Francesco Roca*
ENEA - Energy Technologies Department,
CR Portici, Naples- Italy
3 Technical Departments (~1640 people)

7 Units (~310 people)
White certificates. Radiation Protection Institute, Antartica project, Energy Saving Agency etc

5 Directorates (~610 people)
Central administration, planning and control & logistic,

9 Research Centers

5 local laboratories

Brussels Liaison Office and Territorial offices
Research and Development

**Fusion & Nuclear safety**
- Fusion
- Fission (new gen)
- Radiation protection
- Nuclear safety & security
- Ionizing/non ionizing radiation applications

**Energy technologies**
- CSP and thermal solar energy, including thermal energy storage
- Photovoltaics and smart grids
- Energy efficiency technologies, including efficient conversion and use of energy, electric energy storage
- Bioenergy, biorefinery and greenchemistry
- Smart energy & smart cities
- Sustainable mobility
- Fuel cells and hydrogen
- Sustainable use of fossil fuels
- ICT

**Sustainability of territorial systems**
- Resource efficiency
- Environmental technologies
- Climate change: modeling, adaptation and mitigation
- Prevention and Recovery
- Seismic and natural hazards assessment and prevention
- Bio and nanotechs
- Agrifood
Photovoltaics and Smart Network
- New generation PV systems and concentrated photovoltaic (CPV)
- New PV materials: Thin film, high-efficiency PV cells, organic photovoltaics
- Smart Grids and use services of RES in electricity distribution grids

Thermal and Thermodynamic Solar Division
- Research Facility with linear parabolic collectors and molten salts heat pipes (ENEA patented technology).
- R&D activities on innovative thermal storage system.
- Optimization of solar collectors, development of components and systems for solar cooling

Bioenergy, Biorefinery and Green Chemistry
- Production of syngas from agricultural waste, from biomass, as well as chemicals
- Production of biofuels from micro-algae

Efficient Production, Conversion and Use of Energy
- Electrochemical systems for the conversion and storage of hydrogen energy, supercapacitors
- Co-generation systems, fuel cells, new materials, high-efficiency lithium batteries
- Sustainable use of fossil fuels (CCS)
- Sustainable mobility

Smart Energy
- Smart public lighting
- Smart cities
- Smart Building Energy Management Systems (BEMS) and demand-response systems

ICT (service)
- High Performance Computation
- ICT for running project
Solar Energy in ENEA
Human and lab resources

DIVISIONS

SOLAR THERMODINAMIC & THERMAL DTE-STT
65 permanent staff
2 unit-laboratories

PHOTOVOLATICS and SMART NETWORK DTE-FSN
76 permanent staff
4 unit-laboratories

TECHNOLOGIES AND MATERIAL FOR THE SUSTAINIBILITY SSPT*- 1 unit-laboratories

Laboratories and assigned human resources to Solar Energy

- ITES- Development of components and Solar Pants Lab
- SCIS- Engineering of Solar Technologies Laboratory
- DIN-Innovative Device Laboratory
- TEF-Photovoltaics Technologies Laboratory
- FOSG-Photovoltaic Systems and smart network lab.
- NANO-Nano-materials and Organic devices lab *

*SSPT- Territorial and Production Systems Sustainability Department

ENECA Casaccia & Trisaia

ENECA Portici
SOLAR PHOTOVOLTAICS
IN ENEA
Enea PV Activities: “value chain”

Materials
- Thin Silicon film
- Thin Silicon on polimeric substrates
- Epi-wafer approach
- Thin Polycrystalline (kesterites)
- Nanomaterials & Graphene
- Transparent Conductive Oxide
- Advanced dielectric coating

Devices
- Tandem/micromorph Solar Cells
- aSi/cSi Solar Cells
- High Efficiency cSi Solar Cell (PVC)
- OPV & DSSC Solar cells
- Indoor/outdoor characterization of Solar cells

Systems
- PV Modules
  - Indoor/outdoor Qualification
  - Definition of standards
  - Energy prediction
  - Smart PV modules
  - Reliability Analysis on BOS Components
  - Solar Tracking
  - PV module Recycling

