DOE Solar Energy Technologies Program Peer Review

Technical Track: Supporting Research

Project Name: PDIL Development & Utilization

Principal Investigator: Brent P. Nelson

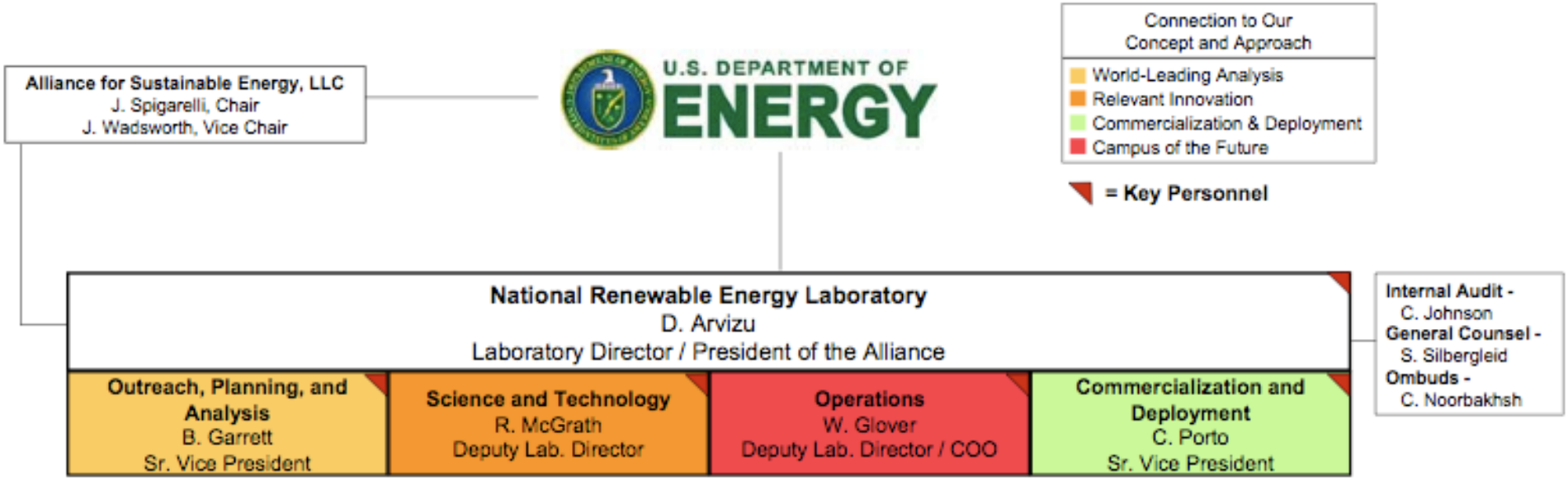
Denver, Colorado

March 9-10, 2009

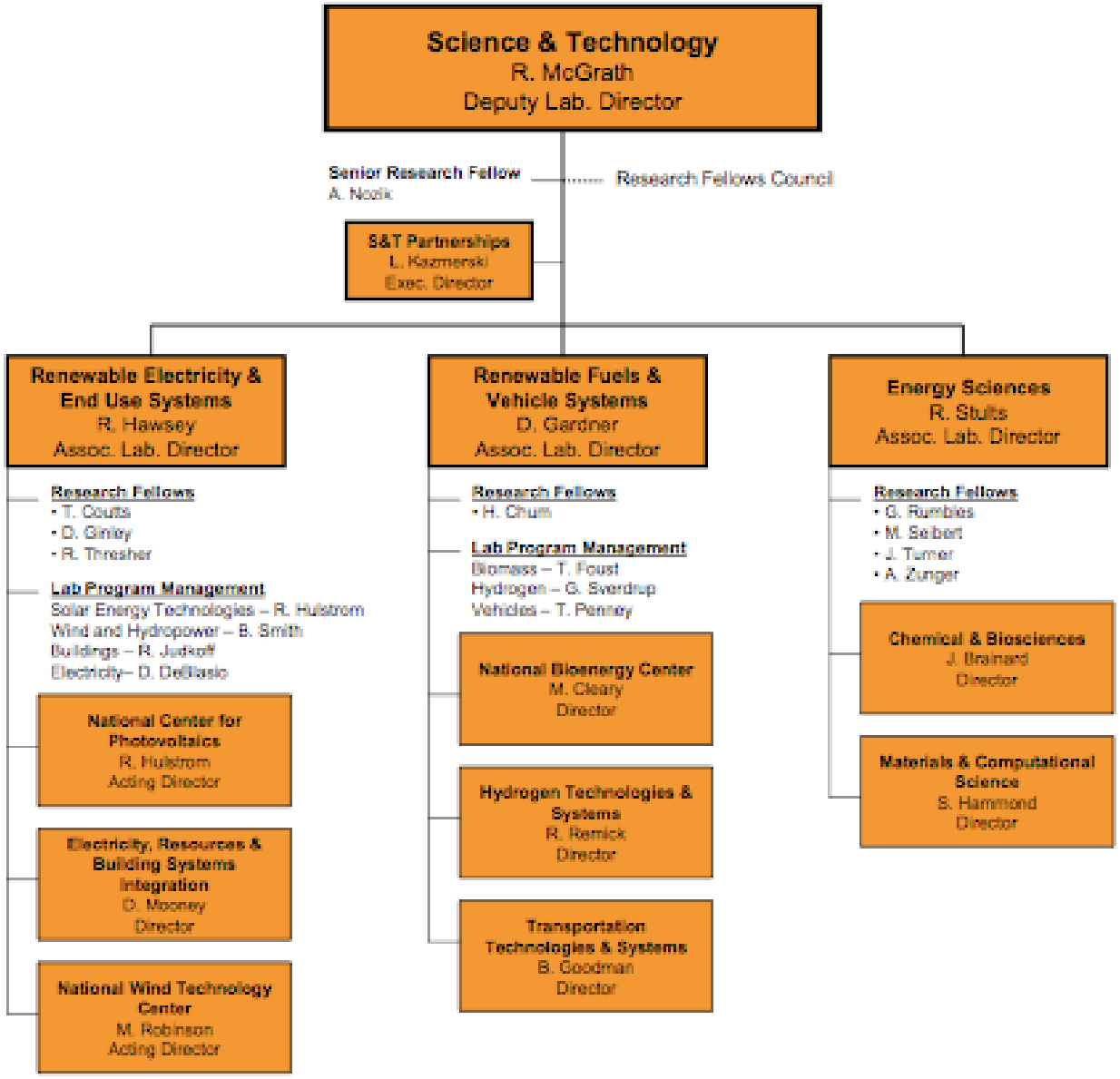
This presentation does not contain any proprietary or confidential information.

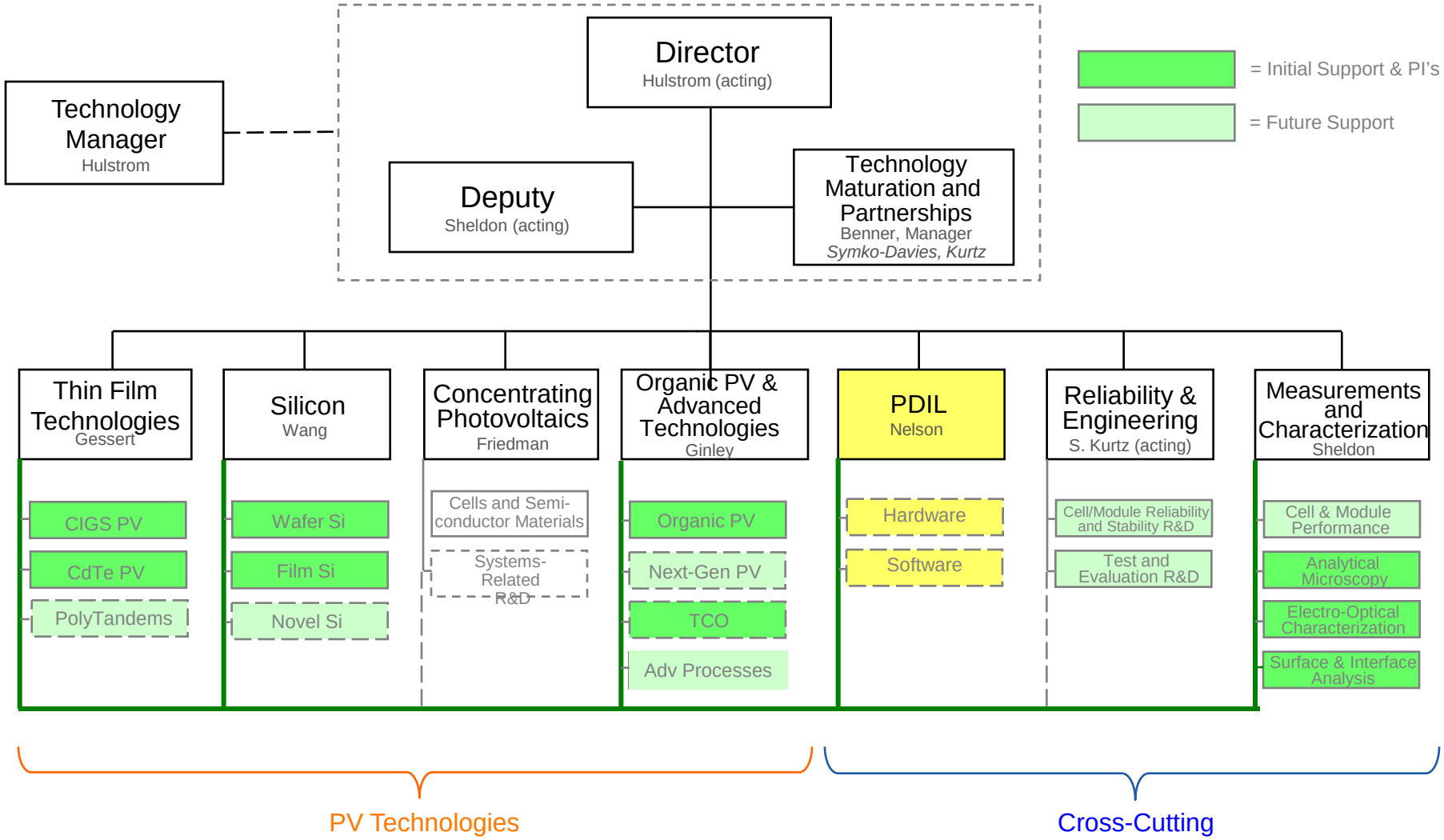
Outline

- NREL and the NCPV
- The difficulty of supporting the PV industry … no standards
- PDIL definition and vision
- PDIL standards
- Bay-by-bay review

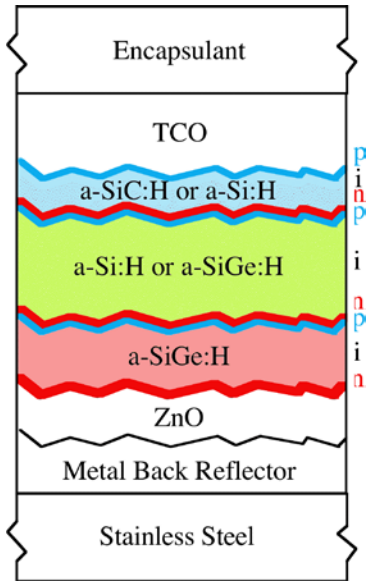

Alliance for Sustainable Energy, LLC
J. Spigarelli, Chair
J. Wadsworth, Vice Chair
U.S. DEPARTMENT OF ENERGY
Connection to Our Concept and Approach
World-Leading Analysis
Relevant Innovation
Commercialization & Deployment
Campus of the Future
= Key Personnel
National Renewable Energy Laboratory
D. Arvizu
Laboratory Director / President of the Alliance
Outreach, Planning, and Analysis
B. Garrett
Sr. Vice President
Science and Technology
R. McGrath
Deputy Lab. Director
Operations
W. Glover
Deputy Lab. Director / COO
Commercialization and Deployment
C. Porto
Sr. Vice President
Internal Audit -
C. Johnson
General Counsel -
S. Silbergleid
Ombuds -
C. Noorbakhsh

