WRIGHT CENTER for PHOTOVOLTAICS INNOVATION AND COMMERCIALIZATION
THE UNIVERSITY OF TOLEDO 1872
Department of Physics and Astronomy
Department of Chemistry
University of Toledo

Overview of "PVIC"

"PVIC" is the Wright Center for Photovoltaics Innovation and Commercialization

a

State of Ohio Wright Center of Innovation supported by the Ohio Department of Development'sThird Frontier Project *

presented by

Robert W. Collins, PVIC Principal Investigator

at

Catalyzing Innovation in PV Manufacturing: An NSF Workshop

May 6-7, 2010

* Program Manager: Anthony Howard, Ohio Department of Development

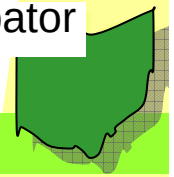
20 Founding Participants:

THE UNIVERSITY OF TOLEDO 1872 · THE OHIO STATE UNIVERSITY · BGSU · Battelle The Business of Innovation · GEO · DUPONT The miracles of science · NewCyte, Incorporated · EMTEC · OWENS CORNING · PILKINGTON INNOVATIONS FOR LIVING™

adg Advanced Distributed Generation LLC · DECKER HOMES · CRG INDUSTRIES · METAMATERIA PARTNERS · LakeShore · mwoe · Honda-OSU Partnership Program · SSOE, INC. ARCHITECTS • ENGINEERS · Solar Fields · itf

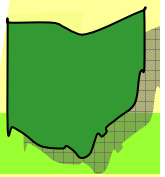
Outline

- **Ohio Department of Development's Third Frontier Project**
- **Overview of PVIC**
  - **Universities - Funding**
  - **Toledo Node Faculty: Present and Future**
  - **Founding and New Members of PVIC**
  - **Membership Strategy and Goals**
- **Investments, Technical, and Educational Activities**
  - **Imagining to Incubating Transitions: Univ. Toledo, BGSU, and Penn State**
    Photon Management for Advanced Thin Film PV
    > Up/down-conversion; MEG; plasmonics; non-imaging concentration
  - **Incubating to Demonstrating Transitions: Univ. Toledo, Pilkington, and DuPont**
    Process and Product Development Support for Thin Film PV
    > All thin film technologies: PECVD/PVD cluster tool for process RD & D
    > Optical metrology for full size module plates
  - **Demonstration to Market Entry Transitions: Univ. Toledo and Solar Kits USA**
    > PV full system design and integration with >90% Ohio content
  - **Education at University of Toledo: PV Cluster Gravitation to Univ. Toledo**
    > School of Solar and Advanced Renewable Energy at Alternative Energy Incubator
    > Univ. Toledo's new Campus of Energy and Innovation at Scott Park



Third Frontier Project
Ohio Department of Development

- Established by Gov. Taft in 2002 as a 10 year $1.6 billion project
- Full financing only secured in 2005 through passage of $500 million bond issue by Ohio voters; this funding ends in 2012
- Recent and projected Third Frontier spending:
  $ 102 million FY 2009
  $ 61 million in FY 2010 and 2011
- Up for renewal May 4, 2010 to extend the program to 2016 with a $700 million bond issue
- One focus of the current renewal -- advanced energy: solar, wind, biomass



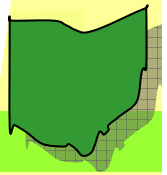
Third Frontier Project
Ohio Department of Development

Project Goals

- Build world-class research infrastructure and expertise within Ohio
- Support early stage formation of capital and development of new products
- Support advanced manufacturing technologies to help existing industries become more productive

Project Outcomes

- Leverage ratio of ~ 10:1
- Credited with the formation of > 500 companies and ~ 50,000 new jobs over its lifetime.



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Center for Photovoltaics Innovation and Commercialization (PVIC): University Members

– ***3 Ohio Universities:***

"Toledo node"
- *– University of Toledo*
  Specializes in thin film PV
- *– Bowling Green State University*
  Specializes in molecular PV

"Columbus node"
- *– Ohio State University*
  Specializes in III-V MJ and nano PV

-- ***20 Founding Participants:***

PVIC Funding from ODOD – Years 1-3 (CY 2007-2010)

• **capital funds**	**$11.0 M**
➢UT	$5.1 M
➢OSU	$3.5 M
➢BGSU	$2.4 M
• **operating funds**	**$7.6 M**
➢ UT	$4.2 M
➢ OSU	$3.3 M
➢ BGSU	$0.1 M
• **total funds**	**$18.6 M**
➢ UT	$9.3 M
➢ OSU	$6.8 M
➢ BGSU	$2.5 M

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PVIC - Toledo Node Faculty in PV

• 1987 Alvin Compaan* (UT, emeritus) from Kansas State/Univ. Chicago	Thin film CdTe PV
• 1990 Dean Giolando* (UT) from Univ. Texas/Univ. Illinois	Thin films for PV
• 1995 Jacques Amar (UT) from Emory Univ./Temple Univ.	Thin film theory
• 1996 Xunming Deng* (UT, on leave) from ECD Troy, MI/Univ. Chicago	Thin film Si PV
• 1997 Felix Castellano (BGSU) from Univ. Maryland/Johns Hopkins	Organic / molecular PV
• 2000 Pavel Anzenbacher (BGSU) from Univ. Texas/Czech. Acad.	Organic / molecular PV
• 2004 Robert Collins (UT) from Penn State Univ./Harvard	Thin film PV / PV optics
• 2004 Sanjay Khare (UT) from Univ. Illinois/Univ. Maryland	Materials theory
• 2005 Sylvain Marsillac (UT) from Univ. Delaware - IEC/Univ. Nantes	Thin film CIGS PV
• 2006 Terry Bigioni (UT) from NASA/Georgia Tech.	Nanotech. PV/PV optics
• 2008 Michael Heben (UT) from NREL/Cal Tech./Stanford	Nanotech. PV / thin film PV
• 2008 Randy Ellingson (UT) from NREL/Cornell Univ.	Nanotech.PV / thin film PV
• 2008 Rashmi Jha (UT) from IBM-NY/NC State	Nanotech. PV

• 2010 Three new positions from ODOD's Ohio Research Scholars Program

3 Open faculty positions one endowed chair and two tenure-track positions

R&D Approach: Gen 2.5 -- targeted enhancements for thin film PV performance

D&D Approach: Leverage Ohio's strengths in PV supply chain components of glass, steel, and polymers -- raw materials, substrates, encapsulants -- for low cost manufacturing

