The following packet gives an overview of the tentative course content and structure for ME 514.

This is my 1st time teaching ME 514 since 2011, and I will be trying some new pedagogical strategies and updating some of the content, especially toward the end of the semester. As we work through the semester I will continuously be evaluating what is and is not working, and trying to change our trajectory accordingly. Therefore everything in this course packet is tentative, and is expected to evolve as the semester progresses.

As broad context, Drs. Okutucu Özyurt, Tari, Yazıcıoğlu, and I are establishing a Concentrating Solar Thermal (CST) laboratory at ODTÜ. The main research thrust for this lab will be Solar Thermal Electricity (STE) technologies, where historically STE was referred to as Concentrating Solar Power (CSP). Details for this lab initiative are given in the attached draft of a conference paper, which is currently under review. Importantly, STE technologies are fundamentally different from solar photovoltaic (PV) technologies, and I am explicitly giving this course to promote STE related research at ODTÜ. Therefore to a large extent non-concentrating thermal technologies, such as flat plate collectors for domestic hot water applications, and PV are outside the scope of this course.

I take a differentiate approach to ME 514 than most if not all other faculty members take to their courses, and it is only by doing something different that I think I can add value to your education. Specifically, I focus on strengthening what I term Core Engineering Skills (CES) related to mathematical modeling of engineering systems, computer programming and debugging of these models, model validation and verification, using the programmed models for parametric, what-if, and simulation studies for research, presentation and interpretation of results, scientific communication, and increasingly innovation. Importantly, these CES are not unique to solar energy, but are important to all areas of engineering, hence the Core Engineering Skills rather than Solar Engineering Skill. While I take this same approach in my 4th year elective classes, at the graduate level I try to approach these CES at a more sophisticated level.

This different approach to my classes also makes the structure of my classes different. Specifically, tentatively I plan to structure ME 514 around the following 4 linked projects:

- **Project 1:** Predict the maximum (extraterrestrial) solar resources on characteristic stationary (non-tracking) surfaces for every hour of one day for any day of the year and any location on earth.
- **Project 2:** Extend Project 1 to predict the actual (terrestrial) solar resources for characteristic STE tracking surfaces for every hour of a typical year (i.e., predict the actual solar resources for all 8760 hours in a year).
- **Project 3:** Extend Project 2 to model the energetic performance of parabolic trough collectors.
- **Project 4:** Extend Project 3 to model a complete STE power plant, simulate the plant’s performance for every hour of a typical year, and explore how this performance changes as key design and operating parameters are changed.

Each project will require extensive computer programming, and scientific communication of your work through written reports and/or oral presentations. Ultimately to do well in the class you will need to develop and perfectly program a fairly complex mathematical model of an STE power plant. Specifically, if within this complex mathematical you accidently program “x*y+273” rather than “x*(y+273)”, all your results are wrong, your discussions are wrong, and you get a low grade even if the error is just a “typo” (I do not give partial credit for programming; a program is either “correct” or “wrong”). Finding these “typo” errors is frustrating and time consuming, and especially in the 2nd half of the semester finding time to debug your program is extremely difficult. However, ODTÜ students are smart, and when I push them hard, they start to develop strategies to debug programs. These debugging skills students develop are extremely
important, and are only developed when students are pushed. If this does not sound fun to you, or at least meaningful or useful, you should not register for this course.

In my 4th year undergraduate elective courses I expect students to program their models using Excel spreadsheets supported by VisualBasic code. In this course I expect students to develop their models in MatLab. Very importantly, my expectation is as a graduate student enrolled in this class, you either know MatLab or you have a sufficiently strong background in another computer programming language that you can teach yourself MatLab. Specifically, although students are expected to spend a significant amount of time using MatLab, I will not spend significant lecture time on MatLab. Therefore knowledge of or the ability to teach yourself MatLab can be considered as an unofficial prerequisite for this class, and I will not dilute the course content to accommodate students who are having trouble finding the time or motivation to complete the MatLab programs.

In general my lectures will be focused on helping you to complete these projects. As such and for example, I will not lecture on 10 different ways to model actual solar resources. Rather I will lecture on 1 representative model for actual solar resources and how to program this model in a sufficiently general manner that it can be used to predict actual solar resources for a surface with any orientation, for any hour of the day, any day of the year, and any location on earth.

As a time-intensive and applied class, I thought the best progression for a typical new MSc student would be to take 3 fundamental classes in the fall, and then take this and one other class in the spring semester. However, due to other course scheduling considerations, I had the choice of either offering this class in the fall, or not offering the course at all. I chose to offer this course in the fall. Therefore if this is your 1st semester in graduate school and you plan on taking 3+ courses, this class is probably only appropriate for you if you see the course content as being really important for you and you have lots of time to spend on the course.

In conclusion, I find if students expect a time consuming course from day one, the students who actually register tend to put in the time to be successful and learn a lot. But if students start the class expecting it to be easy or at least thinking they can pass the course by only working intensively for 1-2 days before an exam, they become shocked at the continuous workload, start to make funny noises (“Hocam, I am working at ASELSAN 60 hours each week, taking 2 other courses, and haven’t slept in 3 days….“), and are not successful.
Syllabus Part 1

ME 514 Advanced Solar Energy Utilization

Fall 2015 (2015-1)

I. Catalog Information

Code: 5690514

METU Credits: 3(3-0)

Prerequisites: Graduate student in ME

ECTS Credit: 5.0


Utilizations of other renewable energy resources; biomass, wind energy, etc.

Learning Objectives and Outcomes: At the end of this course, successful students will have demonstrated the ability to

1. Develop quantitative models for maximum and actual solar resources, solar collector energetic performance, and complete Solar Thermal Electricity (STE) power plants;
2. Program, validate and verify these mathematical models.
3. Use the programmed models for simulation, parametric, and design studies;
4. Post-process data, present in tables and figures, and interpret the significance of these results;
5. Communicate one’s work through formal written reports and oral presentations.

Registration: If you do not attend all classes during add/drops, you may be dropped from the class.

II. Fall 2015 Information

Instructor: Derek Baker (contact information and office hours in Part 2 of Syllabus).

Teaching Assistant: To Be Determined

Meeting Times & Locations: Mon. 8:40-11:30; ME G-103.

Required Texts and Materials: The lectures will be very focused on how to solve projects and will only cover a small number of topics in this book but in great detail. I will post all my class notes online. Having this text is not thought to be necessary to do well in this class.


Grading Distribution:

80% Semester Work (Individual). The following is a tentative break-down of the semester work assuming 4 projects. The number of projects may be increased if simple projects are assigned.

10% Informational presentation.
10% Project 1
15% Project 2
20% Project 3
25% MT
20% Final Project (Group)
The following tables shows an approximate breakdown of the types of skills that will be assessed.

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<thead>
<tr>
<th></th>
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<th>Interpretation &amp; Communication</th>
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<tr>
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<tr>
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**Schedule:**

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<td>Introduction and maximum solar resource modeling</td>
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<tr>
<td>3-5</td>
<td>2</td>
<td>Actual solar resource modeling</td>
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<tr>
<td>6-8</td>
<td>3</td>
<td>Parabolic trough collector modeling</td>
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<td>9-11</td>
<td>Final</td>
<td>Solar Thermal Electricity (STE) power plant modeling.</td>
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<tr>
<td>12-13</td>
<td></td>
<td>Informational Presentations</td>
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<td>14</td>
<td></td>
<td>MT &amp; Wrap-up</td>
</tr>
<tr>
<td>Final</td>
<td></td>
<td>Final project presentations &amp; final project due</td>
</tr>
<tr>
<td>Exam</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Instructor Details, Course Policies, Assessment and Grading:** See Part 2 of the Syllabus.
Syllabus Part 2
ME 514 Advanced Solar Energy Utilization
Fall 2015

1. Instructor: Derek Baker
   Email: dbaker@metu.edu.tr  
   Phone: 210-5217  
   Office: E-105  
   Web: www.metu.edu.tr/~dbaker/
   Office Hours: To be announced after add/drops.