Applications
- Distributed generation
- Large plants
- Hybrid Solar/Thermal application
- Smart grid
- BIPV & Ecobuildings design
- PV demo sites
- Market & Incentives
Thin film silicon based solar cells

Innovative absorber and doped materials for multijunction silicon solar cells

Textured substrates and new architectures for an optical improvement of the thin film Si device performance
Thin film silicon based solar cells: PECVD grown n-SiOx films

CO$_2$/SiH$_4$ = 3, 1.9 Torr

light = Si rich phase
dark = O rich phase

JEOL 2010F 200KeV
EFTEM @ CNR IMM
Catania

H$_2$/SiH$_4$=100, p=1.9 Torr
H$_2$/SiH$_4$=200, p=1.9 Torr
H$_2$/SiH$_4$=200, p=3 Torr
Thin film silicon based solar cells: n-SiOx:H in micromorph devices

P. Delli Veneri, L.V. Mercaldo, I. Usatii Appl. Phys. Lett. 97, 023512 (2010);
**Ligth trapping strategies for silicon based solar cells: Development of MOCVD grown ZnO**

Better infrared spectral response with LPCVD ZnO with respect to commercial TCO.
Light trapping strategies for silicon based solar cells

Double textured ZnO

Development of textured glass

Aluminium Induced Texture
- Metal deposition
- Thermal annealing near 600°C
- Chemical etching

WET etching
In cooperation with University «Federico II» of Naples

Light trapping strategies for silicon based solar cells: periodic and quasiperiodic structures

In cooperation with University of Sannio

Relationship between the cell thickness and the period of textured substrates

Nanostructured substrates obtained by means of Focused Ion Beam (FIB)

Heterojunction a-Si/c-Si solar cells

Solar cell architectures

BEHIND CELL Back Enhanced Heterostructure with INterDigitated contact cell
Heterojunction a-Si/c-Si solar cells

Current status:

$V_{OC} = 644 \text{ mV}$

$J_{SC} = 37 \text{ mA/cm}^2$ on active area

$FF = 73\%$

$\eta = 17.4\%$

Heterojunction a-Si/c-Si solar cells: BEHIND CELL

Back Enhanced Heterostructure with INterDigitated contact cell

This structure allows to enhance cell efficiency up to 24%

Graphene films are grown on copper foil substrates by a non toxic and low-cost ethanol based CVD near 1000°C.

**Current density vs. Voltage**

- $A=0.09 \text{cm}^2$
- $J_{sc}=23.2 \text{mA/cm}^2$
- $V_{oc}=503 \text{mV}$
- FF=47%
- Eff=5.5%

**EQE (%) vs. λ (nm)**

**CZTS** is an interesting PV material for two applications:
- Replacement of **CIGS** with an **indium free materials**.
- Development of a thin film PV device with a gap suitable for tandem application (Eg of CZTS can reach 1.65 eV with a good order level of the Cu and Zn cations).

**ENEA** is developing a complete process to fabricate CZTS devices starting from co-sputtered precursors.
Final goal: tandem cell (thin film + c-Si)