** Faculty entrepreneurs*

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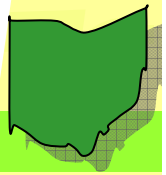
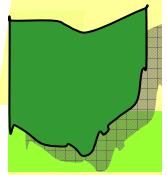


Wright Center of Innovation PVIC
U Toledo / Ohio State / BGSU

Company Members (30 to date, up from **13 founders -- in bold**
new companies* in red)

Advanced DG	First Solar	PlasmaSi, Inc.
AP Alternative, LLC	Greensleeves, Inc.	PPG Industries
Brush Engineered Materials	**Innovative Thin Films**	Replex Plastics
Calyxo USA	**Lake Shore Cryotronics**	Romanoff Electric Co., LLC
CoreTech Management	Leading Edge Coating Solutions	Solar Kits USA*
Cornerstone Research Grp.	Marshall & Melhorn, LLC	Solar Spectrum, LLC
Decker Homes	**NewCyte, Inc.**	**SSOE, Inc.**
DuPont	**Owens Corning**	Tosoh SMD, Inc
Energy Focus, Inc.	**Pilkington**	**Xunlight Corp.***
Ferro Electronic Mater. Sys.	Plaskolite, Inc	Xunlight 26 Solar*
Non-Profit Members	***Utility Advisory Board and **Exchange Memberships**	**Other Organizations partnering with PVIC**
Battelle Memorial Inst.	American Electric Power – Ohio*	Los Alamos National Lab
Edison Mater. Technol. Ctr.	Clean Technology and Sustainable Industries Organization (CTSI)**	NASA Glenn Research Ctr
Green Energy Ohio	Dayton Power & Light*	National Renewable Energy Laboratory
Honda OSU Partnership	Duke Energy*	NIST - Gaithersburg
Toledo Electrical JATC Trust Fund	First Energy*	Oak Ridge National Lab
	Green Energy Ohio**	Regional Growth Partnership
	InterState Renewable Energy Council **	Rocket Ventures



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Membership Levels

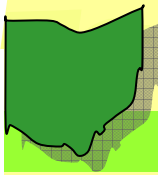
- **Industry Member (Affiliate)**
  Member rates depend on company size, type, location
  - Access to instrumentation and expertise
  - Attendance at semiannual meetings, technical workshops, short courses
  - Collaboration on proposals leading to a research partnership
- **Research Partner (includes Founding Members)**
  Must be an industry member and pay affiliate level dues
  - Maintains funded collaborative research with Center faculty
    -- Cost share in the Center proposal
    -- Subcontractor on a Center proposal
    -- Subcontracts to Center faculty
  - Holds membership on the Industrial Advisory Board
  - Has prioritized access to Center IP generated by research in university-only projects: federal, state, or Center funded

Center Projects

- University research (IP owned by university; accessible to partners)
- Collaborative research (joint ownership of IP)
- Service research (IP owned by industry member)

Boards

- Executive Industrial Advisory Board
- Scientific Advisory Board
- Utility Advisory Board



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Goal of PVIC: Technology Commercialization

PHASES OF DEVELOPMENT TO CREATE PROOF

IMAGINING the Commercial Opportunity	**INCUBATING** to define the Commercial Opportunity	**DEMONSTRATING** Products/Processes in Commercial Context	**MARKET ENTRY** to prove the Commercial Viability	**GROWTH & SUSTAINABILITY** to generate Financial Returns

mobilizing resources for incubating

mobilizing resources for demonstrating

mobilizing resources for market entry

mobilizing resources for growth/sustain

Based on V. Jolly's 1997 book: *Commercializing New Technologies: Getting from Mind to Market...*

with additional literature review and input from BizLogx

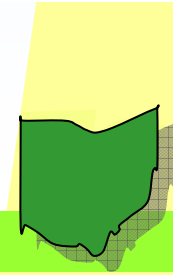
TRANSITIONS TO MOBILIZE RESOURCES

PVIC's Metrics for Evaluation of Success:

Level A: Synonomous with a transition

Level B: Tangible evidence of a clear pathway to a transition

Level C: Project milestone towards a Level B metric



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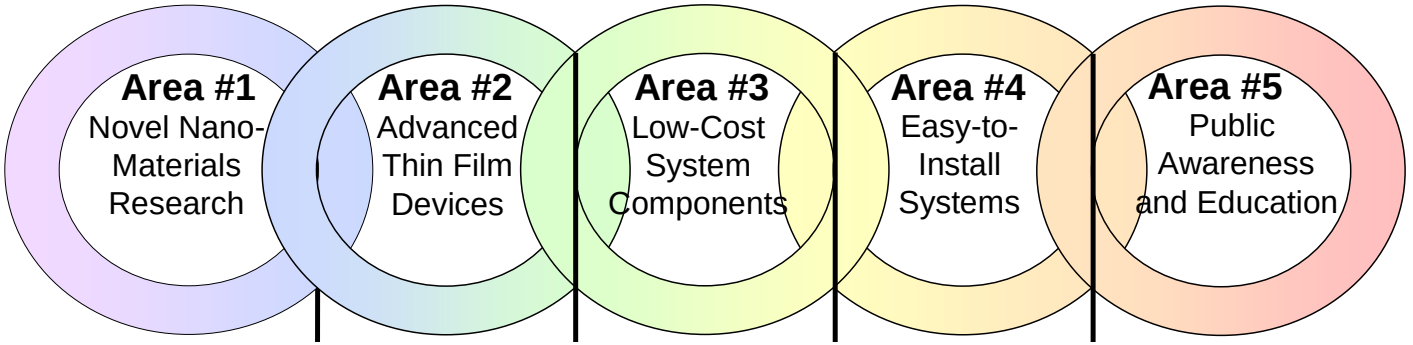
The Process of Technology Commercialization

PHASES OF DEVELOPMENT TO CREATE PROOF

IMAGINING the Commercial Opportunity	INCUBATING to define Commercial Opportunity	DEMONSTRATING Products/Processes in Commercial Context	MARKET ENTRY to prove Commercial Viability	GROWTH & SUSTAINABILITY to generate Financial Returns
	mobilizing resources for incubating	mobilizing resources for demonstrating	mobilizing resources for market entry	mobilizing resources for growth/sustain

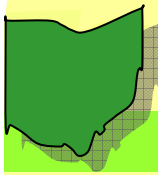
PVIC-UT Activities are Categorized into Areas and Mapped onto the Commercialization Framework

TRANSITIONS TO MOBILIZE RESOURCES



PVIC-UT's Role: **University Research** | **Partnering with Start Up/Existing Co's.** | **Partnering with Existing Companies** | **University Education**

Time to market:	> 6 years	3-6 years	0-3 years	now	now
	AREA #1 Imagining 3rd Generation Photovoltaics Based on New Materials and Nanotechnology	AREA #2 Incubating Advanced 2nd Generation PV Materials and Processes toward Lower Cost	AREA #3 Demonstrating New Higher Performance, Lower Cost PV System Components	AREA #4 Market Entry of Integrated PV Systems for Installations in Ohio and Elsewhere	AREA #5 Sustainability of PV Market through Education, Public Awareness, and Enlightened Policies



Wright Center PVIC Goals

Create an environment in Ohio that is conducive to transitions along the Commercialization Framework by the University, by start-ups, and by established companies.