2. Professionalism, Ethics, Late Submissions, and Make-up Exams

   Professionalism and Academic Ethics: You are expected to behave professionally at all times. Any behavior that could result in disciplinary action at a private company is considered unprofessional and can result in a grade reduction or referral to a disciplinary committee regardless of whether a “rule” was actually broken; an example is waiting to inform me of an excused absence from an exam or assignment as detailed below. I have written reports to the Dean about students who have consistently behaved unprofessionally in my classes but may not have broken any rules, as I think these students should not graduate with a degree from METU. The most important policy with respect to professionalism, academic honesty, and absences for this class is to be transparent with the instructor and TA at all times, not unnecessarily increase their teaching load, and avoid any action that gives one student an unfair advantage relative to other students. If the instructor and TA feel that a student is trying to be transparent and professional at all times, they will give this student the benefit of the doubt and will work very hard to help this student be successful. However, if the instructor and TA feel that a student is trying to hide something, they will assume that this student is at a minimum being unprofessional and possibly being dishonest, and in either case can reduce this student’s grade.

   Specific academic honesty policies for each type of assignment will be given to you. These policies will be strictly enforced. Minimum penalties for cheating will be “- maximum grade”; e.g., if the maximum grade for an assignment is 10 and you cheat, you will receive a grade of -10. People who do not do the assignment will receive a 0. All serious ethical violations will be referred to the Disciplinary Committee.

   Medical Conditions: If you have any medical condition (physical or psychological) that may impact your performance in this class, you must inform me immediately. Failure to do so is irresponsible and unprofessional and can result in a grade reduction. See below for more details.

   Due Time: Due Time herein is defined as the start of an exam, class, due time for an assignment or similar.

   Late Submissions: Late submission policies will be given for all assignments. In general, late penalties consist of two parts. The first part is a reduction in your grade for that assignment, which reflects any advantage this extra time gives you and any extra work this creates for me in grading. The second part is a reduction in your final course average (e.g., -1/100 reduction in final course average for each day that your submission is late), which makes it almost impossible to pass the class without completing all assignments in a reasonable amount of time. This second part reflects the need to demonstrate certain Core Engineering Skills to pass this class that can only be demonstrated through these assignments.

   Excused Absence and Make-ups: To receive no penalty for an excused absence, you must both have a medical report and inform me before the Due Time. A 10%/hour unprofessional penalty is assessed for each hour after the Due Time that you wait to inform me. Therefore if you wait 10 hours to inform me of an excused absence, you will have a 100% late penalty and will receive a 0% on that assignment. No make-up exams or assignments will be given to students with a 100% late penalty.

3. Communication, Assessment and Grading

   Website, Class E-mails and ODTUClass: I will be using ODTUClass extensively. You are responsible for all information I send to your METU email account and post to ODTUClass.

   Attendance: Missing any class without an Excused Absence can have an immediate, negative, and irreversible impact on your grade. The general attendance policy for this course can be summarized as follows: “If you miss class without an excused absence and have a problem, it is your problem and not the
instructor’s.” Specifically, you are responsible for all material covered in class starting from the first hour, even if you register late. I will take attendance regularly after add/drops is over. The instructor and TA will do their best to help students with good attendance to resolve any problems. They will not help students with poor attendance. Unexcused absences should not increase the work load of the instructor or the TA, such as by asking them what you missed. You will receive +1 for each class you attend, 0 for each class you miss, -1 for each time you disturb the class by talking, and -1 if you do not attend class and someone else signs for you. Penalties for signing for someone else on the attendance can range from -1 on attendance to referral to your Department’s disciplinary committee.

**Homework, projects, quizzes and similar, and computer usage:** The course will contain a large number of assignments that may be classified as large homeworks, small projects, take-home exams or parts to one large project. These assignments will require mathematical modeling, significant computer programming, post-processing, presentation and interpretation of results, and formal written and oral scientific communication. I do not intend to give any classical (small) homework or written quizzes not related to the projects; if I decide to change this homework or quiz policy I will announce the change at the start of one class, after which time the new policy becomes effective, even if you missed this announcement.

**Group Projects:** The final project will be group. Groups will be assigned based at least in part on students’ performance to date in the class. Specifically, I will try to group strong students with other strong students, and weak students with other weak students. Students who have not demonstrated basic competencies in core mathematical modeling, computer program, scientific communication and professionalism skills as evidenced by low grades may be placed in individual groups both so they can demonstrate these core skills to pass the class and so they do not negatively impact the grades of others.

**Individual Presentations:** Students will make 1-informational presentation to the class and 1-technical presentation of the results from a project to me.

**Midterm (MT):** The course will have one comprehensive written MT toward the end of the semester.

**Final Exam:** As a project based class, this course will have a final project instead of a final exam.

**Not Attended (NA) Grades:** You can be assigned an NA letter grade for behaving unprofessional, failing to demonstrate a minimum level of academic success in all Core Engineering Skills (CES), failing to complete any assignment (project, presentation or MT), or having an attendance of less than 70%. CES are those that cannot be tested on a written exam and include computer programming, using a computer model for simulation and parametric studies, and written and oral scientific communication of ones work.

**Final Course Grades:** Final course letter grades will be assigned based on a curve. Students will be ranked from top to bottom based on final course averages, and natural “gaps” between course averages, attendance, or other metrics will be sought for grade breaks. The curve will not be based on the catalog grading.

**Resit Exam:** As a project based class with no final exam, a resit exam will not be given.
Sample Report Grading Template for Derek Baker 4th year and Graduate Classes

I. ___ / 00 (-20 to 0) Acknowledgments (Ethics): Collaborating with and seeking help from others in this class is a great way to learn and is encouraged as long as you reference this collaboration and help. If you collaborate with someone your models can be similar but should not be identical. Copying, whether by using someone else’s file, electronic copy and pasting, or manually typing in someone’s code or words, is not a good way to way to learn and if you reference the source from which you copied your grade will be reduced because you created less than students who did not copy (a primary goal for a design class is for students to demonstrate that they can create). Not referencing a person from which you copied/borrowed ideas, words, tables, plots, etc. is unethical, unprofessional, and therefore unacceptable, and can result in a grade of -20/10 for this assignment (students who do not turn in the assignment receive a 00/10) and possible referral to the Department’s Disciplinary Committee. For this class, the simple act of looking at a solution from a previous class is defined as copying, even if you did not electronically copy the solution, manually type in their code, repeat their exact words, etc (i.e. in this class looking at a solution from a previous semester is unethical).

___ Collaboration* ___ Help* ___ Copied: ___ Excel Model ___ Tables ___ Figures ___ Words

*No points off if did not copy.

II. ___ / 00 (-10 to 0) Submission

___ Hard copy of report submitted and all files (Word, Excel, etc) uploaded to ODTUClass.

___ Files named as “aaaaf15px_list#_student#” where aaa is the course number, x is the project number. e.g., 476s15px_21-123456.docx/xlsx.”

