Space Resources

Degrees Offered
• Graduate Certificate in Space Resources - online
• Master of Science in Space Resources (Non-Thesis) - online
• Doctor of Philosophy in Space Resources - residential and online

Program Description
Since the 1990s, Colorado School of Mines has been a leading institution for the study of space resources and their utilization. It has also become a destination for space scientists and engineers, government agencies, aerospace companies, entrepreneurs, the mining and minerals industry, financial and legal experts, and policy makers to discuss all topics related to space resources.

In recent years, growing interest in the identification, extraction, and utilization of space resources by space agencies and the private sector has been driven by an awareness that further development of space travel will be enabled through extraction of extraterrestrial materials for the production of propellants to enable more affordable and flexible transportation, for facilities construction, and for life support. The broad topic of space resources brings together many fields in which Mines has a strong presence, including remote sensing, geomechanics, mining, materials/metallurgy, robotics/automation, advanced manufacturing, electrochemistry, solar and nuclear energy, and resource economics and policy.

In this light, Mines has launched a first-of-its-kind multi-disciplinary graduate program in Space Resources to offer a Graduate Certificate and Master of Science and PhD degrees for college graduates and professionals interested in this emerging arena. The program focuses on developing core knowledge and gaining design practices in systems for responsible exploration, extraction, use, and stewardship of resources in the Solar System.

Space Resources Program
The interdisciplinary Space Resources program is targeted to train recent graduates, as well as professionals interested in expanding their knowledge and skills to address the opportunities and challenges in space resource exploration, extraction, and utilization. Space Resources touches on physical sciences, engineering, and the social science fields. Thus, this program engages faculty members from many academic departments at Mines.

The graduate program for Space Resources includes the following degree options:
• a 12-credit-hour Graduate Certificate in Space Resources offered online,
• a 30-credit Master of Science Non-Thesis (MS-NT) degree in Space Resources offered online,
• a PhD program in Space Resources requiring 36 credit hours of coursework, 36 credit hours of research, and a doctoral dissertation.

The PhD program can be completed on campus and also online for those students approved to conduct their research remotely by their advisor and dissertation committee.

A 12-credit hour Graduate Certificate requires 6 credit hours from two core courses, 6 credit hours from a seminar class and two core project-based courses are required. These project courses allow students to conduct a design, system, or economic analysis focused on the exploration, extraction, utilization, and responsible stewardship of space resources.

Beyond that, MS-NT and PhD students will take 18 credit hours chosen from a variety of elective courses on critical areas in space resources, such as: Remote Sensing and Resource Assessment; Extraction, Processing, and Resource Utilization; Power and Energy; Robotics, Autonomy, and Communications, and Economics, Law, and Policy.

A student who completes a PhD in Space Resources will possess all the training of a Master’s degree holder with further specialization in one or more areas within the space resources field. The completed doctoral dissertation will make original contributions to the field.

Mines’ Combined Undergraduate / Graduate Degree Program
Students enrolled in Mines’ combined undergraduate/graduate program (meaning uninterrupted registration from the time the student earns a Mines undergraduate degree to the time the student begins a Mines graduate degree) may double count up to six hours of credits which were used in fulfilling the requirements of their undergraduate degree at Mines, towards their graduate program. Any 400+ level courses that count towards the undergraduate degree requirements as “Elective Coursework” or any 500+ level course, may be used for the purposes of double counting at the discretion of the graduate advisor. These courses must have been passed with a “B-” or better, not be substitutes for required coursework, and meet all other University, Department, Division, and Program requirements for graduate credit.

Graduate Certificate
This option requires students to take a minimum of 12 credit hours exclusively online. Table 1 lists the courses that will comprise the curriculum for the Graduate Certificate.

Table 1 – Required courses for 12-credit-hour Graduate Certificate in Space Resources

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credit Hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPRS001</td>
<td>SPACE RESOURCES FUNDAMENTALS</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS002</td>
<td>SPACE SYSTEMS ENGINEERING</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS ELECTIVE SPACE RESOURCES ELECTIVE</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>Total Semester Hrs</td>
<td></td>
<td>12.0</td>
</tr>
</tbody>
</table>

Online elective courses can be taken from a variety of important topics on space resources, such as: planetary geology, space operations, remote sensing, resource economics, materials extraction, advanced manufacturing, space law and policy, and other topics which continue to be introduced as relevant subjects are identified and new courses developed (see Table 3).

