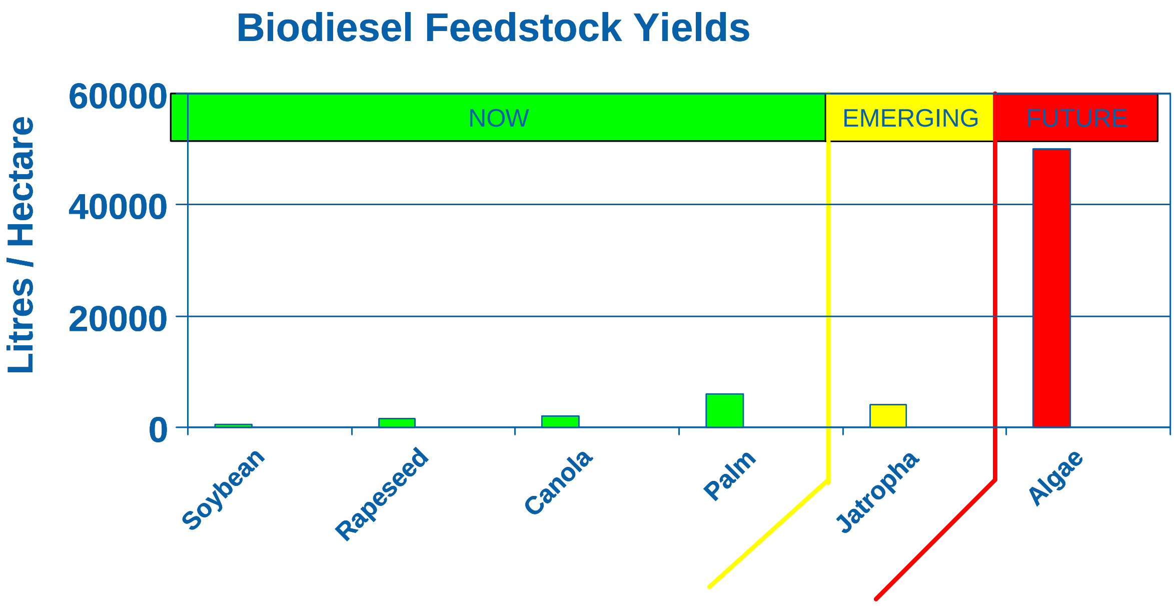

Figure 7: Biodiesel Feedstock Yields

Appendix B:
Mineral Escondida Limitada (MEL) Site Study

Minera Escondida Limitada

Renewable Energy Technology Assessment

Preliminary Findings

January 2008

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Executive Summary

The University of Michigan Erb Institute Masters Project team visited Chile for one week October 2007 to conduct a concept level renewable energy technology assessment for BHP Billiton Base Metals operations in Chile – particularly for the Minera Escondida Limitada copper mine (MEL).

Goals of Assessment

1) To identify renewable energy technologies and configurations that are doable, scalable, strategically aligned, sufficiently mature, and show promise to provide electricity at reasonable cost.

2) To inform the development of a framework for the selection of renewable energy technologies across BHP Billiton's global assets.

   This document will focus primarily on our findings for Goal 1, the identification of promising technologies.

Summary of Preliminary Recommendations:

Concentrated Solar Thermal and Wind Show Most Promise

Concentrated solar thermal power (CSP) and **wind energy** configurations show the most promise for generating large-scale renewable energy projects. BHP Billiton should seek a project proposal for concentrated solar thermal and commission a study of the wind resource. If a 5% renewable energy portfolio standard is enacted, then these two technologies are the only ones that can be developed to meet those legislative requirements in the near term.

Concentrated Solar Thermal shows the most promise to provide reliable, low-cost grid-connected electricity. BHP Billiton should contact a partner such as Acciona Energía, Iberdola, Abengoa Solar, or Solar Millennium to present a project proposal. The team relied on low-resolution solar radiation data from NASA and UNEP's SWERA program, which offered reliable estimates for the solar resource available in the region. Based on this, the team then estimated a levelized cost of electricity (COE) for a concept CSP plant. [211]

The radiation data suggests that northern Chile receives some of the strongest solar radiation in the world, and clocks significant annual sunshine hours owing to the clear, desert climate in northern Chile. Such high-quality solar resource makes the region around MEL a prime location for a "high-performance" CSP project. However, more high-resolution solar resource data (at least 1-2 years of data), and "one-the-ground" assessments will help narrow down ideal locations for siting a CSP plant. The team was unable to secure higher resolution solar radiation data, however we expect such data to be already available from national or local meteorological offices, or from academic

[211] Levelized cost of electricity is expressed in terms of cents per kWh or $ per MWh.

resources. This would eliminate the need for resource studies, and BHP Billiton could move on directly to site selection and project concept development with potential IPPs and project developers.

The key advantage of CSP over the more popular wind power, is the higher ability to predict when electricity will be generated from the renewable resource (the sun), and the inherent ability of CSP technologies to store thermal energy and then dispatch it on as 'as-needed' basis. This allows the plant to deliver electricity during non-sunshine hours as well. Thermal storage technology is still immature and expensive, but most new CSP projects under development today are building in significant storage capacity to extend operational hours of the plants, and thus driving down the net cost of electricity. The one downside of CSP technology is its demand for cooling water in the steam-power generation units.

Wind Power could be appropriate for the northern grid and has the potential to produce relatively cheap power. However, the team was unable to secure sufficient wind resource data, which is needed to develop a reasonable financial assessment. The generally attractive economics of wind power merits a resource and feasibility study with a project developer, such as Pacific Hydro, to determine the quality of the wind resource, select prime locations for siting a wind farm, and to estimate capital investment needs and the projected cost of electricity produced by the project over its lifetime. Resource studies ideally collect data over 1-2 years, and this would input into a financial model to determine economics of the wind power project.

Solar Photovoltaics remain a very expensive option for grid-connected electricity production, but could prove useful in a smaller, less capital-intensive demonstration project for renewable energy. Solar PVs could also be appropriate for remote, off-grid locations where the primary alternative is diesel generators, such as near remote well fields.

Biomass-to-electricity is impractical in Northern Chile because of the high-altitude desert climate and lack of water. Therefore, biomass availability is close to none in the region, and very little biomass can be shipped in on a cost-effective and sustainable basis. This makes biomass power a poor strategic fit for MEL, and therefore, biomass-to-electricity has been eliminated from consideration.

Geothermal Energy is possible in Northern Chile, but there is no information available to determine which specific sites may be suitable to develop for power generation. This is not considered to be a near-term possibility due to the time and financial investment required to explore for suitable geothermal resources before any could be exploited for electricity generation.

