Solar photovoltaic roadmap milestones

**2010**
- Regulatory framework and support schemes
  - Market enabling framework with net metering and priority access to the grid
- Technology development and R&D
  - Continuous R&D funding on medium-term PV cell and system technologies
- Market facilitation and transformation
  - Energy standards taking into account solar PV building regulations and obligations

**2020**
- GW capacity 200
- Market 34 GW/yr
- Regulatory framework preparing large-scale integration of PV into the grid
- Internalisation of external costs for level playing field
- Building codes and standards for PV products and interconnection rules
- Business models for end users and rural electrification
- Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders

**2030**
- GW capacity 900
- Market 165 GW/yr
- Market enabling framework with net metering and priority access to the grid
- Implementation mechanisms for grid investments and storage solutions for full-scale integration of PV
- Energy standards taking into account solar PV building regulations and obligations
- Business models for end users and rural electrification
- Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders

**2040**
- GW capacity 2 000
- Market 127 GW/yr
- Framework for full market competition with priority access to the grid
- Regulatory framework preparing large-scale integration of PV into the grid
- Internalisation of external costs for level playing field
- Building codes and standards for PV products and interconnection rules
- Business models for end users and rural electrification
- Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders

**2050**
- GW capacity 3 000
- Market 141 GW/yr
- Market enabling framework with net metering and priority access to the grid
- Implementation mechanisms for grid investments and storage solutions for full-scale integration of PV
- Energy standards taking into account solar PV building regulations and obligations
- Business models for end users and rural electrification
- Training and education for skilled workforce along the PV value chain; technology outreach to target audiences/stakeholders

**Key actions and respective leading roles for:**
- Government stakeholders
- Market stakeholders (demand side)
- R&D and PV industry stakeholders (supply side)

**SOLAR PHOTOVOLTAIC ROADMAP**

**Solar PV price competitiveness and growth pathway, 2000-2050**

**Key findings**
- By 2050, PV global cumulative installed capacity could reach 3,000 gigawatts, providing 4,500 TWh per year, i.e. around 11% of global electricity production. In addition to avoiding 2.3 gigatonnes (Gt) of CO₂ per year, this level of PV would deliver substantial benefits in terms of the security of energy supply and socio-economic development.
- In the first decade, PV is expected to reduce system and generation costs by more than 50%. PV residential and commercial systems will achieve the first level of grid parity – i.e. parity with electricity retail prices – by 2020 in many regions. As grid parity is achieved, the policy framework should evolve towards fostering self-sustained markets, with the progressive phase-out of economic incentives, but maintaining grid access guarantees and sustained R&D support.
- Towards 2030, typical large-scale utility PV system generation costs are expected to decrease to USD 7 to USD 13 cents/kWh. As PV matures into a mainstream technology, grid integration and management and energy storage become key issues.
- The PV industry, grid operators and utilities will need to develop new technologies and strategies to integrate large amounts of PV into flexible, efficient and smart grids.
- Governments and industry must increase R&D efforts to reduce costs and ensure PV readiness for rapid deployment, while supporting longer-term technology innovations.
- There is a need to expand international collaboration in PV research, development, capacity building and financing to accelerate learning and avoid duplicating efforts.
- Emerging major economies are already investing substantially in PV research, development and deployment; however, more needs to be done to foster rural electrification and capacity building. Multilateral and bilateral aid organisations should expand their efforts to express the value of PV energy in low-carbon economic development.
Solar resource and regional shares of world PV production

- **PV technology status and prospects**

  - Solar PV technology milestones
  - Solar resource and regional shares of world PV production

- **R&D aspects**

  - Industry manufacturing aspects

- **Status and potential**

  - Reach high efficiency over 45%
  - Achieve low cost, high-performance solutions for optical concentration and tracking

- **Types of cell**

  - High-cost, super high-efficiency
  - Low-cost, moderate performance
  - Very high-efficiency, full spectrum utilisation

- **Concentrating PV**

  - Emerging technologies
  - Novel technologies

- **Solar PV technology milestones**

  - PV technology status and prospects

- **Sun 3 Tier Technologies**

  - Emerging technologies
  - Novel technologies

- **Cladding substrate**

  - Glass (3) - flat plate with backsheet
  - Polymer (4) - flat plate with backsheet

- **Thin film**

  - Cadmium-telluride (CdTe)
  - Copper-indium/gallium-diselenide/disulphide (CIGS)
  - Transparent conductive oxides (TCO)