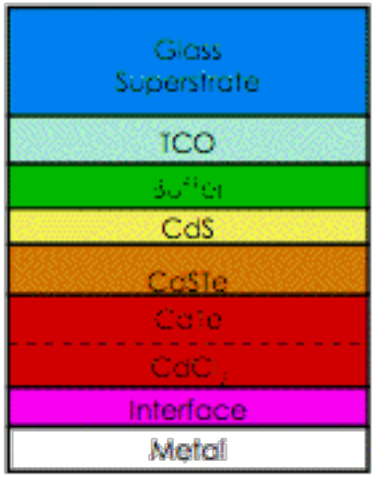
Science & Technology

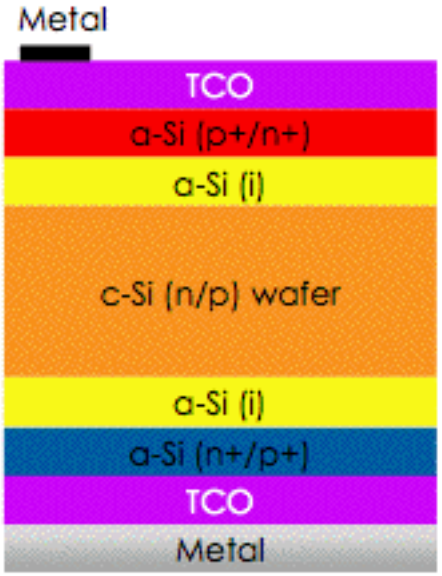


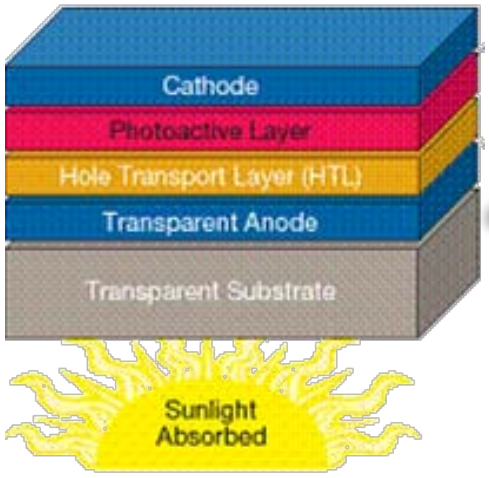

Director
Hulstrom (acting)
Technology Manager
Hulstrom
Deputy
Sheldon (acting)
Technology Maturation and Partnerships
Benner, Manager
Symko-Davies, Kurtz
= Initial Support & PI's
= Future Support
Thin Film Technologies
Gessert
Silicon
Wang
Concentrating Photovoltaics
Friedman
Organic PV & Advanced Technologies
Ginley
PDIL
Nelson
Reliability & Engineering
S. Kurtz (acting)
Measurements and Characterization
Sheldon
CIGS PV
CdTe PV
PolyTandems
Wafer Si
Film Si
Novel Si
Cells and Semi-conductor Materials
Systems-Related R&D
Organic PV
Next-Gen PV
TCO
Adv Processes
Hardware
Software
Cell/Module Reliability and Stability R&D
Test and Evaluation R&D
Cell & Module Performance
Analytical Microscopy
Electro-Optical Characterization
Surface & Interface Analysis
PV Technologies
Cross-Cutting

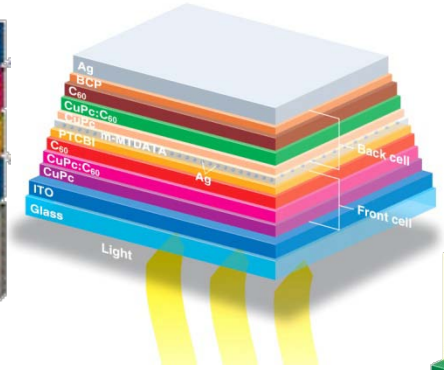
No Standard PV Processes

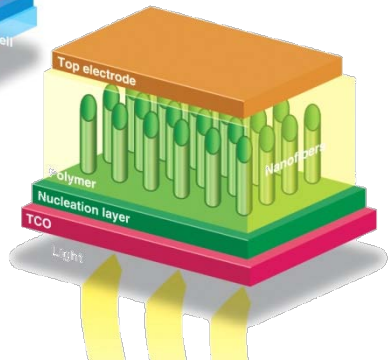


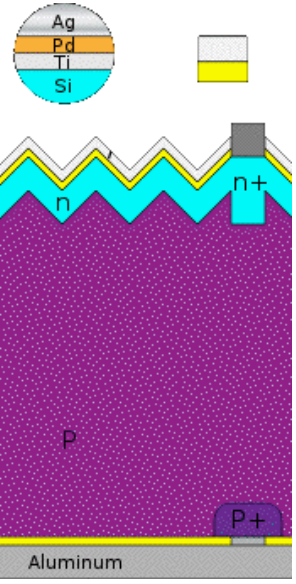








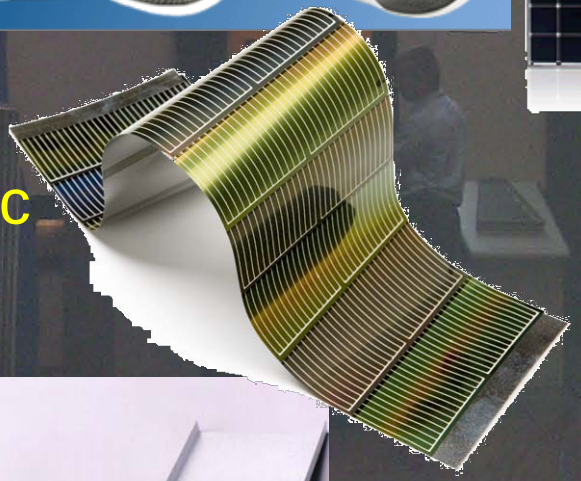


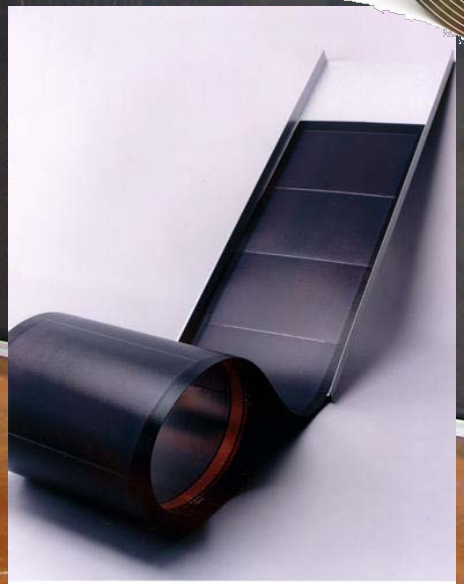


No Material Handling Standards

Glass
- < 1 m^2
- 5.7 m^2

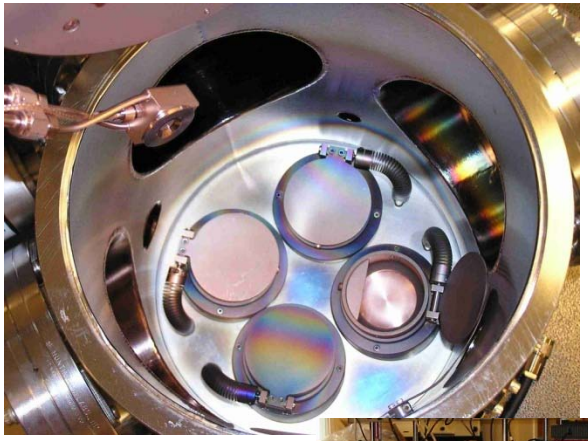
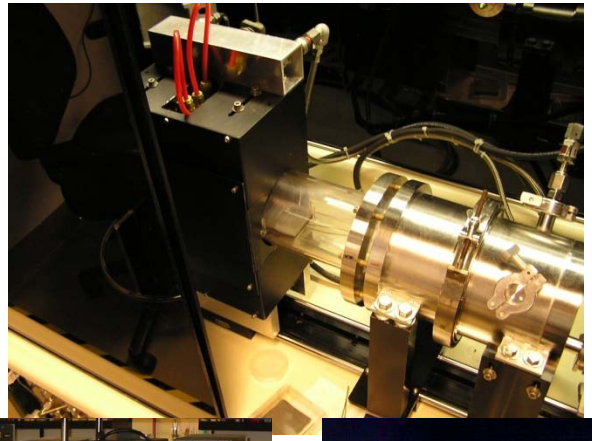
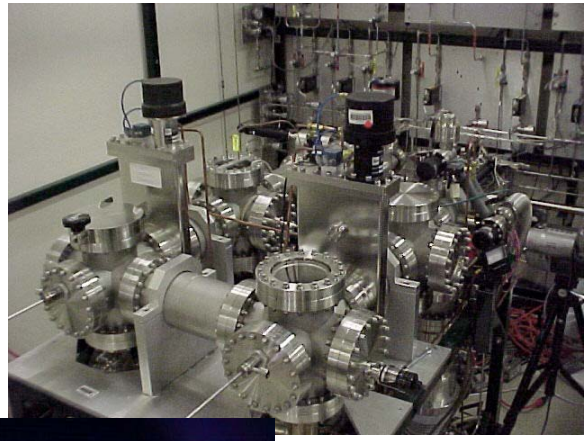
Foils
- Plastic
- Metal

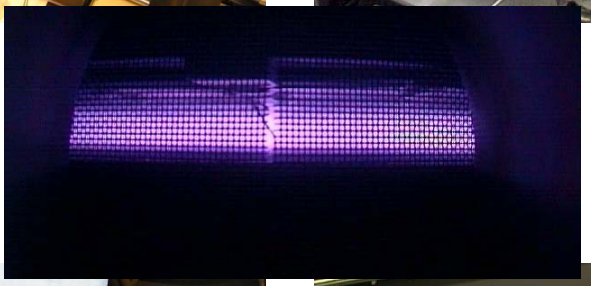


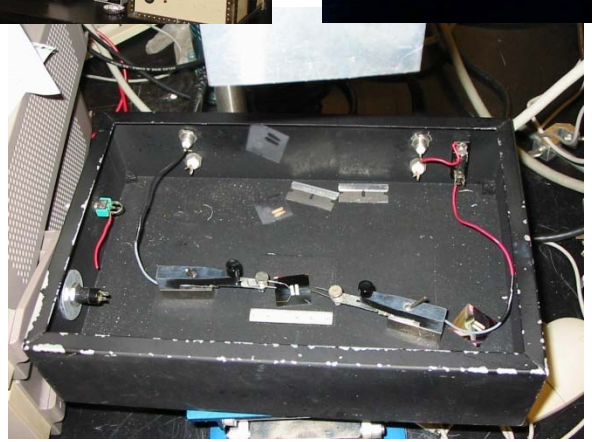
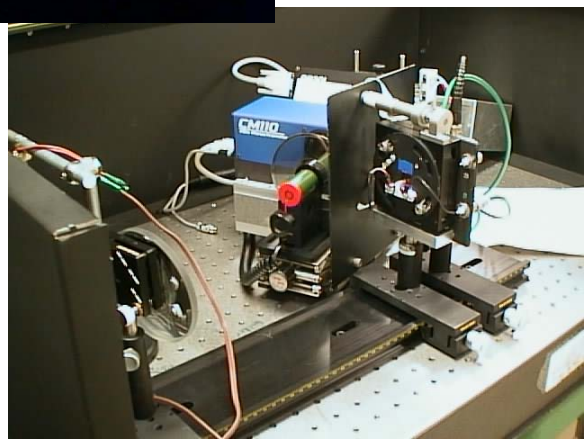


Wafers
- Round
- Square
- Rectangular

Certainly No Research Standards



The PDIL is a Collaborative Facility

Industry and universities work closely with NREL researchers via integrated….