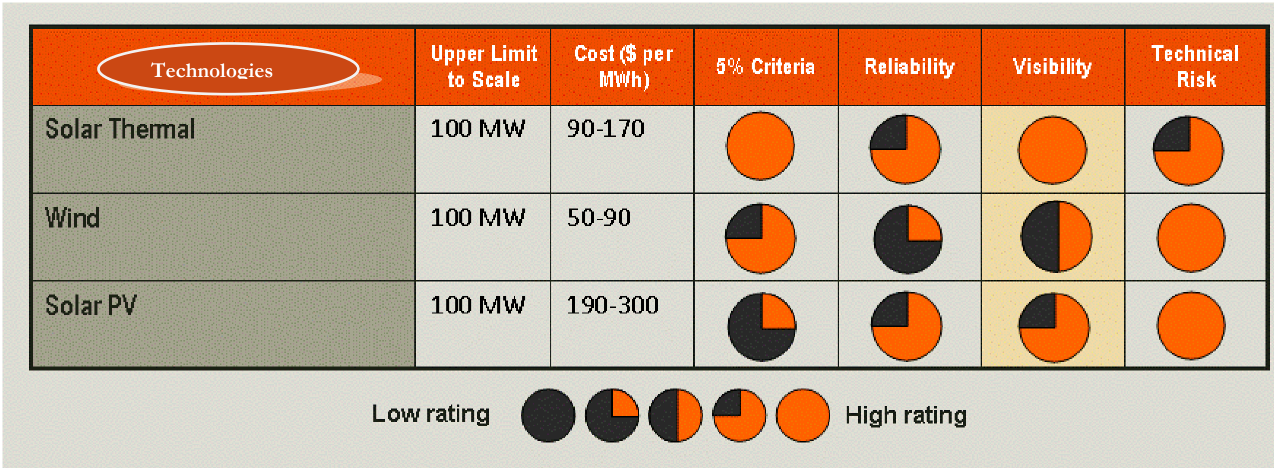


Figure 1: Comparison of CSP, Wind, and Solar PV options for MEL

Next Steps

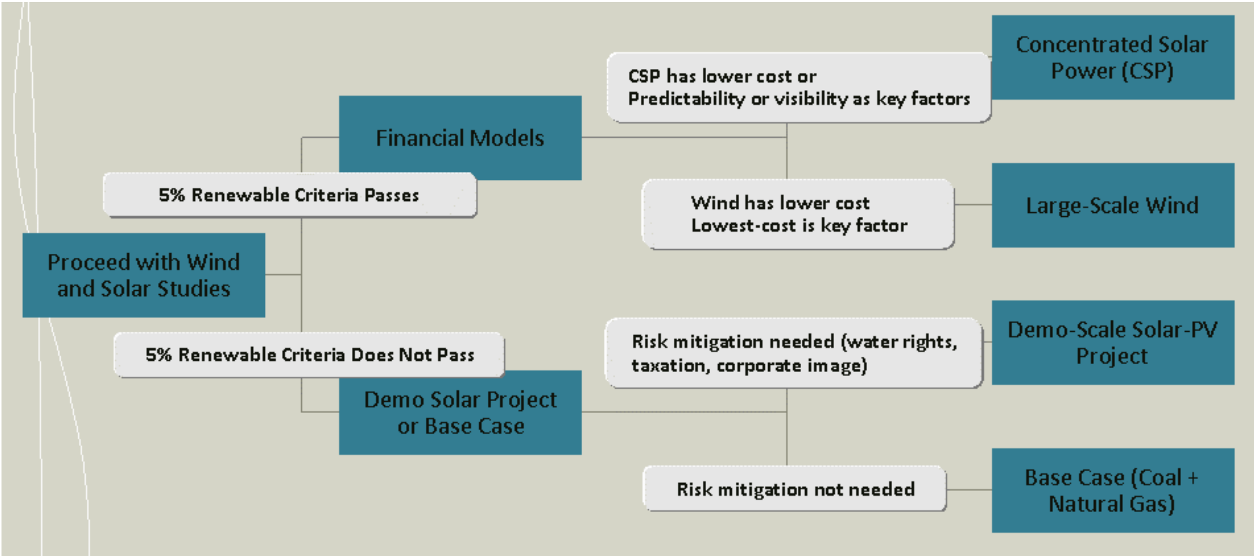
<u>Within 6 months:</u>

1. Commission a study to refine existing solar resource data for the region, and begin preliminary site selection for potential CSP project development.
2. Identify and contact potential solar thermal developers and request development of project concepts.[212]
3. Commission a detailed wind resource study for the region. Duration of these studies will be 1-2 years, unless such data is already available from existing meteorological databases.[213]

<u>12-24 Months:</u>

1. If 5% renewable energy requirement is enacted, elect the most economical technology, commission a feasibility study, and begin negotiating power purchase agreements (PPA's) early in the development process.

[212] Leading developers include Acciona Energies (they have a Santiago office), Iberdola, Solar Millenium AG, Sener, and Solel.
[213] Pacfic Hydro and Acciona Energies, both have expertise in wind power development, and have operations in Chile. Moreover, companies such as 3Tier, that specialize in high-quality wind resource assessment, are rapidly expanding operations in the Latin American region.


Concentrated Solar Power (CSP)
CSP has lower cost or Predictability or visibility as key factors
Financial Models
5% Renewable Criteria Passes
Wind has lower cost Lowest-cost is key factor
Large-Scale Wind
Proceed with Wind and Solar Studies
5% Renewable Criteria Does Not Pass
Risk mitigation needed (water rights, taxation, corporate image)
Demo-Scale Solar-PV Project
Demo Solar Project or Base Case
Risk mitigation not needed
Base Case (Coal + Natural Gas)

Introduction

BHP Billiton engaged the University of Michigan Masters Project team to

A) Identify and evaluate promising renewable energy technologies for use at the proposed Corridor Sands Limitada (CSL) mineral sands mine near Chibuto, Mozambique,

B) Apply our learning to conduct a similar, but accelerated renewable energy assessment of the Minera Escondida (MEL) copper mine in northern Chile, and

C) Generalize our work into a flexible framework for the selection and evaluation of renewable energy technologies across BHP Billiton's global assets.

This document represents our preliminary conclusions for phase B), a brief identification and initial evaluation of the most promising renewable opportunities for MEL.

Our team began work in late 2006 and early 2007 to first conduct baseline research on renewable energy technologies, under the guidance of Dr. Gregory Keoleian at the University of Michigan. As part of phase B), the team traveled to Chile to visit the BHP Billiton Base Metals business unit headquarters in Santiago, the Escondida administrative offices in Antofagasta, and the copper mine site itself in the Atacama Desert.
This document is a summary of our initial identification of promising technologies and configurations for incorporating renewable energy at MEL.

BHP Billiton Base Metals: Renewable Energy Goals and Drivers

For the purposes of this document, we have chosen to focus on renewable energy options from the perspective of BHP Billiton Base Metals in Chile, particularly the Energy group. Thus, to select the appropriate technology for BHP Billiton, the team sought to identify the principal goals and drivers that would influence the adoption of renewable technologies for Base Metals in Chile, and to develop a prioritized list of criteria for the selection of renewable technologies for the site.

Based on our discussions with various stakeholders at BHP Billiton Base Metals including Michael Anglin, Andrés Landerreche Mauricio Ortiz, and Linda Broughton, we have understood the principle drivers for developing renewable energy for Escondida as follows, in priority order:

1. **Compliance with Legislative Requirement:** By enabling the development of renewable energy capacity on the SING, BHP Billiton (and its power generator) will meet the pending renewable portfolio standard legislative requirement (Short Law II) in Chile, which will stipulates that 5% of the energy supplied by power distributors be derived from renewable sources, or be subject to estimated penalty of $27 per MWh.

2. **Fulfill"License to Operate" Imperative and Activate Core Values**: Renewable energy will help BHP Billiton fulfill its strategic commitment to maintaining its "License to Operate" and its commitment to its core charter values of Safety and Environment, Integrity, and the Courage to Lead Change. By lowering the company's greenhouse gas

emissions the company will enhance its reputation globally and nationally (and thus act to increase its "License to Operate") and activate these core charter values. Furthermore, by being the first to deploy large-scale renewable energy in northern Chile, the company will activate its core value of High Performance in technology and energy.

3. **Meet Current and Future Power Demands:** Renewable energy may help alleviate the severe energy crunch on the SING. Excess grid capacity in SING is currently only 270 MW, which severely limits the potential for future projects in the grid. Escondida currently uses approximately 430 MW and its new projects are expected to demand an additional 340 MW by 2012.

Evaluation Criteria for Renewable Energy for Base Metals

Based on the goals and drivers derived from interviews with Base Metals leadership, the team developed the following list of technology-specific criteria for identifying appropriate renewable energy technologies for consideration at Escondida.

1) **Scale:** The technology should be demonstrated capable providing energy at a scale sufficient to meet BHP Billiton's power provider's current and future legislative requirements. In order to meet BHP Billiton's 5% renewable goal, the technology would have to deliver up to 38 MW of energy in the future **(or approximately ~80 W with ~50% capacity factor).**

2) **Visibility:** The technology should present BHP with an opportunity to demonstrate its position as the industry, geographic, and/or technological leader in the responsible and safe implementation of renewable energy projects.

   i. **External Visibility:** The renewable energy technology should generate a positive perception from external stakeholders, including government, community, compatible with the local. The external visibility of BHP Billiton's renewable energy project can expand its "License to Operate" by providing additional energy capacity in the SING for local energy customers (even if the "renewable" portion of the energy is actually purchased by BHP Billiton). Furthermore, selecting a highly visible technology will provide a more demonstrable gesture of via continued Foreign Direct Investment in the local, regional and national economy in which BHP Billiton is operating. Finally, visible projects will provide BHP Billiton with an opportunity to demonstrate its commitment to sustainability on an international level.

   ii. **Internal Visibility:** The technology should also generate positive perception within the company itself. Internal visibility of successful renewable energy projects affords BHP Billiton the opportunity to demonstrate, within assets and across businesses, its commitment to renewable energy and sustainability and increases the likelihood of renewable energy technology scale-up and deployment at other sites.

3) **Proven commercial reliability:** In order to attain the goals of increased license to operate and regulatory compliance, BHP Billiton should give preferential consideration to technologies that are relatively mature and have been demonstrated successful at meeting its specific energy demands. Highly experimental technologies should be thoroughly researched via laboratory-scale studies before being given consideration, as unsuccessful deployment can undermine the company's and the community's confidence in renewable energy.

4) **Lowest-cost economics:** The technology should provide the lowest "levelized-cost-of-electricity" (LCOE) among renewable energy technologies and the LCOE should be comparable with that of fossil fuel, given consideration for carbon credits and other revenue streams. Stability of operating costs over time should also be considered, however, the variable (fuel) costs for renewable energy are low relative to traditional fuels.