Master of Science (Non-Thesis)
The Master of Science degree program is exclusively non-thesis (MS-NT) and online. The MS-NT degree program coursework requires 30 credit hours as laid out in Table 2. For students coming into the program with previous Master or PhD degrees, up to 9 credit hours of relevant courses can be transferred after approval from the Space Resources program director in consultation with faculty members of the program.
The 18 credit hours of elective courses can be selected from any of the various courses listed on Table 3. These courses provide students with a broad interdisciplinary coverage of critical topics in space resources. Additional courses are being developed and introduced on various relevant subjects.

Table 3 – Current elective courses for all degree options of the Space Resources program (additional topics are being introduced as relevant subjects are identified and new courses developed).

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEOL410</td>
<td>PLANETARY GEOLOGY</td>
<td>3.0</td>
</tr>
<tr>
<td>GPGN570</td>
<td>APPLICATIONS OF SATELLITE REMOTE SENSING</td>
<td>3.0</td>
</tr>
<tr>
<td>AMFG501</td>
<td>ADDITIVE MANUFACTURING</td>
<td>3.0</td>
</tr>
<tr>
<td>CEEN501</td>
<td>LIFE CYCLE ASSESSMENT</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS504</td>
<td>ECONOMICS OF SPACE RESOURCES</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS598A</td>
<td>INTERNATIONAL SPACE LAW AND POLICY</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS599B</td>
<td>SPACE OPERATIONS</td>
<td>3.0</td>
</tr>
<tr>
<td>SPRS599</td>
<td>INDEPENDENT STUDY IN SPACE RESOURCES</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**PhD in Space Resources**

The PhD degree program requires 72 total credit hours, consisting of at least 36 credit hours of courses beyond the BS and at least 36 research credit hours. PhD coursework beyond the MS degree program will not be restricted other than approved by the student’s advisor and dissertation committee. The PhD degree allows for both on-campus and online options. The latter requires approval by the student advisor and dissertation committee who will review and approve if the research project can be conducted remotely.

Students who enter the PhD program with an MS degree in a relevant engineering, science, economics, or business field are expected to take at least 12 credit hours of core courses. For students coming into the program with a previous Master Non-Thesis, up to 24 credit hours of relevant courses can be transferred after approval from the Space Resources program director in consultation with the program faculty. For students with a previous Master with Thesis or PhD degrees, up to 30 credit hours of relevant courses can be approved to be transferred, however the student will still be required to take 12 credit hours from core courses. If a total of 30 credit hours of transferred courses are approved and 12 credit hours of core Space Resources taken, the number of research credit hours can be lowered to a minimum of 30 for a total of at least 72 hours of course and research work for graduation.

In accordance with other PhD programs at Mines, students in the Space Resources PhD degree program must successfully complete qualifying examinations, defend their written dissertation proposal, and write and defend a doctoral dissertation, in addition to their course and research work. PhD research is aimed at fundamentally advancing the state of the art in Space Resources. PhD students are expected to submit the dissertation work for at least two archival publications in scholarly journals and present research findings in at least one professional conference.

Students are also required to participate in the Space Resources seminar series both by attending seminars of distinguished speakers and by presenting their research on no less than an annual basis.

PhD students in the Space Resources program will be advised by a faculty advisor affiliated with the program and by an interdisciplinary Doctoral committee, which must contain a majority of faculty affiliated with the program. The PhD degree program culminates in a research dissertation that provides significant scholarly contribution to the Space Resources field.

Because of the interdisciplinary nature of Space Resources, there is significant flexibility in the Program’s curriculum and faculty instructors to allow for students with a diverse range of backgrounds to enter and succeed in their targeted degree program.

Graduates from the Space Resources program will be prepared to serve the growing needs of industry, government, and academia to identify, extract, process, and utilize space resources. Students will have a broad, multi-disciplinary understanding of the overall flow of activities in the development of space resources, and high-level exposure to the different science, engineering, economics, and business disciplines involved in each phase and an understanding of the current state of affairs in space resources across academia, government, and the private sector. A Master’s degree holder will be able to make immediate contributions to any government agency or company pursuing technical activities related to space resources. PhD degree holders will be able to pursue academic positions or contribute as a specialist in industry or government.

**Courses**

**SPRS501. SPACE RESOURCES FUNDAMENTALS. 3.0 Semester Hrs.**

(I, II) This course provides an overview of the space resources field, including the current knowledge of available resources in the Solar System, extraction and utilization systems under development, economic and technical feasibility studies, legal and policy issues, and space exploration architectures that may be enabled by utilizing extraterrestrial resources in the near future. The course will build broad knowledge and develop confidence in problem solving in the space resources field. 8-week online course. 3 hours lecture; 3 semester hours. Prerequisite: Working knowledge of physical sciences, engineering fields, or economics at an advanced undergraduate level, with basic numerical analysis skills using a programming language or spreadsheet calculations.
SPRS502. SPACE SYSTEMS ENGINEERING. 3.0 Semester Hrs.
This course conveys the fundamentals of the systems engineering process as applied to large, complex space systems. It is intended for graduate students with various backgrounds. The students will become familiar with full scope of the systems engineering process from requirements definition, system design, system analysis through system verification. The process will be illustrated with real-world examples from current space systems with an emphasis on systems relevant to the development of space resources. 8-week online course.