## ENEA ranking in CZTS research

<table>
<thead>
<tr>
<th>Growth technique</th>
<th>buffer</th>
<th>Eff</th>
<th>Voc</th>
<th>Jsc</th>
<th>FF</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Frontier (2011)</td>
<td>Stack evaporation + sulfurization</td>
<td>In$_2$S$_3$/CdS</td>
<td>9.2</td>
<td>708</td>
<td>21.6</td>
<td>60.1</td>
</tr>
<tr>
<td>UNSW (2016)</td>
<td>Co-sputt. Cu, ZnS, SnS + sulfurization in S</td>
<td>(Zn,Cd)S</td>
<td>9.2</td>
<td>748</td>
<td>19.5</td>
<td>63.2</td>
</tr>
<tr>
<td>Toyota (2015)</td>
<td>Co-evaporation Cu, Zn, Sn, S + hot plate 570°C in S$_2$/N$_2$</td>
<td>CdS</td>
<td>8.8</td>
<td>710</td>
<td>17.5</td>
<td>71.0</td>
</tr>
<tr>
<td>IBM (2011)</td>
<td>Co-evaporation Cu, Zn, Sn, S + hot plate 570°C in S$_2$/N$_2$</td>
<td>CdS</td>
<td>8.4</td>
<td>661</td>
<td>19.5</td>
<td>65.8</td>
</tr>
<tr>
<td>Osaka Univ. (2015)</td>
<td>Elettrodep. stack Cu-Sn-Zn + Solf. In sealed ampoule with S</td>
<td>CdS</td>
<td>8.1</td>
<td>705</td>
<td>18.0</td>
<td>63.2</td>
</tr>
<tr>
<td>ENEA (2016)</td>
<td>Co-sputt. Cu, ZnS, SnS + sulfurization in S</td>
<td>CdS</td>
<td>7.8</td>
<td>641</td>
<td>18.9</td>
<td>64.4</td>
</tr>
<tr>
<td>Uppsala (2015)</td>
<td>Reactive co-sputtt. Cu, Zn, Sn, S + sulfurization in Ar + S</td>
<td>(Zn,Sn)O</td>
<td>7.4</td>
<td>682</td>
<td>17.9</td>
<td>60.2</td>
</tr>
<tr>
<td>Katagiri group (2008)</td>
<td>Co-sputt. Cu, ZnS, SnS + sulfurization in H$_2$S/N$_2$</td>
<td>CdS</td>
<td>6.8</td>
<td>610</td>
<td>17.9</td>
<td>62.0</td>
</tr>
</tbody>
</table>

Use of a buffer layer better than usual CdS is important to obtain larger values of Voc. This topic will be the next step in the ENEA strategy.
Polymer solar cells - ENEA-SSPT-NANO Laboratory for Nanomaterials and Devices

Research activities on OPV
ENEA-SPTT-NANO

- Blend morphology optimization,
  Modeling and testing of new and commercial materials
- ITO replacement with HC-PEDOT:PSS
- PSC realization on flexible substrates

Deposition techniques (spin coating, R2R printing)
Device testing
Encapsulation: stability study
DISADVANTAGES:

the cathode (Ca/Al) is susceptible to degradation by oxygen and water vapor

PEDOT:PSS (HTL) is hygroscopic and acidic producing fast degradation of ITO
PCE = 10.1 %
FF = 69.3 %
$J_{sc} = 18.0 \text{ mA/cm}^2$
$V_{oc} = 792 \text{ mV}$
20mm$^2$

Polimeric Blend
PTB7-Th:[70]PCBM

OPV : Device architecture

Optimized ZnO film tested as Electron Transport Layer with a donor polymer in a single junction PSC with inverted architecture

Still investigating to improve the morphology of the layer to further improve the performance
Main research topics

- PV, CPV and solar
- Power conversion for RES
- Hybrid solar photovoltaic-thermal plant
- Building integration (BIPV and BAPV)
- Thermal and electric storage
- Test and qualification of PV and CPV components
- Distributed generation and Smart Grids
- Nearly Zero Energy buildings (NZEB’s)
Advanced services for industries

- Innovative PV components design and development
- Power conversion design and development
- Modules qualification tests
- BOS components tests
- Solar plants performances measurements
- Plant sites characterization
ZOOMING IN LABORATORIES

Solar cell characterization laboratory (indoor)
Efficiency tests over concentration solar cells

Photovoltaic module characterization laboratory (indoor)
Accredited laboratory by ACCREDIA

Photovoltaic receiver and module characterization laboratory (outdoor)
Energy performance tests

DMPPT DC-DC converter (indoor)
Design and energy performance tests
Optical components characterization laboratory (indoor)
Optical efficiency tests over primary & secondary components to optimize the production parameters

Mirror characterization laboratory (indoor)
Morphological analysis

Electronic laboratory (indoor)
Design and realization of printed circuit board (PCB)

