Global Review of Geothermal Reporting Terminology

Prepared for members of the International Energy Agency – Geothermal Implementing Agreement

February 2013

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Executive summary

In September 2012, the Executive Committee of the International Energy Agency Geothermal Implementing Agreement (‘IEA-GIA’) commissioned this investigation and report into the inter-relationships between the ‘United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009)’ and a range of existing geothermal energy reporting and classification schemes. The UNFC-2009 is a generic, principle-based system in which estimates of mineral and energy quantities are classified on the basis of three fundamental criteria creating a three-dimensional system:

- Economic and social viability of commercial extraction (E)
- Field project status and project feasibility (F)
- Geological knowledge (G)

This document investigates whether the UNFC-2009 is an appropriate framework upon which to base a geothermal energy classification scheme; examines how existing geothermal energy reporting and classification schemes map to the definitions within the UNFC-2009 framework, and hence to each other; and investigates how the UNFC-2009 might provide the basis for an entirely new global classification scheme for geothermal energy assessments and reporting.

The geothermal energy reporting and classification schemes investigated include:

- Geothermal Energy Association’s ‘New Geothermal Terms and Definitions’ (Nov 2010)

As a case study, the key findings from a seminal report funded by the US DoE and completed by the Massachusetts Institute of Technology (MIT) are interpreted in terms of the UNFC-2009 framework and the six classification schemes listed above. No one existing scheme is able to fully classify the findings of the MIT Report.
The UNECE Expert Group on Resource Classification did not consider geothermal energy when it developed the UNFC-2009. The UNFC-2009 explicitly “does not make reference to energy resources contained in physical fields (of pressure and temperature). It also does not make reference to groundwater resources, although it is applicable to projects that are extracting non-renewable groundwater.” While not explicitly considered, however, the three dimensions of the UNFC-2009—economic, technical and geological favorability—are also relevant to geothermal potential.

The consensus view of the author and a number of reviewers of an earlier draft of this report is that the three dimensions of the UNFC-2009 scheme should be sufficient to design a workable, broadly applicable, classification framework for geothermal energy, within the context of clearly defined project parameters. The first step towards a global classification framework for geothermal energy based on the UNFC-2009 would be to answer:

- Who would use the classification framework?
- Who would maintain and police the classification framework?
- What would be the reportable commodity?
- How prescriptive should the classification framework be?

Once those questions are answered, the ‘E’ and ‘F’ criteria of the UNFC-2009 framework could be adapted for classifying geothermal energy projects without too much modification. The definition of the ‘G’ criterion, however, might need to be extended to encompass non-geological uncertainties around delivery of the commercial product. The reportable commodity might (for example) be defined as ‘useful recoverable thermal energy’, and classified according to the uncertainty around the thermal energy being recovered and ‘used’. The uncertainty would relate to many factors beyond the geological probability of production.

The ‘Expert Group on Resource Classification’ set up by the UN Economic Commission for Europe has begun to look at modifying the UNFC-2009 scheme to encompass renewable energy sources, including geothermal energy. The author strongly recommends that the IEA-GIA engages fully with this process to ensure that any UNFC-2009 classification framework for renewables is 100% aligned with the needs of the geothermal energy sector.
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1.0 Background to this document
The United Nations Economic Commission for Europe recently (United Nations, 2010) published the ‘United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009)’. Quoting from that document: “UNFC-2009 is a generic principle-based system in which quantities are classified on the basis of the three fundamental criteria of economic and social viability (E), field project status and feasibility (F), and geological knowledge (G), using a numerical and language independent coding scheme. Combinations of these criteria create a three-dimensional system.” While the UNFC-2009 is primarily intended for classifying finite natural resources, it provides a possible basis for a generic classification framework for geothermal energy.

In recent years a number of jurisdictions, organizations and individuals have developed or proposed Codes, Protocols, Guidelines and Frameworks to classify geothermal potential, resources, reserves and developments. These documents serve different primary purposes but all seek to quantify and/or categorize the actual or potential realization of thermal and electrical power from geothermal energy. Relevant schemes have included:

- Geothermal Energy Association’s ‘New Geothermal Terms and Definitions’ (Nov 2010)

None of the above documents has yet been accepted as a true or de facto global standard for classifying estimates of geothermal reserves and resources, and none has directly referenced the generic UNFC-2009.

In September 2012, the Executive Committee of the International Energy Agency Geothermal Implementing Agreement (‘IEA-GIA’) commissioned this investigation
and report into the inter-relationships between the UNFC-2009 and the range of existing geothermal energy reporting and classification schemes. The IEA-GIA, as an organization with a global mandate, is interested to move towards a globally adopted classification and terminology framework for reporting geothermal energy potential and production. It shares this goal with other global and intergovernmental organizations such as the International Geothermal Association and the United Nations Economic Commission for Europe.

To that end, this document serves a number of related purposes. Firstly, it investigates whether the UNFC-2009 is an appropriate framework upon which to base a geothermal energy classification scheme.

Notwithstanding the conclusions from the above, it secondly examines how existing geothermal energy reporting and classification schemes map to the definitions within the UNFC-2009 framework, and hence to each other. The examination uncovers ambiguous and synonymous terms and definitions, as well as gaps and overlaps across different schemes. As a case study, the key findings from a seminal study funded by the United States Department of Energy and completed by the Massachusetts Institute of Technology in 2006 are interpreted in terms of the UNFC-2009 framework and the six classification schemes examined.

Thirdly, this document investigates how the UNFC-2009, or a similar three-dimensional classification framework, might provide the basis for an entirely new global classification scheme for geothermal energy estimates and progress reports.

1.1 Acknowledgements
This document was prepared under the auspices of the Executive Committee of the International Energy Agency’s Geothermal Implementing Agreement. A first draft was circulated for review in October 2012. This resulting document is a much-improved version of the first draft after the review process. The author specifically acknowledges feedback and constructive criticism from (alphabetically) Arlene Anderson, Anthony Budd, Dornadula Chandrasekharam, Robert Hogarth, Ladislaus Rybach, Colin Williams, and Daniel Yang. The author also acknowledges the assistance of Mike Mongillo at the IEA-GIA Secretariat for coordinating the project.
2.0 The UNFC-2009 Framework Classification

During the 1990’s, the United Nations Economic Commission for Europe (‘ECE’) developed a uniform system for classifying and reporting reserves and resources of solid fuels and mineral commodities. It did so in response to the wishes of member countries, who recognized that accurate and consistent estimates of extractable fossil energy and mineral resources, with due consideration to social and economic conditions, are essential to build a complete picture of the current and future supply base, and a sustainable extraction strategy, for fossil energy and minerals.

The result was the ‘United Nations Framework Classification for Reserves and Resources of Solid Fuels and Mineral Commodities (UNFC-1997)’, which was endorsed by the United Nations Economic and Social Council (‘ECOSOC’) in 1997. In 2004, the Classification was extended to also apply to petroleum and uranium, and renamed the ‘UNFC for Fossil Energy and Mineral Resources 2004 (UNFC-2004)’.

ECOSOC invited Member States and regional commissions of the United Nations, and other relevant international organizations, to promote the global adoption of UNFC-2004. To facilitate its application, the ECE Committee on Sustainable Energy directed an ‘Expert Group on Resource Classification’ to prepare and submit a revised UNFC for consideration. The Expert Group published a stronger, but simpler, version of the Classification in January 2010—‘United Nations Framework Classification for Fossil Energy and Mineral Reserves and Resources 2009 (UNFC-2009)’.

The UNFC-2009 is entirely compatible with the Committee for Mineral Reserves International Reporting Standards’ (CRIRSCO) ‘International Reporting Template’ and the ‘Petroleum Resource Management System’ (SPE-PRMS) sponsored by the Society of Petroleum Engineers, the American Association of Petroleum Geologists, the World Petroleum Council, and the Society of Petroleum Evaluation Engineers. These two schemes provide the frameworks for most of the mineral and petroleum reporting systems currently operating around the world. The UNECE published a detailed description of how the CRIRSCO and SPE-PRMS map to the UNFC-2009 in October 2009.

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1 Section 6.0 (Bibliography) contains links to the UNFC-2009 and other documents referred to in this report.
2.1 Description of the UNFC-2009

The UNFC-2009 is a generic, principle-based system in which estimates of mineral and energy quantities are classified on the basis of three fundamental criteria creating a three-dimensional system:

- Economic and social viability of commercial extraction (E)
- Field project status and project feasibility (F)
- Geological knowledge (G)

A category number is assigned to each criterion based on its degree of favorability, with 1 being the ‘most favorable’ category and either 3 (criterion E) or 4 (criteria F and G) being the ‘least favorable’ category. A number of sub-categories (e.g. category E3.2) are also defined. ‘Classes’ are defined as combinations of {E,F,G} categories or sub-categories. Numerical coding of classes makes them language independent, as criteria are always quoted in order of {E,F,G}. Figure 1 illustrates the three-dimensional category framework and gives examples of classes. Figure 2 lists a range of possible classes and sub-classes. The following sections define the categories and sub-categories in more detail.

