A new IEA publication launched 1st December
First RE in-depth technology study
Support from the French and US governments
cedric.philibert@iea.org

Formation des Experts Marocains, Oujda, 20 mars 2012
Building on...

- Solar electricity and other roadmaps
- *World Energy Outlook*
- *Energy Technology Perspectives*
- Also starring...
  - Solar heating and cooling
  - Forthcoming IEA Roadmap
  - Solar Fuels
  - From PV and CSP, H₂ and liquids
Growing shares of renewables

All scenarios point out a large growth of renewables

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The primary role of renewables in the BLUE scenarios

Renewables provide from almost half to three quarters of the global electricity mix in 2050
RE generation in 2050 for key countries/regions

The mix varies according to resources
In search of synergies...

- Between various solar technologies
- With other RE/EE technologies

Driven by analyses of the demand for various uses

Source: SunEarth Inc.

Integrated PV-thermal collectors

Source: Solimpeks Solar Energy

Solar thermal collectors

Solar PV panels

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DNI often compares with GHI...

Source: Chhatbar & Meyer 2011
Markets: Electricity

- PV takes all light
- PV almost everywhere
- Mostly at end-users’
- Variable
- Peak & mid-peak
- Grid parity by 2020
- Smart grids

- CSP takes direct light
- CSP semi-arid countries
- Mostly for utilities
- Firm, dispatchable backup
- Peak to base-load storage
- Competitive peak power by 2020
- HVDC lines for transport
Markets: Electricity

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Electricity generation from renewable in 2050, BLUE Map scenario

*Firm & flexible CSP capacities can help integrate more PV*
The CSP Roadmap: 2050

Repartition of the solar resource for CSP plants in kWh/m²/yr, and of the production and consumption of CSP electricity (in TWh) by world region in 2050 as foreseen in this roadmap. Arrows represent transfers of CSP electricity from sunniest regions or countries to large electricity demand centres.

Sources: Breyer & Knies, 2009 based on DNI data from DLR-ISIS and IEA Analysis.
Markets: Buildings

An integrated approach increases efficiency and reduces total costs.
Focus: Space heating and cooling

- Storage is key
  - Compact thermo-chemical?
  - Large-scale heat storage
  - Ground-source heat pumps = effective low-temp storage

(Wind and) Solar electricity + heat pumps the best option for heating?

Thermally-driven or (solar) electricity-driven cooling?

Source: Henning & Miara/Fraunhofer ISES

Source: ESTIF, 2007
Markets: industry

- Large heat needs at various temperature levels in industry and services; low-temp. solar heat available everywhere, demand all year round
- High-temp. solar heat under hot and dry climates
- But solar electricity and biomass key to reduce the use of fossil fuels in industry
Technologies: photovoltaics

- Fast growth & cost decline
- Important role off grid
- Competitive on-grid markets appear: sunny islands and countries with high retail electricity prices, and/or using oil to generate electricity
- Incentive-driven growth concentrated in too few (EU) countries, will spread to China, Japan, USA...
Cost reductions will continue

Cost targets for the residential sector

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
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<tbody>
<tr>
<td>Typical turnkey system price (2010 USD/kW)</td>
<td>3800</td>
<td>1960</td>
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<tr>
<td>Typical electricity generation costs (2010 USD/MWH)*</td>
<td>2000 kWh/kW</td>
<td>228</td>
<td>116</td>
<td>79</td>
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<tr>
<td></td>
<td>1500 kWh/kW</td>
<td>304</td>
<td>155</td>
<td>106</td>
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<tr>
<td></td>
<td>1000 kWh/kW</td>
<td>456</td>
<td>232</td>
<td>159</td>
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</table>

Cost targets for the commercial sector

<table>
<thead>
<tr>
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<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
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<tbody>
<tr>
<td>Typical turnkey system price (2010 USD/kW)</td>
<td>3400</td>
<td>1850</td>
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<td>980</td>
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<tr>
<td>Typical electricity generation costs (2010 USD/MWH)*</td>
<td>2000 kWh/kW</td>
<td>204</td>
<td>107</td>
<td>75</td>
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<tr>
<td></td>
<td>1500 kWh/kW</td>
<td>272</td>
<td>143</td>
<td>100</td>
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<tr>
<td></td>
<td>1000 kWh/kW</td>
<td>408</td>
<td>214</td>
<td>150</td>
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Cost targets for the utility sector

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<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2050</th>
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<tr>
<td>Typical turnkey system price (2010 USD/kW)</td>
<td>3120</td>
<td>1390</td>
<td>1100</td>
<td>850</td>
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<tr>
<td>Typical electricity generation costs (2010 USD/MWH)*</td>
<td>2000 kWh/kW</td>
<td>187</td>
<td>81</td>
<td>62</td>
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<tr>
<td></td>
<td>1500 kWh/kW</td>
<td>249</td>
<td>108</td>
<td>83</td>
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<tr>
<td></td>
<td>1000 kWh/kW</td>
<td>374</td>
<td>162</td>
<td>125</td>
</tr>
</tbody>
</table>

Notes: Based on the following assumptions: interest rate 10%, technical lifetime 25 years (2008), 30 years (2020), 35 years (2030) and 40 years (2050). Numbers in italics are considered more speculative. Sources: IEA 2010d, Bloomberg New Energy Finance, and IEA data and analysis.
Deployment: Are we on track?