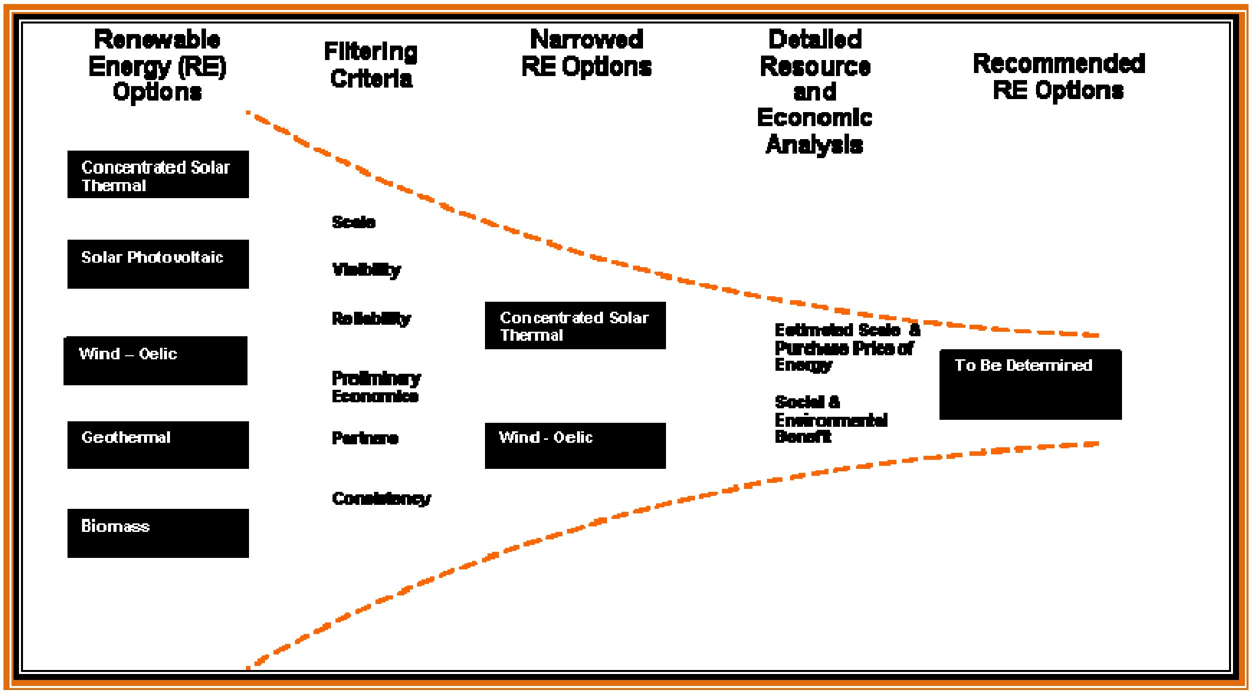
5) **Trusted partner:** BHP Billiton is considering procurement of renewable energy through a "power swap" in which it will use fossil fuel power, but purchase and replace those electrons with renewable energy from a RE generating company. Because its compliance is dependent upon the performance of an external entity (e.g., power provider), the company should ensure that there exists a trusted and experienced power provider for the technology.

6) **Consistency / reliability of electricity production:** As mentioned above, BHP Billiton's compliance is dependent upon the performance of the renewable energy technology. However, its actual operations are not utilizing the power delivered by the renewable energy technology. Therefore, this criteria was ranked last. BHP Billiton should still ensure that the technology is capable of consistent and reliable delivery of the renewable energy that the company can purchase.

Conclusions & Recommendations

Renewable Energy Selection Process

We have focused our recommendations on renewable energy technologies that can be implemented at scales that are large enough to meet regulatory policies that mandate 5% of electricity be procured from renewable sources. The only two technologies we found to be capable of doing this in Northern Chile are wind and CSP, which can be implemented at scales of over 100MW.
A solar-PV project may be the best type of project in the absences of legislation with the 5% renewable energy mandate. A solar PV project's primary value would be visibility at a smaller scale. An optimal location for solar-PV would be a remote well field that is currently powered with diesel generators. This would also place the PR value near one of MEL's most threatened assets—it's water rights.



Technology Recommendations

Concentrated solar thermal power (CSP) offers the best combination of benefits across the prioritized list of criteria we identified for BHP Billiton's Base Metals in Chile. While wind, solar, and solar PV offer some reputational benefits, a CSP project would differentiate itself as a world-class project because it would be the largest project of its kind in South America, and possibly the largest in the world.

The following table summarizes the principle attributes of the technologies that show the greatest potential to meet the criteria for Base Metals in Chile.

Summary of Interim Recommendations, Ranked in Order of Preference						
Technology		Installed "Nameplate" Capacity (MW)	Energy delivered (MWh / year)	CAPEX (USD Millions / MW)	Levelized Cost of Electricity (USD / MWh)	Notes
Renewables	Concentrated Solar Thermal without storage (20% capacity factor)	100 MW	175,200	$248	$171	Operational during sunshine hours only, but storage options available.
	Solar Photovoltaic (20% capacity factor)	5 MW	1,700 *(For a 1MW plant)*	$7	$392	Operational during sunshine hours only, with limited & costly storage options.
	Wind	100 MW	262,800	$144	$61	* Variability in power

	(30% capacity factor)					generation - lack of reliable energy storage options * More data needed to assess potential and risks

Concentrated Solar Thermal Power

Northern Chile has one of the top solar resources in the world. In the long term, developing the capabilities and technologies to implement large-scale solar power projects may also benefit BHP Billiton as it becomes more important to generate and procure renewable sources of electricity across its global assets. From a technical standpoint, a CSP project in Chile appears most promising because of its potential to provide reliable, consistent, low-cost electricity with fairly mature technology.

Pros and Cons of Concentrated Solar Thermal

Pros

- World-class solar resource in northern Chile
- Integrates easily with fossil-fuel combined cycle plants
- Cost of electricity anticipated to be competitive with wind
- Solar resource is reliable year-round and very predictable in this region, making it extremely reliable relative to wind
- Low-risk / fairly mature technology (high-precision mirrors, steam turbines)
- ***Opportunity for a distinctive Tier 1 renewable energy project***

Cons

- No local experience with the technology
- No output at night given current technology
- Capital-intensive with high minimum-efficient-scale of production

Wind Power

The potential for wind energy is currently undetermined given the lack of reliable resource data. The potential for wind power and the scale of risks associated with it can be assessed after collecting one to two years of data using wind-monitoring towers. Should wind energy prove viable, and appropriate land sites are available *close enough to transmission*, wind power is still an unattractive option for base or intermediate load generation because of high variability in the resource itself, and the lack of affordable, large-scale, and commercially available storage options. However, wind power is still an attractive option for *supplementing* base/intermediate load generation, using techniques currently employed by leading utility companies worldwide who have successfully integrated wind energy in their energy supply portfolios.

Pros and Cons of Wind Energy Option

Pros
• Proven technology
• Reliable local service providers are available (Pacific Hydro)
• More cost competitive than other renewable options (except hydroelectric)
Cons
• Low capacity factor (highly variable generation)
• Resource is not reliable or predictable
• May take 1-3 years to purchase turbines from order time
• Possible negative community perception
• Site where resource is optimal may not be
    • Near transmission
    • Available for use

Recommended Technologies to Meet the 5% Legislative Mandate

Concentrated Solar Thermal Power

The Opportunity

Concentrated solar thermal power (CSP) is currently the best large-scale renewable energy option for MEL because it best fulfills the goals of cost, visibility and reliability. It is also in alignment of BHP Billiton's strategy to pursue only Tier 1 projects, projects that are large, efficient, and considered best-in-class. According to country-level data collected by the United Nations Environment Program, north-central Chile receives some of the best solar radiation in the world, and the dry, high-altitude Atacama Desert receives excellent year-round radiation that frequently measures at more than 9 kWh/m^2/day (see boxed area in **Figure 2** below). This is nearly 30% stronger than the best radiation received at existing CSP plants operating in the United States and Spain.

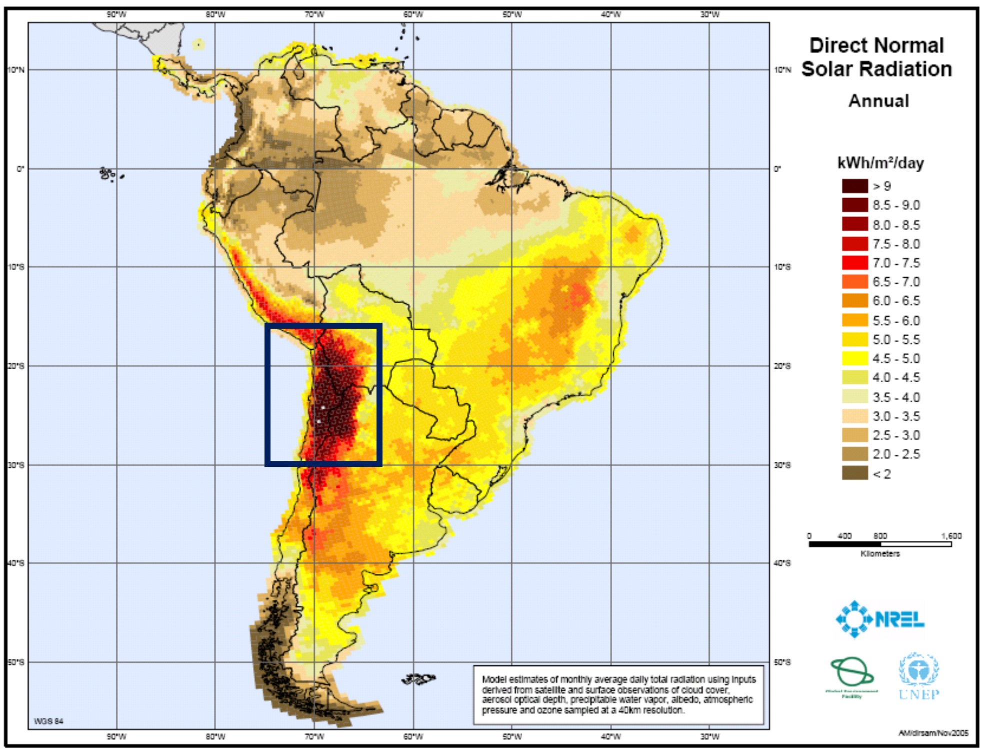
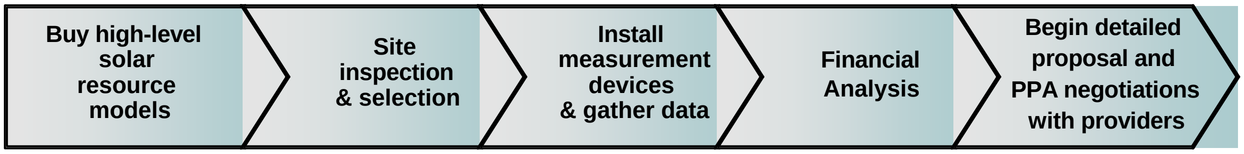


Figure 2: Direct Normal Radiation Map of Chile. Source: UNEP SWERA

CSP is ideal for large-scale power generation (50MW and higher), combines well with existing, combined-cycle fossil-fuel power plants, offers opportunities for energy storage, and offers electricity at costs that are competitive in regions facing high fossil-fuel prices or supply shortages. For base/intermediate load generation, an *integrated solar fossil-fuel combined cycle* model is recommended, in which solar thermal components integrate into the Rankine cyle of an existing combined-cycle power plant (natural gas, coal, oil etc) already serving SING.