How is such an environment generated?

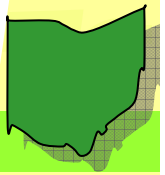
Establish an industry cluster in Ohio that gravitates to PVIC due to its roles in:

- assisting established companies in improving existing products and developing new products
- inventing technology that forms the foundation of new start-up companies
- attracting new start-up and established companies to Ohio

Specifics of these roles:

- state-of-the-art infrastructure for process and product development support
- accessible faculty expertise for collaborative efforts; joint grants/contracts
- trained workforce from certified PV installers to Ph.D. R&D scientists

Current metrics: 5 companies formed or attracted; 350 new jobs in PV; supporting about 6,000 jobs in the PV cluster in Northwest Ohio



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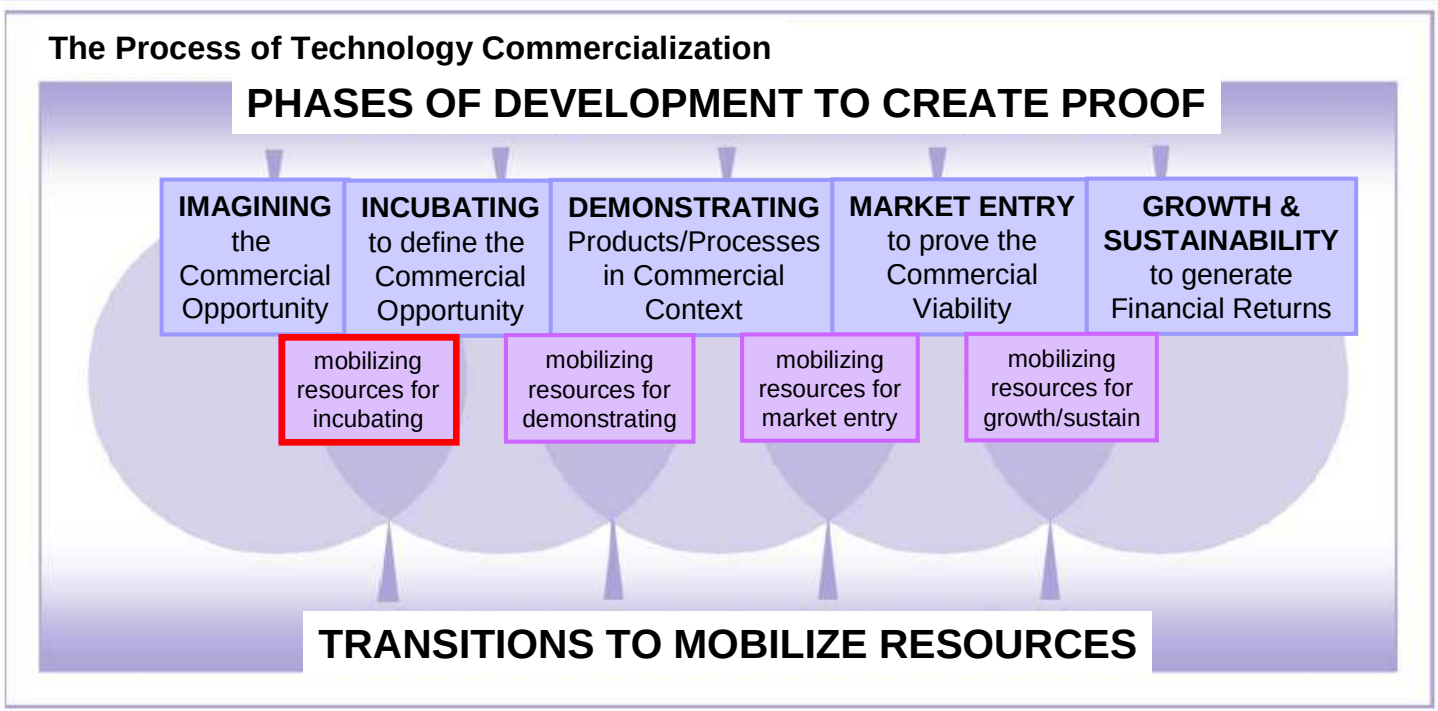
Imagining to Incubating

Area #1: PV Nano/Molecular Materials Research transitioning to Area #2: Small Area Devices



Research collaboration:

U. Toledo
T. Bigioni
R. Collins
R. Ellingson
M. Heben

BGSU
F. Castellano

Penn State
T. Mallouk

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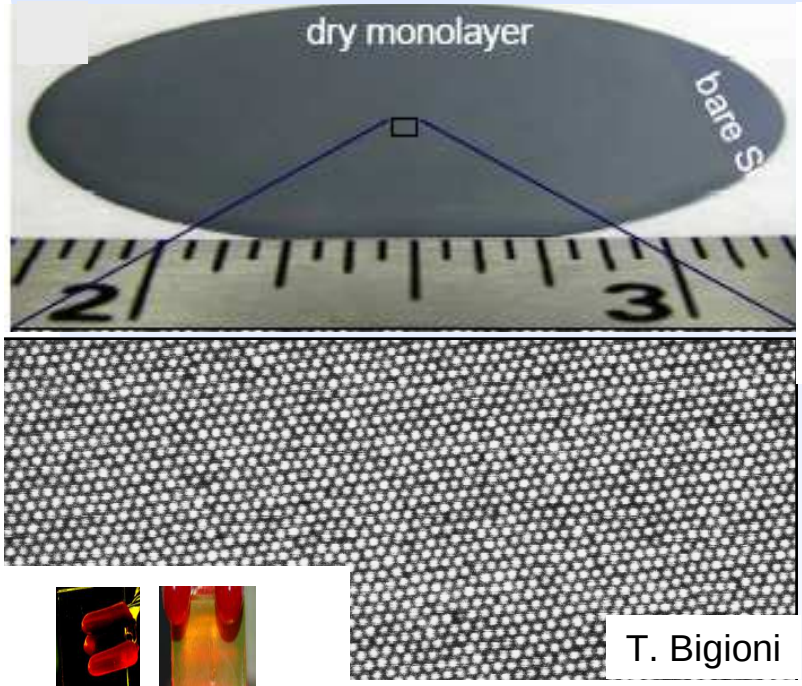
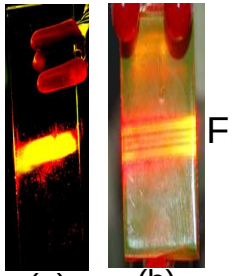
Areas #1 - #2 Photon Management for Advanced Thin Film PV