^ over 1800 person-years PV experience

Equipment

- Deposition
  - CVD, PVD
  - Printing, Spray
  - CBD
- Processing
  - Etching
  - Annealing
- Measurement
  - Compositional
  - Electro-Optical
  - Structural

PV Materials

- CIGS, CdS, ZnO…
- CdTe, CdS, ZnTe…
- a-Si(Ge,N), nc-Si…
- Crystal Silicon Film
- Cross-Cutting
  - TCO's
  - Metal Contacts
  - Barriers
- Organics
- Nano-Based

Data Products

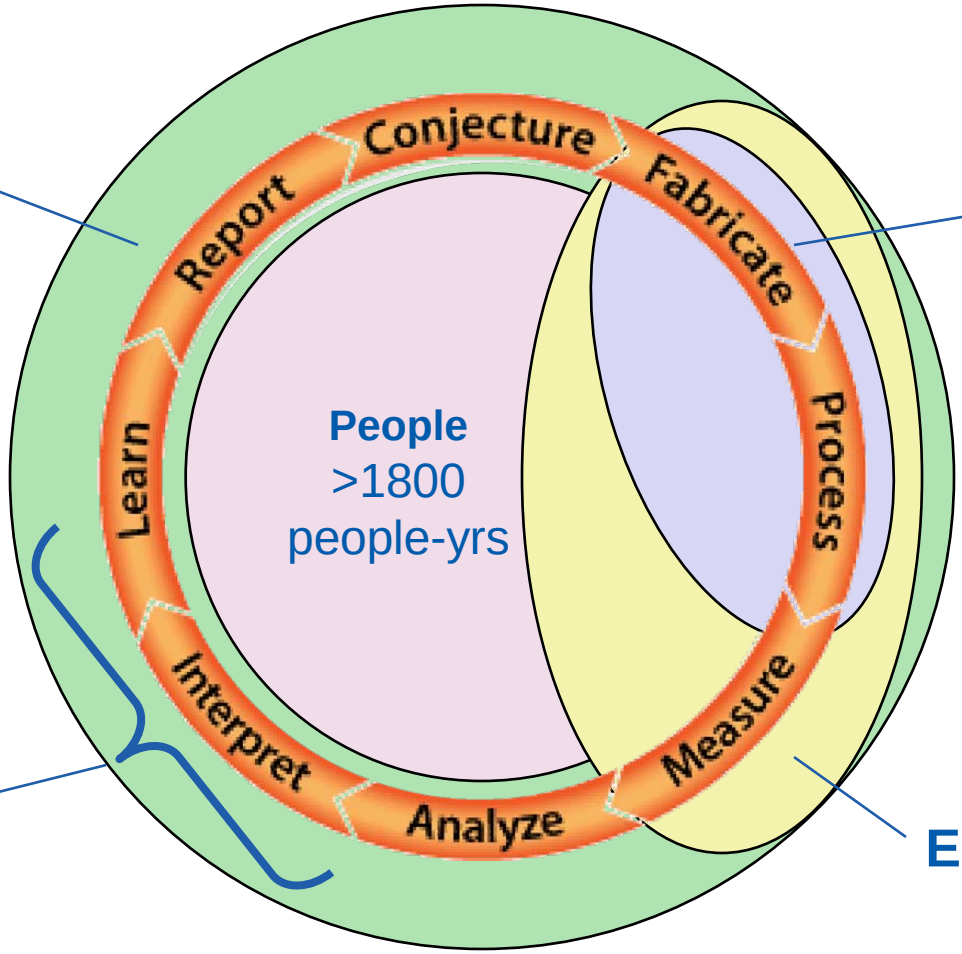
- Automation
  - Reproducible
  - "Recipes In"
  - High Throughput
- PDIL Server/Network
  - Relational Database
  - IP & Cyber Secure
  - Web-Based GUI
- Scientific Computing
  - Data Mining
  - Modeling/Simulation

Vision

- Provide a tool set that
  - facilitates both basic and applied science,
  - on commercially viable sample sizes,
  - with controlled ambient between process steps and measurements,
  - to answer previously inaccessible PV related research questions.
- Controlled ambient transfer between techniques emulates industrial processes with the added ability to
  - Interrupt processes at any point to perform a measurement
  - Mix material systems not fixed in a production line or technology
  - Control and characterize critical surfaces (interfaces) and investigate their impact on subsequent layers
  - Assess process-related source chemistry, surface chemistry and kinetics, and bulk reconstruction
  - Develop new techniques, methodologies, device structures, materials, and tools (growth, processing, and analytical)
- Provide a baseline of world-class cells and materials
- Improved collaborations with university and industry

Material Science Cycle

Data
recipes
instrumentation
results
data mining
modeling
…



Materials
TCO's
metals
semiconductors
…

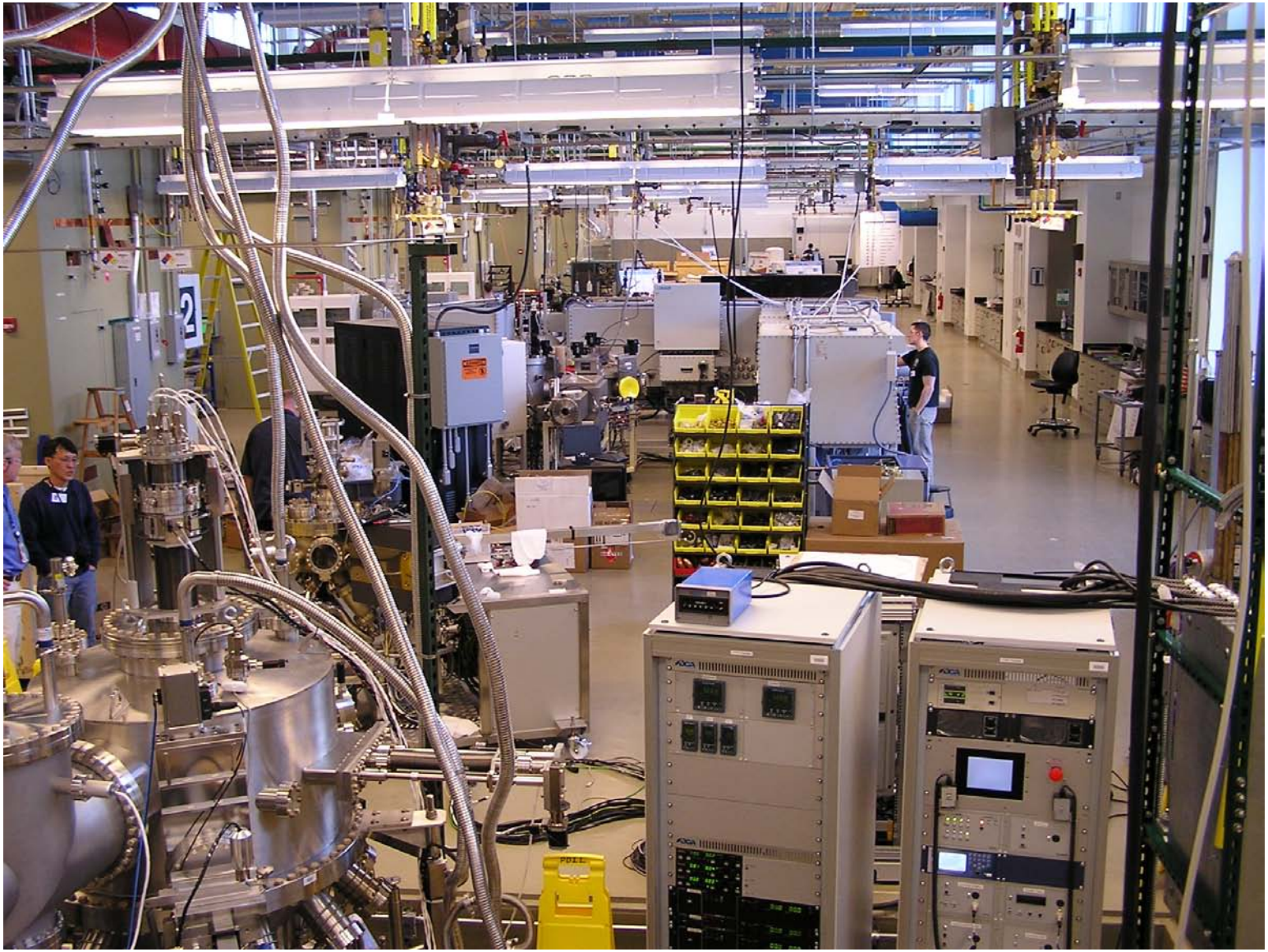
Automation
spend more time
studying data than
creating it

Equipment
deposition
processing
measurement
…

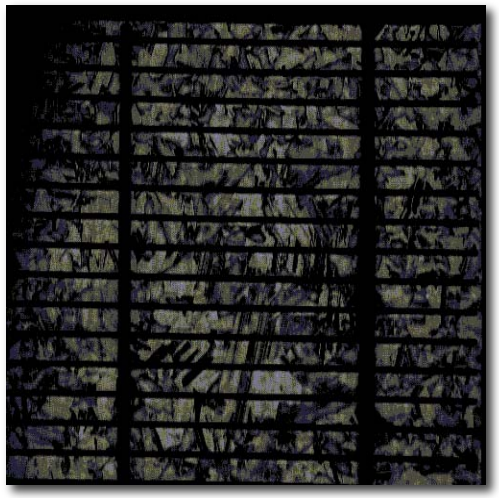
The PDIL = Collaborative Facility Integrating

- Materials
- Equipment
- Data
- People

Facility and Tools



PDIL Size Standard: 157 x 157 mm



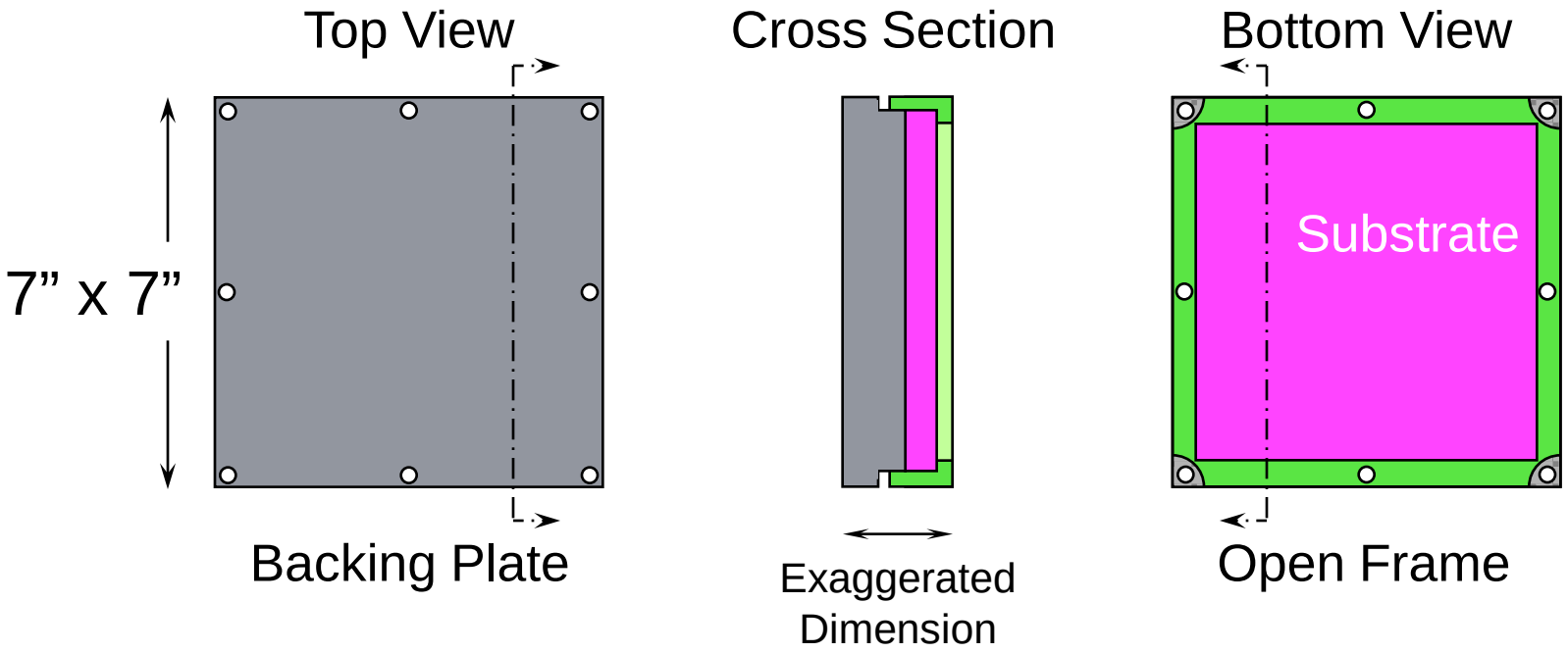
“Commercially Viable”

