INTERNATIONAL MOLYBDENUM ASSOCIATION
THE VOICE OF THE MOLYBDENUM INDUSTRY

Molybdenum in Power Generation

Thin Film Photovoltaic Solar Panels

Molybdenum's contribution to sustainable development in:

- Stainless steels
- Alloy steels
- Superalloys
- Cast iron
- **Mo metal**
- Chemicals

MoRE FOR LESS

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Molybdenum makes an important contribution to sustainable development as a metal, as an alloying element, and as a constituent of chemical products. IMOA's 'MoRE FOR LESS' case studies explore, in more depth, how molybdenum is contributing to sustainable development, a pattern of growth in which resource use aims to meet human needs while preserving the environment.

In particular we will look at how a specific use or application is contributing to the three pillars of sustainability:

ECOLOGY — Environmental performance, resource use, energy efficiency & production and recycling

ECONOMY — Supply chain, lifecycle and materials performance

SOCIETY — Health, safety and wellbeing

This case study explores the manufacture and use of Thin Film Photovoltaic (TFPV) panels to generate carbon-free electricity. Solar electricity emits no CO_2 and is classed as a renewable energy source. TPFV panels have potential advantages over conventional solar panels, and molybdenum is a key component in the manufacture of several different types.

The Challenge

Greenhouse gas (GHG)-driven climate change is one of the biggest challenges facing mankind in the 21st century. Carbon dioxide (CO_2) is the largest contributor to Earth's GHG inventory, with levels rising dramatically since the start of the Industrial Revolution and corresponding to a similarly dramatic rise in average global temperatures.

Fossil fuel combustion produces the majority of man-made CO_2, with approximately 25% of all GHGs coming from electrical power generation. Concerns about CO_2 in particular are therefore driving demand for low-carbon and carbon-free sources of energy.

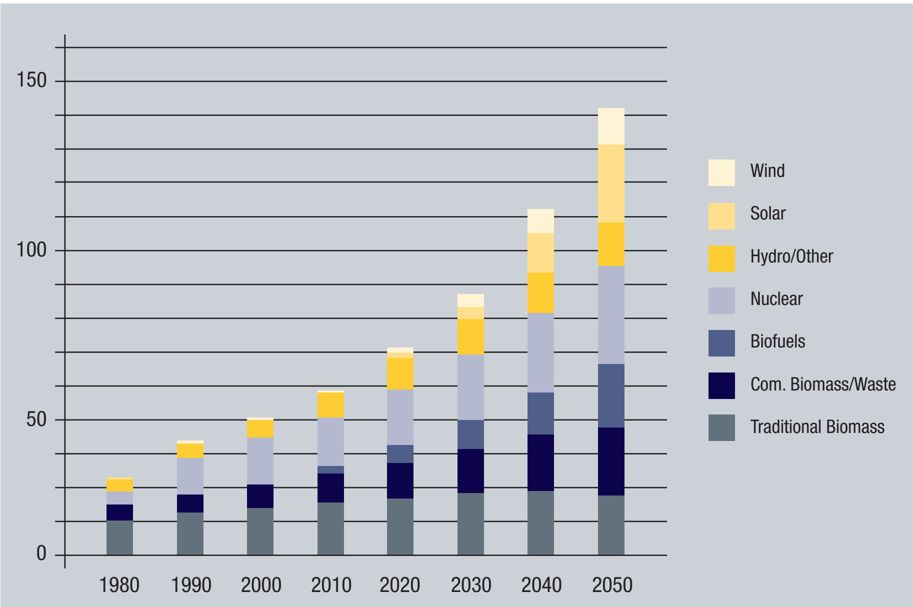

Figure 1: Non-fossil energy growth: energy demand outlook in million barrels oil equivalent per day.
Source: Energy Markets presentation, Royal Dutch Shell plc, April 2012

The Solution

Solar power emits no CO_2 and is classed as a renewable source, along with some other forms of non-fossil generation.

