# Arizona State University

# School of Electrical, Computer and Energy Engineering

# EEE 498/591: Manufacturing Science of Solar Cells

# Fall Session 2012 Syllabus

### Course Description

Silicon photovoltaic solar cells have reached the modern age of high-volume manufacturing. Solar cell manufacturing capacity has expanded 100-fold in the past 15 years, and has reached 10+ gigawatts of annual production. Photovoltaics engineers, scientists and managers must have a good working understanding of how solar cells are manufactured, improved and sustained in real solar cell factories, in order to succeed in their fields.

Students enrolled in this class will learn about the manufacture of silicon solar cells, specifically about engineering in the manufacturing environment. The course covers several engineering tools/methods used by engineers to improve solar cell performance and reduce solar cell cost in manufacturing, namely statistical decision making, cost modelling and regression modelling. Students will use these tools in the course’s virtual laboratory – the Virtual Cell Factory – where they will attempt to “save the company” from eminent bankruptcy.

Students who successfully complete this course will have a practical understanding of the manufacturing engineering skills/tools that engineers use to make improvements in cost and performance in a real solar cell factory environment.

### Assumed Knowledge

Students should have a good foundation in basic mathematics, statistics, physics and chemistry.

### Learning Objectives of This Course

Students who successfully complete this course will:

1. Be able to create good quality graphical models that are appropriate for the data being analysed, including scatter plots, bar charts, histograms, distribution histograms, population distribution histograms, variability diagrams, Pareto charts, and more.
2. Have a good understanding of the normal probability distribution and be able (1) plot the normal distribution, (2) integrate the normal probability distribution over a range using Excel, Minitab and/or standard tables, (3) compute Z and T values using Excel, Minitab and or standard tables.
3. Be able to analyse samples of normally distributed populations to extract (1) an estimate of the mean, (2) an estimate of the standard deviation, and (3) confidence intervals on the mean when the standard deviation is either known or estimated.
4. Be able to compute a statistical comparison of means and draw appropriate conclusions for several cases of the Z (standard deviation known) and T (standard deviation unknown), and for one (test of mean) or two samples (difference of means).
5. Have a good understanding of basic product cost accounting methods and be able to construct cost behaviours models, transactions/conversions, T-accounts, COGM/COGS computations, and financial summary statements.
6. Understand basic manufacturing process-cost modelling and be able to construct a process-cost model from basic cost inputs of throughput, yield, materials, labor etc.
7. Understand several important financial metrics that pertain to engineering decision making, including net present value (NVP), return on investment (ROI), levelized cost of electricity (LCOE), and process-cost.
8. Be able to combine 1-7 above in order to make statistical-plus-cost based decisions about engineering improvements and changes.
9. Be able to construct a single-factor, polynomial regression model, including experiment design, regression coefficient determination, testing of the model and use of the model to make decisions about engineering improvements/changes.
10. Be able to construct a multiple-factor, polynomial regression model using the Screening-to-RSM Design of Experiments approach, including experiment design, screening of significant factors/interactions and use the model to optimize a production process.
11. Have a broad understanding and appreciation of basic principles of photovoltaics manufacturing science and engineering and a good foundation for future learning in this area.
12. Gain improved data handling and analysis skills, especially with MS Excel and Minitab.

### Lecture Times and Locations

This course convenes on Tuesday and Thursday from 4:30 to 7:15 pm. The lecture rooms are given below. Each class period comprises either a lecture or a laboratory component, except on occasions where a laboratory or factory tour has been organized.

|  |  |  |  |
| --- | --- | --- | --- |
| **Day of the Week** | **Time** | **Lecture Room** |  |
| Tuesday | 4:30 – 7:15 pm | Tempe PSA 203 | Lecture Series |
| Thursday | 4:30 – 7:15 pm | Tempe PSA 203 | Virtual Laboratory Series |

### Contact Details

Dr. Jeffrey Cotter

Room: TBA

Phone: TBA

Email: jecotter@asu.edu

Course website: ASU blackboard

VMES website (software downloads):

### Textbooks/Resources, Lecture Notes

**1. Texts and Reference Materials.** The two main texts for this course are:

* Introduction to Photovoltaics Manufacturing Science and Technology – Volume 1 Empirical Modelling by Jeffrey Cotter (2012)