- 6.18” x 6.18”
- large enough for mini-modules
- supports multiple technologies
  - multi-crystalline silicon (square)
  - single crystal silicon (round)
  - ribbon silicon (rectangle)
  - thin-films (a-Si, CdTe, CIGS) on a variety of substrate materials
  - third generation PV

Multiple Substrate Materials

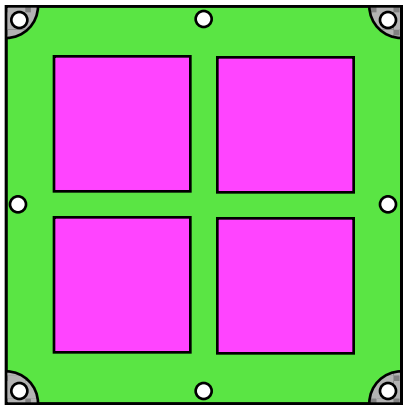
- (poly) crystalline wafers
- soda lime glass
- aluminosilicate glass
- plastics
- stainless steel
- exotic & specialized

Standard Platen for All PDIL Tools

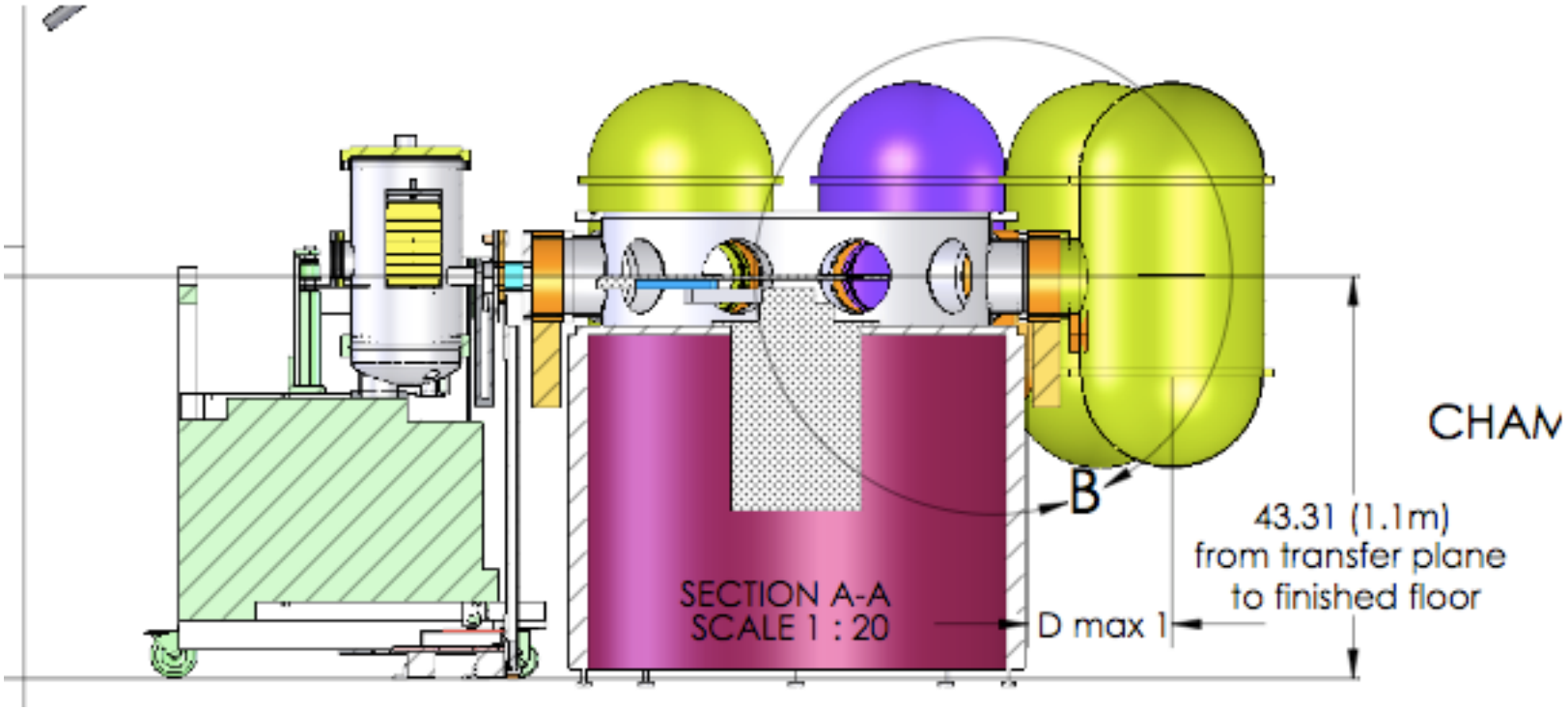


Integrated systems accept the standard 7” x 7” platen form factor

- Inconel, molybdenum, stainless steel, etc.
- different platen configurations accept various substrate shapes and sizes
  - Rounds, squares, multiple smaller substrates
  - Metal foils, plastic sheet, glass, wafers, etc.

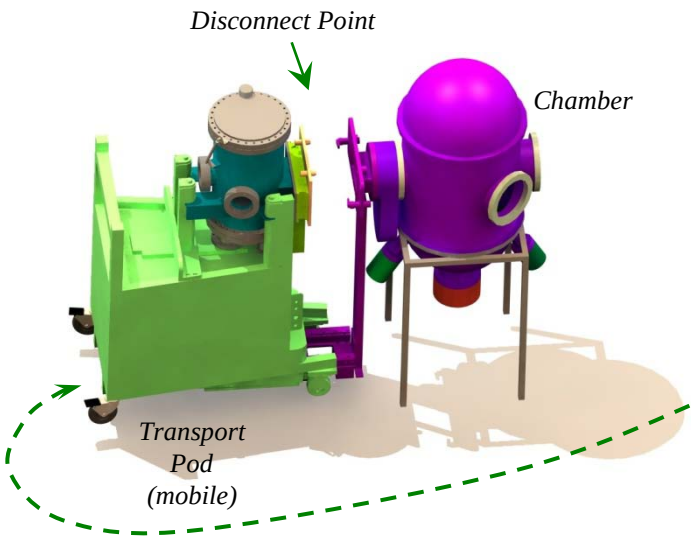


10” CF Flange, 1.1 m AFF

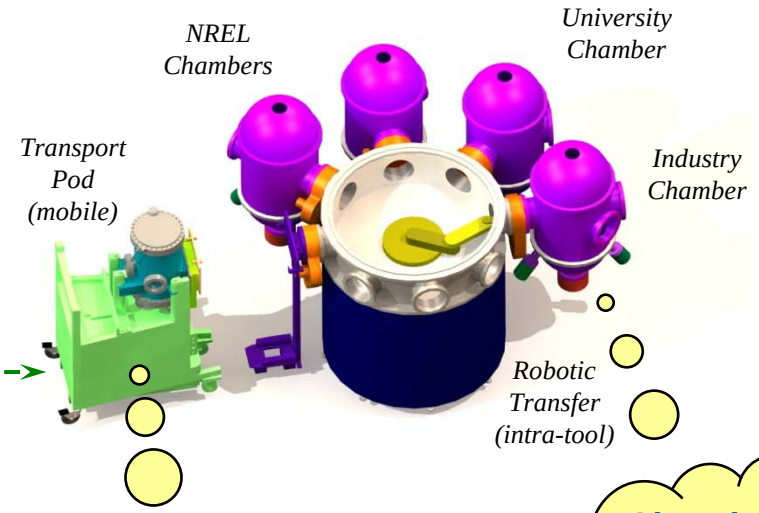


Equipment Integration Standards

Stand-Alone Tools



Integrated Tools: Robotic Transfer



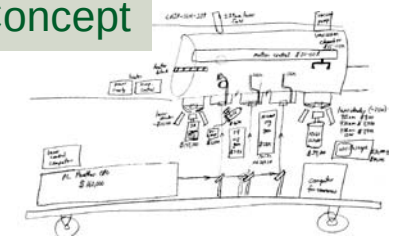
Integration Standards
- Sample size (157 x 157 mm)
- Transfer schema
- Transfer height 1.1 m AFF

Vacuum Inter-Tool Transport
- Controlled ambient between processes or measurement
- Unique at NREL
- At ~6” Unique to all PV

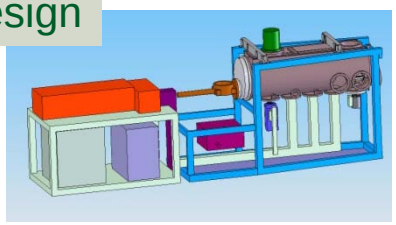
Chambers
- 10” CF, 1.1 m
- Modular
- Expandable