T. Bigioni

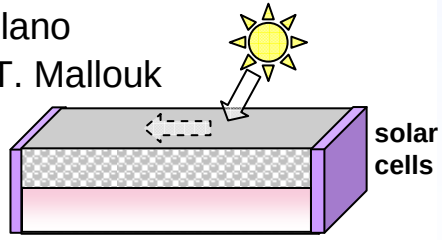


(a) (b)

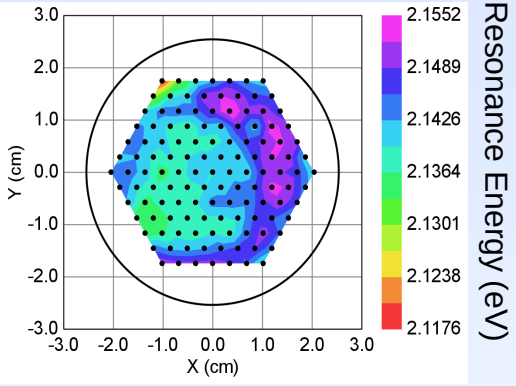
F. Castellano

Digital photos of polymers with upconverting chromophores using: (a) 725 nm and (b) 635 nm excitation.

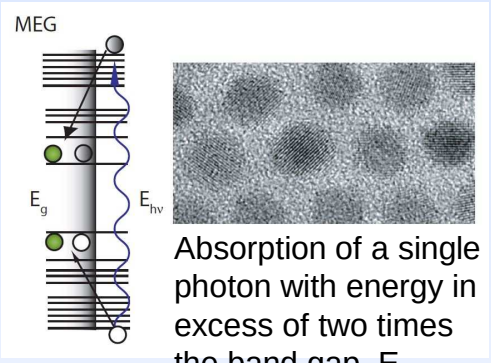
T. Mallouk



Schematic concept of a planar non-imaging concentrator with PV cells at the edges of a low-cost dielectric structure that collects sunlight from all angles.



Spectro-ellipsometry can be used to evaluate uniformity of plasmon resonance energy over the wafer.



Absorption of a single photon with energy in excess of two times the band gap, E_g, produces multiple excitons at the band edge. TEM picture of typical PbSe nanocrystals.

- **Up/down-conversion components**

Goal: collect sub-gap light and light absorbed by glass/TCO/window layers
Status: record lab up-conversion efficiency of 16%

- **Multiple exciton generation**

Goal: avoid thermalization losses
Status: understanding principles / fabricating devices

- **Plasmonic control of energy transfer**

Goal: target energy to chromophores, absorbers
Status: scaling up to large areas

- **Low-x non-imaging concentration**

Goal: Collect diffuse component of solar irradiance
Status: evaluating performance

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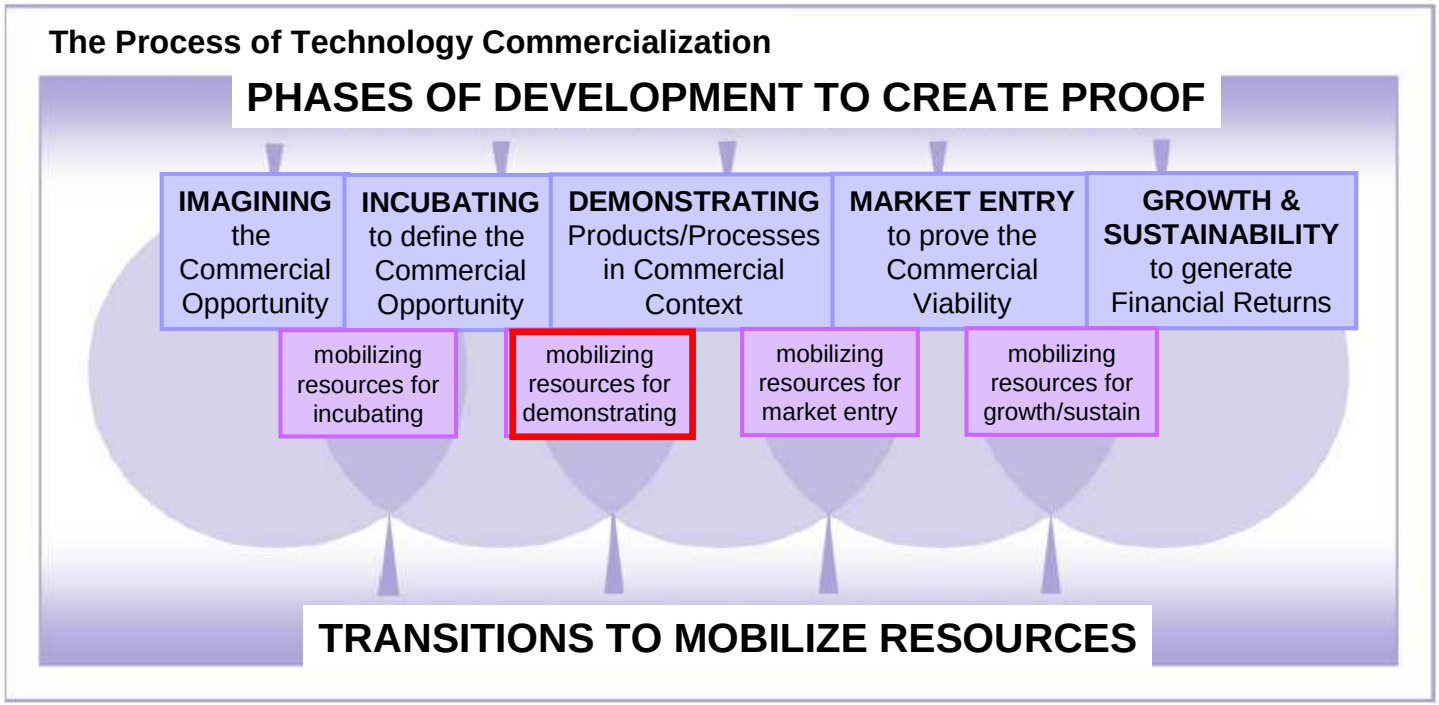
Incubating to Demonstrating