III. ___/P (e.g., P = 4) Demonstrated Presentation, Formatting and Organization Skills


B. ___ Table: (Appropriate for journal of ___ High Quality; ___ Medium Quality; ___ Low Quality; ___ Major Problems/None)
   ___ Table number and descriptive title at top ___ Headings and Units
   ___ Numbers formatted neatly and consistently (e.g., 3-4 significant digits and/or use of exponential format)
   ___ Horizontal lines: 1 at top, 1 at bottom, and 1 between header and content.
   ___ No vertical lines ___ No background shading ___ Compact but not cluttered.
   ___ All tables introduced by number before the table is presented? ___ Clean presentation/overall organization

C. ___ Plots: (Appropriate for journal of ___ High Quality; ___ Medium Quality; ___ Low Quality; ___ Major Problems/None)
   ___ Figure number and descriptive title at bottom ___ Titles and Units for all axes
   ___ Scales for axes appropriate (minimum and maximum numbers) and placed at left and bottom of graph
   ___ Numbers formatted neatly (e.g., 1-2 significant digits is usually sufficient for a graph)
   ___ No title at top ___ Has inside border ___ No outside border ___ No Shading
   ___ Good use of space: Space dominated by results and not legend, axis numbering, etc., compact but not cluttered,
   ___ All figures introduced by number before the figure is presented?
   ___ Clean presentation/overall organization

D. ___ Length: ___ Did not exceed the page limit? ___ Concise?

IV. ___/M (e.g., M = 4) Demonstrated Modeling and Programming Skills: (___ Perfect; ___ Small problems; ___ Demonstrated some knowledge; ___ = no program). You can only demonstrate these skills if you program the model yourself.

V. ___ /D (e.g., D = 2) Discussion

General Writing: ___ Overall quality of English

Discussion: ___ Discuss most important ideas from figures (and table).
   ___ Discuss underlying theory, particularly for unexpected results.

VI. ___ Late Penalty: Late penalties consist of two parts.

A. Assignment grade penalty. This late penalty relates to whether your late submission causes me extra work by requiring me to grade your submission separate from the other submissions, and whether you gain an unfair advantage by turning in your assignment after I give feedback. Note in some cases I may grade and provide feedback really fast.
   -2.0/10: Submitted late but before I finish grading the assignment.
   -4.0/10: Submitted late and after I finish grading the assignment but before I give any feedback.
   -4.0/10: Submitted late and after I give any feedback but before I finish grading.
   -6.0/10: Submitted late and after I give any feedback (even if I am not finished grading).

B. Course average penalty. Completing all projects and doing so in a timely manner is critical to demonstrating the basic competencies required to pass the class. Therefore a -1/100 penalty is assessed to your final grade for each day that your project is late, which effectively means that you cannot pass the class if you do not submit all projects.
1. Course Information

The Intellectual Property (IP) management policies described herein apply to the course in Table 1. The main actions to manage IP in this course are summarized in Table 2 and most importantly include a Non-Disclosure Agreement (NDA). These IP management policies become effective on the 1st day of class and as per Table 2 remain in effect for 5 years (i.e., the NDA remains in effect after you leave the class). Details for these policies are given in the following sections.

Table 1. Course information.

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<tr>
<th>Name:</th>
<th>Advanced Solar Energy Utilization</th>
</tr>
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<tbody>
<tr>
<td>Code:</td>
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</tr>
<tr>
<td>Semester:</td>
<td>Fall 2015</td>
</tr>
<tr>
<td>Instructor:</td>
<td>Derek Baker</td>
</tr>
<tr>
<td>Department/</td>
<td>Mechanical Engineering</td>
</tr>
<tr>
<td>Program:</td>
<td></td>
</tr>
<tr>
<td>Campus:</td>
<td>Middle East Technical University</td>
</tr>
</tbody>
</table>

Table 2. Actions to manage IP.

| Copyrights:     | All course content is copyrighted, including that developed by students. |
| Plagiarism:     | Plagiarism is defined herein as representing someone else’s ideas or words as your own, is antithetical (directly opposed) to innovation, and is prohibited in this class. |
| Trade Secrets and NDAs: | The solutions to all assignments in this class are our trade secrets. Our NDA prohibits you from sharing our trade secrets with students outside this class, including any student in a future class. |
| Length of NDA:  | 5 years from the 1st day of class. |
| Patents:        | Not used.                          |

2. Motivation

As future METU or METU NCC graduates, society expects you to become leaders in developing and commercializing new technologies to benefit society. As an educator at METU, society expects me to prepare you to fulfill this mission. Within this context, as you move forward with your career you will be expected to respect, develop, manage, and exploit IP.

3. Background

Innovation is currently one of the most important words in technology intensive sectors, and as METU graduates you will be expected to be innovative. For the purposes of this document, innovation can be differentiated from invention as follows:

Invention is the creation of knowledge;

Innovation is the novel application of knowledge to benefit society.

While innovation is typically associated with commercial activities, innovation is also possible in non-commercial sectors such as education and non-profits.

Increasingly universities are being expected to foster innovation by developing human resources trained in innovation and exploiting their research for society’s benefit. This emphasis on research exploitation is in addition to the historical expectation that research universities disseminate their research results through publications. To foster innovation at universities, Technology Parks linked to research universities are being opened throughout the world, with METU’s TechnoPark being one example. These technology parks typically contain a Technology Transfer Office (TTO) whose primary mission is to facilitate the exploitation of the university’s research. Silicon Valley is in essence a large technology park strongly linked to Stanford University, and Silicon Valley and Stanford University are extremely good at collaborating to exploit research results for commercial gain. Much of the economic activity in Silicon Valley is associated with technology based Small and Medium Enterprises (SMEs). SMEs include Start-up companies whose survival is predicated on the commercialization of a new technology, and therefore on innovation. Google is great example of what was once a start-up company based on research from Stanford University that has had a significant impact on society.

The European Union Horizon 2020 (EU H2020) research funding program also reflects an increasing expectation from research funding agencies that the research they support should directly benefit society. In many cases, an EU H2020 proposal must include a section on innovation in which IP management and exploitation plans are presented. EU H2020 budgets on the order of 10 M Euro (30 M TL) are common, and therefore if researchers want the EU to give them 10 M Euro for their research, the researchers must convince the EU that their research will lead to innovations.

4. Copyrights

Printed and electronic documents are two form of IP protected by copyrights. In contrast to patents, which generally must be formally registered to be legally recognized, copyrights do not need to be formally registered to be legally binding. Rather merely being the creator of an original work is sufficient to claim copyright ownership of that work. Applying this principle to our class, all original work created in this class will be treated as being copyrighted. Importantly, the copyright for any work created by students for my classes is co-owned by the students and me (since this work was created under my supervision) and includes all reports, computer code, presentation files, etc. created by students. Equally important, my co-ownership of the copyrights for material created by students in my classes...
applies historically to all the material created by students in my past classes. Copying any copyrighted material is illegal unless explicit permission is given by the owners of the copyrighted material. Applying this principle to this class, copying any work from my previous classes, including that created by students, is illegal without my written consent.

5. Plagiarism
Plagiarism is defined herein as representing someone else’s work or ideas as one’s own, and most importantly for this class includes the work and ideas of current and former students. Plagiarism is always unethical and unprofessional, and is illegal if it infringes on someone else’s Intellectual Property Rights (IPR). To avoid any suspicion of plagiarism in this class, always be transparent when using someone else’s work or ideas through proper referencing and the use of quotes if you are using someone else’s exact words. One of the most dangerous forms of plagiarism for this class is representing the work or ideas of another current or former student in this class as your own, such as by using or building on their computer model or report without acknowledging the source.