PDIL Group

Concept



Design



Hardware

Automation & Control

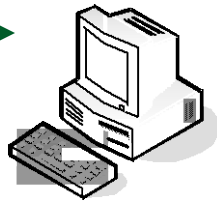
Data Products

Relational Database

File Archive

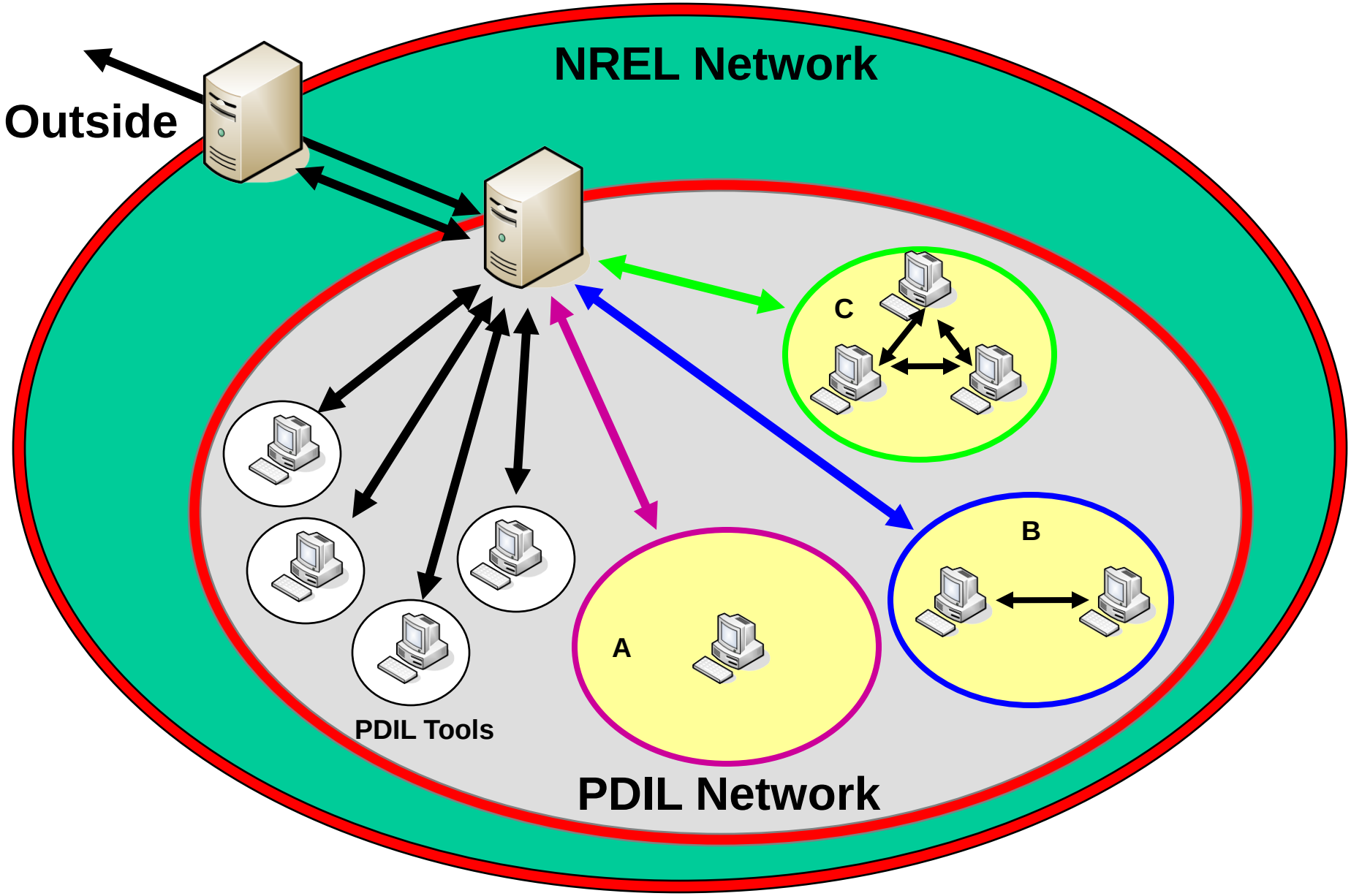
Data Implementation

Investigators

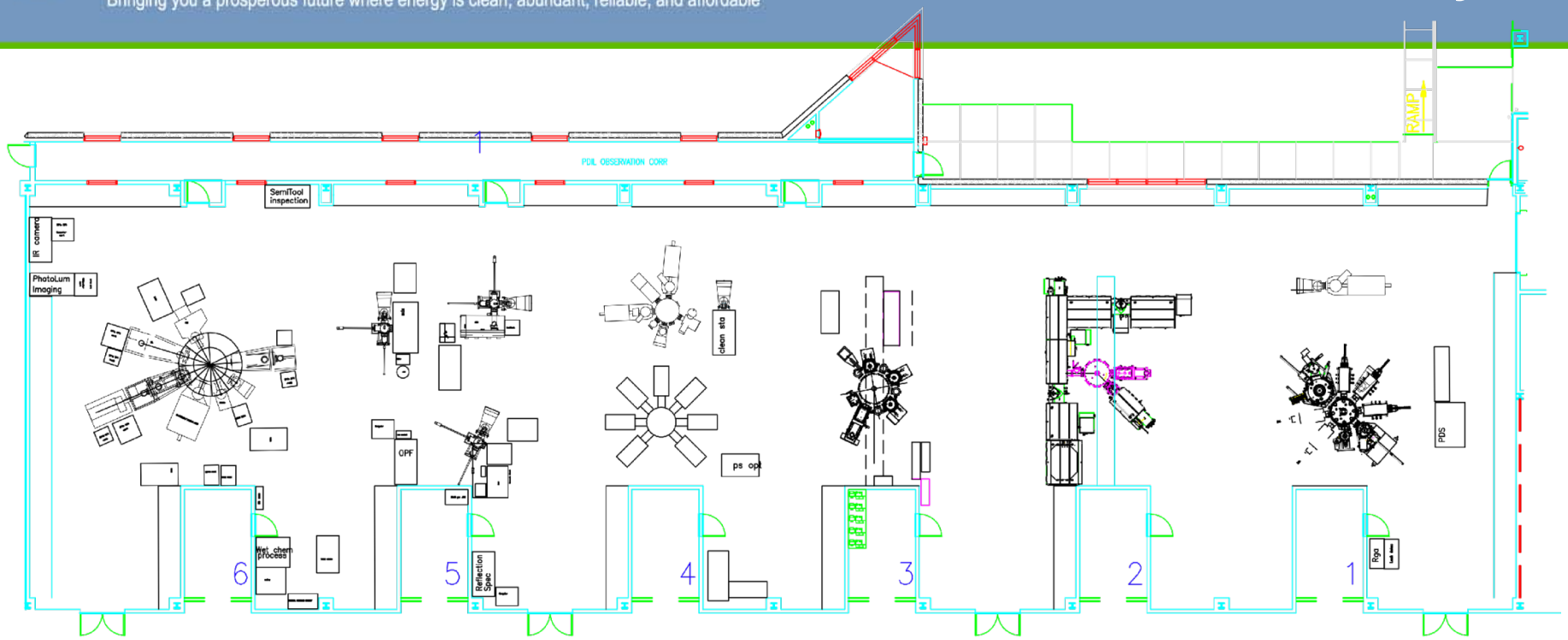


Operators

Data Security - Network

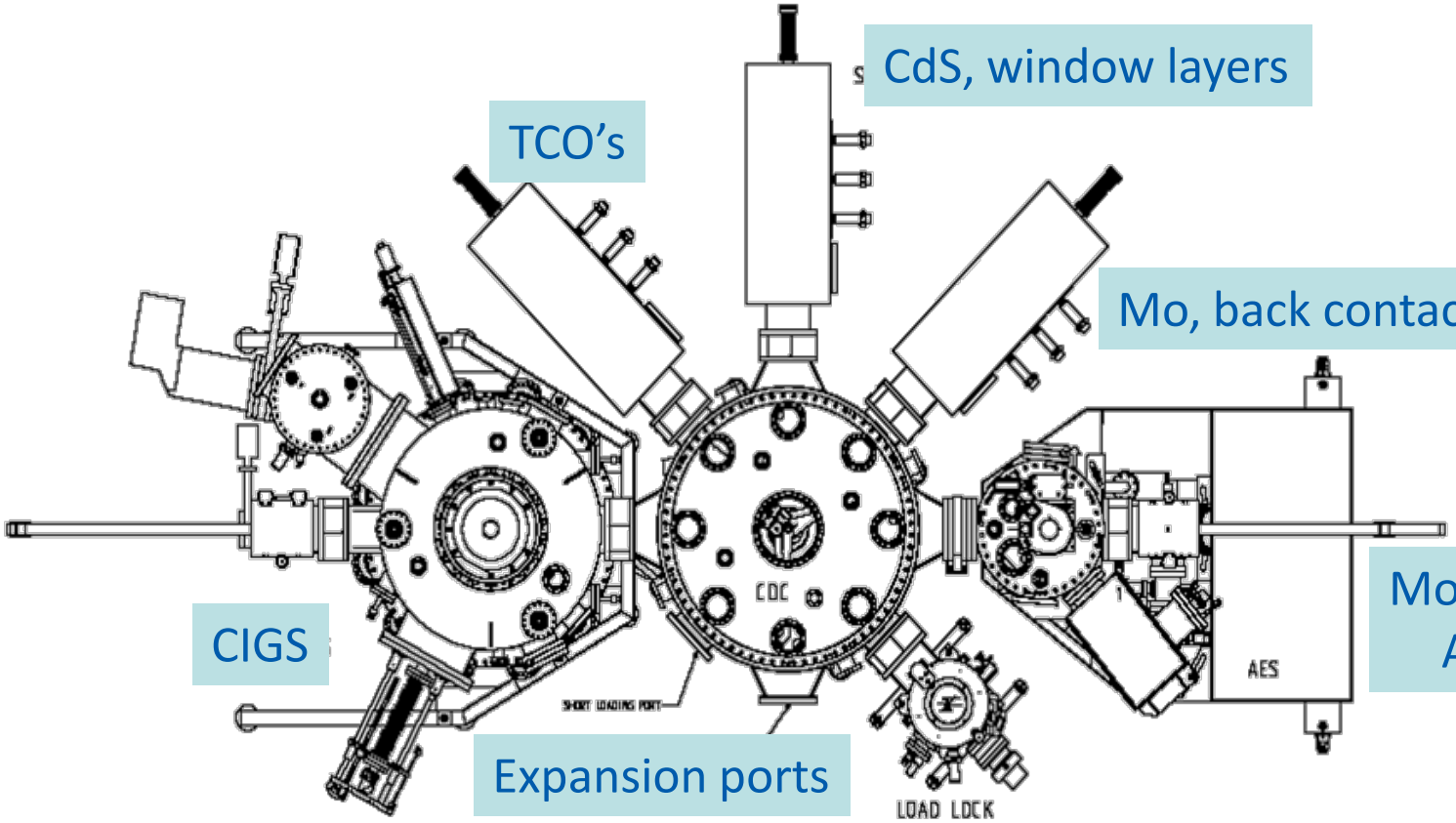


PDIL Layout



1) CIGS
2) Atm. Processing
3) Thin-Film Silicon
4) Si FIlm / CdTe
5) M&C Stand-Alone
6) M&C Integrated

CIGS Cluster Tool

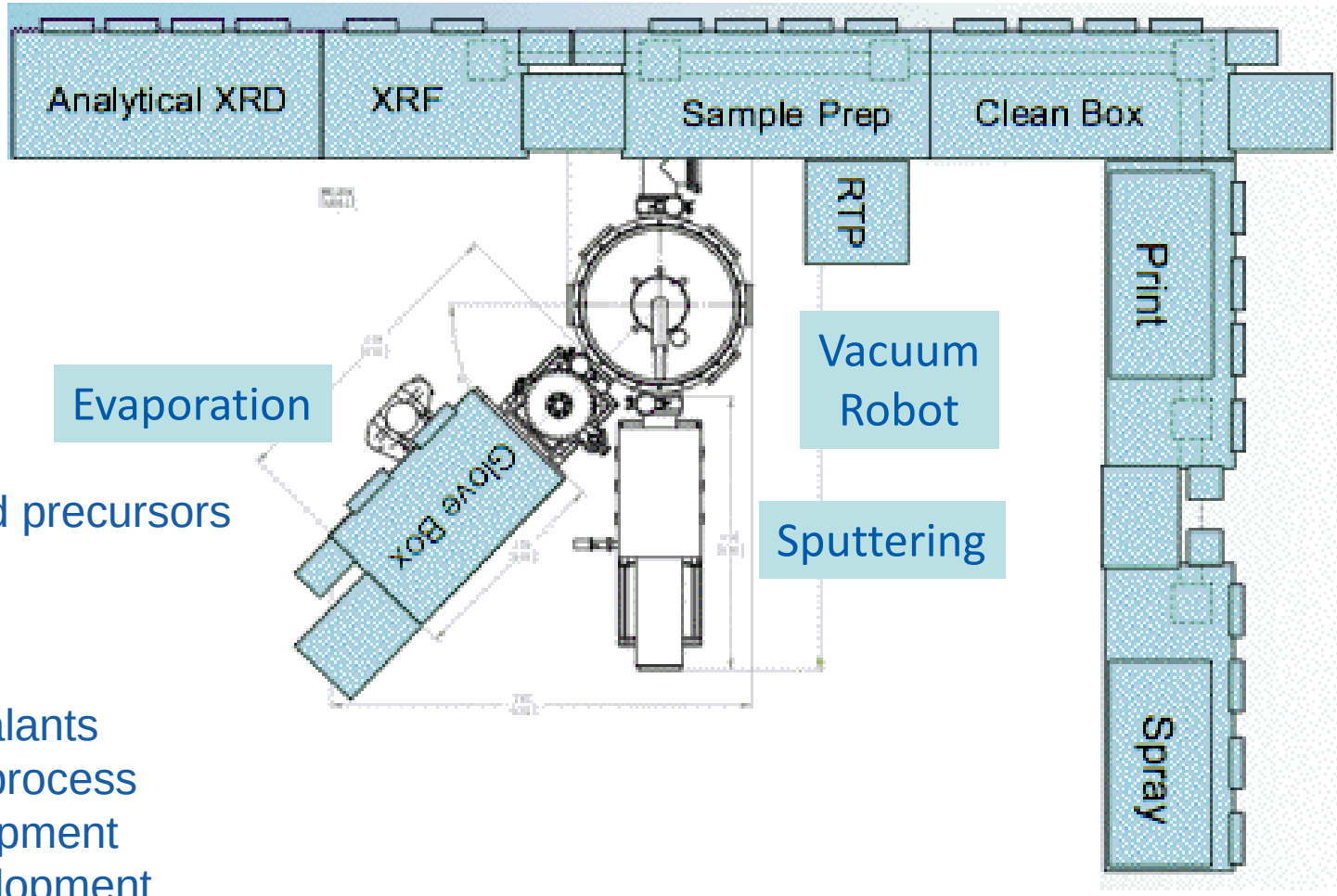


CIGS Projects
- Establish high-quality CIGS
- Critical paths to higher efficiency on large areas