Area 2: Thin Film Devices transitioning to Area 3: Low Cost System Components

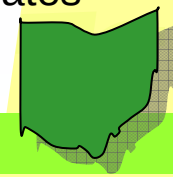


Industry collaborations:

U. Toledo
R. Collins
S. Marsillac
M. Heben

DuPont
polymer substrates

Pilkington
glass substrates



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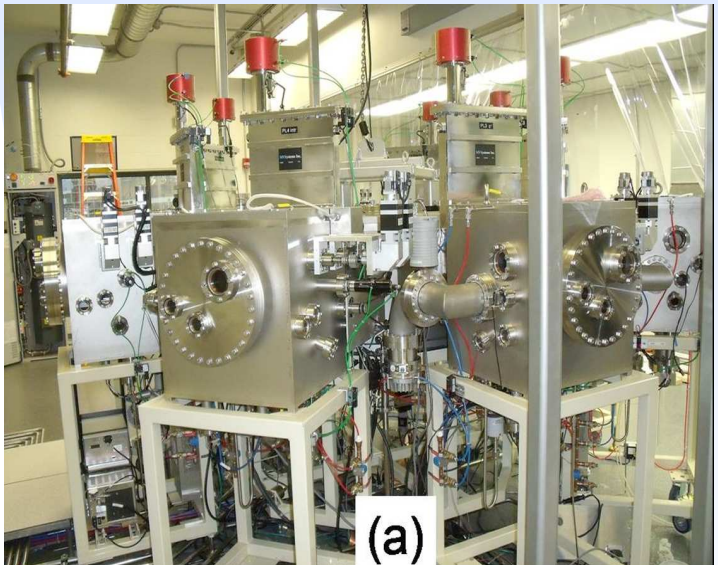
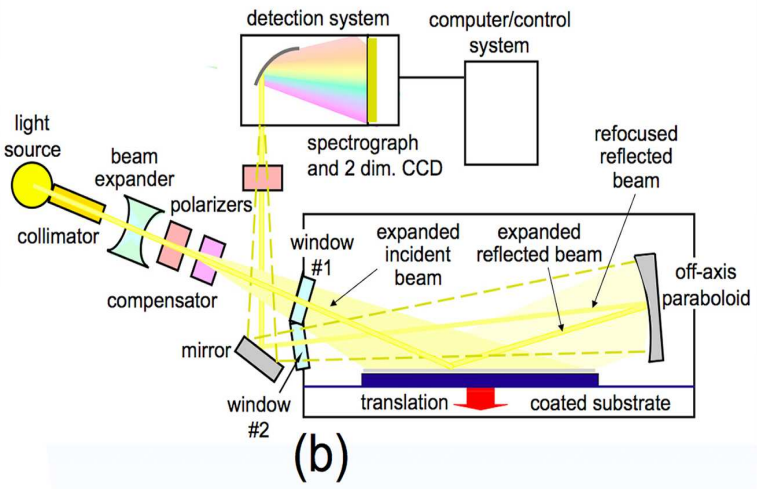
Areas #2 - #3 Novel Approach: Process Development in Roll-to Roll and Rigid Substrate PV Guided by Monolayer Sensitive in Situ Mapping Optics

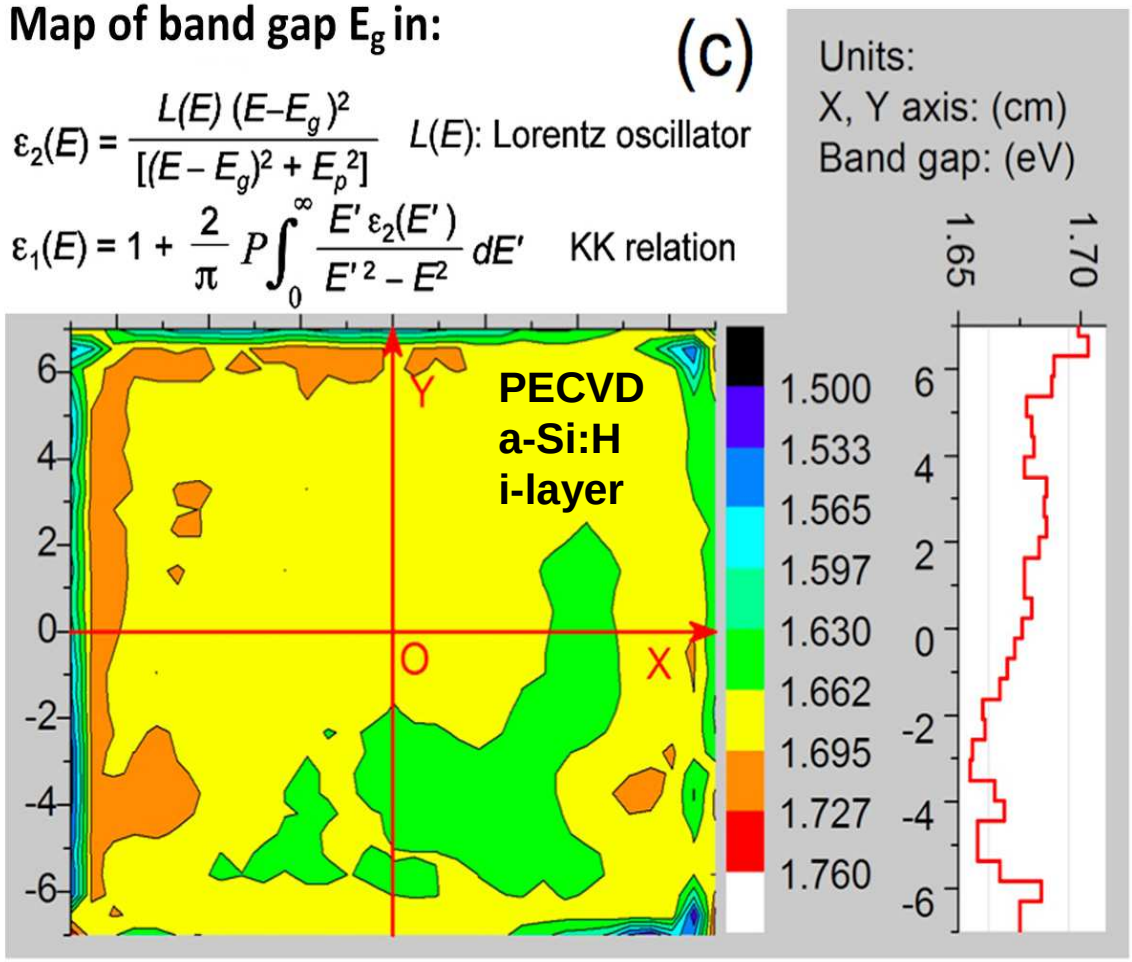




Map of band gap E_g in: (c)

$$\varepsilon_2(E) = \frac{L(E)\,(E-E_g)^2}{[(E-E_g)^2 + E_p^2]}$$ $L(E)$: Lorentz oscillator

$$\varepsilon_1(E) = 1 + \frac{2}{\pi} P \int_0^\infty \frac{E'\,\varepsilon_2(E')}{E'^2 - E^2}\,dE'$$ KK relation