6. NDAs
NDAs are common in sectors where protecting trade secrets and other confidential information from competitors is very important. For example, technology based companies often require new employees to sign NDAs that prohibit sharing the company’s trade secrets with others. NDAs are legally binding documents and one can be taken to court for violating an NDA. NDAs that span 5 years in the US and 10 years in Europe are common, and importantly the NDAs remains in effect during this time period even if an employee leaves the company (e.g., to begin working for a competitor).

Technology companies also require NDAs be signed when receiving services from or collaborating with an outside entity. For example, Plataforma Solar de Almería (PSA, www.psa.es) is one of the largest research centers for Concentrating Solar Thermal (CST) technologies in the world and has unique human resources and Research Infrastructure (RI) for developing and testing CST technologies. Commercial companies often contract to have PSA develop or test new CST technologies, and will require PSA to sign an NDA before starting this work. Similarly, NDAs are very common in university research projects funded by a private company, and being told “Due to an NDA we cannot discuss the research we are doing here” is common during visits to university labs.

As detailed in the next section on Trade Secrets, based on past experience I find I can teach most effectively if I classify all solutions created in this class as our trade secrets, and have you sign an NDA that prohibits you from sharing these trade secrets with anyone outside this class, including students taking this class in the future or taking similar classes at other universities.

7. Trade Secrets
Innovative companies survive based on their ability to create new technologies in response to a problem or opportunity, and to protect and exploit these technologies using patents and trade secrets. While patents register a technology in the public sphere, trade secrets by definition are kept out of the public sphere and are typically protected using NDAs. Innovation is based on a delicate balance of competition and collaboration. Competition is the fuel that drives the innovation process forward, while collaboration is the path that leads to truly innovative solutions. Competition occurs not only between companies, but can also be fostered between groups in innovative companies. For example, to arrive at a diverse set of solutions to a problem, a company may ask several teams to independently create solutions to a problem, such as through a design competition. But at the same time, truly transformative innovations tend to be the product of a creative group characterized internally by a highly collaborative and transparent culture.

Based on my past experience, the best way to teach innovation skills is to treat this class as a group charged with finding innovative solutions to problems defined through a series of projects. We will seek to balance competition and collaboration within the class to maximize learning and innovation. The generated solutions become this class’s trade secrets and are protected using an NDA from competitors.

Our trade secrets will be created through the application of Core Engineering Skills (CES), which are essential to the innovation process. In fact, my main objective in this class is to strengthen your innovation skills by strengthening these CES. Significantly, these CES are not unique to the energy area but are general to innovation across all engineering disciplines. CES include the ability to:

1) Develop, program and validate/verify mathematical models;
2) Use these programmed models to run parametric, what-if, and simulation studies;
3) Post-process results to produce meaningful and professional tables and figures;
4) Communicate one’s work through formal written reports and oral presentations with an emphasis on discussing the underlying theory that leads to these results in general and to unexpected results in particular, and what these results mean in terms of design and commercialization opportunities;
5) Respect, manage, and exploit IPR.

Importantly, item 5 means that you are both 1) prohibited from using content developed in previous classes for items 1-4 based on Copyright and Plagiarism policies, and 2) prohibited from sharing content you develop for items 1-4 with students in future classes based on the NDA you sign.
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Start Date: First day of semester
End Date: 5 years after the first day of the semester
Course: Advanced Solar Energy Utilization
Code: ME 514
Semester: Fall 2015
Instructor: Derek Baker
Department/Program: Mechanical Engineering
Campus: Middle East Technical University (ODTÜ)

I have read and understand the document “Intellectual Property (IP) Management Policies to Promote Innovation in Derek Baker’s 4th Year and Graduate Classes.” I understand that the solutions to all assignments I create in this class are considered Trade Secrets, and I am prohibited from sharing these trade secrets with anyone outside this class, including all students taking this class in the future and all students enrolled in similar classes now or in the future. I also understand that unless otherwise prohibited, I am free and encouraged to collaborate on all class projects with other students in the class as long as I clearly acknowledge and describe this collaboration, but all forms of copying and seeking help from people outside this class including former students is prohibited. I understand that this NDA remains in effect after I leave the class until the End Date specified above, and that breaking this NDA even after I leave the class can have negative consequences for me.

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Date: ______________________________________________________

First LAST NAME: ______________________________________________

Student Number: _______________________________________________

Signature: _____________________________________________________
Concentrating Solar Thermal (CST) Activities and GÜNAM CST Laboratory Initiative at Middle East Technical University

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Abstract: In August 2015 the Turkish Ministry of Development awarded a project to METU’s Centre for Solar Energy Research and Applications (GÜNAM) to create a Concentrating Solar Thermal (CST) laboratory to promote Turkish Research, Technology Development and Innovation (RTDI) in Solar Thermal Electricity (STE), also referred to as Concentrating Solar Power (CSP). In this paper the background for and an initial roadmap for the creation and management of the lab are presented. An overview of the main technological areas relevant to CST and the main characteristics differentiating STE and solar photovoltaic (PV) power plants are presented. The reasons STE power plants have the potential to deliver electricity with a higher value than PV power plants through the inclusion of Thermal Energy Storage (TES) and the hybridization with other thermal energy sources is discussed. The CST lab is being developed to leverage several existing national and international networks to increase the lab’s impact. Most importantly, the lab is being structured to contribute to EU-SOLARIS, which is a European distributed Research Infrastructure on CST currently being developed. Investments in research facilities will provide a foundation for Turkish STE RTDI and complement and support EU-SOLARIS. The paper concludes with a draft of the Mission, Goals, and Objectives, and Access Policies for the lab, which reflect the vision for the lab to be open and accessible to outside users both from Turkey and internationally, to be the main center for facilitating, coordinating, and conducting STE research in Turkey, and to be an active and important player in STE RTDI globally.

Keywords: Concentrating Solar Thermal (CST); Concentrating Solar Power (CSP); Solar Thermal Electricity (STE).
1. INTRODUCTION

Currently Turkey has a large and mature solar hot water industry in which flat-plate non-concentrating solar thermal collectors are used to provide hot water to residences. In recent years interest in using solar energy to produce other high-value products has increased, being led by the development and application of non-concentrating solar photovoltaic (PV) technologies to produce electricity. Globally the large scale application of Concentrating Solar Thermal (CST) technologies to produce electricity, termed Solar Thermal Electricity (STE) herein but also often referred to as Concentrating Solar Power (CSP), predates the large-scale market uptake of PV. In California in the 1980s 354 MW of STE capacity were brought online as part of the Solar Energy Generating System (SEGS) power plants. As of 2014 the global capacity for concentrating solar technologies (~ 4 GW) was small relative to PV (~150 GW) [1]. But according to the International Energy Agency’s STE Technology Roadmap 2014 Edition, STE and PV could contribute 11% and 16% of the global electricity supply by 2050, which indicates a large global growth potential for STE [1]. While currently the STE Research, Technology Development and Innovation (RTDI) in Turkey is not as developed as in some other countries such as Spain and the United States, for many reasons detailed in this paper CST technologies have the potential to be an important part of Turkey’s RTDI base and commercial activities in the future. For example, Trieb [2] projected in 2050 STE and PV installed capacities of 21 and 18 GW for Turkey, and annual electricity productions as 130 TWh and 30 TWh, where the high STE capacity factors is due to the inclusion of storage which allows these plants to operate at night. These growth potentials are reflected in the growing interest in CST technologies in Turkey, including in August 2015 the Turkish Ministry of Development announcing funding for the expansion of Middle East Technical University’s (METU) Centre for Solar Energy Research and Applications (GÜNAM) to include a CST laboratory and the organization of this CSP-TR2015 conference.