Contact: Miguel Contreras

Atmospheric Processing

A unique platform for the development of new process technology for energy conversion



Application of liquid precursors
- absorber layers
- TCO's
- metal grid lines
- encapsulants/sealants

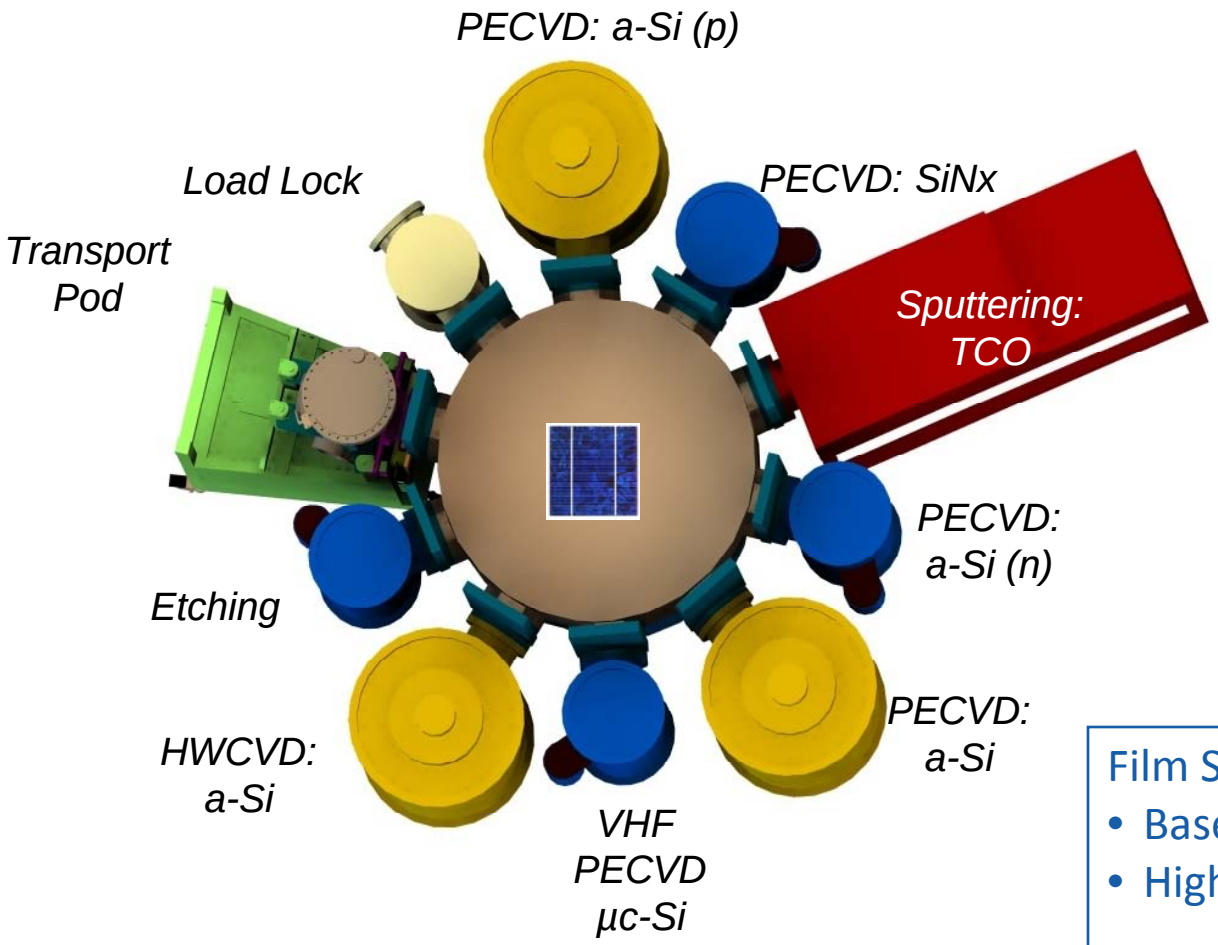
New process and process sequence development

New material development

In-situ diagnostics
- structural characterization
- compositional characterization

Contact: Maikel van Hest

Silicon Cluster Tool

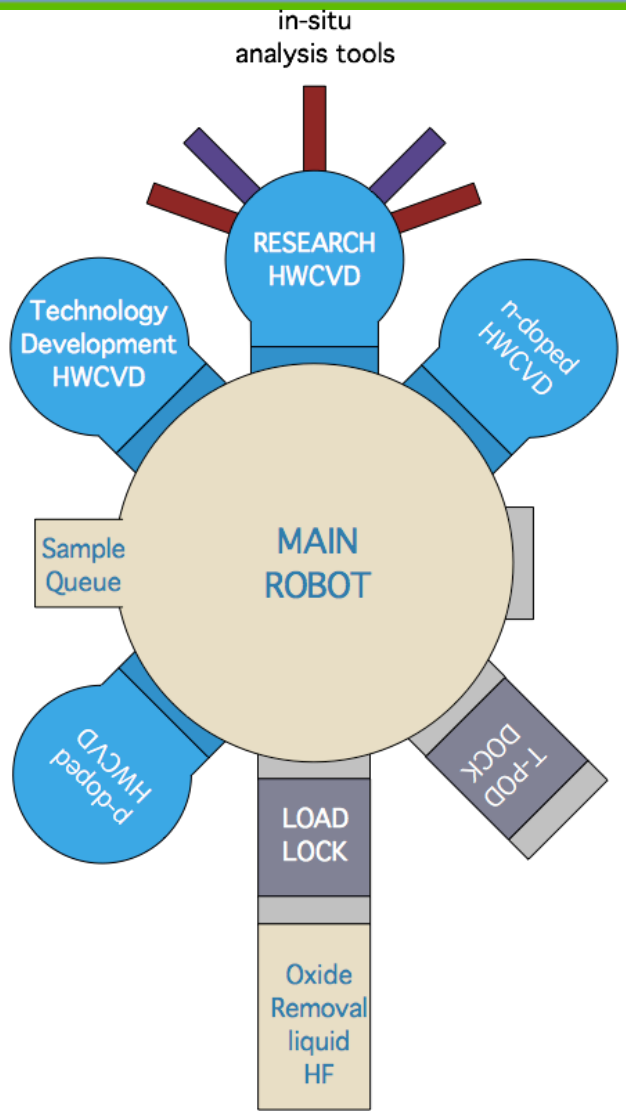


Contact: Qi Wang

Film Si Projects
- Baseline of a-Si films & devices
- High deposition rate nc-Si:H

Wafer Si Projects
- Si heterojunction solar cell
- Passivation of mc-Si

Silicon Wafer Replacement Tool

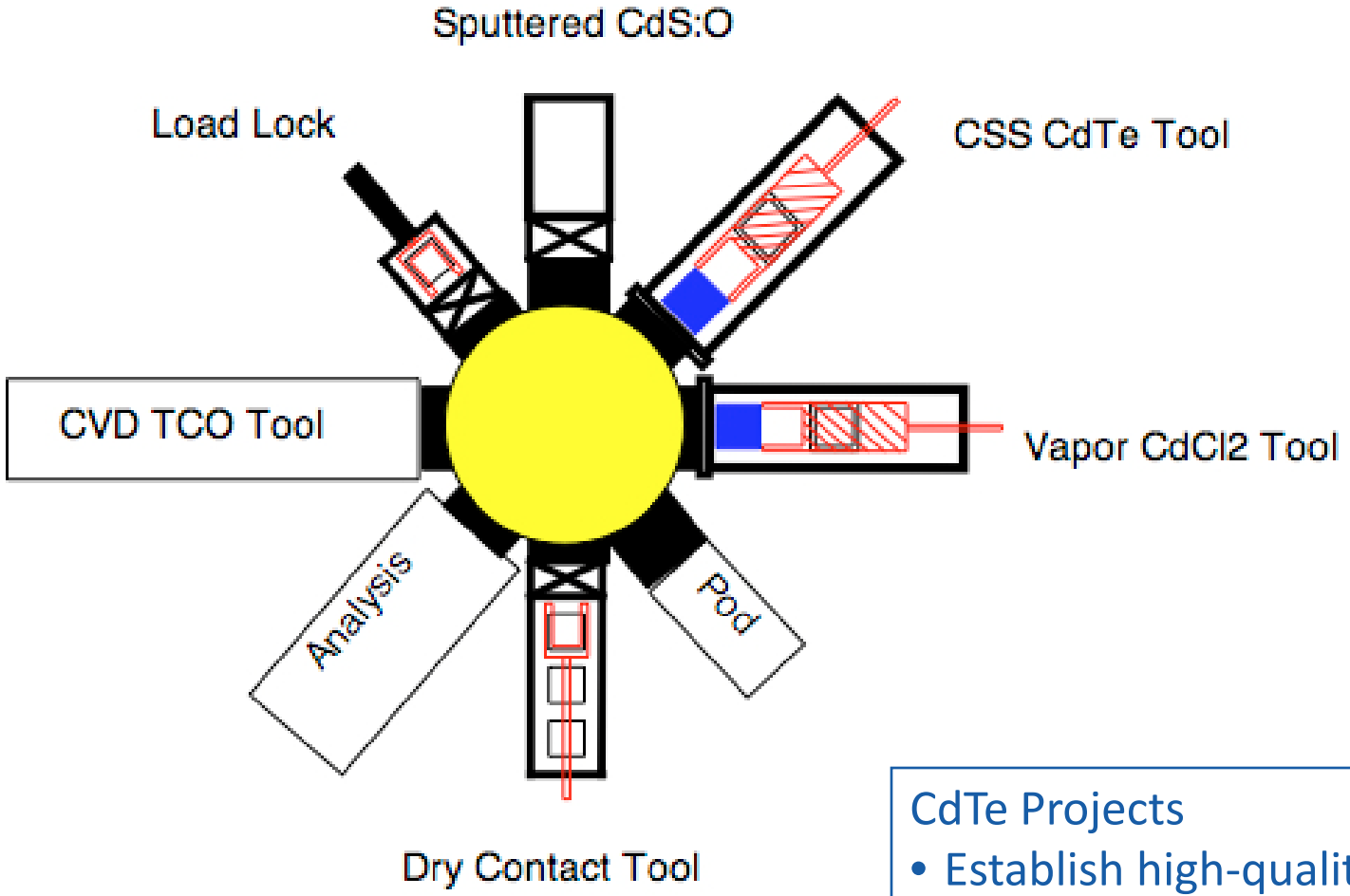


Purpose:

- CVD of thin crystal silicon film (epitaxy)
- Identification of suitable substrates
  - promote c-Si growth
  - low cost
- 156-mm prototyping with industry