Energy demand from non-fossil sources (Figure 1) has grown steadily since the late 20th century and is estimated to more than double in the period to 2050, with the contribution met by solar energy increasing more rapidly. Consumer choice is also expected to drive demand from small-scale and domestic installations.

Solar power is considered a sustainable resource because it consumes only sunlight in generating electricity and can be deployed at either large central stations or dispersed sites. Implementing solar also consumes less energy than other technologies.

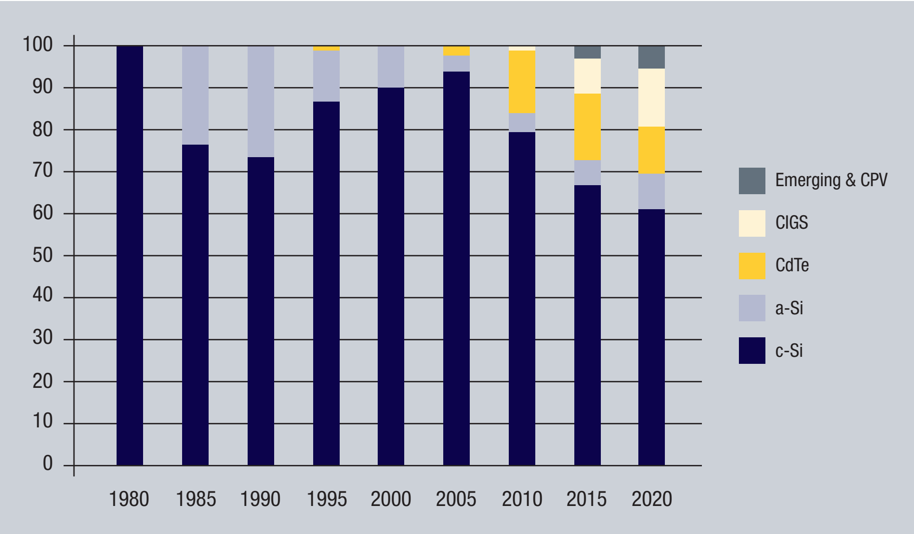

Figure 2: Historical evolution of solar cell technology market share and future trends. Source: 'Solar Generation 6: Solar Photovoltaic Energy Empowering the World 2011' © EPIA 2011, Figure 12, page 26)

On average, Earth's surface continuously receives more than 1000 W/m^2 of solar energy. Photovoltaic (PV) materials convert solar energy to electricity, with the conversion efficiency (CE) of a material measuring efficiency of conversion. The main commercial PV materials today are:

- crystalline silicon (c-Si)
- amorphous silicon (a-Si)
- cadmium telluride (CdTe)
- CIGS (or CIS), an alloy of copper (Cu), indium (In), gallium (Ga) and either selenium (Se) or sulphur (S)

Technologies based on crystalline silicon use relatively thick and rigid wafers in solar panels, whilst the others are thin film technologies. Although the thin film technologies have inherently lower CE values, their advantages in manufacturing, cost and the flexibility in design they offer make them much more attractive than crystalline silicon. Thin film technologies using molybdenum offer superior CE values compared to thin film silicon devices. Figure 2 shows 2011 estimates of market trends for each of these technologies.

How molybdenum can help

Molybdenum plays an important role in the rapidly growing thin film technologies as one of the metals (or the only metal) in the back electrode of a thin film panel, in a layer approximately 500–1000 nm (billionths of a meter) thick (Figure 3). It is deposited using sputtering, where high-energy inert gas plasma ejects, or sputters, atoms from a molybdenum target. When ejected the atoms deposit on a substrate, producing a precisely controlled, high-quality film with excellent adherence.

The properties of molybdenum provide several advantages when molybdenum is a component of the back electrode:

- Molybdenum withstands process temperatures up to 650 °C
- Molybdenum resists high-temperature corrosion by selenium
- Molybdenum allows sodium diffusion from soda lime glass substrates into the absorber during processing, improving CE by about 2%
- Molybdenum forms beneficial selenium compounds at the molybdenum/CIGS interface

Although patents cite alternative electrode materials, molybdenum has the potential to be the material of choice in the future. Molybdenum use in TFPV technologies was estimated at more than 160 MT in 2011. Depending on the growth of demand for TFPV, consumption in 2020 is estimated to be between 1300 and 2600 MT.