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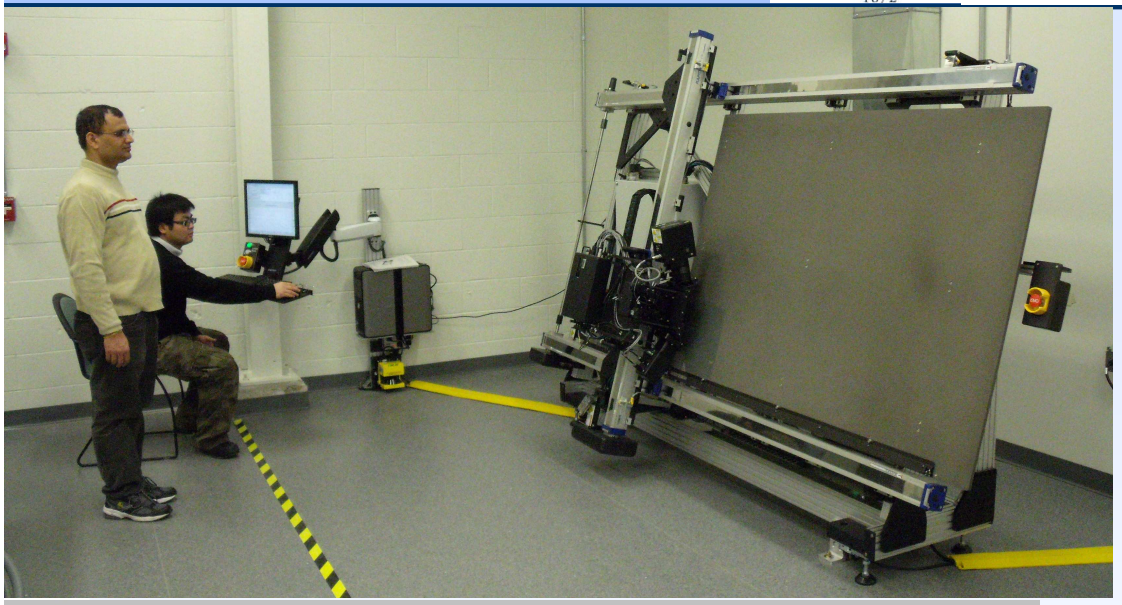
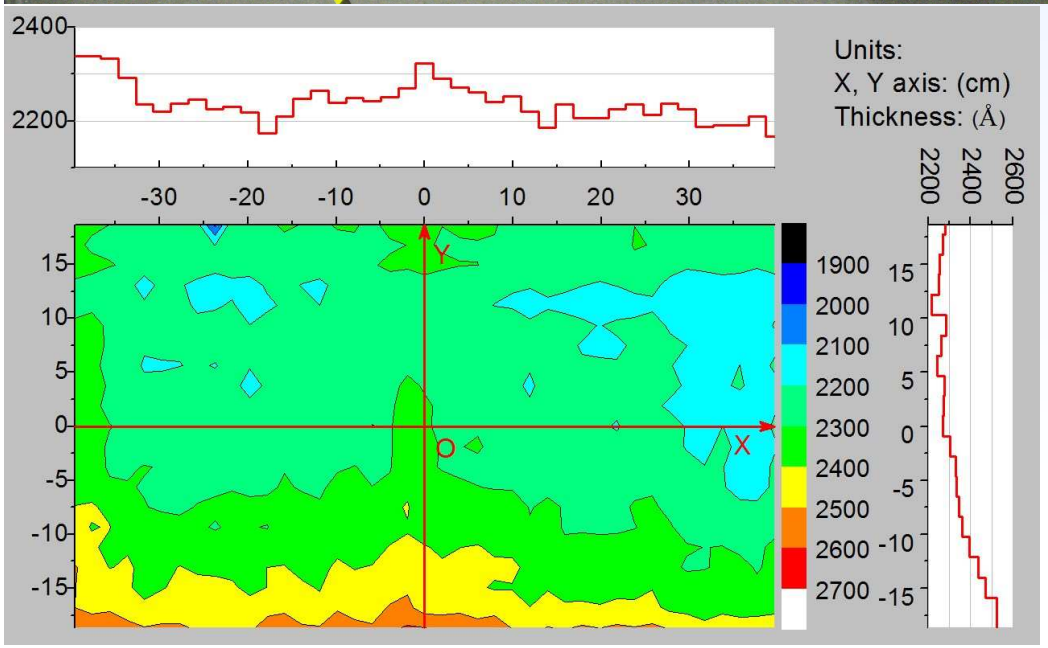
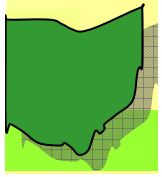


Areas #2 - #3 Off-Line Optical Diagnostics for PV Panels on Foils and Glass Panels

- Mapping size 1 m x 1.5 m
- Auto-focus to characterize and correct for warpage
- Analysis of bulk and surface roughness thicknesses
- Analysis of critical point amplitudes, energies, widths