![Figure 1. UNFC-2009 categories and examples of classes. From United Nations Economic Commission for Europe (2010).](www.hotdryrocks.com)
2.1.1 Economic and social viability of commercial extraction

The first set of categories (the ‘E’ criterion; Figure 3) encapsulates the favorability of the social and economic conditions for establishing a commercially viable project. It considers market conditions and relevant legal, regulatory, environmental and contractual conditions. Factors encapsulated in this criterion include prices, costs, legal and fiscal framework, environmental, social and all other non-geological factors that directly impact the financial viability of a project.
<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Supporting Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>Production and sale has been confirmed to be commercially viable.</td>
<td>Production and sale is commercially viable on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe. Commercial viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.</td>
</tr>
<tr>
<td>E2</td>
<td>Production and sale is expected to become commercially viable in the foreseeable future.</td>
<td>Production and sale has not yet been confirmed to be commercial but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic production and sale in the foreseeable future.</td>
</tr>
<tr>
<td>E3</td>
<td>Production and sale is not expected to become commercially viable in the foreseeable future, or evaluation is at too early a stage to determine commercial viability.</td>
<td>On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic production and sale in the foreseeable future; or, economic viability of production cannot yet be determined due to insufficient information (e.g. during the exploration phase). Also included are quantities of minerals or energy forecast for production, but which will not be available for sale.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Sub-Category Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>E1.1</td>
<td>Production and sale is commercially viable on the basis of current market conditions and realistic assumptions of future market conditions.</td>
</tr>
<tr>
<td></td>
<td>E1.2</td>
<td>Production and sale is not commercially viable on the basis of current market conditions and realistic assumptions of future market conditions, but is made commercially viable through government subsidies and/or other considerations.</td>
</tr>
<tr>
<td>E2</td>
<td>No sub-categories defined</td>
<td></td>
</tr>
<tr>
<td>E3</td>
<td>E3.1</td>
<td>Quantities that are forecast to be produced, but which will not be available for sale.</td>
</tr>
<tr>
<td></td>
<td>E3.2</td>
<td>Commercial viability of production cannot yet be determined due to insufficient information (e.g. during the exploration phase).</td>
</tr>
<tr>
<td></td>
<td>E3.3</td>
<td>On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for commercial extraction and sale in the foreseeable future.</td>
</tr>
</tbody>
</table>

**Figure 3.** Criteria ‘E’ categories and sub-categories. After United Nations Commission for Europe (2010), Annexes I and II.
2.1.2 Field project status and project feasibility
The second set of categories (the ‘F’ criterion; Figure 4) relates to the maturity of project feasibility studies and financial and legal commitments towards the project development. Stages extend from ‘pre-feasibility’, before a deposit or accumulation has been confirmed, through to actual extraction and sales of the commodity.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Supporting Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Feasibility of production by a defined development project has been confirmed.</td>
<td>Production is currently taking place; or implementation of the development project is underway; or sufficiently detailed studies have been completed to demonstrate the feasibility of production by implementing a defined development project.</td>
</tr>
<tr>
<td>F2</td>
<td>Feasibility of production by a defined development project is subject to further evaluation.</td>
<td>Preliminary studies demonstrate the existence of a deposit in such form, quality and quantity that the feasibility of production by a defined (at least in broad terms) development project can be evaluated. Further data and/or studies may be required to confirm the feasibility of production.</td>
</tr>
<tr>
<td>F3</td>
<td>Feasibility of production by a defined development project cannot be evaluated due to limited technical data.</td>
<td>Very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project, indicate the need for further data to confirm the existence of a deposit in such form, quality and quantity that the feasibility of production can be evaluated.</td>
</tr>
<tr>
<td>F4</td>
<td>No development project has been identified.</td>
<td>In situ quantities that will not be produced by any currently defined development project.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Sub-Category Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>F1.1</td>
<td>Production is currently taking place.</td>
</tr>
<tr>
<td></td>
<td>F1.2</td>
<td>Capital funds have been committed and implementation of the development project is underway.</td>
</tr>
<tr>
<td></td>
<td>F1.3</td>
<td>Sufficiently detailed studies have been completed to demonstrate the feasibility of production by implementing a defined development project.</td>
</tr>
<tr>
<td>F2</td>
<td>F2.1</td>
<td>Project activities are ongoing to justify development in the foreseeable future.</td>
</tr>
<tr>
<td></td>
<td>F2.2</td>
<td>Project activities are on hold and/or commercial development may be subject to significant delay.</td>
</tr>
<tr>
<td></td>
<td>F2.3</td>
<td>There are no current plans to develop or to acquire additional data at the time due to limited potential.</td>
</tr>
</tbody>
</table>

Figure 4. Criteria ‘F’ categories and sub-categories. After United Nations Commission for Europe (2010), Annexes I and II.
2.1.3 Geological knowledge

The third set of categories (the ‘G’ criterion; Figure 5) relates to the level of confidence in understanding the geological uncertainty and potential recoverability of the commodity in question. Confidence generally improves following surface or subsurface geological, geophysical and geochemical surveys.

<table>
<thead>
<tr>
<th>Category</th>
<th>Definition</th>
<th>Supporting Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Quantities associated with a known deposit that can be estimated with a high level of confidence.</td>
<td>For <em>in situ</em> quantities, and for recoverable estimates of solid energy and mineral resources, quantities are typically categorized discretely, where each discrete estimate reflects the level of geological knowledge and confidence associated with a specific part of the deposit. The estimates are categorized as G1, G2 and/or G3 as appropriate.</td>
</tr>
<tr>
<td>G2</td>
<td>Quantities associated with a known deposit that can be estimated with a moderate level of confidence.</td>
<td>For recoverable estimates of fluid energy and mineral resources, their mobile nature generally precludes assigning recoverable quantities to discrete parts of an accumulation. Recoverable quantities should be evaluated on the basis of the impact of the development scheme on the accumulation as a whole and are usually categorized on the basis of three scenarios or outcomes that are equivalent to G1, G1+G2 and G1+G2+G3.</td>
</tr>
<tr>
<td>G3</td>
<td>Quantities associated with a known deposit that can be estimated with a low level of confidence.</td>
<td></td>
</tr>
<tr>
<td>G4</td>
<td>Estimated quantities associated with a potential deposit, based primarily on indirect evidence.</td>
<td>Quantities that are estimated during the exploration phase are subject to a substantial range of uncertainty as well as a major risk that no development project may subsequently produce the estimated quantities. Where a single estimate is provided, it should be the expected outcome but, where possible, a full range of uncertainty in the size of the potential deposit should be documented (e.g. in the form of a probability distribution). In addition, it is recommended that the probability that the potential deposit will become a deposit of commercial significance also be documented.</td>
</tr>
</tbody>
</table>

*Figure 5.* Criteria ‘G’ categories. No sub-categories are defined for Criteria G. After United Nations Commission for Europe (2010), Annex I.

2.2 The UNFC-2009 and the classification of geothermal energy

In the context of this current review, it is significant to note that the UNFC-2009 explicitly “does not make reference to energy resources contained in physical...
fields (of pressure and temperature). It also does not make reference to groundwater resources, although it is applicable to projects that are extracting non-renewable groundwater.” The Expert Group on Resource Classification clearly did not consider geothermal energy during its formulation of the UNFC-2009, but this does not in itself disqualify the UNFC-2009 as a possible template for a classification framework for geothermal energy.

The UNFC-2009 and its subordinate classification schemes are specifically designed to classify finite masses or volumes of material. These schemes provide contextual frameworks within which to apportion different quanta of mass (e.g. ounces of gold) or volume (e.g. barrels of oil) from a quantifiable and finite whole. They implicitly assume that the commodity being classified is non-degradable and non-renewable, that the commodity is in the form of a discrete mass or volume that can be quantified (within uncertainty limits), that different portions of the commodity will be reallocated to different classes as a project develops, and that the commodity can be stockpiled after extraction (hence has an intrinsic commercial and/or public value that is not lost upon production), and that uncertainties can be quantified.

Critically, the UNFC-2009 and its subordinate schemes do not explicitly deal with the rate of extraction, the impact of recharge (natural or artificial), the conversion of the commodity to an end product, the possibility that the amount of commodity might vary depending on the purpose to which it will be applied, or a requirement that the commodity be immediately utilized upon production or else lose its entire value. Any classification scheme for geothermal energy needs to consider these and other factors that control the quantity of thermal or electrical energy or power that can be generated by a project.

A fundamental question is what commodity should we seek to classify in the context of geothermal energy? The actual commodity being produced from the well head is thermal energy, but the metric of most relevance for geothermal power generation, for example, is the sustainable (over a defined time period) megawatts of electricity. This metric inherently incorporates a rate of energy extraction and power conversion, rather than just a quantum of recoverable thermal energy or thermal energy in place. As an illustration of how the same quantum of recoverable thermal energy can result in different amounts of electrical power, consider a hypothetical
geothermal reservoir from which 50 gigaliters of geothermal fluid is recoverable at a temperature of 150°C. Such a resource would provide about 10 petajoules (PJ$_{th}$) of heat at the surface, relative to a base temperature of 100°C. The volume of fluid would support (but not guarantee) production at about 50 kg/s for 30 years, providing an average of about 10 MW$_{th}$ of thermal power. An ORC plant might generate 1.4 MW$_e$ (net) from that thermal power.

The same resource could alternatively (if conditions allowed) be produced at 75 kg/s for 20 years. This would provide the same amount of heat (10 PJ$_{th}$) at the surface, but at an average rate of about 15 MW$_{th}$ of thermal power, or 2.1 MW$_e$ (net) of electrical power. A different geothermal reservoir with 19 gigaliters of fluid recoverable at 225°C would also provide the same amount of heat, 10 PJ$_{th}$. This reservoir exploited at 30 kg/s over 20 years would also provide 15 MW$_{th}$ of thermal power, the same as the previous example, but approximately 3.4 MW$_e$ of electrical power due to the higher conversion efficiency of the hotter fluid.

The implication of the above illustration is that while recoverable thermal energy might seem the most appropriate commodity to classify under a scheme such as the UNFC-2009, it does not directly correlate to electrical power except within the context of clearly stated project parameters. But so long as such project parameters are clearly specified, the UNFC-2009 might provide a framework for classifying geothermal power potential.

As noted earlier in this document, the UNFC-2009 is 100% compatible with the CRIRSCO Template for minerals reporting, and the SPE-PRMS for petroleum reporting. The CRIRSCO Template is itself 100% aligned with the Joint Ore Reserves Committee’s Australasian Code for Reporting of Exploration Results, Mineral Resources and Ore Reserves (‘JORC Code’), which in turn provides the main framework for the classification schemes in both the Australian and Canadian Geothermal Reporting Codes. These Codes, therefore, provide practical examples and case studies of the challenges around adopting a UNFC-2009-based classification scheme for the financial reporting of Geothermal Resources and Geothermal Reserves. This is discussed further in Section 3.1.

The Canadian and Australian Geothermal Reporting Codes are both based on the ‘JORC Code’. That is not to say, however, that the ‘JORC Code’ is the only, or even
the most appropriate, UNFC-2009 compatible framework upon which to base a Geothermal Reporting Code. It could be argued that the geological uncertainties around the estimation of Geothermal Resources and Geothermal Reserves are more akin to those of the petroleum sector than those of the minerals sector, in which case the 'SPE-PRMS' might provide a more relevant template for a geothermal reporting scheme. The GEO-ELEC Project in Europe has adopted this position.

The existing Geothermal Reporting Codes only relate to financial asset reporting. Any classification scheme intended for purposes other than financial reporting will almost certainly require different or additional classes to those provided by the Codes. In particular, national assessments of geothermal potential involve classes outside of those defined by the Codes. Direct-use projects might also require a different set of classes.