The objective for this paper is to contribute to forming a national framework to initiate, facilitate and coordinate CST RTDI initiatives in Turkey by summarizing recent activities in CST at METU and a roadmap for the creation and management of a CST laboratory as part of METU GÜNAM. Sections 2 and 3 provide context for these activities and initiatives, with Section 2 presenting a broad overview of CST technology areas along with the areas of primary interest at METU, and Section 3 describing the main groups driving CST activities and initiatives at METU. In Section 4 recent RTDI activities in CST at METU are presented, which lay the foundation for the proposed CST laboratory. Section 5 is a roadmap for the creation and management of the CST laboratory. In Section 6 the main ideas from the paper are summarized, conclusions are drawn, and directions for future work identified.

2. CST TECHNOLOGY OVERVIEW

To provide context and clarity for the rest of the paper in terms of terminology and technologies, in this section the technology naming taxonomy adopted herein is presented, and a representative RTDI Value-Chain for CST technologies is presented and discussed, with a focus on STE technologies.
The naming taxonomy associated with CST technologies has evolved in recent years, with Figure 1(a) and (b) showing two of the most common current naming taxonomies. Importantly, in Figure 1(a) Concentrating Solar Power (CSP) is defined as a thermal technology separate from Concentrating PV (CPV), and CSP is used in place of STE. For clarity, some people (e.g., Goswami in *Principles of Solar Engineering, 3rd Ed.* [3]) explicitly define CSP as Concentrating Solar Thermal Power, with italics added here for emphasis. In contrast, in Figure 1(b) CSP is used as an umbrella term that includes both STE and CPV. Some organizations that historically used the taxonomy in Figure 1(a) are now using that in Figure 1(b). For example, the IEA published the “Concentrating Solar Power Roadmap” in 2010 using the taxonomy in Figure 1(a) and the “Solar Thermal Electricity Roadmap” in 2014 using the taxonomy in Figure 1(b). Herein the naming taxonomy in Figure 1(b) is adopted.

![Diagram](Image)

**Figure 1.** Two common naming taxonomies for concentrating solar technologies. Taxonomy (b) is adopted herein.

As per Figure 1, CST is an umbrella term encompassing all concentrating solar technologies that provide higher temperatures or heat fluxes than non-concentrating solar thermal collectors can practically provide, and solar chemistry technologies. CST technologies include but are not limited to STE, solar chemistry applications including solar fuels and detoxification, solar furnaces, desalination, solar thermal powered heating and cooling applications (HVACR), and material testing. Among CST technologies, STE is generally seen as having the largest market potential. The processes and technologies to convert solar energy into electricity using STE and PV technologies are fundamentally different. STE uses concentrated solar energy to create a high temperature thermal energy source to drive a heat engine, while PV converts solar energy directly into electricity using a semiconductor. These differences in processes and technologies result in STE and PV having different characteristics as summarized in Table 1, with a more detailed discussion below.
Table 1. Main characteristics differentiating STE and PV

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>STE</th>
<th>PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requires large DNI?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Tracking Required?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Size</td>
<td>Large: ~ 10 - 500 MW</td>
<td>All</td>
</tr>
<tr>
<td>Solar response time (Grid Stability)</td>
<td>Slow (Good)</td>
<td>Fast (Bad)</td>
</tr>
<tr>
<td>Energy Storage</td>
<td>Large Scale Thermal Energy Storage</td>
<td>Expensive and Under Development; e.g., Batteries</td>
</tr>
<tr>
<td></td>
<td>Commercially Viable</td>
<td></td>
</tr>
<tr>
<td>Hybridize?</td>
<td>Yes, e.g., geothermal, biomass</td>
<td>No</td>
</tr>
<tr>
<td>Dispatchable &amp; Flexible?</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Water Consumption</td>
<td>Significant if a wet cooling tower is used.</td>
<td>Very small.</td>
</tr>
</tbody>
</table>

A representative CST RTDI value chain is presented in Figure 2. Non-concentrating solar technologies and CPV are also included for context and are denoted using rounded-rectangular and oval shapes. Technologies relevant to CST are denoted using rectangles, with those specific to STE shaded yellow. Each rectangle represents a CST RTDI need based on EU-Horizon 2020 calls or similar. Although not shown explicitly, a need for RTDI at the system level also exists for the synergistic integration of these different technologies. A detailed treatment of STE RTDI needs is presented in the STE Strategic Research Agenda 2020-2050 published by the European Solar Thermal Electricity Association (ESTELA) in 2012 [4].

Referring back to Table 1, DNI refers to Direct Normal Irradiance/Insolation. Direct, but not diffuse solar resources, can be concentrated, and therefore STE power plants only use direct resources. Locations with large DNI resources are very sunny, and therefore STE tends to only be commercially viable in very sunny locations, such as the Middle East and Northern Africa (MENA) and Mediterranean regions. In contrast, PV uses total (direct + diffuse) solar resources and PV is used throughout most of the world. Spatial and temporal variations in DNI resources are much larger than those for total solar resources, and therefore accurate solar assessment is more challenging and important for STE than PV. Active tracking is required to concentrate DNI onto a receiver. As shown in Figure 3, the geometric characteristics of the concentrator and receiver are used to classify STE power plants into one of four categories: 1) Parabolic Dish (PD); 2) Central Receiver (CR); 3) Parabolic Trough (PT); and 4) Linear Fresnel (LF). PD and CR use point receivers while PT and LF use linear receivers. Point receivers require concentrators with 2-axis (2A) tracking. In theory linear CST receivers can use both 2A and 1-axis (1A) tracking, but in practice linear receivers typically use 1A tracking receivers due to cost and the large collector aspect ratios (collector length to width) typical for linear receivers. For each receiver, PD and PT technologies have a single rigid concentrator with a constant aperture area, while CR and LF have multiple
Figure 2. Representative RTDI Value-Chain for CST. Rectangles indicate technologies for CST, with shaded rectangles indicating technologies specifically for STE. Rounded-rectangles and ovals indicate non-CST technologies and are included for context.

Independently tracking concentrators (heliostats for CR and facets for LF) with an effective aperture area that varies throughout the day. The concentrators for PD and PT are always symmetric about a line (PD) or plane (PT) passing through the sun and receiver. In contrast and except for possibly certain times of the year (e.g., solar noon on the equinox), the concentrators for CR and LF are not symmetric about a line (PD) or plane (PT) passing through the sun and receiver. Based strictly on optical considerations, receiver temperatures tend to increase as one moves to the left and up in Figure 3. Consistent with the Carnot Efficiency, higher receiver temperatures tend to translate into higher heat engine efficiencies, and higher overall system (solar to electricity) efficiencies. However, in reality receiver temperatures are often limited by Heat Transfer Fluid (HTF) rather than optical limitations, and in this case for example the use of LF can enable the use of HTFs with higher temperature limitations than say PT. A general trend in STE RTDI is toward higher receiver temperatures, for example by moving from PT to CR or by using HTFs with higher temperature limitations.
In strong contrast to the very modular nature of PV, STE benefits strongly from economies of scale. A general trend in commercial STE systems is toward systems with larger capacities, but there is also research into developing smaller STE systems for distributed generation.