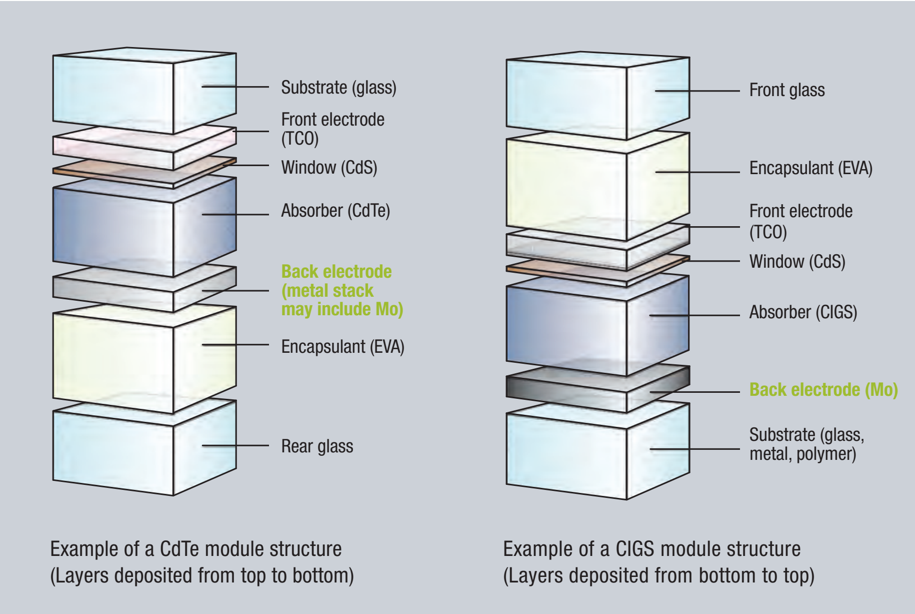

Figure 3: Schematics of the layered construction of thin film solar cells. Molybdenum plays a critical role as a preferred back electrode. Source: Prismark Partners, LLC

Key sustainability benefits

Benefit	Sustainability attribute		
Produces no CO_2 (modeling suggests that only replacing fossil-fired generation with GHG-free sources will have a significant impact on GHG inventory, and by extension, climate change)	ECOLOGY		SOCIETY
Peak PV generation naturally coincides with peak electrical demand, reducing the need for fossil fuel baseload generation	ECOLOGY	ECONOMY	SOCIETY
PV quickly 'pays back' the energy used to build, install, and recycle modules	ECOLOGY	ECONOMY	
Individual companies both promote end-of-life recycling programs and recycle their own internal scrap	ECOLOGY	ECONOMY	
Molybdenum is extracted from the recycled material streams and all unused parts of sputtering targets are recycled	ECOLOGY	ECONOMY	
Produces energy at a fixed cost for over 20 years, whereas fossil energy costs fluctuate and grow over time		ECONOMY	
CIGS and CdTe have some of the shortest energy payback times (EPBT) of all technologies, in the range of 0.9–1.5 years		ECONOMY	
Off-grid PV eliminates power losses incurred in distribution	ECOLOGY	ECONOMY	
PV technologies generate jobs throughout the value chain in manufacturing, installation, operation and maintenance of equipment		ECONOMY	SOCIETY
PV can be easily installed in remote sites, bringing electricity to underdeveloped regions, vastly improving quality of life			SOCIETY

Summary

PV panel manufacturing has been transformed into a mass production industry in the last five years. Thin film technologies using molybdenum have the potential to successfully compete with Si-based technologies and look likely to have an important future role in PV generation.

Molybdenum is a significant raw material in the production of TFPV systems and is likely to remain a key component as technology evolves, increasing the contribution that molybdenum already makes to sustainable development.

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