Recommended Next-Steps



1. Resource models: Obtain high-level solar radiation data and models from research organizations such as Risoe National Laboratory in Denmark and UNEP's SWERA program, or from private companies like 3Tier (Central/South American models expected to be released in early 2008).

2. Site inspection & selection: Based on high-level resource models and land availability, select potential sites for a pilot (8-15MW) or larger-scale (50MW and higher) CSP plants. These sites would ideally be close to grid integration points (substations) in the SING or within reasonable, transmittable distances from the major facilities (such as the water pumping stations, milling, desalination plant, concentration plant).

3. Gather data: If existing direct normal radiation data is unavailable, then conduct measure of direct normal solar radiation for a one full year at the selected sites.
   - Data gathering can be conducted by MEL's own environmental services personnel, or by the local meteorological offices.
   - Alternatively, MEL may contract with solar power system providers to conduct measurement studies.

4. Financial Analysis: Incorporate the solar radiation data profiles gathered in the previous step into financial model and determine the quantity of grid electricity offset expected with a CSP plant. The model should also estimate Cost-Of-Electricity (COE) for a variety of installed capacity options (pilot, medium, and large-scale).

5. Project development: Develop contracts for project development, engineering and construction planning, and negotiate power purchase agreements with solar thermal power system providers.

   - Providers such as Iberdola, Abengoa Solar, and Solar Millennium are present through the entire CSP value chain: project development, engineering/procurement/construction (EPC), operation, and ownership (as an IPP).
   - Acciona Energía, which is a leading player in the global renewable energy industry, including CSP, has a presence in Chile and would be a convenient partner for a CSP study at MEL. While Acciona is primarily in the business of owning and operating CSP plants in Spain and the United States, they are steadily moving upstream in the CSP value chain to also provide initial project development services.

Key Evaluation Criteria:

1. Solar resource
    - Profiles of sunshine hours
    - Predictability and seasonal variability
    - Risk from unexpected natural events (such as volcanic eruptions)
2. Availability of large contiguous tracts of land not used for agriculture/grazing etc.
3. Reliable supply of cooling water
4. Infrastructure: roads, other transportation options, substations/grid connection points

Risks

Primary Risk

- CSP is highly capital-intensive and has a high minimum efficient scale of operation. This offers little optionality for scaling and exit compared to other renewable energy options such as wind or solar photovoltaics.

Minor Risks

- **Resource:** Solar resource is a very reliable in the Atacama region and is thus a low risk factor.
- **Water use:** CSP plants require significant amounts of water for cooling,[214] and unreliability in water supply could affect operations.
- **Land use:** CSP plants require significant land area, and the land can not be simultaneously used for any other operations, such as farming, unlike in the case of wind farms. However, this is not expected to be an issue in the MEL region since vast areas of unused land seem to be available around the mining operations.

- **Dust:** CSP systems use high-quality mirrors that need to be free of dust in order to function properly. Most existing CSP plants today are located in desert-like regions, which are quite dusty. Hence, aside from any unexpected physical factors specific to the MEL region, dust is not expected to be significant risk factor. The mirrors will, however require regular cleaning, likely weekly or biweekly.

Conclusion

Driving a CSP project would immediately make BHP Billiton the leader of what would probably be the world's most efficient, low cost, large-scale solar project in the world. This would position Chile as a leader in the world political setting for solar power, and BHP Billiton as a leader within Chile. Finally, as costs for electricity derived from CSP and solar continue to fall, working with this type of energy source could become an operational advantage for BHP Billiton in regions such as South America, Africa and Western Australia. Some funding for a CSP project could potentially come

[214] Wet-cooling requires significantly more water than does dry-cooling, however, the latter design also lowers the efficiency of the plant.

from BHP Billiton's $300MM Climate Change Fund, as it would help to drive advancement in CSP technology that could help to drive the costs of CSP implementation down for BHP Billiton in the long term.

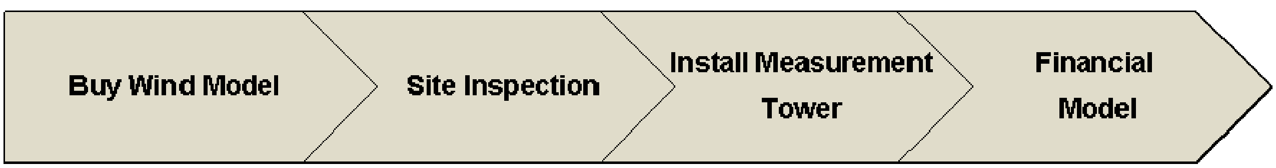
Currently available solar resource data indicates an excellent opportunity for large-scale solar thermal power operations in the region. We recommend that BHP Billiton sign an MOU with a leading CSP provider to initiate preliminary project development activities such as verifying the solar resource potential, selecting and evaluating the best sites for locating a CSP plant, and assessing grid integration opportunities and risks. This will be followed by site-specific financial evaluations and PPA negotiations.

Wind

<u>The Opportunity</u>

Wind power is usually the cheapest source of renewable energy in the presence of a good wind resource. There is currently no known data being collected near the SING that is accurate enough to make a reliable recommendation concerning the projected economics of a large-scale wind development in the SING.

<u>Recommended Next-Steps</u>



1. Use climate modeling software of obtain wind models derived from climate and/or satellite data. There are a handful of services that offer these services including 3Tier, AWS Wind, and others.

6. Site inspection & Screening- Perform on-the-ground validation of appropriateness for siting wind towers. Ideal sites will have good wind resources and will be located near existing transmission lines and a substation.

7. Install wind towers for data monitoring- Collect 1-2 year's of data, measuring at 60-80 meters altitude. The cost for measurement is about $50,000 per measurement tower.

8. Financial Model- Construct financial model using detailed wind data and calculate a Cost-Of-Electricity (COE) based on this model. Begin negotiating for construction and/or power purchase agreement.

<u>Key Evaluation Criteria</u>

- The wind resource
  - Intensity (average wind speed)

  - Reliability (how often it blows, daily or seasonal patterns)
- Distance to existing infrastructure
  - Transmission lines
  - Substations
  - Roads (for installation and maintenance of the towers)
- Environmental and Social Impacts
  - Visual distance from major cities and roads
  - Potential impacts on birds

Risks

The biggest risk factor for wind energy in the Atacama region is the wind resource itself – the availability and unpredictability of the resource. It is crucial to get reliable wind resource assessments for the region to determine the extent of the risk presented by the wind resource. Moreover, the dearth of viable, commercially available energy storage options for wind energy, make wind power a less reliable option for a highly energy-intensive mining operation that presents a nearly flat 24x7 load profile.

Conclusion

We recommend that BHP Billiton Base Metals proceeds with MOU to commission a wind study by Pacific Hydro. BHP Billiton should also evaluate 3rd-party climate models independently prior to negotiating any PPA's for wind power, in order to understand what would be the expected COE in the event that a wind project is developed.

Demonstration-Scale Renewable Energy Technology

Solar Photovoltaics

The Opportunity

Electricity from solar power can also be generated by solar photovoltaic (PV) units. The primary benefits of implementing solar PV instead of CSP are:

- Solar PV can be implemented at smaller scales and is scalable up to10 MW.
- There is more industry and commercial experience today with solar PV. Operation and maintenance is simpler for solar PVs, compared to CSP, and the timeline for construction and full-operation is also likely to be shorter for PVs.
- May make more sense in off-grid or remote locations, such as well fields whose pumps are currently powered by diesel fuel.

However, solar PV is less economical than CSP at larger scales because it has fewer scale-economy opportunities to exploit. The largest solar PV facility today is only 13MW.

Sample cost calculation for a demonstration solar PV project

The table below shows a sample calculation for a concept 1MWp solar PV farm near Escondida Copper Mine in Chile.

Capacity factor (CF)	*Location*: Northern Atacama Desert, Chile (24.16°S 69.04°W)[1] *Average insolation*: 375 W/m^2 (Source: SWERA[1]) *CF for this location:* 375 W/m^2 ⁄ 1000 W/m^2 = 37.5%†
Capital costs	\$4 to \$7 million
Annual O&M costs	\$33,000
Cost of electricity	14.5 – 21.1 ¢/kWh[1]

† Note that the capacity factor calculated here is much higher than most other locations worldwide, because the average insolation received at this location is among the highest in the world. Based on this capacity factor, the expected (actual) power output of this farm will be 3.75MW *(37.5% x 10MWp).*

Conclusion

Solar PV would still be a promising smaller scale project even though it would not meet the potential 5% renewable energy criteria because it would still provide high visibility for BHP Billiton Base Metals at a much lower CAPEX than that required for CSP. Solar PV could also work as a demonstration project within BHP Billiton, to show that large operations can implement renewable energy technologies successfully if they do so strategically and opportunistically.