SPRS503. SPACE RESOURCES SEMINAR. 1.0 Semester Hr. 
(I, II) The Space Resources Seminar will engage students in the program with current research and developments related to space resources. Students will assess the importance and relevance to the space resources field in the near-, medium-, or long-term of topics covered in lectures presented by technical experts from a variety of disciplines. They will report and analyze events, news, and research publications and develop scientific, technical, and economic arguments for their impact and relevance to the space resources field, while also responding thoughtfully and critically to other students’ contributions. Students will synthesize the information presented during the entire course by contributing in teams to a final report with an analysis of the most important developments in the science, technology, economics and policy of space resources during the course period. 8-week online course. 1 hour seminar; 1 semester hour.

SPRS504. ECONOMICS OF SPACE RESOURCES. 3.0 Semester Hrs.
This course provides an overview of economics and business topics that are commonly found in the space industries. Students will build a basic knowledge of economics, finance, and business issues that are relevant to space resource markets and industries. The big picture is to help provide perspective on what investors or the financial officers at companies are investing in and planning for in or around the space industry.

SPRS501. SPACE RESOURCES PROJECT I. 2.0 Semester Hrs.
This course will provide graduate students in the program with directed team-based project learning by exploring the design, planning, and analysis of missions, processes, systems, science, business, and economics for space resources assessment, extraction, and/or utilization. The course will meet formally online once a week for one hour and include a 10-15 minute discussion on relevant design aspects of space mission, processes, and/or systems. In this regard, it will build on content learned in the Space Resources Fundamentals, Space Systems Engineering, and other courses in the Space Resources Program. Students will collaborate in multi-disciplinary teams, typically of up to 5 students. Teams will be advised by a course instructor with significant industrial aerospace design experience and supported by faculty affiliated with the Space Resources program from relevant disciplines on campus. For teams with students in space resource economics, detailed economic analysis will be incorporated into those projects. Student teams will prepare a preliminary design, planning and analysis report early in the semester, one interim progress report, and a final report and project presentation. 16-week online course.

SPRS502. SPACE RESOURCES PROJECT II. 3.0 Semester Hrs.
This course will provide graduate students in the program with directed team-based project learning by exploring the design, planning, and analysis of missions, processes, systems, science, business, and economics for space resources assessment, extraction, and/or utilization. The course will meet formally online once a week for one hour and include a 10-15 minute discussion on relevant design aspects of space mission, processes, and/or systems. In this regard, it will build on content learned in the Space Resources Fundamentals, Space Systems Engineering, and other courses in the Space Resources Program. Students will collaborate in multi-disciplinary teams, typically of up to 5 students. Teams will be advised by a course instructor with significant industrial aerospace design experience and supported by faculty affiliated with the Space Resources program from relevant disciplines on campus. For teams with students in space resource economics, detailed economic analysis will be incorporated into those projects. Student teams will prepare a preliminary design, planning and analysis report early in the semester, one interim progress report, and a final report and project presentation. 16-week online course.

SPRS598. SPECIAL TOPICS IN SPACE RESOURCES. 6.0 Semester Hrs. 
(I, II, S) Pilot course or special topics course. Topics chosen from special interests of instructor(s) and student(s). Usually the course is offered only once, but no more than twice for the same course content. Prerequisite: none. Variable credit: 0 to 6 credit hours. Repeatable for credit under different titles.

SPRS599. INDEPENDENT STUDY IN SPACE RESOURCES. 0.5-6 Semester Hr.
Students can do Individual research or special projects supervised by a faculty member. The student and instructor will agree on the subject matter, content, and credit hours. Prerequisites: Independent Study form must be completed and submitted to the Registrar.

SPRS707. GRADUATE THESIS / DISSERTATION RESEARCH CREDIT. 1-15 Semester Hr. 
(I, II, S) Research credit hours required for completion of Doctoral dissertation. Research must be carried out under the direct supervision of the student's faculty advisor. Variable class and semester hours. Repeatable for credit. Prerequisite: Instructor approval.

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ANGEL ABBUD-MADRID, Professor of Practice

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