Historically STE and PV power plants and wind energy systems have tended to operate as uncontrolled power generation sources with the goal of maximizing electricity generation. However, the increasing penetration of uncontrolled electricity production from solar and wind sources into the grid is making it more difficult to match supply and demand at the grid level and maintain grid stability. Electricity produced by power plants that can deployed to match supply and demand and maintain grid stability (termed dispatchable and flexible power plants) has more value than electricity produced by power plants with uncontrollable output. Currently one of the main drivers for STE RTDI is its larger potential to be a dispatchable and flexible source of electricity than PV or wind, and therefore produce electricity with a higher value than PV or wind. STE systems tend to have large thermal masses that reduce short-term fluctuations in output due to short-term fluctuations in solar resources relative to PV systems, which helps to maintain grid stability. The hybridization of STE power plants with other thermal energy sources such as biomass, geothermal, and fossil fuels can lead to greater dispatchability, including the ability to generate electricity at any time of the year and operate as a baseload plant. Dispatchability can also be increased through energy storage. Relative to technologies to store electricity, the Thermal Energy Storage (TES) technologies used for STE power plants are more commercially mature and is included in many TES power plants, allowing these power plants to produce electricity late into the summer evening when demand and prices for electricity are high and solar resources are low to non-existent. Flexible power plants can quickly and efficiently vary their output in response to variations in supply and demand. Flexible power plants operating out-of-phase with PV and wind energy systems can increase grid stability and enable greater penetration of PV and wind energy systems into the grid. Therefore when operated as a flexible power plant, STE power plants complement rather than compete against PV and wind technologies. Many of the design strategies to increase the flexibility of STE power plants also apply to other thermal power plants (e.g., coal), and therefore the development of flexible thermal power plants is an RTDI area that cuts across and has applications in many power generation areas.
Consistent with trends in Carnot efficiency and assuming a Rankine cycle, the power block’s efficiency tends to increase not only with increases in receiver temperature but also with decreases in condensing temperature. Both wet and dry cooling towers are used in STE power plants to cool the condenser. While wet cooling towers result in lower condensing temperatures and therefore higher efficiencies (especially in low-humidity locations typical for STE power plants), the evaporative cooling process also consumes liquid water. Turbine inlet temperatures tend to be lower for STE power plants than for combustion power plants, and therefore STE power plants tend to have lower power block (thermal) efficiencies than combustion power plants, and consequently larger waste heat production per unit power output. This large waste heat production results in large water consumption per unit electricity when wet cooling towers are used, which is particularly problematic for STE power plants since water resources tend to be limited in areas most appropriate for STE power plants (e.g., deserts). Moving to dry cooling towers eliminates most of the water consumption but also causes lower thermal efficiencies due to higher condenser temperatures. Therefore a current STE RTDI need is for cooling towers with high thermal performance and low water consumption.

3. CONTEXT FOR ACTIVITIES AND INITIATIVES

In this section the main networks forming the foundations for and influencing the CST activities at METU are described, with these activities being described in Section 4. These networks in particular provide important context for understanding the CST lab initiative presented in Section 5.

At the university level, METU has identified energy as one of its main research thrusts. Currently METU is home to the largest research centers in Turkey on solar energy (GÜNAM, described below) and wind energy (RÜZGEM/METUWIND). Therefore the CST lab initiative aligns with METU’s research thrusts.

3.1. GÜNAM

GÜNAM is METU’s Centre for Solar Energy Research and Applications and is directed by Turan. GÜNAM currently includes more than 20 METU faculty members from many different departments working across a diverse range of solar energy areas. Most GÜNAM faculty members are working on PV technologies, GÜNAM has sophisticated research facilities to support PV RTDI, and GÜNAM is participating in the Joint Programme on PV as part of the European Energy Research Alliance (EERA). The success of GÜNAM in PV RTDI, the potentially large STE market in Turkey, and the strategic location of Turkey as a gateway to the rapidly emerging STE markets in the MENA and Eastern Mediterranean regions led to GÜNAM being invited to participate in the EU-SOLARIS project on CST described below.
3.2. SEG

The Sustainable Energy Group (SEG) is an informal research group created within METU’s Department of Mechanical Engineering (ME) in the Spring of 2015. The group currently has 10 faculty members working across a wide range of sustainable thermal energy conversion technologies and on sustainable energy systems. The four faculty ME members leading the CST lab initiative are all part of SEG, and these faculty members see significant opportunity for synergistic collaboration on STE with other SEG members due to the cross-cutting nature of many of the STE RTDI needs.

3.3. EU-SOLARIS

Turan, Baker and Okutucu Özyurt are participating in the EU-SOLARIS project (www.eusolaris.eu) via GÜNAM. EU-SOLARIS is a project co-funded by the 7th Framework Programme of the European Union to create a large distributed Research Infrastructure (RI) for CST technologies of European character and global reach, and is included in the 2010 European Strategy Forum on Research Infrastructures (ESFRI) Roadmap. Importantly, EU-SOLARIS is a project to coordinate usage of existing and investments in new CST RI at the European level, which in turn will be used to foster, contribute and promote RTDI in STE. EU-SOLARIS consists of 13 scientific partners from 9 different countries (Cyprus, Greece, France, Germany, Israel, Italy, Portugal, Spain, and Turkey), one Ministry partner from Spain, and one EU Industry Association partner, which are presented in Figure 4. The project is currently in its preparatory phase in which the legal, managerial, and financial frameworks to constitute and manage EU-SOLARIS are being created. GÜNAM’s participation in this project has been important for developing a network with the leading researchers and research institutions in STE in Europe, and understanding the current state-of-the-art and RTDI needs.

3.4. ICHMT

The International Centre for Heat and Mass Transfer (ICHMT) is an international, non-governmental, non-profit professional organization, its secretariat is located in ME at METU, and its Secretary General Faruk Arınc is a SEG member. ICHMT’s objective is to promote and foster international cooperation in the science of heat and mass transfer and its applications. Most STE technologies are grounded in heat transfer, and in many cases in mass transfer also, and ICHMT integrates the METU ME Department into a global network of leading researchers in these areas.
3.5. Turkish CST Industry

As described below, one of the main objectives for the CST laboratory is to strengthen Turkish companies working in STE and make them competitive at the global level. Two leading Turkish STE companies are Greenway CSP (www.greenwaycsp.com) and Hittite Solar (www.hittitesolarenergy.com). Greenway CSP has completed and is testing a 5 MWth CR system in Mersin, Turkey. The plant is significant in that it uses Direct Steam Generation (DSG) in the tower to produce steam at 550 °C, which is significantly higher than the 400 °C receiver temperature typically for commercial PT power plants, and is developed based on Turkish rather than imported technologies. Hittite Solar also uses DSG technology but in this case in a novel PT collector design and has also developed a TES technology for use with DSG. Hittite Solar has tested and demonstrated its technologies at the Solar Technology Acceleration Center (SolarTAC) outside of Denver, Colorado, in the US.

4. RECENT CST RESEARCH ACTIVITIES

The CST lab initiative will leverage recent CST research activities at METU and more fundamental research in ME at METU in the areas of thermal sciences and micro- and nano-technologies, especially those related to heat transfer fluids, surface coatings, and materials for and design of TES systems. For brevity, the research initiatives related to CST specifically are summarized below, while those related to more fundamental research led by Okutucu Özyurt and Yazıcıoğlu are not. The CST related research is broadly classified into 6 categories: 1) Modeling and simulations of STE power plants; 2) Solar-geothermal hybrid electric power plants; 3) Micro-STE using an Organic
Rankine Cycle (ORC); 4) Energy storage; 5) Solid particle receivers; and 6) Thermal powered cooling cycles.