Contact: Chaz Teplin

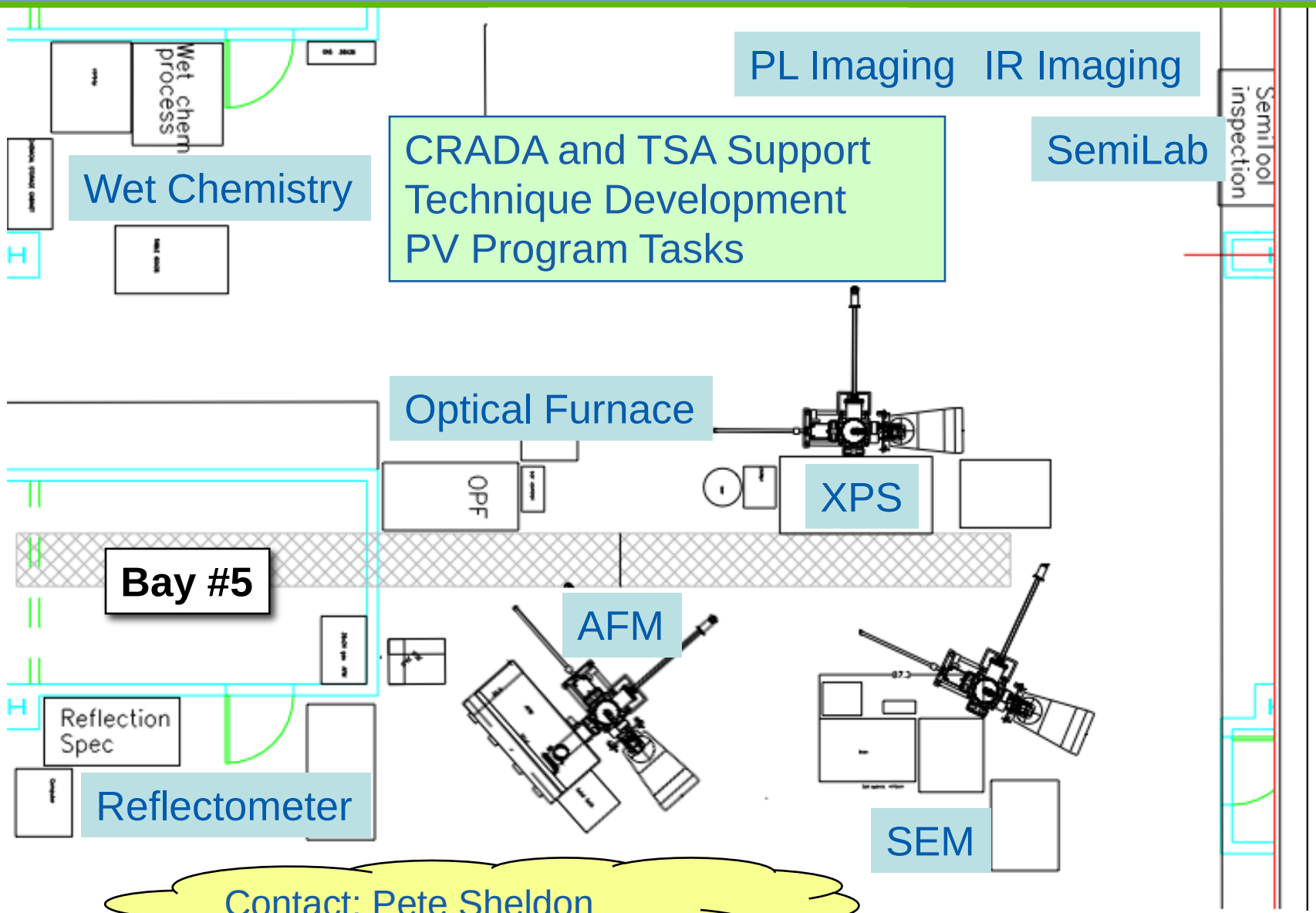
CdTe Cluster Tool



CdTe Projects
- Establish high-quality CdTe
- Replicable research reactors

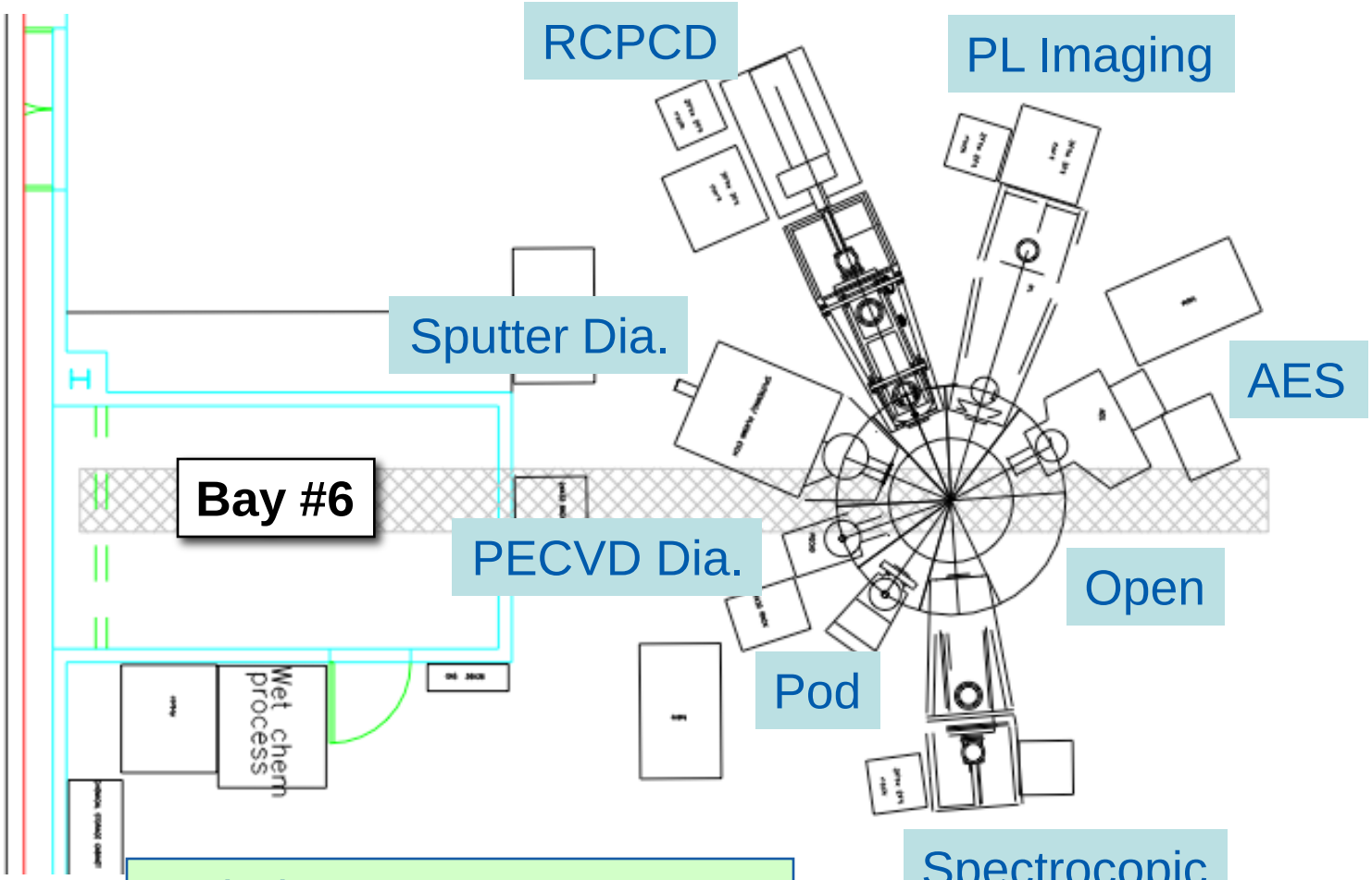
Contact: Tim Gessert

M&C PDIL Bay 5



Contact: Pete Sheldon

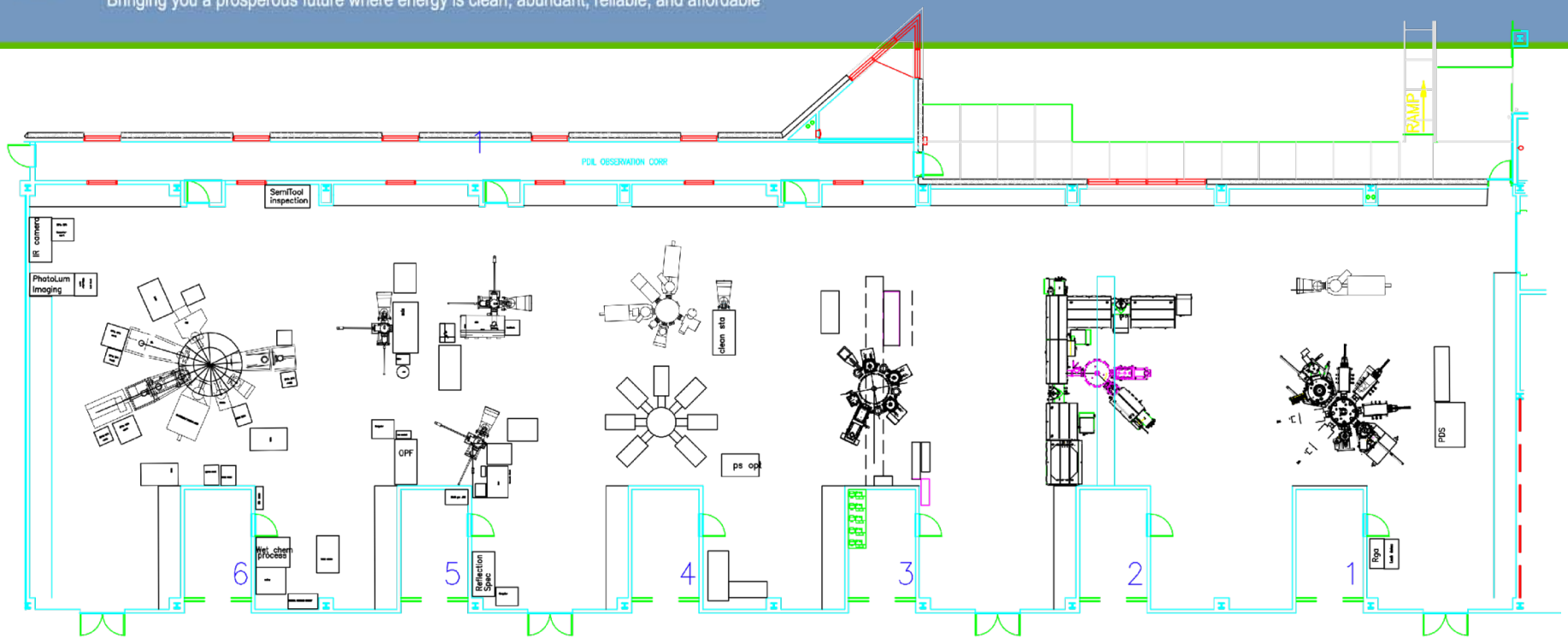
M&C PDIL Bay 6



Technique Development
CRADA and TSA Support
PV Program Tasks

Contact: Pete Sheldon

PDIL Status



6) M&C Integrated

5) M&C Stand-Alone

4) Si FIm / CdTe

3) Thin-Film Silicon

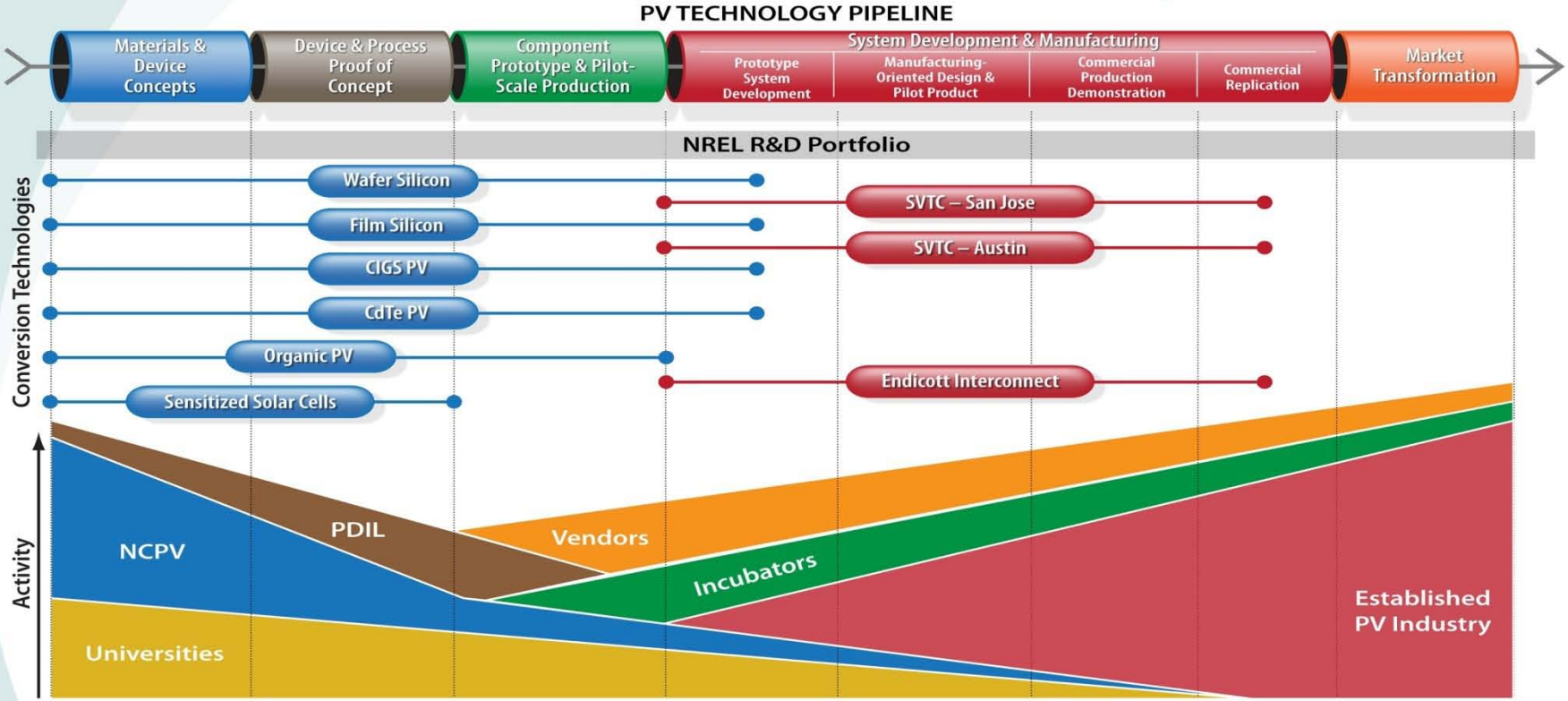
2) Atm. Processing

1) CIGS

Questions

???

The PDIL's Place in the R&D Space



Unique Advantages of the PDIL

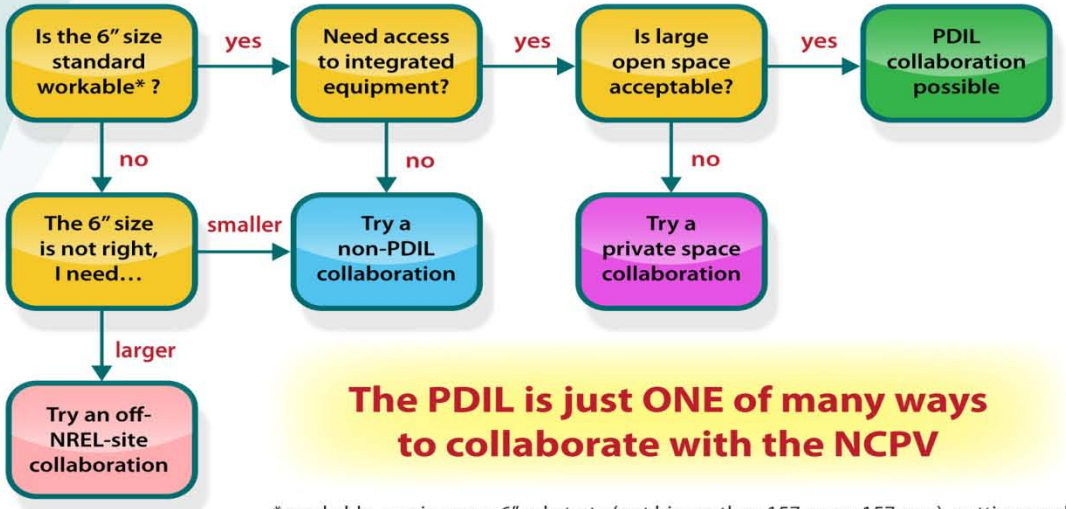
Prior to PDIL
- small area
- high efficiency
- laboratory processes
- independent equipment
- no standards
- exposure of interfaces
- data islands
- low sample throughput
- no module prototyping

PDIL Advantages
- commercially viable area (basic science still possible)
- **bridge the efficiency gap**
- **bridge the cost gap**
- integrated, flexible equipment
- standardized size and transport
- controlled ambient between steps
- automated data systems
- accelerated throughput
- potential **mini-module** processing

Industry
- large area
- lower efficiency
- low-cost processes