Well... not for CSP!
• Prices for many technologies have been declining (dotted line, right hand scale).
• Growing set of circumstances in which RET are competitive (straight line, left hand scale)
Technologies: solar thermal electricity

- Key value of STE/CSP is in thermal storage to better match demand
  - effective and cheaper than electrical storage
- Concentration requires good direct irradiance
- Many different designs and options

Source: Torresol Energy
On-going CSP targets and plants

Target: 2 746 by 2014; 5 079 by 2020; 323.5 dish 38; tower 50; troughs 1 270; Fresnel 30; tower 50; troughs 850
Planned: Spain 2 746 by 2014; 5 079 by 2020; troughs 323.5 dish 38; tower 50; troughs 1 270; Fresnel 30; tower 50; troughs 850
Under construction: France 540 by 2020; Fresnel 12
Operational: Italy 600 by 2020; troughs 55; troughs 5/30

Target: 1 000 by 2015; troughs 231.1; troughs 50; 1 000 tower 100
Planned: China 1 000 by 2015; troughs 231.1; troughs 50; 1 000 tower 100
Under construction: Jordan Fresnel 100
Operational: UAE troughs 100

Target: 2 000 by 2020; troughs 125; troughs 20/470
Planned: Morocco 2 000 by 2020; troughs 125; troughs 20/470
Under construction: Sudan Fresnel 2 000
Operational: South Africa 200 by 2014; 1 200 by 2030; tower 100

Note: xx/yy: for Integrated Solar Combined Cycle or fuel saver systems, xx indicates the solar capacity, yy indicates the overall capacity.

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Emerging challenges: grid integration

Variability is not new, but it does get bigger

Load-matching rather than base-load

**A. with baseload**
- Fast peaking (e.g. gas, hydro, combustion turbine)
- Intermediate peaking (e.g. natural gas combined cycle)
- Baseload (coal or nuclear)

**B. without baseload**
- Flexible source (e.g. solar thermal with storage)
- Inflexible source (e.g. wind or solar without storage)

Source: Mills and Cheng, 2011
Time of use payments are key

### SCE

<table>
<thead>
<tr>
<th>Monthly Period</th>
<th>On-Peak</th>
<th>Mid-Peak</th>
<th>Off-Peak</th>
<th>Super-Off-Peak</th>
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</thead>
<tbody>
<tr>
<td>Winter</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>3.13000</td>
<td>1.35000</td>
<td>0.75000</td>
<td></td>
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</table>

### PG&E

<table>
<thead>
<tr>
<th>Monthly Period</th>
<th>Super Peak</th>
<th>Shoulder</th>
<th>Night</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun-Sept</td>
<td>2.204900</td>
<td>1.122370</td>
<td>0.689880</td>
</tr>
<tr>
<td>Oct-Dec, Jan&amp;Feb</td>
<td>1.057830</td>
<td>0.934770</td>
<td>0.763840</td>
</tr>
<tr>
<td>Mar-May</td>
<td>1.145880</td>
<td>0.846340</td>
<td>0.642350</td>
</tr>
</tbody>
</table>

### SDG&E

<table>
<thead>
<tr>
<th>Monthly Period</th>
<th>On-Peak</th>
<th>Semi-Peak</th>
<th><em>Off-Peak</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov-June</td>
<td>1.1916</td>
<td>1.0790</td>
<td>0.7928</td>
</tr>
<tr>
<td>July-Oct</td>
<td>1.6411</td>
<td>1.0400</td>
<td>0.8833</td>
</tr>
</tbody>
</table>
Possible roles of storage

- Thermal storage can be used to shift production, to extend it to base load or to concentrate it to super peak load
Back-up/hybridisation

- Firming capacities
- Increase the solar share in the mix
- Walk the learning curve

Currently in use:
- Back-up or routine fuel use in PT plants; efficient?
- Fresnel pre-heating feedwater in coal plants
- Steam augmentation in bottoming cycles (ISCC)

Options to be developed:
- Main steam augmentation in efficient coal plants
- Hybrid solar-gas with combined cycle
Storage for large-scale variable RE

- Small or large, batteries are expensive
- G2V to avoid curtailment. V2G to shave peaks?
- Pumped-hydro plants the reference solution
  - 140 GW in service, much more necessary
  - Daily/weekly storage does not require large areas
  - Can be built on the coast or offshore using seawater
  - Less efficient than thermal storage but affordable

Technologies: solar fuels

- From hydrocarbon (incl. biomass) or water
- Cheaper with high-temp. heat than electricity?