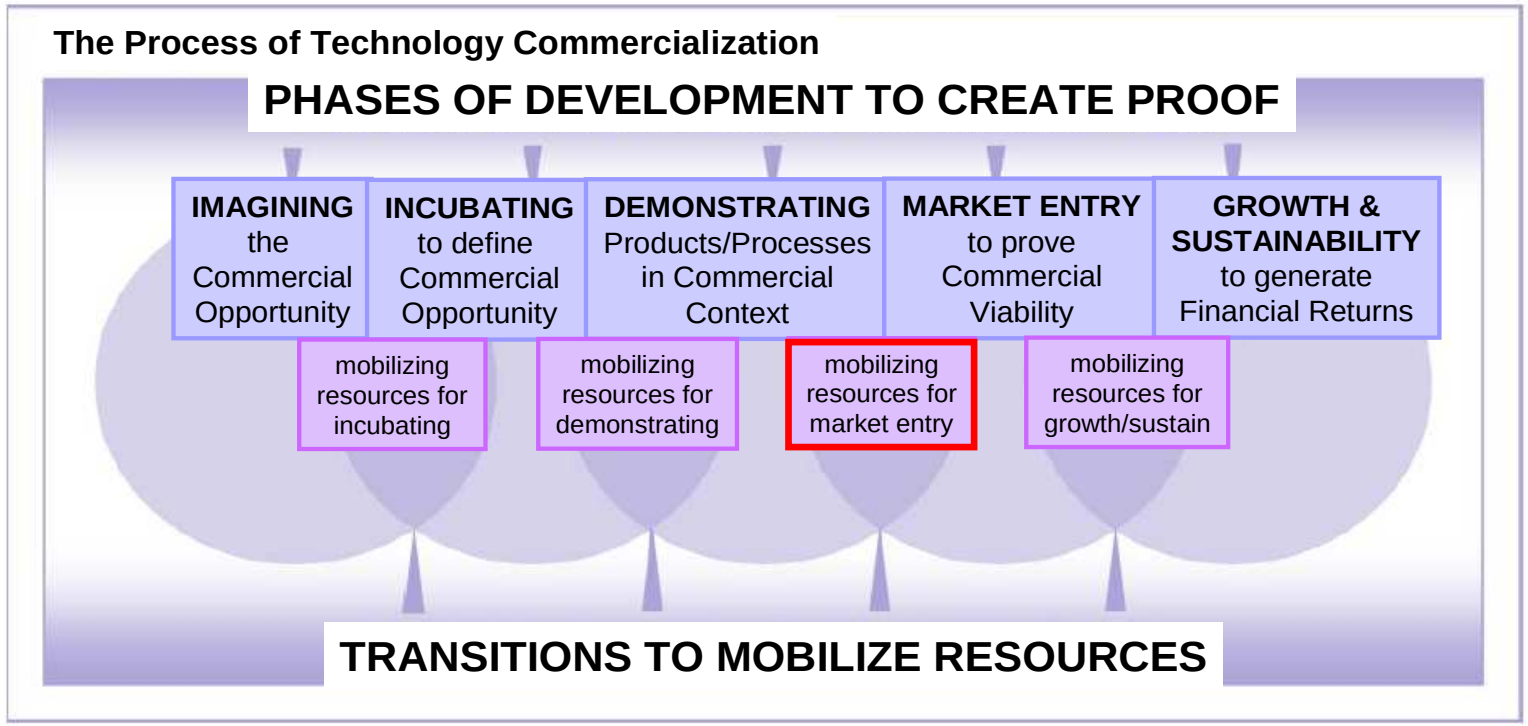


(Left) 80 cm x 40 cm map of bulk layer thickness of CdS (in Ångstroms) on Pilkington TEC-15 glass plate. The two curves (top and right) show the CdS thickness profiles along the X and Y axis.



Demonstrating to Market Entry

Area 3: Low Cost System Components transitioning to Area 4: Easy to Install Systems



Demonstration collaborations:

U. Toledo

Solar Kits USA
joint venture between
Advanced DG
and
McMaster Energy Enterprises

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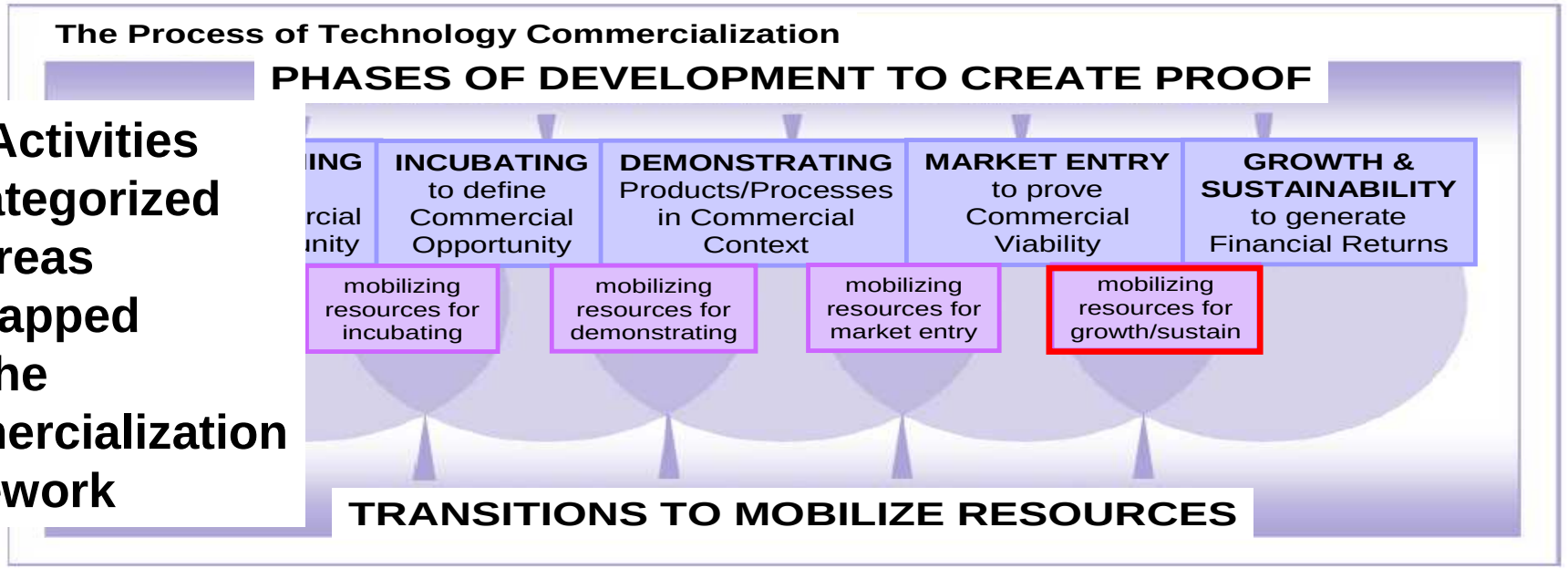
Area #3 - #4 Example: Low Cost PV Systems