Heat storage laboratory (indoor)
Performance test on components and control and management algorithms
ENEA: Development of experimental equipment and operative procedures to carry out a complete performance analysis of the small power ECOSOLE prototype installed at ENEA in Portici

opto-electronic devic installed parallel on tracking surface to verify azimuth and altitude misalignment – vs- tim

pyrheliometer on the tracker to characterize the effective DNI incident on the modules surface (Tracking losses)

Bracket for pyrheliometer
Plate for OED
ECOSOLE PROJECT

Modules features:

✓ Geometrical concentration ratio: 940X
✓ Optic: SoG Fresnel lens + prismatic quartz element
✓ Triple junction commercial solar cells from different manufacturers: EMCORE, AZUR SPACE, SOLAR JUNCTION
✓ Geometrical layout: array of 6x12 receivers
✓ Housing realized in aluminum thin sheet

Tracker features:

✓ Modules are arranged on 4 pre-calibrated maxi-modules
✓ Motion: two perpendicular series connected slewing drives with brushless motors
✓ Hybrid tracking algorithm using the sun ephemeris and a sun camera: the tracking is adjusted in order to reach the maximum module power output
✓ The tracker panel can turn upside down for cleaning and to protect the parquet from sand storm and from the moisture condensation effects
SOLAR THERMODYNAMIC & THERMAL IN ENEA
Brief history of ENEA CSP Solar Technology

2001 To 2003
• Project Start-up Government Role
• Lab R&D: Prototype Design

2004 To 2007
• PCS Facility: Prototype Operation start-up
• Components test and qualification

2008 To 2009
• Industrial Demo plant Industrial Role
• Demo design and construction

2010
• Start-up demo plant
Main Activities

Thermal and Thermodynamic Solar Division mainly operates to promote and carry out different research strategic lines, and innovation projects, which are quite relevant for the development of CSP technology in Italy and abroad:

• **Research**: new solution for thermal fluid (new molten salt mixtures, gas, water), critical components (receiver system, steam generator, storage system), and solar plant configuration (power generation, hybrid plants, desalinization, process heat, solar cooling, solar fuel)

• **Advanced services**: Support to industry for components development, testing and qualification in ENEA facilities; support to engineering firms and utilities for design and construction of power plant of different size and for various applications.
Main Activities

- **Transfer Technology**: dissemination and transfer of research results to industry and exploitation for production purposes

- **Training and information**: activities aimed at broadening sector expertise and public knowledge
Solar thermal energy at low and medium temperature

- Quality and Reliability Test Laboratory for low temperature collectors
- Energy characterisation of collectors for uses at medium temperature (i.e. up to 300° C)
- Development of thermo-fluid-dynamic models for the optimisation of solar collectors, evaluation and optimisation of components for solar cooling systems
Solar coatings

Innovative technology: CERMET-based stratified thin films containing AlN-WN nano-composites, produced inside vacuum deposition apparatus by sputtering processes – ENEA Patent

Advantages: Maximum operation temperature (550 °C) higher than other commercial products (400 °C). Unique product in the worldwide market.

Solar coating patented by ENEA and licensed to Archimede Solar Energy (ASE, Angelantoni Group) to produce receivers for high temperature purpose.

Technological transfer of production processes Agreement between ENEA and ASE industry to give technological support on production line: performance qualification and additional R&D activity for product improvement.

Industrial sputtering apparatus to fabricate ENEA solar coating at the manufacturing site - Massa Martana (PG, Italy)

Production yield Up to 70,000 receivers/year
Optical Selective Solar coating:

Optical characteristic of CERMET nano-composites:
- High absorptance of solar radiation
- High transparency in infrared spectral region

Thermo-optical parameters of an efficient ENEA solar coating:
- $\alpha_s > 95\%$
- $\varepsilon_h < 13\%$ at $550\,\degree\mathrm{C}$

Very high solar absorptance $\alpha_s$

Low thermal emissivity $\varepsilon_h$ at the operating temperature (low thermal loss)
The main initiatives are implemented within the Agency in the framework of:

- **EU ACTIVITIES:**
  - EURATOM;
  - Projects funded by the EU
  - EERA-European Energy Research Alliance
  - European Technology Platforms
  - RTD Framework Programme Committees
  - Strategic Initiatives

- **BILATERAL COOPERATION**

- **MULTILATERAL COOPERATION.**
Solar Energy in ENEA: R&D Contacts

**SOLAR THERMODYNAMIC & THERMAL**
Eng. Tommaso Crescenzi  
DTE-STT

**PHOTOVOLATICS and SMART NETWORK**
Dr. Ezio Terzini  
DTE-FSN

**TECHNOLOGIES AND MATERIALS FOR THE SUSTAINIBILITY**
Dr. Dario Della Sala  
SSPT*-PROMAS

**Components and Solar Plants Development lab**
Eng. Alessandro Antonaia  
DTE-STT-SCIS

**Engineering of Solar Technologies Laboratory**
Eng. Antonio De Luca  
DTE-STT-ITES

**Innovative Device Laboratory-DIN**
Dr. Paola Delli Veneri  
DTE-FSN-DIN

**Photovoltaics Technologies Laboratory - TEF**
Dr. Eng Mario Tucci  
DTE-FSN-TEF

**Photovoltaic Systems and smart network lab - FOSG**
Dr, Eng. Giorgio Graditi  
DTE-FSN-FOSG

**Nano-materials and Organic devices laboratory**
Eng Carla Minarini  
SSPT*-PROMAS-NANO

*SSPT- Territorial and Production Systems Sustainability Department

Email: name.surname@enea.it
A European Project supported through the Seventh Framework Programme for Research and Technological Development

Grant agreement no: 609788

http://www.cheetah-project.eu/

Cost-reduction through material optimisation and Higher EnErgy outpuT of solAr pHotovoltaic modules joining Europe’s Research and Development efforts in support of its PV industry

THEME [ENERGY.2013.10.1.5] [Integrated research programme in the field of photovoltaics]
34 partners from 16 European countries
TECHNICAL OBJECTIVES / STRATEGIC ORIENTATIONS

- Use of less, cheaper and sustainable materials
- Increase of overall performance

TOPICS

4 main topics:
- Silicon wafers and cells
- Thin-film PV
- Organic PV
- Module technology

3 secondary topics:
- Building Integrated PV
- Concentrated PV
- Novel PV technologies

ACTIVITIES

- Research Activities ➔ technology developments
- Fostering long-term European cooperation
- Accelerating the transfer to PV industry

http://www.cheetah-project.eu/
Coordination activities: developing the basis for long-term research and giving access to the knowledge to researchers and industry

**WP2**
FOSTERING THE USE OF EXISTING FACILITIES AND EXPERTISE
Leader: ENEA

**WP3**
MOBILITY AND INTERNATIONAL COOPERATION ACTIVITIES
Leader: HZB

**WP4**
DISSEMINATION, INTERNAL AND EXTERNAL COMMUNICATION
Leader: JÜLICH

**WP5**
ACCELERATION OF INNOVATIONS’ IMPLEMENTATION
Leader: SOLARPOWER EUROPE

JRA: improving the services provided and fill in the gaps: more power with less materials

**WP6**
ULTRATHIN WAFER DEVELOPMENT
Leader: ISE

**WP7**
CELL PROCESSING OF ULTRATHIN WAFERS
Leader: CEA-INES

**WP8**
MODULE DEVELOPMENT FOR ULTRATHIN X-SI CELLS AND THIN FILMS
Leader: ECN

**WP9**
ADVANCED LIGHT MANAGEMENT OF THIN-FILM PV
Leader: HZB

**WP10**
VERY LOW-COST ORGANIC PV
Leader: DTU

http://www.cheetah-project.eu/
CHEETAH KNOWLEDGE EXCHANGE PLATFORM
http://www.cheetah-exchange.eu

http://www.cheetah-project.eu
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Thanks for your attention!