These characteristics makes solar PV ideal in situations where

- Visibility is the most important driver,
- BHP Billiton is not legally obligated to buy more than 10 MW of renewable energy from the grid system (no 5% renewable energy requirement)

  OR

- Electricity supplied from solar PV offsets electricity that is being supplied by diesel generators (such as at a remote, non-grid-connected well pumping station).

Exploration-Stage Renewable Energy Technology

Geothermal

The Opportunity

When geothermal energy can be developed it can be a large, reliable, and cheap source of renewable energy. These factors alone make geothermal energy one of the most valuable sources of renewable energy, but the high costs of finding the resource and uncertain legal protection of exploration rights for geothermal energy often lead to it becoming relatively underdeveloped. A large proportion of the costs of converting geothermal energy into electricity occurs at the exploration stage (usually over 50%). This is because an exploration well must be drilled before a decision can be made about whether to develop a site, often costing up to $2MM per well or more. Little is publicly known about where there may be geothermal energy sites in Northern Chile that could be profitably developed. This lack of data is probably due to:

- Low historic electricity prices that made the costs of geothermal exploration unattractive relative to the potential rewards
- Legal treatment of geothermal rights that are less than certain given a lack of precedence
- Lack of initiation by government research geologists and existing power providers

Conclusion

Geothermal should be re-examined as a potential long-term suppliers of energy to the SING. In the short term, it may be worthwhile to perform a quick review of hotsprings sites within 50 km of the SING transmission and distribution network to look for potential projects. "It has been said that there are no commercial geothermal fields that could not have been discovered by an intelligent layperson".

In the long term, BHP Billiton may wish to act as one leader as part of a consortium to establish a system that spreads the costs and benefits associated with exploration of geothermal resources. For example, a consortium of mining companies, power providers, and the federal government could co-invest into a company or organization responsible for exploring geothermal resources with the goal of commercializing them. By co-investing, these organizations would hypothetically be seeking to minimize their individual risks around geothermal energy exploration while working proactively to develop geothermal power as a renewable energy component in the future. Developing Chile's geothermal energy supply could help Chile and its companies meet future regulations and corporate targets without sacrificing efficiency, economics or reliability.

Given Chile's location, there is a reasonable probability that there is a significant resource endowment of geothermal energy that could be developed profitably but several years of exploration will need to take place before specific projects are identified. Because there are no specific projects that can be identified we are not considering geothermal energy to be a viable renewable energy option for the SING at this time.

Impractical Renewable Energy Technology for MEL

Biomass

The Opportunity

The Master's Project team met with Aldo Cerda, Manager of Forestry, Industry, and Sustainable Tourism from Fundación Chile, a non-profit institute whose mandate is to develop and incubate new business ideas in Chile. In 2005, BHP Billiton Escondida Mining became a co-founding partner of Fundación Chile. During the meeting, Señor Cerda described a biomass-to-electricity opportunity to transport sustainably produced biomass from the south of Chile to the north via ship and combust it in cogeneration facilities or coal-fired power plants.

Fundación Chile has partnered with Forest Ethics, a high-visibility sustainable forestry NGO to develop a method of harvesting biomass in native forests that uses low impact methods and community labor. The Fundación Chile forestry operations currently produce biomass for $20/bone dry ton.

One European company currently transports chipped biomass from this operation to several of its cogeneration plants in the north of Chile with combined capacity of 400 MW. MEL is currently in the process of taking bids for a large coal-fired power plant that would come online in 5 to 7 years. There is potential for MEL to utilize this sustainably produced biomass by co-firing it with coal in the planned coal-fired power plant. Co-firing biomass can displace between 1 and 20 percent of the coal which will reduce CO2 emissions and may cost-effectively meet renewable energy regulations (currently being proposed in the Chilean legislature).

Conclusion

The Master's Project team's initial conclusion is that this opportunity is not promising for the following reasons:

Technical risk may be unacceptable to power producers. Modification to the specs of the coal plant will be necessary. While these may not be major modifications, they have the potential to delay project implementation and increase capital expenditures. Retrofitting a coal power plant to accept biomass is more costly and even less attractive, therefore the opportunity window closes after the design phase of the power plant. Power producers may be reluctant to take on the additional technical risk of combusting biomass and may require a price premium to do so.

Resource availability is uncertain. There is currently not enough sustainably produced biomass to justify these modifications and no guarantee that there will be in the future. The ability to purchase feedstock from multiple sources to mitigate price and quantity risks is of utmost importance when planning a biomass to electricity project. With only one source of sustainably produced biomass in the region, a secure supply cannot be guaranteed.

Stakeholder perception of utilizing biomass may be negative. There is a risk of negative perception to utilization of biomass to generate electricity since biomass harvesting may be seen as a destructive practice despite the methods employed by Fundación Chile and Forest Ethics. Sourcing biomass outside of the Fundación Chile/Forest Ethics partnership opens up additional risks especially if it is not certified as sustainable by a reputable organization. One of the key drivers for MEL in utilizing renewable energy is the associated positive reputational benefit. Co-firing biomass in a coal fired power plant may not confer this reputational benefit, therefore it is currently a poor strategic fit for MEL.

Impacts on CO_2 Emissions and CO_2 Credits Generated

The project's impact on GHG emissions was approximated by calculating a baseline, emissions factor for the SING electricity grid in the absence of the project and multiplying this baseline emissions factor by the amount of energy (MWh) generated by the project. The Clean Development Mechanism under the Kyoto Protocol requires use of a "combined margin" baseline methodology for calculation of the mass of CO2e emissions offset by grid-connected electricity generating projects. This methodology reflects a project's effect on GHG emissions of (1) the operation of current power plants (referred to as the operating margin) and (2) the impact of new facilities expected to be built (referred to as the build margin). See **Table 1** for the specific emissions factors used. Although detailed, plant-specific data is needed to calculate a "combined margin baseline", the Team used generalized data regarding the current and future power mix and emission factors provided by MEL to approximate the combined margin baseline using the equation below. [215]

$$Combined\_Margin = \frac{OM_{year1} + BM_{historical}}{2}$$

Annual CO_2e emission reductions resulting from a renewable energy project installed in the SING are estimated to range from 2,566 t CO_2e (for 1 MW wind) to 1,026,558 t CO_2e (for 200 MW solar thermal) as illustrated in **Table 2** below. The CO_2e emission reductions resulting from a renewable energy project are highly dependent upon project size and the technology capacity factor.

Although the project will likely decrease BHP Billiton's global carbon emission footprint, the project's ability to generate saleable carbon emission reduction credits is seriously compromised by legal requirements to deploy renewable energy under Short Law I and II. In order to generate carbon reduction credits under either the Kyoto Protocol's Clean Development Mechanism or a voluntary carbon program, the project must be demonstrated to be "additional". In layman's terms, "additional" means anything above and beyond what is required by law or what is financially viable without the income stream provided by carbon credits. Short Laws I and II are likely to require that power generators deploy renewable capable of delivering 5% of their current installed capacity. If renewable energy deployment is required by law, it would be difficult to establish the "additionality"

[215] Where OM = Operating Margin; BM = Build Margin. The effect of a specific project upon the electricity grid can be thought of in terms of its effect upon operations (OM), and its effect upon capacity additions (BM).

of any project prior to the meeting of this regulatory burden. After the 5% requirement has been met, however, BHP Billiton may find it easier to demonstrate the "additionality" of renewable energy projects, as the projects would no longer be necessary to meet the generator's regulatory burden. Therefore, BHP Billiton might consider encouraging independent power generators to meet their 5% obligation prior to deployment of this project. If the project did qualify for carbon credits, this could conservatively (carbon price assumed to be $10/ton) generate income streams reflected in **Table 2** below.

Table 1: Emissions Factor Calculation for SING

Energy Carrier	Emission Factor (ton/MWh)	Operating Margin SING	Build Margin SING	Previous SING Mix
Coal	1.04	48.30%	55.28%	29.20%
Pet Coke	1.32	19.75%	23.61%	20.60%
Diesel	0.71	27.30%	0.77%	0.70%
Diesel & Fuel Oil	0.76	0.30%	1.14%	0.30%
Fuel Oil	0.79	2.50%	1.32%	0.15%
Natural Gas	0.45	1.50%	17.43%	48.60%
MEL Emission Factor (ton/MWh)		0.987727	0.992515	0.804256

Table 2: CO2e Emission Offset and Credit Calculation

Project Type	Project Size	Project Capacity Factor	CO2 Offset	Value of CO2e Offsets	Percent of MEL Energy Use
	(Name Plate MW)	(%)	(tCO2e/year)	($/year)	(%)
Solar Thermal	1	60%	5,133	$51,328	0.14%
	50	60%	256,639	$2,566,394	6.98%
	100	60%	513,279	$5,132,788	13.95%
	150	60%	769,918	$7,699,181	20.93%
	200	60%	1,026,558	$10,265,575	27.91%
Wind	1	30%	2,566	$25,664	0.07%
	50	30%	128,320	$1,283,197	3.49%
	100	30%	256,639	$2,566,394	6.98%
	150	30%	384,959	$3,849,591	10.47%
	200	30%	513,279	$5,132,788	13.95%

Appendices

Technologies Overview

Biomass-to-Electricity
Biomass is defined as "plant material, vegetation, or agricultural waste used as a fuel or energy source." Biomass may be converted into electricity via two basic methods. The most common method is to combust it in a steam boiler to drive a turbine. This may be done in a specifically designed biomass fired boiler, or the biomass may be mixed up to 20% with coal in a process know as co-firing. Biomass may also be converted into synthesis gas in a process called gasification and then burned in a gas turbine or gas engine. Gasification is a more expensive process but results in higher conversion efficiency.