- H$_2$ easier to use blended with natural gas, could be stored then used in balancing plants
- Can be converted into various energy carriers

Source: PSI/ETH-Zürich
Renewables need government support to deliver…

Global government support for renewables-based electricity generation in the New Policies Scenario

Global government support for renewables reached $37 billion in 2009 and grows to $140 billion in 2035; support costs per unit of electricity fall over time as technologies mature
The way forward: testing the limits

- A possible vision, under severe climate constraints, if other low-carbon energy options are not available...

- Where are the technical limits to solar energy?
  - Many electricity technologies converging towards USD100/MWh (incl. CO₂) around 2030 [Roadmaps, ETP]
  - Cost no longer main limit, but footprint, variability and convenience issues
  - Not necessarily least cost, but affordable options:
    - Sunny and dry climates, where CSP dominates
    - Sunny and wet climates, with PV backed by hydro
    - Temperate climates, with wind power and PV backed by pumped-hydro and solar-H₂/NG balancing plants
  - Assuming efficiency improvements as in ETP but further electrification of buildings, industry and transport:
    - Under best conditions, solar energy (mostly electricity) could become a key contributor to the global energy mix
    - Some fossil fuels still needed in transport, industry, electricity
500 000 km² of hypothetical on-ground solar power plants

Source: landartgenerator.
Testing the limits: 2060

- Base load: 11%
- Hydropower: 10%
- Wind power: 28%
- Solar fuels: 2%
- Natural gas: 1%
- PV: 20%
- CSP: 28%

### Technology Capacity (GW) Electricity generation (TWh/y)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Capacity</th>
<th>Electricity generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV</td>
<td>12 000</td>
<td>18 000</td>
</tr>
<tr>
<td>CSP</td>
<td>*6 000</td>
<td>25 000</td>
</tr>
<tr>
<td>Solar fuels</td>
<td>**3 000</td>
<td>2 000</td>
</tr>
<tr>
<td>Wind power</td>
<td>10 000</td>
<td>25 000</td>
</tr>
<tr>
<td>Hydro power and marine</td>
<td>1 600</td>
<td>9 000</td>
</tr>
<tr>
<td>Base load (Geothermal, nuclear, solid biomass w. CCS)</td>
<td>1 200</td>
<td>10 000</td>
</tr>
<tr>
<td>Natural gas</td>
<td>**3 000</td>
<td>1 000</td>
</tr>
<tr>
<td>Total</td>
<td>**3 000</td>
<td>90 000</td>
</tr>
</tbody>
</table>

* Thermal storage would give CSP plants an average capacity factor of almost 50%. **Shared capacities.
Capacities requires for peak demand after sunset with low winds in non-CSP areas

- Pumped hydro, 2 500
- Wind, 1 000
- DSM, 300
- Hydropower, 1 600
- Base load, 1 200
- CSP Imports, 400
- N. Gas + H2, 3 000

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Testing the limits:
Total final energy by sources, 2060

- Oil 5%
- Gas and coal 8%
- Baseload 7%
- Biofuels 13%
- Biomass heat 6%
- Geothermal heat 1%
- Hydropower 6%
- Solar fuels 1%
- Solar heat 4%
- CSP 18%
- Wind 18%
- PV 13%
# The way forward: policies

<table>
<thead>
<tr>
<th>Integrated approach</th>
<th>Current gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support to R&amp;D</td>
<td>Solar Fuels</td>
</tr>
<tr>
<td>Support to innovation</td>
<td>Process heat</td>
</tr>
<tr>
<td>Addressing split incentives</td>
<td>Solar obligations for DHW (but Israel and Spain)</td>
</tr>
<tr>
<td>Pushing toward integrated solutions</td>
<td>Buildings regulations (but in the EU)</td>
</tr>
<tr>
<td>Addressing financing needs (e.g. off-grid solar electricity)</td>
<td>Linking MDA, climate change money and microfinance</td>
</tr>
<tr>
<td>Support to early deployment</td>
<td>Not all sunny countries support deployment</td>
</tr>
</tbody>
</table>
A global approach is needed

- The bulk of the forthcoming growth of energy demand is in sunny countries
  - 7 out of 9 billion people, growing economies

- Solar provides access to modern energy services
  - Potentially changing the lives of 1.4 billion people

- Solar energy has the potential to become a key contributor to final energy demand
  - Under the assumptions of a massive penetration of electricity, efficiency improvements and willingness to decarbonise the energy sector

- Efforts/benefits need to be shared globally
  - “Spend wisely, share widely”