Figure 6 presents a possible set of re-definitions of the UNFC-2009 categories and sub-categories from Figures 3, 4 and 5 in the context of a geothermal power generation project. In this example it is assumed that the commodity being classified is 'recoverable heat'. Note that these definitions are provided only as an example of how the UNFC-2009 three-dimensional framework might be adapted for classifying geothermal power generation.
<table>
<thead>
<tr>
<th>Category</th>
<th>Sub-Category</th>
<th>Category / Sub-Category Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>E1</strong></td>
<td>E1.1</td>
<td>Heat to be converted and sold as electricity; commercially viable on the basis of current local energy market conditions and realistic assumptions of future market conditions. PPA in place.</td>
</tr>
<tr>
<td></td>
<td>E1.2</td>
<td>Heat to be converted and sold as electricity; not commercially viable on the basis of current local energy market conditions or realistic assumptions of future market conditions, but becomes commercially viable through feed-in tariffs, renewable energy certificates, or other considerations. PPA in place.</td>
</tr>
<tr>
<td><strong>E2</strong></td>
<td>E3.1</td>
<td>Heat available for production, but which will not generate revenue. e.g. parasitic load</td>
</tr>
<tr>
<td></td>
<td>E3.2</td>
<td>Commercial viability of electricity generation cannot yet be determined due to insufficient information on costs or revenue. e.g. during exploration</td>
</tr>
<tr>
<td></td>
<td>E3.3</td>
<td>On the basis of realistic assumptions of future local energy market conditions, there are not reasonable prospects for thermal energy to be commercially converted to electricity in the foreseeable future.</td>
</tr>
<tr>
<td><strong>F1</strong></td>
<td>F1.1</td>
<td>Electrical power is currently being generated.</td>
</tr>
<tr>
<td></td>
<td>F1.2</td>
<td>Capital funds have been committed and power generation facilities are under construction.</td>
</tr>
<tr>
<td></td>
<td>F1.3</td>
<td>Sufficiently detailed studies have been completed to demonstrate the feasibility of electrical power generation using a defined technology; development intended in the foreseeable future.</td>
</tr>
<tr>
<td><strong>F2</strong></td>
<td>F2.1</td>
<td>Project activities are ongoing to justify the development of electrical power generation facilities in the foreseeable future.</td>
</tr>
<tr>
<td></td>
<td>F2.2</td>
<td>Project activities are on hold for reasons not necessarily related to energy potential or geological knowledge; construction of electrical power generation facilities may be subject to significant delays.</td>
</tr>
<tr>
<td></td>
<td>F2.3</td>
<td>Sufficiently detailed studies have been completed to demonstrate the non-feasibility of electrical power generation using any current power conversion technology. e.g. fluid too cold, hot, acidic etc</td>
</tr>
<tr>
<td><strong>F3</strong></td>
<td></td>
<td>Very preliminary studies based on a defined power generation technology indicate the need for further data to better define the temperature, flow, recoverability and other characteristics of the geothermal energy.</td>
</tr>
<tr>
<td><strong>F4</strong></td>
<td></td>
<td>Heat cannot be produced through any currently available technology. e.g. too deep, impermeable with no possibility of enhancement, etc. (Only stored heat could be reported in this sub-category.)</td>
</tr>
<tr>
<td><strong>G1</strong></td>
<td></td>
<td>Quantities of heat could be categorized discretely, with each estimate reflecting the level of confidence in the geological knowledge associated with that portion of the heat. The estimates would be categorized as G1, G2 and/or G3. e.g. Measured, Indicated, Inferred.</td>
</tr>
<tr>
<td><strong>G2</strong></td>
<td></td>
<td>Heat could alternatively be characterized as a probabilistic distribution in terms of ‘low’, ‘medium’ and ‘high’ scenarios. These would be equivalent to G1, G1+G2 and G1+G2+G3. e.g. P10, P50, P90.</td>
</tr>
<tr>
<td><strong>G3</strong></td>
<td></td>
<td>Heat estimated mostly from assumed parameters not yet constrained with any confidence by exploration data; subject to substantial uncertainty. Where a single estimate of heat or power is provided, it should be the ‘most probable’ (’P50’) estimated outcome but, where possible, a full range of uncertainty in the estimated heat should be documented. e.g. in the form of a probability distribution</td>
</tr>
</tbody>
</table>

**Figure 6.** Possible re-definition of categories and sub-categories of the UNFC-2009 for classifying recoverable heat intended for geothermal power generation.
3.0 Geothermal Reporting Codes and other classification schemes

This section describes existing schemes for classifying geothermal energy exploration and development data and projects. Each scheme is described in its original published terms and interpreted in the context of the UNFC-2009.


The Canadian Geothermal Code for Public Reporting (CCPR) was published in 2010. The Canadian Geothermal Code Committee prepared the CCPR, at the request of the Canadian Geothermal Energy Association (CanGEA), to provide a minimum standard for public reporting of geothermal data, including a scheme for classifying geothermal potential. The CCPR is intended to cover all public documents, including company quarterly and annual reports, websites, technical presentations, updates for shareholders, presentations to stockbrokers and/or investment analysts.

The CCPR is an example of industry self-regulation. The CCPR is not yet endorsed by the Canadian Securities Exchanges or any other regulator involved in Canadian Securities regulation, so adherence by a company to the CCPR is on a voluntary basis. All CanGEA member companies are encouraged to comply.

According to CanGEA, the primary objectives of the CCPR are:

- “To provide a reporting basis that is satisfactory to investors, shareholders and capital markets, such as the Canadian Securities Exchanges, in a similar manner that existing Canadian instruments provide for the reporting of Mineral and Petroleum Resources.”

- “To be applicable to geothermal plays in both Canada and internationally since the Canadian Securities Markets are utilized for the exploration and development of both national and international geothermal plays for companies based in Canada and in other jurisdictions.”

The CCPR’s structure is closely based on the JORC Code, including adopting the JORC Code’s governing principles of ‘transparency’, ‘materiality’ and ‘competence’. In terms of classifying geothermal potential, the CCPR again closely follows the JORC Code by adopting a two-dimensional classification scheme (Figure 7).
Figure 7. Two-dimensional classification scheme defined by the CCPR. From Canadian Geothermal Energy Association (2010).

The CCPR provides a range of definitions to standardize the context in which common terms are used.

- "**Geothermal Play** is used as an informal qualitative descriptor for an accumulation of heat energy within the earth’s crust. It can apply to heat contained in rock and/or in fluid. It has no connotations as to permeability or the recoverability of the energy.” This term provides an alternative to “resource” or “potential” when describing the earth’s heat in broad or general terms. It is an attempt to remove ambiguities in the definition of “resource” in particular.

- "**A Geothermal Resource** is a Geothermal Play which exists in such a form, quality and quantity that there are reasonable prospects for eventual economic extraction. Portions of a Geothermal Play that do not have reasonable prospects for eventual economic extraction must not be included in a Geothermal Resource.”

- “**A Geothermal Reserve** is that portion of an Indicated or Measured Geothermal Resource which is deemed to be economically recoverable after
the consideration of both the Geothermal Resource parameters and modifying factors. Geothermal Reserves should be associated with an identified development plan.”

Geothermal Resources and Reserves are reported in units of recoverable thermal energy (MW\textsubscript{th}-years). If the intention is to convert the thermal energy into electricity, then a public report may also state the estimated electrical energy in appropriate units (MW\textsubscript{e}-years), using subscripts “th” (thermal) and “e” (electrical) to distinguish between the values. All recovery and conversion factors must be clearly stated.

The CCPR recognizes three classes of Geothermal Resource: Inferred, Indicated and Measured, in order of increasing level of geological confidence. Geothermal Reserves are a reclassification of parts of Indicated and Measured Geothermal Resources after considering ‘Modifying Factors’ (production, economic, marketing, legal, land access, environmental, social and government factors). Two classes of Geothermal Reserves are recognized (Probable and Proved) based upon confidence in both the underlying Geothermal Resource estimate and in the Modifying Factors.

There is no overlap between individual classes of Resources and Reserves. A quantum of energy cannot be simultaneously counted in more than one class, though it can move from one class to another if the level of geological knowledge or any of the ‘Modifying Factors’ change.

Statements of Geothermal Reserves intended to generate electrical energy should disclose the intended net rate of generation for the life of the project (e.g. X MW\textsubscript{e} for Y years) or the net total saleable electrical energy generated over the life of the project (e.g. GWh\textsubscript{e}). Geothermal production rates should be reported in thermal power units (MW\textsubscript{th}).

The classes defined by the CCPR can be mapped to the UNFC-2009 framework. The horizontal axis on Figure 7 maps to an amalgam of the ‘E’ and ‘F’ axes of the UNFC-2009 scheme, with the ‘Modifying Factors’ incorporating of a range of technical feasibility and economic factors. The vertical axis on Figure 7 maps most closely to the ‘G’ axis in the UNFC-2009, reflecting the degree of confidence in the geological information underpinning the Resource or Reserve estimate. Figure 8
suggests, in both tabular and graphical format, values for UNFC-2009 categories corresponding to the different classes defined by the CCPR.

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<thead>
<tr>
<th>CCPR classes</th>
<th>UNFC-2009 categories</th>
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<td></td>
<td>‘E’</td>
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<tr>
<td>Geothermal Resource</td>
<td>Inferred</td>
</tr>
<tr>
<td></td>
<td>Indicated</td>
</tr>
<tr>
<td></td>
<td>Measured</td>
</tr>
<tr>
<td>Geothermal Reserve</td>
<td>Probable</td>
</tr>
<tr>
<td></td>
<td>Proved</td>
</tr>
</tbody>
</table>

![Figure 8. Suggested mapping of CCPR classes within the UNFC-2009 framework.](image)

The CCPR (and related Australian Code) can trace its structure directly back to the UNFC-2009, so represents an example of how a UNFC-2009 based classification scheme can operate for geothermal energy in practice. A number of salient points can be identified.
Firstly, the CCPR is intended to govern the financial reporting of Geothermal Resources and Geothermal Reserves in so far as they represent the financial assets of a company. Only bodies of thermal energy delineated by direct exploration results can be classified, which is why the CCPR classification scheme occupies a relatively limited sub-section of the three-dimensional UNFC-2009 classification space (Figure 8). Estimates of national geothermal potential, for example, which might occupy the G4 sector of the UNFC-2009 space, cannot be classified under the CCPR scheme.

Secondly, the commodity being classified as a Resource or Reserve under the CCPR is ‘recoverable thermal energy’. While the CCPR also allows a company to state the estimated converted electrical energy (or electrical power for a defined length of time), the scheme does not, strictly speaking, classify electrical power potential. The CCPR thus suffers from the limitation identified in Section 2 in that recoverable thermal energy is not a good proxy for electrical power generation.