Concentrated Solar Power (CSP)
A concentrated solar thermal power facility uses mirrors to focus solar heat energy on tubes which contain heat transfer fluid. This fluid is heated to very high temperatures and used to create steam which drives a turbine to generate electricity. The three main variants are parabolic trough (most common), central receiver, and parabolic dish.

Solar Photovoltaics
A solar cell is composed of positively and negatively charged layers of semiconductor material arranged to create an electric potential when light contacts the cell surface. This electric potential causes a flow of electrons which is captured as electric current. The two main types of solar cells are crystalline silicon and thin film. Solar cells are arranged in groups to create modules which can be mounted on rooftops or other surfaces. A group of solar modules makes up a solar array.

Wind
Wind energy is generated by wind turbines which range in "nameplate" capacity between 500kW and 5MW. The most common range is between 1MW and 3MW. Turbines will actually generate only 30-35% of their "nameplate" capacity on average, depending on the wind resource, height, and location of the tower.

Geothermal
Geothermal power plants utilize steam from underground water reservoirs that have been heated by geologic activity to drive a turbine that generates electricity. Some geothermal power plants extract the steam and release it while others reinject it into the reservoir. Exploration for geothermal resource is similar to petroleum exploration in that it involves identifying promising areas and drilling test wells.

Preliminary Project Concepts

Concentrated Solar Thermal Power

PROJECT: 100 MW Concentrated Solar Thermal (grid-connected)

GOALS:

- Fulfill BHP Billiton's 5% renewable energy requirement
- Maximize reliability of power while achieving a reasonable COE
- Generation of CO_2 emission credits under CDM mechanism that could be sold via BHP Billiton Marketing
- Reduce emissions as part of BHP Billiton and/or Chilean national policy
- May qualify for funding from BHP Billiton's Climate Change Policy Fund

COST and TIMELINE: Estimated COE of $9-$15 per MWh; 2-4 years to develop

DESCRIPTION:
Northern Chile has one of the world's best solar energy resources. A large-scale, CSP facility may be constructed with a preliminary estimated COE of $9/MWh (based on personal communication with Peter Duprey, CEO of Acciona North America). In this configuration, CSP would pre-heat steam, and route through the same turbines are also supplied by the steam supplied from a natural gas (LNG-supplied) power plant. Benefits of this configuration would include:

- Fulfill BHP Billiton's 5% renewable energy requirement
- Reduction in the amount of LNG consumed (incremental value of CSP = value of LNG offset)
- Potential reduction in size of storage facilities needed for construction of future LNG terminals
- World-Class solar energy project to enhance BHP Billiton's corporate reputation
- May qualify for funding from BHP Billiton's Climate Change Policy Fund

POTENTIAL STORAGE STRATEGY: Integrate CSP into additional reservoir storage capacity
A CSP facility could also potentially be integrated with energy needs pumping water from the Coloso facility. This facility is expected to be expanded to require a total of about 240 MW, with roughly 80% of the expanded energy needs to be associated with pumping water from sea level to Escondida. If additional reservoir storage capacity was built at the time of the expansion, some pumps could be run during the day that would be powered by energy from the CSP. Having additional water storage and pumping capacity would also allow BHP Billiton to choose to monitor energy prices on the SING and pump more water during times when prices were lower. A more detailed study would need to be performed to see if this additional value was worth the tradeoff of building additional water storage and pumping capacity.

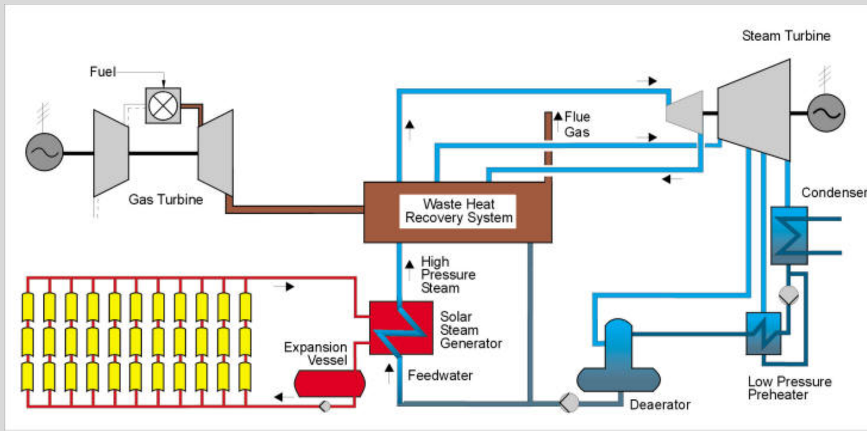
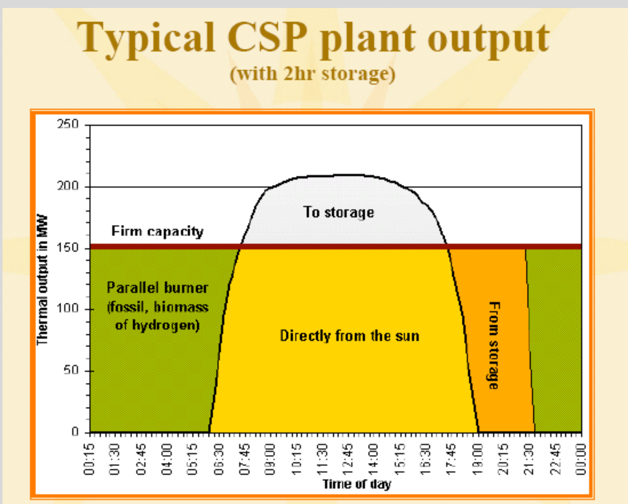
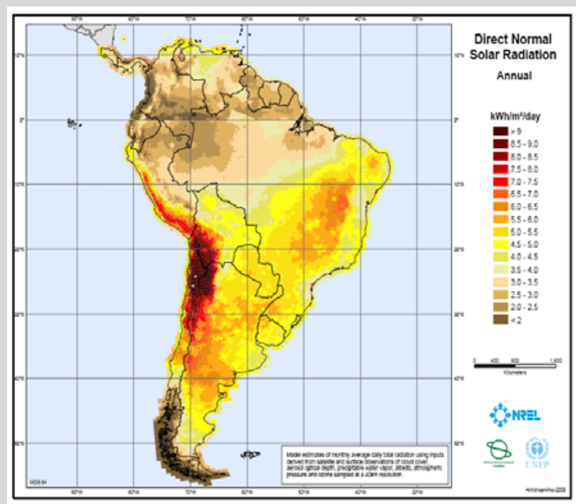


Photo source: NREL

Pumped Storage: Area under the curve is hypothetical power supplied by CSP. If additional storage and pumping capacity were designed into the pending Coloso expansion, the CSP could offset the *power* requirements of Coloso in addition to the *energy* requirements.





Source: Sandia National Laboratories **Source: SWERA**

Preliminary Project Concept: Wind Farm

PROJECT: 100 MW Wind Power Facility

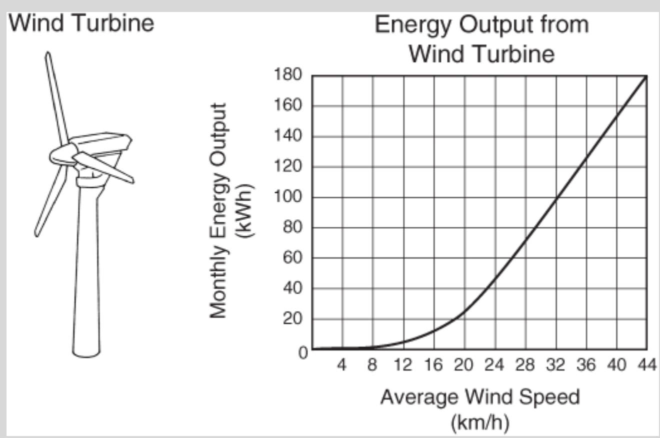
GOALS:

- Fulfill BHP Billiton's 5% renewable energy requirement
- Minimize cost of energy, less certain power reliability
- Generation of CO_2 emission credits under CDM mechanism that cold be sold via BHP Billiton Marketing
- Reduce emissions as part of BHP Billiton corporate policy

COST and TIMELINE: Estimated COE of 6-12 cents/kwi-$120 per MWh; 3-4 years to develop

DESCRIPTION:
It will take at least 1-2 years for data collection to determine if wind is an attractive option, and an additional 1-2 years to order and install the turbines. MEL has recently signed an MOU with Pacific Hydro to investigate the feasibility of wind power. An example wind farm with 100 MW of rated capacity might consist of 50 2-MW turbines. This facility would not produce the full 100 MW of power it is rated for except for when it receives the most optimal wind speeds. The ability to predict when the turbines will generate power would be limited by the understanding of local wind patterns. Benefits of a wind farm would include:

- Economic value for developer = value of electricity sold to the grid
- Fulfill the 5% renewable energy requirement
- Low technical risk because wind power technology is very mature
- High operational risk depending on the predictability and variability of wind resource
- May qualify for funding from BHP Billiton's Climate Change Policy Fund



Preliminary Project Concept: Solar Photovoltaic

PROJECT: Solar-PV pumping augmentation at well site

GOALS:

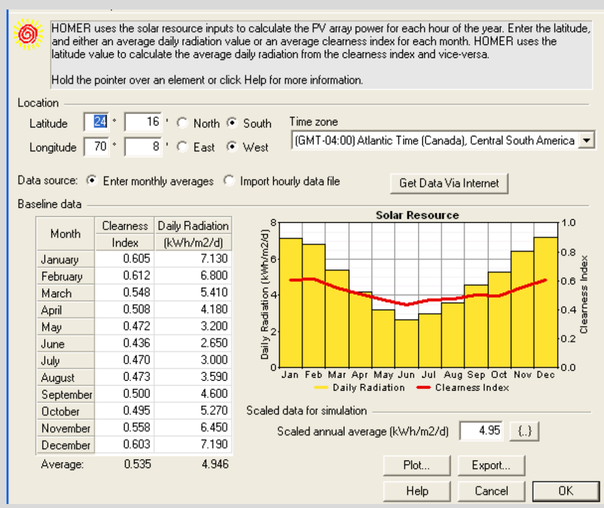
- Initiate a visible renewable energy project
- Reduce risk of losing water rights

COST and TIMELINE: Estimated COE of $15-$20 per MWh; 2 years to develop

DESCRIPTION:
Escondida has several well fields currently being powered by diesel generators. Solar PV arrays could be installed to power some of the energy required to pump these facilities during the day. Benefits would include:

- Offsetting of diesel fuel used to power these pumps during the day
- Reduced transport costs for getting diesel to these sites due to lower diesel requirements
- Generation of CO2 emission credits under CDM mechanism that cold be sold via BHP Billiton Marketing
- Public visibility near valuable water rights that may be considered to be in jeopardy of being revoked.

The NPV of the project would be calculated from the value of diesel fuel being offset, reduction of transport costs, and potentially a reduction in the risk factor associated with the incremental value of losing the associated water rights (an upgrade to the Coloso Reverse Osmosis facility).



Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.605	7.130
February	0.612	6.800
March	0.548	5.410
April	0.508	4.180
May	0.472	3.200
June	0.436	2.650
July	0.470	3.000
August	0.473	3.590
September	0.500	4.600
October	0.495	5.270
November	0.558	6.450
December	0.603	7.190
Average:	0.535	4.946

Background: Escondida Base Case and the Northern Chile Grid

Current and Future Electricity Demand at MEL

The current base-load power demand at MEL is 410 MW with peak loads reaching the 430 MW range. The power demand is split between the main mining/processing facility at Escondida and the water purification and copper concentrate dewatering facility located at the port of Coloso. At Escondida, the vast majority of power is consumed by the milling (~800,000 MWh/year) and electrowhinning (~400,000MWh/year) processes. At Coloso, the majority of power is consumed in copper concentrate dewatering (~39,000 MWh/year) , water purification (~39,000 MWh/year), and pumping (~350,000 MWh/year).

MEL currently has six contracts with three power generators to supply over 500 MW. Prior to 2004, 48% of MEL's power was derived from natural gas, and 49% from coal and pet coke. In response to Argentinean natural gas export restrictions, MEL's current power portfolio has shifted to 68% coal and pet coke, 27% diesel, and 1.5% natural gas. The future power portfolio is expected to be 78% coal and pet coke, 17.4% natural gas, 1% diesel, and 1% fuel oil. The transition from natural gas to diesel power has led to a 23% (or 675,000 tons CO2e/year) increase in carbon emissions at MEL (see **Table 4** below).

Table 4: Fuel mix and GHG emissions factor for Chilean grid

Energy Carrier	Emission Factor (ton/MWh)	New MEL Mix	Old MEL Mix
Coal	1.04	48.30%	29.20%
Pet Coke	1.32	19.75%	20.60%
Diesel	0.71	27.30%	0.70%
Diesel & Fuel Oil	0.76	0.30%	0.30%
Fuel Oil	0.79	2.50%	0.15%
Natural Gas	0.45	1.50%	48.60%
MEL Emission Factor (ton/MWh)		0.99	0.80

Chilean Electricity Industry and Regulatory Framework

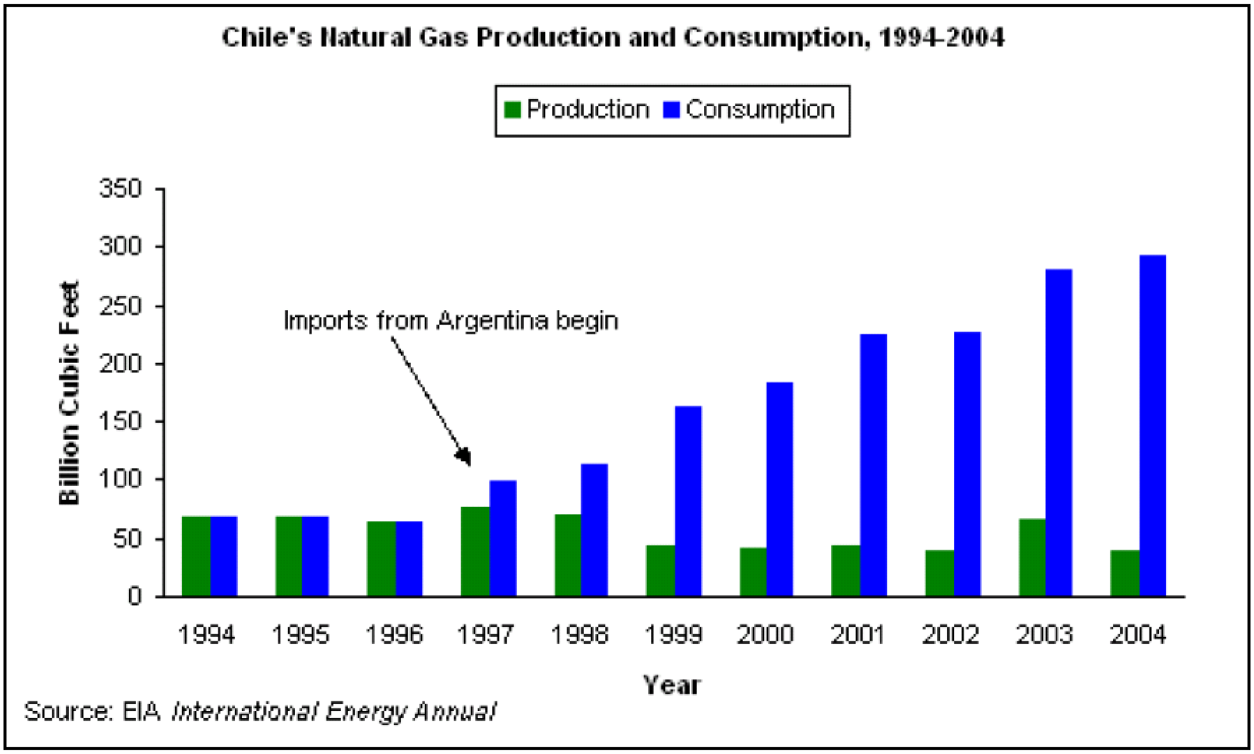
The Chilean electricity industry is heavily privatized, with the government present only in a regulatory, monitoring, and indicative planning capacity. The market is partially regulated. Those consumers with electricity usage below 2,000 kW are part of the regulated market. Those with an electricity demand above that figure, or with other non-standard requirements, are free to negotiate their own contracts. The latter customers account for about 55% of total electricity sales.

Renewable Energy Policy

Historically, Chile's regulatory framework has been neutral with respect to the technologies and energy sources used to generate electricity and these sources all had to compete on similar terms. However, in January 2006, Short Laws I & II proposed extending benefits to renewable energy production. The Short Law I established preferential conditions for renewable projects of less than 20MW by exempting small plants from trunk transmission tolls, dispatching 100% of generation to the grid, and guaranteeing a price equivalent to the node price determined by the regulated price for utilities. The Short Law II will establish additional benefits, stipulating that 5% of the energy tendered by distributors must be supplied using renewable energy sources with a proposed penalty of approximately $27/MWh for non-compliance. This will put the long-term levelized cost of electricity at approximately $.08 per kWh ($ 55 / MWh + $27 MWh penalty).

Chilean Grid

The Chilean electricity grid is divided into four autonomous grids. MEL's power is derived solely from the northern grid or Sistema Interconectado del Norte Grande (SING), which had an installed capacity of 3,634 MW at the end of 2004. Unregulated customers account for over 90% of electricity sales in the SING, due to the presence of large mining customers including MEL. Total demand on the SING grid is approximately 1,890 MW, of which MEL is responsible for 28%. In 2004, natural gas imported from Argentina accounted for approximately 58% of the installed capacity, while coal accounted for 33% and other non-renewable sources comprised the remaining 9%. Until recently, imported natural gas from Argentina accounted for over 80% of Chile's natural gas supply, with only 20% generated internally.



The SING was initially burdened by massive overcapacity—peak electricity demand reached just 39% of capacity in 2002—a result of the simultaneous construction in 1998-99 of two rival gas pipelines from Argentina and their associated combined-cycle electricity-generating plants, when there was a market for only one such project. However, beginning in 2004, Argentina began restricting natural gas supply, and the installed capacity shrank to only 2,160 MW. As a result the SING maintains a very low operating reserve margin, and the opportunities to implement new projects with significant power demand are limited.

Since 2004, Argentinean natural gas exports to Chile have fluctuated between 20-50 percent below contracted volumes, with natural gas flows ceasing completely on some occasions. At times Argentina has completely cut natural gas exports to Chile. The import cuts have caused shutdowns at power plants and forced power generators to switch to costlier fuels, such as diesel. Along with the cuts in volumes, Argentina has also increased natural gas prices: in July 2006, Argentina increased its natural gas export tax to 45 percent, from 20 percent. Continuing structural difficulties in Argentina's natural gas sector will likely lead to continuing supply problems in the future.