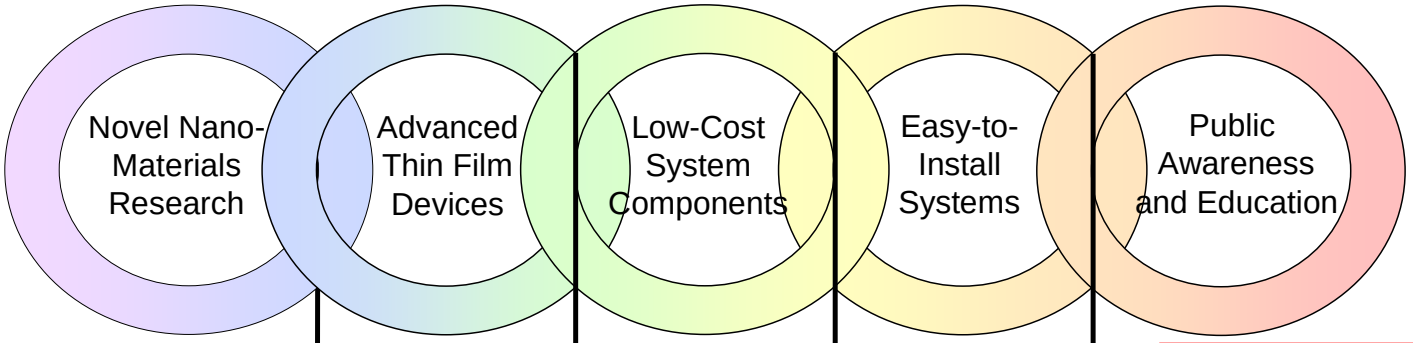
- Set up work stations for PV system design including CAD software PVIC company Solar Kits USA
- Provided assistance including:
  - -- Proposal writing for ODOD programs, industry, and state RFPs
  - -- Technical support to Solar Kits USA for a 1 MW Air National Guard PV Array
- Provided a forum for company-company partnering
- Established training courses for PV installers: certificates and 2 yr. degrees

The affordable megawatt solar energy system concept of Solar Kits USA was introduced at the ASES National Conference in Cleveland, Ohio in July 2007.

A 1 MW solar field at the 180th Air National Guard Base (Toledo Express Airport) integrated and installed by ADG using Solar Kits USA components (>90% Ohio content).

PVIC Activities are Categorized into Areas and Mapped onto the Commercialization Framework





PVIC-UT's Role: **University research** | **Partnering with Startups/Existing Co.'s** | **Partnering with Existing Companies** | **University education**

Time to market: > 6 years | 3-6 years | 0-3 years | now | now

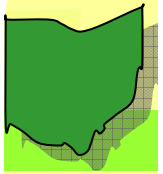
AREA #1 Imagining 3rd Generation Photovoltaics Based on New Materials and Nanotechnology

AREA #2 Incubating Advanced 2nd Generation PV Materials and Processes toward Lower Cost

AREA #3 Demonstrating New Higher Performance, Lower Cost PV System Components

AREA #4 Market Entry of Integrated PV Systems for Installations in Ohio and Elsewhere

AREA #5 Sustainability of PV Market through Education, Public Awareness, and Enlightened Policies

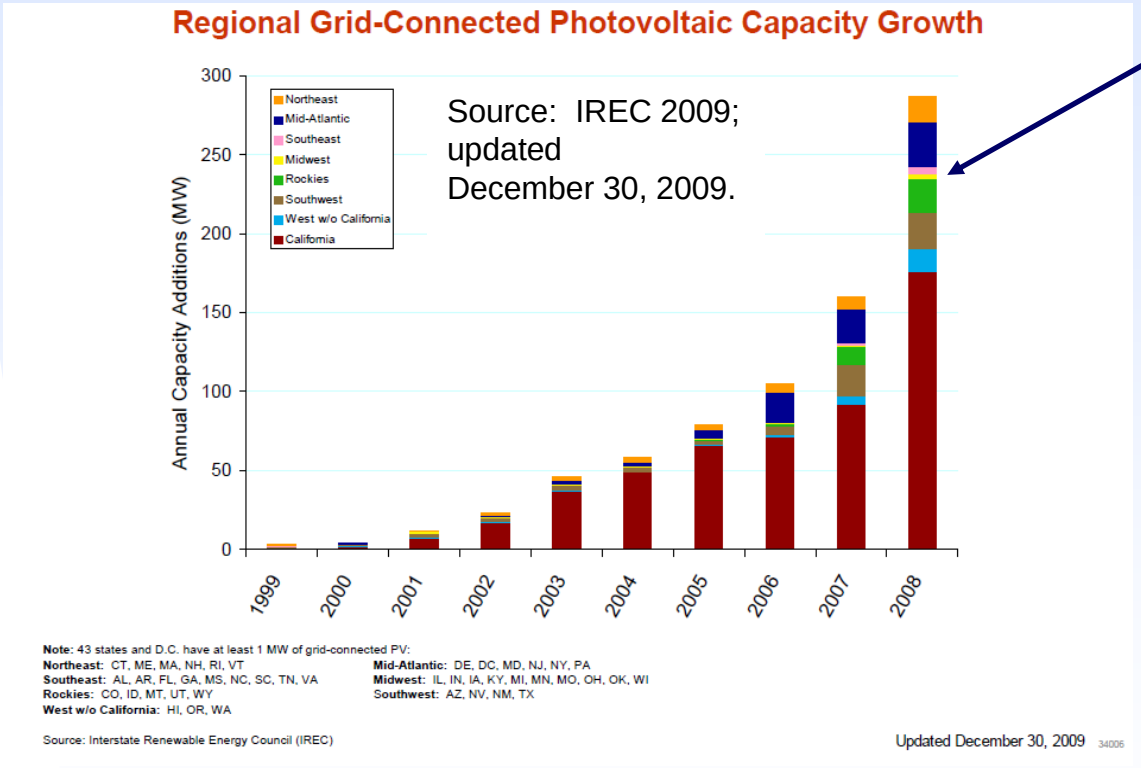


Area #5 Progress in Education at Univ. Toledo

- Intercollege Ph.D. program is being established in Renewable Energy
  Five new courses have been developed with a focus on PV:
  -- *Semiconductors I and II*; *Optics of PV Materials*; *Metrology* (Collins)
  -- *Introduction to Solar Cells* (Marsillac)
  Currently used for a professional masters degree program in PV.
- A new School has been established:
  University of Toledo's School for Solar and Advanced Renewable Energy
  Location: Clean and Alternative Energy Incubator for research and development and graduate education in proximity with incubation activities
- UT's Scott Park Campus has been dedicated as a Campus of Energy and Innovation for demonstration and deployment projects

University of Toledo: Clean and Alternative Energy Incubator

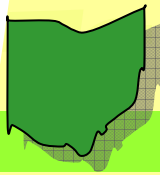
Challenge for Ohio: Lack of a Local Market



Among the state groupings, the 10 state Midwest region had the lowest increase in PV capacity < 5 MW in 2008.

In 2008, approximately 260 MW of the 407 MW of solar panels produced in the US, ~64% of the total, came from this region and within 100 mi of Toledo OH
-- thanks to First Solar and Unisolar (and NREL's Thin Film Partnership).

Meanwhile across the lake ... Ontario, Canada, has 80 MW in construction (Sarnia) and 95 MW in-process under RESOP, the Renewable Energy Standard Offer Program.



Thank you for your attention !

Questions and Discussion