The key to the successful operation of the CCPR is its adoption of the JORC Code’s principles of transparency, materiality and competence. The Code forbids a company to state a Geothermal Resource, Geothermal Reserve, or any derived estimate of electrical power potential, without also providing adequate supporting contextual information and data. In other words, estimates of Geothermal Resources and Geothermal Reserves can only be reported in the context of clearly defined project parameters, and adequate supporting evidence must be provided. Furthermore, a ‘Qualified Person’ must formally take responsibility for a Resource Statement.

A Qualified Person must have a minimum of five years relevant resource assessment experience and be a member of an association with a Code of Ethics. The Qualified Person must also be a member of CanGEA. As a general guide, Qualified Persons should be confident in their own minds that their peers would consider them competent to assess the type of Geothermal Play under consideration.

Different Qualified Persons might apply different assumptions about project lifespan, recoverability, economic cut-off temperature, base temperature and other relevant parameters and arrive at very different estimates of recoverable heat for the same Geothermal Play. Furthermore, different Qualified Persons might make different judgments with respect to their confidence in the geological data underpinning the energy estimate, and thus report the Resource in different classes (e.g. Inferred
versus Indicated Resource). The Code is not prescriptive with respect to these matters, so long as the assumptions themselves are clearly stated and the Qualified Person accepts responsibility.

Ladislaus Rybach presented a paper titled “The Future of Geothermal Energy’ and its Challenges” at the World Geothermal Congress in Bali in 2010. In the paper, Rybach opposed the general use of the common term ‘Geothermal Potential’ to describe estimates of energy or power on the basis that the term is much too vague. He instead proposed a set of classes for Geothermal Potential that could be used as qualifiers for such energy or power estimates.

Rybach defined ‘Geothermal Potential’ as “not yet developed geothermal energy” and proposed five different classes of Potential based on the degree of technical and economic favorability. Each successive, more favorable, class is a sub-set of the previous class. The relationship between the five classes is illustrated in Figure 9 and described below.

![Figure 9. Relationship between classes of ‘Potential’ as proposed by Rybach (2010).](image)

**Theoretical Potential** is the upper limit of thermal energy that is available for possible future extraction from a given volume of rock. It is defined solely by thermodynamic limits. Due to insurmountable technical, structural and administrative limitations only a small fraction of the Theoretical Potential can ever actually be realized. The Theoretical Potential, therefore, is not an appropriate basis for estimating the possible contribution of geothermal energy to a market.
Technical Potential is that fraction of the Theoretical Potential that might be realized within the limits of current technology. Rybach used the word ‘technology’ in a broad sense, encompassing not only engineering technology but also cultural, ecological, legal and regulatory restrictions. Technical Potential is, thus, time and location dependent, describing the maximum contribution that geothermal energy could make towards the energy demand under local and current ‘technical’ limitations.

Economic Potential is that fraction of the Technical Potential that can be economically realized within the local energy market. Economic Potential considers the total cost of a geothermal project (commissioning, operation and decommissioning) relative to other energy systems competing in the same market. It is time and location dependent and can change rapidly in response to changes in externalities such as oil price, taxation and subsidies. What’s more, different approaches to economic assessment might result in different estimates of Economic Potential.

Sustainable Potential is the fraction of Economic Potential that can be sustainably produced. Its actual value will depend on the definition adopted for ‘sustainability’. It might be indefinite production with no appreciable impact on the geothermal source, production for a minimum of 100 years, or another definition. However, whatever the definition adopted, ‘sustainability’ inherently relates to a rate of extraction, a parameter not covered by the UNFC-2009 classification scheme. As such, no dimension of the UNFC-2009 classification scheme can directly distinguish Sustainable Potential from Economic Potential.

Developable Potential is the fraction of the Economic or Sustainable Potential that can be developed under realistic conditions. It is time and location dependent and might take into account such things as the availability of land, human capital, drill rigs or finance. It is usually smaller than the Economic Potential but could conceivably be greater if geothermal energy is developed for reasons other than direct economic return on a project (e.g. energy security, energy diversity, technical demonstration or research).

One significant difference between Geothermal Resources and Geothermal Reserves as defined by the Geothermal Reporting Codes and the classes of
Geothermal Potential proposed by Rybach is that the former are independent of each other, whereas the latter form a series of nested sub-sets. In other words, a quantum of energy identified as a Geothermal Resource under the Reporting Codes cannot be simultaneously counted as a Geothermal Reserve, whereas the Economic Potential of a region is part of the larger Theoretical Potential.

Figure 10 suggests UNFC-2009 categories corresponding to the different classes of Geothermal Potential proposed by Rybach (2010), in both tabular and graphical form.

<table>
<thead>
<tr>
<th>Rybach (2010) classes</th>
<th>UNFC-2009 categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘E’</td>
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<tr>
<td>Theoretical Potential</td>
<td>3.2–3.3</td>
</tr>
<tr>
<td>Technical Potential</td>
<td>2–3.3</td>
</tr>
<tr>
<td>Economic Potential</td>
<td>1.1–2</td>
</tr>
<tr>
<td>Sustainable Potential</td>
<td>1.1–2</td>
</tr>
<tr>
<td>Developable Potential</td>
<td>1.1–1.2</td>
</tr>
</tbody>
</table>

**Figure 10.** Suggested mapping of Rybach (2010) classes within the UNFC-2009 framework.

The Australian Geothermal Reporting Code Committee developed the Australian Code for Reporting of Exploration Results, Geothermal Resources and Geothermal Reserves (Australian Geothermal Reporting Code; AGRC) on behalf of the Australian Geothermal Energy Group and the Australian Geothermal Energy Association. Like the Canadian Code, the AGRC provides a minimum standard for public reporting for all public documents. The first edition of the AGRC was published in 2008, with an updated second edition published in 2010.

To all intents and purposes, the classification scheme of the AGRC is the same as the Canadian Code, with the only point of difference being the use of ‘Proven’ instead of ‘Proved’ for the Reserve class. Indeed, the Canadian Code was intentionally closely based on the earlier Australian Code, and the two jurisdictions mutually recognize Resource Statements prepared in compliance with each other’s Codes. To that end, suggested UNFC-2009 categories corresponding to the different classes defined by the AGRC (Figure 11) are the same as for the Canadian Code.

The rules around company reporting under the AGRC are the same as for the CCPR. The commodity being reported and classified is recoverable thermal energy, a ‘Competent Person’ (another minor terminology difference between the two Codes) must formally take responsibility for each Resource or Reserve estimate, and any such estimate can only be reported in the context of clearly defined project parameters and with adequate supporting evidence provided. The classification scheme is not prescriptive with respect to project parameters and relies on the subjective judgment of the Competent Person.

A Competent Person must have a minimum of five years relevant resource assessment experience and be listed on the Register of Practicing Geothermal Professionals maintained by the Australian Geothermal Energy Group. Above all, Competent Persons should be confident in their own minds that their peers would consider them competent to assess the type of Geothermal Play under consideration.

In practice, application of the Australian Reporting Code to ‘Engineered (or Enhanced) Geothermal Systems (EGS)’ and ‘Hot Sedimentary Aquifer’ geothermal plays has produced very large values of Geothermal Resources because there is no requirement for the energy estimates to be stated in the context of clearly defined
development projects. In effect, all thermal energy that might technically be recovered from a geothermal play, with a reasonable expectation of one day being economic, can be reported as a Geothermal Resource. The huge, virtually unbounded (or bounded only by the limits of exploration licenses), volumes of hot rock lead to huge estimates of recoverable thermal energy.

<table>
<thead>
<tr>
<th>Australian Geothermal Reporting Code classes</th>
<th>UNFC-2009 categories</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>‘E’</td>
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<tr>
<td>Geothermal Resource</td>
<td>Inferred</td>
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<td>Indicated</td>
<td>2</td>
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<tr>
<td>Measured</td>
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</tr>
<tr>
<td>Geothermal Reserve</td>
<td>Probable</td>
</tr>
<tr>
<td></td>
<td>Proven</td>
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</table>

**Figure 11.** Suggested mapping of Australian Geothermal Reporting Code classes within the UNFC-2009 framework.
3.4 ‘New Geothermal Terms and Definitions’ (2010)

The Geothermal Energy Association (GEA; Washington DC) annually collates data and disseminates a ‘US Geothermal Power Production and Development Update’. In 2010, the GEA released a new Guide to help its members voluntarily report relevant geothermal development data for the annual Update.

The GEA released the Guide as a public document entitled “New Geothermal Terms and Definitions.” It provides the broader global geothermal community with a possible framework of definitions for reporting geothermal development progress. The Guide divides the development of a geothermal project into four Phases, and defines a ‘Resource Estimate’ and an ‘Installed Capacity Estimate’ for each Phase. The different Phases correspond to progressive steps along the development pathway and incorporate aspects of ‘Resource Development’, ‘Transmission Development’, and ‘External Development (incorporating permitting, financing and power sales)’.

At each Phase, the Resource Estimate is the reporting company’s estimate of the total recoverable thermal energy. The Installed Capacity Estimate is that portion of the Resource “that the developer deems to be viable for the economic production of electricity under existing economic conditions”, reported in terms of converted megawatts of electrical power. The total thermal energy required to power the Installed Capacity over its lifespan must be less than the Resource Estimate.

The Guide is unusual in that it covers both recoverable thermal energy and electrical power under the one classification scheme. As a development moves through progressive Phases, the two estimates advance from ‘Possible’ through ‘Delineated’ to ‘Confirmed’. The different classes of Phases and Estimates are described in more detail below.

Phase 1: Resource procurement and identification

A geothermal power or direct-heat development can be considered as ‘Phase 1’ if it meets each of the following conditions:

1. Resource Development—at least two of the following are completed:
   - Literature survey completed
   - Geological mapping completed, geophysical and geochemical sample sites identified
• Geochemical and geophysical surveys in progress

2. Transmission Development—the following is completed:
   • Internal transmission analysis

3. External Development—the following are completed:
   • Land purchased or lease acquired
   • Permitting process for exploration drilling is underway

Given that the above conditions are met, the developer can report estimates of ‘Possible Resource’ and ‘Possible Installed Capacity’. The Possible Resource is an estimate of the recoverable thermal energy available for the project at a “level of confidence appropriate to the stage of development”. The Possible Installed Capacity is that portion of the Possible Resource that the developer “deems to be viable for the economic production of electricity [or direct-heat] under existing economic conditions”, expressed in terms of generated thermal or electrical power.