**2. Hardware and Software Applications.** The laboratory section of this course uses the following hardware/software:

* Windows PC (laptop suggested) – at least one machine per group of 3-4 students
* “Virtual Manufacturing Execution System” software (free with the above textbooks)
* Microsoft Excel or equivalent
* Minitab – freely available via ASU’s My Apps portal
1. **Additional Reference Material**: In addition, the following reference materials may be helpful:
* **Solar Cell Books**: A pretty good reference for basic photovoltaics is:
	+ Applied Photovoltaicsby[Stuart R Wenham](http://www.amazon.com/s/ref%3Dntt_athr_dp_sr_1/180-2996242-0766205/180-2996242-0766205?_encoding=UTF8&field-author=Stuart%20R%20Wenham&ie=UTF8&search-alias=books&sort=relevancerank), [Martin A Green](http://www.amazon.com/s/ref%3Dntt_athr_dp_sr_2/180-2996242-0766205/180-2996242-0766205?_encoding=UTF8&field-author=Martin%20A%20Green&ie=UTF8&search-alias=books&sort=relevancerank), [Muriel E Watt](http://www.amazon.com/s/ref%3Dntt_athr_dp_sr_3/180-2996242-0766205/180-2996242-0766205?_encoding=UTF8&field-author=Muriel%20E%20Watt&ie=UTF8&search-alias=books&sort=relevancerank) and [Richard Corkish](http://www.amazon.com/s/ref%3Dntt_athr_dp_sr_4/180-2996242-0766205/180-2996242-0766205?_encoding=UTF8&field-author=Richard%20Corkish&ie=UTF8&search-alias=books&sort=relevancerank)
* **Engineering Statistics Books:** There are a number of good engineering statistics books, my favorites are:
	+ Design and Analysis of Experiments by Douglas C Montgomery
	+ Engineering Statistics by Douglas C Montgomery, George C Runger and Norma F Hubele
* **Cost Accounting Books:** Accounting is a wide field, if you’re looking for a book, check for a chapter on Process Costing or Product Costing, in addition to basic info on cost behaviors, T-accounting and financial statements. For example
	+ Cost Accounting by Cecily A Raiborn, Michael R Kinney and Jenic Prather-Kinsey

**4. Lecture Notes.** Lecture notes will be made available on the course blackboard as they are presented in class.

### Assessment

The assessment of the course consists of tutorial assignments three assignments and a final examination paper.

|  |  |
| --- | --- |
| **Assessment** | **Weight** |
| Midterm Test 1 | 20% |
| Tutorials/Homework | 10% |
| Assignments (2 at 15% each) | 30% |
| Final Exam | 40% |
| Total | 100% |

1. All material presented during the session will be examinable unless otherwise noted.

2. The two assignments are due at the beginning of the tutorial class period, as listed on the course schedule. They must be submitted with a completed cover page, to be distributed via the course blackboard.

3. Tutorials are due at the end of the workshop period in which they are assigned.

### Student Responsibilities and Class Policies

**1.** **Late assignments** will be penalized 5% plus 5% per day that the work is late, to a maximum penalty of 50%. Late Assignments will be accepted; however, once the solutions are presented, the maximum penalty will apply.

**2. Tutorials** are due at the end of the class period in which they are presented. Only five of tutorial will be assessed, see the attached Lecture, Lab and Assessment Syllabus, below. They will be accepted up to 1 week late with no penalty.

2. Attendance and Attention. Students are recommended to attend all lectures and labs, to avail themselves of the subject resources (as above), to complete their assignments on time and to the best of their ability, participate in the workshops, and to be fully aware of the course syllabus, including any announcements or changes to that syllabus.

Students are expected to not distract their colleagues during lectures and tutorials.

**3. Plagiarism.** Students are expected to understand the university’s academic honesty and plagiarism policies. Penalties will apply for breaches in these policies.

### Lecture, Lab and Assessment Syllabus

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Week** | **Day** | **Lecture Syllabus\*(Tuesdays)** | **Workshop Syllabus\*(Thursdays)** | **Assessment Syllabus\*** |
| 1 | Tues | No class |  |  |
| Thurs |  | Course Administration and Overview; Teaching and Learning Survey; Introductory Lecture; Solar Cell Fabrication Lecture |  |
| 2 | Tues | 0. Saving Virtual Solar Inc. (An Introduction)1. Graphing and Graphical Models2. Normal Probability Fundamentals |  |  |
| Thurs |  | Tute 1: Introduction to VMES, Excel and Minitab Tute 2: Graphing Data from the Virtual Fab | Tute 2 Worksheet Due at End of Class |
| 3 | Tues | 3. Population Estimations based on Samples4. Statistical Comparison of Means (Z Tests)ASSIGNMENT 1 HANDOUT |  |  |
| Thurs |  | Tute 3: Statistical Process Design for ShuntsTute 4: Choosing a Better Screen Print Paste | Tute 4 Worksheet Due at End of Class |
| 4 | Tues | 5. Statistical Comparison of Means (T Tests)6. Basic Cost Accounting and Cost Modelling |  |  |
| Thurs |  | Tute 5: Choosing a Better Wafer VendorTute 6: Revisiting the TEXTETCH Process Design | Tute 5 Worksheet Due at End of Class |
| 5 | Tues | 7. Introduction to Basic PV Financial Metrics8. Midterm Test (1.25 hour, in class)ASSIGNMENT 2 HANDOUT |  | ASSIGNEMNT 1 DUE |
| Thurs |  | Midterm test reviewTute 7: The Big List of Second Source Opportunities | Tute 7 Worksheet Due at End of Class |
| 6 | Tues | 9. Regression Models10. Design of Experiments I – Screening |  |  |
| Thurs |  | Tute 8: Optimizing ARC Depo TimeTute 9: Designing a Screening DOE for DEPDIFF | Tute 8 Worksheet Due at End of Class |
| 7 | Tues |   |  |  |
|  | Thurs |  |  |  |
| 8 | Tues | 11. Design of Experiments II – Response Surface12. Workshop/Overflow/Assignment Preparation |  |  |
| Thurs |  | ASSIGNEMENT 2 “OPS” PRESENTATIONSExam Review and Preparation | ASSIGNMENT 2 DUE |

\*Subject to change to meet the pace of the class