4.1. Modeling and Simulations of STE Power Plants

Much of the recent CST research activities at METU have been in the area of modeling and simulating the performance of STE systems. More general modeling and simulation activities executed in collaboration with Baker are described in this section, while activities for more specific lines of research are described in the relevant sections below. Usta (MSc, 2010) developed a model of the 6th SEGS unit (SEGS VI) in TRNSYS, validated the model using published results, and simulated the performance of this system in Antalya, Turkey [5][6]. Can Uçkun (MSc, 2013) developed a mathematical model for DSG in PT collectors, integrated this model into a larger TRNSYS model of the entire power plant, and ran several simulation and parametric studies [7]. Yılmazoğlu of Gazi University collaborated with Baker to extend his PhD research supervised by Durmaz to investigate the energetic and economic potential to repower the Soma-A thermal power plant using CST [8]. Sadati and Qureshi [9] and Ali, Zuberi, Tariq, and Mohiuddin [10], all from the METU Northern Cyprus Campus (METU NCC), collaborated with Baker to investigate the potential to integrate STE with other renewable energy generating technologies to supply electricity to the Multan province and city of Karachi, respectively, in Pakistan. METU MSc students Bilyaz, Singh, and Karshenass extended the SEGS VI modeling work by Usta [5][6] by running simulations for Larnaca and Güzelyurt on the island of Cyprus, and comparing the predicted performance of the system to that for Antalya, Turkey, and Kramer Junction, California, where SEGS VI is located [11].

4.2. Solar-Geothermal Hybrid Electric Power Plants

Solar-Geothermal Hybrid Electric Power Plants (SGHEPP) have several potential strengths including providing baseload/dispatchable power from clean energy sources, and relative to stand-alone Geothermal Electric Power Plants (GEPPs) better management of geothermal resources and greater power output in the summer. The synergistic thermal integration of CST and geothermal into a hybrid power plant also faces several challenges. MSc student Özalevli directed a TÜBİTAK TEYDEP project (Grant 7120763) in collaboration with BSc student Sömek and industrial partner BM Holding to develop, install and test a pilot SGHEPP at BM Holding’s Gümüşköy GEPP in Aydın, Turkey, with Baker serving as a consultant [12] [13]. To support this project, Baker received an EU-SFERA grant (Grant 228296) which allowed Baker, Özalevli, and Sömek to visit the Centro de Investigaciones Energéticas Medioambientales y Tecnológicas-Plataforma Solar de Almería (CIEMAT-PSA) in Spain and gain knowledge on installing and testing PT collectors. Currently the PhD student Bonyadi is collaborating with Pulyaev of STEAG Energy Services GmbH and Baker to develop a model for a novel SGHEPP with what is expected to have significantly superior energetic performance relative to the existing systems.
4.3. Micro-STE using an Organic Rankine Cycle (ORC)

A company received a grant to design, install and test a CST driven tri-generation system to provide electricity, cooling, and heating at METU NCC, with METU NCC providing infrastructure support such as land, foundation, and a building. The system used micro-PT collectors coupled to an ORC. The receiver temperature of ~ 100 °C was much lower than that for large scale commercial systems (~400 °C) and the system was designed to produce ~ 10 kW_e. For several reasons the project was not successful and funding was terminated before the system was fully constructed. Although the system was never operational, the facility has provided a rich framework for theoretical studies. Pehlivantürk and Özkan collaborated with Baker to model the system and explore the possibilities of repowering the ORC with evacuated tube collectors [14]. Uzgören of METU NCC guided several METU NCC MSc on theoretical studies related to this system, with Bamgbopa (2012) modeling the ORC [15] [16] [17], Timur (2013) modeling the performance of wet and dry cooling towers [18] [19], Hasany developing and applying models at the system level (2013) [20], and Yousefzadeh (2015) developing a novel control strategy for the system [21].

4.4. Energy Storage

In research directly related to energy storage for CST, Tufan Akba (MSc, 2014) collaborated with Yazıcıoğlu and Baker to develop a model for a 2-tank molten salt TES, coupled this model with a PT model in TRNSYS, and ran several simulation and parametric studies assuming different thermal demand profiles [22]. In more cross-cutting energy storage research, Taştankaya (MSc 2014) and Kaya (MSc 2015) collaborated with Tari and Baker to develop models for TES for Advanced Adiabatic Compressed Air Energy Storage (AA-CAES) systems, with Taştankaya focusing on sensible TES [23] and Kaya expanding this work to include latent TES [24].

4.5. Solid Particle Receivers

Solid particle receivers are used in CR systems where the traditional working fluid in the receiver is replaced by fluidized solid particles that serve as both the absorption and storage medium. Once heated, a fluid is passed over these particles and the hot fluid is used to drive a heat engine. Bilyaz (MSc 2015) is collaborating with Tari to develop a model of a novel solid particle receiver [25][26].

4.6. Thermal Powered Cooling Cycles

Thermal powered cooling cycles can be used for sensible and latent cooling in HVACR systems, with CST being just one of many possible sources for the thermal energy to drive the system. The research at METU on these cycles has focused on the underlying processes to convert heat into cooling rather than the source of the heat to drive the cycle. This research includes adsorption, absorption, and desiccant systems. The work on the adsorption systems is the most extensive and is led by Yamali, Kaftanoğlu, and Baker. Demirocak (MSc, 2008) performed a thermodynamic and
economic analysis of a solar powered adsorption cooling system [27]. Taylan (MSc, 2010) performed theoretical studies on the performance of solar powered adsorption cooling systems including the impact of several cycle enhancements and modified bed designs [28][29]. Solmuş (PhD, 2011) performed experimental and numerical studies on the heat and mass transfer inside the adsorbent bed [30] [31] [32] [33] [34]. Ahmet Çağlar (PhD, 2012) performed numerical and experimental studies on a thermal-wave adsorbent bed [35] [36]. Bonyadi (MSc, 2014) performed theoretical and experimental studies on using advanced porous materials in adsorption beds [37].

In addition to this work on adsorption systems, Karshenass (MSc 2014) collaborated with Yamalı and Baker to develop a model for desiccant dehumidification and applied this model to an application on a Mediterranean island [38] [39]. Özkan (MSc 2015) collaborated with Yazıcıoğlu and Baker to design and model a novel rectifier using a ceramic hollow fiber membrane contactor for a miniaturized absorption cooling device [40].

5. CST LABORATORY INITIATIVE

In August 2015 GÜNAM was awarded an expansion project from the Turkish Ministry of Development (www.mod.gov.tr) that includes establishing a CST lab focused on STE RTDI. The co-authors of the present paper are in the early stages of developing a roadmap to establish and manage this CST lab, and a draft of this road map is presented in this section covering the Mission, Goal, and Objectives (MGOs) of the lab, envisioned research facilities and access policies.

5.1. Mission, Goals and Objectives

Mission: For GÜNAM to be recognized nationally and internationally as a center of excellence in STE by being the main center for performing, facilitating, and coordinating STE RTDI and human resource development (HRD) at the national level, and to be an active and important contributor to STE RTDI at the international level.

Goal: To expand GÜNAM’s research facilities to include a CST lab that is visible, open and accessible to outside users, and impactful at the national and international levels in STE.