**Phase 2: Resource Exploration and Confirmation**

A geothermal power or direct-heat development can be considered as ‘Phase 2’ if all the conditions of Phase 1 are met and it also meets each of the following conditions:

1. Resource Development—at least one of the following is completed:
   • Temperature gradient holes drilled
   • Slim hole drilled
   • Full size discovery well drilled

2. Transmission Development—at least one of the following is completed:
   • Interconnection application submitted and queue position established
   • Transmission feasibility study underway

3. External Development—the following are completed:
   • Permit for slim hole applied for or approved
   • Permit for production well applied for or approved

Given that the above conditions are met, the developer can report revised estimates of ‘Possible Resource’ and ‘Possible Installed Capacity’. The Possible Resource has the same definition as in Phase 1, but the level of geological confidence is higher because some drilling has been completed. Likewise, the Possible Installed Capacity at Phase 2 has the same definition as Phase 1, but with a greater level of confidence.
Phase 3: Permitting and Initial Development

A geothermal power or direct-heat development can be considered as ‘Phase 3’ if all the conditions of Phase 2 are met and it also meets each of the following conditions:

1. Resource Development—at least two of the following are completed:
   • At least one full size production well drilled and operational
   • At least one full size injection well drilled and operational
   • Reservoir characterization completed and sustainable reservoir capacity determined

2. Transmission Development—at least two of the following are completed:
   • Interconnection feasibility study complete
   • System impact study underway or complete
   • Interconnection facility study underway
   • Transmission service request submitted

3. External Development—at least two of the following are completed:
   • Plant permit application complete or in process
   • Power purchase agreement secured or in negotiation
   • Financing secured, or being secured, for portion of project construction

Given that the above conditions are met, the developer can report estimates of ‘Delineated Resource’ and ‘Delineated Installed Capacity’. The Delineated Resource is an estimate of the total recoverable thermal energy once the geothermal reservoir has been characterized with a reasonable level of confidence through exploration drilling and testing. As above, the Delineated Installed Capacity is that portion of the Delineated Resource that the developer “deems to be viable for the economic production of electricity [or direct-heat] under existing economic conditions”, expressed in terms of generated thermal or electrical power.

Phase 4: Resource Production and Power Plant Construction

A geothermal power or direct-heat development can be considered as ‘Phase 4’ if all the conditions of Phase 3 are met and it also meets each of the following conditions:

1. Resource Development—at least two of the following are completed:
   • Plant equipment on order
   • Plant construction underway
   • Production and injection drilling underway
2. Transmission Development—both of the following are completed:
   • Interconnection agreement signed
   • Transmission system service request studies completed

3. External Development—all of the following are completed:
   • Plant permit(s) approved
   • EPC contract signed
   • PPA secured

Given that the above conditions are met, the developer can report estimates of ‘Confirmed Resource’ and ‘Confirmed Installed Capacity’. The Confirmed Resource is an estimate of the total thermal energy recoverable from a reservoir that has been characterized with a high degree of confidence through extensive exploration drilling and testing. As above, the Confirmed Installed Capacity is that portion of the Confirmed Resource that the developer “deems to be viable for the economic production of electricity [or direct-heat] under existing economic conditions”, expressed in terms of generated thermal or electrical power.

The Phases and estimates of Resource and Installed Capacity defined in the GEA Guide can be can be mapped to the UNFC-2009 framework, noting that the Installed Capacity Estimate is by implication a subset of the Resource Estimate. Progressive Phases of development relate to simultaneously increasing technical, economic and geological favorability. Figure 12 suggests UNFC-2009 categories corresponding to the different Phases and estimates of Resource and Installed Capacity defined in the GEA Guide, in both tabular and graphical format.

The progressive phases of Resource Estimate and Installed Capacity Estimate effectively define two separate one-dimensional classifications of the same geothermal resource. The Resource Estimate classification is, in practice, a scheme that moves simultaneously towards more favorable geological certainty and technical feasibility, independent of economic viability. The Installed Capacity Estimate defines the most economically viable portion of the Resource Estimate at each Phase.
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<td>1.1–1.2</td>
<td>1.2</td>
<td>1</td>
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</table>

**Figure 12.** Suggested mapping of GEA Guide classes within the UNFC-2009 framework.

Beardsmore, Rybach, Blackwell and Baron published “A Protocol for Estimating and Mapping Global EGS Potential” (the ‘Protocol’) in the Transactions of the Geothermal Resources Council Annual Meeting in 2010. That document was reviewed and endorsed by the International Geothermal Association (IGA) and the Executive Committee of the International Energy Agency Geothermal Implementing Agreement (IEA-GIA), subject to revisions recommended by the IGA. A manuscript incorporating those revisions was prepared in May 2011, but has not yet been officially published.

The purpose of the Protocol is to provide consistent methodologies and assumptions for estimating the available heat and electrical power generating potential of ‘Engineered (or Enhanced) Geothermal Systems (EGS)’ over broad geographic regions such that the results for different regions can be directly compared. This will eventually allow a self-consistent inventory and map of the distribution of EGS potential around the globe. The Protocol is not intended as a tool to assess the commercial viability of EGS at specific sites, or for financial reporting.

The Protocol provides instructions for estimating ‘Theoretical Potential Power’ and ‘Technical Potential Power’. The Protocol defines Theoretical Potential Power as the electrical power that could be generated if all heat available down to 10 km depth in the basement (relative to 80°C above average surface temperature) could be produced and converted to electricity over a 30-year period. Technical Potential Power is defined as that portion of the Theoretical Potential Power that could be derived from heat down to 6.5 km depth in the basement, with between 2% and 20% recoverability, excluding areas of restricted land access, and limiting the allowable thermal drawdown of the system to 10°C. In most cases, the values of key geological parameters such as sediment thickness, heat flow, thermal conductivity, density and specific heat capacity are based on approximations and assumptions.

Figure 13 suggests UNFC-2009 categories corresponding to Theoretical Potential Power and Technical Potential Power as defined in the Protocol for Estimating and Mapping Global EGS Potential. These correlations assume that the key geological parameters are all estimated.

‘GEO- ELEC’ is a project funded through the ‘Intelligent Energy Europe’ program of the European Commission. The aim of the project, with partners in eight countries (Germany, France, Greece, Italy, Spain, Belgium, Iceland and the Netherlands), is to produce a pan-European inventory and map of geothermal resources that can be developed for electricity production on the 2020 and 2050 timeline horizons.

In late 2011, the GEO-ELEC partners released a draft document describing a unified reporting and classification scheme for categorizing the geothermal potential of

<table>
<thead>
<tr>
<th>Protocol for Estimating and Mapping Global EGS Potential classes</th>
<th>UNFC-2009 categories</th>
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<td>‘E’</td>
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<td>Theoretical Potential Power</td>
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<tr>
<td>Technical Potential Power</td>
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</tbody>
</table>

Figure 13. Suggested mapping of ‘Protocol for Estimating and Mapping Global EGS Potential’ classes within the UNFC-2009 framework.
Europe—“A Resource Assessment Protocol for GEO-ELEC” (van Wees et al., 2011). The draft GEO-ELEC Protocol incorporates aspects of the standard petroleum classification scheme, the existing Geothermal Reporting Codes, and the ‘Protocol for Estimating and Mapping Global EGS Potential’ described above. It proposes assessing the European geothermal potential at three different levels of technical and geological certainty.

**Level 1—Global European prospective resource assessment for EGS**

This will be a Europe-wide assessment of ‘Technical Potential Power’ from EGS as defined in the ‘Protocol for Estimating and Mapping Global EGS Potential’. Key inputs will base maps of temperature and rock type to calculate total stored heat in different depth intervals, geographic filters with information on natural reserve areas etc, and a relatively low ‘recovery factor’ of 1% for the proportion of the total heat that can be produced at the surface. Technical Power Potential will be derived in terms of electrical power over a 30-year plant life for two different types of plant: ‘binary’ power conversion for fluid temperature >100°C and ‘conventional’ power conversion for fluid temperature >150°C.

**Level 2—Prospective Undiscovered Resources**

Following the standard petroleum classification scheme, the GEO-ELEC Protocol defines a ‘Prospective Undiscovered Resource’ as the amount of heat that is estimated to be commercially recoverable from as-yet undrilled geothermal plays, assuming that the technical capability exists to drill and confirm the existence of such ‘undiscovered’ resources. The Level 2 assessment will be restricted to areas delimited by existing geological data that provide reasonable confidence that suitable geothermal reservoir conditions exist. The GEO-ELEC partners propose to quantify Prospective Undiscovered Resources for:

- Hot Sedimentary Aquifers—specifically restricted to karstic, over-pressured units shallower than 4 km depth. The extent and volumes of these prospective units will be estimated from existing seismic and petro-physical data.

- Hot rock suitable for EGS—relatively high temperature, non-porous, non-magmatic rocks. Prospective areas will have recent (Tertiary and Quaternary)
tectonic activity (especially recently active faults), and/or indications of vertical flow conduits (springs or surface heat flow anomalies).

- Magmatic areas—as yet undrilled volcanic centers with indications of active hydrothermal systems from surface temperature measurements, seismicity records, geology and geothermometry.

**Level 3—Contingent Resources and Reserves**

The GEO-ELEC Protocol defines ‘Contingent Resources’ and ‘Reserves’ following the standard petroleum classification scheme. Contingent Resources are accumulations of recoverable heat that have been confirmed through drilling. Subdivisions include:

- Marginal Contingent Resources—associated with technically feasible projects that are currently economic (or projected to be economic with reasonably forecast improvements in conditions) but not committed for development.

- Sub-Marginal Contingent Resources—thermal energy for which there is insufficient information to clearly define a recovery plan, or for which analysis indicates that portions of the energy, although technically feasible to recover, could not be economically developed even with reasonably forecast improvements in conditions.

Reserves are accumulations of thermal energy that can be economically recovered by a defined commercial project. Reserves are additional to Contingent Resources, not a subset.

GEO-ELEC aims to quantify Europe’s Contingent Resources and Reserves using industry and government reports on drilled prospects. Estimates of Contingent Resources and Reserves might each be sub-classified according to geological confidence and project status.

Figure 14 suggests UNFC-2009 categories corresponding to GEO-ELEC’s proposed assessment levels and classes, in both tabular and graphical format.
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<thead>
<tr>
<th>GEO-ELEC’s assessment classes</th>
<th>UNFC-2009 categories</th>
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<td>‘E’</td>
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<tr>
<td>Level 1 Technical Potential Power</td>
<td>3.2</td>
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<tr>
<td>Level 2 Prospective Undiscovered Resources</td>
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</tr>
<tr>
<td>Level 3 Sub-Marginal Contingent Resources</td>
<td>2–3.3</td>
</tr>
<tr>
<td>Marginal Contingent Resources</td>
<td>1.1–1.2</td>
</tr>
<tr>
<td>Reserves</td>
<td>1.1–1.2</td>
</tr>
</tbody>
</table>

Figure 14. Suggested mapping of GEO-ELEC’s assessment classes within the UNFC-2009 framework.