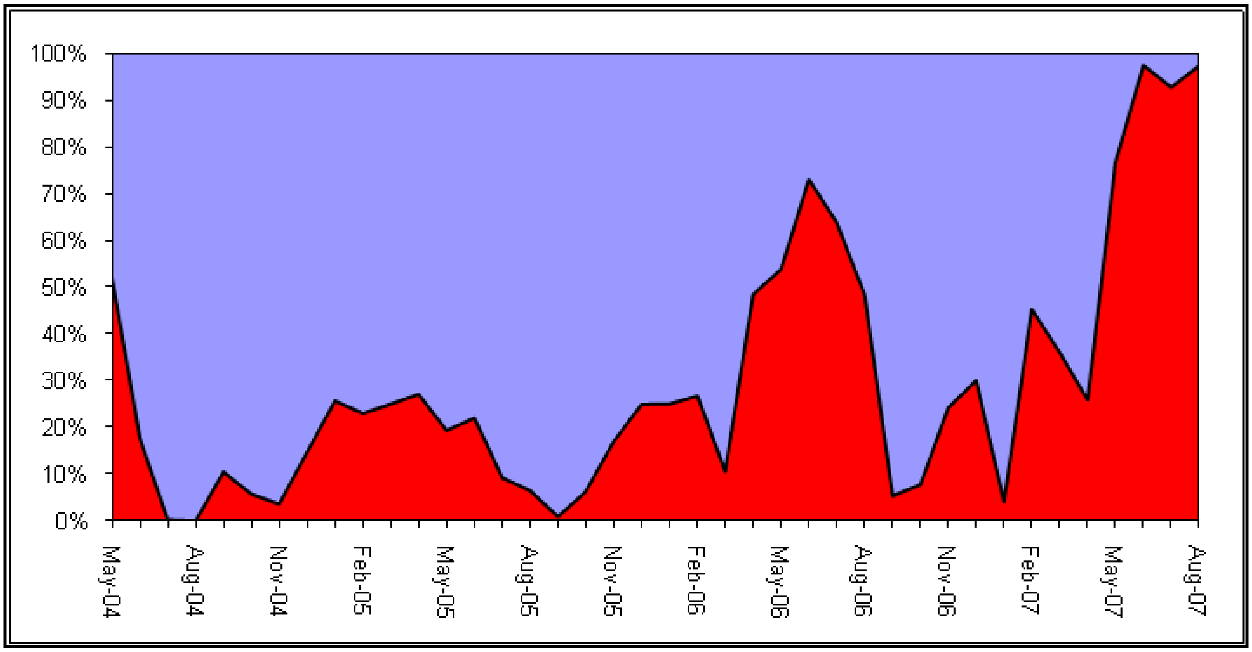


Figure 3: Percentage of natural gas supply export contracts restricted by Argentina, May 2004-Aug 2007

MEL Response to Restrictions in Natural Gas Supply

As a result of the switch from natural gas to diesel and coal as the predominant power sources, the current levelized cost of electricity on the SING has risen dramatically to $170/MWh. In light of impending power shortages and high electricity prices, BHP Billiton has pursued alternative sources of power generation to ensure security of supply. The interim solution (2007 – 2010) has been to replace the gas generation with diesel at current power generators, while exploring alternative mid- to long-term solutions. The mid-term solution involves the construction of a liquefied natural gas (LNG) regasification terminal to supply existing natural gas combined cycle generating facilities. Suez and Codelco formed a joint venture named GNL Mejillones and to develop such an LNG regasification terminal at the port of Mejillones (near Antofagasta). The regasification facility will supply natural gas sufficient to generate 1,100 MW of electricity. GNL Mejillones has signed contracts with BHP Billiton (MEL) for the sale of up to 150 MW beginning in 2009. In the long-term (2010 – 2026) BHP Billiton is arranging to secure power purchase agreements for up to 340 MW of supply from a new coal plant that will be connected to the SING.

A Brief Primer on Concentrated Solar Thermal Power

Due to the relative unfamiliarity of with concentrated solar power (CSP) systems, we felt it might be beneficial to offer more detail on this technology here.

Concentrating solar power systems use concentrated solar radiation as a high temperature energy source to produce electrical power. These clean energy technologies are appropriate for Sunbelt applications where direct solar radiation is high. The first commercial plants have been in operation in California since the mid-1980s, providing the 354 megawatts of the world's lowest-cost solar power. The many types of systems under development (including parabolic troughs, power towers, and dish/engine systems) for different markets vary according to the concentration devices, energy conversion methods, storage options and other design variables.

Parabolic trough systems are the most commonly used CSP technology today, and the recommended CSP technology option for MEL. They use mirrors to concentrate sunlight onto heat-transfer tubes containing a heat-transfer fluid such as synthetic oil. This heated oil is routed through a heat exchanger to generate steam that drives as electricity producing turbine.

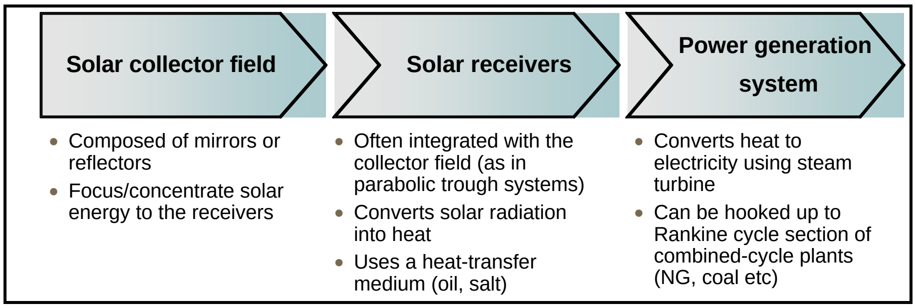


Figure 5: Components of a typical CSL plant. Source: Bandyopadhyay 2007.

While parabolic trough systems are the most proven CSP technology today, several newer technologies with greater potential in terms of cost, efficiency, and optional scalability, are now in demonstration or research stages worldwide.

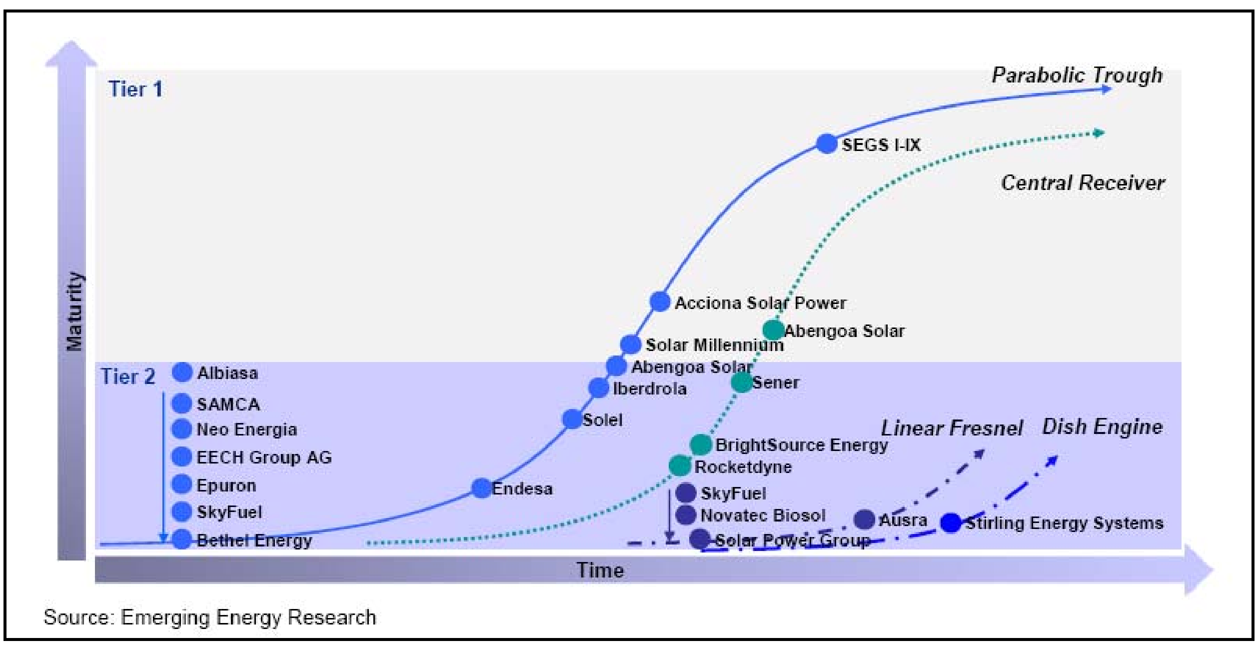


Figure 6: CSP Technology Curve, showing major technology providers. Source: Emerging Energy Research, 2007.

Description of Costs

Average installed capital cost of a 'stand-alone' CSP plant is estimated at around $4500/kW. CSP technologies use mirrors to capture heat from the sun to generate steam, which then runs a steam turbine to generate electricity. Just the concentrating mirrors and the power generation unit account for about 80% of the capital cost.

For the recommended 'integrated solar fossil-fuel combined cycle' plant configuration, the solar increment would incur a reduced capital cost of $2700/kW.

Moreover, for larger solar thermal installations, the per-kW capex decreases because of economies of scale in procurement of components, transportation, and installation.

Operating cost for CSP plants is relatively small, at approximately $50/kW, and large plants show significant economies of scale in this cost category.