- rigid processes
- no standards
- no interface studies

PDIL
Process Development & Integration Laboratory

Is the PDIL Right for YOU?

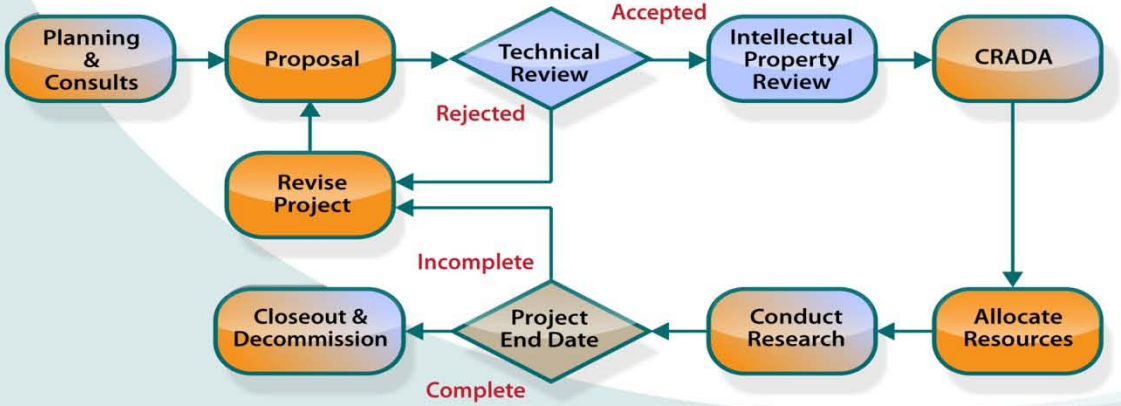


The PDIL is just ONE of many ways to collaborate with the NCPV

* workable = using an ~ 6" substrate (not bigger than 157 mm x 157 mm), putting smaller substrates in a larger platen, or cutting an ~ 6" piece out of a larger substrate

PDIL Proposal Process

All integrated processes require having an NCPV "champion"



NREL Collaboration Methods

Cooperative Research & Development Agreements (CRADAs)

Subcontracted Research (RFPs)

Sponsored Research or Work-for-Others (WFO)

- Interagency Agreement-Government (IAG)
- Funds-In Agreement (FIA)
- Technical Services Agreement (TSA, typically > $25K)
- Analytical Services Agreement (ASA, < $25K)

Foreign National Program

Teacher, Graduate, and Internship Programs

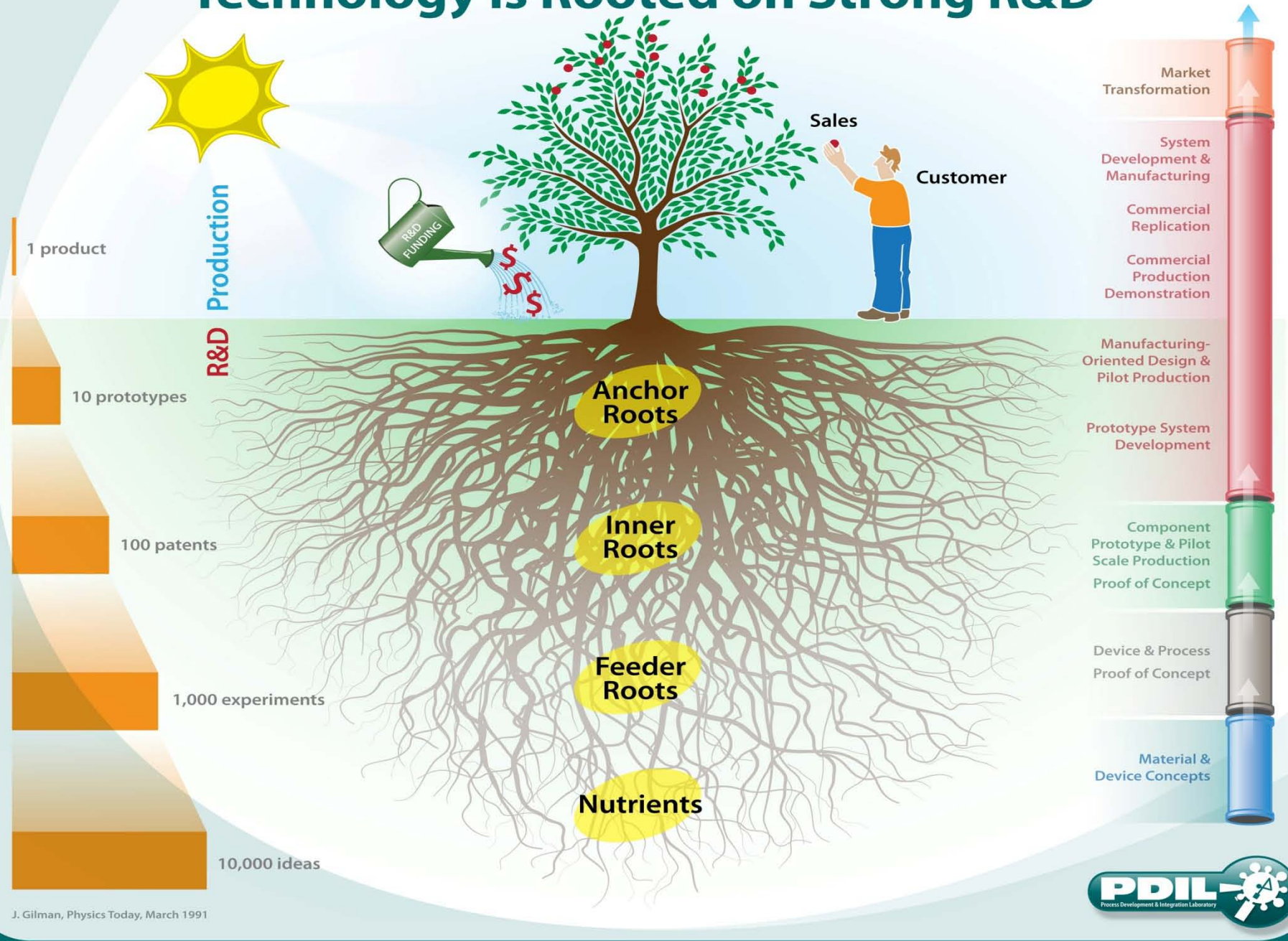
No-funds transfer collaboration on an NCPV project

Sabbaticals (to NREL or by NREL staff externally)

http://www.nrel.gov/technologytransfer/

PDIL
Process Development & Integration Laboratory

Technology is Rooted on Strong R&D



J. Gilman, Physics Today, March 1991

PDIL Process Development & Integration Laboratory