3.7 The ‘MIT Report’—a case study

The Report has been widely and freely distributed around the world. Its findings (chiefly that “with a reasonable investment in R&D, EGS could provide 100 GW\textsubscript{e} or more of cost-competitive generating capacity in the next 50 years”; MIT, 2006; p1.3) have directly influenced energy policy in the United States and elsewhere. For this reason, it is useful to interpret the findings of the MIT Report in terms of the UNFC-2009, even though the MIT Report is a domestic geothermal assessment and does not present itself as a classification scheme or protocol for broader adoption.

The MIT Report defines EGS (‘enhanced geothermal systems’) as “all geothermal resources that are currently not in commercial production and require stimulation or enhancement. EGS would…include conduction-dominated, low permeability resources in sedimentary and basement formations, as well as geopressured, magma, and low-grade, unproductive hydrothermal resources. In addition, …coproduced hot water from oil and gas production.” (MIT, 2006; p1.10).

A key outcome of the MIT Report is a series of tables of ‘resource base estimates’ in exajoules (EJ\textsubscript{th}), ‘potential power generation from coproduced fluids’ in MW\textsubscript{e}, and ‘total recoverable energy’ (in MW\textsubscript{e} over 30 years) for different values of recoverability of thermal energy through EGS. Given the impact of the MIT Report on global geothermal policies, it is useful to interpret how its ‘resource base’, ‘potential power generation’ and ‘total recoverable energy’ estimates map to the UNFC-2009 scheme and the frameworks of the other schemes discussed in this document.

While not proposing a formal classification scheme or reporting framework, the MIT Report nevertheless splits ‘resource base estimates’ into five classes. These are described below and discussed in terms of the UNFC-2009 framework.

**Geopressured geothermal resources**

This class refers to thermal energy stored in permeable sedimentary rocks at pressures much higher than hydrostatic pressure. Water recovered from these formations in the Gulf of Mexico basin also typically contains significant amounts of dissolved natural gas. Thus the total energy potential of the recovered fluid includes thermal, mechanical (pressure) and chemical (natural gas) energy. The US DoE demonstrated the technical feasibility of producing power from these resources over a few months from late 1989 to early 1990 by running a 1 MW\textsubscript{e} plant on the Pleasant
Bayou well near Houston, Texas. Energy prices at the time made the plant sub-commercial, but under present market conditions such a project might be economic.

The MIT Report reproduces two earlier estimates of the thermal energy available from geopressed fluid in the Gulf of Mexico basin. The first estimate of 46,000 EJ\textsubscript{th} was by Papadopulos \textit{et al.} (1975), derived from reliable information about geological structure, sand thickness, temperature and pressure, but limited information on porosity and permeability. They limited their assessment to the depth of the deepest well (at the time) in the onshore Tertiary sediments. In terms of the UNFC-2009, therefore, the resource estimate could be classified as E2 (thermal energy available but not yet commercially confirmed), F1.3 (feasibility of power production has been demonstrated), G2 (estimate based on geological data of moderate reliability).

The second estimate presented for geopressed geothermal resources in the MIT Report was 110,000 EJ\textsubscript{th}, after Wallace \textit{et al.} (1979). Wallace and co-workers extended the geological extent of the assessment of Papadopulos \textit{et al.} (1975) to deeper, undrilled formations and regional extrapolations, thus incorporating less reliable geological information. In terms of the UNFC-2009 classification, therefore, the additional 64,000 EJ\textsubscript{th} estimated by Wallace \textit{et al.} (1979) could be classified G4 (estimated from assumed parameters), while the total 110,000 EJ\textsubscript{th} could be classified as G3 (geological data of low reliability).

**Coproduced fluids**

This class refers to thermal energy contained in volumes of hot water produced as a byproduct of hydrocarbon production. Rates of coproduced water production are reasonably well known, and ‘off the shelf’ binary power conversion units are widely available for fluid temperatures greater than about 100°C. Although the concept had not been demonstrated at the time the MIT Report was published, the report recognizes that “collecting and passing the fluid through a binary system electrical power plant could be a relatively straightforward process” (p2.30). The technical viability of the concept has since been demonstrated in the United States (e.g. Johnson and Simon, 2009) and elsewhere (e.g. Xin \textit{et al.}, 2012).

The MIT Report presents a table of total volumes of coproduced water from hydrocarbon wells across 31 states in 2004, and the inferred total flow rates for each
state. The report then estimates from the total flow rates the ‘equivalent geothermal power’ that might be generated if all the flow was passed through binary power plants, for a range of assumed average fluid temperatures between 100°C and 180°C. For California, for example, the ‘equivalent geothermal power’ estimates range from 462 MW\(_e\) for 100°C water to 2,205 MW\(_e\) for 180°C water. The report acknowledges, however, “there is not actual information available for the temperature of the [coproduced] waters” (p2.30), and that “some of the fluid is produced from dispersed sites and may not be appropriate for use” (p2.30).

In terms of the UNFC-2009, the ‘equivalent geothermal power’ estimates for coproduced water could be classified as E2 (thermal energy available but not yet commercially confirmed), F3 (further data required to better constrain temperature, flow etc), G3–G4 (estimate based on measured and assumed parameters).

**Conduction dominated sedimentary EGS**

This class refers to thermal energy stored in sedimentary rocks between 4,000 m and 10,000 m depth. The MIT Report assumes that while there might be some remnant natural porosity and permeability in sedimentary rocks at those depths, such rocks are unlikely to support commercial flow rates for geothermal systems without artificial permeability enhancement.

The Report estimates the total thermal energy contained in deep sedimentary rocks by calculating the possible temperature of such rock units from estimates of surface heat flow and thermal conductivity. The total volume of the units is estimated from models of basement depth, and assumptions are applied for density and specific heat capacity. The Report estimates a ‘resource base’ of 100,000 EJ\(_{th}\) of thermal energy in sedimentary rocks between 4,000 m and 10,000 m depth in the USA.

In terms of the UNFC-2009, this estimated sedimentary EGS ‘resource base’ could be classified as E3.2–E3.3 (commercial viability cannot yet be determined, but much will never be commercial), F3–F4 (further data required to better constrain temperature, flow etc; but much will not be recovered), G3–G4 (based on measured and assumed parameters).
Conduction dominated basement EGS

This class refers to thermal energy stored in basement rocks between 3,000 m and 10,000 m depth, and assumes that the naturally low permeability of all basement rocks can be artificially enhanced. The MIT Report estimates the total thermal energy in these rocks by calculating the possible temperature of such rocks from estimates of surface heat flow and thermal conductivity. Rock volume is considered in discrete 1,000 m thick depth slices, and assumptions are applied for density and specific heat capacity. The Report estimates a ‘resource base’ of 13,300,000 EJ\(_{th}\) of thermal energy in basement rocks between 3,000 m and 10,000 m depth in the 48 conterminous states of the USA, and another 3,200,000 EJ\(_{th}\) in Alaska.

In terms of the UNFC-2009, this ‘resource base’ could be classified as E3.2–E3.3 (commercial viability cannot yet be determined, but much will never be commercial), F3–F4 (further data required to better constrain temperature, flow etc; but much will not be recovered), G3–G4 (based on measured and assumed parameters).

The MIT Report goes on to estimate the total thermal energy that might be recovered from the basement using EGS techniques. It divides the total stored energy into different depth, temperature and recoverable fraction categories, and tabulates the values in terms of net megawatts of electricity over a 30-year extraction period. The total for a 2% recoverable fraction is 1,249,000 MW\(_e\) for the 48 conterminous states.

In terms of the UNFC-2009, the basement EGS ‘recoverable energy’ could be classified as E3.2 (commercial viability cannot yet be determined), F3 (further data required to better constrain temperature, flow etc), G3–G4 (based on measured and assumed parameters).

Conduction dominated volcanic EGS

The last class of EGS ‘resource base’ the MIT Report presents refers to thermal energy stored around geologically recent volcanic zones in Alaska (9,000 EJ\(_{th}\); Smith and Shaw, 1979) and the conterminous states (65,000 EJ\(_{th}\); excluding Yellowstone), plus a ‘resource estimate’ of 1,395 MW\(_e\) published for Hawaii (Lovekin et al., 2006).

In terms of the UNFC-2009, the volcanic EGS ‘resource base’ could be classified the same as the sediment and basement estimates described above; E3.2 (commercial...
viability cannot yet be determined), F3 (further data required to better constrain temperature, flow etc), G4 (estimate based on assumed parameters).

Figure 15 attempts to collate the findings of the MIT Report into their various UNFC-2009 classes, and to interpret them in terms of the other classification and reporting schemes examined in this document. It can be observed that:

- No current scheme can fully classify the range of ‘resource estimates’ presented in the MIT Report
- The GEA’s ‘New Geothermal Terms and Definitions’ comes closest
- The Australian and Canadian Reporting Codes are particularly ill suited
- Estimates of ‘Recoverable Energy’ from conduction dominated basement EGS can be at least partly classified under all the schemes examined
- Most schemes are unable to classify the ‘Geopressured Resource’ estimate of Wallace et al. (1979)

<table>
<thead>
<tr>
<th>Geopressed resources</th>
<th>Conduction dominated EGS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Papadopulos et al. (1975)</strong></td>
<td><strong>Wallace et al. (1979)</strong></td>
</tr>
<tr>
<td>E</td>
<td>2</td>
</tr>
<tr>
<td>F</td>
<td>1.3</td>
</tr>
<tr>
<td>G</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<tr>
<td>Economic Potential</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>Partly Inferred Resource</td>
</tr>
<tr>
<td>Technical Potential</td>
<td>n/a</td>
<td>Technical Potential</td>
<td>Phase 3—Delineated Resource</td>
<td>n/a</td>
<td>Theoretical Potential</td>
</tr>
<tr>
<td>Partly Phase 1—Possible Resource</td>
<td>Phase 1—Possible Installed Capacity</td>
<td>Partly Phase 1—Possible Resource</td>
<td>Partly Phase 1—Possible Resource</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theoretical Potential</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<td>n/a</td>
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</tr>
<tr>
<td>Technical Potential Power</td>
<td>Prospective Undiscovered Resources</td>
<td>Partly Sub-Marginal Contingent Resources</td>
<td>Technical Potential Power</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Includes Sediment, Basement and Volcanic systems ** Basement systems only

**Figure 15.** Suggested mapping of the MIT Report classes to the UNFC-2009 framework and other classification schemes.
4.0 Gaps, limitations, overlaps and ambiguities between classification schemes

Figure 16. Comparison of geothermal schemes mapped to UNFC-2009 categories:
Figure 16 presents the six classification schemes discussed above in the graphical format of the UNFC-2009 three-dimensional scheme. This figure provides a direct visual comparison and a platform for a discussion of gaps, limitations, overlaps and ambiguities between the schemes.