- **PV technology status and prospects**

  - Photovoltaic electricity generation in TW***

  - Targets for residential sector
  - Targets for commercial sector

- **Utility**

  - 1 000 TWh/yr

- **Commercial**

  - 5 000 TWh/yr

- **Residential**

  - 1 000 TWh/yr

- **Global Horizontal Irradiance (GHI)**

  - Region: OECD North America
  - Region: OECD Pacific

- **Photovoltaic capacity in GW**

  - 2010
  - 2020
  - 2030
  - 2040
  - 2050

- **Solar PV economic milestones**

  - Typical turn-key system price (2008 USD/kWc) *

  - Typical electricity generation costs (2008 USD/kWh)

  - Total costs (2008 USD/MWh)

  - Typical turn-key system price (2008 USD/kWc) *

  - Typical electricity generation costs (2008 USD/kWh)

  - Total costs (2008 USD/MWh)

  - Photovoltaic capacity in GW

  - PV system price levels from 2030 USD/kW (2008 USD/kWc at 35% efficiency)
PV technology status and prospects

Solar PV technology milestones

- Thin film technologies (2010 - 2020)
  - Improvement of efficiency and stability to the level needed for first commercial applications
  - Emergence of novel conversion principles and device concepts at lab-level
  - Potential of novel high-efficiency production technologies

- R&D aspects
  - 30% market share of global PV production
  - Thin film modules:
    - Cadmium-telluride (CdTe)
    - Copper-indium/gallium-diselenide/disulphide
  - Emerging technologies:
    - Dye PV
    - Printed CIGS

- PV technology status and prospects

- R&D aspects
  - Improvement of efficiency and stability to the level needed for first commercial applications
  - Emergence of novel conversion principles and device concepts at lab-level
  - Potential of novel high-efficiency production technologies

- Industry manufacturing aspects
  - High-rate deposition
  - Roll-to-roll manufacturing
  - Packaging

- Advanced materials and concepts

- Novel concepts
  - Advanced materials and concepts
  - Improved cell structures
  - Improved deposition techniques

- Emerging technologies
  - Improved substrates and passivation
  - Transparent conductive oxides (TCO)

- Novel technologies
  - Low cost, moderate performance
  - Very high efficiency, full spectrum utilization

- Emerging technologies
  - Improved device structures
  - Improved design and production processes

- Advanced inorganic thin-film technologies
  - Very high efficiency; full spectrum utilization
  - Intermediate band gaps, tc

- Wide variety of new conversion technologies

- Concentrating PV
  - High cost, high efficiency
  - Law cost, moderate performance

- Novel technologies
  - Very high efficiency, full spectrum utilization

- Standard market growth
  - Increasing number of countries through 2020

- Solar resource and regional shares of world PV production

- Global Horizontal Irradiance

- Solar PV economic milestones

- Targets for residential sector
  - 2008: 4 000 TWh/yr
  - 2020: 1 800 TWh/yr
  - 2030: 1 200 TWh/yr

- Targets for commercial sector
  - 2008: 4 000 TWh/yr
  - 2020: 1 800 TWh/yr
  - 2030: 1 200 TWh/yr

- Targets for utility sector
  - 2008: 4 000 TWh/yr
  - 2020: 1 800 TWh/yr
  - 2030: 1 200 TWh/yr

- Photovoltaic electricity generation in TWh

- Shares of global production
  - Developing Asia: 10%
  - Latin America: 2%
  - OECD North America: 6%
  - OECD Europe: 31%
  - OECD Pacific: 28%
  - Africa and Middle East: 16%
  - Asia: 10%

- Solar PV technology status and prospects

- Economic milestones
  - Typical levelised cost of energy (LCOE) (2008 USD/MWh)
    - Residential: 4.1 USD/MWh
    - Commercial: 1.0 USD/MWh
    - Utility: 0.7 USD/MWh

- Typical electricity generation costs (2008 USD/MWh)
  - Residential: 4.1 USD/MWh
  - Commercial: 1.0 USD/MWh
  - Utility: 0.7 USD/MWh

- Solar PV technology status and prospects

- R&D aspects
  - Improvement of efficiency and stability to the level needed for first commercial applications
  - Emergence of organic-based concepts

- Emerging technologies
  - Improved device structures
  - Improved deposition techniques

- Advanced materials and concepts

- Novel concepts
  - Advanced materials and concepts
  - Improved cell structures
  - Improved deposition techniques

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