Objectives: Invest in research facilities and initiate activities that support the following objectives:

1. National Objectives:
   a. Develop and strengthen Turkish STE industry through industrial collaborations;
   b. Develop and strengthen Turkish STE RTDI and HRD by attracting, developing, and graduating Ph.D. students, attracting, developing, and retaining new faculty members, and by collaborating with other Turkish universities including hosting visiting researchers.

2. International Objectives:
   a. Allow Turkey to contribute to and strengthen a constituted EU-SOLARIS distributed RI by having at least some research facilities complement those within the EU-SOLARIS consortium, having these research facilities be part of EU-SOLARIS for at least part of the year, and continue contributing to the development and execution of EU-SOLARIS;
b. Become active members in key international STE research organizations;
c. Be actively involved in international STE research projects.

5.2. Research Facilities

As indicated explicitly in the MGOs, investments will be made in research facilities to support STE RTDI specifically rather than CST RTDI more broadly. Investments will be made in research facilities that will provide a foundation for STE RTDI in Turkey and that strengthen EU-SOLARIS. The envisioned research facilities will focus on the following technology areas.

1. Solar simulator: A solar simulator is an indoor facility that uses lamps to simulate concentrated solar fluxes, and is one of the most basic and versatile research facilities for RTDI in concentrating solar technologies. As an indoor facility using lamps, usage of the facility does not depend on the available solar resources and therefore can be used throughout the year.

2. Solid particle CR (SPCR) test bench: A flexible test bench to study SPCRs will be developed, which will be coupled with the solar simulator.

3. TES test bed: A flexible test bed will be developed to test novel TES designs and materials.

4. Material characterization: Significant RTDI opportunities exist in the areas of heat transfer fluids, surface coatings and storage materials, and characterization of the thermal properties of new materials is important. Investments will be made in basic research facilities to measure at least thermal conductivity and viscosity to support these RTDI efforts.

5. Computational facilities: The experimental facilities will be supported by computational facilities for numerical research throughout the STE value chain presented in Figure 2.

Work will continue as part of EU-SOLARIS to identify critical RI that is lacking within the EU-SOLARIS consortium, and the list of research facilities above may be modified so that GÜNAM can more actively contribute to EU-SOLARIS through research facilities that are important and unique at the European level and that build on existing strengths at METU.

5.3. Access to research facilities

As indicated in the Goal, the CST Lab is to be developed and managed so that the research facilities are open and accessible to outside users. Access to the facilities will be based on the activity’s contributions to the lab’s MGOs rather than advancing the research agenda of a specific person. This objective is consistent with the expectations of the Ministry of Development and EU-SOLARIS. One indicator for the lab being successful is that there will be competition among multiple potential users for the same research facility, at which point access policies will be needed to manage access to these facilities. Many EU-SOLARIS members have extensive experience in managing access to their RIs, and one of the ongoing tasks within EU-SOLARIS is to develop clear policies to manage access to the EU-SOLARIS distributed RI. In the immediate future a need for a detailed assess policy for the METU CST lab is not seen, and the best strategy to develop access policies appears to be to wait until the EU-SOLARIS access policies are finalized.
and then adapt and simplify these to the needs of the CST lab. However, a broad initial ordering for access priority can be given to help understand how the lab will be developed and managed. As indicated above, at least some of the facilities for at least part of the year are expected to be integrated into the EU-SOLARIS distributed RI on CST. Although the details for access to EU-SOLARIS facilities are not finalized, tentatively outside users from anywhere in the world can request access to these facilities by applying to EU-SOLARIS, which will grant access based in part on the scientific excellence of the proposed research. Having these outside users use the METU CST lab is expected to keep the CST lab, and therefore Turkey, at the cutting-edge of CST RTDI. For access to the facilities outside of EU-SOLARIS, e.g., by METU users, priority will be given to users in the following order.

1. **STE Users**: Significant lab capacities are envisioned beyond those committed to or used by EU-SOLARIS. Access to these capacities will be managed by the CST lab with priority given to STE RTDI activities.

2. **CST Users (Non-STE)**: If unused capacities still exist after fulfilling all STE RTDI needs, access will be granted to those doing non-STE CST RTDI.

3. **Non-CST Users**: If unused capacities still exist after fulfilling all CST RTDI needs, access for non-CST RTDI will be granted. Specifically, many of the envisioned research facilities are not unique to CST but rather can be used to support RTDI across a broad range of areas both within and outside the thermal science.

In cases where significant scientific or national needs can be demonstrated, non-STE CST users and non-CST can be given priority over STE users.

6. **CONCLUSIONS**

Concentrating Solar Thermal (CST) technologies is an umbrella term that includes Solar Thermal Electricity (STE), also referred to as Concentrating Solar Power (CSP), and many other technologies. Due to differences in the underlying energy conversion processes, CSP and solar photovoltaic (PV) technologies are fundamentally different technologies with very different characteristics. In particular and relative to PV, STE power plants have the potential to be more dispatchable and flexible if Thermal Energy Storage (TES) is included or the STE power plant is hybridized with other thermal energy sources such as biomass. The electricity provided by dispatchable and flexible power plants has a higher value, and this potential to provide high-value electricity is the greatest strength of STE relative to PV and the main driver for STE Research, Technology Development and Innovation (RTDI). While the STE RTDI and industry in Turkey is relatively immature relative to that in some countries, Turkey has a large STE potential due to both large domestic solar resources and its access to the large markets in the Middle East and Northern Africa (MENA) regions. To exploit this potential in August 2015 the Turkish Ministry of Development granted the METU Centre for Solar Energy Research and Applications (GÜNAM) a project to create a CST lab.
The CST lab will target RTDI in STE specifically rather than CST more broadly. The conversion of solar resources into electricity using STE technologies spans a wide-range of technology areas with different RTDI needs, and many of these areas are cross-cutting with other thermal energy conversion technologies. General trends are toward higher efficiencies through higher receiver temperatures, for example by moving from linear to point receivers and the use of new heat transfer fluids and materials in the receiver with higher temperature limitations, and increasing dispatchability and flexibility through TES and hybridization. The proposed research facilities for the CST lab include a solar simulator, test stands for particle absorber central receivers, and facilities to support RTDI into thermal energy storage and materials. The co-authors implementing the CST lab will leverage existing national and international networks to maximize the outcomes of the CST lab. Most importantly, the vision is for the CST lab to be integrated into EU-SOLARIS, which is envisioned to be a European distributed Research Infrastructure on CST.

The lab’s Mission, Goals, and Objectives (MGOs), and Access Policies reflect the vision for this lab to be the main center for facilitating, coordinating, and performing STE RTDI at the national level, to be an active and important contributor to STE RTDI at the international level, and to be open and accessible to outside users from both Turkey and internationally working in the STE field. Work is continuing to refine and expand this roadmap including the following: 1) creating an External Advisory Board consisting of key experts both nationally and internationally to guide the development and execution of this lab; 2) developing and executing initiatives to promote collaboration with Turkish industry; and 3) developing and executing initiatives to promote collaboration with other Turkish universities.

Abbreviations

CSP Concentrating solar power
CST Concentrating solar thermal
RTDI Research, technology development, and innovation
STE Solar thermal electricity
TES Thermal energy storage

Acknowledgements

This work is in part supported by the EU-SOLARIS Project (FP7 Grant 312833, CP-CSA_FP7-INFRASTRUCTURES-2012-1) and the EU-SFERA project (Grant 228296).

References