4.1 Gaps and limitations

As mentioned earlier in this document, the Expert Group on Resource Classification clearly did not consider geothermal energy during its formulation of the UNFC-2009. The UNFC-2009 “does not make reference to energy resources contained in physical fields (of pressure and temperature). It also does not make reference to groundwater resources, although it is applicable to projects that are extracting non-renewable groundwater.” These limitations do not in themselves disqualify the UNFC-2009 as a possible template for a classification scheme for geothermal energy, but such a scheme will need to clearly define and address the unique attributes of geothermal energy that differentiate it from finite mineral and energy commodities.

A significant gap in the UNFC-2009 with respect to geothermal energy is its inability to express the ‘sustainability’ of a geothermal project. ‘Sustainability’ incorporates elements of extraction rate, fluid and heat recharge, power conversion, and temperature and pressure drawdown, none of which are addressed in the published UNFC-2009 scheme. This gap is evident in the inability of the three-dimensional space of the UNFC-2009 scheme to distinguish ‘Economic Potential’ from ‘Sustainable Potential’ on Figure 16b.

The six geothermal classification schemes discussed in this document each have individual limitations and gaps with respect to the three-dimensions of the UNFC-2009 scheme. Each of the geothermal schemes is either one or two dimensional, so none can independently express all three dimensions of the UNFC-2009.

Of the six schemes, the Australian and Canadian Geothermal Reporting Codes arguably provide the most relevant case studies because they trace their origin directly back to the UNFC-2009 via the ‘JORC Code’ and the ‘CRIRSCO Template’. In effect, the Codes provide direct experience of classifying geothermal potential within an abridged UNFC-2009 framework.

The Reporting Codes each condense the three-dimensional UNFC-2009 framework into a two-dimensional scheme with one axis expressing geological confidence and
the other axis capturing technical and economic viability. Given that the purpose of the Codes is to regulate the reporting of financial assets by commercial entities, they have little need for classifying geothermal energy that is non-commercial, or estimates based on assumed data. Hence the Codes provide no class for non-recoverable heat; no class for heat produced in non-commercial or research projects, which have high technical and geological confidence but low economic viability (UNFC-2009 category E3, F1, G1); and no class equivalent to Prospective Undiscovered Resources as proposed by the GEO-ELEC project, which are presumed to be commercial but are based on assumed data.

The reportable commodity under the Codes is ‘recoverable heat’. As explained earlier in this document, recoverable heat on its own does not directly correlate to electrical power, so the Codes are limited in their ability to classify electrical power potential.

The five classes of Potential proposed by Rybach (2010; Figure 16b) define a one-dimensional scheme that covers a broad spectrum of the three-dimensional UNFC-2009 classification space. The step from Theoretical Potential to Technical Potential follows the ‘F’-axis of the UNFC-2009 scheme, while progression from Technical Potential through Economic Potential to Developable Potential mostly tracks the ‘E’-axis of UNFC-2009.

Geological confidence only has a minor influence on the classes of Potential. This insensitivity to geological certainty is the major gap in the scheme. For example, an estimate of Theoretical Potential derived from assumed values of geological parameters is classified the same as an estimate based on accurate geological measurements.

Also, unconventional geothermal schemes being pursued in various locations around the world, such as enhanced geothermal systems (EGS) and exploiting supercritical fluids, highlight a gap between Theoretical and Technical Potential. Energy recovery by such schemes has not yet been developed to the point that it can be routinely “realized within the limits of current technology”, but is also not “defined solely by thermodynamic limits.” The potential of these techniques therefore occupies a region somewhere between Theoretical and Technical Potential. This is seen in the
discrepancy between the regions identified as Technical Potential on Figures 16b and 16e.

GEA’s ‘New Geothermal Terms and Definitions’ (Figure 16d) are intended for reporting progress of commercial geothermal developments. It is really an amalgam of two one-dimensional schemes. The Resource Estimate follows a path of simultaneous improvements in geological confidence and project feasibility (UNFC-2009 ‘F’ and ‘G’ axes), while the Installed Capacity Estimate defines the most economically favorable (‘E’-axis) portion of the Resource Estimate. Similar to the Geothermal Reporting Codes, there is no class within the GEA scheme for accumulations of heat with low technical chance of recovery, or power production for non-commercial purposes.

The ‘Protocol for Estimating and Mapping Global EGS Potential’ is intended for regional to continental scale inventories of geothermal potential. It proposes just two classes for estimating geothermal power. Although these are termed Theoretical Potential and Technical Potential, they both fall within the bounds of Theoretical Potential, as defined by Rybach (2010; Figure 16b), when viewed in the UNFC-2009 classification space (Figure 16e). Application of the Protocol should be limited to its intended purpose.

The GEO-ELEC ‘Resource Assessment Protocol’ encompasses three separate inventories of geothermal potential, which plot within three separate segments of the UNFC-2009 classification space. Level 1 and Level 2 estimates fall within narrow bands, while the Level 3 classes cover a wider space (Figure 16f). All three levels of estimates are classified according to economic and technical viability, equivalent to the ‘E’ and ‘F’ axes in the UNFC-2009 scheme. The GEO-ELEC classes do not specifically distinguish between different levels of geological knowledge. However, there is scope within the class definitions for ‘low’, ‘medium’ and ‘high’ estimates, which would correlate to different locations on the ‘G’-axis of the UNFC-2009 framework. The GEO-ELEC scheme also provides no specific class for non-commercial geothermal energy extraction.

4.2 Overlaps and ambiguities

There are various degrees of overlap between the six reporting and classification schemes discussed above when they are translated into the three-dimensional
UNFC-2009 scheme. That is, situations where the same quantum of heat could be accurately classified under different schemes.

In terms of overlap, the greatest degree of overlap in intent, terminology and classifications is between the Australian and Canadian Reporting Codes. This is not surprising given that the Codes are closely and intentionally inter-related. The classes defined by the Codes are also, arguably, the most aligned with the UNFC-2009 scheme because their classification structure can be directly traced back to the UNFC-2009 through the JORC Code and CRIRSCO template.

Rybach’s (2010) proposed classes of ‘Potential’ overlap with most categories in the other schemes. For example, Technical Potential in Rybach’s terminology covers Measured Resources (Australian and Canadian Reporting Codes), Delineated Resources (GEA), and a portion of Sub-Marginal Contingent Resources (GEO-ELEC). Rybach’s classes, therefore, provide a possible high-level tool for understanding and interpreting the inter-relationships between some of the other schemes.

Five of the six schemes define a class within the \{1,1,1\} sector of the UNFC-2009 framework, or estimates of thermal energy that will be recovered by an economically and technically viable project, underpinned by reliable geological data. The Canadian and Australian Reporting Codes categorize such thermal energy as a Proved (or Proven) Reserve; Rybach (2010) categorizes it as Developable Potential; GEA members would report it as Confirmed Installed Capacity Estimate; and the GEO-ELEC project categorizes it as a Reserve under its Level 3 assessment.

Overlaps in classifications as described above are not surprising given the various degrees of overlap in the purposes for which the schemes have been developed. The overlaps themselves should not cause any undue confusion, but it could be argued that, where they do overlap, the same term should be used by all schemes to describe the same quantum of heat.

Using different terminology to describe the same quantum of heat might not be ideal, but there is far greater risk of confusion where different schemes use the same terminology to describe different quanta of heat. The greatest potential for confusion lies in the ambiguous definitions and wide range of qualifiers for a ‘Resource’. While the word ‘Reserve’ seems to be used exclusively to describe thermal energy that can
be economically and technically extracted under present conditions, ‘Resource’ has a much broader range of meanings across the schemes. Under the Australian and Canadian Codes, a Resource is an accumulation of heat for which there is reasonable potential for eventual economic extraction. The GEA and GEO-ELEC schemes, however, define a Resource in a broader sense that includes all available heat, whether the heat might be economically extracted or not (analogous to a ‘Geothermal Play’ under the Reporting Codes).

To refer to a Resource in a generic sense, therefore, can lead to misunderstandings if no specific classification scheme and qualifying term are implied. Qualifying terms include Measured, Indicated, Inferred, Confirmed, Delineated, Possible (Phase 1 and Phase 2), Marginal Contingent, Sub-Marginal Contingent and Prospective Undiscovered. Some of these qualifiers imply thermal energy that is technically and economically recoverable while others do not.

There is (perhaps surprisingly) minimal overlap in the definitions of these many Resource classes when viewed within the three-dimensional UNFC-2009 framework (Figure 16). They each serve different purposes and refer to precise quanta of heat underpinning different technical and commercial stages of geothermal developments. There is little chance of ambiguity in a statement of ‘Resource’ if the statement includes the relevant classification scheme and qualifier.
5.0 The UNFC-2009 for classifying geothermal energy

The IEA-GIA is interested to move towards a globally adopted classification and terminology framework for reporting geothermal energy potential and production. Such a framework would provide consistent terminology for global inventories of geothermal energy, existing power generation, and potential for future growth. Such inventories are essential if geothermal energy is to feature in global future energy plans. The IEA-GIA shares this goal with other global and intergovernmental organizations such as the International Geothermal Association and the United Nations Economic Commission for Europe. The UNFC-2009 might provide a starting point for developing such a framework.

A number of fundamental questions need to be asked and answered prior to developing any broad classification framework for geothermal energy.

Who would use the classification framework?

A broadly applicable framework would need to suit the requirements of a broad range of users. These might include energy planning authorities, regulatory authorities, domestic organizations tasked with mapping natural resources, industry representative bodies, commercial developers, international and intergovernmental organizations, development banks, and other financial institutions. In addition, it might cover projects for electrical power generation, steam production, direct or cascaded use of thermal energy, or even thermal storage and recovery. If broad ‘buy-in’ is to be achieved, then representatives of each of these end-user groups should be included in any process to develop a new classification scheme.

Who would maintain and police the classification framework?

Existing mineral and fossil energy classification and reporting schemes are maintained and policed by professional associations. An association with significant global reach and financial resources would need to take ‘ownership’ of any new geothermal classification and reporting framework.

What would be the reportable commodity?

This is arguably the most fundamental question and one not easily answered. ‘Recoverable thermal energy’ is the commodity most closely analogous to existing mineral and fossil energy classification schemes. But the quantity of ‘recoverable
thermal energy’ is intimately linked to the specific end use for the energy, far more so than for mineral and fossil energy deposits. It can only be estimated in the context of very clearly defined project parameters. Additionally, as previously stated in this report, recoverable thermal energy is not a good proxy for electrical power generation potential. If a primary aim of a classification scheme is to provide potential financiers with confidence, then reporting recoverable heat for an electrical power project might not achieve that aim.

Alternative reportable commodities might include ‘thermal energy in place’, ‘recoverable thermal power’, ‘end-use power or energy (thermal or electrical)’, or a range of others. Each would have its own advantages and limitations. Should a new classification scheme provide flexibility to report a range of commodities?

**How prescriptive should the classification scheme be?**

Prescriptive methodologies provide confidence that all resource estimates are carried out in the same way and can be directly compared. This would assist with financial risk reduction. However, the spectrum of possible geothermal plays is wide, so defining prescriptive methodologies that would apply across all possible geothermal systems (EGS, hot sedimentary aquifers, hydrothermal systems) would pose a considerable challenge. Furthermore, prescriptive methods might hamper the uptake of new technologies and methodologies that decrease exploration risk.

An alternative approach would be to follow the example of the Australian and Canadian Codes by setting a minimum level of disclosure and accountability for data and interpretations that underpin each resource estimate or project update. The topic of prescribed methods is discussed more in the next section.

**5.1 Classification framework versus prescribed methodology**

It is important to distinguish between the concept of a classification framework and prescribed methodologies for estimating geothermal potential. How a quantum of recoverable thermal energy (or electrical power potential) is **classified** is, in principle, independent from how it was **estimated**. The Australian and Canadian Geothermal Reporting Codes, for example, are indifferent to how Geothermal Resources and Geothermal Reserves are estimated, so long as the parameters underpinning the reported estimates are clearly and fully disclosed and endorsed by a Qualified or Competent Person. The Codes provide a consistent terminology and classification
framework so that all companies ‘speak the same language’ when reporting energy assets. It is left almost entirely to the Qualified or Competent Person to decide how to quantify and classify those assets.

The Geothermal Reporting Codes, however, dictate the minimum level of supporting evidence and disclosure that must accompany any statement of Geothermal Resources or Geothermal Reserves. A companion volume to the Codes, the Geothermal Lexicon, provides guidance for the Qualified or Competent Person on ‘best practice’ for assessing geothermal potential. The QP/CP is not obliged to follow the Lexicon, but the Codes require the QP/CP to justify their decision if they stray too far from the methods outlined in the Lexicon.

The point is that any terminology and classification framework for geothermal energy can only be defined in parallel with a firm set of rules about how the framework is to be implemented. Without such rules, there can be no confidence that values reported in the same class around the world are, in fact, directly comparable. Rules might include prescribed methods for estimating resources and reserves; prescribed milestones for defining project maturity; prescribed statistical methods for probabilistic determinations; minimum levels of disclosure; prescribed methods for financial projections; legal accountability on individuals for resource and reserve estimates; minimum requirements for feasibility studies; prescribed default values for unmeasured parameters; etc. Perhaps a compromise would be standardized Tables of Contents for resource reports or project updates, where a prescribed set of criteria would have to be addressed through collected data or justification for omission.

The rest of this document leaves the need for such rules to one side and considers only whether the three-dimensional UNFC-2009 scheme might be adopted or adapted for classifying geothermal energy potential.

5.2 A 3D classification framework for geothermal energy

It has already been mentioned several times in this document that the Expert Group on Resource Classification did not consider geothermal energy when designing the UNFC-2009 scheme. The UNFC-2009 was designed to classify finite and discrete accumulations of a commodity in the ground, without reference to energy in physical fields, extraction rates or end-uses of the commodity. Its three dimensions of
economic, technical and geological favorability are, however, also relevant to geothermal potential.

The first step towards a global classification scheme for geothermal energy based on the UNFC-2009 scheme would be to interpret the three dimensions of the UNFC-2009 scheme in the context of geothermal energy. If all the unique aspects of geothermal energy can be captured within the three dimensions and a rigorous set of ‘rules’, then no additional dimensions are necessary. These unique aspects include the ubiquitous nature of thermal energy in the ground (every location is potentially underlain by an EGS ‘resource’ with limited geological constraint); the potential for indefinite sustainability of production and therefore ‘infinite’ recoverable energy; the fact that recoverable thermal energy alone is not a good proxy for power generation (see Section 2.2); the fact that geothermal energy must be sold into a local market (thus an ‘Inferred Resource’ of recoverable heat in one location might have a greatly different intrinsic value to an ‘Inferred Resource’ of the same magnitude in a different location); the fact that some developments sell heat (or volumes of steam) while others sell electricity (different commodities underpin different companies’ valuations).

The consensus view of the author and a number of reviewers of an earlier draft of this report is that three dimensions should be sufficient to design a workable, broadly applicable, classification framework for geothermal energy, within the context of clearly defined project parameters. Earlier in this document, Figure 6 presented one example of how the existing UNFC-2009 categories might be redefined for geothermal energy, but it is by no means the only possible solution. The three dimensions of the UNFC-2009, and how they relate to geothermal energy, are presented again below.

**Economic and social viability of commercial extraction**

From Section 2.1.1, “the ‘E’ criterion encapsulates the favorability of the social and economic conditions for establishing a commercially viable project. It considers market conditions and relevant legal, regulatory, environmental and contractual conditions. Factors encapsulated in this criterion include prices, costs, legal and fiscal framework, environmental, social and all other non-geological factors that directly impact the financial viability of a project.”
This definition is as relevant for geothermal projects as it is for mineral and fossil energy developments. The degree of favorability could be linked to the security of tenure over the geothermal resource; sales contracts (for example, PPA’s); production subsidies; volatility of local prices; O&M costs (including possible penalty costs for CO₂ production); social acceptability; sustainability of production (indefinite versus planned depletion); and the degree to which all of these are confirmed for the proposed lifespan of the project.

**Field project status and project feasibility**

From Section 2.1.2, “the ‘F’ criterion relates to the maturity of project feasibility studies and financial and legal commitments towards the project development. Stages extend from ‘pre-feasibility’, before a deposit or accumulation has been confirmed, through to actual extraction and sales of the commodity.”

A development pathway criterion is also relevant for geothermal projects. A recent publication from the Energy Sector Management Assistance Program (ESMAP; see Bibliography) of the International Bank for Reconstruction and Development (World Bank Group) defines seven stages of geothermal energy developments:

- Preliminary survey
- Exploration
- Test drilling
- Project review and planning
- Field development and production drilling
- Construction
- Start-up and commissioning

These stages, in effect, define increasing degrees of project feasibility and could form the basis for categories in this criterion. Note, however, that recoverable thermal energy would remain largely uncertain prior to the test drilling stage of development.

**Geological knowledge**

From Section 2.1.3, “the ‘G’ criterion relates to the level of confidence in understanding the geological uncertainty and potential recoverability of the commodity in question. Confidence generally improves following surface or subsurface geological, geophysical and geochemical surveys.”
This criterion effectively encapsulates project uncertainty or 'risk'. Geological risk is clearly important and relevant for assessing geothermal energy potential, but uncertainty in geothermal projects extends beyond constraining the initial magnitude of the heat resource. Different reportable commodities or products (heat in place, recoverable thermal energy, recoverable thermal power, generated electrical power, etc) would have different levels of uncertainty. A 'high-confidence' estimate of one commodity does not necessarily imply the same high confidence for a derivative commodity. For example, consider a project where the reportable commodity is 'recoverable thermal energy' but the proposed commercial product is electricity. After an exploration program, the developer correctly reports recoverable thermal energy with high 'geological' confidence. This sends the message that the project is 'low risk', but masks the fact that the project’s commercial success relies on unproven power conversion technology.

The example above illustrates that the ‘G’ criterion should seek to capture all risks that impact on the commercial product of a project, not just the geological risks. As well as uncertainties related to the initial state physical parameters of the resource (volume, temperature, pressure, porosity, permeability and so on), other risks might relate to the extent to which the proposed technology for field development has previously been demonstrated (for example, production from hydrothermal systems versus EGS projects); the degree to which scaling or corrosion might impact on long-term performance; ease of reinjection; power conversion uncertainty (for example, due to novel plant types or uncertainty around heat rejection from the plant); parasitic power loads; predicted temperature and pressure drawdown; impact of natural heat and fluid recharge (this is upside risk); and other factors.

The definition of the ‘G’ criterion might, therefore, need to be extended for a three-dimensional geothermal classification framework, in order to encompass non-geological risks. The reportable commodity might (for example) be defined as ‘useful recoverable thermal energy’, and classified according to the certainty that the thermal energy could be recovered and ‘used’. Uncertainties would relate to many factors beyond the geological probability of production.

As for the other criteria, the ‘G’ criterion could only be assessed in the context of clearly defined project parameters.
5.3 Recent activity by the UNECE

The ‘Expert Group on Resource Classification’ set up by the UN Economic Commission for Europe has itself begun to look at modifying the UNFC-2009 scheme to encompass all renewable energy sources, including geothermal energy. Several presentations were delivered to the Expert Group at a session in Geneva in May 2012 (see links to presentations by Falcone and Williams in the Bibliography). A ‘Renewable Reserves Working Group’ has been set up under the auspices of the Expert Group to look at applying the UNFC-2009 to renewable energy resources and reserves. The Working Group “recognizes the importance of being able to assess and quantify renewable energy resources in a consistent and transparent way.”

The Working Group held its first workshop in London over 31 October – 1 November 2012. A single representative—Prof. Dr. Gioia Falcone of Clausthal University of Technology in Germany—represented the geothermal sector at the Workshop. The key messages and many presentations from that Workshop are publically available (see Bibliography).

A key message from the Workshop was: “Following a review of existing classification systems, the experts at the Workshop agreed that the UNFC-2009 offered the potential to be applied to renewable energy resources. Such a broadening of the scope of application of the UNFC to renewables could allow a meaningful comparison of renewable energy resources with non-renewable resources.”

The author strongly recommends that the IEA-GIA members engage fully with this process to ensure that any modified UNFC-2009 classification framework for renewables is 100% aligned with the needs of the geothermal energy sector, and acceptable for the sector to broadly adopt and promote.
6.0 Bibliography of relevant documents


